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MINUTES OF PROCEEDINGS
OF THE
INSTITUTION
OF
CIVIL ENGINEERS;
WITH
ABSTRACTS OF THE DISCUSSIONS.

VOL. XIX.

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SESSION 1859-60.  
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EDITED BY
CHARLES MANBY, F.R.S., M. INST. C.E., HONORARY SECRETARY;
AND
JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

INDEX, PAGE 677.

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CONTENTS.

No. of Paper.	Subjects.	Author of Papers.	Date.	Page.
	Remarks on opening of Session, as to deaths of Brunel and Robert Stephenson.	J. Locke, M.P..	1859 Nov. 8	1
1,000	Bells at the New Palace, Westminster (1 plate).	J. James . . .	..	3
	Appendix : Time occupied in raising the Great Bell.	Ditto . . .	..	12
	Discussion on Bells at the New Palace, Westminster.	..	..	13
1,002	Government Waterworks in Trafalgar Square	C. E. Amos . .	„ 15	21
	Appendix : List of places supplied . . .	Ditto . . .	..	28
	Discussion on Trafalgar Square Waterworks (1 plate).	..	..	30
	Parallel-motion Safety-valve.	J. Poole . . .	„ 22	52
1,005	Arterial Drainage and Outfalls (2 plates) .	R. B. Grantham	„ 29	53
	Discussion on ditto	..	..	86
	Election of Members	..	Dec. 6	130
	Annual General Meeting	..	„ 13	131
	Election of Council	..	..	132
	Annual Report.	..	..	133
	Abstract of Receipts and Expenditure . .	..	..	166
	Appendix to the Annual Report : Memoirs	..	..	168
	Memoir of Earl De Grey	..	..	168
	„ Isambard Kingdom Brunel : .	..	..	169
	„ Hugh Ebrington Fortescue . .	..	..	173

No. of Paper.	Subjects.	Author of Papers.	Date.	Page.
	Memoir of William Hartree	..	1859 Dec. 13.	174
	,, Daniel Mackain	..	..	175
	,, Robert Stephenson, M.P.	..	..	176
	,, Thomas Storey	..	..	182
	,, Alexander Wright	..	..	183
	,, James Barrett	..	..	185
	,, Samuel Bennett	..	..	186
	,, Robert Cantwell	..	..	186
	,, George Gardner Donaldson	..	..	186
	,, Robert Barlow Gardiner.	..	..	188
	,, Edward Highton	..	..	188
	,, John Houldsworth	..	..	189
	,, Edward Hughes	..	..	190
	,, George Mills	..	..	191
	Premiums Awarded	..	..	193
	Subjects for Premiums	..	..	194
	Original Communications, list of	..	..	201
	Catalogue of Presents	..	..	203
	List of Officers.	..	..	213
	Election of Members	..	1860 Jan. 10	214
	Address on Election as President	G. P. Bidder .	..	214
	Restoration of Cracked Bells by tin soldering	S. A. Varley .	,, 17	229
1,009	Lindal Tunnel, Furness Railway (1 plate)	F. C. Stileman .	,, 24	229
	Discussion on ditto	..	..	238
1,015	Communications in Brazil	E. B. Webb .	,, 31	240
	Discussion on ditto	..	..	255
	Election of Members	..	Feb. 7	263
1,017	Netherton Tunnel Branch, Birmingham Canal.	J. R. Walker .	..	263

No. of Paper.	Subjects.	Author of Papers.	Date.	Page.
	Appendix: Experiments as to the power of Bricks to resist a crushing force.	J. R. Walker .	1860 Feb. 7.	276
	Discussion on Netherton Tunnel . . .	..	..	277
1,014	Construction of Artillery (20 woodcuts) .	J. A. Longridge	Feb. 14	283
	Appendix: 1° Force of Gunpowder (1 woodcut).	Ditto . . .	..	322
	,, 2° Effect of Twist (5 woodcuts)	Ditto . . .	..	325
	,, Conditions of stress of a cylinder built up of concentric rings.	C. H. Brooks .	..	329
	,, Effect of rotation in correcting deviation due to want of symmetry of projectile.	Ditto . . .	..	335
	,, Error produced by the axis of the trunnions not being horizontal (1 woodcut).	Ditto . . .	..	336
	Discussion on Construction of Artillery (8 woodcuts).	..	..	338
	Breech-loading Rifles	McKenzie & Wentworth.	..	461
	Election of Members	..	Mar. 6	461
1,010	Combined Steam	Hon. J. Wethered	,, 27	462
	Discussion on ditto	..	..	468
	Election of Members	..	April 3	489
	Resolution to adjourn over Easter Tuesday	..	..	489
	Invested property of the Institution . .	..	,, 17	490
1,018	Railway Breaks	W. Fairbairn .	..	490
	Discussion on ditto	..	..	518
1,019	Works on River Severn, near Tewkesbury (1 plate).	E. L. Williams.	,, 24	527
	Discussion on ditto	..	..	534
	Election of Members	..	May 1	546
1,024	Coal-Burning in Locomotive Engines (1 plate)	D. K. Clark .	..	546
	Discussion on ditto	..	..	564

No. of Paper.	Subjects.	Author of Papers.	Date.	Page.
1,025	Indian Railways: Great Indian Peninsula Railway (1 plate).	J. J. Berkley .	1860 May 8	586
	Discussion on ditto	..	..	611
	Election of Members	..	,, 22	625
1,027	Strains on Continuous Beams (4 woodcuts)	J. M. Heppel .	..	625
1,028	Breakwaters, Part II. (1 plate)	M. Scott . .	..	644
	Discussion on ditto	..	..	651
	Measurement of Gas	W. Crosley .	..	674
	President's Conversazione	..	June 5	675
	Index	..	..	677

INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1359-60.

November 8, 1859.

JOSEPH LOCKE, M.P., President,
in the Chair.

At the commencement of the proceedings, Mr. LOCKE, M.P.,
—President,—thus addressed the Meeting :—

GENTLEMEN,

I cannot permit the occasion of opening a new Session to pass, without alluding to the irreparable loss which the Institution has sustained, by the death, during the recess, of two most honoured and distinguished Members.

In the midst of difficulties of no ordinary kind, with an ardour rarely equalled, and an application both of body and mind almost beyond the limit of physical endurance; in the full pursuit of a great and cherished idea, BRUNEL was suddenly struck down, before he had accomplished the task which his daring genius had set before him.

Following in the footsteps of his distinguished parent, Sir Isambard Brunel, his early career, even from its commencement, was remarkable for originality in the conception of the works confided to him. As his experience increased, his confidence in his own powers augmented; and the Great Western Railway, with its broad-gauge line, its colossal engines, its large carriages, and its bold designs of every description, was carried onward, till it ultimately embraced a wide district of country. The same feeling induced him, in steam navigation, to construct the 'Great Western,' the largest steamer of the time, afterwards surpassed by the 'Great Britain,' to be, in its turn, eclipsed by the 'Great Eastern,' the most gigantic experiment of the age. This 'Great Ship' was Brunel's peculiar child: he applied himself to it in a manner which could not fail to command respect; and if he did not live to see

[1859-60. N.S.]

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its final and successful completion, he saw enough, in his later hours, to sustain him in the belief, that his 'idea' would, ultimately, become a triumphant reality.

The shock which the loss of Brunel created, was yet scarcely thoroughly felt, when we were startled by the announcement, that another of our esteemed Members had been taken from us.

Of that friend, I feel it to be a difficult task to speak, without giving way to feelings better fitted for the closet than a public assembly. ROBERT STEPHENSON was the friend of my youth, the companion of my ripening years, a competitor in the race of life; and he was as generous as a competitor, as he was firm and faithful as a friend. This will, I know, find an echo in the hearts of all around me; and your feelings will supply that laudation, in which it would seem inappropriate for me to indulge.

Like Brunel, Robert Stephenson commenced his professional career under his Father, George Stephenson. His early years were devoted to the improvement and construction of the Locomotive Engine, and to him we owe the type of those machines, many of which are now actually in use on railways. From the time of the Liverpool and Manchester Railway, when our joint Report contributed, in a great degree, to the adoption of the Locomotive Engine as the means of transport, and of the subsequent London and Birmingham Line, with its long Parliamentary contests, its Kilsby Tunnel, and other difficulties inherent in so new an undertaking, a multitude of other lines followed, in which there had to be foreseen and provided for, numerous difficulties, all of which were met and surmounted with coolness and consummate skill. Among these great works may be mentioned the Royal Border and High Level Bridges, and more especially, the Conway and Britannia Bridges, which were the first examples, on so vast a scale, of the Tubular principle, invented by him; as also the Bridges across the St. Lawrence and the Nile, remarkable alike for their grandeur of conception and successful execution.

To my present hearers, the enumeration of the works in which Robert Stephenson was engaged would be as a "twice-told tale." Still we cannot look back without interest upon the days of the 'Battle of the Gauges,'—the discussions upon the Atmospheric System,—and the numerous topics which have been argued within and beyond these walls.

In the enjoyment of a distinguished name and reputation, Robert Stephenson, like Brunel, has been cut off while still in the middle period of life; and although he pursued his profession with persevering energy, although he accomplished in it those triumphs of the successful application of a mind well trained and stored with practical and theoretical knowledge of various kinds, and achieved

some of the greatest works of art which have been witnessed in our day, he obtained, at the same time, an eminence in the scientific world rarely reached by any practical professional man.

It is not my intention, at this moment, to give even an outline of the works achieved by our two departed friends. Their lives and labours, however, are before us, and it will be our own fault if we fail to draw from them useful lessons for future guidance. Man is not perfect, and it is not to be expected, that he should be always successful; and as, in the midst of success, we sometimes learn great truths before unknown to us, so also we often discover, in failure, the causes which frustrate our best directed efforts. Our two friends may probably form no exception to the general rule; but judging by the position they had each secured, and by the universal respect and sympathy which the public has manifested for their loss, and remembering the brilliant ingenuity of argument, as well as the more homely appeals to their own long experience often heard in this hall, we are well assured, that they have not laboured in vain. We, at least, who are benefited by their successes, who feel that our Institution has reason to be proud of its association with such names as BRUNEL and STEPHENSON, have a duty to perform, and that duty is to honour their memory and to emulate their example.

I ought to add, in conclusion, that amongst the many private and public bequests made by Robert Stephenson, is one to this Institution, of the munificent sum of Two Thousand Pounds.

No. 1,000.—“On the Process of Raising and Hanging the Bells, in the Clock Tower, at the New Palace, Westminster.” By JÁBEZ JAMES, Assoc. Inst. C.E.

THE subject of lifting heavy weights and of moving huge masses has occupied the attention, and brought forth the inventive genius, of practical men, both in ancient and modern times; and though few, or no records remain of the methods employed in moving the masses piled up in the days of antiquity, it is evident, that if the ancients were not acquainted with the use of mechanical appliances, they possessed, at least, a knowledge of the means of combining human forces, unknown at the present day. The results they obtained are, however, thrown into the shade by the purely mechanical operations now in use, by which such masses as the tubes of the Britannia and of the Saltash Bridges are raised with certainty and facility. Feeling it to be incumbent upon all to record the means of successfully accomplishing any work, however unimportant, these brief particulars, relative to the hoisting of the great bell,

and four quarter-bells, to the chamber at the top of the Clock Tower, at the New Palace of Westminster, have been compiled, not for the purpose of comparing the operation with greater works, but with the intention of supplying an additional link in connection with works of a similar character; and as locality, and description of material, as well as the available means for its execution, must, at all times, materially affect the arrangements for such an undertaking, it is presumed, that the Paper may not be wholly uninteresting.

From the papers and correspondence relating to the clock and bells, ordered by the House of Commons, it appears, that the connection of Mr. E. B. Denison, Q.C., with the bells, commenced about the beginning of the year 1855. Sir Charles Barry, who had been applied to on the subject by the Secretary of the Commissioners of Works, recommended, that a specification should be drawn up by Mr. Denison, who was more particularly competent, not only from his knowledge of the manufacture and requisites of bells, but also from his having designed and superintended the construction of the clock; and that, in the selection of the metal to be employed, he should be associated with the Rev. W. Taylor, F.R.S., who had devoted much time and attention to the construction of bells. He further recommended, that if the Board should determine to adopt the principle of competition, application should be made to four bell-founders; Messrs. Mears, Messrs. Warner and Sons, Messrs. Taylor and Son of Loughborough, and Mr. John Murphy of Dublin: but if the commission should be given at once, he thought it would be advisable to intrust its execution to the first-mentioned firm. Mr. Denison, accordingly, at the request of the Commissioners, sent in a specification with a list of all the founders in England who had cast large bells, to whom it should be submitted for tender, but especially recommending Messrs. Warner and Sons, who, at the suggestion of Mr. Taylor and himself, had recently undertaken a series of experiments, in order to arrive at the best form and thickness for large bells. Subsequently, in consequence of Mr. Denison's refusal to admit the Chief Commissioner of Works as a third referee, his services were declined. A further correspondence ensued between the Secretary, Professor Wheatstone, and Sir Charles Barry, "in regard to the size, weight, and shape which should be adopted in the construction of these bells," which resulted in the Commissioners requesting those gentlemen "to collect information respecting the most esteemed chimes in France and Belgium, and whether there are, in either of those countries, makers acquainted with the traditions of the art, or who have applied the modern discoveries of science to the improvement of bells, or to efficient substitutes for them."

When Sir Benjamin Hall became Chief Commissioner, on the death of Sir William Molesworth, he consented to the terms proposed by Mr. Denison, and a specification for supplying the five bells was, eventually, issued, from which the following is an extract:—

“The fifth, or hour-bell, is to weigh 14 tons, as nearly as possible, and the quarter-bells are to be of such notes, that they would be, respectively, the first, second, third, and sixth, of a peal of ten, the hour-bell being the tenth; they are to be fitted to stocks of such size and in such manner as may be approved by the referees, or any two of them; but they will not be required to swing, and are, therefore, not to have gudgeons. They are each to be furnished with a clapper, and a fixed pulley, or a crank, so that they may be rung with a rope on occasions, if required. As it is understood not to be possible to calculate exactly the weight of the bells before they are cast, the tender is to state at how much per cwt. you will supply them, and also your estimate of the probable weight of the several quarter-bells, assuming the great bell to be 14 tons, with a separate item for the cost of the fittings and delivery at the Clock Tower of the Houses of Parliament, and the time at which you will engage to deliver them. The whole of the work is to be done under the directions of Edmund Beckett Denison, Esq., one of her Majesty’s Counsel, the Rev. William Taylor, F.R.S., of 73 Oxford Terrace, and Professor Wheatstone, of King’s College, London, or any two of them, and payment is not to be made until they, or two of them, have certified their final approval of the bells, after they are hung in the tower. The tender is also to state for what sum you will undertake to raise and hang the bells. All the bells, except the great one, can be taken up inside the tower; the great one is too large for the space left clear inside, and must be taken up outside. There will be no framework to provide, as the top of the tower will be built with the requisite beams, or supports to carry the stocks. The Commissioners reserve the right to get the bells raised and fixed by the builders, if they find, that it can be done more cheaply by them, by means of the tackle now in the tower belonging to them.” This tender was prepared, mainly, from the form furnished by Mr. Denison and forwarded by him to the Secretary of the Commissioners of Works, on the 30th of February, 1855.

It may be here noticed, that Mr. Denison, in his work upon Clocks, Watches, and Bells, says, in alluding to the Westminster great bell:—“but for the alteration made by Mr. Denison in the usual shape of the bell, a bell of 14 tons could not have been taken up between the walls.”

¹ Vide “A Rudimentary Treatise on Clocks, Watches, and Bells, with a full account of the Westminster Clock and Bell.” By E. B. Denison, M.A., Q.C. Page 106.

The first large bell, which weighed 15 tons 18 cwt. 1 qr. 22 lbs., was cast by Messrs. Warner and Sons, the successful competitors, at Norton, near Stockton-on-Tees; it was brought by sea to Messrs. Maudslay's wharf, Lambeth, where it was landed, on the 30th of October, 1856, and was immediately afterwards conveyed in a truck to the base of the clock tower, where it was lifted from the carriage by means of a double-purchase crab, and suspended from a staging, erected especially for the purpose of making various experiments on the tone of the bell. This bell was subsequently ascertained to be fractured, and was, therefore, condemned on the 24th of October, 1857. The fracture took place on the opposite side from where it was struck by the clapper, which weighed 12 cwt. The fracture passed from the lip, through the sound bow, and extended up the waist of the bell, and was about 40 inches in length. It appeared clean, but the metal had a coarse dull appearance, and was full of very minute holes, which were noticed on other parts of the bell, when it was afterwards broken up. The operation of breaking up the bell was commenced on the 16th of February, 1858, and lasted about five days, when it was removed for the purpose of being recast.

The second large bell, which weighed 13 tons 10 cwt. 3 qrs. 15 lbs., was cast, at Whitechapel, by Messrs. Mears, after competition, by tender, with Messrs. Warner and Sons, and was received on the 5th of May, 1858, at the New Palace, where, like the former bell, it was suspended from the same staging, in order to undergo certain tests.

The four quarter-bells, cast by Messrs. Warner and Co., were delivered at the clock tower on the 18th of June, 1858, and were hung at equal distances round the large bell, for the convenience of sounding, &c. In consequence of the third quarter-bell being condemned, as defective, it was removed to be recast. The new bell was received on the 10th of September, 1858, and all the bells were sounded, and otherwise experimented upon, by Mr. E. B. Denison, and the Rev. W. Taylor, on the 22nd of the same month.

The hoisting of the bells to the bell chamber was immediately commenced. The first quarter-bell, weighing 1 ton 1 cwt. 0 qr. 23 lbs., was lifted on the 23rd of September, in three hours; the second quarter-bell, weighing 1 ton 5 cwt. 1 qr. 2 lbs., on the 24th, in three hours and a half; and the third quarter-bell, weighing 1 ton 13 cwt. 2 qrs. 13 lbs., on the 26th, in four hours. These three bells were raised by means of a double-purchase crab, with a single chain, made of rod iron, $\frac{7}{8}$ ths of an inch in diameter. The fourth quarter-bell weighing 3 tons 17 cwt. 2 qrs. 13 lbs., was raised in six hours, on the 30th of September, by a double chain of the same diameter, in a similar manner.

When instructions were given by Sir Charles Barry, the archi-

tect of the New Palace, to carefully consider the best method for raising the large bell to its permanent position in the bell chamber, he expressed an earnest wish, that all due economy should be observed, while, at the same time, he desired, that every attention should be given to insure the safe accomplishment of the undertaking. After some consideration of the usual methods adopted for raising heavy weights, Mr. Quarm, the clerk of the works, decided, in conjunction with Mr. James, that a crab, with blocks and a fall, would be the most economical, safe, and efficient plan; and it was thought, that by making some alterations to a crab on the works, in order to give it additional power, so as to convert it into a treble-purchase crab, it would, with some large blocks, be sufficient for the purpose. A new chain-fall which could be relied upon, was manufactured by Messrs. Hawks, Crawshay, and Co.; it was a chain $\frac{7}{8}$ ths of an inch in diameter and 1,500 feet in length, made of the best cable bolt iron, and was proved to a strain of 10 tons. This chain was reeved through two three-sheaved blocks, so that the weight of the bell would be distributed over the several multiples of the chain, according to the number of reevings. This, with a standing chain, gave a power equal to about 70 tons according to the proving strain; the breaking strain of a single chain being about $13\frac{3}{4}$ tons, according to the navy proof. The bell was 9 feet in diameter at the sound bow, and 7 feet $10\frac{1}{2}$ inches in height, and the tower shaft, up which it was to pass, was only 8 feet 6 inches by 11 feet 1 inch; it was not, therefore, possible to lift it by its crown and with its mouth downwards; consequently, it became necessary to construct a cradle in which it should rest on its side.

This cradle, (Plate 1., Figs. 4, 5, 6, and 7,) was composed of strong timber, well bolted and tied together. The bell was then lifted into the cradle and securely packed and made fast in every direction, (Figs. 6 and 7,) in order to prevent its slipping. Two friction rollers were attached to the cradle at the top, and two at the bottom of each of the four uprights; and four lengths of timber were bolted to the shaft from the bottom to the top, forming guides, (Figs. 4 and 5,) for the rollers to rub against. This precaution was necessary, in consequence of the great and unequal weight at the sound bow, rendering it impracticable to suspend the bell with the cradle, from the centre; the centre of gravity having to be found by the appliances of short lifts, and the adjustment of the clip and shackle. A flitch beam with two plates 22 inches wide, 14 feet long, and $\frac{3}{4}$ ths of an inch thick, was securely fixed between six timbers, to which the upper block was made fast by means of a shackle and clip, the lower block being attached with a shackle and clip, to an oak beam firmly secured to the cradle, by massive bolts and straps. The treble-purchase crab, already alluded to, was fixed on a strong staging in the cast-iron lantern

at the top of the tower, in such a position as to leave a distance of about 19 feet between the bottom of the crab and the crown of the bell, when the latter was raised to its proper position. It was impossible, that the single barrel of the crab could take up all the chain, without incurring the risk of surging, consequent upon the coiling of the chain in so many thicknesses. It was important to avoid this, particularly as the bell had to be raised up a dark shaft of very restricted dimensions, where the cradle and bell could not be seen after being raised about 12 feet from the base of the tower, until it was landed in the clock room; several lifts were, therefore, made, as described in the tabular statement given in the Appendix, (page 12), wherein is also registered the time occupied for each lift and for the fleeting of the chain.

An iron chain-stopper of a special construction was made, for the purpose of holding the chain, during the fleeting, on the drum of the crab. This stopper was made of two pieces of wrought iron, shaped and recessed at the meeting parts, to receive three, or four links of the leading chain. These halves being bolted together, formed, as it were, one solid block of iron, with the chain held fast in the centre. The stopper was wedged-up on two stout timbers, placed upon each side of the leading chain, and the weight was then removed from the crab and taken up by the stopper, the chain being, at the same time, fleeted to the other end of the drum of the crab, ready for a fresh lift; the stopper was then removed, until another fleeting took place, when the same operation was repeated. An ordinary chain-stopper might have been used for this purpose, but it was considered, that it would not be so efficient. The slack was taken off the large crab, by means of another chain-fall from a purchase crab fixed in the clock room, so that, in the event of any accident occurring to the slack part of the chain, it would be held by the back crab. The weight of the bell, with the cradle and ironwork, together with the chain, blocks, &c., was about 25 tons, exclusive of friction. The whole of the arrangements made in the tower for lifting the bell, is shown in Fig 2.

The process of hoisting commenced at six o'clock on the morning of the 13th of October, and was continued without intermission, until noon of the following day, when the bell was safely landed on a staging in the clock room. The cradle was then disconnected, and the bell was turned over, (Fig. 8,) with the crown upwards. An eye-bolt was passed through, and being now clear of the shaft, the bell was lifted in the usual way, from the clock room to the bell chamber, on the 20th of October. It was raised a total height of 201 feet $3\frac{1}{4}$ inches, at an average velocity of about 6 feet 5 inches per hour, as shown in the Appendix, and securely packed up in its proper position, upon timbers

placed across the shaft through which the bell had ascended. Before the bell could be permanently fixed, certain works had to be executed; the whole of the staging, the crab, and the other apparatus employed in lifting, had to be removed, and the cross tubular beam to which the bell was to be suspended, had to be fixed and riveted in its place. It was not before the 11th of November, 1858, that the bell was suspended to the carriage, prepared to receive it and its four quarter-bells. This carriage, (Fig. 3,) was formed of twelve cast-iron standards, three on each side of the tower, their ends resting in cast-iron shoes, securely tied by tension rods and couplings, crossing from one side of the tower to the other, and around the walls. The standards carried a square framework of wrought-iron girders, riveted together at the angles, and braced by angle brackets to standards; india-rubber pads being placed between the standards and the girders, and rollers under the cast-iron shoes, to prevent any vibratory disturbance to the outer walls of the tower, and to allow for expansion, or contraction. The four quarter-bells were suspended, in a similar manner, from four diagonal wrought-iron girders, riveted at each angle to the framework of the carriage. The arrangements made for hanging the bells in the tower, are shown in Fig. 1.

Steam power had been applied in raising to a height of about 160 feet on the Victoria Tower, some cast-iron girders, each 12 tons in weight, which required to be all dropped into their places together. An undulating motion was, however, observed to have been produced through the beat of the valve; consequently, that mode of raising the bell was considered objectionable, as not being sufficiently steady, taking also into account the narrow aperture through which it had to pass, and the manner in which it was obliged to be slung; manual labour was, therefore, adopted.

The first experiment upon the bells took place with the clapper, on the 18th of November, when Mr. Denison ordered a temporary hammer to be made, weighing 3 cwt. 1 qr. 12 lbs., and six shifting pieces, weighing 38 lbs. each, so as to ascertain the right weight and proper fall of the hammer necessary to bring out the full sound of the bell, which was rigidly bolted up to the girders, with a gasket packing placed between them and the bell. Previous to the second experiment, which was made by Mr. Denison on the 25th of November, Mr. Quarm, on his own responsibility and unknown to Mr. Denison, ordered the bolts to be slackened. Mr. Denison was surprised at the effect, and he was then informed by Mr. Quarm, that he had reduced the fall of the hammer to 8 inches. This amount of fall not proving satisfactory, a third experiment was made with a hammer lifting 20 inches and weighing 5 cwt. 1 qr. 16 lbs., on the 29th of November,

when Mr. Denison ordered the weight of the hammer to be increased. A fourth experiment was, therefore, made on the 1st of December, with a hammer weighing 6 cwt. 3 qrs. 10 lbs., and with a fall of 13 inches. Mr. Denison then decided, that such should be the permanent arrangement for striking the hours; it was, accordingly, carried out, and continued in operation until the 29th of September, 1859, when the bell was discovered to be fractured in two places. One of the cracks is precisely in the same position in this bell, as the fracture in the former one,—exactly opposite to the place where it was struck by the hammer,—the other being at a distance of about 2 feet from the first. The first fracture is 15 inches in length, and the second, about 24 inches, but at present, it does not extend through the thickness of the bell, nor within 2 inches, or 3 inches of the lip.

The hammer of the first quarter-bell weighs 56 lbs. and falls 7 inches; that of the second weighs 60 lbs. and falls 8 inches; that of the third weighs 80 lbs. and falls 9 inches; and that of the fourth weighs 200 lbs. and falls 10 inches. These weights are exclusive of the weight of the levers.

The whole of the works were carried out by Mr. Henry Hart, assistant to Mr. Jabez James, under the personal superintendence of Mr. Thomas Quarm, clerk of the works.

The Author believes, that the following information, for which he is indebted to the Rev. W. Taylor, F.R.S., will not be without interest, as affording means of comparing the Westminster Bell with the other large bells of Europe.

The great bell at Lucerne, which is slightly ornamented, is 7 feet 11 inches in diameter, 6 feet 1 inch in height, and about 8 inches thick, the ball of the clapper being about 1 foot in diameter. These dimensions must be considered as only approximative, as he had no instruments for measuring them. The bell, which was cast in 1636, and weighs $5\frac{1}{2}$ tons, is rather narrow in the waist and thin towards the top, and has been turned twice, to enable the clapper to strike in a different place. It has no wheel, and it swings in an arc of only about 100° . Being struck about half-way up, it gives a note as good, nearly, as when struck in the proper place, but a fourth higher. A priest of the cathedral stated, that when the bell was new, the note was A, but that now it is, according to the present pitch, A $\flat$. This would show the pitch to have risen half a note; but by Mr. Taylor's fork, the note was B $\flat$.

The great bell at Cologne is 7 feet $10\frac{3}{4}$ inches in diameter at the skirt, 6 feet 2 inches high, and, so far as he could judge, $9\frac{3}{4}$ inches thick at the sound bow. The circumference of the ball at the clapper is 2 feet $10\frac{1}{2}$ inches; the stock is 19 inches in depth and 13 inches thick. The bell requires ten men to swing it

in an arc of about 150° . The weight is about 11 tons, or a little more. It is not ornamented, and looks rather thick in the waist: it has not a complete wheel. The note is G, rather flat. It hangs in a frame of wood, inside the stone walls of the tower, at about 140 feet, or 150 feet above the ground. This wooden frame rests upon a projecting part of the wall, about 10 feet from the ground.

The great bell in the church of St. Gudule, at Brussels, which dates from the year 1481, is 7 feet $1\frac{1}{2}$ inch in diameter at the skirt, 3 feet $4\frac{1}{2}$ inches in diameter at the top, and 5 feet 6 inches in height. It weighs nearly 6 tons, and it is rather cylindrical in the waist. It is hung below the stock, fastened to a piece of wood 12 inches beneath. It is not rung by ropes, but by eight men treading alternately on the ends of boards, placed transversely upon the stock. The note is G, or G $\sharp$. All these bells have excellent tones, especially that at Cologne, which, when swinging, seems to fill the whole town with a deep, full, and musical sound.

According to Otte, a German author, the great bell of Moscow weighs 144,000 lbs., is 18 feet in circumference, and 21 feet in height; the clapper weighs 4,200 lbs. This bell, which is much ornamented, was cast in 1817.

The largest bell ever cast, called Isar Kolokot, weighs 400,000 lbs.; it is 22 feet $5\frac{1}{2}$ inches in diameter, 21 feet $4\frac{1}{2}$ inches in height, and its greatest thickness is 25 inches; the ball of the clapper is 6 feet in circumference. This bell, which is much ornamented, was cast in 1734; but being broken immediately afterwards, it was left on the ground till 1837, when the Emperor Nicholas caused it to be placed upon a pedestal, or block of masonry.

The great bell at Erfurt was cast in 1497, by Gerhard Von de Campis, and is called Maria Gloriosa. It weighs 252 cwt., or, as is now thought, 276 cwt.; it is $8\frac{1}{4}$ Rhenish feet in diameter, $6\frac{7}{8}$ feet in height, and $8\frac{1}{4}$ inches thick at the sound bow. On the crown are seven ears, each weighing 1 cwt., by which it is suspended; the clapper weighs 11 cwt. Sixteen men ring it by means of four ropes, which divide at the bottom into four others; but when rung 'up to set,' it took twenty-eight men. In favourable winds, it is heard well at a distance of fourteen English miles. The note is E.

The great bell of St. Peter's, at York, weighs about $10\frac{1}{2}$ tons. It never has yet been rung 'up to set,' although thirty-six men have tried to raise it.

The usual proportion of metal in the Continental bells is 4 parts of copper to 1 part of tin.

The Paper is illustrated with a series of diagrams, from which Plate 1, (Figs. 1 to 7,) has been compiled.

[APPENDIX.

APPENDIX.

The Raising of the Great Bell, which was at the height of 2 feet 8½ inches from the ground, was commenced at the NEW PALACE, WESTMINSTER, at Six o'clock, A.M., on the 13th of October, 1858, and continued until noon of the following day.

No. of Fleets.	Periods of Fleeting.		Time employed in Raising.		Height Raised.		Total.
No.	h.	m.	h.	m.	ft.	in.	ft. in.
1	7	0 A. M.	1	0	6	10	6 10
2	8	30	1	30	6	10	13 8
3	9	45	1	15	6	10	20 6
4	11	15	1	30	6	10	27 4
5	12	45 P. M.	1	30	6	10	34 2
6	2	15	1	30	6	10	41 0
7	3	30	1	15	6	10	47 10
8	4	55	1	25	6	10	54 8
9	6	18	1	23	6	8	61 4
10	7	47	1	29	6	10	68 2
11	9	21	1	34	6	10	75 0
12	10	54	1	33	6	11½	81 11½
13	12	20 A. M.	1	26	6	11	88 10½
14	1	47	1	27	6	9½	95 8
15	3	17	1	30	6	11	102 7
16	4	14	0	57	6	9½	109 4½
17	5	0	0	46	6	10½	116 3½
18	5	40	0	40	6	11	123 2½
19	6	17	0	37	6	11	130 1½
20	7	3	0	46	6	8	136 9½
21	7	50	0	47	6	8	143 5½
22	8	40	0	50	6	9½	150 3
23	9	18	0	38	6	10½	157 1½
24	10	5	0	47	6	10	163 11½
25	10	40	0	35	6	9½	170 9
26	11	10	0	30	5	0	175 9

It was again raised from the Clock Room to the Bell Chamber, at a Quarter past Nine o'clock, A.M., on the 20th of October, 1858.

No. of Fleets.	Periods of Fleeting.		Time employed in Raising.		Height Raised.		Total.
No.	h.	m. A.M.	h.	m.	ft.	in.	ft. in.
1	9	45	0	30	7	0	182 9
2	10	27	0	42	6	9	189 6
3	11	5	0	38	6	10½	196 4½
4	11	25	0	20	2	2½	198 6¾
Height raised as above							198 6¾
Add height from the ground, at the commencement							2 8½
Total height							201 3½

[MR. ARTHUR FRY

Fig. 2.

PLATE I.

VOL. XIX

Mr. ARTHUR FRY¹ said, he was not practically acquainted with the art of bell-founding ; he could only inform the Meeting, that Messrs. Warner and Sons attributed the fracture of their bell, to the enormous weight of the hammers with which it had been struck.

Mr. QUARM had noticed, at various times, in the striking of the present large bell, a difference of sound. When the hammer did not rest upon the bell after the blow, the sound was good and clear ; but if the hammer was not immediately recovered by the recoiling apparatus, and was thus allowed to rest on the bell, it produced a chattering and a numbness in the sound which impeded the vibrations, and, to use the technical expression, 'stunned' the bell. The Rev. W. Taylor, he believed, was also of opinion, that the chattering of the hammer upon a bell operated most prejudicially upon the sound, as well as upon the bell itself. If a bell was fairly struck with a hammer of a moderate size, the weight was not of much importance ; but if the hammer was allowed to rest on the bell after the stroke, it would, sooner, or later, destroy it. The effect of an ordinary clapper striking a bell, was very different from that produced by the whole force of the weight of a clock hammer. The weight of an ordinary clapper resting, after the blow, on the side of the bell, when it was in the act of turning, with its mouth upwards, was very different to that of a hammer weighing 7 cwt., striking with all its force of gravity, upon the outside of the bell, when in a comparatively rigid state. He was opposed to the opinion, that the resting of the hammer upon the bell, and the defective arrangement of the apparatus for striking, had not materially conduced to the fracture of the bell. He attributed the fracture of the first bell, to the excessive weight of the clapper used in making the experiments, and the enormous power required in pulling it, eight men having been so employed under Mr. Denison's direction.

Mr. CHARLES MAY observed, that the first bell was struck by a blow from the inside ; the fracture, consequently, could not have been due to chattering. He was present at the experiments upon the first bell, and he heard it crack very distinctly ; he mentioned it at the time the blow was struck, and the fact was soon afterwards verified. He believed the fracture to have been due to the hardness of the composition employed in the manufacture ; for no large bell with so great a proportion of tin, could possibly resist a succession of heavy blows. The clapper, which weighed 12 cwt., was a mass of wrought iron of an elliptical section. He measured

¹ Mr. Loseby, at the commencement of the discussion, offered some remarks on the subject, but as they have been already published in several scientific periodicals, they are, by the Bye-Laws, Section xiv., clause 3, precluded from appearing in the Minutes of Proceedings.

the extent of the impression which had been made upon the wrought-iron clapper, and found it to be about 4 inches long and $2\frac{1}{4}$ inches wide. There was not any visible impression upon the inside of the bell, the metal of which was, consequently, harder than wrought iron. He thought the designer of that bell could have known little, or nothing of the alloys of tin and copper, or he never would have adopted those proportions. With but a very slight increase of tin, the result was a composition more brittle than glass. He had no doubt, that the defective quality of the bell, had arisen from its thickness, and the too great proportion of tin. He could not venture to say, whether such a mass of metal could be made by a very long process of annealing. In Mr. Mallet's work on Artillery,¹ a list was given of the atomic proportions of different alloys of copper and tin. In weight, 6 atoms of copper to 1 of tin were in the proportion of 76·29 to 23·71. The metal used in the composition of the bell, was in the proportion of 76·29 parts of copper to 24·27 parts of tin, or about 2 per cent. more tin. If the above-named atomic proportion was aimed at, the quantity of tin was nearly right, as this metal was apt to diminish in melting more than the copper; but Mr. Mallet put its specific gravity at 8·75, whereas that specified in the contract was 8·9. Mr. Mallet marked this alloy as 'brittle.'

Mr. QUARM stated, that the first bell had been also frequently struck on the outside by a hammer weighing 12 cwt., and that the proportions of the metals were the same in both bells. He did not attribute the failure of the bell exclusively to the chattering. The metal was excessively hard, and required a powerful blow to produce the sound. This hardness, and the brittleness due to the too great proportion of tin in the composition of the bell, combined with the weight of the hammer employed for striking it, and the defective apparatus used to take up the recoil of the hammer after the blow, were the causes of the fractures.

Mr. W. SMITH observed, that the Paper related only to the mechanical means employed to raise the bell to its position; but the discussion had turned upon the composition of the bell. He had been informed, that the proportions actually used were 7 parts of tin to 22 parts of copper; but it was desirable to have that fact stated authoritatively, as he had understood, that Mr. Denison did not recognise as authentic, any statements relative to the bells, or their casting, unless made by himself. It was also desirable to know, whether the contractors for the bells were permitted to make any variation from the specification supplied to them by Mr. Denison, in whom, he believed, was vested the entire responsibility.

¹ Vide "On the Physical Conditions involved in the Construction of Artillery." 4to. By R. Mallet. London, 1856. Page 82.

Mr. CHARLES MAY said, there was no mention of the quality of copper used in these bells. It was well known, that Russian copper was charcoal-smelted, and so superior to any manufactured in England, that the Russian copper coinage was largely introduced into this country, for the use of certain classes of artists. He thought it probable, that most of the Continental bells were made of charcoal-smelted copper, which would give them greater toughness than those made of copper smelted by coke.

Mr. BRAMWELL inquired whether the metal of the first bell was used in casting the second bell; and if so, in what way the proportions were ascertained in the second casting; for he was not certain, that the same proportions of tin would remain, after repeated and long-continued fusion.

Mr. GEORGE MEARS replied, that in accordance with the stipulations of the contract, the metal of the first bell was used in casting the second bell, with the addition of new metal made in the same proportions as before. The composition was limited to 22 parts of copper and 7 parts of tin, and the specific gravity to 8.9, from which no variation was permitted. The contract further provided, that the bell was not to be paid for, until Mr. Denison and the Rev. William Taylor had certified in writing to the First Commissioner, their approval of the bell, and that they were to be at liberty to reserve their certificate until the metal had been analysed. A piece was, accordingly, taken by Mr. Denison, for the purpose, as Mr. Mears was informed, of being analysed; after which, payment was made on the joint certificate of the referees.

Mr. GREAVES remarked, that the lift of the hammer was stated to be 13 inches; but it did not appear whether that was a vertical motion, or a movement at some particular angle.

Mr. POLE said, that as the musical quality of the Westminster bells had been alluded to, he could state, that the lower, or B bell of the quarters, seemed imperfect; it gave the impression of being too flat in pitch, but the note was generally indistinct, and the tone disagreeable. The other three quarter-bells, E, F $\sharp$, and G $\sharp$, were better, and the chimes would, he conceived, have an agreeable effect, if the lower bell were perfect.

The great bell had a serious musical defect, as in addition to its principal note E, and the harmonics properly accompanying it, it sounded also a false note, not contained in the harmonic, or indeed in any musical scale; something between C $\sharp$ and D. This was very prominent, and the effect to those living near was excruciating, the defect in tone being universally complained of, even by those who were unable to define its musical nature. No such false note was observable in the first bell; and as the evil had

latterly, he believed, become worse, he was inclined to attribute it, either to the crack, which was understood to have existed some time before it was discovered, or to some injudicious mode of striking the bell.

Mr. SEWELL inquired whether bell-founders had turned their attention to the effects of the sound, or vibration waves caused by the heavy hammer, as the cause of fracture of the Westminster bells. From observations, some years ago, of the peculiar clean fractures of railway axles near the naves of the wheels, or at the angle of the bearings, he was led to the conclusion, that the granulated point of fracture coincided with the angular point where the concussive wave of vibration, arising from the impacts of the flanges of the wheels against the rails, would be arrested by the nave of the wheel, or the angle of the axle bearing. A similar conclusion was arrived at, in regard to the effects of the vibratory waves of expansion and contraction, in injuring the plates of boilers, at particular parts, where those waves were arrested by riveted joints, or angles, and he had stated those views in a Paper "On Steam Boiler Explosions," read, in 1854, by Mr. W. Fairbairn, (M. Inst. C.E.,) before the British Association at Manchester.¹

"Some years since, the writer called the attention of a leading manufacturer of boiler plates to this description of plates, but some objections were urged as to the difficulty of rolling thick-edged plates, but it cannot be an insuperable one in these days of progress. Another source of injury to boilers, and one that is seldom noticed, is the liability of the plates being subjected to chisel cuts, and the joints to caulking-tool nicks. Experiments on the strength of iron have, in many instances, accidentally shown the decided loss of strength by abrasions of the surface so slight, that they were not detected until the early fracture of the iron showed their injurious effect, and ordinarily, little care is taken to avoid such abrasions of the surface in making boilers. With such cuts, or nicks at any part of a boiler, where the vibrations of contraction and expansion are arrested by any sudden change in the thickness, or the level of the surface, the fibrous structure of the iron is liable to slow, but certain injury. Analogous to this source of fracture are the numerous well-known instances, of railway axles breaking with more, or less depth of a crystalline appearance from the surface, but with the central portion fibrous. Much discussion has taken place on this apparent conversion of iron, originally fibrous, into a crystalline state, but it appears to the writer, that this conversion is strictly local, and confined to a sectional line, where some change of the diameter of the axle journal arrests the surface-wave of vibration, produced by the oscillation of the vehicle, so that a broken axle may exhibit a crystalline appearance at the fracture, and be quite fibrous on each side of that fracture. Generally, the fracture presents a worn appearance more, or less deep, next a crystalline aspect, whilst the centre shows the original fibrous structure of the axle. Incipient fracture had commenced at the surface, and attrition had afterwards worn it there, whilst the steadily deteriorating vibratory concussions were destroying the fibrous iron in the line of these concussions, until fracture took place under an

¹ Vide the "Mining Journal," 1854.

ordinary load, which had been safely carried many hundreds of times. It is well known to practical men, that fractures chiefly occur at the angle of the journal next the wheel, and appear to be due to the waves of vibration being arrested by these angular changes of the surface. The cohesion is ultimately injured there, beginning at the surface, and gradually deepening, therefore the time of fracture will be more, or less prolonged, according to the peculiar circumstance of each case. The crystallization is thus believed to be confined to the line of fracture, where contrary currents meet, or are arrested by irregularity of surface; and if this is a correct view of the cause of these axle fractures, it shows, that whenever iron has to sustain numerous constant vibrations, whether produced by motion as in railway axles, or by heat and pressure as in boilers, abrupt angles, or shoulders should be avoided, so far as it is practicable to do so."

On seeing the heavy hammer striking the first Westminster bell, suspended from a frame in New Palace Yard, and considering the probable effect of the meeting of the powerful waves of sound, or vibration thus produced, and passing round the bell in opposite directions, he had stated his belief, that it was only a question of time, how long the cohesive power of the bell metal would resist the granulating tendency of the meeting of these waves of vibration, before fracture would ultimately occur; and as anticipated, the first bell failed at a point almost immediately opposite the part struck, and the second bell had likewise failed by fracture opposite the point of impact of the heavy hammer against the bell. If, then, the conflict of the waves of sound, or vibration, set in motion by the blows of the heavy hammer tended to produce, first, a more granular structure of the metal, and, secondly, ultimate fracture, it would appear, that the power of cohesion was unequal to resist the vibrating power of disintegration, and that under such circumstances, fractures were only questions of time. If this view of the cause of the fractures of the bells was approximately correct, it followed, that cohesion to resist the vibrating force of such heavy blows, was an element to be duly considered in the composition of bells, as well as the proportion and thickness of metals to produce the required musical tones.

The meeting of opposite tidal, or river waves would illustrate, on a magnified scale, the meeting of the vibrations, or sound waves of bells, just as the force of a tidal wave against a wall, or rock, illustrated the effects of arresting the wave of concussion in railway axles, where pieces of iron even, of 3 inches and 4 inches in diameter, became quite granular at that part only, and fracture took place so frequently, as to lead to a change in the form and size of the axle bearings.

It appeared to him, that the fractures of the bells had arisen, from the cohesive power of the metals having been destroyed at the point of meeting of the opposite vibratory waves of sound, and that other bells similarly made and struck would share a similar

[1859-60. N.S.]

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fate, unless the force of those vibrations could be lessened, or the cohesive force of the metal be sufficiently increased to successfully resist them, as in ordinary bells.

Mr. J. W. PAPWORTH said, that in old bells, such as the Bourdon, (1680,) of Notre Dame, at Paris, the clapper was frequently of harder material than the bell. On striking glass bells, which from their material were as good for experiment as metal bells, there was no difference of sound due to the greater, or less hardness of the clapper, which might be of metal, or of wood; the striking force, and not the hardness of the clapper, being productive of more, or less sound. The easiest way of breaking a glass bell was either to put something immovable and hard, as small as a pin's point, against the bell opposite to the place where it was struck; or to give repeated blows, however light, with great rapidity. He suggested for consideration, whether the shortness of the interval between the blows, did not tend to cause fracture in metal bells. With regard to the composition of old bells abroad, he believed, that not only the Russian bells, but those of the Continent generally, contained other metals besides those of tin and copper, and that the point deserved consideration, although he admitted, that the quantity was very limited, perhaps so much so, that founders would probably think it too trivial to produce any result of practical importance. The treatment of copper by charcoal had, of course, been always and universally, the practice abroad.

Mr. CHARLES MAY suggested, that the experiment should be tried, of drilling a hole through the bell at the end of the crack. He had known that plan to have been followed with success, in bells of moderate size. Perhaps it might be found, as in the case of the last bell, that there was some extraordinary mistake as to its thickness. To ascertain the thickness of the first bell, recourse was had to drilling, whilst by the simple expedient of an inside and outside template, it might easily have been ascertained to the twentieth part of an inch.

Mr. JAMES said, in reply, that according to the best authorities, the proportions used in the German bells, were 80 parts of copper and 20 parts of tin. The vertical fall of the hammer last employed upon the Westminster bell was 10 inches, and the lineal movement 13 inches. He was present, on one occasion, with Mr. Denison at the foundry of Messrs. Mears, when an experiment was made upon three small bells of different alloy. The first, which contained no silver, broke into many pieces from a smart blow of a knife. The second, which contained silver to the extent of sixpence, broke after a certain number of blows; but the third, which contained a shilling, withstood the greatest number of blows, although it also, eventually, broke. He then suggested to Mr.

Denison, the propriety of making some alteration in the alloy of the great bell. He would add, that he thought the addition of silver to the alloy did not improve the sound of the bell, but it gave greater toughness to the metal.

The holes were drilled in the first bell by Mr. Denison's special order. With regard to the experiment suggested, he believed it to be useless, for if a bell was cracked, it would produce a different note, and in some cases, no correct note at all.

Mr. APPOLD believed the experiment of drilling would answer. He produced a small bell, which had been sawn through to the extent of $1\frac{1}{4}$ inch, yet it still sounded.

Mr. JOHN MURPHY,—through the Secretary,—stated, that in his early days, he had had considerable experience in the different qualities of copper. In a work of such vast importance as the great Westminster bell, the copper should be selected, and proved to be what is technically called 'tough copper,' bending easily, both when hot and cold. Bell and brass-founders, in general, paid little attention to this point, and were satisfied with what was termed 'made metal,' or metal made at other establishments to a certain consistency of temper. Although theorists were aware, that copper was the predominant metal in bells, they did not know the best proportions for producing a good tough bell, nor the quantity of granulated tin required to give to the metal a proper tenacity. Some founders did not use either granulated tin, or refined tin, but the common block tin. When granulated tin was used, with certain proportions of refined tin, and pure virgin copper, proper care being taken during the fusion, and every precaution used to insure a perfectly dry mould, a good sound bell must be the result. Another very important point in casting, but one often neglected, was to break away the solid core while still at a black red heat, to allow of the contraction consequent upon the cooling of the bell: this could easily be effected by mechanical appliances placed at the bottom; nor was there any danger to be apprehended, for red-hot bell-metal was as flexible as india-rubber. Bells had often been cracked, by allowing their cores to remain inside till they were cold. With respect to the shape of bells, the best rule for producing a good vibration was to make the width at the mouth, or widest part, double of that at the narrow part inside, close to the crown, and its perpendicular height inside, three-fourths of the diameter at the mouth. He would not recommend, that the material of the present bell should be employed in the recasting, as it would be too much impoverished by the frequent melting.

The bell constructed by himself, which was selected by Mr. Dent to strike the hours, in connection with his great clock in the centre of the hall of the Great Exhibition of 1851, was pur-

chased by the Great Northern Railway Company, and was now in use at King's Cross Station. It was composed of the purest copper, and of both refined and granulated tin, in certain proportions; its weight was about $28\frac{1}{2}$ cwt. The diameter at the mouth, which was 4 feet 7 inches, was rather more than double the width at the upper part inside, and the perpendicular height was a little less than three-fourths of the widest diameter. The thickness of the sound bow was $3\frac{3}{4}$ inches. The note was D. The same note could be produced with 5 cwt. less of metal, but the bell would be weak and bad.

November 15, 1859.

GEORGE P. BIDDER, Vice-President,
in the Chair.

No. 1,002.—“On the Government Waterworks in Trafalgar Square.”¹ By CHARLES EDWARDS AMOS, M. Inst. C.E.

IN 1843, the Government, desiring to obtain a good supply of water for the fountains in Trafalgar Square, came to the conclusion, that the source suggested by Mr. James Easton was the most economical for the purpose, and determined, that his plan should be adopted. At that time, large sums of money were paid to the water companies for supplying the public offices, and Mr. Easton's scheme was so framed as to include the supply for those offices, as well as for the fountains.

The water was to be obtained and raised by engine power, from the springs beneath the London clay. The quantity of water required for condensing the steam of the engine, being too great to be taken from the main spring, it was considered expedient to use cooling ponds, and that a small quantity of water, in excess of that required for the public offices, should be taken from the springs, which, by running continually into the cooling ponds, would keep the water clean, and in a state fit for the purpose of condensation. The basins of the fountains were intended to form the cooling ponds. The water from them was to be taken for the use of the condenser, and afterwards raised into a cistern, whence it was to be conveyed to, and pass through the jets of the fountains, where, meeting with the resistance of the air, it would be partially cooled and be returned to the basin, for further circulation. Besides the quantity so taken for the use of the condenser, any further quantity could be raised from the basins by pumps, so that the supply to the fountains could be regulated to any extent that might be desired.

Data having been furnished as to the extent of the required water supply, estimates were given both for the erection of the works, and for the annual cost of working. It was found, that the yearly interest on the cost of erection, added to the cost of work-

¹ The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

ing, would be less than the sum hitherto paid annually for the water supply to the public offices, and that, consequently, the playing of the fountains could be effected without cost to the Government. A contract was then made with Messrs. Easton and Amos for the whole of the works, which were commenced about the middle of January, 1844, a piece of ground having been selected in Orange Street, as a site for the steam engines. The first well was commenced at a level of 42 feet above Trinity high-water mark; it was of an oval form, 9 feet by 6 feet 10 inches, for a depth of about 15 feet, when it assumed a circular form to a depth of 174 feet from the surface. A cast-iron pipe, 15 inches in diameter, was then driven through 30 feet of plastic clay and to a further depth of 10 feet into a stratum of gravel, sand, and stones, and was left standing several feet in the well. Within this pipe, another, 7 inches in diameter was driven through 35 feet of green sand, and carried down 3 feet into the chalk formation, and the boring was then continued to the total depth of 300 feet from the surface.

The strata passed through were :—

	Feet.
Made earth	15
Gravel	5
Loam and gravel	10
London clay	145
Plastic clay	30
Gravel, sand, and stones	10
Green sand	35
Chalk	50
Total depth	<hr/> 300 <hr/>

A considerable quantity of water was obtained from the sand, by the 15-inch pipe, but the greater quantity came from the chalk, by the 7-inch pipe.

A second well was sunk in the inclosure immediately in front of the National Gallery, where the surface was 28·83 feet above Trinity high-water mark. This well, which was 4 feet 6 inches in diameter, was carried down 3 feet into the plastic clay, at 168 feet from the surface. A 14-inch pipe was then driven through the plastic clay, and into the gravel, sand, and stones beneath it. Within the 14-inch pipe, one of 7 inches in diameter, was driven through 42 feet of green sand, and 3 feet into the chalk, and the boring was continued to the total depth of 383 feet. The pipes were left standing some distance in the well, and most of the water came up the 7-inch pipe. The springs were stronger than those in the well in Orange Street.

The strata passed through were:—

	Feet.
Made earth	9
Gravel	5
Loam and gravel	7
Gravel	2
London clay	142
Plastic clay	30
Gravel, sand, and stones	11
Green sand	42
Chalk	135
Total depth	<hr/> 383 <hr/>

A tunnel, 6 feet in diameter, and about 400 feet in length, was driven to connect the two wells, the bottom of it being about 123 feet below Trinity high-water mark.

The engine house was erected, and a tank, in two compartments, was placed over it. The compartment which received the water directly from the springs, and which was intended to contain the low-service supply for the public offices, had an overflow, to take the excess of water into the other compartment which was intended to supply the fountains, through a pipe leading beneath Trafalgar Square, the pavement of which is about 17·83 feet above Trinity high-water mark. Another tank, intended for a high-service supply, was placed on the top of a tower, 15 feet square, carried up to the height of 54 feet. A catch well, 4 feet 6 inches in diameter, and 32 feet deep, was sunk immediately outside the engine house. A tunnel was driven from it beneath Castle Street and the National Gallery, containing the pipes for bringing back the water from the basins of the fountains, to the catch well.

A high-pressure condensing steam-engine, on the Cornish principle, having a cylinder 30 inches in diameter, with a length of stroke of 6 feet, was erected to work two pumps from the outer end of the beam; one of them was 11½ inches in diameter, with a length of stroke of 2 feet 6 inches, and capable of raising 100 gallons of water per minute, from the springs to the tank; the other pump was 18 inches in diameter, with a length of stroke of 5 feet, and capable of raising 550 gallons from the catch well into the tank, for condensation and for the supply of the fountains.

A high-pressure single-acting steam-engine, having a cylinder 30 inches in diameter, with a length of stroke of 5 feet, was erected to work a pump 10 inches in diameter, and with a length of stroke of 5 feet. This pump had, in addition to its bucket, a plunger, 6½ inches in diameter, working through its stuffing box, and by this means a delivery of water was effected, both with the up-stroke

and with the down-stroke. This engine was intended only as an auxiliary, when the principal machine needed repair.

The works were finished in December, 1844. The water rose to within 90 feet of the surface, or about 48 feet below Trinity high-water mark, and was found to be of good quality. The engine was first used on the 31st of December, 1844, and when pumping 110 gallons of water per minute, it could only lower the water in the well 4 feet. A list of the offices and places to which the water was supplied, is given in the Appendix : (page 28.)

In 1846, a further demand for water having been made, the 11½-inch pump was removed, and one 18 inches in diameter, with a length of stroke of 2 feet 6 inches, was substituted, capable of raising 350 gallons of water per minute, from the springs. The Circular Basin, on Constitution Hill, was covered in at this time, and has since been used as a low-service reservoir. In December, 1847, Buckingham Palace was supplied from the works. In 1848, a pipe was continued from the main, near the Circular Basin, on Constitution Hill, to the Serpentine and to Knightsbridge Barracks ; but some previously unknown defects in the old pipes, connected with the arrangement, interfered with the proper working, and the service was discontinued. This pipe was afterwards used for bringing water from the Serpentine, to the canal in St. James's Park. In 1849, a further extension of the works was made, by sinking a second well in the engine house, and the erection of a steam engine of 60 H.P., on Woolf's principle. This well was 6 feet 6 inches in diameter, to the depth of 100 feet ; and, to give more space for the pumps, it was gradually enlarged to a diameter of 7 feet, and continued to the total depth of 176 feet ; a tunnel being driven to connect it with the other wells.

A bore pipe, 15 inches in diameter, was driven through the plastic clay, within which it was intended to drive a smaller pipe, through the sand into the chalk, and then to continue the boring as in the other wells. In driving the large pipe a mishap occurred, which caused sand to come up the bore hole, and to mix with the water. The hole was stopped with bags of clay ; and no further use has been made of it, than as a sump well to contain the pumps. The accident arose in this way : the well sinkers were instructed to leave the 18-inch pipe imbedded in the stratum of gravel, sand, and stones, which rests upon the green-coloured sand, keeping the top of the pipe standing up in the well, above the level at which the water would be stationary ; then to drive the internal pipe through the sand into the chalk formation, as had been the previous practice at these works. In driving the pipe, great resistance was caused by the 'hugging' of the plastic clay, and considerable percussive force had to be used to force the pipes down ; in consequence, several of the screws which held the joints

were shaken out. The Author considers, that the workmen drove the pipe too low, and that it passed through the layer of gravel, sand, and stones, into the sand beneath. Openings having thus been made for the escape of water through the screw holes, sand followed, in sufficient quantity to cause inconvenience. The only remedy which appeared certain, was to stop the pipe with bags of clay, and there was less hesitation in doing this, as it was found, that the other bore pipes gave sufficient water to keep the engine fully at work.

The steam engine has two cylinders, the larger being 35 inches in diameter, with a length of stroke of 6 feet; and the smaller one, 22 inches in diameter, with a length of stroke of 4 feet. It works one double-acting pump $13\frac{1}{2}$ inches in diameter, with a length of stroke of 3 feet, for the supply to the fountains, and two 18-inch pumps, with a length of stroke of $20\frac{1}{2}$ inches, for raising water from the springs into the tanks, above the building. At an average speed of sixteen strokes per minute, the fountain pump throws about 660 gallons, and the two spring pumps together, 600 gallons per minute.

In 1852, the tank tower was raised 20 feet, for the purpose of giving a better supply, at high service, to the upper tanks, in the river front of the Houses of Parliament.

The 60 H.P. engine is now principally used, and the supply of water from the springs is abundant. The pumping of 600 gallons per minute, equal to 432,000 gallons in twelve hours, lowers the water between 20 feet and 24 feet; it then remains stationary, as long as the engine is kept working. The height to which the water will stand when at a state of rest, varies in wet and dry seasons; but the head does not appear to be gradually lowering. When the works were first put in operation, in 1844, the water rose to within 48 feet of Trinity high-water mark, in the well in front of the National Gallery. From observations extending over a considerable time, it has been ascertained, that in July and August, 1845, it stood within 43 feet of Trinity high-water mark, and afterwards, as follows:—

Years.	Least Depth below T. H. W. M.	Greatest Depth below T. H. W. M.
1846 . . .	43 feet.	57 feet.
1847 . . .	43 "	$66\frac{1}{2}$ "
1848 . . .	60 "	63 "
1849 . . .	51 "	62 "
1850 . . .	52 "	62 "
1851 . . .	56 "	64 "
1852 . . .	56 "	63 "
1853 . . .	55 "	63 "
1854 . . .	55 "	65 "
1855 . . .	56 "	64 "
1856 . . .	53 "	73 "

and on the 1st of December, 1858, it stood at 66 feet, being about the same level as in 1847.

There is no doubt, that in these wells, the greatest portion of the water is obtained from the chalk. This is confirmed by two facts; first, that when boring into the chalk beneath the well in front of the National Gallery, the auger, or boring tool, dropped suddenly several feet, clearly indicating, that a fissure was struck; and secondly, that when any repairs are needed at the bottom of the pump work, it has frequently been the practice to plug the 7-inch pipes which are driven into the chalk, and thus to stop the water from rising in them, when an engine soon empties the wells. That large quantities of water do exist, and are stored in the chalk, is proved by the supplies afforded from that source, to the towns of Brighton, Croydon, Deal, Epsom, Ramsgate, and Woolwich.

The uncertainty, however, of obtaining a good supply in the chalk is forcibly shown, by the facts connected with the well sunk on the premises of Messrs. Truman, Hanbury, and Co., some particulars of which were given in a Paper by Mr. Davison, read before the Institution in the year 1842.¹ In the autumn of 1856, the Author was consulted by that firm, as to the means of obtaining a greater supply of water. He recommended, that the original plan, as described by Mr. Davison, should be carried out; this was to continue cylinders through the sand, to that depth which showed the greatest indication of water, and to set them fast in the chalk; then to tunnel on both sides of the well, continuing the process until a sufficient quantity of water was obtained. The bore hole had been deepened, in 1850, from 400 feet to 530 feet, and the chalk, at that depth, being perfectly dry, it was useless to bore deeper. This recommendation having been adopted, the works were commenced in 1857. The pump work was removed, and a length of 110 feet of cylinders, 7 feet in diameter, was placed within the fixed cylinders, and driven firmly into the chalk, the sand and water above the chalk being completely shut out. The water in the cylinders had stood within 98 feet of the top, or about 63 feet below Trinity high-water mark. The removal of the concrete from the bottom of the well, by the aid of the chisel and the miser, in 90 feet of water, was a very laborious and expensive operation, particularly as the concrete was found to be composed of granite stones, furnace bars, cement, etc., all of which had to be broken by the chisel. The well was then dug to the depth of 300 feet from the top, being discontinued at that depth, as no water came up the bore hole. At the depth of 285 feet, the chalk showed indications of water, and the floor of the tunnels was com-

¹ *Vide Minutes of Proceedings Inst. C.E.*, vol. ii., 1842, p. 192.

menced. These tunnels, 5 feet 6 inches high and 4 feet wide, were driven north and south ; that on the north side to the length of 57 feet, and that on the south side to 48 feet. The quantity of water now obtained, does not exceed $12\frac{1}{2}$ gallons per minute, equal to 18,000 gallons in twenty-four hours.

The cost of the works in the well was . . .	£1,900
„ of the pumps	450
Total	<u>£2,350</u>

The water of the springs in the sand has been taken by tapping the cylinders, and the water now flows free from sand. It is evident, that the water from the sand springs may be safely taken, without disturbing the sand, merely by drawing the supply from the bottom instead of, as hitherto, from near the top of the sand.

A well was sunk at Messrs. Combe and Delafield's brewery, under Mr. Easton's direction, to the depth of about 48 feet into the chalk ; no tunnels were driven, and the quantity obtained from that source was 70 gallons per minute. The water stands 26 feet higher in this well than in the Trafalgar Square well, when the water in both wells is in a state of rest.

APPENDIX.

	£.	s.	d.
The Cost of the Works, as completed in 1844, was	8,392	18	8
The Working Expenses per annum, as per contract, were	492	10	0

The Places supplied, and the Revenue derivable therefrom, at the rates previously paid for Water, were :—

For Watering the Streets, &c., including Whitehall, Parliament Street, the two Palace Yards, Carlton Terrace, Cockspur Street, Charing Cross, Parliament Square, the Sessions House, Westminster	245	18	0
St. George's Barracks, Castle Street	100	0	0
National Gallery	10	0	0
Royal Academy	10	0	0
Office of Woods	10	0	0
Gwydyr House	15	0	0
Admiralty	42	10	0
Foreign and Colonial Offices, and the Chancellor of the Exchequer's House and Office, Downing Street	76	15	0
Treasury	50	0	0
Pay Office, Civil Service	8	8	0
Home Office	20	10	0
Board of Trade	20	0	0
Council Office	24	0	0
Whitehall Chapel	1	12	0
Exchequer Office and Mr. Phipps' House, Middle Scotland Yard	8	8	0
Exchequer Seal and other Offices	5	2	0
Two Official Houses in Spring Gardens	6	14	0
No. 5, Whitehall Place	3	3	0
Horse Guards, War Office Department, Whitehall Yard	46	8	0
New Houses of Parliament	200	0	0
	£904	8	0

Nothing is charged in the above list for the water supplied to the fountains, nor for the following places which were added and supplied :—

State Paper Office.
 Mr. Phillips's House.
 India Board.
 Parliamentary Offices, Abingdon Street.
 Sir George Rose's House.
 Mr. Currey's House.
 Museum of Economic Geology.
 Conduit in Middle Scotland Yard.

The Places supplied and the present Revenue, are :—

	£.	s.	d.
St. George's Barracks, Castle Street	100	0	0
National Gallery	10	0	0
Royal Academy	10	0	0
Office of Woods	10	0	0
Gwydyr House	15	0	0
Admiralty	42	10	0
Foreign and Colonial Offices, and Chancellor of the Exchequer's House and Office, Downing Street	76	15	0
Treasury	50	0	0
Pay Office, Civil Service	8	8	0
Home Office	20	10	0
Board of Trade	20	0	0
Council Office	24	0	0
Whitehall Chapel	1	12	0
Exchequer Office and Mr. Phipps' House, Middle Scotland Yard	8	8	0
Exchequer Seal and other Offices	5	2	0
Two Official Houses in Spring Gardens	6	14	0
No. 5, Whitehall Place	3	3	0
Horse Guards, War Office Department, Whitehall Yard	46	8	0
New Houses of Parliament, supply of Water equal to 250,000 gallons per day, during the meeting of Parliament, at 3d. per 1,000 gallons, 130 days	406	5	0
Ditto, 235 days at 60,000 gallons per day	176	5	0
State Paper Office	4	4	0
Mr. Phillips's House	4	0	0
India Board	20	0	0
Parliamentary Offices, Abingdon Street	15	0	0
Sir George Rose's House			
Mr. Currey's House			
Museum of Economic Geology	5	0	0
Conduit in Middle Scotland Yard	20	0	0
Buckingham Palace and Swiss Cottage	73	0	0
Buckingham Gardens	137	7	4
Royal Mews	120	0	0
St. James's Palace	164	4	0
Marlborough House	36	0	0
Ordnance Office, Pall Mall	30	0	0
Mews, late the Queen Dowager's	31	10	0
Wellington Barracks and Queen's Guard Room, Buckingham Palace	105	0	0
St. Martin's Baths and Washhouses	180	0	0
St. Martin's Roads	82	12	6
Penitentiary	120	0	0
Supply to the Fountains, 500 gallons of water per minute, equal to 300,000 gallons per day, at 1½d. per 1,000 gallons, or per year	684	7	6
Watering the Inclosures in St. James's Park	20	0	0
	<u>£2,893</u>	<u>5</u>	<u>4</u>

[Mr. Amos

Mr. AMOS repeated the statement contained in the Paper, that the water in the wells had not diminished; during a very dry season, it was gradually lowered, but in wet weather, it rose again to its original level. At the present time there was plenty of water, the principal portion of which, in his opinion, came from the chalk, into the well on the left-hand side of the front of the National Gallery. In other instances, the same success might not have followed from operations in the chalk; for the railway cuttings had shown, that whilst the chalk formation was, sometimes, extremely friable, it was, at other times, so hard, as effectually to prevent the infiltration of water. The sinking of the wells called for no particular remark, the results being such as were ordinarily met with in practice. The miners' dial was found to be useless, owing to the iron in the London clay affecting the magnet.

In answer to a question from the Reverend Mr. Clutterbuck, as to the period of the year in which the level of the water had been ascertained, in 1847 and 1858, at which times, it was stated to have been the same,—Mr. Amos said, that the level was taken in each case, at precisely the same period, in December of each year.

The Reverend J. C. CLUTTERBUCK said, he had devoted considerable attention to the subject, and had, some years ago presented to the Institution several Papers,¹ which had contributed, he had been assured, to its elucidation. The main point sought to be established in the Paper under discussion, appeared to be, that an abundant and reliable supply of water could be obtained from the wells in Trafalgar Square. Instances, however, had been quoted, amongst others, that of Messrs. Trumar Hanbury, and Co., in which the results were very different; and he had been told by Mr. Barclay, that in his establishment, the had been obliged to renounce all dependence upon water from the chalk, and could only rely upon the water companies for a regular supply. That being the case, he presumed it would be admitted as a general proposition, that a considerable amount of money had been uselessly spent by various establishments, in trying to procure a large permanent supply of water, from the sand and chalk underneath London. In all his publications upon the subject, from 1841 up to the present time, he had given repeated cautions, not to rely upon being able to pump a large supply of water from the chalk, for either sufficient water would not be obtained, or mischief would ensue in other quarters. So long ago as the year 1840, in speaking of the deep wells in London, he said:—"that the exhaustion of water from these wells lessens, or destroys the supply to others near them, is well known, in spite of the mystery thrown over the

¹ *Vide Minutes of Proceedings Inst. C.E., vol. ii., 1842, p. 155; 1843, p. 15 and vol. ix., p. 151.*

subject. The aggregate of these causes must produce some general effect. It has even been suggested, that a connection may be traced between the known, and otherwise unaccountable, defalcation of water in the River Colne, and others, on every Monday, and the probable periodical depression and replenishment of the water level under London; a solution of this obscure problem which is not absolutely impossible. This subject is beset with no ordinary difficulties, arising chiefly from the geological condition of the centre of the basin, where the continuity of the water level, as it exists in the chalk, is interrupted by the superincumbent London and plastic clays: a portion of the difficulty would, however, be removed, if the relative freedom of passage to the water, by the chalk and sand beds of the plastic clay formation, were correctly ascertained, which, as a part of the whole question, is open to practical and scientific investigation, well worth the time which those who have opportunity, may be inclined to bestow upon it."¹

He had never seen any reason to depart from that statement. It was certain, that from an aggregate of causes, a general depression of the water level under London had been produced. This opinion was confirmed by the statement in the Paper, that the level of the water in the wells was, originally, 48 feet below Trinity high-water mark, and that it stood now at 66 feet below that level. In endeavouring to ascertain the sources of that water, he had been irresistibly led to the conclusion, that there was an infiltration from the river; because he found, that the depression under London was extending more rapidly towards the north of the river, than at the centre of the greatest abstraction by pumping, and he believed it would also be found, that the depressed level rose towards the tidal outfall. In his Paper of 1850, he had particularly alluded to these facts as worthy of notice, and important subjects for future investigation. He there observed:²—“It has been before stated, that the natural vent, or outfall, of the chalk waters under London, is the mean tide-level in the River Thames, below London Bridge; and that the normal, or natural condition of the water level, has been entirely altered, there being a permanent depression, varying from 50 feet to 60 feet, at the lowest point.³ As the level in each well is lowered, by pumping, a vacuum, at a still lower level, is formed, by which the drainage from above is accelerated, and by which the waters of the Thames, passing over the outcrop of the sands of the plastic clay and chalk,

¹ Vide “A Letter to Sir John Sebright, Bart.,” by James C. Clutterbuck, M.A. Tract. 8vo. (pp. 78). Watford, 1841. Page 14.

² Vide Minutes of Proceedings Inst. C.E., vol. ix., p. 154.

³ “It has been reported, that at Messrs. Reid’s well, after a cessation of pumping for twenty-four hours, the water in the large subterranean reservoir, excavated in the chalk, does not rise to within 100 feet of Trinity high-water mark.”

will naturally descend through those strata, and thus the natural outfall is converted into a source of supply, and the drainage is reversed. This supposed influx of the tidal waters, which, from the geological condition of the basin, at the point in question, must take place, would be easily proved; first, by having a correct series of geological observations made when sinking wells; secondly, by ascertaining to what extent, alternations of level in wells, within certain limits, are coincident with the tide; and, thirdly, by a strict and close chemical examination of the nature of the waters, to ascertain whether those ingredients with which tidal waters are usually charged, are there present. As facts are collected and published, it will be shown, that a copious infiltration of water from the bed of the River Thames does actually take place; indeed, this source of supply never fails, varying only with the height and strength of the tides. It is certain, that this must, in a great measure, counteract the drainage from other quarters; but what the ultimate effect will be upon the other sources of supply, is a problem to be solved by time."

That was the conclusion at which he had then arrived, from his own observation; and the sections since published by Mr. R. W. Mylne, in which was given the outcrop of the sand and chalk, confirmed that statement. If the reasoning based on these facts was correct, it followed, necessarily, that filtered Thames water was being pumped from these wells. In a Paper by Mr. Frederick Braithwaite, (M. Inst. C.E.,) read before the Institution in May 1855, it was shown, by the analyses of different waters,¹ especially that obtained from the wells at Trafalgar Square,² that there was a larger quantity of saline matter than was ordinarily found in chalk water, and which could not be accounted for by the solution of salt, in the strata through which the water passed, or in which it was found. He did not wish to detract from the quality of the water, but it was a positive fact, that it contained 25·7 grains of sea salt per gallon. He knew, that tidal water had found its way into wells, at other places where they had been sunk below the level of the tidal outfall; such had been the case at Ramsgate, at Portsmouth, and, more particularly, at Liverpool, where the wells invariably drew in the salt water, if sunk below a certain level. At Portsmouth, there was great danger of the dockyard and of the town itself being, at some future day, deprived of water. He had been asked to give his opinion upon the state of the wells at Haslar Hospital, and he soon found, that one of them was impregnated with salt. After carefully examining the water in the surface gravel, into which some of the wells of the hospital were sunk,

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 509.

² *Vide* *ibid.*, p. 520.

he ascertained, that the salt water came through a bed of sand beneath the subjacent clay, into which the tidal water found its way, from an artificial, and not from a natural, cause; this evil had now been remedied by shutting out the tidal water, and sinking the bore pipe into a lower stratum of sand. Many of the wells in Portsmouth were tidal, showing that the water by which they were supplied, had its outfall in the sea; if, therefore, those wells should, at any time, be drawn upon to a great extent, he believed, that the tidal water would infiltrate into them. The Government should be cautious how they treated those wells. He had heard, that a private company had been allowed to acquire a source of water, of which the Government had thus permitted themselves to be deprived, although it was, probably, the only source whence could be procured a supply of pure water for the town. It was a difficult geological problem, whence the water in the deep wells at Portsmouth was derived, and how so much water found its way into the sand beds above the plastic clay, where it was collected at different levels. There was another instance in point, close to the Institution; the water from the Thames supplied, to a certain extent, the works in St. James's Park. It had been stated, that more water could be raised there at high water than at low water; though it came superficially, differing in that point from the deeper wells, still it came in to replace a depression below the tidal outfall. The special attention of Engineers should be directed towards watching the quality, as well as the quantity, of the water, and the level at which it stood in the wells.

Mr. FREDERICK BRAITHWAITE said, that in 1846,¹ the subject having been again referred to in 1850,² and in 1856,³ he had exhibited and described a chart, showing the situations of the deep wells of the Metropolis, and he had brought under notice an Artesian-well system, then projected for supplying London with water, to the extent of 140,000,000 gallons per day, by sinking eighty wells on the north side, and forty wells on the south side. He stated at the time, from his own experience upon the subject, as well as that of his Father and his Brother, that such a scheme could not possibly succeed. Numerous letters and pamphlets were published to show, that he was in error, and that by sinking 300 feet, or 400 feet, any requisite supply of water could be obtained; Providence having, of course, placed it there, in anticipation of the existence of London on the ground above. The project, however, was ultimately abandoned.

Mr. Braithwaite now exhibited two diagrams; the first, showing the monthly rainfall and the percolation through Dickinson's rain

¹ *Vide Minutes of Proceedings Inst. C.E.*, vol. v., p. 478.

² *Ibid.*, vol. ix., p. 165.

³ *Ibid.*, vol. xiv., 512.

gauge, from 1838 to 1858, also the daily rainfall for 1856; the second, showing the average monthly decrease of the water at Messrs. Combe and Co.'s well, taken daily from 1837 to 1857, when the well became dry, as he had predicted the year before. He then referred to two wells upon the premises of Messrs. Combe and Co., both of which were originally sunk to within 40 feet of the chalk; but in one of them very deep borings had been, subsequently, made into the chalk, yet only a few gallons of water per minute were obtained. More water being required, it had been stated, that by sinking a well on the backbone of the chalk, an "inexhaustible supply could be obtained." Had that assertion been correct, it would only have been necessary to sink the iron cylinders in the first well into the chalk. But a new well being deemed desirable by the then advisers of the firm, cylinders were driven through the sand strata into the chalk, shutting out the sand springs; deep borings were carried into the chalk, as had been already done in one of the wells above alluded to, and with the same result; very little water being obtained. It was only by boring holes into the sand strata, that a supply of 70 gallons per minute could be procured, but this quantity was not derived from the chalk.

Mr. Braithwaite next referred to the well in Covent Garden, from which, the pumps being 15 feet, or 20 feet above the level of those of Messrs. Combe and Co., no water could be obtained after the early morning. Here again, an inexhaustible supply was promised from the chalk, into which it was proposed to drive a pipe, 12 inches in diameter; but this pipe failing, one, 3 inches in diameter, was substituted. As in the last case, no water was obtainable from the chalk, and the pumps were, eventually, lowered, as advised by him in the first instance.

It had been argued, that if there was an average rainfall of 30 inches per annum, 10 inches would flow into the river, 10 inches would be evaporated, or be absorbed by the land, and the remaining 10 inches would percolate into the deep springs under London. He contended that, in that estimate, a sufficient allowance had not been made for evaporation. If the quantity of water in the London basin was annually replenished by 10 inches of rainfall, how was it possible, that by the abstraction of a few million gallons daily, so serious a depression should have taken place as that shown from actual daily gaugings, extending over the last thirty-two years? He did not attach too high an importance to rain gauges, as bearing upon this question, for much depended upon the absorbent nature of the soil, which varied greatly in different localities. It would appear, that at certain periods, a large quantity of rain fell in Hertfordshire, whilst there was little, or no percolation; the evaporation, consequently, had been very nearly

equal to the rainfall. It must be apparent, that the necessity for an additional supply of water in any locality, must arise from the excess of evaporation, or waste, over the rainfall. The supply of water necessary for the Serpentine, and for the ornamental water in St. James's Park, must be regulated by that excess. Mr. Glaisher had come to the conclusion, that from any surface of water exposed to the rays of the sun and the action of wind, the evaporation would be equal to 30 inches per annum. The average rainfall, had been, of late years, only 24 inches; consequently, the requisite additional supply would be only 6 inches. If, as had been publicly stated, it was found necessary to pump 500,000 gallons per day into the ornamental water in St. James's Park, which, upon an area of 40 acres, would be 1 inch per day, and 1,000,000 gallons per day into the Serpentine, which upon an area of 80 acres, would also be 1 inch per day, that supply would amount, for three hundred days, to 25 feet per annum, whilst the loss by evaporation was only 6 inches per annum. It was clear, that any amount of pumping in excess of 6 inches, must be required to meet a deficiency, arising from some other cause than the waste by evaporation. What, then, became of this enormous quantity of water? It could not evaporate; it did not overflow; it must, therefore, pass by filtration into other channels, as had been stated by competent authorities; so that, if the quantities alleged were correct, an endless chain of water was being pumped over and over again, to no useful purpose. The extent of under-drainage, and the present improved system of tillage which brought the land, mechanically, into a state fit for the absorption of water, would sufficiently account for a large amount of rainfall not reaching the springs, so as to afford that inexhaustible supply of water, which had been calculated upon from those sources.

Mr. HOMERSHAM had gathered from the Paper, this important fact, that, in December, 1858, after yielding daily, during eleven years, a very considerable and increasing quantity of water, the Trafalgar Square wells remained at the same level as in December, 1847. If, therefore, in the wells upon the premises of Messrs. Combe and Co., there had been, during these eleven years, a gradual depression of the level of the water, it could not have arisen from any deficiency in the London basin. The present Paper furnished a refutation of the title of the one read before the Institution, in 1850, "On the periodical alternation and progressive permanent depression of the chalk-water level under London,"¹ and also of the argument by which it was attempted to be supported. It was evident, that in the Trafalgar Square wells, that depression had not taken place, and his own experience con-

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 151.

firmed the fact, that when wells were properly made and sunk, in suitable localities, into the chalk, the water would stand, during a series of years, at the original level. To account for the permanence of the water level in the Trafalgar Square wells, it was asserted, that there was an increasing quantity of salt in the water, which led to the inference, that the source of supply was the Thames. This was a chemical question, and upon the authority of Mr. Dugald Campbell, who analysed the water in 1847, and again in 1857, he asserted, that instead of the saline matter having increased, it had actually diminished. Speculative opinions were thus met by two facts: first, that the level of the water in the Trafalgar Square wells was not permanently lowered; and secondly, that it contained less saline matter now, than formerly.

The impossibility of obtaining a large supply of water from the chalk had been repeatedly urged; but an appeal to facts controverted this statement also. In 1853, a company was formed to supply Charlton, Plumstead, and Woolwich, with water from the chalk. The wells and principal works were executed under his direction, and a supply of 600,000 gallons per day was the result. The works were opened in 1854, and in 1857, the quantity of water required, owing to the rapid increase in the number of consumers, became so large, that a new bore hole, 18 inches in diameter, was carried down from the bottom of the well, to a further depth of 500 feet, and the supply was thereby increased to more than 1,000,000 gallons per day; yet the water in the well now stood at the same level as at first. The Kent Water Company who, up to 1854, had obtained their whole supply from the River Ravensbourne, which had become deteriorated by sewage, finding that the consumers preferred the pure soft chalk-water of the Plumstead Company, had followed their example, and had sunk a well, from which they obtained a supply of 1,250,000 gallons per day. It was an important fact, that the sinking of that well had not produced any effect whatever upon the supply of the Plumstead works. Pleased with their success, the Kent Company proceeded to sink another well, not 500 yards distant from the first, which yielded an additional quantity of more than 1,500,000 gallons per day, and they had thus obtained from the two wells during the last two, or three years, nearly 3,000,000 gallons per day; yet the level of the water remained the same as when the wells were first used. The same company had either sunk, or were now sinking, a third well. Thus, in consequence of competition, a large suburban district of the Metropolis was now supplied with water from the chalk, and that water was practically free from chloride of sodium, containing no more salt per gallon, than the Thames water above Teddington Lock. He would not, at present, discuss the complicated question

of the amount of evaporation, but would simply record his dissent from the opinions which had been expressed upon the subject.

Mr. FREDERICK BRAITHWAITE observed, that the analysis made by Dr. Clark showed, that the water from wells on the north side of the Thames, contained 79·9 grains of sea salt per gallon, and little, or no carbonate of lime. It was important also to bear in mind, that the Plumstead well water was procured from the chalk, whilst the water in the wells of Trafalgar Square was chiefly derived from the sand, and it, undoubtedly, contained a large proportion of salt. The London basin did not extend so far as Plumstead; no fair-comparison could, therefore, be instituted between the wells at that place and those under London.

The Rev. Mr. CLUTTERBUCK remarked, that his Paper which had referred to, having been written in 1850, could not be made answerable for what had since occurred. Up to that time there had been, undoubtedly, a depression in the level of the water; and from the diagram presented by Mr. Braithwaite, it appeared, that it had continued up to the present day. With regard to the analyses of water, he suggested, that it would have been more satisfactory, if the samples taken at different periods, had been analysed by the same person; and it was also very important to know from what spot they were taken. The water in the basins at Trafalgar Square would, probably, be found to contain a greater quantity of salts than the water in the well, because, in passing several times through the fountains, it would be subjected to evaporation, whereby the bulk of the water would be decreased, whilst all the saline particles would remain.

Mr. HEMANS mentioned, with a view of obtaining some explanation of it, a singular circumstance that had fallen under his own observation. Having occasion to sink a well for railway purposes, in a large district of cavernous limestone, in the west of Ireland, a shaft, 9 feet in diameter, was carried down about 50 feet, or 60 feet, when a supply of water was obtained, but not in sufficient quantity. An auger, 3 inches in diameter, was then introduced to the further depth of 30 feet, when, to the surprise of all, instead of obtaining more water, that which had been previously secured, entirely disappeared. He could only account for the sudden disappearance of the water, on the supposition, that some channel had been opened, connected with the sea, although it was at a distance of thirteen miles. The bottom of the auger hole was just above the level of the sea, but it was far below that of the adjacent rivers. The phenomena of the district were altogether extraordinary: the rivers disappeared for a distance of three miles, or four miles, when they re-appeared upon the surface.

Professor TENNANT offered some remarks upon the supply of water in London. The population was increasing at the rate of

fifty thousand per annum, whilst the water supply, on the contrary, had considerably diminished. Thirteen years ago, in most of the leading thoroughfares, a good supply was obtained from wells sunk into the gravel; there were several in the Strand, but they were now closed, in consequence of the quantity of gas which had penetrated through the soil, rendering the water no longer available for the inhabitants of the locality. It was a very important question, how this water was to be obtained. The supply from the chalk was not constant; there were several means of verifying the fact, and it might be variously accounted for. The supply from the rainfall was, to a great extent, carried off by the sewers, and the loss arising from that cause, was continually increased by the expansion of the town. Another cause, which operated upon a large scale, was the construction of the intercepting sewers, which not only drained the water from the wells in their direction, but also the water both from the gravel and from the sand below it.

Mr. PETER BRUFF proposed to call the attention of the Meeting to a deep boring, recently made at Harwich, for the purpose of obtaining fresh water, which had been attended with some extraordinary results; but before giving a detailed account of this failure, for such it had been, he would notice another boring that he had made in the same locality, which presented different features. The town of Colchester, in Essex, containing about twenty thousand inhabitants, had been, since the year 1808, supplied by a company, with water from the land springs overlying the London clay in that neighbourhood. In 1850, in consequence of the springs having, to a great extent, run out, and become contaminated, it was found imperatively necessary to seek for a more efficient supply. The company having, through legal and other difficulties, failed in obtaining a surface supply, he advised, that a trial boring should be made into the chalk, which was carried down to a depth of about 340 feet from the surface, but with no satisfactory result. As it was found necessary to insert pipes for the entire depth, and they could not be forced down of a uniform size throughout, he was compelled to introduce smaller pipes, until the bore, at the depth stated, became useless. Another well, 9 feet in diameter, was subsequently sunk to a depth of 40 feet, and he then bored till the depth from the surface was 353 feet, when a fissure in the chalk was reached, from which was extracted a quantity of fine broken flint, and an abundant supply of excellent water suddenly burst forth, which had sufficed for the wants of the town from the year 1851 to the present time, and no diminution in the yield appeared to have taken place. The strata passed through were:—

Soil	6 feet.
Gravel	4 „
London clay	70 „
Mottled clay	20 „
Green sand	3 „
Dark plastic clay	40 „
Chalk with flints	210 „
<hr/>	
Total	353 feet.
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The bore hole was protected throughout its whole depth, by wrought-iron pipes, 8 inches in diameter, and perforated at the bottom to the height of 20 feet. The water now stood at about 5 feet above high-water mark, the same level as nine years ago. The wants of a town like Colchester were not large, averaging about 1,250,000 gallons per week ; but the supply might, if necessary, be very much increased.

He would now refer to the boring of Harwich, which town was situated immediately upon the sea coast, about eighteen miles east of Colchester. The great importance of obtaining an adequate supply of fresh water, not only for the inhabitants, who had almost entirely to depend upon the rainfall, but also for the shipping which frequented the capacious harbour, would be inferred from the fact, that during the great French war, the North Sea fleet was largely dependent upon Harwich for supplies, especially of fresh water, which had to be brought from long distances in boats, as none could be obtained in the town. Even during the late Russian war, when a few gunboats put into the harbour, water had to be sent by railway to supply their wants. Many attempts had, in consequence, been made, both by the Government and others, to obtain an adequate supply of fresh water. The earliest authentic account was that of a boring made by some private individuals in 1820, when a very small quantity was obtained from the strata above the chalk, which was entered at a depth of 64 feet from the surface. The boring was then continued to a depth of about 400 feet, but as the salt water rose in the bore hole, after sinking some distance further in the chalk, the attempt was abandoned. Several other local efforts to obtain fresh water had been subsequently made ; but after an investigation of the circumstances, he came to the conclusion, that in none of the cases, had the parties gone to the expense of jointing their pipes, with sufficient accuracy. He determined, therefore, to use cast-iron pipes, with water-tight joints, and to sink them sufficiently deep into the chalk to shut out the salt water, and thus to reach those capacious springs which had been ascertained to exist, at no very great

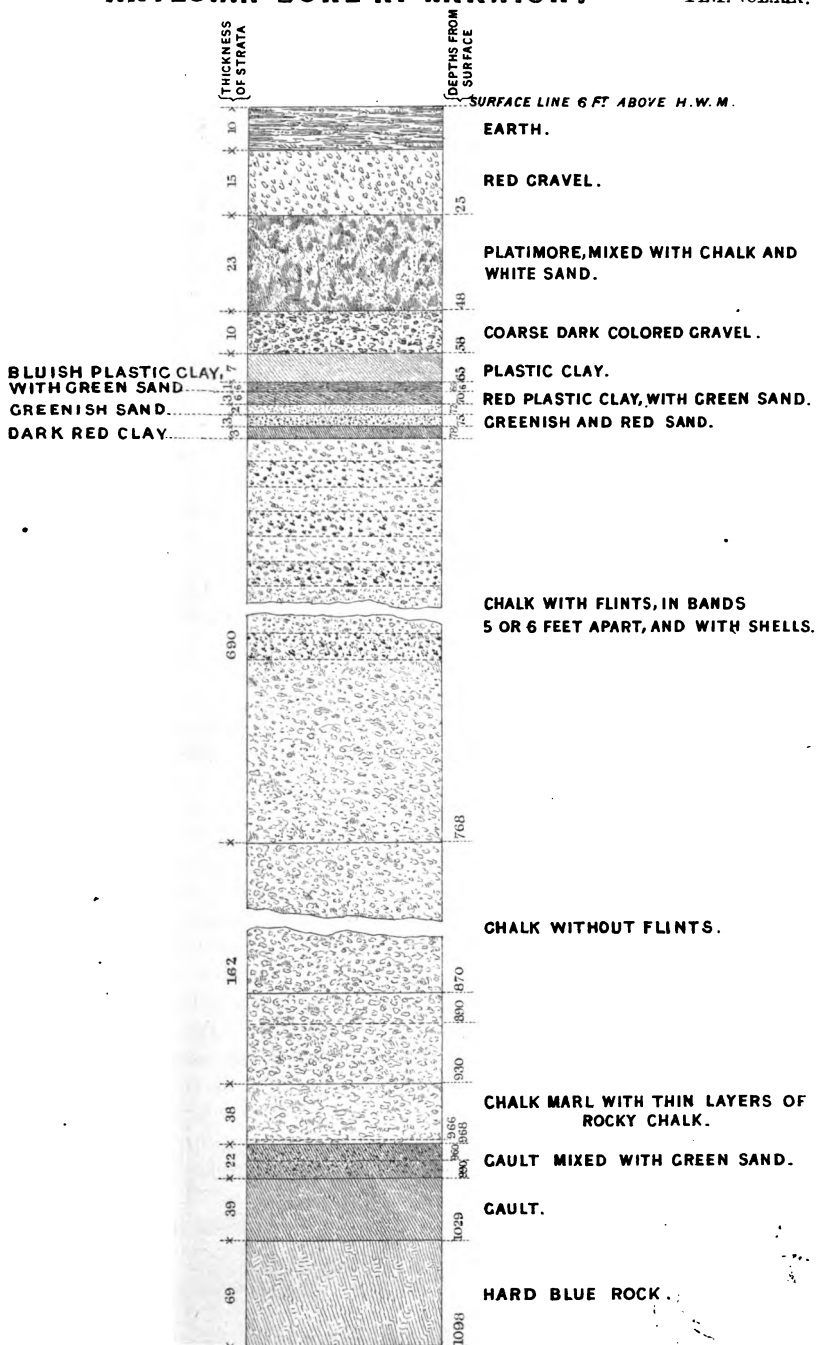
distance, in the chalk. His first operation was to sink a shallow well, on what had formerly been the foreshore of the harbour; from the bottom of the well, cast-iron pipes, 10 inches in diameter, in lengths of 9 feet, with water-tight joints, were forced down 50 feet into the chalk, a depth, he supposed, sufficient to prevent the salt water from descending into the bore hole; but with no other result than salt water, of precisely the same character as in the harbour and sea immediately adjacent. The pipes were then forced down to a depth of 480 feet, and the boring was continued, passing through numerous bands of flint in the upper stratum of chalk, one of which was of considerable thickness, but without any fresh-water springs being, apparently, tapped, as the bore hole remained filled with salt water. He finally resorted to the expedient of pumping, by which the surface of the water was lowered $3\frac{1}{2}$ feet in twelve hours, by the extraction of about 200,000 gallons; but on ceasing to pump, it again rose 7 inches in five minutes, 2 feet in three hours, and it recovered its original level in less than eight hours, without any apparent difference in the character of the water. On further consideration, he thought he would endeavour to pass through the chalk, and so, possibly, obtain water from the upper green sand. He proceeded with the work down to that stratum, which was fairly denoted, but so mixed with marl and gault, as scarcely to be permeable; and he was again disappointed. He then determined to penetrate through the gault, hoping to obtain an abundant supply from the lower green sand, the equivalent stratum to that which supplied the Artesian well at Grenelle, in the Paris basin; but a few grains of coloured sand mixed with gault, were the only indication of the existence of that formation. He next thought of attempting to reach the Wealden clay formation, but whilst deliberating whether to proceed, or abandon the work, an extremely hard rocky stratum was struck upon, somewhat resembling slate, having a line of cleavage with bed joints dipping considerably, and apparently, containing no fossils; for which neither he, nor the most eminent geologists who had been consulted, could account. The different strata passed through were shown in Plate 1^A. Having called attention to specimens of the rock to which he had referred, Mr. Bruff remarked, that the boring remained in that state to the present time. The water ebbed and flowed in the pipe with the tide, but not to the same extent as in the adjacent harbour: the difference in the oscillation was considerable, although high and low water were marked nearly at the same times.

In a Paper upon this boring, read before the Geological Society, on the 16th of December, 1857,¹ Mr. Joseph Prestwich observed,

¹ *Vide* "The Quarterly Journal of the Geological Society of London," vol. xiv., page 249.

ARTESIAN BORE AT HARWICH.

PL. 1. VOL. XIX.



“that this result had, necessarily, an important bearing on the evidence furnished by the Kentish Town well,¹ and, combined with the fact of coal rocks having been found by the deep boring at Calais, it tended to prove Mr. Godwin Austen’s view of the existence of a westward extension of a ridge of the crystalline and palæozoic rocks of the Franco-Belgian area, beneath portions of the cretaceous deposits of the south-east of England.” The failure in obtaining fresh water by boring through the chalk at Calais, a few years since, of which an account was to be found in Mr. Prestwich’s work on “Water-bearing Strata,”² and the failure at the Kentish Town well, referred to in the extract just given, appearing to be somewhat analogous to that at Harwich, it would, in Mr. Bruff’s opinion, be useful and interesting, if the strata of the whole were grouped. The apparent impossibility of obtaining fresh water from the chalk formation at Harwich, though it was found in abundance at Colchester, and also at Ipswich, twelve miles north of Harwich, would denote the existence of some local fault within that short distance. He might add, that a similar unsuccessful attempt had been made by the late Mr. Warner, the bell-founder, to obtain water upon his estate at Walton-on-the-Naze, on the same coast, and about six miles from Harwich. In that case, also, it was found impossible to get rid of the salt water.

He did not know the total sum which had been expended at Harwich, but the wages alone amounted to £2,054. 15s., exclusive of tools, pipes, and superintendence. The cost of the last 70 feet of the boring into the hard rock, was at the rate of £13. 5s. 8d. per foot. The surface of the ground at the well, was 6 feet above high water, and the top of the chalk was 74 feet below it. At Colchester, the level of the top of the chalk was 121 feet below high-water mark.

As interesting for comparison and reference, he gave a list of the strata passed through, in boring for water for some large tannery works, made about the year 1855, at Combs, near Stowmarket, as furnished to him by the proprietor, Mr. Webb, who obtained an abundant supply of water, which was believed to come from the upper green sand. Mr. Bruff had no means of accurately stating the level of the surface above high water, but he judged it to be about 70 feet.

¹ *Vide* “The Quarterly Journal of the Geological Society of London,” vol. xii., page 6.

² *Vide* “A Geological Inquiry respecting the Water-bearing Strata of the Country around London, &c.” By Joseph Prestwich, Jun., F.G.S. 8vo. London. 1851. Page 208.

Clay to the sand and first springs . . .	30 feet
Sand to the chalk, (very solid) . . .	27 „
Chalk with flints	504 „
Chalk without flints	240 „
Chalk with marl	73 „
Upper green sand	10 „
Gault	11 „

Total from the surface . . . 895 feet.

Mr. BAZALGETTE said, that assuming the correctness of the statement, that the rainfall was disposed of in three equal portions, it was evident, that the portion which passed off by evaporation was not available at all; that the greater portion of that which passed into the rivers was, at the time of heavy rains, or within a short period afterwards, carried to the sea, under the name of flood waters, leaving comparatively little available for water supply; and that thus, the main source whence it could be obtained, was the portion absorbed into the earth. The companies which supplied London derived, therefore, the bulk of their water from that portion of the rainfall which, after being absorbed by porous strata, had penetrated through its fissures down to the valleys, to rise again in springs, and to supply fresh water to the Thames. It appeared to be admitted, that it was objectionable to derive the supply of water for the Metropolis from the Thames, and that, if practicable, some other source should be resorted to. The large existing demands upon the waters of the Thames had, during dry seasons, tended to injure the navigation by reducing the scour; and of late years, the abstraction had greatly increased, as appeared from the returns of the water companies. The river, consequently, had become unwholesome and offensive; indeed, the sanitary condition of the Thames might be determined with certainty, by gauging the quantity of water flowing over Teddington Lock, and taking into account the then state of the thermometer. It, therefore, became of importance to ascertain, whether a sufficient supply of water for the Metropolis, could not be derived from that portion of the rainfall which was absorbed into the chalk, and did not reflow into the Thames, without reducing the quantity of fresh water flowing down the river, or producing injury in other respects. So many conflicting opinions had been given with regard to the permanency of that supply, and it varied so materially in different portions of the London basin, that it became important to inquire into the character of the chalk at those places, and the whole of the conditions under which the supply was found to exist, or had failed. Such

information would be very valuable, and would, probably, afford data, from which to judge of the presence, or absence of water, before sinking. The 8 inches, or 9 inches, of rainfall per annum, which was absorbed into the vast chalk basin surrounding London, still remained to be accounted for, and a bare statement of facts, that certain wells were depressed whilst others remained at their original level, was an insufficient basis on which to found an argument, that an important source of water supply might not be derived from the chalk formation, or that the present injurious demand upon the waters of the Thames should be continued.

Mr. FREDERICK BRAITHWAITE said, his attention had been directed, for many years, to the quantity of water that could be abstracted from the deep wells under London, more particularly on the north side. He believed geologists were agreed, that on the south side of London there was a fault in the chalk, from which a supply of water could be obtained. This would account for the fact, that at Plumstead, a large quantity of water was pumped daily, without interfering with the supply in a neighbouring well. He had repeatedly stated, that, owing to the fault above alluded to, the south side of London could not be considered as situated in the same field of water as the north side. For fifteen years past, it had been repeatedly and publicly asserted, that the water in the wells at Trafalgar Square was obtained from the chalk, and from no other source. He had accidentally discovered, that instead of being derived from the chalk springs only, it also came from the sand springs. As an argument against the sand springs, and to account for the increased supply of from 100 gallons to 600 gallons per minute, it was stated, that an enlargement of the far-extending fissures of the chalk, was caused by the friction of the water passing through them. To abstract 100 gallons per minute, at the atmospheric pressure, from fissures extending a distance, say of twenty miles, the diameter of the bore pipe ought to be 9 inches, whereas the pipe in use was stated to be only 7 inches in diameter. But when the quantity so obtained was 600 gallons per minute, a pipe, not less than 19 inches in diameter, would be required. Again; the quantity of chalk which must have been displaced by the enlargement of fissures extending over twenty miles, was enormous, yet no account of it had been given. It appeared from the Paper, that a tunnel was driven from the well in Trafalgar Square to that in Orange Street; but it ought also to have been added, that, owing to the want of proper precautions in driving this tunnel, the sand springs burst in and nearly drowned the well sinkers. The Paper also stated, that the blowing of the sand arose from the 'hugging' of the pipes whilst being driven through the clay, in consequence of which, the screws became detached, and a quantity of sand fell in through the

screw holes. But it was not until sand had been pumped, for several days, into the cisterns of Buckingham Palace and elsewhere, that the fact was discovered. The blowing of the sand was caused, as he had predicted, by excess of pumping over a limited area. There was nothing exceptional in the case of this well; it was neither more, nor less, than an ordinary sand-spring well, from which Buckingham Palace, the Government Offices, and the Baths and Wash-houses, were supplied with water highly impregnated with saline matter.

Mr. Braithwaite then called attention to other Tables and diagrams, prepared by him since the commencement of the discussion. The first contained different analyses of the well water in Trafalgar Square, as reported by Mr. Dugald Campbell, by the College of Chemistry, and by Dr. Clark. According to Mr. Campbell, the number of grains of saline matter, omitting the salts of potash, was 58·85 per gallon, whilst the analysis of the College of Chemistry, made subsequently to that of Mr. Campbell, showed the number of grains to be 69·9 per gallon, being an increase of 11·05 grains. At a previous discussion upon this subject,¹ Mr. Campbell maintained, that there had been an absolute decrease of saline matter. The error arose from the omission of the 13·67 grains of sulphate of potash, as shown in the analysis of the College of Chemistry. Dr. Clark reported, that this water contained 79·8 grains of saline matter per gallon; and he further stated, that by boiling this water, the bicarbonate of soda it contained, became carbonate of soda, which would act medicinally on the kidneys. Other Tables exhibited analyses of the real chalk water at Tring and at Watford, and that supplied by the water companies; they were found to contain from 14 grains to 19 grains of carbonate of lime, with a trifling quantity of other saline matter, per gallon. The surface level at Messrs. Combe and Co.'s well was 74 feet, at the Orange Street well it was 55 feet, and at the Trafalgar Square well only 43 feet above Trinity high-water mark, or 31 feet below Messrs. Combe and Co.'s well, which would account for the water standing in the Trafalgar Square well, so much nearer the surface; and it was due to that cause, and not, as had been erroneously stated, to the extraordinary strength of the springs. In December, 1844, the level of the water in the Orange Street well was 48 feet below Trinity high-water mark, and in December, 1847, 66 feet, showing a loss of 18 feet of water in the short space of three years; whereas the level of the water in Messrs. Combe and Co.'s well at those periods was, respectively, 61 feet and 69 feet below Trinity high-water level, or a loss of only 8 feet. It should further be observed, that the level

¹ Vide Minutes of Proceedings Inst. C.E., vol. xiv., pp. 519, 520, and 522.

he had given was the average of one month's gauging, whereas that of the Author was only a single gauging; but if the gaugings had been taken simultaneously in the two wells, there was no doubt, that the levels of the water would have been the same.

Mr. HOMERSHAM said, that in different publications upon the subject by Mr. Taberner,¹ and Messrs. Easton and Amos, it was admitted, that there had been variations in the level, for after a heavy rainfall, or much snow in the winter, or a very wet season, the water in the wells increased in the following spring, and under opposite circumstances, the level of the water fell; but this did not controvert the fact distinctly stated in the Paper, that the water in the Trafalgar Square well stood, in December, 1858, at the same level as in December, 1847, although large and increasing quantities of water had, during that period, been daily pumped from it. He had, since the opening of the discussion, received a letter, confirming the statement he had already made, from Mr. Dugald Campbell, who said:—"I have examined chemically the water of the Trafalgar Square wells, on three different occasions, between the years 1850 and 1857, and each time I have found a decrease in saline contents, altogether amounting to rather more than $7\frac{1}{4}$ grains per gallon. Combe, Delafield, and Co.'s well water I examined in 1845, and again in 1850; on the last occasion, there was a decrease in saline matter of rather more than $8\frac{1}{4}$ grains per gallon." With regard to the statements, as to the general and permanent depression of the level of the water, in the wells sunk into the chalk in the north of London, it was advisable, that the situation and particulars of the wells, in which this had been noticed, should be given, and the quantity of water daily pumped, as also the manner in which the observations were made. Unless the assertions were thus corroborated, not by an isolated instance, but by numerous examples, no weight could be attached to them.

In the Paper read before the Institution in 1842, it was stated, that when the water level in the Colne, at Watford, was unduly raised by heavy rains, a simultaneous effect was produced in the chalk wells of London.² In 1852, Mr. Homersham personally examined several wells in London, in order to test the accuracy of the statement, but he was unable to detect any trace of evidence in support of it, and he believed that idea to be purely imaginary.

The Reverend Mr. CLUTTERBUCK had been much surprised at the assertion, that the Trafalgar Square wells formed a notable

¹ Vide "The Past, the Present, and the probable Future Supply of Water of London." By John Loude Taberner. London, 1847. And "A Letter to the Editor of the 'Daily News.'" By Messrs. Easton and Amos; dated 5th of December, 1849.

² Vide Minutes of Proceedings Inst. C.E., vol. ii., 1842, p. 158.

exception to the variations and depressions, which had taken place in the other deep wells of London. On reference to the discussion on the Paper by Mr. Barlow, read before the Institution in 1854, he found Mr. Homersham to have said :¹—"Now on the other hand, Messrs. Easton and Amos deliberately stated, that the level of the water, in the well near Trafalgar Square, was quite as high now as when the well was first sunk, ten years since." That assertion could not be reconciled with the Paper now under discussion, in which it was allowed, that there was a difference of 18 feet between the levels of 1844 and 1847; consequently, within the period alluded to in the extract. The statement also, that the wells at Plumstead had not affected the level of those in the neighbourhood, had been distinctly denied by Mr. Dickinson. With regard to the general statements Mr. Clutterbuck was supposed to have put forth without adequate foundation, he would content himself with saying, that, when possible, he had personally taken the measurements on which he relied. He was not aware, that he had ever stated, that the wells in the chalk to the north of the Colne, in Hertfordshire, were gradually and permanently losing their water. He had been told, that such was the case; and by one gentleman in particular, who was, he believed, about to give evidence before a Committee of the House of Commons to that effect, stating that he had noted a defalcation of water to the amount of 70 feet, in a certain well in Hertfordshire. But Mr. Clutterbuck advised him to have patience, and the water would, eventually, return; accordingly, in the notable year 1852, in which Mr. Dickinson registered 41·14 inches of rainfall and 14·63 inches of percolation, through Dalton's gauge, the well in question, with others, regained its water, and the springs and rivers were filled to overflowing. He was convinced, that the same effects would always be produced, on the recurrence of a year like that of 1852. There was also an instance, in the north part of London, of a well,—that belonging to the New River Company,—which stood in 1840, at 110 feet, and sank in 1850, to 124 feet; or 33 feet, and 47 feet below Trinity high-water mark, respectively. It was by observing the variations in this well, that he was enabled to tell, when pumping was, or was not going on, at Reid's Brewery.

The year 1847 was that fixed upon in the Paper, to be compared with December, 1858. Now 1847 was a year in which the percolation of water was very limited; the water level was, therefore, unusually depressed. The register of percolation, through Dalton's gauge, was entirely blank from February to December in that year.

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 83.

He deliberately asserted, that the water question was not to be dealt with by searching after hidden sources of supply, but by taking the water which showed itself above ground. If artificial means were resorted to for the use of towns, the apparent purity of the water might attract a population ; but the failure of the sources of supply from exhaustion, might endanger its being, at some future day, deprived of water. The water question assumed, every year, a more serious aspect, and he felt certain, that if it was tampered with, mischief might easily be done, which could never be repaired.

He wished to direct the attention of the Meeting, to Brighton, which was peculiarly situated. The outfall of the chalk water was into the sea ; in taking the water, therefore, from the chalk at Brighton, no streams were affected, and no injury was done, except to the wells. Large quantities of water had been pumped up there ; in the last year, however, the supply had considerably diminished. Many years ago, he had measured the wells in Brighton, and he had since had the measurements of others, taken about four years ago, supplied to him. On visiting those wells in February last, he found many domed over, and others filled up ; in some there was water, but several were perfectly dry. Between the last-mentioned periods, the water in a well near the Cavalry Barracks had sunk 50 feet, and one within the barracks had lost 42 feet and was hopelessly dry. This was also the case with two wells, one of which had lost 31 feet, and the other 40 feet ; in a third, nearer the sea, there was a defalcation of 33 feet ; and in another, in the town itself, though still containing water, there had been a loss of 25 feet. After such instances, it would be most imprudent to venture on supplying London, from wells in the chalk. The only serious and permanent defalcation of water to be feared, in the chalk districts, was from the exhaustion produced by pumping water from shafts and wells.

Doubts had been attempted to be thrown upon the assertion he had formerly made, that when the water level near the Colne was suddenly raised by heavy rains, a simultaneous effect was produced on the chalk wells in London. He maintained such to have always been the case ; for the same cause that affected the Colne, affected the wells also. He did not say, that because the Colne rose, therefore, the wells rose ; but that when the Colne rose, the wells rose also.

Referring again to the Trafalgar Square wells, he said, it would have been more satisfactory if gaugings had been made daily, or weekly, and if these records had been incorporated in the Paper. As it was a Government establishment, such a register ought to have been kept. As to the alleged capability of the wells to furnish 600 gallons per minute, he should be glad to know, how

long that rate could be maintained. He had repeatedly given warnings upon this subject, and he had the satisfaction of knowing, that his advice had, on many occasions, been useful to those by whom it had been sought.

Mr. HOMERSHAM inquired, whether the New River Company's well in the Tottenham Court Road was the only one upon which Mr. Clutterbuck founded the assertion, that there was a gradual depression of the water level in the north of London.

The Reverend Mr. CLUTTERBUCK replied, it was the only one of which he had the daily measurements. He might mention, in addition, that Messrs. Reid and Co.'s well was known to have been considerably depressed, as also those of Messrs. Meux and Co. and Messrs. Combe and Co., to the latter of which allusion had already been made during the discussion.

Mr CHARLES MAY could carry the comparison between the depth of the chalk at Colchester and Harwich, and high-water mark, as far as Ipswich, where he superintended the sinking of a well at the works belonging to his own firm. The level of the chalk was about high-water mark, or between 60 feet and 70 feet above that of Harwich, thus showing, that the dip of the chalk was in that direction. There was an abundant supply of water in the chalk at Ipswich. There was a large tract of rising country behind, and the chalk cropped out on the upper side of the Orwell, into which ran numerous streams of fine water. He had no doubt whatever, of the depression of the water in the wells of London. In Cowper Street, City Road, the pumps of a well had been twice lowered since 1832, the water level having sunk, at least, 30 feet, though the quantity of water abstracted was always the same.

Mr. HAWKSHAW, V.P., said he was called upon, some years ago, to report upon a scheme for supplying London with water from Watford, by sinking a large well adjacent to the River Colne, and he then found, as appeared to be still the case, that there existed some misconception upon what he considered to be a very simple question. Water could not be pumped from wells sunk into the chalk, or into any other water-bearing stratum, beyond certain quantities, without affecting the level of those wells. This would be evident upon a little consideration. Subterranean reservoirs, as he might, perhaps, be permitted to call them, were similar to all other reservoirs, and followed precisely the same laws. If a well was sunk into a subterranean reservoir, into which the water happened to come in faster than it was pumped out, that reservoir would remain full; that is to say, it would continue at the precise level which happened to be determined by the natural point of overflow, or escape. But if the water was pumped out faster than it came in, then the level must, of necessity, be reduced. This rule would apply to all wells, whether under London, or else-

where. A certain given quantity of water only could be obtained from the chalk; whenever that quantity was exceeded, the level of the reservoir, from which the water was pumped, would be lowered. He thought a part of the confusion that seemed to prevail on this question, arose from the disposal of the rainfall which it was usual to make, and which had been repeated during the discussion; that one-third was disposed of by evaporation, one-third by the rivers, and one-third by absorption, or infiltration, and that this last portion alone was available for pumping. Now there was no such thing as infiltration in that sense; vegetation absorbed a certain portion of water, and another portion sunk into the ground. But it was evident, that so much of the rainfall as sunk into the earth, and was not taken up by vegetation, or by evaporation, merely passed below the surface again to run out elsewhere, if not immediately into the sea, then into streams, or rivers; consequently, the water which flowed along the streams and rivers, or found its way into the sea, must be the measure of that portion of the rainfall which penetrated the ground by infiltration. He was surprised, therefore, to find it was still considered possible to sink a well into the chalk, and pump from it an unlimited quantity of water, without affecting either the level of the well, or the quantity carried off by the rivers. He did not dispute the statement, that there were places where large quantities might be pumped without lowering the level, because there might be, at those places, a much greater influx than the quantity abstracted; but there was no water-bearing stratum anywhere, from which it was not possible to pump such a quantity of water, as would gradually exhaust it. In some cases, this might be a slow process, because, in addition to the annual quantity obtained from infiltration, a supply might be drawn from water, lying below the level of what might be termed the natural outlet, and accumulated there during long periods of time.

Mr. RAWLINSON agreed with the explanation just given, as to the philosophy of water-bearing strata; for there could be no fresh water upon the surface of the earth, nor in the subsoil, which was not due to evaporation from the ocean and other water surfaces; consequently, it was only the volume of fresh water which had been taken up by the atmosphere, which was returned to the earth.¹ Springs were the lips of reservoir basins in the substrata, out of which fresh water poured. Erroneous notions had been entertained, as to the depth at which water was to be procured.

¹ It has recently been ascertained, that the salt water of the ocean, when passed through considerable thicknesses of sand, or of sandstone rock, is filtered, and becomes fresh. But as the surface of the land is, necessarily, above the level of the ocean, and the substrata are supplied from the surface, the filtration from the ocean to the land must be very limited.—R. R. February, 1862.

Many persons imagined it was only necessary to bore deeper to obtain a greater supply ; but nothing could be more fallacious. In the new red sandstone, the coal measures, the chalk, and other geological formations, the great volume of water existed in the strata, at a depth of from 300 feet to 900 feet. He was acquainted with coal shafts, in which an immense quantity had to be tubbed out between those depths, but below 1,000 feet very little water was found ; indeed, in some very deep coal pits, water had to be sent down to lay the dust of the roads along the workings. Similar instances were to be met with in the coal pits at Pendleton and Monkwearmouth, and in those on the Duke of Newcastle's estates near Worksop. Deep well-water was also, generally, of bad quality, because it contained an excess of mineral matter. He could confirm the statements and warnings of Mr. Clutterbuck, as to the caution Engineers should exercise in relying, for large communities of people, upon a supply of water from wells. Ancient Rome, and New York, were originally supplied with water from wells ; Liverpool was partially so supplied at present ; and Manchester was originally supplied from wells in the alluvium and new red sandstone. Yet Rome found it necessary to erect numerous aqueducts, to bring into the city a volume of water equal to the amount of 350,000,000 gallons per day ; New York poured in 30,000,000 gallons per day ; Liverpool, from 12,000,000 to 20,000,000 gallons per day, in addition to that supplied by the wells. In Manchester, they had also resorted to a surface supply, and were furnished with from 10,000,000 to 20,000,000 gallons per day. In all those cases, the local wells had to be abandoned, or to be largely assisted from sources where the water was at the surface ; and that was the only safe method of water supply for large communities. At the same time, wells should not be wholly repudiated for small populations, who could not afford the expense of bringing water from long distances.

With regard to sinking wells near the sea coast, the failure at Harwich should not deter Engineers from making attempts in that direction, but should lead them, before sinking, to examine fully into all the natural conditions of the locality. At Worthing, a well had been sunk, the surface of which was about 30 feet above high-water level, and was situated at less than a quarter of a mile from the sea coast. The surface water was tubbed out by cast-iron cylinders to a depth of 70 feet, and then the chalk was bored into for a further depth of 295 feet ; the full depth of the well was thus 365 feet. Fresh water was pumped from this well, and no diminution had as yet taken place, nor was the water in any degree salt. The quantity pumped, however, was only about 150,000 gallons per day, but the strata of the district were capable of yielding a much larger supply. There was another

question involved in pumping from chalk, or limestone, or other similar strata; those strata must gradually waste away. Taking the average degree of hardness of the water at 16 grains per gallon, in every 1,000,000 gallons, there was raised more than a ton of carbonate of lime, or chalk. Whether the water was taken from a river, or from a well, the quantity of solid matter was the same. Taking only 80,000,000 gallons of this water, although it was really nearer to 100,000,000 gallons, as the daily supply for London, the total contents of solid lime, or chalk, would be 29,794 tons per annum, or more than 81 tons per day.

It was stated in the Paper, that the fountains in Trafalgar Square were inflicted upon the public, because it was found they could be supplied with water, "without cost." Such a consideration ought to have had no weight with the Government. The fountains and basins brought ridicule on the national taste; they were of no public use, and certainly, they were not ornamental.

Mr. AMOS could vouch for the perfect accuracy of the contents of the Paper. He had not contended for theories, nor had he expressed any opinion as to the quantity of water which might be derived from the chalk formation, for the supply of London. Neither had he said, that the quantity of water in the springs of the Trafalgar Square wells, had suddenly increased from 100 gallons to 600 gallons per minute. In the first instance, 100 gallons per minute were thought sufficient; when a larger quantity was required, 300 gallons per minute were obtained; and now 600 gallons per minute were pumped. He had stated in the Paper, that the abstraction of that quantity had lowered the water 24 feet, but beyond that point, the level could not be depressed. In reply to the remark, that a daily record of the height of the water ought to have been kept, he stated, that the contractors both for sinking the wells and for working them, had, during eleven years, taken daily records of the height of the water. He had not thought it desirable to introduce long columns of figures into the Paper, but had simply given the highest and lowest levels at which the water stood, in each year, during that period.

Mr. LOCKE, M.P.,—President,—in closing the discussion, said, some observations had been made which materially simplified this question, and which were entirely in accordance with his own experience. Most Engineers who had been engaged in tunnelling through the chalk, must have observed, that after several days' rain, the water percolated through, until it reached the level of the tunnel, which, from being perfectly dry, became wet, the water dropping from the roof and sides on to the floor of the tunnel. As the percolation continued, the water level descended, until the roof, sides, and floor became perfectly dry as before. This perco-

lation would continue until the water reached the level of its natural outfall.

He had often sunk wells into the chalk, and he had always found a variation in the water level. This fact, however, would not be conclusive in cases where water was being drawn from wells, much below the natural outfall, or the level of the sea. In those cases, he apprehended the rise, or fall would depend on the extent of water-bearing strata, under the influence of the absorption caused by pumping.

November 22, 1859.

JOSEPH LOCKE, M.P., President,
in the Chair.

The discussion upon the Paper, No. 1,002, "On the Government Waterworks in Trafalgar Square," by Mr. C. E. Amos, occupied the whole evening, to the exclusion of any other subject.

POOLE'S PARALLEL-MOTION SAFETY-VALVE.

After the Meeting, Mr. John Poole exhibited and explained his Parallel-Motion Safety-Valve.

It was pointed out, that the ordinary valve simply rested on its face, or seat; its vertical, or upward motion being guided by a spindle on the lower side, passing through a bar, or feathers in the steam pipe. The area of the discharge pipe was thus reduced one-third, and in some cases, as much as one-half. This valve was pressed upon by a weighted lever, moving on a centre, or hinge on one side. When in a state of rest, the lever and the centre of the spindle were at right angles to each other; but as soon as the valve rose, the angle became acute. This brought an unequal load upon the valve, and caused friction, inducing a tendency in the spindle to twist, and in the valve, to jam, or stick. The guide spindle, being below the valve face, was also liable to be corroded by foul, or dirty water, and was exposed to unequal contraction and expansion. It was likewise found, that these valves, when out of order, invariably leaked on the side nearest the hinge of the lever.

In the Parallel-Motion Safety-Valve, the spindle being on the upper side, the seat, or face was flat, and the discharge pipe was free from interior incumbrances, so that less leverage and weight were necessary. The spindle passed through a guide above, and the parallel motion was attached to the centre of the spindle, on which the valve was hinged. It was shown, by a sectional model, that the radial action of the lever did not control the vertical action of the valve, which, therefore, could not jam, or stick in its seat.

November 29, 1859.

JOSEPH LOCKE, M.P., President,
in the Chair.

No. 1,005.—“On Arterial Drainage and Outfalls.”¹ By RICHARD
BOXALL GRANTHAM, M. Inst. C.E.

IN the Address of Mr. Simpson, delivered on the 10th of January, 1854, on taking the Chair for the first time after his election as President, it is remarked, in alluding to the subject of Land Drainage, that “there has been less attention paid, in the majority of instances, to the question of outfall, as single farms and even single fields could be operated upon, at the pleasure of the owners and occupiers. The experience of recent wet seasons (1852 and 1853) has, however, proved, that large tracts of upland have been drained, to the detriment of lower levels; it has also become evident, that arterial drainage, in many agricultural districts, demands more attention, than it has hitherto received, and that the trunk lines, or the principal watercourses, and the fields contiguous to them, will be liable to be as constantly flooded in wet seasons, as they have been during the last two years, to the great injury of the pasturage, and the serious detriment of all farming operations in low lands, if measures for the arterial drainage and for the improvement of the trunk lines, or principal watercourses, continue to be disregarded. The obstructions of brooks and streams, arising from milldams, and from artificial, as well as natural weirs, applied to exclusive uses and to the irrigation of particular and comparatively unimportant properties, are too frequently maintained, to the disadvantage and injury of large tracts of land.”²

The foregoing extract accurately describes the general state of many important districts, in which property to a large amount is rendered totally useless. In the present improving and progressive state of agriculture, both arterial and subterranean drainage, but especially the former, demand the particular attention of Civil Engineers, as it is only through that body, who in their daily

¹ The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

² *Vide Minutes of Proceedings Inst. C.E.*, vol. xiii. pp. 200-1.

avocations are accustomed to take enlarged and comprehensive views of such questions, that the subject can be properly canvassed, and some efficient plan of proceeding be devised and adopted. The skill of the Engineer will be, however, comparatively useless, unless aided by the power of the Legislature.

The Author is so impressed, chiefly from his own practice and experience, with the importance of this subject, that he is confident a vast amount of good will result from the establishment of effective legislative powers, and that it will afford a comparatively new field for the exercise of professional skill and ability. These considerations have induced the Author to bring the subject before the Institution, in the hope, that it may be fully discussed, and thereby attract public attention, with a view to the full recognition of its importance, and the necessity of adopting some general legislative measure, giving facilities by which arterial drainage and outfalls may be carried out, on a comprehensive plan, and be effectively maintained in working order.

It is proposed, first, to call attention to some of the evils arising from the want of a combined system of operation; secondly, to give an account of the existing impediments which prevent the adoption of arterial drainage; thirdly, to describe the class of works necessary to be carried on; and lastly, to point out some of the leading principles in the construction of drainage works, by which the object in view may be accomplished.

There is, perhaps, scarcely a district in this country where one of two conditions does not exist: either the lands cannot be drained at all, or they are injuriously affected by the drainage of those above them. The first of these cases is exemplified in those districts lying between the sources of streams, and extending for some distance towards the natural outfall; so that the owner of an estate, situate between those limits, cannot legally straighten, or deepen the stream, or river running through the estate, and thereby drain his land, because he would, by so doing, inundate his neighbour's land lower down the stream. In many cases a single person, who is unwilling to drain his property, may prevent any improvements by adjoining owners, however much they may desire them.

PIPE DRAINAGE.—Subterranean, or pipe drainage has generally been adopted as the first step in the improvement of land. The vast benefits which have resulted from the judicious application of this system will, undoubtedly, lead to a great extension of it. But even on its present scale, in addition to the field drains and ditches being better cleared out, it has already created a large increase in the quantity of water flowing down rivers, brooks, and minor streams.

The effect has been, that the water is discharged in a shorter time than formerly, causing more frequent floods, the brooks and minor streams being, in numerous instances, insufficient to convey away the large quantities of water which so suddenly flow down; and, at other times, the rivers and streams contain less water than formerly; in many cases, not sufficient for the ordinary supply of the country, or of the towns which may be dependent upon them.

To give some idea of the increase in the extent of pipe, or under-ground drainage within recent years, the following circumstances may be quoted. About ten years ago, power was given, by Parliament, to the Government, to lend £4,000,000, under the sanction and control of the Inclosure Commissioners of England, for the drainage of land, and for erecting and repairing farm buildings, &c. Subsequently, private drainage companies have obtained similar powers, subject to the control of the same Commissioners, and up to this time there have been expended by these means, in the subterranean drainage alone of about 800,000 acres of land, a sum of upwards of £4,000,000. A large quantity of land has also been drained by the Crown, by corporate bodies, and by private individuals, the exact amount expended in which it is impossible to ascertain, but it may be estimated at double the sum previously named. There still remain large tracts of land that require to be so drained, and from the beneficial effects hitherto produced, an annually increasing extent will, probably, undergo the same treatment. It may be imagined, that if, from the above number of acres alone, the water falling upon the surface can now be run off, in the course of a few days, to the arterial drains and outfalls, instead of slowly trickling through the soil as before that system of drainage was applied, how absolutely imperative it is, that provision should be made to carry off the water in the most direct and efficient manner, and that, in many works executed for the purpose, there should be ample allowance to meet a much larger flow of water.

Mr. Bailey Denton, (Assoc. Inst. C.E.,) in his Paper, "On the Progress and Results of the Under-drainage of Land in Great Britain," read at the Society of Arts in December, 1855,¹ gives full details of what had been done up to that time, and of the probable amount that would, at some future day, be required. There was no particular reference to arterial drainage and outfalls, beyond the expression of an opinion, that the main and tributary outfalls throughout the country must receive attention, as soon as possible, and that provision should be made on an effective scale.

¹ Vide "Journal of the Society of Arts," vol. iv. p. 45.

MILLS, WEIRS, &c.—Another cause of the difficulty of draining land is the existence of mills, weirs, dams, and other obstructions in rivers, as well as their crooked and confined channels; all of which impound the water upon the uplands, to the injury, in some cases, of ten, twenty, and even fifty-fold the value of the mill, or property maintained by the dams. Another question to be dealt with is, that public roads cannot, in all cases, be interfered with, to admit of better outfalls; the existing culverts, or bridges, being rarely either sufficiently deep, or capacious, so as to admit of the application of an arterial system of drainage.

The other part of the subject,—the injury which lands suffer by being inundated by the drainage of the uplands,—is as extensive as that already alluded to, and is attributable to nearly the same cause,—the want of combination among the possessors of property in executing land-drainage works, the vast expense of which would otherwise be entailed upon single individuals. In some cases, too, it is almost impossible to form sufficiently capacious channels, and outfalls to carry off the surplus waters, and it is always a hardship, that one person should be able to improve his position at the expense and annoyance of others. This is strongly exemplified by the experience of the drainage of towns, under the Public Health Act, where, at the commencement, no provision was made at the outfall, for the disposal of the sewage; showing a want of forethought which should, in future, be avoided in land drainage, before any general and complete system is undertaken. Both these cases are well illustrated by the instance which Mr. Simpson has kindly allowed to be referred to—that of a proposed drainage in the vicinity of Wareham, in Dorsetshire.

WAREHAM.—In 1855, Mr. Simpson was consulted by the Trustees of the Right Honourable the Earl of Eldon, as to the best means of draining and improving the marsh land belonging to the estate, in the neighbourhood of Wareham. This town is surrounded by marshes, which are stagnant during a great portion of the year. The trustees, being owners of house property, were also anxious on that account to improve the sanitary state of the locality. The entire marsh land of this district is about 3,000 acres in extent, of which it was proposed to include 2,550 acres. It is situated, chiefly, on the borders of the North and South Rivers, extending from below the confluence of these rivers, in the Wareham Channel, to about four miles above the town. The breadth of low land in both valleys averages, together, about three quarters of a mile; and at the lower end, near the Wareham Channel, the width is rather more than one mile and a half.

The soil is principally alluvial deposit, brought down by the rivers during floods; and where isolated attempts have been made to drain small portions of it, evidence has been afforded of its great fertility. The whole of this land has, at some remote period, been reclaimed by the neighbouring landowners, from the estuaries of the North and South Rivers. Small embankments of mud have been thrown up on each side of the river channels, following their circuitous course along the muddy foreshore; the materials being obtained by excavating a side ditch close to the embankment. The lower drainage is provided for by other ditches, (acting also as fences), which communicate with trunks, having sluice flaps fixed in the embankment at various points, for discharging the drainage into the rivers at low water of every tide. No attempt has ever been made to divert the upland streams, which frequently do great mischief during floods, and permanently maintain the water in the ditches at a much higher level, than it would otherwise remain from the tidal drainage. These works have existed many years, and are kept in tolerable repair by the respective landowners.

The range of tide in the Wareham Channel, into which this district drains, does not exceed 6 feet on the average, during springs, and $3\frac{1}{2}$ feet during neaps. The general surface of the marsh land on the lower side of the town, varies from 2 feet to 3 feet below high-water mark of spring tides. Above Wareham it rises gradually inland, until, at Holme Bridge, on the River Frome, one mile and a half from Wareham, it is about 12 feet above high water. At East Stoke Mill, about three miles from Wareham, the land is 25 feet above that level. This affords facilities for drainage by gravitation, and the proposed works were arranged so as to discharge by outfalls, continued down the side of the river, to a level sufficiently low to prevent the lands being injured by backing up the water during floods. It was also intended, that the river should be properly embanked, to confine the flood waters to its channel.

At the lower end of the marshes, below Wareham, where the great bulk of the land is situated, the surface is only $2\frac{1}{2}$ feet above low water of neap tides, which is the maximum power of the present system of drainage at such periods; and if 1 foot is allowed for accumulation in the ditches, between the tides, the average depression of the drainage will be only 18 inches below the surface of the land during neap tides. This is totally insufficient for the outfall. In order, therefore, to effect the complete drainage of this part of the marsh land, and to depress the water in the ditches to a permanent level of about 3 feet below the tide, so as to afford a clear outfall for the under-drainage pipes, (in-

tended to be laid at a depth of not less than $3\frac{1}{2}$ feet below the surface,) it was obviously necessary to resort to mechanical aid. Mr. Simpson recommended, that a small steam engine should be provided, to be used in connection with upper and lower reservoirs. These reservoirs were to be formed out of the old river channel, which could be made available for the purpose, at a trifling expense. This arrangement of reservoirs forms an important feature of these plans. It was proposed with the object of reducing the pumping lift to a minimum, and of economising the cost of construction and of working, to the greatest possible extent. The lower reservoir receives the accumulation of any sudden fall of rain beyond the power of the engine, and prevents, by the extent of surface, any material rise in the water level of the ditches, or dikes. The upper reservoir discharges the accumulated drainage at low water, and then receives the continued discharge from the engine between tides, at a level not much above low water. This would, otherwise, have to be pumped either to high-water line, or to the level of the tide for the time being, as is generally the case in similar districts where pumping is resorted to.

In the event of its being deemed advisable to promote a Bill in Parliament, or in case of any general Act being introduced, which could be made available for carrying out large drainage projects, it was recommended, that in addition to perfecting the drainage of the Wareham district, comprising the lands of East Stoke, Carey, Keyworth, Arne, and Middlebere, provision should be made for reclaiming upwards of 500 acres of mud land from Wareham Harbour, at present covered with about 2 feet of water at high-water spring-tides. It may be observed, that the straightening and deepening of the river below Wareham Bridge would, no doubt, greatly improve the navigation, without imposing any charges, or dues on the shipping, as the expense of the river improvements would not be so onerous on the landowners, as to induce them to seek relief by a charge on the navigation. The intended new works comprised several cuts, for straightening and improving the channels of the North and South Rivers, for diverting the upland waters from the marshes, and for conveying the lower drainage waters to the pumping station near the South River Head, together with embankments at Middlebere and Wareham Bays. No ditches were to be excavated near the side of the new embankments, for the purpose of procuring material for their foundation, as sufficient earth might be obtained from the adjoining high ground, and from the partial excavation of the reservoirs. The existing ditches were to be filled up, where the present embankments were retained, as it was thought their strength was much impaired by the ditches at the foot of the slope. These ditches also en-

couraged vermin, whose burrowing frequently caused leakage through, and ultimately a breach in, the embankment. The lower drainage was to be lifted by a steam engine of 20 H. P., with upper and lower reservoirs for containing the accumulated drainage. There was to be a syphon pipe under the North River, for conveying the drainage from the Keyworth lands, together with sluices for discharging it into the Wareham Channel, near the North River Head, and everything requisite for the complete and perfect drainage of the district, under legislative powers.

The cost of carrying out this general scheme was estimated at £22,000. It would involve an average annual charge of 7s. per acre on the whole district, to provide for interest of capital expended, and for the cost of working and maintenance, after deducting the annual value of the reclaimed land.

In case the attempt to introduce a general scheme should fail, in consequence of the absence of unanimity on the part of the landowners, or the want of a General Act of Parliament, Mr. Simpson deemed it advisable to point out the next best course, viz., the adoption of some limited plan, providing, chiefly, for Lord Eldon's land, and which should be capable of being carried out, as much as possible, independently of other proprietors. This alternative obviously involved considerable difficulty; because the relative situation of other lands, belonging to dissenting, or unfavourable owners, rendered them likely to be benefited at Lord Eldon's expense; and because no complete, or efficient scheme could be carried out, which did not provide for the alteration of the navigable part of the river below Wareham,—a proceeding not unlikely, in the absence of Parliamentary powers, to meet with some opposition from the public, and from a few persons who pertinaciously insisted, that the river should be maintained in its present course. Having these difficulties in view, four alternative plans were submitted, termed private projects Nos. 1, 2, 3 and 4,—in addition to that called a public project,—so as to enable Lord Eldon's trustees and agents to select that plan which would be least likely to interfere with the property of opposing owners, and which would best meet the circumstances of the case, after negotiating with the parties interested. Regard was also had to the probable ultimate extension of the adopted plan, as a more general scheme of which this would then form an integral part, without involving any material additional outlay, for alteration and reconstruction of works.

The following statement gives the comparative estimated cost of the several propositions :—

WAREHAM.—DORSET.
DRAINAGE OF THE ARNE ESTATE AND ADJACENT PROPERTIES.
STATEMENT of the various DRAINAGE PROJECTS, COMPARATIVE COST OF WORKS, MAINTENANCE, ETC.

PROJECTS.		Land Improved.	Land Reclaimed.	Total Land in Drainage District.	Land Drained, the property of Lord Eldon.	Total Outlay for Construction of Works.	Total Annual Charge per Acre.
		Acre.	Acre.	Acre.	Acre.	£.	s. d.
PUBLIC PROJECT.—East Stoke, Carey, Keyworth, Arne, and Middlebere Districts		2,050	500	2,550	1,300	22,000	7 0
PRIVATE PROJECT.—No. 1. Wareham, Bestwall, Giggers, Isle, Arne, and Middlebere Districts		840	400	1,240	1,200	13,310	7 7
Ditto	No. 2. Wareham, Bestwall, Arne, and Middlebere Districts	730	190	920	900	9,944	10 11
Ditto	No. 3. Whitefield, Arne, and Middlebere Districts	500	180	680	680	6,479	9 6
Ditto	No. 4. Ditto	500	180	680	680	6,545	10 4

The reclaimed land is valued at £20 per Acre.

This example embraces nearly all the difficulties and evils which would generally occur in most districts, and which it is so desirable should be provided against and remedied.

Having now, in a general manner, referred to the causes of the injury which arises from the present state of things, the next point for consideration is the impediments which exist. These must mainly be attributed to the state of the law, which, as it at present stands, is totally unsuited to the existing and advancing state of society, and to the interests of the holders of property. For while it jealously watches many unprofitable and useless rights and forms connected with property, it as surely prevents the wants and necessities it ought to assist and modify, from being attended to. It has been said, that the powers of the Legislature must aid the skill of the Engineer. But the plans of the Engineer are easy of execution, compared with the removal of the complications which are thrown over the whole question by the law, and these must be removed before any real good can be attained. The few attempts at legislating upon the subject have been ill-designed, and too feeble and timid to grasp the whole question, in an effectual manner. The best measure which has ever been proposed, in the Author's opinion, was the Bill of the Earl of Carlisle, in 1852, which it is to be hoped, with additional provisions, may yet be made to accomplish the great objects of improved arterial drainage and outfalls. The law, at present, prevents arterial drainage being carried out on a combined and comprehensive system, by not allowing a person to deal with his own property in this respect as he best can; neither is it sufficient to allow of certain things being done, in order to facilitate such objects as would enable individuals, or associated bodies, to act for the good of all concerned. In fact, nothing can be effected, until the law is modified and changed, and its powers enlarged and liberalised.

The points involved in this question, which more immediately concern the Engineer, are the straightening and deepening of both internal and tidal rivers; and the removal of mills, dams, weirs and other obstructions, in order to produce uniform inclinations towards the outfalls of streams. The gradients, or inclinations, should be adopted with reference to the soil, through which the rivers flow, to obviate the scouring action of the water on the banks and bottom of the streams. It is also necessary to impound the surplus water, so as to preserve a uniform minimum supply to the channels of rivers at all times, and to provide works for carrying off field drainage, for the irrigation of adjoining lands, for the reconstruction of bridges and culverts under public roads, and for the application of the water to the supply of towns and villages, which, in many cases, may be altogether deprived of supplies by any complete system of drainage.

IRELAND.—The Author conceives, that some allusion should be made to the drainage works which have been executed in Ireland, as they form the best examples of arterial and outfall works in the United Kingdom.

In the year 1846, when Ireland was visited with one of the greatest calamities that can befall a country, the deprivation of food, the Government proposed that, for the sake of giving employment to the people, arterial drainage works should be undertaken, and that the lands should be charged with the cost, "in proportion to the benefit conferred;" the assent of the owners being first obtained to a limited outlay, and the Government lending a certain proportion of the money, and granting the remainder. The urgent necessity that immediate employment should be given, taxed the utmost energies of the Engineers, acting under the Board of Works, who designed and executed the several works with the utmost rapidity; so that in five months and a half, no less than one hundred and one districts were surveyed, and the works planned, estimated, and, with few exceptions, commenced. Owing to this rapidity, many, as might have been expected, were imperfectly and wrongly projected, and the cost, ultimately, much exceeded the original estimates. Subsequently, when the pressure caused by the famine had been somewhat relieved, several of the works were stopped, for want of the assent of the owners to a further expenditure. A Government Commission, consisting of Sir Richard Griffith, Bart., Sir William Cubitt, (Past-President Inst. C.E.,) and the late Mr. Rendel, assisted by Mr. John Clutton, was then appointed to inquire into twelve of the districts. Their Report, which was published in 1853, gives a full account of all that had been done up to that time, describes the extent of the works, and recommends the manner in which they should be completed. In that Report it is stated, that the works exceed 385 miles in extent; the catchment basins comprehending an area of 1,139,182 acres, of which about 77,546 acres were liable to injury by floods.

It is generally admitted, that great benefit has resulted from these works, which were mostly designed upon a comprehensive scale, and would serve as outlets for heretofore pent-up and flooded waters. Large districts, which formerly were always under water, are now entirely freed from it, and capable of profitable use. These drains are, in many cases, sufficiently large to allow an extended area to be discharged into them, at any future time.

The great drawback to the efficient working of this system is, that there was not, at first, so far as the Author can learn, any provision made, by which the works were to be maintained and kept in repair after the first year. Another objection is, that a

large sum of money was expended in works for improving, and in some cases, creating water power, which proved totally useless and inconsistent with the primary object of the drainage schemes.

The following Table, (page 64,) gives the results of five cases, in different parts of Ireland, out of the one hundred and one which were executed, but they afford a fair average of the whole. It shows the area of land drained in each case, the total cost, the original annual value of the lands drained, and the increase upon the annual value; also the rate of the cost per acre, and the annual charge to defray principal and interest.

These drainage operations were principally undertaken under the Acts of Parliament 5 and 6 Vic. cap. 89; 8 and 9 Vic. cap. 69; and 9 Vic. cap. 4; the latter of which was generally called the 'Summary Proceedings Act,' and which was to find employment for a starving population. Other Acts were passed in the following years up to 1850,—to appoint additional Commissioners, to continue 9 Vic. cap. 4, and several for providing additional funds for loans and advances on works of drainage. Many of the provisions which are contained in the above Acts, would serve as excellent precedents for legislation on the subject in England.

DRAINAGES IN IRELAND.

NAME OF THE DRAINAGE DISTRICT.	LANDS DRAINED, OR IMPROVED.															
	Area of Lands within One Mile of the Lands Drained, or Improved, belonging to the same Proprietors as the Lands Drained, or Improved.		Area of Lands Drained, or Improved.		Total Cost.		Original Annual Value of Lands Drained, or Improved.		Increase in the Original Annual Value of Lands Drained, or Improved.		Cost of Works per Acre.		Annual Charge per Acre of Principal and Interest.			
	A.	R. P.	A.	R. P.	£.	s. d.	£.	s. d.	£.	s. d.	£.	s. d.	£.	s. d.		
District of the Blackwater, in the Counties of Meath and Kildare ..	11,010	1 31	3,827	2 18	12,115	16 6	2,119	1 8	1,034	7 9	3 3 3	4 0				
District of Lough Neagh, in the Counties of Antrim, Armagh, Down, Londonderry, and Tyrone. ..	59,002	1 31	29,625	1 24	156,277	14 10	25,656	2 5	9,953	17 7	5 5 6	6 0				
District of Oranhill, in the County of Galway	2,303	2 19	974	0 16	3,871	16 2	260	12 5	315	10 1	3 19 6	5 9				
District of Borrisokane, in the County of Tipperary	4,433	3 29	1,517	0 39	10,038	17 11	728	7 10	505	19 5	6 12 4	6 6				
District of Shinrone, in King's County and County of Tipperary	5,533	1 4	1,288	3 7	8,209	2 9	..	..	434	19 7	6 7 4	6 3				

BEDFORD LEVEL.—The next great work of arterial drainage and outfalls, as an illustration of what has been done in reclaiming a large area of country from the effects of stagnant water and floods by drainage, is that of the fen districts, which presents, probably, the largest work of the kind in the world, and to which many of the first Engineers have devoted much time and skill.

This enormous tract of land was probably, at first, an estuary of the Wash, into which the Rivers Witham, Welland, Glen, Nene, and Ouse were discharged. In the north of Lincolnshire, the fens do not extend more than 4 miles, or 5 miles inland; but in the south of that county they are 20 miles wide, and from Lynn to Peterborough, which is the broadest part, they are 30 miles wide. This width is maintained for some miles further south, until arrested by the oolitic elevations of Huntingdonshire and Cambridgeshire. The fens terminate a few miles south of Ely, and the whole length of the district is about 130 miles. With the exceptions of the Lincolnshire Wolds to the north, and a small tract which penetrates it to the south and south-west, the whole fen has nearly one level, which is often beneath that of the sea, especially about its middle and southern parts. Its original condition may be readily conceived from these elementary facts. The water flowing into and falling upon so extensive an area, from elevations too small to impel it onward, would naturally be arrested in a marsh, whose lowest point was midway between the sea and its inland borders. The result was a large fresh-water estuary, which, for many ages, was probably the sole characteristic of the fen.

The principal rivers, forming the present water drains to this district, are the Witham, the Welland, the Nene, and the Ouse. As fen rivers, the Witham and the Welland transport inconsiderable quantities of fresh water to the sea. The more important sewers of the district are the Ouse and the Nene, both of which rise in the same county, and after taking directions nearly at right angles, discharge themselves into the Wash within a few miles of each other. The River Ouse is, probably, one of the most tortuous in the kingdom. Its main branch rises at Gentworth, about 10 miles N.N.W. of Buckingham, which is about 80 miles from Lynn, but it passes over about 160 miles in its course. The River Nene originates in two springs, north and south of Daventry. Its course is easterly to Northampton, where it becomes navigable. The direct distance to the outfall at the sea is 60 miles; but the course of the river is nearly 100 miles in length. At Peterborough it enters the fens, being chiefly conducted through this region by artificial cuts, so that its original channels are, in some cases, hardly traceable. The valley of the Nene is lost 30 miles before it falls into the sea; that of the Ouse extends no further than St. Ives, and runs a course, afterwards, of 50 miles between

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that town and Lynn. The valleys of the Glen and the Welland terminate on the borders of Lincolnshire. It will be apparent, that these rivers all seek a common outlet, over lands which are no higher than their beds, and are only prevented by embankments from distributing themselves over the soil. When it is considered how great an extent of country these rivers drain, and what large bodies of water are at all times discharged through their mouths, it is hardly surprising, that the exertions of science and ingenuity have scarcely been sufficient, to keep the fens from relapsing into the general morass from which they seem to have been reclaimed. The extent of country drained by the Wash, includes the entire Counties of Cambridge, Huntingdon, Bedford, Northampton, and Rutland; nearly one-half of Norfolk; one-third of Suffolk; one-half of Buckinghamshire; three-fourths of Lincolnshire; and a small part of Leicestershire; comprising altogether about 5,000 square miles.

Having given the general character of the fens, and of the rivers which discharge into them, the Author proposes to describe the means which have been adopted to reclaim them, and to raise them to their present valuable and flourishing condition.

It is unnecessary to enter into the history of the former works, which were commenced in the reign of Charles I., about the year 1639. For although highly interesting and instructive, they were on a limited scale, affecting, probably, only parts of the fens, and have been superseded by subsequent undertakings, on a more extended scale and with more ample means.

From 1720 to 1750, works were projected, or executed by Vermuyden, Westerdyke, Dodson, Scotton, and Kinderley. It is not requisite, in elucidation of the subject of arterial drainage and outfalls, nor does the Author propose, to enter into minute details of the works which have been recently executed, in carrying out the system of drainage in the fens.

The Bedford Level, (Plate 2,) is divided into three parts, called, respectively, the South, the Middle, and the North Levels. To commence with the SOUTH LEVEL. This division is drained by the Ouse and the Bedford Rivers which, as well as the Well Creek, have been, for many years, variously treated. The first Denver Sluice, placed at the confluence of these rivers, by keeping up the waters of the Bedford River to a higher level, caused all the fens in this district to be flooded. But in 1713, that sluice was carried away. It was then expected, that the tide would deepen the Ouse, and from the increased in-draught of water, give a readier discharge. But in 1720, it began gradually to silt up, and to such an extent did this proceed, that the South Level became more flooded than before. Many proposals were made to remedy this state of things. In 1750, Labelye rebuilt the sluice. But as the

harbour of Lynn still suffered from the accumulations of sand and silt, it was proposed to straighten the Ouse, by cutting off a bend in the river above the harbour. This would have had the effect of reducing the distance from about 7 miles to 3 miles, and of giving a greater depth of outfall. After several years of delay, caused by the opposition to the scheme, an Act was passed, in 1795, to carry out the Eau Brink Cut. It was not, however, until after the lapse of twenty-one years, that this work was commenced. It was opened in 1821, and the effect upon the drainage of the country fully answered the expectations of the Engineers engaged. It not only lowered the low water at its upper end 6 feet, or 7 feet, but it improved the navigation up to, and in, the harbour of Lynn. In consequence, it was possible to lower the cills of the Denver Sluice 6 feet, the effect of which made a manifest change in the South Level. The tide, that before hardly lifted itself in the Bedford River, now penetrates almost to the end of it. That river was considerably deepened, and the channel of the Ouse, formerly so much silted up below Denver, was speedily cleansed, by the increased speed and body of tide that scoured through it. The estimates which have been made, from time to time, for the formation of the Eau Brink Cut, are strange documents now that the actual expense is known. The cost has been about £600,000, and is rated upon the lands drained by the rivers having their outlet into the Ouse, which amount to 250,000 acres, including a portion of the Middle Level.

The next portion of the subject is the NORTH LEVEL. For a great number of years, this vast tract was suffered to drain by the crooked course of the Old Nene River, the internal drains being kept cleared, as far as it was possible, where there was not a good outfall. The consequence was, that the Nene continued to silt up, and became less and less capable of discharging the waters, not only from the back country, but from the lands along its banks.

The first attempt at improving the outfall was proposed by Kinderley in 1721. In 1770 a cut, commencing 5 miles below Wisbeach, was completed; but it was only $1\frac{1}{2}$ mile in length, and only half of that which had been proposed by Kinderley. Whatever benefit may have been derived from this beginning, it tended to prove the principle, that a more extended work would have been more beneficial. It has gone to this day by the name of Kinderley's Cut. Besides the unsatisfactory state of the discharge of the waters of the Wisbeach River, four breaches of the banks occurred between 1763 and 1770. Kinderley's Cut directed attention to the root of the evil, but further efforts were necessary. It was soon found, that the immense sandbanks immediately below the cut, which had been partly cleared away by

its operation, began to accumulate to such an extent as to cause, so early as 1804, great anxiety to the owners and occupiers of land, draining by this outfall, while the navigation to Wisbeach was in an equally unsatisfactory state. Not only did agriculture suffer, and land become of less value, but the navigation was totally destroyed for large shipping, and the trade was chiefly carried on by small craft and by lighters, which conveyed the cargoes to and from the shipping, lying at anchor at Sutton, exposed to immense risk and causing great expense. The agriculturist, the merchant, and the mariner thus experienced great anxieties for their respective interests, from being constantly exposed to loss and expense. At last, the Corporation of the Bedford Level instructed Mr. Rennie to "report his opinion on the Wisbeach Outfall, and the drainage of the extensive washes lying between the two branches of the Nene, as also the North Level, &c."

Mr. Rennie made his Report in 1814, and the levels taken by him showed, that between Wisbeach Bridge and Gunthorpe Sluice, a distance of about $5\frac{1}{2}$ miles, the fall was only 6 inches; but from Gunthorpe Sluice to Crabhole, a distance of about $5\frac{1}{2}$ miles, the fall was 13 feet. From these remarkable facts, it was evident, "that the high shifting sands, which lie between Gunthorpe Sluice and Crabhole, form one of the great bars to the discharge of the waters of the Nene; and that the levels prove so incontestably where the obstruction lies, that little reasoning is required. If the outfall of the Nene is to be effectually improved, it must be by a new channel, from the mouth of Kinderley's Cut to the level of low water in the bay; and no place seems so eligible, both in point of distance and depth of water, as Crabhole." Mr. Rennie also recommended, that the river should be deepened and widened as far as the Horseshoe at Wisbeach, and a cut be made thence to Rummer's Mills, and thence to Peterborough.

This Report was published about the period of the peace, after the battle of Waterloo; but the wet harvest of 1816 brought so much distress upon the agricultural interest, that it was impossible to impose further taxes at that time for carrying out so magnificent a scheme. The plan lay dormant, therefore, till 1818, when it was revived with increased energy.

About this time it was proposed to build a bridge and make an embankment at Sutton Wash, to establish a direct communication between the Counties of Lincoln and Norfolk. In the interval between 1818 and 1826, nothing was effected, in consequence of the opposition of the town of Wisbeach, to any improvement in the River Nene, as proposed by Mr. Rennie, and to the bridge and embankment, which were also opposed by the agricultural interest. But owing to the perseverance of the Duke of Bedford,

Mr. Tycho Wing, Lord William Bentinck, and others, the Bridge Committee, and the North Level Commissioners resolved upon forming the channel from Kinderley's Cut to Crabhole; together with the bridge and embankment. After much negotiation between the above parties, the town of Wisbeach, the South Holland proprietors and others, a sufficient sum of money was procured to carry out the above plans. The Act was obtained in 1827, and after some material alterations and improvements, suggested by Messrs. Jolliffe and Banks, had been adopted, and many difficulties incidental to such a work had been overcome, it was completed. The water was turned through the new passage in June, 1830; but before the scour, required to deepen the new channel, could act with sufficient effect, it was necessary to dam off the old channel. The result was most successful; but the effect of the opening upon the bridge, which was built during the formation of the New Cut, was extraordinary. At the flow and ebb of the tide, large holes were scooped out above and below the bridge, and great fear was entertained of its destruction; this, however, was remedied. The effect of the scour, upon the sides and bottom of the cut, was so great, that it was necessary to protect the banks, with a large quantity of stonework.

The following were the dimensions at the lower end of the New Cut, at Crabhole:—

Width at the top	270 feet
Ditto bottom	165 „
Depth	24 „

At the upper part, at Kinderley's Cut:—

Width at the top	200 feet
Ditto bottom	135 „
Depth	24 „

or a regular depth of 8 feet below low water. The cost of the Cut, or new channel of the Nene, from Kinderley's Cut to Crabhole, was £200,716.

As soon as this great work was accomplished, the North Level Commissioners set about adapting the internal drains to the new state of things. A new sluice was constructed to discharge the waters of the level into the Nene, the sill of which was laid 5 feet deeper into the old channel than the one which it succeeded; and there was an opening for waterway of 36 feet, instead of 17 feet as formerly.

The main drain in connection with this sluice was formed up to Clough's Cross, a distance of $8\frac{1}{4}$ miles, 8 feet deeper than the Old Shire Drain, and six times its capacity. From Clough's Cross, the new drains diverge into two lines, called, respectively, the New

South Eau and the New Wryde, which receive the waters from every district of the North Level, including Newborough, Borough Fen, and Great Portsand. When the works were opened in 1834, their efficacy was found to surpass the most sanguine expectations of the promoters. The opening of the Nene Outfall had an extraordinary effect upon the town of Wisbeach, where it added from 10 feet to 12 feet to the depth of water in the river, solely by the action of the scour occasioned by the lowering of the outfall. To accomplish this, Mr. Rennie had estimated, that it would cost, together with the deepening of the river through the town to Rummer's Mills, £56,544, but this expense was nearly all saved by the scour. The increase in the trade of the town of Wisbeach has been equally extraordinary. The tonnage which, in 1829, was 55,040, rose to 63,180 in 1830, the year in which the Nene Outfall was opened; and to 167,443 in 1847, since which time the Author has no further information.

The total sum expended upon the whole of the works has been upwards of £100,000, which has fallen upon the land, and the area drained is 200,000 acres. The cost of the new outfall was £200,000, of which the North Level Commissioners contributed £140,000, in addition to £150,000 expended on the internal drainage, making together £290,000, besides providing for the maintenance of the works. At the time, it was believed scarcely possible, that the agriculturists could bear up against so heavy a burden, but it has been found, that the money has been well spent, and that land, which twenty years previous to 1848, was only worth £5 per acre, would then fetch from £60 to £70 per acre.

The third and last portion of the fen district is the MIDDLE LEVEL. This part of the fens presents a much more complicated system of drainage than the others, having a network of leams, drains, eas, and rivers, running in all directions, except the proper ones; in some cases at right angles to the outfall, and at others almost in a contrary direction. The principal artery of this area, is the Old River Nene, which takes a very circuitous course. It runs through Whittlesea, Ugg, and Ramsey Meres, and thence to March and Upwell, where it is connected with the Ouse, by a junction with Popham's Eau and Well Creek. It had, for many years past, been a source of contention, between those using it as a navigation, and the owners of land requiring to make it available for drainage. As it was used as a navigation long antecedent to its being adopted for drainage purposes, the navigation had a prior claim. During the continuance of these disputes, the river was gradually being filled with weeds and mud, so that it became useless as a navigation, and little better as an arterial drain.

The remedies which had, in 1795, been applied to the fens, consisted merely in cleansing drains, which had become so grown

over as to be impassable to the waters, repairing where repairs could hardly remedy, and altering in such a manner, that it only made the system still more embarrassed. It was expected, that the forming of the Eau Brink Cut, would have given great facilities to the drainage, by means of a superior outfall; but the benefits were withheld, owing to the opposition of the parties concerned. In 1800, when matters were at their worst, Mr. Rennie was consulted. He proposed a series of catchwater drains, to be carried along the foot of the high grounds, to intercept all the waters that would otherwise have spread themselves over the fens, ultimately to be drained off at great cost and probable injury to the land.

The success which attended the carrying out of this principle in the Lincolnshire Fens, under Mr. Rennie, induced the Corporation of the Bedford Level to request him to make a survey of, and prepare a plan for the general drainage of that level. Almost every great work which had been undertaken in the fens, was the result of the pressure from loss and misfortune to the owners of land, by bad drainage, floods, and insufficient and ill-cared-for banks. Such was the case when Rennie was requested to make his report in 1808. In the previous spring, thousands of acres had been overflowed, banks had been breached, sluices had been blown up, and damage done, to the amount of, at "least, £1,000,000 sterling." The plan proposed, which was one of the most comprehensive ever brought forward for the relief of the levels, may be briefly described as insisting on the making of the Eau Brink Cut a preliminary necessity, and then surrounding the whole fen with catchwater drains. The two Bedford Rivers were to be converted into one, by a drain carried through the middle of the Wash, from Mepal to Denver, and the Wash itself thereby drained. A new cut was proposed from Whittlesea Mere, in lieu of the Old Nene River and its extensions, to be continued thence to the Eau Brink Cut, and a drain was to be carried to the same point from Grunty Fen. These were the principal works proposed to be made, but the extent of the design, and the estimated expense of upwards of £1,000,000 sterling, so alarmed those, who, by an unfriendly season, had suffered to more than that amount, that this great design was never carried out.

Important as the results were which the making of the Eau Brink Cut had accomplished, many other works were required to second the relief it gave, or promised.

A large portion, amounting to one-third of the Middle Level, is situated along the borders of the Nene, from which an embankment alone separates it. This portion, which was in a wretched state as regards drainage, had to send the floods, that came within a few yards of the Nene, a distance of thirty miles, through crooked

and shallow drains, to gain their discharge into the Ouse. The consequences that followed were, that much of the land was nearly worthless, the least flood inundated it, and reeds and osiers were the only crop, raised upon quagmires and bogs. Many proprietors of this portion, seeing the success of the Nene Outfall and the drainage of the North Level, felt that their own was favourably situated for enjoying the same benefits. There was fertility and prosperity, well-stocked farms, and an abundance of grain and crops north of the Nene ; while there was little else but morasses, meres, bogs, reed fields and sterility to the south of it.

In 1836, at a public meeting held at Peterborough, Sir John Rennie, (Past-President Inst. C.E.,) was instructed to re-examine the plans, &c. made by his Father, himself, and others, with a view of re-adjusting them, according to the altered circumstances of the river, by the operation of the Nene Outfall. In 1837, Sir John Rennie reported the defects in the drainage and navigation, and pointed out various methods for removing them. The chief purpose of the promoters of this work was to secure a navigation to Peterborough, for small-sized vessels, and to enclose Morton's Leam Wash. The third point, that of draining 50,000 acres of the Middle Level, was only half adventured on, and was stated with hesitation. Sir John was instructed to consider the question of the Middle Level as distinct from the others, as the proprietors were averse to interfering with the present course of draining into the Ouse. But this, notwithstanding, became the basis of the whole scheme, and it was the destruction of it.

The district proposed to be drained, which contains 50,000 acres, was comprised between the Old Nene and South Morton's Leam Bank. It extends from Whittlesea Mere on the west, to Guyhirne on the east. Running through the centre of this area are two drains in one line, Bevil's Leam and the Twenty Feet River, which Sir John Rennie proposed to excavate, and continue from Guyhirne through Whittlesea Mere to Caldecot, making a branch drain from Pond's Bridge, through the southern portion of the fen, and surrounding the whole, from Standground to Ramsey Mere and Monk's Lode, with a catchwater drain. The estimate for this was £120,000. Since 1841, several Engineers have surveyed and reported upon schemes for improving the drainage of the Middle Level, but none of the plans have been carried out.

It seems, that there were two opinions, or rather two plans, proposed upon the subject of the best outfall for the southern part of the Middle Level. Sir John Rennie strongly advocated that at Sutton Bridge into the Nene, while others were in favour of draining into the Ouse.

The summer, autumn, and winter of 1841 were extremely wet seasons, and the continued heavy rains inundated the Middle

Level. All the rivers were swollen, the mills for pumping from the back drains were totally inadequate to discharge the enormous quantity of water that had accumulated, and the water rose to 14 feet above zero at the Old Bedford Sluice. Denver Sluice was in danger, and banks were torn down by the violence of the torrent.

The proprietors again bestirred themselves, and they determined to consult Mr. James Walker, (Past-President Inst. C.E.,) who was instructed, "that immediate steps should be entered into, for the better drainage of the whole Middle Level, by means of an improved outfall, and by widening and deepening the internal rivers," and "to direct his attention to the state of the River Ouse below Denver Sluice, with a view to consider, whether any and what improvement can be made in that river, to render it more effective for the drainage of the Middle and South Levels:" also "to have regard to the effect which the measures he might recommend would have upon the navigation." Mr. Walker received his final instructions at a meeting of the Committee, at Ely, on the 27th of April, 1842, when it was left to him to report fully upon the subject in all its bearings, and upon the various schemes suggested, which he might consider requisite, for enabling him to propose "the most effectual measure for the better drainage of the Middle Level, having regard to the navigation within that district."

The area of the Middle Level of the fens, upon which Mr. Walker had to survey and report, was about 140,000 acres, exclusive of the high lands about Whittlesea and March. With the exception of these lands, the whole of this vast area was drained by artificial means. This has arisen, partly from the lowness of some parts of the fens, partly from the internal drains not having been adapted to the improved state of the Ouse, and partly from the navigation levels having been fixed too high, to allow of advantage being taken of the recent improvements for drainage.

Mr. Walker, in his Report of 1842, refers to the propositions made by Mr. Rennie in 1809, which have been before alluded to; also to those of Sir John Rennie for draining the Middle Level into the Nene.

Mr. Walker fully discussed the levels and distances of the several rivers and drains, and the schemes proposed by others. He then came to his own proposition, that of separating the navigation from the drainage, and carrying the present rivers and drains over the main drains, which, he suggested, should be made straight through the Middle Level. He proposed three lines of drains for selection, two being alternative lines, but the termini were the same in all. The drain which he finally selected was to commence

at the upper end of the Eau Brink Cut, above the Marsh-land Sluice to Caldecot Farm, on the west side of Whittlesea Mere. It was to be level for its whole length, which was 31 miles, but it was only partially carried out. It extends $11\frac{1}{4}$ miles from the upper end of the Eau Brink Cut, and communicates with Popham's Eau and the Sixteen Feet River, which are two of the main drains of the Middle Level.

The main drain, or as it is now called, 'Walker's Cut,' as at first made, in 1847, had a bottom width of 50 feet at its lower end, of 40 feet at its junction with Well Creek, and of 30 feet above Well Creek. The level of the bottom was 5 feet below low water in the Ouse at the outlet, with an upward inclination of 1 inch per mile, as far as Well Creek, where sluices were placed to keep up the water in that river for navigation. The cills of the Well Creek Sluices were laid at the same level as that of the Outlet Sluice, which was placed at the upper end of the Eau Brink Cut, consisting of three openings of 20 feet each; and the cill was placed about 8 feet below the level of low water in the Ouse at that place. In 1848, it was determined to deepen, with a few exceptions, all the main rivers and drains of the Middle Level, —about 110 miles,—from 4 feet to 7 feet, with bottom widths varying from 12 feet to 30 feet; (the exceptions were Well Creek, the Old River Nene through Upwell and Outwell, the Old Bedford River, King's Dyke through Whittlesea, and the course of the Old Nene through Farcet;) to construct an aqueduct under Well Creek; to make new cuts, or junctions between the Sixteen and Forty Feet Rivers, between the Twenty Feet River and Bevill's Leam, and between Bevill's Leam and Conquest and Yaxley Lodes; to make a small catchwater drain between Stilton Brook and Yard's End Dyke; to place locks at Upwell, Horsway, and Ashline, for the purposes of navigation; also to make several internal drains and other district works. In consequence of these works, which were all completed in 1852, the water in the rivers and drains was lowered 6 feet.

The cost of the whole of the works above referred to, including Parliamentary and law expenses and purchase of land, has been £410,000.

In 1857, it was determined to take another step towards the completion of Mr. Walker's original design. This was by deepening Walker's Cut 4 feet, or 1 foot below the outlet cill, with a level bottom for its whole length of $11\frac{1}{4}$ miles, keeping the bottom width as before, viz., 50 feet at the lower end and diminishing to 40 feet at Well Creek. Up to this point the work was completed last year, and it is now being continued upwards. Each step that has been taken in the improvement of the drainage, since 1842, has been attended with the most satisfactory results,

of which the best proof is, that the money, which is raised by taxation, is collected without difficulty.

The Norfolk Estuary Company have been, for some time past, reclaiming the land from the sea at the mouth of the Ouse, and have cut a new channel, from below Lynn, which has reduced the level of low water in the Eau Brink Cut, and has much improved the drainage of the Middle and South Levels.

ANCHOLME LEVEL.—The next case, by way of illustration, is that of the Ancholme drainage. In 1845, a Paper was read before the Institution, by Sir John Rennie, giving "An account of the Drainage of the Level of Ancholme, Lincolnshire." It is introduced here, as specially bearing upon the subject of "Arterial Drainage and Outfalls," and as demonstrating the good that has resulted from a well-directed and comprehensive system of drainage. The works were many years in progress, arising from various causes, but they have at last been completed.

The level, consisting of about 50,000 acres, extending about 24 miles southward from the Humber, was, from a very early period, the object of attention. From 1290, when Edward I. issued a commission to inquire into its state, and for several successive reigns, commissions were appointed, plans were proposed, and occasionally some works were performed, which rendered partial relief. But from want of attention, the level relapsed into a very bad state, and so matters remained until 1769, when an Act of Parliament was obtained, under which a sluice at Ferraby, where the Ancholme joins the Humber, was made, a lock was constructed, and the river was straightened and improved as far as Bishop's Bridge, a tax being levied upon the land for the purpose of paying for these improvements. Although the outfall cill was placed 8 feet above low-water spring-tides, much benefit resulted from these works. Still the flood water was prevented from getting away, and the drainage was in such a very defective state, that the land was unfit for tillage, and, except in fine seasons, crops of barley, or oats only grew upon the most favoured parts of the level.

Not only had 50,000 acres of low level to be drained, but the water from about 150,000 acres of the high lands bordering on the east and west sides of the level was to be provided for. To prevent the discharge from so great an area descending upon and overflowing the level, catchwater drains were brought into use, for the first time, upon any general enlarged scheme. These catchwater drains diverted and carried off the surplus water, and were the means of supplying the drains in the low lands with water for

¹ *Vide Minutes of Proceedings Inst. C.E., vol. iv. p. 186.*

irrigation and navigation in dry seasons; which is as essential as the drainage in excessive wet seasons. Some of the propositions made in 1801, by the late Mr. Rennie, were carried out, but the others were not executed.

The Paper then states, that Sir John Rennie was called upon, in 1824, in consequence of the works, from insufficient funds, not having been carried out as proposed, of their getting out of repair, and of the insufficiency of the drainage, to make a report, plans, and estimates. The works, including the building of the Ferraby Sluice and Lock, the bridge over them, and the bridges over the main river, are minutely described. The benefits derived from the satisfactory completion of these works are thus enumerated:—“The sure principles of drainage,—catchwater drains for the high-land waters, and improved rivers and drains for the low-land, or fen waters,—have been established, and the whole of the Ancholme Level is now converted into a rich arable district, capable of producing the finest crops of every kind.”¹

PRINCIPLES OF IMPROVING RIVERS IN FLAT COUNTRIES.—In the Paper on the Ancholme, as well as in all that has been introduced relative to the fen district, some of the leading principles of the drainage of level areas were noticed, and they have since been carried into execution. They were, first, the formation of catchwater drains for intercepting high-land waters; secondly, the separation, as much as possible, of navigation from drainage, in improving rivers; thirdly, the proper slopes, or inclinations, to which the bottoms of improved rivers, or newly-cut drains, discharging into tideways, should be formed; fourthly, the proper depth at which the cills of outfalls into tideways should be laid; and, fifthly, the formation of overfall weirs and reservoirs for the retention of mud and sand.

First. There seems to be no doubt, that both in level areas, and also where there is considerable fall, catchwater drains are of great utility, and in the latter case, they can be made of great value for irrigation, for water power, and for storage.

Secondly. As to the separation of navigation from drainage, the Author has long been of opinion, that the one is incompatible with the other, each being designed for distinct purposes; and the interest of maintaining the one is frequently inimical to that of the other. But in some of the old rivers, it would involve so great an expense to separate them, that it is preferable to continue them together; in any newly-designed drainages, however, the two may, in most instances, be kept distinct.

Thirdly. In a few counties, the improved rivers, or drains may,

¹ *Vide Minutes of Proceedings Inst. C.E., vol. iv. p. 199.*

in nearly all cases, be made level ; for they then serve as reservoirs for the water, during the time the sluices are closed, the water suffers less friction, and as Smeaton states, the whole body of the water is in motion.

Fourthly. The depth at which the cills of outfalls should be placed below low water, has produced some controversy. There can be little doubt, however, that about 2 feet may be adopted. In the Middle Level drainage, as before stated, the outfall sluices into the Ouse have been laid 8 feet below low water. This was probably done in anticipation of a lowering of the Ouse below Lynn, of which it is capable, and which is now being effected by the Norfolk Estuary Company, to the extent of 5 feet, or 6 feet through Vinegar Middle to Lynn Deep.

Fifthly. This is a provision which may, or may not, be requisite. If the river, or streams convey mud and sand, then such a work would be useful, as it would prevent the drains from becoming choked, as well as admit of their being cleared out in dry weather, without interfering with the action of the drains.

A principle which has not been referred to may be mentioned, as included in the resources open to the Engineer ;—where the bottoms of rivers and streams can only be sunk at shallow depths below the land, and those rivers and streams are subject to sudden and short floods, banks may be erected on each side, so as to retain the floods : this is an inexpensive system, as the earth taken out will form the banks.

Another principle is, in some cases, necessarily applied to assist draining ;—elevating water from back drains, by machinery, either to the higher level, or for the purpose of discharging them into main drains, which may be on the same level as the internal drains. This principle was carried out, to a great extent, in draining Whittlesea Mere a few years since.

YORKSHIRE.—In many parts of Yorkshire there are large drainage districts, mostly under the jurisdiction of Commissions, having Acts of Parliament enabling them to raise money, execute works, and levy taxes upon the lands. Several of them have done much good, in reclaiming lands which were valueless, in fact morasses and swamps, and bringing them into such a condition as to become fertile and of considerable value.

An estate in Yorkshire, of about 2,250 acres in extent, at Thornton, near Pocklington, is at this time, suffering considerable injury from the want of facility for draining the water from it. The present means consist in discharging the water into a drain which joins a brook called the ' Four Beck Ends,' at about $3\frac{1}{2}$ miles from the Derwent. This brook receives the drainage of two other

streams, which bring water from 40,000 acres of land. The fall in this distance is only 3 feet 6 inches, and the width about 9 feet.

This estate has had 300 acres of the best land, for the last ten, or twelve years, almost always under water, and the remainder more, or less injured. The district was formerly under the jurisdiction of the Howden Court of Sewers, which was instrumental in keeping the watercourses open for the passage of surface water; but in consequence of litigation, it has long since ceased to act.

Many more cases might be mentioned, in which works have been carried out, or are in progress, particularly in connection with the Ouse and the Derwent, showing the advantages that can be derived from combination, on the part of those interested, in improving their estates; thus conferring great national benefits by bringing more land into profitable productiveness, giving employment in the localities, and improving the salubrity of the district in which they are situated.

HAINAULT FOREST.—This forest, (formerly a royal forest,) is situated in the County of Essex, about a mile and a half to the north of the Eastern Counties Railway, between Ilford and Romford. The allotment made to the Crown contains about 2,000 acres; it was disafforested in the year 1853, and all the timber, consisting of oak and hornbeam pollards, was cleared off in the three following years. The land, in its original state, was covered with a thick growth of underwood, as well as of timber, coarse grass, rushes, and weeds, and the greater part of it was a mere swamp. The formation of the ground consists of a level plain, part of it known as Fairlop Plain, lying at the foot of a ridge of land sloping towards the south. Another ridge projects into it from the east, and at the foot of these ridges are valleys, which bring down the water from beyond the limits of the Crown allotment. The soil on the northern and south-eastern sides is generally a strong brown clay; the remainder of the allotment is mixed clay and gravel.

The first operation in the reclamation was that of making the roads and arterial drains. It will be observed, (Plate 3,) that some of the roads and arterial drains are parallel, affording materials for the formation of the roads, and preventing, at the same time, much severance of the land.

The three principal valleys are, first, the Dog Kennel Brook which extends from the southern boundary of the allotment at Little Heath, and runs nearly due north to the northern boundary, where it receives the drainage of the ridge upon which Chigwell Row stands, and branching off at the second road towards the north-east, receives the drainage of that part of the same ridge.

Out of the Dog Kennel Brook, about half a mile from its outlet at Little Heath, the Well Ridden Brook branches off, towards the north-east, and receives the drainage of the land for some distance beyond the boundary of the allotment. A little above where the last brook branches off from the Dog Kennel Brook, and on the opposite side, is a small drain, the Aldborough Hatch Drain, which receives the drainage of the west and north-west parts of the allotment, and the lands north of it. A small portion of land on the west side is drained by a separate outfall. This is the only portion of the water which is not discharged by the Dog Kennel Brook outlet.

In each of these valleys, straight and regular open drains have been formed, proportioned to the quantity of water it was calculated they would have to carry off. Into these open drains all the mains of the pipe drainage, which has been executed over an area of about 2,000 acres, have been carried; as well as the surface water of the allotment and lands adjoining. The water which formerly passed through these valleys, can scarcely be said to have been carried off by streams, as there was little, or no indication of any ditch, or track by which it could be discharged; but it found its way over a great part of the land, where it lay for weeks, destructive both of vegetation and health, till it was mostly carried off by evaporation. It was frequently Midsummer before the land was sufficiently dry to walk upon; consequently, little produce was grown, and the quality was almost worthless.

The length of the Dog Kennel Open Drain in one line, from the south to the north-east, is about $3\frac{1}{2}$ miles; the area drained by it is upwards of 3,000 acres. The Well Ridden Drain, to the north-east, is $1\frac{1}{2}$ mile in length, and receives the drainage of 670 acres. The West Drain is $1\frac{1}{4}$ mile in length, and drains 452 acres.

It was expected, that the water from the high ground surrounding the allotment, and from the large quantity of underground pipes in the allotment, equal to 615 miles in length, would be discharged in large quantities and in very short periods. The following dimensions and slopes were, therefore, given to the drains; the bottom of the Dog Kennel Drain at its outlet, was made 6 feet in width, and from 4 feet to 5 feet deep; the bottom width diminishing gradually to 2 feet at the upper end. The inclinations given to the bottom are shown on the section accompanying the plan, (Plate 3). The natural fall of the valley, at the surface of the land, to the second road, is 1 in 171, and 1 in 125 for some distance above the road. This fall would have been too great, under the circumstances before-stated, and the velocity of the water would have been such as to destroy the sides and bottoms of the drains. Overfalls, built of brick, were, there-

fore, put in the drain, as indicated in the plan and shown on the section. By these means the gradients were reduced from 1 in 171 to 1 in 330 in the lower part, and from 1 in 125 to 1 in 200 in the upper part. These overfalls, which vary from 10 feet to 3 feet in width of opening, and rise from 3 feet to 5 feet, were so constructed, by inserting boards into grooves, as to be capable of being made into dams, for storing water in dry seasons for cattle, or other purposes, and for irrigating the land on both sides. The Well Ridden Drain was the only other drain that was treated in this manner; its gradient was reduced from 1 in 147 to 1 in 200, by two overfalls.

The dotted lines on the map, (Plate 3,) show the pipe drains, the smaller pipes leading into larger, or main pipes, which discharge into the open drains at the points shown. The minor drains accurately describe the contour profile of the land, their direction being always that of the greatest fall.

At one of the farm buildings a tank was constructed to supply the premises with water, and there is a feeder leading to it, branching out of the Dog Kennel Drain, where a dam is placed to regulate the quantity of water.

The system adopted in thoroughly draining this large district was, to have as few open drains as possible; and mains with large pipes were extensively used, considerably increasing, of course, the first cost. But the area of land thereby gained for profitable cultivation was increased in proportion, and the labour of tillage largely reduced; independent of which it is found, that agriculturists neglect the mouths of under-drains, if they are numerous. It is, consequently, good economy to have as few outlets as possible.

The result of the arterial drainage in connection with the underground drainage has been, to carry off all the rainfall with the greatest facility, and in no case have any of the open drains overflowed, but the water has all been confined within the banks.

This forest, from having been from time immemorial almost a waste and useless, has now become a valuable farm, and what was formerly a refuge for thieves and poachers, now affords the means of profitable employment to many persons.

INDIAN RIVERS.—The Paper having thus far treated of works of drainage executed and proposed in this country, a reference to the systems of dealing with rivers in India and in Northern Italy may prove interesting.

The Report by Captain Baird Smith, R.E., to the Court of Directors of the East India Company, in 1856, gives an interesting and instructive description of the manner in which the

large rivers in the Madras Presidency, the Cauvery, the Coleroon, the Kistnah, and the Godavery, are brought under control, and adapted to the purposes of irrigating immense tracts of country. These rivers drain enormous areas, their lengths being from 400 miles to 600 miles, and having drainage areas of from 20,000 to 30,000 square miles. They run upon the crest of ridges, through the deltas near the outfall into the sea, which have been raised by the continual deposit of gravel and other materials brought down from the upper countries. At the head of these deltas, weirs, or dams are erected across the river, which, in the case of the Kistnah, is 2 miles, or 3 miles wide; and other training and protecting works are constructed along their sides, to confine the waters to their channels. This system is adopted at every suitable spot on each river. These dams are provided with under-sluices, or escapes, as they are called, to let off extreme floods, or clear off deposited material. At these dams the proper works, such as sluices, escapes, &c., for conducting the water to the irrigation channels, are constructed. The volume of water which flows down these rivers during times of flood is enormous; and were it not for the substantial and comprehensive character of the works, they would be destroyed; occasionally, they do suffer great injury. The immense quantity of water that is required to irrigate the sugar, rice, and other lands, makes it necessary to provide extensive works. Many of these works are of great age, and several are, at the present time, in course of construction. The Government provides the means for carrying them out, and they are all under the management of Officers of the Indian Engineers. The return for the outlay arises from an increased quantity of land being brought into cultivation, and that of an improved description, which is taxed in proportion.

Perhaps the most extraordinary works connected with irrigation in the Madras Presidency, are the tanks. They are more properly applicable to the subject of arterial drainage, than that of irrigation, connected with rivers, as they assimilate to the English system of storing water, and, as suggested in this Paper, form good examples of a mode of regulating the water in English rivers, under the altered circumstances which are now taking place. There are forty-three thousand of these tanks kept in repair, and ten thousand others in the Madras Presidency alone; many of them being of considerable magnitude. According to Captain Baird Smith, the united length of the embankments of these tanks approaches to 30,000 miles; and they comprise three hundred thousand works of masonry in sluices, waste weirs, &c. The lands irrigated by these tanks are estimated to produce £1,500,000 sterling annually to the Government, and they are supposed to have cost £15,000,000 sterling.

[1859-60. N.S.]

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The largest tank at present in repair, as a specimen of many, is that of the Veeranum Tank, which has 12 miles of embankments and 35 square miles of area, and is of very ancient date. It now yields the Government £11,450 annually.

Although the introduction of the irrigation works of India into this Paper is rather a digression from the subject of arterial drainage, the Author has briefly noticed them, partly as highly interesting to Engineers, illustrating the manner of dealing with large rivers and bodies of water, and partly as the works may be applicable to drainage operations, as well as to irrigation, although the one system is quite the reverse of the other. But as works for irrigation, they are totally unsuited to any part of this country, being far too extensive. Nevertheless, the Author would propose, where practicable, to connect arterial drainage, especially in rapidly-inclined countries, with tanks, or reservoirs, since they may become most useful in many ways, as aids to agriculture, or the supply of towns.

ITALIAN RIVERS.—Paul Frisi, who was professor of mathematics at Milan, published an excellent treatise, about the year 1760, on rivers and torrents, which was confined chiefly to the rivers in Italy. About that period much controversy was carried on, as to the proper method of regulating the Rivers Po, Sammoggia, Reno, Savena, Idice, and Sillaro, many of which, except the Po, discharged their waters into the Plains of Lombardy, and were conveyed to the sea by the River Primaro. Several attempts were made to bring all these rivers into one channel, the Benedictine Canal, and so conduct them into the Primaro. Frisi discusses fully, and with much ingenuity and knowledge, the circumstances connected with these torrent rivers, and he gives valuable information, as to the materials brought down by them, as well as to the natural formation of the higher beds of rivers, and of the rectification and formation of river beds, the velocities of single rivers and artificial canals, and of rivers united and divided, the slopes, or velocities of rivers, and the distribution of the slopes on rivers which convey mud and sand. But the chief information derived from a perusal of his work, relates to the regulation of rivers which bring down from the Apennines, both on the east and the west sides, bodies of gravel which fill up their beds, and require a particular treatment, according to the circumstances of the several cases. The alterations in the course of the River Po, for instance, have been very extensive, caused, principally, by the tributary rivers bringing down gravel and other matters, which were deposited in its course, and diverted it into an entirely different channel.

Many of the most eminent mathematicians of the time were

engaged in devising plans for diverting the rivers from the valleys of the Sammartina, of the Arno, from the Vale of Chiana, and the Plains of Leghorn, and of Pisa. All the works that were undertaken, were for the improvement of the drainage and outfall of very large rivers, subject to sudden floods bringing down every species of obstruction and detriment, so as to control them and give them a proper action.

The want experienced in this country of arterial drainage arising from the introduction of pipe drainage, and the greater attention paid by those who have the management of land, in clearing the uplands of water, has not been as yet felt in many countries, such as Northern Italy ; so that there are few, if any, examples of the descriptions of works in those countries, which this Paper more directly treats of and advocates.

The great hydraulic works of Northern Italy all relate to irrigation and navigation, and perhaps no other country in the world possesses such a large and valuable collection of literature on these subjects as is to be found at Milan. The canals of Martesana, the Naviglio Grande, and some others, besides serving the purposes of navigation, are also used as channels for irrigation. The great hydraulic works are principally devoted to irrigation, which, as a system, has been established from a very remote period, and has been carried out to an enormous extent. The Governments of the several kingdoms of Northern Italy are the owners, as they were, originally, the undertakers of, nearly all the largest irrigation channels, and private families are owners of, or have vested rights in, many of them. Strict, but equitable laws and regulations are laid down, for the use of the water taken out of these channels by the occupiers of land adjoining, for which they pay a tax. The mode of measurement of the water so distributed, is conducted on a different system in every kingdom.

A large number of Engineers find employment upon these works of irrigation, in executing them, keeping them in repair, advising as to the proper modes of irrigation, under the various circumstances that arise, and settling disputes ; and they are thus, in numerous ways, connected with a system spread over so vast an area of country, in such a complicated, entangled network of drains.

Interesting as this question is, and one which may be studied with great profit, it does not bear upon the present subject, except as before remarked, in the case of the Indian rivers, so far as arterial drainage may be made to supply the means of irrigation to a great extent.

In upland, or internal rivers and streams, such as are referred to in the last few cases, the leading principles which should be the guide in improving them are : first, the straightening their

channels from the sources to the outfall; secondly, the making them of the proper widths requisite to take in all the flood waters, having regard to the inclinations; thirdly, the formation of shallow, rather than deep drains, in nearly all kinds of soils; fourthly, the regulating, or adjusting the inclinations of the bottoms, so that the velocity of the water may be checked, to prevent the erosion of the sides and bottoms, and the removal of the gravel, sand, and mud to the lower levels; and fifthly, the providing the means of storing up the waters in reservoirs, or tanks apart from drainage, at convenient points, for agricultural and industrial purposes, such as supplying cattle in dry seasons, for irrigation, for small water wheels, and for supplying towns, or districts with water.

The system of banks on each side of shallow drains, may be advantageous in localities in which sudden floods occasionally occur, so as to save excavation and waste of land, because these banks, and the spaces between them and the rivers, are available for pasture lands, if the former are properly formed.

COMMISSIONERS OF SEWERS.—It appeared to the Author, that the Commissioners of Sewers, who are acting in every part of the country, having jurisdiction on the borders of the sea, or tidal rivers, ought not to be passed over without some notice, in consequence of the antiquity of their constitution, the position which they hold in many districts, and of their connection with the objects of this Paper.

The Commissioners of Sewers were first instituted in the reign of Henry VI., for the purpose of repairing sea-banks only. But in the reign of Henry VIII., (23 Henry VIII., cap. 5,) they were better organised and invested with fuller powers, and may be said from that time to have been enabled to act and to be of some service. The law was afterwards amended in Elizabeth's reign, (13 Elizabeth,) and now they are acting under the 3 and 4 Will. IV., cap. 22. Their duties are to repair sea, or river banks, and to keep the main drains and outfalls of level districts in repair, and clear them for the passage of water. This is done by jury presentments, compelling the owners and occupiers of adjacent lands to perform all necessary repairs and works.

The objects for which they were constituted are of great importance, and the duties are generally well performed, but their powers are not extensive enough to meet the exigencies of the improved state of society and the management of land, which makes them, as a body, less effective and useful than they might be. The machinery for taxing is unsatisfactory, requiring for new works, three-fourths of the owners and occupiers to consent to the work being undertaken, and the same proportion to agree to the tax. The services of the Commissioners, whose powers are renewed

periodically by the Lord Chancellor, are gratuitous, and it is only a matter of surprise, that any one can be found to act, except when they are directly interested in the lands to be protected and drained. In the case of ordinary repairs, or works under a certain amount, the Commissioners can order their officers to perform them, or compel the owners to do so. The Author has lately executed a work, which the owners of the lands and river were compelled to undertake at a large cost, under one of the Courts of Commissioners.

The whole constitution of these commissions requires, in the Author's opinion, to be remodelled, and large and more effective powers must be given to them, in the event of any fresh legislative measure being carried upon these subjects.

There are many more instances of the improvement of rivers, both proposed and executed, than those which have been noticed in this Paper. The system pursued in Holland has not been touched upon. This in itself would be sufficient for a Paper; but the length to which this communication has already extended, precludes a more complete and detailed account. Some of the cases could only be generally described, and they must be merely taken as illustrations, presented in the hope of promoting a more universal improvement, and that the subject may attract the attention its importance demands, and lead to more perfect and liberal legislation.

The Paper is illustrated by a series of diagrams, from which Plates 2 and 3 have been compiled.

Mr. LOCKE, M.P.,—President,—said, that whether the views of the Author, relative to the advisability of legislative interference in the drainage of lands passing through numerous properties, were generally concurred in, or not, all must agree, that there were instances in which obstinate landowners would not allow their land to be improved, notwithstanding the advantages which they might derive from it; whilst, on the other hand, there were men of progress, who were desirous of carrying out these improvements, and willing to pay their quota of the expense. There were great difficulties in dealing with a question of this kind; but it had been treated with fairness in the Paper, especially with regard to compelling landowners to carry out improvements against their will. The Paper also contained a history of several important operations, projected and carried out, showing the progress of arterial drainage, which must be interesting to every one who had given any attention to the subject.

Mr. BAILEY DENTON had been engaged, for several years past, in operations of under-drainage, by which he had become aware of the want of some comprehensive measure for the control of arterial drains and outfalls; or rather, some central commission, with powers to facilitate the drainage of land. One point of importance, which had been alluded to in the Paper, was the difficulty experienced by landowners in finding an outlet for injurious water, owing to the opposition of parties who held interposing lands. It was a fact, that at this time, there were no tangible means of compelling landowners to allow the water from another estate to pass through their property, however important the improvement sought to be effected, and however small the value of the interposing land. He was, at the present moment, draining an estate belonging to Lord Palmerston; and the lower part of that estate must remain a comparative swamp, if the owner of the property lying still lower, would not consent to an outlet through it. He alluded to the case of Lord Palmerston to show, that the Premier of England was in the same position as the smallest freeholder, and in confirmation of the necessity of affording some easy and cheap means of redress. Another inconvenience very generally experienced, was the absence of any law by which a common watercourse, however tortuous, or deficient in capacity, could be straightened, or deepened. An Act, called Lord Lincoln's Act, enabled a person aggrieved by the stoppage of an existing watercourse to make a complaint before a magistrate, who had power to order the party to clear, or scour out, that watercourse; but there was no power to order it to be deepened, or otherwise improved. Much had been said, of late years, about deep drainage; and he could speak from experience, of the enhanced value of agricultural property from that operation. Now



Welney
d ford + River
WASH
d ford River

P A R I S H O F H A V E R I N G

SHOWING

Well,

Well

Well

Dr. A. T. N.

$$A \text{ --- } R$$

Brooklyn

Riddle

Graphical Scale for Plan and Section.

Vertical Scale for Section

Chains

ago Feet

Branch Drain to Boundary of Street

Fox Burrows

1 1/2" wide d^o

1 ft wide at the bottom

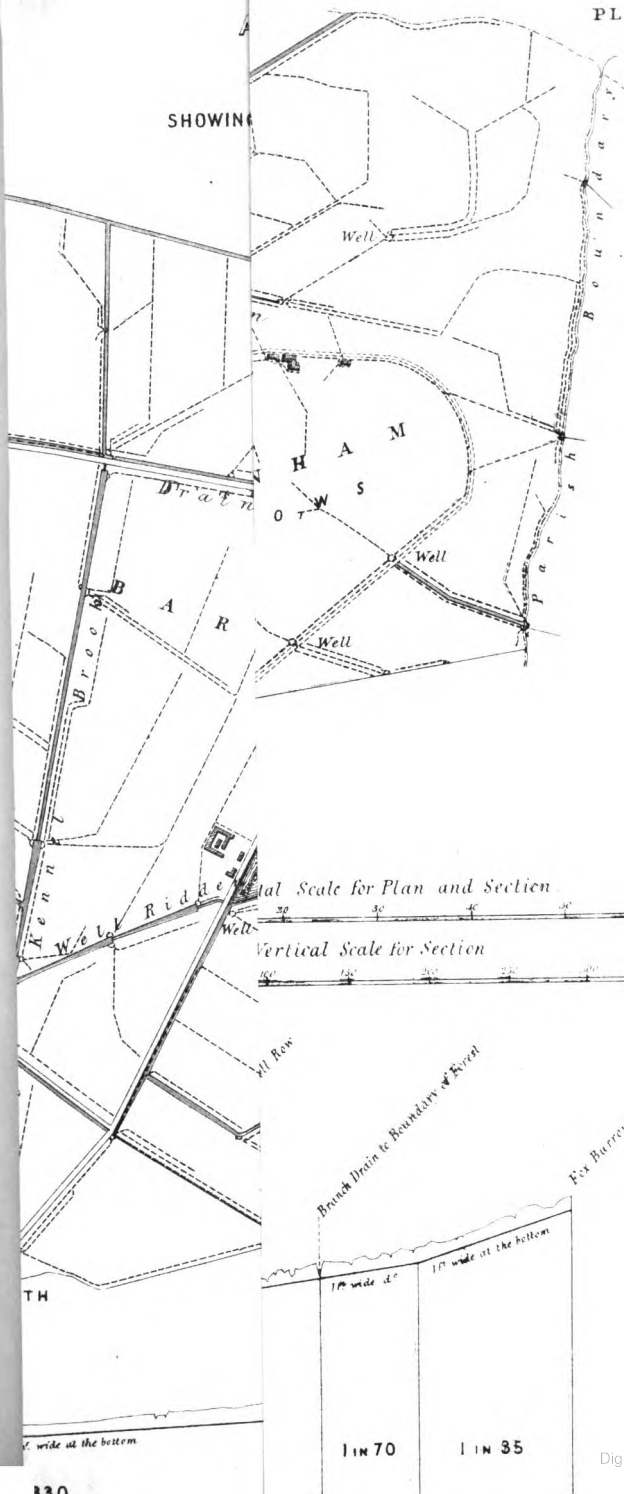
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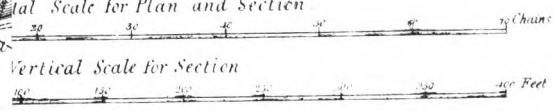
P A R I S H O F H A V E R I N G

SHOWING



Scale for Plan and Section

Vertical Scale for Section



Branch Drain to Boundary of River

Fox Burrows

1 ft wide at the bottom

1 ft wide at the bottom

1 IN 70

1 IN 35

scarcity of water for cattle, and in which the inhabitants of the villages were left almost without that common necessary of life.

Another important matter was, the necessity of regulating the discharge of the refuse of towns into the arterial streams. He considered, that any commission dealing with arterial drainage, should embrace that topic. He could speak from observation, that many streams which had been used profitably for household purposes, and for the supply of towns, were now unfit for those purposes. There was another view of this part of the question, which had a commercial bearing on the value of rural property; the depreciation in the beauty of the rivers. Streams, which were formerly clear and pleasing in the landscape, were so no longer; and he considered that question not entirely devoid of interest and importance. The way he proposed to bring about this great desideratum of a controlling commission was, that some commission of inquiry should be appointed by Government to look into these minor matters, as well as the more important one of main outfalls. He thought the minor matters to which he had alluded would be considered, in the eyes of agriculturists, as more important and urgent, and therefore, more likely to meet with support in the Legislature, than the large and comprehensive measure of dealing with millstreams, involving the opposition of millowners.

Mr. JOHN CLUTTON mentioned several instances, in which efforts to carry out improvements, and to increase the fertility of land, had been frustrated. Some years ago, a considerable district in the vicinity of Maldon, in the County of Surrey, was drained by Mr. Easton. When Mr. Clutton undertook the management of the estate, he found, that one of the bridges, which had been lowered, had been stopped up again, by order of the county surveyor. That obstruction had been placed there by the surveyor, simply on account of some little disagreement with the owners of adjoining land about charges. The whole of the invert was filled up to the original level with concrete; thereby stopping all the drainage water of the district. There was no legal power to compel the removal of the obstruction, and it was only effected by the payment of a sum of money, to enable the county magistrates to undo what they had wrongfully done. A large sum had been expended in the improvement of the district; but the arch of the bridge being filled up with concrete, the outlay was rendered useless, the produce of the land was diminished, and the health of the resident population was injuriously affected. After the impediment had remained there for about fifteen years, the concrete had been removed; and in the year 1858, other parties in the district brought a Bill into Parliament for further improvements. This Bill was strenuously opposed by one landowner, who used every effort

to prevent the drainage being carried through one of his fields; and thus the possible improvements of the whole district were prevented. Surely there ought to be some general measure, which should frustrate trivial opposition to large plans of improvement, such as he had alluded to. The parties to whom he referred, were at considerable expense to bring in the Bill, but their efforts were destroyed by the opposition, in fact, of a single person.

He happened to be attached to the Commission in Ireland, to which the Author had alluded. He thought the state of the streams in this country very inferior to their condition in Ireland, where they had been improved under the pressure of the famine. Arterial drainage was there carried out on a large scale; and although much of the work was costly, yet great improvements had been effected. The landowners complained of the cost, but the land was improved to a large extent. A tax of one shilling was objected to, although the land had been improved to ten times that amount. He thought the value of drainage, especially of arterial drainage, was not so fully appreciated as it ought to be. He knew land near the Thames, which might be made worth three times its present value, if the drainage was properly carried out. There were innumerable obstructions to drainage, which, in the existing state of the law, there was no power to remove. There were cases in which mills not worth £50 a year, were damaging large districts to the extent of hundreds of pounds. It appeared to him unaccountable, that some general and comprehensive measure had been so long delayed; but with the aid of the great practical body of Engineers, represented by the Institution, he had no doubt it would, eventually, be obtained.

Mr. SIMPSON, (Past-President,) said, this subject had occupied a great deal of his attention, and, in his younger days, a portion of his professional income was derived from surveys and plans for draining and improving landed estates. The same obstructions existed then as at the present time, through the opposition of other landowners. More than forty years ago, he had found difficulties in obtaining outlets for land drainages, and they had increased, from year to year, owing to the circumstance, that the landowners in the higher parts required, in carrying out their modern plans of drainage, to let the water down through the estates in the low lands. He had been for many years acquainted with the valley of the Baveley Brook, to which allusion had been made, and he could state that, whereas formerly, it required three-quarters of an inch of rainfall to flood that valley, now only half an inch sufficed; some of the higher lands at Merton, Maldon, and in the direction of Sutton having been under-drained with tiles and pipes. Many similar cases might be mentioned. The fact was, that the drainage of the upper lands threw the water more rapidly into the small brooks

and streams in the lower lands ; and grass lands, which had formerly been seldom flooded, were now, to their great detriment, frequently visited with floods, and kept in a swampy state. This was not only the case in Surrey and in Middlesex, but in many other counties of England, and he had long thought it a great evil. At present there was no effectual remedy ; but he hoped the magnitude of the mischief would shortly lead to some general legislative measure, enabling the landowners to combine, not only to carry out a proper system of drainage, but to maintain it when once executed ; for much of the evil complained of arose from the existing drainages not being properly maintained, causing injury to the lower lands. He had known cases in which, after £8,000, or £10,000 had been expended, the drains were not maintained after seven years ; because the lands, in some cases, belonged to minors, or were in the hands of trustees, or under the control of guardians of incapacitated persons, so that there being no one to contribute to the expense, the drainages went out of repair ; and under such circumstances, as much injury was done to the lower lands as if there had been no drainage at all.

The project for the drainage of the low lands in the neighbourhood of Wareham was one in which the late Lord Eldon took great interest. Walking over the estate one day with his Lordship, wheat was observed growing upon land 4 feet above the point of drainage of the salt water. The tenant was persuaded to improve the drainage, by which he was enabled to sow with wheat 20 acres of land, that, previously, was not worth five shillings per acre, whereas now it was worth, at least, two pounds per acre. If a thorough system of drainage could be introduced there, 2,200 acres of land would be rendered very valuable. Some of the landowners, however, objected to drain, notwithstanding it could be done with a natural outfall of 12 feet. Instead of this, they suffered the lands to be flooded during three, or four months in the year, which rendered it comparatively unproductive. In the lower lands, near Wareham, where great benefit would result from such a system of drainage, nothing was done, and one gentleman had stated, at a public meeting, that if the work would cost only one shilling per acre, he would not do it ; the fact being, that he could not command the money, and he was, therefore, determined not to consent to the measure.

Sir JOHN RENNIE, (Past-President,) fully agreed with the opening remarks in the Paper, as to the difficulties that were experienced in carrying out measures for arterial drainage, without specific Acts of Parliament empowering the construction of particular works. Each case differed from every other, and required special provision to enable a proper plan of drainage to be effected : and he thought, there would be great difficulty in carrying into

execution, any general rule which might be laid down. In fact, in this country, where the rights of property were so complicated, he was afraid, that any general measure, to be effectual, would be so injurious by its interference with those rights, that he doubted the propriety of attempting to establish such extensive changes as would, necessarily, be involved.

The Author had made especial mention of the drainage of the levels of Cambridgeshire, Lincolnshire, and other places in England. This was a subject which required considerable research, in order to ascertain the varying state of the drainage of those districts at different periods, the works that had been carried out, and the results produced. Without entering into minute particulars, he would, as briefly as possible, mention a few facts relative to the history of the drainage of the fens, in which, he might add, he had been rather extensively engaged. The Romans were said to have greatly contributed to the improvement of the drainage of these districts, and several of their works, such as the Caerdike, the Podike, the Causeways, &c., still remained as specimens of their skill. As the shores, or sea line of the Great Wash formerly extended much further inland than at present, it was probable, that their labours were, to a considerable extent, successful. From their departure from Great Britain, A. D. 422, until the reign of Stephen, A. D. 1060, the Roman works were abandoned, and no others were executed, so that the fens were little better than a vast lake, or swamp, except the higher parts, such as Ely, March, Ramsey, Whittlesea, Thorney, and Crowland, which formed so many islands rising out of the waste of waters, accessible only by boats, or by causeways connecting them with the high lands. But at a much later period, considerable results had, no doubt, been obtained by the improvement of the drainage in the Middle Level. That district, which contained about 150,000 acres, lay between the Nene and the Ouse, and for centuries back, the drainage had been in a very bad state. Now with regard to the period when the Nene and the Great Ouse discharged their united waters into the Great Wash, at the town of Wisbeach, which was situated about the centre of the Wash. In former ages, that outfall was said to have been good; yet in the course of time, the alluvial matter brought down from the interior, as well as the sand driven in from the Great Wash by the easterly winds, obstructed, or blocked up the mouths of the Great Ouse and the Nene, to such an extent, that they could scarcely discharge their waters with any effect. In consequence of this obstruction, the Great Ouse was driven back and diverted from its course, and approached within about 3 miles of the Little Ouse, at a place called Littleport Chair. The whole country through which the Great Ouse passed, was then flooded to such a degree, that the inhabitants of the

district were placed in the greatest difficulty, and not knowing how to get rid of the water by the old outfall, they made a cut about 3 miles long, from Littleport Chair to the Little Ouse, at Rebeck; thus the whole, or greater portion of the waters of the Great Ouse, the Cam, the Little Ouse, and their tributaries were discharged into the Great Wash, at Lynn. There was, in consequence, a great accession of water at this new outfall, which materially improved it. This took place about the year 1292. The north portion of the Middle Level, the North Level, and South Holland suffered in the same proportion, and were so overwhelmed with water, that the highest parts only were called summer land; that is, they were only grazed and cultivated for a few months during the year, and for the remainder, they, as well as the other lands, were more, or less, under water.

It was not until about the time of Charles I., that this subject again attracted serious attention, when very protracted discussions took place as to the best means of remedying the then deplorable state of things. A commission was accordingly appointed, and a contract was made in 1630 with Francis, Earl of Bedford, to drain the fens, for which he was to receive 95,000 acres as a recompense. The Earl employed Sir Cornelius Vermuyden, a Dutchman who had settled on Hatfield Chase, to make plans for the intended work, which was said to have been completed in fourteen years; but it afterwards proved defective, and the contract was annulled. Charles I., who was fond of speculation, then determined to undertake the work himself, employing Vermuyden as his Engineer, but the Civil War intervening, the contract was never carried into effect. The drainage was subsequently completed in 1652, according to Vermuyden's plan, by William, Earl of Bedford, and his associates. By this plan, the channel of the Great Ouse was shortened 10 miles, by a new cut, about 21 miles long, from Earith to Denver, where a sluice was placed across the united channels of the Great and Little Ouse, the Grant, or Cam, and the Stoke, Brandon, and Mildenhall Rivers, so that all the floods of the Great Ouse above Earith were discharged through this new channel, without passing through the South Level. Several other interior drains, sluices, &c., were also executed in connection with the above works. After much discussion, Vermuyden's plan was carried into effect, and the level of the water was considerably lowered; and 95,000 acres of land were awarded to William, Earl of Bedford, and the parties who, jointly with him, had incurred the expense of the drainage. After some years, it was proved, that the level was not well drained, and that Lynn Harbour was injured. Then followed endless discussion and litigation. At last, in 1713, Denver Sluice was undermined and blown up by the waters, and the tide, in consequence, was again admitted to its old receptacles,

whereby Lynn Harbour was improved. In 1750, in spite of strong opposition, Denver Sluice was rebuilt. Some partial improvement was then effected in the South Level; but the drainage still remained very imperfect. The superior velocity of the great mass of water coming from the straight New River, greatly retarded, or over-rode the waters discharged through Denver Sluice; but if the Old River had been properly embanked and improved, and had been connected with a judicious system of interior works, the drainage navigation and outfall would have been far better improved and maintained without the sluice at Denver, which was improperly applied there. It would be tedious to go into details of the various plans subsequently proposed by the most able Engineers of the respective periods, including Westerdike, Kinderley, Armstrong, Labelye, Golborne, Watté, Elstobb, Smeaton, Mylne, Page, Huddart, &c. Their plans were fully discussed; but nothing further of consequence was executed. The South Level, including the high lands around it, containing 173,000 acres, and the Middle Level, containing about 150,000 acres, had been separated from the North Level, of which the area was about 50,000 acres. About the year 1724, Bridgeman, who was evidently possessed of considerable ability, proposed as the only remedy for the drainage of the Middle and South Levels, to make a cut from a place called Eau Brink, about a mile below German's Bridge, to Lynn; by which means, he argued, the river would be brought into better working condition and the water in it lowered by about 5 feet. It required many years of further discussion, before it was finally considered absolutely necessary to carry out that plan, in order to improve the drainage; and it was not till 1795, that the first Act was obtained. At that period, the cost of the cut was estimated at £39,985; but in consequence of the numerous investigations and the litigation which subsequently occurred, (notwithstanding that the Act was obtained,) the whole of the money, which had been raised by local taxation, was expended before the work could even be begun. No one would submit to fresh taxation, and the Act, consequently, was not, at that time, carried into effect.

In 1809, the Bedford Level Corporation applied to the Father of Sir John Rennie, to make a complete examination of the South and Middle Levels, and to report upon them. In 1810, he made a Report, in which he entered fully into the cause of the evils, viz., the defective state of the outfalls and channels of the rivers, and the bad system of internal drainage. He proposed, as a remedy, that the Eau Brink Cut should be made according to Captain Huddart's award, that the other bend on the Ouse above Magdalen Bridge should also be cut off, that an entire new cut should be made for the Ouse from Denver Sluice to Earith, that the other

rivers should be improved, and that either a new improved and enlarged sluice should be constructed instead of Old Denver Sluice, or that the tide should be admitted into the old river above, without the sluice. With regard to the interior works, he proposed, that there should be a complete system of arterial and subsidiary drains connected with the Ouse at the Eau Brink Cut, and that capacious catchwater drains should be made between the Nene near Peterborough, and the Ouse at Earith, along the base of the high lands between these places; also that another catchwater drain should be made from the Ouse at Earith, thence skirting the base of the high lands in the South Level, and entering the Ouse below Denver Sluice. By these means, the whole of the high-land water coming from the higher level, would have been intercepted and discharged into the upper part of the Rivers Ouse and Nene, where there was ample fall; and thus the water from the low lands, having less fall, would have been discharged at the lower part of the river, at the head of the Eau Brink Cut, without being interrupted by the high-land waters. This plan for the drainage of about 300,000 acres was estimated to cost £1,300,000. At that time it was, however, unfortunately considered too great an undertaking, although, considering the amount of land to be drained, the cost was very moderate, and would have been amply repaid; no steps, therefore, were taken for several years. At last, in 1818, as the drainage was still in a very defective state, it was resolved, in the first instance, to execute the Eau Brink Cut. A new Act of Parliament was accordingly obtained, with ample powers to raise the necessary funds, and in 1821, the cut was completed according to Huddart's award, together with numerous interior works required by the Act of 1793, which could not be altered, although Mr. Rennie was desirous, that the money should be expended more profitably in carrying into effect other works, according to his plan. By the completion of the Eau Brink Cut, the low-water line was lowered about 5 feet at the upper end of the cut, which produced a corresponding improvement in the general drainage. Although only a small portion of Mr. Rennie's plan had been carried out, sufficient advantage was supposed to have been obtained, and it was not until 1844, that the proprietors of the Middle Level, finding they had not received the benefits which they had anticipated, obtained an Act of Parliament to complete their interior drainage. They adopted that portion of Mr. Rennie's plan which proposed to make a main drain from Whittlesea Mere to the head of the Eau Brink Cut, although in rather a different line, but they omitted a most material part of his plan, his catchwater and subsidiary drains. The plan was executed, although it was evident, that it would not be sufficient to drain Whittlesea Mere and the adjacent low lands, without steam and other works,

for this district was the lowest and the furthest from the Eau Brink Cut, being distant from it about 30 miles. It should be observed, that when a general plan could not be adopted, and it was only required to drain small detached districts, Mr. Rennie had previously, in the year 1789, proposed to drain Swaffham and Bottisham Fens, amounting to about 5,000 acres, in the South Level, by steam power, which he afterwards accomplished in 1821. Had the catchwater drains between the Nene and the Ouse been adopted, the high-land water would have been discharged about 30 miles above, and the low-land waters would have been well carried off to sea, before the high-land waters had joined them. When the work was completed, it was found, that a good drainage could not be effected by it, until some further works were undertaken, such as steam power for the district adjacent to Whittlesea Mere, and an improvement in the outfall below Lynn, which was proposed by Sir John Rennie in 1839, and for which an Act of Parliament was obtained in 1846. In 1849, the late Mr. Robert Stephenson and Sir John Rennie were called upon to arrange what was really required, a complete and comprehensive plan for the improvement of the outfall below Lynn: the result was a similar plan to that of 1846, and in 1850, an Act of Parliament was obtained to carry it into effect. The Eau Brink Commissioners for the general drainage of the fens and the Corporation of Lynn were so convinced of its importance, that they agreed to contribute towards the expense £60,000 each, or £120,000. This plan was, accordingly, carried into effect under the direction of Mr. Robert Stephenson and Sir John Rennie, and the result had fully justified the anticipations that had been formed. A further lowering of the low-water mark, to the extent of about 6 feet, had been gained, which, added to the former gain of 7 feet, made a total of 13 feet. Seven feet had been gained by the Eau Brink Cut at the upper end, viz., 5 feet by the original cut according to Huddart's award, and 2 feet by the subsequent enlargement of that cut by Mr. Telford and Sir John Rennie. Six feet had been gained at the lower end in Lynn Harbour, by the Norfolk Estuary Cut. It should be observed, however, that between the periods of making the Eau Brink Cut and the Norfolk Estuary Cut, the low-water mark had risen nearly 2 feet at the lower end of the Eau Brink Cut, by the accumulation of sand in the outfall below Lynn, so that the total fall gained at the upper end of the Eau Brink Cut might be estimated, at present, at about 9 feet; but in proportion as the inclination of the current above adjusted itself to the fall gained below, a further lowering of about 2 feet might be expected, at the upper end of the Eau Brink Cut, thus making a total gain of about 11 feet, or nearly the same as had been gained by the Nene Outfall Cut. These great works, there-

fore, had completely effected the drainage of about 500,000 acres of land, besides greatly improving the River Ouse and the harbour of Lynn.

The great object, in works of this class, was to keep the rivers and their outfalls in as perfect order as possible; and as the channel of a river could only be maintained in proportion to the quantity of water passing through it, it was necessary to bring as much water into the channel, as could be discharged within a given time. By means of Mr. Rennie's catchwater system of drainage, which he applied in 1806, with the greatest success, to the drainage of 75,000 acres of very low lands in the neighbourhood of Boston, but which had been unfortunately omitted in the Bedford Level, the high-land water would have been discharged about 30 miles above the point of discharge of the low-land water into the Eau Brink Cut: thus all the upland water would have passed through the channel of the river, which would have materially contributed to keep it open, and the further advantage of a supply of fresh water from the higher level would have been obtained for the use of the district, during the dry season of summer. This was an important part of the question, because in dry seasons, not only the lands, but the inhabitants of the fens, together with their live stock, suffered considerably from the scarcity of water. In draining particular districts, therefore, attention must be directed not merely to getting rid of the water, but rather to the means of obtaining perfect control over it, so that the proper quantity might be retained, or discharged, as each individual case might require. He believed, that the time would come when drainage would, in many cases, be combined with irrigation and the means of storing and providing water during seasons of scarcity.

The North Level was drained by the Nene, or Wisbeach Outfall, which had greatly suffered from being deprived of the waters of the Great Ouse. In the reign of Henry VIII., Bishop Morton, a distinguished prelate, having a large interest in the district, consulted the best authorities of the day, and it was finally decided to make a new straight cut for the Nene, from just below Peterborough to near Wisbeach, by which the old channel of the river would be shortened about 7 miles. This cut was made and was called Morton's Leam, or Cut, under which name it existed at the present day. It was beneficial, so far as it went, but it bore no proportion to the magnitude of the obstructions in the outfall below Wisbeach, which amounted almost to a complete stoppage of the navigation and drainage. It became necessary, therefore, to discharge a considerable portion of the waters into the outfall below Wisbeach, by the Old Shire Drain which discharged its waters into the Great Wash about 5 miles below Wisbeach; and Kinderley, a well-known Engineer of the day, was consulted. He

at once saw, that the great obstacles to improvement were below Wisbeach, and in order to remove them, he proposed, that a new short straight cut should be made about 4 miles below Wisbeach, just above the outfall of the Old Shire Drain. This work, of which a portion still existed bearing Kinderley's name, was, notwithstanding great opposition on the part of the Corporation of Wisbeach, completed in 1773, and was attended with great beneficial results. Various Reports upon the improvement of the interior drainage were subsequently made by Smeaton and other able Engineers, but they were not acted upon. In 1809, 1813, and 1814, Mr. Rennie made three Reports; one for the improvement of the Nene from Peterborough to the sea at Crabhole, 13 miles below Wisbeach, and the other two for the drainage of the low lands comprised within the North Level, South Holland, and the adjacent districts: still nothing was effected. In the year 1826, Mr. Telford and Sir John Rennie were consulted; they recommended, that in the first instance, that portion of Mr. Rennie's plan for the improvement of the outfall below Wisbeach to Crabhole, should be carried out: an Act of Parliament was accordingly obtained for that purpose, and this great work, called the Nene Outfall, was placed under their joint direction; it was completed in 1830, with very beneficial results. The low-water line was lowered 10 feet 6 inches, which afforded an opportunity of giving a complete drainage to the whole of the above districts, and effected an important improvement in the navigation to Wisbeach. Mr. Telford and Sir John Rennie subsequently proposed to improve the Nene up to Peterborough, upon a plan similar to that of Mr. Rennie, by a cut avoiding Wisbeach, and converting the old channel passing through it into a capacious wet dock connected with the New River, which would have been a great advantage to both; but nothing further was done at the time. Mr. Telford, however, executed a plan for the improvement of the interior drainage of the North Level, similar, in some respects, to that of Mr. Rennie, but as he did not carry the outfall low enough, subsequent works were necessary. In 1836, and again in 1840, Sir John Rennie proposed, that the upper part of the river from the Nene Outfall Cut to Goldicut Staunch, or Lock, about a mile above Peterborough Bridge, should be improved, avoiding Wisbeach by a direct cut to the river, and converting the old channel through the town, into a wet dock in connection with the New River. He also proposed, that the water from 55,000 acres of low level around Whittlesea Mere, which then drained into the Great Ouse, should be brought back to the original outfall, the Nene, at Bevil's Leam. This project was opposed, and ultimately, the district was drained into the Ouse, according to the Middle Level plan of 1844 before-mentioned. The whole of the water

[1859-60. N. S.]

from the 55,000 acres was thus carried round by the Lynn Outfall, 10 miles farther than was necessary for the drainage; whereas if the water had been allowed to drain into its natural outfall, the Nene, the whole country would have been perfectly drained at far less expense, and the Nene might have been effectively improved, without such a severe tax upon the small district of low lands which contributed towards it, as well as the town of Wisbeach.

The Ancholme drainage had already been described by Sir John Rennie in a former Paper, and it was only necessary to say, that the Ancholme was one of those cases where a sluice was carried across the main river, with great advantage. In fact, a sluice was not only applicable, but indispensable, to preserve the drainage and navigation, for otherwise, the strong current of the Humber, and the great quantity of alluvial matter with which its waters were charged, would have so completely overpowered the Ancholme and have filled up its channel, that the whole level would have been inundated, and the navigation would have been destroyed. The sluice, however, was adopted, and both the drainage and the navigation had been most effectually obtained.

Many districts in Yorkshire, such as Hatfield Chase and others, were chiefly drained upon the old plan, and they were still, in many cases, in a very defective state. In 1813, Mr. Rennie made a complete plan for the drainage of Hatfield Chase, which, however, was never carried into effect; though it was believed, that it would have amply repaid the outlay.

He had now finished his remarks on the drainage of this country, and he would merely observe, that the main principles of drainage and navigation were:—the improvement of the rivers and their outfalls;—a judicious system of main, interior, and subsidiary drains, with sluices in connection with the rivers, at the most convenient places for the low-land waters;—and catchwater drains for the high-land waters.

He would not allude to the Irish drainages, because it was a question upon which there were great differences of opinion. The drainage of Lombardy would occupy too much time to discuss it properly. A great deal of money had been spent in that country upon drainage operations, and the attention of numerous scientific men had been given to the subject. The rivers there were upon a much larger scale, and so different in their character, when compared with the rivers in this country, that the same system which had been so necessary here, would not altogether apply there. The rivers, from the repeated raising of their embankments, had become the repositories of the débris and alluvial matter brought down from the Alps, to such an extent, that their beds had, in many cases, been elevated 10 feet, 15 feet, and even 20 feet above the level of the ground which they were intended to drain, so that great expense

was being continually incurred in altering their channels. This was not a good system, but by proper measures the evil might be obviated. He would, probably, have occasion, hereafter, to make some remarks upon this important question, relative to the best mode of preventing the débris from entering the plains, and to the disposal of the alluvial matter by warping, so as to keep the main channels of the river clear. The Indian rivers, also, were so different to those in this country, that they required a specific mode of treatment. In fact, every district, not only with respect to the character and extent of the rivers, but to many other circumstances, required special consideration, and must be treated, each according to its own conditions.

With regard to irrigation, there could be no doubt of its value, and he thought the subject deserved more attention than had, hitherto, been directed towards it; almost the only great work of that character in this country which had been scientifically carried into effect, was that by the Duke of Portland, at Welbeck, in Nottinghamshire, upon which about £50,000 had been expended.

Mr. FOWLER said, with regard to the political economy involved in the question of arterial drainage, it had been suggested, that a commission should be appointed, with considerable powers, for carrying out these works. But it might so happen, that among the commissioners incorporated, there would be found some one single individual of great independence, great statistical ability, and altogether so influential as gradually to absorb in himself all the power of this body, and at the same time, he might be disposed to employ unprofessional rather than professional men, to urge the laying down of pipes infinitely too small for their purpose, and in curved instead of straight lines. Now if the whole drainage of the country, and all works connected with it, were at the mercy of such a board, he need not ask whether such a state of things would not bring about evils infinitely greater than those sought to be remedied. It was perfectly true there were cases in which, through the obstinacy of one individual, benefits to others were prevented, even though the proposed measures might also be beneficial to the opposing party himself. That was, doubtless, a great evil, but he repeated, that he did not think such an evil could be remedied, except at the risk of creating greater ones. But it was not only to drainage, that obstacles were sometimes interposed by individuals, but also to roads. It might be desirable to carry through some one's property, a road which would be beneficial to all parties concerned, but if he objected, there was no law to compel his consent. The experience of most men would suggest a vast number of cases where individual obstinacy had caused great inconvenience, but which it might not be wise to make the subject of special legislation. Remembering

what had already taken place, he repeated, that to create a board with such powers as had been suggested, would be productive of evils infinitely greater than those which they sought to remedy.

With regard to arterial drainage, he would attempt to give direction to the discussion by a reference to one, or two principles. He considered the Ancholme drainage a case where the outfall was not dependent upon the discharge of the water from the level itself; and the Witham as a case where it was dependent, but where the tide was shut out. The Ouse and the Nene were cases in which the outfall was dependent upon the discharge of the water from the level, but the tide was admitted. The Ancholme drainage, upon which the Institution had the valuable Paper, presented by Sir John Rennie in 1845, was one in which the tide was not admitted at all. The tidal current of the estuary of the Humber swept past its sluice entrance and kept it free: and it was not dependent upon the discharge of water from the land. The Ancholme was a combination of drainage and navigation, with catchwater drains. The drainage was perfect so far as freedom from inundation was concerned, whilst the means of irrigation were afforded by the catchwater drains: and it combined, better than at most other places, drainage and navigation. Other cases of the kind had been treated upon the plan of Vermuyden, who having a great dislike for tidal water, excluded it wherever it was practicable; and in some cases, he was right. To the Witham, Vermuyden's principle was applied of shutting out the tide above Boston; but in that case it was wrong, because the outfall was dependent upon the mode in which the water was discharged, and consequently, the navigation had been imperfect ever since. At Boston, there was a large expanse of low land, over which the water struggled to get into the deep water of the Wash: the outfall, therefore, was dependent upon the way in which it was discharged. If the water was permitted to go up by the Witham in the same way as by the Ouse and the Nene, the Witham would be in a different condition to that in which it was at present. The Ouse and the Nene might be termed open rivers;—the Nene perfectly so,—and the Ouse, up to Denver Sluice.

The Nene was a river which had been really benefited by the alterations already effected. The outfall was very good, and all that was now wanted was to carry out improvements up the river; and by removing obstructions and properly attending to the banks, it would become a fine river. The Ouse was of a similar character to the Nene, and had fairly repaid all the care bestowed upon it. Every improvement had been of great value both to navigation and drainage. Sir John Rennie had described the large amount of drainage that had been carried out in that district: Mr. Fowler, however, did not think, that 13 feet had been gained at Lynn;

still, at the present time, the Ouse below and above Lynn was a complete river. The cut constructed by Sir John Rennie and the late Mr. Stephenson, was certainly one of the finest engineering works in the country. The cut was 2 miles in length, and from 600 feet to 700 feet in width; and a more successful result had never been obtained. He thought there was no branch of engineering science which required more care, than such cases as this. The material was easily acted upon by scour; and even if cut originally in straight lines, it was easily distorted and turned into irregular forms. That required to be corrected: and it was the province of the Engineer to decide upon the materials that should be used to protect the slope of the cut, upon the form to be given to the slope, and upon the means of maintaining the improvements at the smallest expense. The first depth obtained was seldom so much as was subsequently arrived at. These improvements were obtained at the risk of damage to the banks; as the depth increased, the banks must be protected, and constant watchfulness was necessary to carry them out with safety. In this respect it was impossible to lay down any general principles. The Engineer must consider every case separately, as it occurred to him: but as a rule, a formation of rubble stone at the foot of the slope was a good system, for directing the general current, and the upper part of the slope was kept in form with less difficulty. A minor improvement had been lately introduced into the works of the Norfolk Estuary, by creosoting the stakes; and it was believed, that this small additional expense was attended with advantage. He expressed his entire concurrence with the remark of Sir John Rennie, that it was impossible to lay down any general principle as applicable to all conditions and circumstances. The conditions of every case must be carefully and separately considered: and he especially cautioned Engineers against the adoption, like Vermuyden, of an inflexible principle in all cases.

SIR JOHN RENNIE explained, that the Ouse might be considered an open river, not only as far as Denver Sluice, but up to Earith, 20 miles beyond. The gain at Lynn had been 7 feet by the Eau Brink Cut, and a further gain of 6 feet had resulted from the works undertaken in 1850 by Mr. Robert Stephenson and himself.

MR. JAMES COOPER said, there was one part of the Bedford Level which had been much improved by a large cut, or drain, and other works executed by Mr. Walker, and he would direct attention to that gentleman's Report of 1842, in which he recommended, for the improvement of the Middle Level, the entire separation of the navigation from the drainage. This was a new idea at that time, and one which it was, at first, considered quite impracticable to accomplish. The difficulty arose from the country being very flat, and from the rivers, which had been regulated for the combination of

both objects, requiring to be kept at such a low level, that a drain, it was thought, could not be carried sufficiently low to pass under them, and still have the required inclination for carrying off the water. Mr. Walker succeeded in convincing the landowners of the advantages to be derived by constructing a large and deep drain with a level bottom, and of the great improvements which would be effected in the Middle Level, by the severance of the drainage from the navigation. After much discussion, and a successful, although severe Parliamentary contest, it was determined to carry out a portion of the scheme. A drain was made, about 10 miles in length, passing under one of the rivers of the district, and connected, at its upper end, with two other main rivers. This had the effect of lowering the level of the water 6 feet in the whole of the rivers of the district, thus greatly improving the drainage, and drying up Whittlesea Mere. The principal work consisted of a large outlet sluice at the top of the Eau Brink Cut, having three openings, each 20 feet wide, with the sills 8 feet below low-water mark in the Ouse. The bottom width of the drain was 40 feet at the upper end, and 50 feet at the lower end, with a depth of 9 feet below low-water mark, at the outlet. The course was perfectly level for about 10 miles, passing under Well Creek by an aqueduct, of which the span was about 40 feet; and at that point, sluices were placed across the drain to regulate the water above. Thus the level of the water was completely under command; in summer, it could be kept up for the purpose of navigation and for the supply of fresh water, and it could be allowed to run off in the winter. If Mr. Walker's original scheme had been carried out through the level, the country would have been in a still better condition, for in so large a district, containing 140,000 acres, the interests of all parties as to the proper level of the water could not be consulted. He believed, that at the present time, no portion of the Bedford Level was better drained than the Middle Level. The district was drained in ordinary floods with an average fall, at the surface, of 1 inch per mile, and in extraordinary floods, the average fall was not more than 2 inches per mile.

The carrying out of any general legislative enactment on drainage, would be attended with difficulty, on account of the varieties of opinion which existed on the subject. Throughout the Bedford Level district, almost everybody entertained peculiar amateur opinions upon drainage questions, and it would be found impossible to devise a measure which would be satisfactory to all parties. Considering also the difficulties interposed in other localities by the millowners, it would appear to be better, on the whole, that special application should be made to Parliament, in each individual case.

Mr. HEMANS remarked, that as the Paper led to the inference of some general drainage Act being desirable for England, he thought something more than a passing notice should be given to Ireland, as it was an instance particularly in point. That country had derived considerable benefits from the drainage of a great extent of its surface. From the different railway works which he had carried across the drained districts, he knew there was every reason to be satisfied with the engineering results, so far as they alone were concerned. But the working of the Act relative to drainage had been of a most arbitrary character, and nothing could be more unsatisfactory than placing such extensive powers in the hands of any board. The first step taken was the passing of a Summary Proceedings Act, (partly for the relief of the poor during the famine,) by which power was given to the Board of Works to execute drainage to any extent which appeared, in their judgment, to be desirable, on the application of any single landowner in the first instance, and supported afterwards by a majority at a public meeting. The consequence was, that in a short time, more than one hundred districts were examined and reported upon for drainage. The limit of expenditure was fixed not to exceed, on an average, £3 per acre, upon the whole of the district; but before the works were half completed, the whole of the money had been expended; no results, therefore, were, in the first instance, obtained. Application was then made to the proprietors for their consent to a larger amount of taxation, in order to complete the works. On the refusal of the proprietors, Parliament was induced to institute an inquiry, which was conducted by the late Mr. Rendel, and others, by whose Report it was ascertained, that to complete the works, at least £2,000,000 would be required, instead of £1,000,000, which was the amount of the original estimate. The ultimate measure adopted was to impose upon the ratepayers a tax, to be levied on the amount of the original estimate only; to reduce the works within the extent to which they ought, originally, to have been confined; and to throw the remainder of the expenditure upon the Consolidated Fund. This decision created great dissatisfaction, as it inflicted an unjust burden upon the general resources of the country. But no provision had been made for the maintenance of the works which had been completed. Thus, notwithstanding the favourable circumstances under which this legislative measure was executed, no opposition being offered, and the country requiring labour and improvement, yet it had resulted in failure. Such also he had observed to be the case throughout its working. He did not attribute the blame to the Commission, or to the Engineers who carried out the works,—the fault was in the attempt to legislate

upon the subject in such a manner, conferring arbitrary powers, without imposing proper checks upon a large expenditure.

Mr. FREDERICK BARRY thought there had been some misapprehension with regard to the general way in which arterial drainage in Ireland had been carried out. The first Act was passed in 1812. It appointed the Commissioners of Public Works, in Ireland, Commissioners of Drainage, and it enabled any landed proprietor, on presenting a memorial, and guaranteeing the cost of the survey, to get a report from them upon the drainage of his land along any river, or lake. This report was then to be lodged with the Clerk of the Peace of the county in which the lands were situated, together with schedules and plans; the schedules to state the quantity of land to be drained, their actual value, and the increased value, if the drainage works were carried out, as also the proportion of the expense to be paid by each proprietor upon the completion of the works. The assent of two-thirds of the proprietors was then to be obtained before the works could be commenced. Modifications were subsequently introduced by the Act of 1846, which was passed for the purpose of giving profitable employment to the labouring classes during the famine; and, as the preliminary investigations and surveys were made in a 'summary' way, the object being to afford immediate relief, the Commissioners were not empowered to expend more than £3 per acre, without again collecting the assents. These assents not having been given in eleven districts, a Commission of inquiry was issued; but he did not think they reported, that £2,000,000 would be required to complete the works, as he found that, up to the 31st of December, 1858, the total expenditure in one hundred and twenty-one districts, of which one hundred and ten were completed, and the remaining eleven nearly so, was only £2,342,746.

It had been inferred, that no power was given to maintain the works after completion. In this he did not agree, as, after the district was handed over to the proprietors, the latter had, under the Drainage Acts, authority to maintain the works. For that object they elected trustees amongst themselves, appointed their own Engineer, and fixed the amount to be raised for maintenance and repairs. He saw no reason against passing a general law on the subject, permitting, under certain conditions, the proprietors of flooded and injured lands to execute works for their relief and to levy rates, the Board of Trade acting as arbitrators in cases of dispute.

In conclusion, he would mention, that in Ireland, up to the end of 1858, there had been 1,450 miles of river channels excavated and scoured, unwatering 6,372,000 acres, nearly one-third of the whole country, by which means 284,577 acres of land had been

freed from flooding. One hundred and ten districts had been completed, on which awards had been made, showing that 145,000 acres of land had been drained, at a cost of £5. 19s. 11d. per acre, the increase in the annual letting being £40,000.

Mr. BIDDER, V.P., said, that in the course of the discussion, some remarks had fallen which called for observation. It seemed to have been inferred, that the Irish Commission was a great financial success, because 175,000 acres had been drained at a cost of £5. 19s. 11d. per acre. Now that represented a capital of about £1,000,000; and, as the rental value of the land was stated to have been increased £40,000 per annum, the return upon the outlay was only 4 per cent. He could not, therefore, regard that instance as at all favourable to the establishment of a Commission of such a character as that which had been described.

He regretted, that the discussion had been rather of a political than of a scientific character. The object of the Institution was to promote scientific and practical discussions; those of a political character being purely incidental. On this part of the subject he would only remark, that both as an Engineer and as a citizen, he was decidedly opposed to all centralisation. Human nature was, no doubt, a very imperfect agent to deal with; still it was, in many respects, superior to the artificial systems intended for its control.

Although the subject had been introduced with great care and research, and although a most interesting narrative of drainage works had been added by Sir John Rennie, yet further discussion upon scientific facts was highly desirable. An exact statement of facts in the treatment, whether right, or wrong, of any one river, was of infinite value; whether it was a tidal scour, or backwater from land streams, the relative value would be of vast importance; and he hoped another Session would not pass over, without this subject receiving the attention which it deserved. Sir John Rennie had stated, that the effect of the Eau Brink works had been to lower the water 7 feet at Lynn; such might have been the case at the upper end of this cut, but at Lynn the datum line had risen. It had again been lowered 6 feet by the operation of the New Cut; but the water at Lynn was certainly, at present, not 13 feet below the level at which it stood, before the Eau Brink Cut was made: he thought it had not been reduced more than 4 feet. He alluded to this, in order to show the absolute necessity of a correct and complete record of the phenomena which had occurred, in every river the bed of which had been altered.

The arterial drainage of the country was of the utmost consequence; but the results said to have been obtained were most anomalous. It had been asserted, that in some instances, the effect of under-drainage had been to swell the rivers, and to cause

more water to flow from the land. He doubted, however, whether floods would be increased by under-drainage, or whether more water would flow off the surface of the land. Although contrary to preconceived opinions, and the result of *à priori* reasoning, he rather believed, that under-drainage would diminish the extent of floods, that a greater quantity of water would be evaporated, and that, consequently, less would be discharged into the rivers.

Mr. W. A. BROOKS was desirous of obtaining some information, which he believed to be in the possession of several Members, with reference to the levels taken for the drainage of the eastern fen districts; he wished also to know how far the alterations which had been made since the year 1767, had affected the great streams of that district. A vast tract, extending 40 miles from the ancient seaboard, had been converted into land fit for agricultural purposes, partly by deposits of sand of marine introduction, and partly by alluvial deposits. Referring to the levels taken by Elstobb and Smeaton in 1767, he found, that at the east end of Kinderley's Cut, (which was the first work constructed,) there was, at that time, a depression of 14 inches in the high-water level, which he attributed to the contracted nature of the channel. That depression showed the necessity of having ample waterways, which he considered had been too much neglected in the great works in Cambridgeshire, Norfolk, and Lincolnshire. At the Horseshoe Hole there was a depression of 2 feet 1 inch; at Wisbeach Bridge, of 2 feet 3 inches; at Cold Harbour, of 2 feet 10 inches; at Guyhirne, of 3 feet 11 inches; and at Knar Lake, 9 miles above Wisbeach, to the extent of 6 feet. The last was a depression equal to the spring-tide flow of the Red Sea at Suez; and if the same amount of depression took place throughout the proposed cut at the isthmus, there would be no lift of tide, or tidal influence experienced at a distance of 17 miles from the Red Sea. In a Report by Sir John Rennie, in December, 1836, it was stated that, as a result of the improved drainage, there was a depression of the low-water surface to the extent of 10 feet at the North Level Sluice, and that sluice had been placed 8 feet lower than the Old Gunthorpe Sluice. Now, the old flow of the tide, by the levels to which he had referred, was 12 feet 7 inches, which, added to the 10 feet, would give 22 feet 7 inches as the height of the column of water, or tidal flow, supposing that the high-water level remained the same as in 1767; but Sir John Rennie gave, by his levels of 1836, a flow of only 16 feet 10 inches, which would show at that place, a depression of 5 feet 9 inches of the high-water surface. It was very desirable to have this difference, or increased depression of the level at high water, correctly ascertained; and he hoped, by mentioning the subject, it might lead to the produc-

tion of the levels of the Old Eau Brink Cut, or of the Ouse in its ancient and in its present state; and also of other valuable documents in connection with the River Witham. He thought those long narrow cuts in the Nene and the Ouse courses were not likely to be very successful; there would be a very confused navigation at the outfalls. He believed it would be desirable, that an enlargement should be made, to allow a greater influence of the tidal element, in the new channels which were laid down on the plan. (Plate 2.) If those long narrow channels were carried out, a great depression would take place in the level of the tidal column, entering each channel.

Mr. J. COCKBURN CURTIS said, that the question of the improvement of tidal drainage was a question of measurements and facts. He was glad to learn, that Mr. Brooks proposed collecting and discussing the tidal observations which had been made in reference to the Norfolk Estuary and its dependent drainages, and he should be happy to place at his disposal, for that purpose, the observations which he had made, when called upon by the Eau Brink Drainage Commissioners, in 1849, to investigate the subject. In order to ascertain the extent of improvement, the only philosophical and logical mode of proceeding was, to compare the physical state of a drainage with its previous condition at different epochs of its history, and to consider the combination of elements at work, constituting what might be termed the natural economy of the estuary, in relation to itself alone, and to no *à priori* test. The facts would, of necessity, present themselves with endless variety of combination, and with every shade of difference; and it was possible that, in the present state of hydraulic science, there was no department of the profession in which the Engineer was so strictly called upon to divest himself of all preconceived notions, and to confine himself to the investigation and application of the facts and physical laws of the individual case before him, as in questions of this character.

There was one point in connection with the Norfolk Estuary improvements to which he would call attention, and which forcibly struck him during his examination of the Nene and Ouse improvements. He alluded to the importance of designing the outfall of a tidal drainage in such a manner, that the artificial channel where it debouched into the estuary, should be, with regard to direction, slope, and section, in harmony, as nearly as possible, with the natural tidal conditions of the estuary and of the natural deep-water channel which formed the principal axis of the incoming tidal wave; where this had not been attended to, he had generally noticed, that a low-water bar was formed, and that the outfall pursued an uncertain and tortuous course until it reached the deep-water channel.

Where a straight cut was substituted for a natural channel of greater expanse and curvature, it was obvious, that the fall became suddenly concentrated on a small portion of the length of the channel, and the downward motion of the water would have a tendency to 'plough up' a bar at its termination: this could only be avoided by increasing the width and sectional area of the low-water channel as it entered the estuary, so as to bring the slope of the water passing down the cut, at its lower levels, in unison with the natural slope of the tidal wave in the estuary. The width of the channel had been increased in this manner, to a certain extent, in the case of the Nene, and he believed also in that of the Ouse Outfall, but not sufficiently in either; and in both cases, the direction of the channels had not been designed with sufficient regard to the principal axis of the in-coming tidal wave. At the time of Mr. Curtis's examination of the Nene Outfall, there was a low-water bar of the character he had just described, at a short distance beyond the termination of the new low-water channel, and in giving evidence before the Committee on the Norfolk Estuary Bill, he pointed out, that with the dimensions and direction then proposed, a similar result would, probably, take place at the new outfall for the Ouse. He had not had a subsequent opportunity of inspecting the locality, but from the Admiralty Chart and Sailing Directions, compiled since the execution of the works, he was led to think, that his opinion had been justified by the existing facts of the case. It was with great diffidence, that he ventured to make those remarks, upon works designed by the eminent Engineers who had executed the improvements of the Nene and Ouse Outfalls. He by no means wished to undervalue the great advantages which had, doubtless, accrued from their execution, both to navigation and to drainage; his object was simply to point out certain elements, which, he thought, had not received sufficient consideration, and by attention to which it was possible, that a much greater extent of improvement might have been obtained, at an equal, if not at considerably smaller expense.

The investigation of a great number of tidal observations on different rivers and estuaries had led him to notice the importance, in certain cases of tidal drainage, of preserving, as far as possible, the character and volume of the tidal wave, in its passage up and down a river. In such cases it was not only necessary, that a critical examination should be made of the river, in its high and its low-water states, but the whole profile of the wave should be observed, in its passage up and down the river, at as many stations as possible. Such observations, when reduced in the ordinary manner to diagrams of time, height, and distance, and compared with the profile and volume of the derivative wave, never failed to show any irregularity, or diminution of the tidal

force ; and by such a process, the whole of the tidal facts of the case became vividly impressed on the mind.

Tidal drainage might be considered as a race against time, and in some rivers more water was discharged out of the river by the rapid reflux of the tidal wave, than could possibly be discharged by the slower action of the current, or stream ; hence the importance of proportioning the tidal mouth of a drainage channel to the tidal conditions of the estuary into which it debouched, and the necessity for maintaining the outfall free from bars, so as to preserve a clear entrance and exit for the lower portion of the tidal wave.

There was no doubt, that the theoretical determination of the form of a channel which should, under given circumstances, exactly answer the conditions of discharging a given amount of fresh-water drainage, and yet preserve the greatest amount of tidal force was, in the present state of tidal hydronomy, a difficult problem ; still he thought it could always practically be done, by a careful observation of the physical forces at work at the land and seaward ends of the proposed channel. The law of motion of the tidal wave had, to a certain extent, been determined in relation to channels of uniform depth and section, but he was not aware, that any attempt had been made to determine the law of the change in its volume, due to the friction of the slope, curvature, or variation of section of the channel through which it passed. He had little doubt, that with a sufficient number of tidal observations, these elements of the computation could be ascertained, and that hence laws might be established, whereby the best form of channel for the conservation of the tidal force could be determined with theoretical, as well as practical exactness.

The Thames was frequently cited as an example of a theoretically perfect river ; it was also stated, that from recent observations, the tides at London Bridge rose and fell from 4 inches to 6 inches above and below the corresponding levels of the same tide at its entrance. As far as his knowledge at present extended, he thought, that under similar conditions, such a channel, gradually enlarging seaward, was best calculated for the upward and downward propagation of the tidal wave.

Although from an early period he had been placed under circumstances which had practically familiarised him with the forces and motion of water, and the subject had always been to him a matter of study and interest, he should not have ventured to put forward his views, except for the candid and encouraging tone of that portion of the President's Inaugural Address¹ which

¹ *Vide* p. 219. Mr. Bidder had been elected President, and had delivered his Inaugural Address before the conclusion of the discussion.—ED.

related to Hydraulic Engineering. He hoped, that others who possessed greater and more mature knowledge than himself, would also respond to that call, and by the mutual contribution of the information and experience already possessed, rescue that branch of the profession from the stigma of empiricism, which, although to no small extent justified by want of sound knowledge on the subject, was one which, it must be remembered, could be wiped away by the careful discussion and classification of well-established facts, and their reduction to natural laws.

Mr. ORMISTON was not well acquainted with the subject of land drainage, his attention having been principally directed to river improvements. He was, for some years, connected with the Clyde, which had been more improved than any other river. Those improvements were commenced about the year 1768, under the direction of Mr. Golborne. Up to that time, little inconvenience appeared to have been felt from the land floods. The improvements then proposed and shortly afterwards executed, consisted in narrowing the river, so as to give more scour to the channel. The channel was certainly deepened, but its capacity to discharge land floods was, at the same time, materially lessened. This soon became disagreeably evident, in the increased height of the land floods, the highest of which, on record, took place in March, 1782, when the water rose 18 feet above high-water of spring tides, overflowing a large portion of the low part of the city of Glasgow, and the surrounding country, and doing great damage. The evil continuing, in 1799, Mr. Rennie was consulted upon the causes of this increased height of the land floods, which, by the local authorities, were, in a great measure, attributed to a weir, or bank of stones, which had been thrown across the river to protect the foundations of Glasgow Bridge. He reported, that the weir had not materially affected the river, and that the principal cause of the floods was the increased drainage of the country above Glasgow; that he believed the improvement of the river would give some relief, but that it was not to be expected, that the floods would ever fall to their old level. The improvement suggested by him, and carried out, gave an increased area to pass off the floods, and somewhat reduced their level; still every winter the quays were flooded, and it was not until recently, that complete relief had been obtained, by carrying out, under Mr. Walker's direction, the great improvements in widening and deepening the channel according to his plans, for which an Act had been passed in 1842. The depth of the river had been increased from 18 inches, or 2 feet, as Golborne found it, to 20 feet; and at Glasgow, to one place which was the gorge of the river ten years ago, at least three times the sectional area had been given. One effect of the improvements had been to reduce the low-water line 8 feet,

and, so far as land floods were concerned, instead of their rising to the height mentioned, they now seldom reached to more than 6 feet above high water; the quays and town, consequently, were no longer flooded. Another advantage was, that the floods ran off in a very short time. The lines adopted were laid down on precisely the principle advocated in the discussion;—a gradual widening as they approached the frith, with easy bends and a regular bottom.

Mr. LOCKE, M.P., (Past-President,) observed, that Mr. Ormiston would materially add to the value of his remarks, by furnishing the Institution with a chart, or plan, indicating the improvements in the Clyde since 1842.

Mr. LEACH offered some remarks upon the improvements in the Thames, which had undergone considerable alterations during the last thirty years. The removal of Old London Bridge must be considered as having had a great effect in producing these alterations; but he thought more was attributed to that cause than was strictly due to it. He estimated, approximatively, that the quantity of material dredged out of the river, westward of London Bridge, since the removal of the old bridge, had been 6,000,000 cubic yards, and he attributed the lower level of the ebb tide quite as much to the dredging out of material, as to the removal of the old bridge itself. The difference in the low-water level at Teddington Lock, which was the end of the tidal flow, was, from 1810 to the present time, 4 feet 10 inches, and in the last 14 miles of the upper portion of the tideway, there was a very considerable depression of low water. There was, consequently, a much larger amount of tidal water than formerly, but he had not found any material change in the level of high water; not more, indeed, than was fairly attributable to the greater momentum which the tide retained, in consequence of the removal of the obstructions occasioned by the old bridge. Little had been effected for the upper part of the tidal way of the Thames, which still required improvement; but he knew, that it was the intention of the Conservators of the Thames, as soon as circumstances would permit, to turn their attention to this subject, with a view of creating an effective depth for navigation, throughout the whole extent of the tidal range. Other parts of the river beyond that range had been altered, within the last thirty, or forty years. Several weirs had been erected, from which an injurious effect upon the drainage of the adjoining land had been anticipated; but in the majority of instances, the result, on the contrary, had been to give an increased value to the land. In the part of the Thames to which he alluded, it had been observed, that where these weirs did not raise the water higher than 4 feet below the level of the meadow lands, the productiveness was increased. Below the weirs, the surface of the

water had been depressed, and the drainage of the adjacent land thereby improved. The attention of the Conservators had been directed towards obtaining correct tidal observations, in order to judge of the effects of the works which they had in contemplation. He did not expect, that the level of ebb tide would be diminished below Westminster Bridge, but he thought, that above that point, the improvements would have the effect of materially depressing the level of low water.

Mr. LOCKE, M.P., inquired whether the level of low water at Teddington Lock had been affected to the extent of 5 feet, or that the flow of the tide was 5 feet lower; as also, whether there were any recorded observations of the flow of the land water over Teddington Lock.

Sir JOHN RENNIE inquired whether the Corporation of London had established any system of gauging so as to afford correct data, and if so, what was the difference in the high-water level, occasioned by the removal of Old London Bridge. The late Mr. Giles had stated, from personal observation, that the difference was then about 10 inches, or 11 inches; he wished to know whether, from observations subsequently made, the tide had still further increased.

Mr. LEACH replied, that the ebb became 5 feet lower from the year 1810, but the depression had principally occurred, since the removal of Old London Bridge. He had gauged the flow of water over Teddington Lock, but he had not been able to arrive at any satisfactory results. His impression from observation was, that the water discharged amounted to about 500,000,000 gallons in twenty-four hours. The Corporation of London, whilst they were the Conservators of the river, had established a few gauges, and had been about to increase their observations to a considerable extent; the standard to which all those which had been collected were referred, was the Trinity level of high water. The high-water level above London Bridge, as far as he could judge from facts that could be ascertained, had not been materially affected by the removal of the old bridge, or by the subsequent dredging that had taken place above it.

Mr. LOCKE, M.P., said it had been stated, that notwithstanding the removal of 6,000,000 cubic yards of material from the Thames, the high-water level had not been materially changed, but as the river had been, at the same time, affected in other ways, it was still desirable to ascertain whether the dredging of so large a quantity of the bed of the Thames might, or might not, have affected the level of high water.

But the discussion had wandered away from the original question of drainage. It was the object of the Paper to show, that by certain operations in the fens of Lincolnshire and in some districts in the west of England, considerable tracts of land had been

brought into cultivation, by shortening cuts, by making straight channels, and by lowering the level of the water. That was a very different question from the improvement of tidal harbours, the object and intention in the improvement of which was, generally, to raise the level of the tide and so to increase the depth of water; the object of drainage being, on the contrary, to lower outfalls, and thus more effectually to get rid of the upland waters; and these two objects were sometimes antagonistic. Whilst, therefore, discussing the question of drainage, it was important not to misconceive terms, but, like metaphysicians, first to define the terms, or objects to be aimed at. It appeared to him, that the Paper itself had been lost sight of, and the reference to the effects of the removal of Old London Bridge and the conditions of the tides in the Thames, had little bearing on the drainage of lands, and the best means of bringing them into a state of cultivation. Whilst one class of operations might be useful and valuable for one object, they might be detrimental for the purposes of the other. The operations in the Thames and in the Clyde could afford neither an answer to, nor a refutation of assertions made in the Paper, with respect to those undertaken for a totally different purpose, that of bringing fresh land into cultivation. The improvements of the Nene might have been carried on with a double object, for draining the lands as well as improving the navigation; but the sole object of the improvements in the Clyde was to create a harbour at Glasgow. He was delighted to hear, that those magnificent works had increased the depth of water at Glasgow, from about 18 inches to 20 feet, and it reflected great credit on the Engineer who could, by artificial means, produce such results. But the improvement of the Clyde had little, or no reference to drainage, which sought for the means of permanently lowering the level of the outfall; whilst in the other case, the object was to raise the tidal stream, and thus to improve the navigation. It was important, in this discussion, to have a distinct issue; to determine the best means of establishing a tidal harbour, and the proper methods of drainage for the recovery of land, the importance of which was felt by no one more than by himself.

Mr. WILLIAM J. CLUTTON, as a land agent in the north of England, had lately to drain large areas of land for farming purposes, and he would draw attention to a few of the difficulties he had encountered. A great deal of the land upon which he had operated was in the vale of York, and exceedingly flat; that and other parts of the county not being more than 25 feet above mean-water level at Liverpool. The object in view was not only to bring fresh land into cultivation, but to prevent the loss, for want of drainage, of the old land. Many large districts in Yorkshire were under water for weeks together, but they were

[1859-60. N.S.]

capable of perfect drainage, if the co-operation of all the parties interested could be procured. During the last two years he had been engaged in various cases, involving more, or less litigation, in order to compel the occupiers of lands bordering upon streams for a length of three miles, to put those streams into a good state of repair, and to keep them within their old and proper beds. The effect had been to relieve about 400 acres of land; but as the proprietors acted under compulsion, they merely did that for which they were legally liable at the time, and although the works of repair, which were only executed in 1857, would have continued efficient, if they had been maintained, they had been allowed to relapse into their former state. It was imperative, that some means should be adopted, for compelling those who had land on the outfalls of large districts of country, to keep those outfalls in such a condition, that no injury should result to their neighbours. At present, it was frequently impossible to drain, because there was no power to compel the parties below to fulfil their obligations, and to keep their rivulets sufficiently clean, deep, and wide, to carry off the surplus waters which the old outfalls would discharge, if they had been kept open to their full dimensions.

Mr. BEARDMORE remarked upon the suggestion for creating some Government inspection, or supervision of drainage operations, that there was already in existence an Inclosure Board, but, according to his own observation, that Board did not stipulate for the perfect drainage of inclosures which they sanctioned. It appeared of the utmost importance, that every new inclosure should have most efficient provision for all future drainage. Certain preliminaries were gone through, but amongst all the queries of the Board, it was not thought necessary to put the question,—Have you provided, or are you providing for the thorough drainage of the lands to be inclosed? If the supervision of the Inclosure Board was to be maintained, or that of any similar body should, hereafter, be resolved upon, the sooner that desideratum was added to their requirements, the better.

He differed from the opinion which had been expressed, that the tidal question should not be mixed up with that of the drainage of lands. The lowering of an outfall for drainage, if the tide was to be admitted, could not be considered, without taking into account the effect of its admission. If outfalls of that character were lowered, the new conditions which the tidal water must assume, should be carefully examined. The spring-tide high-water of the Nene, at Peterborough, stood in 1850, from 2 feet to 3 feet below the same high-water at Wisbeach. When the Commissioners began to open the channel at the latter place, it was generally expected, that the tide would rise higher, and damage the barrier banks, which were assumed to be not

sufficiently high. Much alarm was thus incidentally caused to the neighbourhood, from the lowering of the level of low water at Wisbeach, which was intended for the purpose of clearing floods, and of draining about 3,000 acres of land below Peterborough. In lowering tidal outfalls, and those of an ordinary upland river, very different conditions presented themselves. So far as the maintenance of tidal estuaries was concerned, the preservation and regulation of the tidal flow was, in his opinion, infinitely more valuable in its effect than that of back water. The present state of things, and the means of dealing with them, were utterly dissimilar from those which existed forty years since, when the steam dredger had not been introduced. No upland water could be compared with the volume of additional tidal water and the regulation of its flow, afforded by the 6,000,000 cubic yards which had been dredged out of the Thames, inasmuch as the tidal flow had the superior advantage of acting in alternate directions, without the disadvantage of silt which was attached to flood waters. The condition of this river had not realised the serious predictions to which the removal of Old London Bridge had given rise. Its removal had, undoubtedly, thrown the tide higher up, especially in respect of its culminating point; but he believed the enormous dredging which was carried on, had greatly tended to keep down the flushing of the tide, to flatten, in fact, the profile of high water by the increased sectional area. He could say, with some degree of certainty, that the tide did rise higher below London Bridge by 6 inches; and the average above the London Docks was, probably, from 4 inches to 6 inches higher at spring tides, than before the removal of Old London Bridge.

Mr. HAWKSLEY said, that the Paper, as he understood it, was essentially a Paper upon agricultural drainage, but he agreed with the opinion, that it could not be fully considered, without treating also of a variety of other drainages. So intimately was agricultural drainage connected with the others, that no discussion upon the subject could be complete which did not take into account, not only agricultural drainage, but also ordinary river drainage, tidal drainage, and even town drainage; because, so far as town drainage was concerned, it was very intimately mixed up with the question of outfall and the benefits of agricultural drainage itself, and especially so with regard to the questions which arose in connection with the Metropolis. A great error prevailed with regard to the under-drainage of land. In many parts of the country the land was over-drained. It was quite possible to remove too much of the under-water, or in other words, it was possible to remove it to too great a depth from the surface. It was possible to produce such an arid condition of the surface, as to render it unfit for the growth of several descriptions of

crops, of which the most distinct proofs were to be found in the fen districts. In the winter, these districts were drained as low as the level of the outfalls would permit; but in the summer, the crops deteriorated if the water continued, during the hot months, to drain off to the winter level. To remedy this the farmers not only obstructed the delivery of the water, but in many cases, they brought water to feed the ground from the adjacent rivers, through the drainage; because they found, that if they reduced the water to more than 30 inches, or 36 inches below the surface, the weight and succulency of the crop was less than if the water was kept up to that level. Such was the case over no less than 500,000 acres of land; and if true over half a million acres in the fen districts, it was true, more, or less, over all parts of the kingdom. He had observed, that in many places, there were persons professing to have great theoretical knowledge of drainage, who everywhere adopted their own peculiar systems, without regard to the differing qualities of the soil and the varying circumstances of the case, one advocating a systematic deep drainage of 5 feet, another, a systematic deep drainage of 6 feet, and so throughout. All such dogmatism was exceedingly wrong. In dry weather, the stiff clay lands became hard and cracked, and in such instances, the replenishing rain waters would run through the cracks into the drains. The ground was not properly fertilised, and it would not, in consequence, bear full crops. In Worcestershire, where there was a stiff surface soil with gravel underneath, they had, in many instances, cut through the pan of the gravel and let off the water from below; the result was, that the weight of the crops was much diminished. It had been alleged, by Liebig and others, and with some truth, that by carrying the water too rapidly from below, the soil was exhausted of many of the salts. No doubt such was the fact, and that great damage was inflicted in that respect by over-drainage; the soil might be washed by means of the rains until nothing was left in it but what was insoluble. On the other hand, if land was not drained sufficiently, the capillary attraction would draw up the moisture from below, great evaporation would occur from the surface, and the land would not only be kept cloddy, but its temperature would be materially reduced. He knew a case in the north of England, where the land was very moist; but when it was afterwards drained, the temperature of the soil had risen 7° , a result equal to the removal of the estate 200 miles, or 300 miles further south. But it was not beneficial to remove so much of the feeding moisture of the land, that green crops could not grow upon it, and the plants themselves must exhaust their powers in making long fibrous roots, in order to penetrate the land to a great depth for the purpose of deriving nutriment.

The next subject which had been discussed, and which formed a leading topic of the Paper, was the difficulty under which certain agriculturists and landowners laboured in removing the water from their estates, because other proprietors lower down would not concur in the improvement of the general drainage; but this grievance was alleged very much upon the same principle, on which the waggoner appealed to Hercules to lift his wain out of the mire. Why should Government be called upon for relief, in cases of this nature? He thought there was nothing more improper than the interference of the Government with private rights; it was the very worst principle that could be adopted; it was bad for the Government itself, bad for the proprietors, and bad for the public. There was no difficulty in effecting this object, if the efforts were properly directed. It generally happened in these cases, that those who were anxious to drain their lands wished to do so at the expense of others, although there was little difficulty in accomplishing the object, if they would only pay for it. If they would recompense the proprietors below, they could generally get a road through, and could improve the watercourses. A man who had bought a water-logged estate for £20 per acre, and was desirous, by cutting fresh outfalls, to increase its value to £100 per acre, complained of the injustice of his neighbour, because he would not allow the water to pass through his land, and called for the interference of the Government to compel him. Now there was no just reason for such complaint; the man held his land under certain natural conditions. If he wished to convert it from those conditions, he could, in general, easily accomplish his object by the expenditure of the necessary amount of money. But in most places there was already in existence, or could be brought into existence, a valuable commission, under an enactment of Henry VIII., called the Sewers Commission, which had charge of all watercourses in the locality; by setting that Commission in proper operation, it was possible for any person to get his land drained, so far as he had the legal right to do so. If he wanted more than these legal rights, Parliament was the proper tribunal to apply to. If an appeal was made to the Secretary of State, as he could not personally hear the parties, visit the locality, and investigate the case, he would, probably, send down some inferior person imbued with his own peculiar notions, who would make a report behind the back of all the parties concerned; the Secretary of State would then act upon that report, and make, perhaps, an order affecting the property rights of, and coercing individuals, who would be little, if at all, benefited by this particular operation. To show how unjust and impolitic such a course would be, he might mention the case of the supply of water to the Metropolis. Five, or six years ago, that subject underwent a long Parliamentary

investigation during two whole sessions, and during the course of the inquiry several gentlemen connected with the Government, and others not so connected, brought forward certain schemes. Now, if the matter had been left to the decision of the Government, and if any of those gentlemen had been at the head of the department, his own scheme, and no other, would have been permitted; the consequences would have been still worse, if by any chance, one of the competitors should have been afterwards nominated to the place of the first. If the Government could act, it was utterly impossible for it to decide upon the relative value of schemes of this character; and if compelled to act, nothing but dissatisfaction would be the result. The carrying out of similar projects should be left to private enterprise, assisted by proper local authority unconnected with Government.

He differed from the opinion, that the consideration of the upland waters was of little importance in this question; he thought, on the contrary, that they had a very great and beneficial effect. He quite admitted, that in estuaries, and in rivers discharging into tidal estuaries and within tidal action, the tidal water played the principal part in the operation; but, supposing there was no upland water, the action of the tide would gradually cause the deposit of matter at the head of the channel, and contract its length, until, finally, it would become obliterated. In a channel where there was a small amount of upland water, the tide flowed and ebbed in the same quantity, but the ebb would, in general, preponderate, because of the addition of a certain amount of upland water. If that amount was so small, that it could not of itself, or even in conjunction with the tidal water, produce a sensible effect upon the scour, yet, small as was its quantity, it would determine the advance to the sea of any matter removed by the tide; under those circumstances there would be no deposit at the head of that channel, which would keep itself open for ever. He considered it important, therefore, to secure as much upland water as possible at the head of the stream. If the quantity was large, it would, added to the operation of the receding tide, and under many circumstances, deepen the channel. If, for instance, the quantity of tidal water was 20, and the quantity of upland water only 1, then, inasmuch as the scouring action was in proportion to the squares, the scouring effect of the receding tide would be greater than the effect of the incoming tide, by 10 per cent. He had no doubt, that a similar action was produced in the Thames, especially since the removal of Old London Bridge, and was at the present moment operating with good effect.

As Old London Bridge had been referred to, he might call attention to a point which had not been mentioned. Before the old bridge was removed, the fall there amounted to 5 feet. The

reason why the high water had not been found to be materially increased was, that a large amount of water was formerly held pent-up behind the old bridge, and consequently, it was not necessary, at that time, for so much water to pass beyond London Bridge as at present, in order to bring it up to the high-water mark. Reference had been made to the quantity of water flowing down the Thames in dry weather. About ten years ago, during an extraordinarily dry season, he had occasion to gauge some of the weirs; on that occasion he had ascertained that, instead of 90,000,000 cubic feet passing over Teddington Weir per day, as in the case in ordinary seasons, there only passed over about 60,000,000. He had also ascertained since, by a great number of comparisons, not only of the Thames, but of the chalk lands draining into it, that the whole quantity of water drained from the valley of the Thames into the sea, did not exceed a depth of 6 inches per annum. The fall of rain was not disposed of, as had been represented, in three equal parts: one-third lost by evaporation, one-third passing into the rivers, and one-third disappearing altogether. The evaporation was nearly a constant quantity, averaging about 15 inches, and inasmuch as the average rainfall near London was about 23 inches, and in some cases as low as 18 inches, it followed, that there were only a few inches which passed to the sea. Such, he believed, were the actual results, as nearly as could be ascertained from the discharge by the rivers.

With regard to the formation of bars, and the advantage of curved channels, he confessed, so far as the effect of artificial works upon the inland channels of the country was concerned, all his experience and all his calculations went to prove, that the straighter the channel, the greater would be the effect produced. The tide would come up with greater ease, and the water would go out to a lower level, by a straight channel than by a curved one. Bars were all produced upon the same principle, by a very simple operation. Matter in mechanical suspension was brought down the river, under circumstances which enabled it to be borne by the current, till it got into a wider place, where the velocity of the water was diminished; and the absence of motion caused the deposition of the matter at the mouth of the river, forming impediments to navigation, which could only be removed by artificial means.

Mr. MANNING,—through the Secretary,—expressed his intention, at some future time, of laying before the Institution a Paper on the Arterial Drainage of Ireland. He would confine himself at present to the correction of two errors which had arisen relative to those works. First, that the Report of the Government Commission, published in 1853, gave a full account of all that had been done up to that time, the area of lands subject to floods being

77,546 acres. This statement was only applicable to eleven, out of one hundred and twenty-one districts, then either finished, or in course of execution ; the fact being ; that at the close of the year 1852, 205,032 acres of land had been already drained, and about 130,968 acres more were in progress, making a total of 336,000 acres. Secondly, that the great defect in the system was, the absence of any provision for maintaining the works and keeping them in repair after the first year. Now, on their completion, the Commissioners of Public Works in Ireland made an award, which allocated the proportion of the expenditure to be repaid by each proprietor, including the cost of one year's maintenance, in advance from the date that the district was handed over to a Board of Trustees. To this Board, composed of, and elected by proprietors, was given, by Act of Parliament, the power to levy, thereafter, such annual rate as was necessary for the repair and maintenance of the works ; and, in case of their neglect, or refusal to act, the Commissioners of Public Works were, on certain forms being complied with, empowered to cause such works of maintenance to be executed, and to levy them upon the proprietors, in the proportions set out in the final award.

Mr. BAILEY DENTON,—through the Secretary,—remarked, that it had been inferred from the observations he had made, that he had advocated the establishment of a central commission to carry out, compulsorily, the vast work of river reform and mill compensation : now this was far from his intention. His experience in drainage works had so frequently made him acquainted with the want of outfall, by the accidental interposition of a neighbour's land, which must be crossed to secure a discharge of injurious waters,—with the defective character of the shallow and tortuous watercourses which now existed, (without any reference to mills,) —and with the inability of a majority of improving landowners to bind even a single objector to any work, were it ever so desirable, that he was personally inclined to confine his efforts towards obtaining a remedial measure dealing with those minor evils by themselves, rather than to complicate the question by connecting them with those of main rivers and mill compensation, although he felt convinced, that ere long, that very important subject would force itself upon public attention. No one connected with drainage would think of delegating to a central board, sitting in the Metropolis, the execution of works of arterial drainage ; at the same time, no one acquainted with the working of the Tithe Commission, the Inclosure Commission, the Copyhold Enfranchisement Commission, and the Under-drainage Commission, could doubt, that a central commission to administer a general Act for the improvement of outfalls, with power to appoint Civil Engineers duly qualified to act as Assistant Commissioners, would fully meet the requirements

of the case. With the Inclosure Commission, the actual work of inclosing and allotting was performed by persons appointed by the landowners interested, the duties of the Commission being simply to see, that the Act of Parliament was complied with. So it might be with a commission for the improvement of outfalls; the landowners might appoint their own Engineer, and the Commissioners simply facilitate his operations by the legal administration of the Act.

In bringing the whole subject before the Institution, the Author had given an opportunity of suggesting the best mode in which the Legislature should deal with it, and he submitted, that it was of the greatest importance to the country, so largely interested in this important matter, and to numerous members of the engineering profession who might be most profitably engaged in agricultural drainage, that an opinion on the legislative part of the subject should not be withheld; for so monstrous were the evils continually arising, that it could only be a question of time when the remedy should be supplied. It was the opinion of many, that each evil should command its own remedy, and that a special Act should be obtained for each district drainage and each separate outfall; but those who had acted on commissions of this sort knew full well, that the immense waste of money in Parliamentary proceedings and the practical evils resulting from the incompetent character of the tribunals before whom these measures were brought, prevented any very general adoption of such a system. The cost of the Act for the Middle Level Drainage, 1848, was £10,990. That of the Norfolk Estuary Acts had been £40,112. 10s., one-third of the amount of the contract for the whole of the works, which was £142,000. The eight Acts of the Eau Brink Cut could not have cost less than £100,000, and a striking fact with regard to them was, that those eight Acts, had now become obsolete; the Commissioners were seeking to repeal the whole, and to establish a system of conservancy more in accordance with the existing state of things. But the cost of, perhaps, the most recent and certainly the most unsatisfactory, specimen of outfall legislation, was the Nene Valley Drainage. In that case, £30,083. 0s. 10d. had been expended in Parliamentary proceedings, yet the progress made in the works rendered it so doubtful whether any benefit whatever would result from them, that the landowners were now disposed to let matters remain as they were, rather than involve themselves further, by another application to Parliament. The extent of land to be benefited by the Nene drainage was, at the utmost, 16,000 acres, so that nearly £2 per acre had been expended in Parliamentary proceedings alone. How strangely did this contrast with the fact, that the average actual cost of under-drainage was only £5 per acre, including all expenses, and that

the average cost of the administration of the Under-drainage Commission did not exceed two shillings per acre.

Doubts had been expressed, whether the extension of under-draining had the effect of increasing the floods, and of diminishing evaporation. He proposed, at some future day, to present to the Institution the results of some experiments he had undertaken in order to arrive at correct conclusions on those important points; the deductions were somewhat at variance with former teachings, but an exposition of the facts would elicit useful information from others who had conducted similar inquiries. In the meantime, he would simply observe, that the experiments proved, that with the exception of some anomalies which presented themselves in clay soils, tending to confirm the doubts which had been expressed, the extension of under-drainage throughout the wet lands of the kingdom, of all descriptions, must very materially increase the discharge of water to the main outfalls, during the winter months.

Mr. GRANTHAM remarked, that in drawing up the Paper which he had presented to the Institution, he thought, in the first instance, that it would have been useful to have classified the different descriptions of rivers in England, in order that the special mode of treatment of each river might have been discussed. He, however, considered subsequently, that such a mode of dealing with the subject would be too complicated, and would not, perhaps, be so intelligible as the plan he had afterwards adopted, of confining his observations to those rivers which ran through level, or fen districts, and those which ran through upland districts. He had endeavoured, in the Paper, to lay down the general principles which should, in his opinion, be adopted, for carrying out a proper system of arterial drainage and outfalls, and upon the subject of the drainage of the fen districts, he had referred to the Paper of Sir John Rennie, on the Ancholme Drainage. He had mentioned the adoption of catchwater drains; he had dwelt upon the mode in which main drainage should be carried out in connection with tidal rivers, and the level at which the sills of gates and sluices should be placed; and he had called special attention to the principle, that the main drains should become the receptacles of drainage waters when the locks, or gates were shut. The next question he had attempted to deal with, was that of the drainage of internal, or upland rivers, and the mode in which the channels should be straightened, so that the waters should be confined and used in the most economical manner for all purposes, both town and agricultural. He had pointed out, that there should be a power to irrigate adjoining lands, and he had alluded to the mode in which drains of that kind, with great velocity, should be formed, suggesting, that the velocity should be checked by steps, or overfalls at certain places, and that the velocity of the water and the

slopes of the drains should be regulated according to the necessity of the soil. That plan had been successfully adopted in the Hainault Forest drains, to the extent of 3 miles, or 4 miles; the water never overflowed the banks, and the works fully answered all the purposes intended. If he had been allowed to do so by the Commissioners of the Woods and Forests, he had intended to take gaugings at each of the overfalls, in order to ascertain the exact quantity of water which was discharged over the area drained between one overfall and another, and to have kept a rain gauge on the estate, so as to ascertain, as nearly as possible, the amount of rainfall, and compare it with the actual quantity of drainage and the evaporation from the area of 2,000 acres. He admitted the importance of drainage into tidal rivers; but at the same time, he thought the discussion had digressed too far into the question of the management of tidal harbours. He had referred to the treatment of some of the Indian rivers, which required works for irrigation and navigation, upon a scale infinitely more extensive than those in this country, and afforded excellent lessons in the mode of training rivers which brought down large quantities of sand, stone, and sediment in times of flood, requiring for their control the greatest skill and care on the part of the Engineer. He had also referred to the best authorities upon the mode of drainage pursued in other countries; and had pointed to the works of Paul Frisi and others, as they afforded a great deal of information, which would be found most valuable. He had also recommended those interested in the subject, to consult the published work of Captain Baird Smith, B.E., on the drainage of Northern Italy and the Madras Presidency. The latter authority had taken great pains with the subject, and being wholly uncontrolled in his investigations, had collected the best possible information.

The Paper did not allude to any particular legislative measure by which drainages should be regulated. It was limited to a statement of the fact, that the want of legislation on the subject was a great impediment in carrying out inland drainage upon a large scale. Mr. Grantham had personally experienced that want, in which he had been confirmed by those who had been largely engaged in drainage operations. The managers of large estates, and landowners themselves, would be glad to have some power of enabling them to effect arterial drainages and outfalls. It was, no doubt, a difficult question to decide upon the nature of the remedy; there were numerous instances in which it would appear desirable to bring some legislative powers to bear, but in any case, he certainly should not put the matter into the hands of special commissioners, for fear of the creation of such a body as that of the General Board of Health, which had done so much mischief in the drainage of towns. The only power he desired, would be

a permissive power; and he thought the Inclosure Commission presented, as nearly as possible, a model of that which was required for dealing with the subject of general drainage. The agricultural interest of the country was, he believed, very well satisfied, upon the whole, with the manner in which the Inclosure Commissioners had exercised the powers intrusted to them, and such great benefit had resulted from their proceedings, that scarcely a dissentient voice had been raised against them. The Engineers of this country need not be under any apprehension, if work of this description was put into their hands. The Commission did not pretend to control; it had merely a permissive power, and that was all that was required in drainage. It was a mistake to suppose, that he wished for any board, or commission to exercise a controlling power, or that he was an advocate for centralisation in matters of this kind, opposed, as he had always been to the application of that system to agriculture, or any other branch of industry: at the present day, such a proposition would give umbrage to the whole country. The Institution of Civil Engineers, composed, as it was, of practical men, was the body by which the question could be best discussed, and the difficulties best considered; and their opinions would be found of great value and assistance, should the Legislature entertain any proposal upon the subject. There could be no doubt, that in the drainages of large districts, such as the fens, improvements could only be carried out under the authority of special legislative enactment, and he considered the Bill introduced in 1853, by the Earl of Carlisle, as the best model for adoption.

Some rather discouraging remarks had been made with reference to pipe drainage, which was a question largely mixed up with arterial drainage. Although the Paper was purely agricultural, he had determined to bring it before the Institution, because, at the present moment, Engineering was the science which could best come to the assistance of agriculture. The adoption of a regular system of arterial drainage and outfalls would give immense employment to Engineers, and would open out a new and highly interesting field of occupation. Speaking from his own experience, there were few branches of the profession which called forth so much interest as that under discussion. He agreed, that under particular circumstances, drainage might be carried to too great a depth, but no general principle applicable to all cases could, in that respect, be laid down: in some cases, a drainage of 5 feet would be beneficial, whilst in another it would be productive of disastrous results. He had introduced the Irish drainage as an example of what might be effected, under a combined and uniform system, to relieve large areas of land injured to an enormous extent, and in many instances, rendered totally valueless by pent-

up and stagnant waters. The grand defect in the system was, that there was no provision for maintaining these costly works.

Mr. BIDDER,—President,—said, that having been called to the Chair since the opening of the discussion, his present position precluded him from expressing, at any great length, his views upon the question, his duty now being rather to watch the discussion than to take part in it. He would merely remark, that some of the worst bars on the coast had no connection at all with the outfall of rivers; and that there were cases in which the land water absolutely obstructed and diminished the quantity of the scour. He fully concurred in the opinion, that dogmatic draining was utterly impracticable. The level of the land, the nature of the soil, and a variety of other circumstances required to be taken into consideration, in determining the depth to which the drainage should be carried. The late Mr. Tycho Wing, who had devoted much attention to drainage, had ascertained, that for the fens, the best level was 2 feet 6 inches below the surface. When the drains were deeper, the crops deteriorated, and when they were higher, the effect was equally injurious. He would also remark, that there were two kinds of drainage to be considered: on the one hand, drainage wholly independent of, and unconnected with, tidal rivers; and on the other hand, drainage which must flow into rivers affected by tidal action, when the question became dependent upon their levels being 2 feet, or 3 feet higher, or lower. For those reasons, he did not consider the discussion to have deviated from the scope of this interesting Paper. The subject, however, was by no means exhausted, and he hoped, that at some future time, it would again be brought under consideration. Further communications from those who had directed their attention to the subject would lead to discussions of the highest importance to the profession.

Mr. J. HODGSON JONES,—through the Secretary,—confirmed the observation which had been made relative to the obstruction of drainage by the farmers, in some parts of the fens, during summer. The fact was undoubtedly correct, but in his opinion, it did not militate against the general argument, that deep drainage should be regarded as the rule, and shallow drainage as the exception. As the name of the late Mr. Tycho Wing had been mentioned, as an authority for fixing the maximum depth to be given to drains in the fen districts at 2 feet 6 inches, it was important to state, that in the latter years of his life, his views upon that point had been considerably modified. Indeed, the question of prospectively lowering the water level in those districts had been anxiously discussed by him: in many instances he recognised the necessity of increasing the depth to 4 feet, and he became fully impressed with the advantages to be obtained by deep draining.

In the fen districts, under the top soil, clay, loam, and occasional veins of sand were generally found, so that the drainage most beneficial to those districts would, in many cases, be somewhat similar in character to that for clay soils, provided that, in times of drought, the water levels in the ditches could be raised. Such a provision was rendered necessary by the peculiar character of the fen surface-soil, and was, in some cases, effected by a supply for the cattle being led into the ditches from an independent source.

Mr. HAWKSLEY complained, that his views upon the state of drainage in England had been misconceived. So far from thinking, that it was in a disastrous condition, and that it had been carried out to too great extent, he thought, on the contrary, that drainage had not been carried far enough. His objection extended only to the great depth which had, in many cases, been given to drains, whereby the surface of the land had become too dry for green crops, requiring a large amount of moisture. Many crops, such as turnips, beet-root, and mangold-wurze, which yielded from 20 tons to 40 tons per acre, and consisted of about 90 per cent. of water, could not be raised, unless the roots of the plants penetrated sufficiently deep to reach an ample supply of moisture. In Worcestershire, in the north of England, and also in the south of England, by draining to too great a depth, the ground cracked, and it became quite impossible to raise any other than cereal crops; the produce even of those crops, if the drought was continuous, was sensibly diminished. In those instances, the drainage had been injurious; not perhaps invariably, because every fifth, or sixth year, there might be a great deal of rain. He protested, therefore, against any system of drainage, founded upon general theories of a fallacious character, without reference to the chemical and the natural circumstances of each particular case. When drainage was carried out to a moderate depth, and the drains were made more numerous instead of so far apart, he was the greatest advocate for it, feeling convinced, from his personal observation and experience in England, Scotland, and Ireland, as well as on the Continent, that the effect of arterial drainage was to remove the land several degrees further towards the south; and that, if judiciously carried out, it would tend, very materially, to improve cultivation.

In opposition to his views as to the imprudence of intrusting the power of dealing with lands and watercourses to Government authorities, one of the most favourable cases of Government interference had been adduced. But it was hardly fair to call the Inclosure Commission, a Government commission; for the action of that body was as free as the action of the Judges of the Law Courts, and was independent of the Government for the time being. The object of the Inclosure Commission was simply to dissolve partnerships, which had become disadvantageous and

unsatisfactory to all the parties concerned. But the duty of a Government commission appointed to deal with rivers, estates, buildings, mills, or other property, would be the very reverse, the object then being to compose partnerships, and to compel people to concur in some act to which, probably, they had the utmost objection. Such a mode of action, whenever it had been attempted, had always led to great opposition in this country. The proper tribunal was either Parliament itself, or a commission similar to that of Henry VIII., which had, upon the whole, worked well, and had proved exceedingly serviceable, where it had not been suffered to fall into desuetude.

He would now briefly refer to the amount of rainfall and the quantity of water flowing therefrom into the rivers. In one of the largest cases with which he was acquainted, the Liverpool Waterworks, he had ascertained, that ten years ago, the total rainfall of that district of Lancashire was from 54 inches to 56 inches, a quantity which was unknown in the neighbourhood of London. The whole of the water flowing down the brooks and streams passed over gauges, and a register was regularly kept every four hours, during two years, which proved to be years of more than average rainfall. It was then found, that all the water which fell, was discharged to within 10 inches; and that whilst the average quantity of rain water upon that area of 10,000 acres was about 25,000,000, or 26,000,000 gallons per day, not more than about 1,500,000 gallons came out by the springs. He had also gauged the water in more southerly districts, where about 16 inches of rainfall out of an average of 22 inches was evaporated, leaving only 6 inches to be disposed of in other ways. Such had been the case with the River Thames, a result which, in his opinion, explained, in some degree, the foul state of that river during the last few years.

On the subject of town drainage, he would simply correct the general but erroneous impression which prevailed, that because the matter which went into the sewers was exceedingly valuable as a fertilising agent, therefore, that which came out of them must be equally valuable. Many persons seemed yet to be ignorant of the destructive effects of oxygen, on the manurial elements contained in sewage water.

Mr. BIDDER,—President,—deprecated the introduction of so very important a subject as the sewage of towns into a discussion upon arterial drainage, more especially, as it had not been alluded to in the Paper. The observations of the last speaker would have the full weight to which they were entitled from his position as an Hydraulic Engineer, and the philosophical and discriminating manner in which he had examined the subject; it was only to be regretted, that he did not embody them in a Paper, for the benefit of

the Institution. Some remarks, quite true in themselves, however, with regard to the scour of rivers, the President could not allow to pass, without alluding to the limits to which their application extended. It had been stated, that the effects of land water and scour should be added to the ebb tide. Those remarks were applicable to a harbour with a large estuary behind it, which was emptied at every tide, and a river falling into it over a weir ; in that case, undoubtedly, the land water was added to the ebb. It should not, however, be forgotten, that it was as essential to have a vigorous flow as well as a vigorous ebb. In the case of the River Thames, it was well known, that high water occurred at Gravesend one hour and a half sooner than at London Bridge ; and that at Southend, at the mouth of the river, it was flood two hours, or three hours earlier than at London Bridge ; at Richmond, low water was, probably, coincident with high water at the mouth of the river. Between Richmond and Teddington Lock, over which the land water passed during the whole time of the flood tide, the current in one portion of the river would be flowing up, at the same time that, in another portion, it was running down. In that case he did not say the land water was ineffective, but he said it was a question for investigation. At low water, the entire current would, for the moment, flow in one direction ; on the ebb tide, it would be precisely the converse. How far these conditions were consistent with the idea, that the whole of the land water was added to the ebb, was a subject for investigation and discussion, and he hoped it would, on a future occasion, receive the attention which its importance deserved. It had also been stated, that the formation of bars was due to the deposition of matter brought down by the rivers to their mouths. As far as his own observation went, he doubted whether one single particle brought down by a river was deposited in the shape of a bar ; and whether the bar, in some cases, was not a simple continuation of the adjoining beach. At Yarmouth, the bar was composed of the shingle and sand adjoining : whereas in rivers where there was no analogous coast, as at Dartmouth and Falmouth, there were no bars whatever. In Holland, and in the estuary of the Lynn Deep, the whole substratum of the reclaimed land was formed from sea sand, and the flocculent matter deposited above, constituted the fertilising portion.

The subject of Government interference with the details of the drainage of land in this country, had been so often alluded to in the discussion, that although foreign to the objects of the Institution, he could no longer refrain from expressing his views upon the subject. As to existing rights, all must agree, that the remedy for the preservation of streams in a proper and healthy condition, ought to be sharp, speedy, and economical. That result had not

yet been attained ; for the Courts of Law, whether acting by injunction, or otherwise, were cumbrous, expensive and unsatisfactory tribunals. Neither judge nor counsel had any knowledge of engineering science ; the arguments adduced were often, therefore, as ridiculous as could well be conceived. For cases of this nature, a special court was necessary, presided over by a judge conversant with mechanical laws. He was decidedly opposed to any compulsory interference with private rights. It behoved Parliament to be very cautious before granting such power to any board, except upon the clearest evidence and upon public grounds. Railway, Dock, Canal, and Road Companies were not permitted to deal compulsorily with a single acre of land, until they had proved they were about to confer some benefit upon the public.

Great inroads had already been attempted in this direction, for at the end of the last Session of Parliament, the Government passed an Act, vesting in the hands of the Secretary of State, the power to deal with certain private property, or in other words, delegating that power to the nominee of some Government Board, for the Secretary of State could not, personally, investigate all the necessary details.

He would conclude his remarks by reading an extract upon this subject, from a pamphlet written by the great orator, Edmund Burke :—

“The clearest line of distinction which I would draw, whilst I had any chalk to draw my line, would be this :—that the State ought to confine itself to what regards the State, or the creatures of the State, namely, the exterior establishment of its religion, its magistracy, its revenue, its military force by sea and land, the corporations that owe their existence to its fiat ;—in a word, to everything that is truly and properly public ; to the public peace, to the public safety, to the public order, to the public prosperity. Statesmen who know themselves, will, with the dignity which belongs to wisdom, proceed only in this, the superior orb. Whatever remains will, in a manner, provide for itself.” Speaking of the tendency of French politicians to fail in discriminating between what belonged to laws and what manners alone could regulate, he observed :—“The once mighty State, which was nearest to us locally, nearest to us in every way, and whose ruins threaten to fall upon our heads, is a strong instance of this error. I can never quote France without a foreboding sigh. The hand of authority was seen in everything and every place. All, therefore, that happened amiss in the course even of domestic affairs was attributed to the Government, and, as it always happens in this kind of officious universal interference, what began in odious power ended always, I may say, without an exception, in contemptible imbecility.”

December 6, 1859.

JOSEPH LOCKE, M.P., President,
in the Chair.

THE following Candidates were balloted for and duly elected :—
ARTHUR CHARLES CROSSE, WILLIAM HENRY PURDON, and
WALMSLEY STANLEY, jun., as Members; JOHN AIRD, jun.,
EDWARD COTTAM, WILLIAM HENRY RICHARDS CURLL, JAMES
BENJAMIN DUNN, JOHN EVANS, JOSEPH FISHER, jun., FLEEMING
JENKIN, JAMES KIMBER, JOHN HERBERT LATHAM, JOHN FOLLIOTT
STOKES, JOSEPH TAYLOR, and JOHN THWAITES, as Associates.

The discussion upon the Paper, No. 1,005, "On Arterial
Drainage and Outfalls," by Mr. R. B. Grantham, occupied the
whole evening, to the exclusion of any other subject.

ANNUAL GENERAL MEETING.

December 13, 1859.

JOSEPH LOCKE, M.P., President,
in the Chair.

MESSRS. W. B. BRAY, W. HAYWOOD, and A. C. HOBBS, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council.

The list of the attendances of the Members of Council for the past year was read, and the Ballot was commenced; the balloting-papers being sent for examination, at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. Pole and Maudslay, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear statement they have laid before the Meeting; and that Messrs. Maudslay and Kingsbury be requested to undertake the office of Auditors for the ensuing year.

The Telford and Watt Medals, and the Council and Manby Premiums, which had been awarded, were presented.

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Bidder, V.P., returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Joseph Locke, M.P., President, for his strenuous efforts in the interests of the Institution, for his extraordinary

attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Locke, M.P., returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Secretary, and to Mr. James Forrest, the Assistant Secretary, for their constant zeal and devotion to the interests of the Institution, the ability displayed by them in the execution of their duties, and their attention to the individual wishes of the Members.

Mr. Manby and Mr. Forrest returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

GEORGE P. BIDDER.

Vice-Presidents.

John Fowler.		John Hawkshaw, F.R.S.
Charles H. Gregory.		John R. M'Clean.

OTHER MEMBERS OF COUNCIL.

Members.

Sir W.G. Armstrong, C.B., F.R.S.		George W. Hemans.
Joseph Cubitt.		John Murray.
John E. Errington.		J. Scott Russell, F.R.S.
Thomas E. Harrison.		George Robert Stephenson.
Thomas Hawksley.		Joseph Whitworth, F.R.S.

Associates.

William Bird.		Captain Mark Huish.
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Resolved,—That the thanks of the Meeting be given to Messrs. Bray, Haywood, and Hobbs, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office, and that the ballot-papers be destroyed.

ANNUAL REPORT.

SESSION 1859-60.

It has hitherto been the practice to give, in the Annual Reports, a succinct account of some of the engineering works in progress, or which have been completed during the preceding twelve months; and even, in exceptional cases, to allude to remarkable projects. From this custom it is not intended to depart on the present occasion; although the time is approaching, when the Report may be restricted to the affairs and the state of the Institution. If it is observed, that foreign undertakings occupy a principal place in the present summary, it may be partly explained by the fact, that a great number of the Members and Associates are employed abroad; while of those who remain in the United Kingdom, a large proportion are similarly engaged, in connection with important works, in course of execution, in all parts of the world. Every year extends the field of operations for the exercise of professional skill; and wherever civilisation and commerce may reach, there also will arise the necessity for the labours of the Engineer.

Commencing at home, it may be stated, in reference to the Main Drainage of the Metropolis, that the first contract for these works was let, early in the present year, to Mr. Moxon for £152,430. This portion is called the 'Northern High Level Sewer,' and is about nine miles in length, extending from Hampstead to the River Lea. The heaviest part of this contract, involving works to the amount of £80,000, has been already completed. The next contract was, for the 'Southern High Level Sewer,' extending from Clapham to Deptford Creek, and being, with its branches, about nine miles and a half in length. This contract was taken, last July, by Messrs. Helling and Yeoman, for £217,000; and the works are progressing vigorously in several localities. The third contract, for the 'Southern Outfall Sewer,' from Deptford Creek, under Woolwich, to Erith Marshes, about seven miles and a half in length, will be let immediately. Several other important works would have been

in a much more forward state, but for the strike in the building trades.

Designs and tenders for pumping engines, of 500 nominal H.P., intended to raise the sewage into the Southern Outfall Sewer, at Deptford Creek, were received, from a selected number of engine manufacturers. These were reported upon, in June last, by a Committee, composed of Mr. Robert Stephenson, (our late President,) Mr. Joshua Field, (Past-President Inst. C.E.,) Mr. John Penn, (M. Inst. C.E.,) Mr. G. P. Bidder, (V.P. Inst. C.E.,) Mr. T. Hawksley, (M. Inst. C.E.,) and Mr. J. W. Bazalgette, (M. Inst. C.E.); when new designs for engines and pumps, such as were recommended by the Committee, were ordered to be prepared by Mr. Hawksley, and are now ready for submitting to the manufacturers.

With a view to the purification of the waters of the Thames during the summer months, 4,300 tons of lime, 500 tons of chloride of lime, and 56 tons of carbolic acid, were used in deodorising the sewage; and an important Report upon this subject has been obtained from Drs. Hofmann and Frankland.¹ A new bridge for the approach to the Victoria Park is being built over the Linthouse Cut, at a cost of £5,000. A portion of the main drainage sewer is being constructed in the Uxbridge Road, at a cost of about £10,000; and works of improvement, cleansing, and repairs, to a large extent, have been carried on, in connection with the main sewers of the Metropolis, during the past year. A temporary pumping engine, of 100 H.P., is being erected by Mr. R. Daglish, jun., (Assoc. Inst. C.E.,) at the mouth of the Earl Sewer; and that main sewer is about to be diverted and reconstructed, with a view to the immediate relief of the southern low-level districts, from floods, pending the construction of the main drainage works.

The Metropolitan Board of Works is now fairly at work, with ample funds at their command; and the public will expect, within a short period, evidence of improvement commensurate with the expense incurred.

The possible effects of these works on the River Thames, in concentrating the sewage matter to two spots, and the abstraction of a large body of water from the higher reaches of the river, for the supply of the Metropolis, have been much discussed; and it is evident, that the question must soon be carefully considered, in order to determine what remedial measures, if any, are necessary, to preserve the régime of the river.

The extension of the railway communications of the Metropolis, as well as bringing the termini of the existing lines nearer to the

¹ Vide "Metropolitan Board of Works.—Report on the Deodorisation of Sewage. By Dr. Hofmann, F.R.S., and Dr. Frankland, F.R.S. 12 August, 1859." No. 24.

most densely populated districts, has latterly received much attention. The contracts for the works on the Metropolitan Railway, under the direction of Mr. Fowler, (M. Inst. C.E.,) have just been let, and will be immediately proceeded with. The line commences by a junction with the Great Western Railway, and terminates at Victoria Street, opposite to Farringdon Street, having a branch to the Great Northern Railway. It is to be constructed on the mixed-gauge system, and will be completed, it is expected, in less than two years from the present time. A considerable portion of the line will be open work, with retaining walls; but some parts will necessarily be in tunnel. The tractive power intended to be employed is peculiar. It is proposed to condense the steam used in the locomotive engine, and to reduce the size of the ordinary fire box, so as to have as little inconvenience as possible from the steam, and from the products of combustion. This undertaking is looked upon with much interest, not only by the profession, on account of the nature of the works, but also by the public; for, if successful, it may be expected to introduce a complete system of metropolitan sub-railways.

The Victoria Station and Pimlico Railway, also under Mr. Fowler, intended to connect the railways on the south side of the river, near to Battersea, with a station in the heart of Belgravia, and within three-quarters of a mile of the Houses of Parliament, is making rapid progress, and will be opened, it is believed, in the ensuing summer. One of the principal works is the bridge over the Thames,—the first, for railway purposes, yet built in the Metropolis. It will consist of four wrought-iron arches, with abutments and land arches, and is so far advanced, that there is every reason to think it will be completed, within twelve months from the time of laying the first stone.

In the last Session of Parliament, a great number of Bills were promoted, having a similar object to those last mentioned. The Charing Cross Railway, for which an Act was recently obtained, has been brought forward, mainly, with the view of affording a west-end terminus to the South Eastern Railway. It will involve the construction of a bridge across the Thames, where the present Suspension Bridge now stands, and the terminal station is intended to be formed on the site of Hungerford Market. The proposed bridge will consist of eight openings, each of 154 feet, which will be spanned by wrought-iron girders. It will be of sufficient width to carry four lines of way, and there will also be two public footways, one on each side of the bridge. The design for this structure has received the approval of the Conservators of the River Thames and of the Admiralty; and it is expected, that the works, which are under the direction of Mr. Hawkshaw, (V.P. Inst. C.E.,) will be commenced immediately.

The West London Railway Extension will connect the North Western and the Great Western, with the South Western, and the Brighton and South Coast Railways; thus completing the communication between the lines north and south of the River Thames, and enabling passengers and goods to pass through the Metropolis without the delay, inconvenience, and expense of a change of conveyance. The line will be about 3 miles in length. It commences at the Kensington Basin, follows, nearly, the course of the canal, crosses the river at Battersea, and joins the South Western Railway at Falcon Bridge, near to which it also effects a junction with the Crystal Palace Line, and with the Victoria Station and Pimlico Railway.

A branch from Kingston to Twickenham, on the South Western (Windsor) Line, and improved junctions at Barnes and Kew, will place the populous district of Kingston, in communication with the northern and eastern suburbs of the Metropolis.

From the number of new projects again brought forward for the coming Session, it is evident, that great interest continues to be felt on the subject of improved metropolitan railway communications; several of them promise to be important, in giving increased accommodation to the public, as well as improving the lines of which they will form branches.

Among the lines of railway recently completed in England, may be mentioned the Portsmouth, and the Shrewsbury and Crewe Railways, both executed under Mr. J. Loeke, (President Inst. C.E.,) and Mr. J. E. Errington, (M. Inst. C.E.) The main object of the Portsmouth Railway was to shorten the distance between the important naval depôt situated at that place, and the Metropolis. Its length is rather more than 32 miles, and the distance is reduced by it from 94 miles to 73 miles. The principal work upon the line was a cutting at Haslemere, upwards of 80 feet in depth for a quarter of mile in length, and containing upwards of half a million cubic yards of material. This was executed through the Wealden clay, and it was found, that a deep intercepting drain on the west side proved very beneficial in preventing slips. The Shrewsbury and Crewe Railway, which is about 32 miles in length, and passes over the Cheshire Plains, connects the manufacturing districts of Lancashire and Yorkshire with North Wales. The chief point of interest in the works, was the manner in which the heavy Cheshire clay was successfully dealt with, by observing great care in the drainage.

In the Lake district, the Coniston Railway has recently been completed, as well as branch lines from the South Staffordshire Railway, to Cannock, Norton, Tipton, and Darlestone, under Mr. J. R. McClean, (V.P. Inst. C.E.,) and Mr. F. C. Stileman, (M. Inst. C.E.)

The Severn Valley Railway, under Mr. Fowler, is intended to

connect the Oxford, Worcester, and Wolverhampton Railway, near Kidderminster, with Shrewsbury, and its system of railways. The works have been commenced about twelve months, and will be completed, it is expected, next year. The line is 40 miles in length, and runs along the valley of the River Severn, taking the rising ground at a sufficient level to keep it well above the waters of the river. There will be two tunnels through the new red sandstone, which formation prevails for the greater part of the line. The bridges will be numerous, including one of cast iron over the Severn, at Arley, in a single arch of 200 feet span and 20 feet rise. At Hagley, about nine miles from Stourport, a very large natural slip occurs, in the clay of the coal measures. This slip is believed to be still slowly progressing, but no exact observations have recently been made. It has forced out of its natural course, the bed of the river, which now runs in a curve round the base. An attempt to take the railway cutting through it has proved so difficult, from the treacherous character of the soil, that a deviation of the line at that point has been determined upon, in order to lighten the works.

The works on the Extension Lines to the West of England, in connection with the South Western system, are being vigorously prosecuted by Mr. Brassey, (Assoc. Inst. C.E.,) under the direction of Mr. Errington. The Salisbury and Yeovil Railway has been opened to Gillingham, a distance of about 20 miles, being as far as the operations at the heavy tunnel there, at present permits. It is expected, that these lines will be completed throughout, to Exeter, early in the ensuing summer.

Passing now to hydraulic works, it may be stated, that considerable progress has been made with the extension works of the Grand Surrey Docks, the trade of which, though consisting almost entirely of timber, has hitherto been much restricted, by the limited dimensions of the entrance lock, the insufficient depth of water over the cills, the inadequate water and yard accommodation for timber and deals, and the want of access to the high road. The new works comprise a timber pond of $15\frac{1}{2}$ acres, an inner dock of 12 acres, and a basin of nearly 3 acres, connected with the former by a pair of gates, and to the upper portion of the old dock by another pair of gates, and communicating with the River Thames by an entrance, 250 feet in length between the gates, and 50 feet in width. The total area of water, including the additions, amounts to about 50 acres. The depth of water over the cills of the outer and upper gates, is 9 feet at Trinity low-water, or 27 feet at Trinity high-water, and over the cills of the two inner gates it is 1 foot less. The basin and inner dock have each a depth of 26 feet of water at Trinity high-water mark, and the

latter is connected with the new timber pond by an opening, crossed by a bridge 30 feet in span. This timber pond is connected with the old pond in a similar manner, so that the old and the new systems are in efficient communication. The side walls of the lock and basin are of brickwork, backed with concrete, and the platforms of the invert and gates, are of similar construction. The gates are cellular, and are built of iron boiler-plates. The entrance wharfing, outside the lower gates, is composed of cast-iron piling, with concrete behind; the upper part, above low-water mark, being of creosoted timber, also backed with concrete. The new works include a swing bridge across the entrance, a commodious communication with the Deptford Road, and considerable additions to the deal yards. They were designed by Messrs. Bidder and Joseph Jennings, and are being executed, under their superintendence, by the contractors, Messrs. George Baker and Sons, Mr. Kingsbury, (Assoc. Inst. C.E.,) taking the immediate direction of the works. The gates are being made and erected by Messrs. Robert Stephenson and Co., of Newcastle-upon-Tyne.

During the past year, several dock and harbour works have been completed, under the direction of Mr. Abernethy, (M. Inst. C.E.) The new docks at Swansea have an area of 17 acres, with an entrance 70 feet in width, and a lock 300 feet long and 60 feet wide, having a depth of water of 25 feet over the cill. These docks are capable of accommodating the largest class of shipping, and have on the quays, drops for the shipment of coal, which, together with the machinery for the bridges, gates, and cranes, are worked by hydraulic power, supplied by engines of 130 H.P., with accumulators at different points of the dock. At Newport, a dock, having an area of 8 acres, with an entrance 60 feet in width, has been opened. Hydraulic lifts have been provided, by which the waggons are raised from the level of the quays, to the necessary height for discharging the coal into the holds of the vessels. The five hoists are capable of loading 30,000 tons of coal per week. All the dock appurtenances are worked by hydraulic apparatus, supplied by an engine of 70 H.P.

At Silloth, on the Solway Frith, a pier has been completed, for a length of 1,000 feet, into deep water, so as to accommodate steamers at all times of the tide. The rails are laid, to the termination of the pier, at a level of 50 feet above the bed of the sea. In connection with the pier, a dock has been completed, of 4 acres in area, with an entrance 60 feet in width, and a depth of 25 feet over the cill; the sea channel being excavated to the same depth. The hydraulic lifts invented by Sir William Armstrong, (M. Inst. C.E.,) have, as in the other cases named, also been adopted, for the shipment of coal, and for working the dock gates, cranes, and appurtenances.

At Blyth, in Northumberland, a pier and breakwater have been completed, 4,500 feet in length, for the shelter of the harbour; and a sea channel, of the same length, has been dredged and excavated, for the admission of the larger class of coal vessels.

At Penarth, near Cardiff, the River Ely, at its confluence with the Bristol Channel, and for some distance inland, has been converted into a tidal harbour, by regulating, embanking, and improving its course. The slopes have been protected by stone pitching; and accommodation has been provided, by the erection of staiths and wharves, for shipping coals and for commercial purposes. A railway, 6 miles in length, connects the harbour with the Taff Vale Line. A dock is now in course of construction, in connection with the harbour. It will have an area of about 15 acres, and there will be an entrance basin of about 3 acres. These works are under the joint charge of Mr. Hawkshaw, and Mr. S. Dobson, (M. Inst. C.E.)

At Southampton, Mr. Alfred Giles, (M. Inst. C.E.), has just completed the deepening and enlarging of the inner dock, and the construction of a new entrance 56 feet wide, with a depth of water over the sill of 28 feet at high-water spring-tides, a swing bridge spanning the entrance.

At Southport, Mr. Brunlees, (M. Inst. C.E.), is constructing a pier, three-quarters of a mile in length, composed of cast-iron piles and columns, carrying wrought-iron lattice girders.

The Norfolk Estuary works, for completing the banks of the River Ouse at the entrance to the Wash, and for reclaiming considerable tracts of land from the sea, are in active progress, under Sir John Rennie, (Past-President Inst. C.E.), and Mr. Forster, (M. Inst. C.E.); whilst at Eastbourne, Sussex, new waterworks have been completed by Messrs. M^cClean and Stileman.

In the Report of a former year,¹ allusion was made to the plan for supplying the city of Glasgow with water, from Loch Katrine; which was being carried out under Mr. J. F. Bateman, (M. Inst. C. E.) This great work is now nearly completed, and was formally inaugurated by Her Majesty Queen Victoria, in the month of October last. The storage provided for the water is sufficient for 50,000,000 gallons per day. It is conveyed to its destination by an aqueduct 34 miles in length, comprising seventy tunnels 8 feet in diameter, nine of which are of considerable length, through rock of the most obdurate description. There are also twenty-five important iron and masonry aqueducts, over rivers and ravines, some of them being of considerable height. This work, which has afforded employment to about three thousand persons

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xvii., pp. 76, 77.*

in the locality, has been executed through a district of the wildest and most inaccessible description. The time occupied in the execution of the works has been within three years and a half, and the cost has been £630,000, about 10 per cent. in excess of the Parliamentary estimate, after allowing for some additional works.

In the West of Scotland, the Castle Douglas and Dumfries Railway, starting by a junction at the latter place with the Glasgow and South Western Line, has recently been opened. Its length is about 20 miles. From Castle Douglas, the Portpatrick Railway is being actively pushed forward, with the view of completing the communication with Ireland by the short sea passage, *viâ* Portpatrick and Donaghadee. The line is about 61 miles in length, and it is expected, that the works will be completed early next autumn. There are several large viaducts in progress of construction. One over Loch Ken, consists of three openings, each 130 feet, spanned by bow-string wrought-iron girders, and two smaller openings at each end. The two principal piers are above the water line; the foundations having been laid on cast-iron tubes, at a depth of 33 feet and 38 feet below the level of the water. There are masonry viaducts over the Blackwater of Dee, the Little Fleet Water, the Big Water of Fleet, and the River Luce, varying from 40 feet to 75 feet in height. Over the River Cue there is a viaduct of five openings, each 80 feet, spanned by wrought-iron plate girders, resting on timber piers. It is intended to open the line to Stranraer during the ensuing autumn, and in the following year to Portpatrick, by which time it is believed the Government harbour there will be completed. The works on the Portpatrick Railway are being executed under the direction of Messrs. B. and E. Blyth, (MM. Inst. C.E.)

Considerable progress has been made, during the past year, in the development of the railway system of Ireland. The lines from Longford to Sligo, Athenry to Tuam, Newry to Armagh and to Warren Point, and Dungannon to Omagh, under Mr. Hemans, (M. Inst. C.E.), comprise some considerable tunnels and other large works. The lines from Athlone to Roscommon, and thence to Castlereagh and Castlebar, (ultimately to be extended to Westport, Ballina, and Boyle,) under Mr. Fowler and Mr. F. Barry, (M. Inst. C.E.), and from Athlone to Tullamore, Killarney to Tralee, Mallow to Fermoy, under Mr. Le Fanu, (M. Inst. C.E.), with some others of less importance, have been prosecuted at the same time. The connection of the central town of Longford with the seaport of Sligo, a distance of about 60 miles, will give an important extension to the Midland Great Western Railway, which will then have termini at Galway, Sligo, and Dublin, with lines down to the water's edge, at each of those three harbours,

thus embracing a system of railways, upwards of 300 miles in length, in the most central position in Ireland.

The most desirable port on the Western Coast of Ireland, for the station of the Atlantic steamers to America, was, for some time, a subject of discussion. Ultimately, Galway was selected for that purpose, and subsidies have since been guaranteed by England and Newfoundland, to the amount of £91,000 per annum, for the fortnightly conveyance of mails and passengers both ways. A considerable saving of time, in the transit between the United States and Great Britain, is to be expected from the adoption of the Galway route; it also possesses an equally powerful recommendation in the fact, that the difficult and dangerous coast navigation either on the north, or the south shores of Ireland, towards the Mersey, will be avoided.

It may be mentioned, as an element in the advancing prosperity of Irish Railways, that the two principal Companies, the Midland Great Western and the Great Southern and Western, have, after several years of loss, by competition, agreed to submit the whole district occupied by their lines and canals to the consideration of arbitrators, who will allot to each Company their proper sphere of action, so as to remove all ruinous competition. As this arrangement embraces the railway system of more than two-thirds of the whole country, it is one of great importance.

At Londonderry, a bridge is being built, of which Mr. Hawkshaw is the Engineer, for the double purpose of carrying a railway and a roadway over the River Foyle. In this instance, the railway is placed beneath the roadway. At the High Level Bridge, Newcastle, the reverse is the case. The Londonderry Bridge will consist of six main openings, each 120 feet in span, of a centre swing bridge, with two openings of 45 feet span each, and of two land openings, at each end, of about 60 feet span. The piers are being formed by sinking cylinders in the bed of the river, and the openings will be spanned by wrought-iron girders. By means of this bridge, a junction will be effected between the Londonderry and Enniskillen, and the Londonderry and Coleraine Railways, which, at present, have their termini on opposite banks of the river.

The only other works of note in Ireland recently completed, are a Graving Dock for ocean steamers, at the mouth of the Liffey, near Dublin, by Mr. G. Halpin, (M.Inst. C.E.,) and the Cork Waterworks by Sir John Benson.

Important lines of Submarine Telegraphs have recently been completed; and the anticipated greater certainty and speed in working them, indicate progress in this new branch of engineering science. Of these should first be mentioned the Red Sea Line, which extends from Suez to Aden, a distance of 1,200 nautical

miles, with two intermediate stations at Cosseir and Suakim. The cable was manufactured and submerged by Messrs. Newall and Co., under the superintendence of Mr. Lionel Gisborne, (Assoc. Inst. C.E.) The electrical arrangements have been carried out by Messrs. Siemens, Halske, and Co., of Berlin. This cable is not, at present, actually in operation; it is proposed, however, to extend it from Aden to Kurrachee. Other lines, between Constantinople and the Greek Islands, have been laid by Messrs. Newall and Co., and Mr. C. W. Siemens, (Assoc. Inst. C.E.); and but for a defect in a cable, lately submerged between Candia and Alexandria, India would, probably, have been telegraphically connected with the mother country, before the end of the present year. The British Government has ordered a cable for a line from Falmouth to Gibraltar, which will ultimately be extended to Malta and Alexandria, and form part of a great line to India. Mr. Lionel Gisborne has been appointed the Engineer, and Mr. C. W. Siemens, the Electrician to this undertaking. The Government has authorised a series of carefully-conducted experiments to be made, with a view to determine the best insulating medium, and the most effective outer covering for deep-sea lines.

A great step has been gained in the transit to the East, by the opening of the entire Egyptian Railway, between Alexandria and Suez, including the extensive wrought-iron bridge across the Nile, at Kaffre Azzayat. This bridge, which consists of thirteen spans of 128 feet each, was executed by Messrs. R. Stephenson and Co., and Mr. H. Grissell, (Assoc. Inst. C.E.), under the immediate superintendence, in this country, of Mr. G. R. Stephenson, (M. Inst. C.E.); and was fixed by Mr. E. Price, (Assoc. Inst. C.E.), the contractor for the bridge, under the direction of Mr. Henry James Rouse, the Chief Engineer to H. H. Said Pacha, Viceroy of Egypt.

In order to secure the safety of travellers, the Peninsular and Oriental Steam Navigation Company had urged upon H. H. Said Pacha, the Viceroy, through Mr. Davidson, their Superintendent in the Mediterranean, the necessity for the construction of a double line of rails between Alexandria and Cairo; for a regular system of trains; for an increased staff of English telegraphists; and for the employment of European engine drivers, station masters, &c. The three last suggestions were approved by the Viceroy, and the requisite orders have been issued for carrying them into effect. As regards the comfort of travellers, the Viceroy, among other improvements, has ordered:—first, the employment of a suitable number of competent officers, to superintend the arrangements for the landing and embarkation of the passengers at Alexandria and Suez, and for the protection of their

property; secondly, the establishment of proper vehicles for the conveyance of passengers between the railway station, or hotels, and the wharf at Alexandria, and between the railway terminus at Cairo and the hotels; and thirdly, the construction of proper stations and waiting-rooms, with European male and female attendants, at Alexandria, Kaffre Azzayat, Cairo, the Centre Desert Station, and at Suez.

From a return made to an order of the House of Commons, it appears, that the public works on which interest has been guaranteed by the Indian Government, and the amount guaranteed in each case, are:—

	£.
East Indian Railway .	12,731,000
Eastern Bengal „ .	1,000,000
Calcutta and South Eastern „ .	250,000
Madras „ .	6,000,000
Great Southern of India „ .	2,000,000
Great Indian Peninsula „ .	10,000,000
Scinde „ .	1,000,000
Punjaub Railway (including a line from Delhi to Lahore)	4,000,000
Bombay, Baroda, and Central India Railway	2,500,000
Indus Steam Flotilla	250,000
Madras Irrigation and Canal Company	1,000,000
	<hr/>
	£40,731,000

The rate of interest guaranteed in nearly all these cases, is 5 per cent.

Some of these works have been alluded to in previous Reports, but the following statement of the progress made, may be interesting.

The works on the East Indian Railway have latterly proceeded with a rapidity before unknown. In Bengal, 45 miles have been opened, between Burdwan and the River More. This section crosses the River Adjai, with a bridge consisting of thirty-two arches, and the River More with a bridge of twenty-four arches, all of 50 feet span, and executed in brickwork; besides numerous smaller, but still considerable, streams. By the middle of next year, the Ganges will have been reached at Rajmahal. The bridges over the Keeul, consisting of nine spans of 150 feet, over the Soane, of twenty-eight spans of 150 feet, over the Tonse, of seven spans of 150 feet, and over the Jumna, of fifteen spans of 210 feet, are making satisfactory progress. The foundations consist, in all cases, of brick wells, sunk from 20 feet to 50 feet

through sand and gravel, and the superstructures are to be of iron girders, sent out from this country. The line between Allahabad and Cawnpore, 126 miles in length, is in full operation. The great stations at Allahabad and Cawnpore are rapidly advancing towards completion. The line beyond, as far as Agra, only waits the arrival of the permanent way. The rest of the line as far as Delhi, the route of which has been altered since the mutiny, is in full progress. The surveys of the line from Allahabad towards Bombay, called the Jubbulpore branch, were checked in the early part of the year, by the unsettled state of the country, and the murder of the two Chief Engineers, Messrs. Evans and Linnel. The surveys have again been commenced, it is to be hoped, under happier auspices. The receipts amount, on the line at present opened in Bengal, to £35 per mile per week; with an average passenger fare of less than seven-sixteenths of a penny per mile, and a rate for goods of less than one penny per ton per mile.

Of the Great Indian Peninsula Railway, 195 miles have been opened for traffic. This includes, on the South Eastern Line:—

From Bombay, viâ Callian, to Campoollee at the foot of the Bhore Ghât	71 miles
From Khandalla, at the top of the Bhore Ghât, to Decksal	106 „

and on the North Eastern Line:—

From Callian to Wassind	16½ „
The Mahim Branch	1½ „

Total	195 miles.
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It is stated, that the traffic returns have been most satisfactory; and as an evidence of the large use made of the line by the natives, it may be mentioned, that in the twelve months ending June, 1859, there were nearly twelve hundred thousand third-class passengers. Probably by this time, the South Eastern Line has been opened 50 miles beyond Decksal; and by Midsummer next, it is hoped, that the North Eastern Line will be ready for traffic from Wassind to the foot of the Thull Ghât, a distance of 25 miles, and from the summit of the Thull Ghât to Nassick, a similar distance of 25 miles. The works are now in progress on this contract as far as Bhosawul, being a length of 190 miles, under Messrs. Wythes and Jackson,—from Bhosawul to Jubbulpore, a distance of 332 miles, under Messrs. Duckett and Stead,—and upon the Nagpore Branch, a length of 263 miles, under Messrs. Lee, Watson and Aiton. The entire system is upwards of 1,100 miles in length.

The works upon the Bhere and the Thull Ghâts are of a very remarkable character, and cannot be done justice to by a cursory notice ; it is to be hoped, therefore, that they may form the subject of future communications for the evening meetings. They comprise lofty viaducts, and numerous tunnels through hard trap rock. The viaducts were, at first, wholly composed of masonry, but latterly, iron girders have been substituted for the stone arches, as it was found impossible to obtain the services of the requisite number of masons, to complete the works as originally designed, within a reasonable time. The late Mr. Robert Stephenson was the Engineer-in-chief up to the period of his decease, since which Mr. G. Berkley, (M. Inst. C.E.) has been appointed. Mr. J. J. Berkley, (M. Inst. C.E.) is the Chief Resident Engineer in India.

On the Madras Railway, the principal works recently completed are the bridges over the Rivers Cauvery and Thoota. The former has twenty-two, and the latter twelve openings, each of 65 feet. These are spanned by wrought-iron plate girders, resting on masonry piers. The bridge over the River Palaar is composed partly of arches of masonry and partly of wrought-iron plate girders, on masonry piers, the spans in this case being also 65 feet. The line has already been opened to Goriattam, a distance of 96 miles from Madras, the eastern terminus ; and the traffic on that section has shown the native appreciation of this mode of travelling. It is expected, that the line will be opened, by the end of the year, as far as Salem, a distance of 206 miles from Madras, and about half way to Beypore, the western terminus. The whole of the main, or South Western Line, 405 miles in length, will, probably, be opened towards the end of 1861, when there will be a through communication, by railway, across the peninsula, between the Coromandel and the Malabar coasts. The works on the North Western Line, which joins the South Western Line, 42 miles from Madras, have just been commenced. The whole of the Madras Railway is being constructed entirely by the Company's Engineers, without the intervention of contractors ; and the system has hitherto been found to answer satisfactorily. The Engineer-in-chief is Mr. Hawkshaw, and the Chief Resident Engineer in India is Mr. J. M. Heppel, (M. Inst. C.E.)

In Scinde and the North-West Provinces of India, the lines of communication, consisting of the railway between Kurrachee and Kotree, 110 miles in length, the steam service upon the River Indus, and the Punjaub system of railways connecting Mooltan with Lahore, Umritsir and Delhi, are making rapid progress, under the direction of Mr. T. A. Yarrow, (M. Inst. C.E.). The railways are being constructed departmentally, that in Scinde by Mr. John Brunton, (M. Inst. C.E.), and that in the Punjaub by Mr. William Brunton, (M. Inst. C.E.), as Resident Engineers.

[1859-60. N.S.]

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The navigation of the River Indus, between the upper terminus of the Scinde Railway, and the lower terminus of the Punjaub Railway is effected by steamers of exceedingly light draft, constructed from designs of Mr. Yarrow, by Mr. J. Scott Russell, (M. Inst. C.E.,) and by Messrs. Richardson, Duck and Co. The vessels for the tug service are being built of corrugated galvanised iron by Mr. John Hamilton, (Assoc. Inst. C.E.) The construction of the entire flotilla in India is intrusted to Mr. Alfred Warren, as Naval Architect and Marine Engineer.

The Eastern Bengal Railway has been commenced, and measures have been taken for vigorously prosecuting the works. The line starts from Calcutta, on the east side of the Hooghly, and its course runs up the left bank of that river, the East Indian Railway being on the right bank. It extends to Kooshtee, on the River Ganges, being a distance of 108 miles from the starting point, and it will pass through a district containing a population of about six hundred inhabitants per square mile. These works were originally under the direction of the late Mr. Brunel, but they have now been transferred to Mr. Hawkshaw.

Among the new lines which have been begun in India during the past year, is the Great Southern of India, under the direction of Mr. G. B. Bruce, (M. Inst. C.E.) It will intersect the delta of Tanjore, and is intended, ultimately, to connect this rich district with the interior, by means of a junction with the Madras Railway, and also to open up the extensive cotton districts of Madura and Tinnivelly in the south of India. The ultimate length of the line, as proposed, will be 300 miles. Of this 80 miles have been sanctioned by Government, and are now in process of construction, from Negapatam to Trichinopoly. The country has been found peculiarly favourable for the construction of a railway, and it is one of the most populous and flourishing districts in the south of India.

A commencement has also been made of the Calcutta and South Eastern Railway, under Mr. J. A. Longridge, (M. Inst. C.E.,) a line which, although of small extent, will greatly benefit the commercial interests, by opening to the trade of Bengal, a new port of great capability. The difficult and dangerous navigation of the Hooghly, and its gradual deterioration, coupled with the increasing size of the ships trading to India, naturally directed attention to the Mutla, an inland creek of easy access and navigation, with a minimum depth of water of 6 fathoms at low water of spring tides, up to within 30 miles of Calcutta.

During the present year the first steps have been taken in an enterprise which, though upon an experimental footing at present, promises, if its results are as favourable as there is good reason to anticipate, to rival even the railways in magnitude and

importance. Allusion is made to the formation of the Madras Irrigation and Canal Company, (the Act of Incorporation of which was obtained in May, 1858), for the construction of canals of irrigation and of transit, throughout the Madras Presidency and the adjoining states; and ultimately, in other parts of India. There is ample evidence to show, that the employment of capital in the provision and distribution of water, for the thirsty plains of India, is highly profitable; and that an abundant field still remains untouched. It is a favourable sign of the vigour infused into the administration of this vast empire, on its assumption by Her Majesty's Government, that measures have already been taken, on a comprehensive scale, to test the possibility of realising these advantages. The first operations of the company have reference to a plan for turning the waters of the Upper Kistnah and Zoombuddra through the valley of the Koondaur, into the bed of the Pennar, a smaller stream which falls into the sea near the town of Nellore. By this means, coupled with the formation of a canal, joining the Pennar with the Pulicat Lake, and the improvement of the existing line of navigation thence to the city of Madras, a communication is proposed to be made, by water, to the extent of 200 miles, between the capital and the inland districts, which, although fertile and populous, containing many millions of inhabitants, have, hitherto, been practically excluded from foreign markets, in consequence of the almost entire absence of serviceable roads. It is also hoped, that by a judicious outlay in improving the beds of the Upper Kistnah, and its affluents, the means of navigation may be still further extended, for some hundreds of miles into the interior. It is expected, that the cost of the works above referred to, will amount to from one, to two millions sterling, according to the extent to which the scheme is prosecuted. The experiment at present sanctioned, is limited to the expenditure of one million. There are many other projects of equal magnitude and promise, which only await investigation and approval. One of the chief of these, and perhaps the most likely to be first entered upon by the company, is a series of works for the irrigation of the delta of the Mahamiddy, in the neighbourhood of Cuttach, upon the same principles and with works of a similar character to those, which have been so successfully executed by the Madras Government, in the delta of the Godavery. The cost of the works required for improving the delta of the Mahamiddy would, probably, be from two to three millions sterling. The Engineer-in-chief of this undertaking is Colonel J. T. Smith, M.E., (Assoc. Inst. C.E.,) who, having formerly been in the Department of Public Works, became familiar with the habits of the natives, and with the methods of irrigation and of tillage to which they are accustomed.

Many suggestions have been made for the construction of a

pier, or landing jetty, at Madras, and for some years past, Colonel Sykes, M.P., has strenuously urged the erection of a pier, composed of iron columns founded on Mitchell's screw piles. This work has now been commenced by Mr. F. Johnson, and is being vigorously prosecuted. The length of the pier will be 1,000 feet, and the width $40\frac{1}{2}$ feet, with a T-head 160 feet in length. The platform will be 15 feet above high-water mark.

The Indian Government, under the advice, chiefly, of Sir Proby Cautley, established, during the past year, competitive examinations for the admission of young Engineers into the Public Works Department in India. The applications were numerous; but it was found, that although many of the candidates possessed a competent knowledge of the fundamental principles of the science of Civil Engineering, and had acquired an acquaintance with its details and practice, yet they were deficient in a "knowledge of the mathematical laws by which the theory of Engineering is governed." Thus, only one candidate in sixteen could be recommended for admission to the public service. The examiners, therefore, advised, that the scale by which the merits of the candidates had been tested should be modified, or extended; and this recommendation has been followed, with very beneficial results to the public service.

The distant and flourishing, though comparatively little known, island of Mauritius is also seeking to obtain the advantages of a system of railways. A survey of the island, conducted for this purpose, at the instance of the Colonial Government, by Mr. J. A. Longridge, during the winter of 1858-59, has shown the great local benefits which the railway system will confer on the colony. It is fully expected, that before the end of the next year, the works will be in active progress, and from the peculiar features of the country, they will furnish materials for future communications of considerable professional interest.

Turning to the Continent of Europe, allusion must be made to the railway system in Spain, which is rapidly extending. It originated, exclusively, with English Engineers, principally Members, or Associates of this Institution, who have, unfortunately, too often reaped little, or no reward for their skill and labour; the practical execution of many of the principal lines having fallen into the hands of French Engineers, from the circumstance of the capital having been chiefly raised by the Bank of the Cr dit Mobilier of France, or by the corresponding establishment in Spain, which is, in some degree, dependent on it. But the locomotive engines and other rolling stock have been, to some extent, supplied by English manufacturers. Several short lines in the vicinity of the great cities of Seville and Barcelona have been for some time in

operation; and in the course of the present year, the great line from Madrid to Alicante, with a branch to Valencia, was opened throughout. Other branches of this trunk line are in progress to Toledo and to Ciudad Rodrigo. Two main lines are in progress from Madrid towards France. First, the Northern of Spain, which proceeds by the Escorial, Valladolid, Burgos, Miranda and Vittoria, to the southern slope of the Pyrenees, at Alsasua. Secondly, the North Eastern route, which is by Guadalajara, Zaragoza, Tudela, Tafalla and Pamplona to Alsasua, where it joins the Northern of Spain, and whence a common line is projected to traverse the Cantabrian Pyrenees to Villafranca, and onward by Tolosa, St. Sebastian, and Passages, to Yrun, on the frontier of France, only 20 miles from where the French lines at present terminate. Of the above two trunk lines, parts of the Northern of Spain Railway, in the easier districts, are advancing towards completion, but no portion has been actually opened for traffic; whilst on the difficult parts, little has been effected. On the other line, towards Zaragoza, the first section from Madrid to Guadalajara has been opened for traffic, and some progress has been made on the other portions, particularly between Tudela and Pamplona. A commencement has been made at the bridge over the River Ebro, which is to be founded on iron cylinder piers, with wrought-iron girders spanning the openings. This bridge will be three-quarters of a mile in length. Great exertions are making on the line between Barcelona and Zaragoza; and it is stated, that during the last spring, as many as seven thousand men were at work upon it. Of the line from Santander to the head of the Grand Canal of Castile, which was under the directions of our late Member, Mr. Alfred S. Jee, the northern section near Santander, and the southern section next the canal, at Alar del Rey, have been opened for some time. The central portion of this line, passing near Reinosa, is also now in course of construction.

The Biscayan Railway, from the Port of Bilbao, to Miranda, on the Ebro, and thence along the right branch of the river to near Tudela, is now in course of construction by Messrs. Brassey, Paxton, and Wythes, under Mr. Vignoles, (M. Inst. C.E.) The length of this railway is upwards of 150 miles. It will traverse the Cantabrian Pyrenees, by a gradient of 1 in 70 for about 12 miles. The works are heavy in many places, particularly on leaving Bilbao, and on the ascent from the north, up the mountains. From the summit the fall is very easy, along the narrow valley of the River Bayas down to the Ebro. The manner in which the capital for the Biscayan railway was raised, deserves notice, as affording a good illustration of what commercial necessity will effect, and a splendid example to the rest of their countrymen, given by the merchants of a small Spanish town of less

than forty thousand inhabitants. Bilbao had, till lately, almost a monopoly for the supply of Madrid, and the intermediate country, with colonial produce; the merchants being men of wealth, and connected with the colonies, particularly with Cuba. The partial opening of the railway from Madrid to Alicante, began to affect the trade of Bilbao. The principal inhabitants immediately pressed their case upon the Spanish Government, and obtained a subvention of £5,000 per mile, towards a railway from that port; and among themselves and their colonial correspondents, they raised the required capital, in a few weeks, to complete the line into the interior. It will join the Northern Railway at Miranda, on the Ebro, and the Zaragoza Line, near Tudela. Thirty per cent. on the shares has been already paid, without a single defaulter, and the Engineers and contractors are pushing on the works with such vigour, that at the end of 1860, the railway will reach the foot of the mountains; and it is believed, that by the end of 1861, the line will be carried over the Pyrenees and through the passes beyond, to the Ebro; and that a third year will complete the works to near Tudela.

Two other main lines have been surveyed for the Spanish Government; one, about 200 miles in length, from Ciudad Rodrigo to Merida and the frontiers of Portugal, near Badajos, where it will join the line from Lisbon to Badajos; the other from the Northern Railway of Spain, near Valladolid, and through the Province of Galicia to Lugo, whence it will branch north-west to Corunna, and south-west to Vigo. Various other lines have been surveyed, and some smaller ones are in progress; but relative to them, authentic information is wanting.

The Spanish Government is anxious to extend railways throughout the Peninsula; and subventions are offered, varying from £4,000 to £6,000, and even £7,000 sterling per English mile, to induce capitalists and others to embark in these undertakings. But the interference of the Government in all the details of construction, through the medium of officials at every stage, forms too great a drawback to tempt English capital, except under peculiar circumstances. The iron and rolling stock for all the Spanish railways will, no doubt, be supplied from England; as it has been found, that they can be furnished from thence, better and cheaper than from the workshops of France, Belgium, or Germany.

In Italy, in Piedmont, and in Austria, political events have temporarily arrested the formation of new lines of railway; although the want of connecting lines, such as that between Genoa and Nice, by the shore of the Mediterranean, is universally admitted.

In Prussia and in Germany few great works are in progress, and only some comparatively unimportant branch lines of railways have been executed.

Holland has, at length, awakened from its apparent lethargy, and the States have authorised the formation of upwards of 600 miles of railway, which will involve the construction of three bridges of unusual extent, besides a vast number of smaller works of very difficult character. A grand ship-canal from Amsterdam direct to the sea is also projected, as well as the construction of a pier at Skeveningen, where passengers and mails from England can disembark from the steamers, at a distance of only four miles from the Hague.

In Sweden and in Norway the railways are slowly, but steadily, extending. In Denmark, the Government has employed Mr. Alfred Giles to effect the reclamation of a tract of land from the harbour of Copenhagen, and to construct 900 lineal feet of deep wharfage, and a dry dock 250 feet long, 61 feet wide, and 21 feet deep. These works, which are connected with the dockyard by a swing bridge over a canal 90 feet wide, necessitated the construction of a coffer dam 1,250 feet in length.

At Copenhagen, water and gas works have been recently constructed, under the superintendence of Mr. Simpson, (Past-President Inst. C.E.) The project of Mr. Murray, (M. Inst. C.E.,) to extend the harbour southward of the fortifications, has recently received the sanction of the Danish legislature. It is proposed to cut a channel 5 miles in length, through Kallebod Strand, between the islands of Amager and Zealand, into the deep water of the Baltic; and to reclaim land with the materials dredged in the new harbour. If carried into effect, this project will add much to the prosperity of the city.

The English system of waterworks appears to be making considerable progress abroad. During the past year, important works for the supply of Altona, from the Elbe, at a distance of eight miles, and under somewhat special circumstances, have been completed by Mr. Hawksley, and other works have been commenced by the same gentleman, in association with local Engineers, for the supply of the city of Stockholm, in Sweden, and of Bridgetown, in Barbadoes. As these works involve peculiarities of construction, consequent on the adaptation of waterworks to the requirements of climates in which the extremes of heat and cold prevail, a description of them will hereafter be presented to the Institution.

In Russia, the Riga and Dunaberg Railway, under the direction of Mr. Hawkshaw, is progressing, and will be completed, it is expected, in the course of the year 1861. Of the extensive system of railways being constructed under the direction of M. Zeiller,

for the *Crédit Mobilier of France*, the portion between Königsberg and Dunaberg has been already traversed by the Emperor, and will soon be open to the public.

The policy of the Imperial Government of Brazil has long been directed to every class of public improvement, and particularly to the internal communications, among which the railways stand first in importance. Four commercial cities on the seaboard have been selected as the starting points of railways, to proceed into the interior, viz., Recife, or Pernambuco, Bahia, Rio de Janeiro, and Santos. Upon the capital to be invested in these undertakings, the Brazilian Government offers a guarantee of 5 per cent., and also indorses a further guarantee of 2 per cent., by each province which these lines are to pervade, making an assured interest of 7 per cent.

The first section of the Don Pedro Segundo Railway at Rio de Janeiro was executed by Mr. E. Price, under a contract with the Brazilian Government; the length of the line is about 30 miles. Arrangements are making for extending it into the interior of the country, as soon as the important question of the mode of surmounting the great ascent from the coast, is settled.

The Pernambuco Railway was designed by Messrs. De Mornay, and the line was originally laid out by the late Mr. Borthwick. The works had made a slight progress prior to his death, which was shortly followed by that of Mr. Rendel, his successor. The direction of the works, which are being vigorously prosecuted, is now undertaken by Mr. Gregory, (M. Inst. C.E.), and Mr. Peniston, (M. Inst. C.E.), and the length under execution is about 80 miles. The first section, from Recife to Villa da Cabo, a length of about 19 miles, was opened on the 9th of February, 1858, and the traffic is so far developed as to produce, even now, a very fair return. The second section, of $17\frac{1}{2}$ miles, which will open up an increased traffic in sugar, &c., is in a forward state, and will, probably, be completed by the spring, or summer of next year. The works on this section are heavy, and they have been impeded by a wet season of unusual severity.

The Bahia Railway is under the direction of Mr. C. Vignoles, by whose Son, Mr. Hutton Vignoles, (M. Inst. C.E.), the line was originally laid out, and to him is intrusted the management of the works, the contract for which was taken by Mr. J. Watson, (M. Inst. C.E.) The length of this railway is nearly 80 miles, of which the first 30 miles are of a difficult character, including a viaduct about 1,000 yards in length, over an arm of the sea. It is erected on Mitchell's screw piles, with wrought-iron beams spanning the openings. The whole of the details of this viaduct were worked out by Mr. Francis Shields, (M. Inst. C.E.) This viaduct

will, probably, be completed early in January next ; the first section of the railway will be opened by Midsummer, 1860 ; and the entire line will be completed in the course of the year 1863.

Both the Pernambuco and the Bahia Railways are designed to terminate, ultimately, on the River San Francisco, at, or near the point where further navigation towards the ocean ceases, which is nearly 300 miles above the mouth of the river. About midway in this distance occur the Grand Falls of Paulo Affonso, said to be only second to those of Niagara. An exploring expedition, sent by Mr. Vignoles, and conducted by Mr. Vivian, assisted by Mr. Walter Croubace, has determined, that a practicable, and not expensive route, may be found in continuation of the present Bahia Line: the total distance from the port of Bahia, to Ivaziero, on the left bank of the River San Francisco, being 400 miles. The concession of the extension is in the hands of the Bahia Railway Company. From the above projected terminus, the river, with its tributaries, is navigable for vessels not exceeding 6 feet draught, for upwards of 1,000 miles. It passes through land of the richest character, promising well for the future prosperity of the Brazilian Empire, when this region shall be opened.

The railway from Santos is better known as the San Paulo Line, the province through which it is to pass. The surveys and explorations were made two years ago, under the direction of Mr. Brunlees, by Mr. Fox. The peculiar character of the country appears to have led to the proposal for adopting inclined planes of about 1 in 10, for upwards of 5 miles. The whole country is very rugged and difficult, and will, it is believed, require other planes of 1 in 75 and 1 in 50 for short distances.

Several hundred miles of macadamised roads have been laid out by Mr. Hutton Vignoles, through the Province of Bahia, partly in connection with the railway, and under the energetic management of Mr. Watson, the contractor, they are fast approaching to completion. The works of the Mangaratiba Serra Road have also been carried out by Mr. E. B. Webb, (M. Inst. C.E.) The hydraulic works in front of the city of Rio de Janeiro, are now assuming considerable dimensions, under the care of Mr. C. Neate, (M. Inst. C.E.); and Mr. Law has undertaken the construction of the docks for that city. Gas works have also been established at Rio de Janeiro and at Pernambuco, which are said to be paying 15 per cent. ; and similar works are in contemplation for Bahia.

In Brazil, the talents and energies of English Engineers are duly appreciated. Mr. C. B. Lane, (M. Inst. C.E.,) is the Chief Engineer to the Home Government at Rio ; and Mr. W. Martineau, (M. Inst. C.E.,) at Pernambuco. In addition, most of the

Assistant Engineers, foremen and gangers, are Englishmen, and almost the whole of the iron, rolling and other stock, for these undertakings, has been sent from this country. The works have also, for the most part, been executed with English capital.

It is to be regretted, that Mr. Robert Stephenson did not survive to see the successful final completion and opening of the great Victoria Tubular Bridge, across the St. Lawrence, at Montreal. This structure is nearly $1\frac{1}{2}$ mile in length, the greatest span being 330 feet. It is unexampled in extent, and in the massiveness and peculiar construction of the masonry piers for resisting the pressure of the ice.

The principal Papers read during the past session were:—
“Description of the Line and Works of the Railway from Lisbon to Santarem,” by J. S. Valentine, (M. Inst. C.E.); “On the Railway System in Ireland, the Government Aid afforded, and the Nature and Results of County Guarantees,” by G. W. Hemans, (M. Inst. C.E.); “On the use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America,” by T. S. Isaac; “Description of a Breakwater at the Port of Blyth; and of Improvements in Breakwaters, applicable to Harbours of Refuge,” by M. Scott, (M. Inst. C.E.); “On the Performances of the Screw Steam-Ship ‘Sahel,’ fitted with Du Trembley’s Combined-Vapour Engine; and of the sister ship ‘Oasis,’ fitted with Steam Engines worked expansively, and provided with partial Surface Condensation,” by J. W. Jameson, (Assoc. Inst. C.E.); “On the Coefficients, T_e and T_r , of Elasticity and of Rupture in Wrought Iron; in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals,” by R. Mallet, (M. Inst. C.E.); “Account of Experiments upon Elliptical Cast-Iron Arches,” by T. F. Chappé, (M. Inst. C.E.); “On the Water Supply to the City of Melbourne, South Australia; comprising a brief description of the Melbourne Gravitation Waterworks,” by M. B. Jackson, (M. Inst. C.E.); “On a New System of Axle Boxes, not requiring Lubrication, and without Liability to Heating,” by P. A. de Brussaut; “On the Permanent Way of the Madras Railway,” by B. M’Master, (Assoc. Inst. C.E.); “Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction,” by W. J. Kingsbury, (Assoc. Inst. C.E.); “On the Tyne Docks at South Shields; and the mode adopted for Shipping Coals,” by T. E. Harrison, (M. Inst. C.E.); and “On the Manufacture of Malleable Iron and Steel,” by H. Bessemer.

The following Telford and Watt Medals, and Council and Manby Premiums of Books, have been awarded to the Authors of some of these communications :—

1. A Telford Medal, to Michael Scott, M. Inst. C.E., for his Paper, "Description of a Breakwater at the Port of Blyth; and of Improvements in Breakwaters, applicable to Harbours of Refuge."
2. A Telford Medal, to Robert Mallet, M. Inst. C.E., for his Paper, "On the Coefficients, T_e and T_r , of Elasticity and of Rupture in Wrought Iron, in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals."
3. A Telford Medal, to Henry Bessemer, for his Paper, "On the Manufacture of Malleable Iron and Steel."
4. A Telford Medal, and the Manby Premium, in Books, to William Joseph Kingsbury, Assoc. Inst. C.E., for his Paper, "Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction."
5. A Watt Medal, to James Wardrop Jameson, Assoc. Inst. C.E., for his Paper, "On the Performances of the Screw Steam-Ship 'Sahel,' fitted with Du Trembley's Combined-Vapour Engine; and of the sister ship 'Oasis,' fitted with Steam Engines worked expansively, and provided with partial Surface Condensation."
6. A Council Premium of Books to Thomas Sebastian Isaac for his Paper, "On the use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America."
7. A Council Premium of Books, to Matthew Bullock Jackson, M. Inst. C.E., for his Paper, "On the Water Supply to the City of Melbourne, South Australia; comprising a brief description of the Melbourne Gravitation Water-works."

It should be mentioned that, in accordance with an established rule, two of the Papers, being by Members of the Council, Mr. Harrison and Mr. Hemans, were not considered in the adjudication of Premiums.

Although the Papers have been comparatively few in number, they are in excellence and in the variety of the subjects treated, quite equal to those of former years, as was evident from the interesting and animated discussions to which they gave rise. Indeed, about one-half of the whole number of Meetings was entirely occupied by

discussions, which are often the means of eliciting valuable and extended information that would not, otherwise, be obtained.

The Papers by Mr. Valentine, Mr. Hemans, Mr. Isaac, and Mr. M'Master referred to Railways in Portugal, Ireland, the United States, and India, respectively. That by Mr. Valentine, a "Description of the Line and Works of the Railway from Lisbon to Santarem," gave an account of the first railway executed in Portugal. After alluding to the entire absence of facilities for internal communication in that country, prior to the year 1853, the method of granting concessions, which was founded on the French system, was detailed. It was agreed, that this system was objectionable, as it fettered the freedom of action of the Engineer, on whom the responsibility, in reality, rested. The concessions subsequently granted were then alluded to, and a narrative was given of the mode of obtaining land for railway purposes. The line and works were next minutely described, and it was shown, as a result, that the partial opening of the line, for passenger traffic alone, had proved, that the peasantry preferred that mode of travelling to the old and slow methods to which they had been accustomed, even though it was more expensive.

The Paper by Mr. Hemans, "On the Railway System in Ireland, the Government Aid afforded, and the Nature and Results of County Guarantees," was suggested by the Address of Mr. Locke, M.P., President, which related chiefly to French railways. It appeared, that in 1836, Ireland was a blank, as far as regarded railways. In that year, a Government Commission was appointed "to inquire into the manner in which railway communications could be most advantageously promoted in Ireland." The main recommendations of their Report, which was finally made in July, 1838, were considered sound and good. These were examined in detail, and were contrasted with the results which had actually taken place. No steps, however, were taken by the Government, so that speculation languished, until the time of the railway movement in England, when the country began to make for itself, and with little regard to anything like a national system, the various lines now in existence, almost all of which were originated in 1845 and 1846. One of the recommendations of the Commission was, that Government should advance the capital required for the construction of the chief lines, and that the principal and interest of such advances should be secured on local, or baronial rates, in such districts as should consent so to obtain the benefit of railways. This had been successful in the only case attempted, the line from Athlone to Galway; but, for some unaccountable reason, the most determined official opposition was given to the guarantee clauses in the House of Lords, and hence, many districts were even now deprived of the benefits of railways.

In Mr. Isaac's Paper, "On the Use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America," allusion was first made to the Baltimore and Ohio Railway, extending from the city of Baltimore, on the Chesapeake Bay, to Wheeling, on the Ohio River. It was stated, that this was the first railway in operation in the United States, the company having been organised in 1827, and a portion of the line opened in 1830. In the construction of this road, the various ranges of the Alleghany Mountains had to be encountered; and attention was particularly directed to the daring enterprise, which could project and undertake the construction of a railway, at that early period, through a region where the difficulties were of such a gigantic kind. The more immediate object of the Paper, was to describe the Mountain Top Track, on the Virginia Central Railroad, where it crossed the Blue Ridge Mountains, at Rock Fish Gap. It was $4\frac{1}{2}$ miles in length, with a ruling gradient of 1 in 18.87; but on the lower half mile of the eastern slope, the gradient was 1 in 17.86, on curves of 570 feet radius and upwards, and the minimum gradient, on curves of 500 feet radius, was 1 in 22.22. The length of the eastern slope was 2.37 miles, with an average gradient of 1 in $20\frac{1}{2}$, and of the western slope 1.89 mile, with an average gradient of 1 in 22.22. This track had been successfully worked by locomotive power for upwards of four years, without a single accident. It was stated, that experience had proved, that a locomotive could draw a load double its own weight up a gradient of 1 in 17, at a speed of 8 miles per hour. In the course of the discussion, the circumstances under which steep gradients could, with propriety, be adopted, were considered; and it was remarked, that inclines of 1 in 10, or 1 in 17, or even 1 in 40, would only be resorted to from necessity, as, for instance, where it was desirable to prevent a break of gauge in a long line of railway, as they were attended with a heavy cost for working expenses.

Mr. M'Master, in his Paper, "On the Permanent Way of the Madras Railway," remarked, that two leading features in the construction of railways in India were, the cheapness of the works entirely dependent on native labour and the resources of the country, and the expense of those dependent upon England for the supply of materials. He stated that, as yet, almost every part of the permanent way had to be supplied from England; though he believed, ultimately, the forests and jungles of India would be found capable of supplying many hard and durable woods suitable for sleepers, as well as for other purposes.

Mr. Scott, in his "Description of a Breakwater at the Port of Blyth, and of Improvements in Breakwaters, applicable to Harbours of Refuge," referred also to the theory of waves, and to the

theory of hydraulic construction, including the form and methods of building. After describing the port of Blyth, and the means adopted for improving the harbour by the erection of a breakwater, consisting of a timber casing filled with stone, the Author proceeded to remark, that the systems pursued at Dover, Alderney, Portland, and Holyhead did not appear to secure rapid execution. He, therefore, suggested, that the plan of construction successfully adopted at Blyth, might be employed in other cases. He argued that, even if the new arrangements were regarded merely as a means for forming the backbone, as it were, of a more permanent structure, it was the best and cheapest method of attaining the object desired; and that, under the new system, a harbour would be inclosed in five years, instead of occupying twenty years, as on the old system. This Paper led to a prolonged discussion, in the course of which the works at Portland, Holyhead, Dover, Alderney, &c., were alluded to, the relative merits of flat slopes, or vertical faces were entered upon, and the advantages of the proposed system were strongly contested. Mr. John Murray, in his remarks on the form and cost of breakwaters, spoke of the plan adopted by the French Engineers at Marseilles, of not mixing any small material with the large blocks, and suggested the extension of the system, by the use of material of different sizes at various depths. He also advocated the use of béton blocks of 20 tons weight, for the upper portions. The system upon which the Harbours of Refuge were being executed, was thought to be objectionable, and it was urged, that no person should be placed upon a commission of inquiry on this subject, who was pledged to any particular views; nor should the execution of any work be intrusted to any member of a commission, by whom that work had been recommended.

The Paper by Mr. Kingsbury, "Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks, &c.," gave a minute account of the different works involved in this undertaking, which, from their magnitude, and the peculiarity of their construction, presented considerable interest. It will be remembered, that the sides of the entrance of the channel leading to the tidal basin, and of the lock, were described as being composed of concrete walls, faced with cast-iron piles and plates. The side walls of the jetties were described as a combination of cast-iron piles, vertical brick inverts and concrete, with clay puddle. A detailed account was also given of the wrought-iron gates and caisson, and some remarks were made upon the form adopted in their construction. A caisson of peculiar form and construction was stated to have been used in place of a cofferdam, in completing the entrance works. The new caisson was built of a rectangular form in side elevation, the heel posts being vertical, and shaped like those of the gates. In plan, it was similar to one leaf

of the gates, and it extended across the span of 80 feet between the lock walls. It was divided into four horizontal and two vertical compartments, so arranged, that by regulating the admission of water into them, it could be floated with the convex side downwards, nearly in a horizontal position, and be raised into an upright position when required. The casualties which occurred during the construction of the docks were fully described; and the latter portion of the Paper treated of the advantages of the cylindrical form adopted for the gates, with respect to economy of material and general arrangement.

The Paper, "On the Tyne Docks at South Shields, and the mode adopted for Shipping Coals," by Mr. T. E. Harrison, described the utilisation of a large area in the Tyne, called Jarrow Slake, previously covered with water at spring tides. The extent of the works and the mode of execution were then detailed, from which it appeared, that the first operation was to form a large culvert round the head of the dock area, to receive and carry off the upland waters. The sustaining power of the mud, or slake, was found, by experiment, to amount to 7 cwt. per superficial foot. The primary object of these docks was, to provide accommodation for the shipment of coals brought to South Shields by the North Eastern Railway Company. The extent of this trade was alluded to. A brief account was then given of the different methods of shipping coals used at the northern coal ports during the last forty-seven years, and the reasons which induced the adoption in the Tyne Docks, of the system of shipping by spouts. The arrangements for delivering the coal at different levels, so as to suit the varying level of the ship's deck, for economising space at the jetties, by letting the vessels overlap each other when at the shipping places, and for saving manual labour, by laying out the ground above, so that gravity was called into operation to the utmost possible extent, were all minutely described. Great expedition had been thus attained, and it was mentioned, that on the day of the opening, a screw steamer entered the docks, received on board 420 tons of coal in fifty-five minutes, and immediately went to sea.

Mr. Jameson, in his "Account of the Performances of the Screw Steam Ship 'Sahel,' fitted with Du Trembley's Combined-Vapour Engine; and of the sister ship 'Oasis,' fitted with Steam Engines worked expansively, and provided with partial Surface Condensation," gave, in the first place, a brief description of the combined-vapour engine. From this it appeared, that the principle of the engine was based upon the fact, that the condensation of a liquid, such as water, boiling at a high temperature, might be effected by surrounding an external condenser with a liquid, such as ether, boiling at a low temperature. Thus, in a steam boat

with a combined engine, one cylinder would be worked with steam in the ordinary manner, and the other cylinder, with the vapour of ether. After alluding to the experience gained in the 'Du Trembley,' the 'France,' and the 'Brésil,' and to the application of the system in the 'Sahel,' 'Zouave,' and 'Kabyle,' an examination was made of the tabular records of the performances of the two ships, 'Sahel' and 'Oasis.' From this the following results, in favour of the combined-vapour engine, were deduced; first, a weight and place available for 50 additional tons of cargo, or an increase of one-sixth; secondly, a diminution in the consumption of fuel of 40 per cent.; and thirdly, an increase of one-ninth in the speed of the ship. There were attendant disadvantages, but still the actual saving was believed to be such as to merit attention. Only three accidents had occurred during five years, and these were stated to have taken place, when the engines were not at work, when the fires were extinguished, and the ships were in port. No extra insurance had ever been paid on the ships, on account of their having ether on board. In the discussion, the opinion was expressed, that surface condensation would, ultimately, supersede condensation by injection. A comparison of the performances of the combined-vapour engine with those of ordinary-vapour marine engines, made by experienced builders, seemed to show, that the latter consumed, at least, one-half more fuel than the former; and that in fact, the combined engines were as economical, in the consumption of fuel, as some of the best engines employed for pumping. The disadvantages of working without a steam jacket to the cylinder, especially when using steam very expansively, were also pointed out. It was urged, that the true measure of the efficiency of an engine, was the quantity of water passing through it, as steam, in a given time, and that there was no practical value in the employment of ether; for if high-pressure steam was used, expanded in a double cylinder engine, with proper precautions against radiation, equally economical results would be obtained.

In the Paper, "On the Water Supply to the City of Melbourne, South Australia; comprising a brief description of the Melbourne Gravitation Waterworks," Mr. M. B. Jackson described, first the situation of the city, and then the different schemes which had been proposed during the fourteen preceding years, for supplying it with water, a necessity which was increasing in importance, as at the end of 1857, the population amounted to nearly one hundred thousand inhabitants. Finally, it was decided to adopt the River Plenty as the source, in accordance with the suggestion of Mr. Blackburn. The water was derived from the Mount Disappointment range of granitic hills, whence there flowed a number of streams, which, when united, after passing through the swamps,

formed the River Plenty. The works, which were carried out by the Author, consisted in cutting a watercourse, from the river to the Yan Yean reservoir, through a ridge of hills, which necessitated a tunnel a quarter of a mile in length, and in forming an embankment across a valley, between two spurs of hills, in order to retain the rain and flood waters in the reservoir. There was a well tower at the foot of the inner slope of the embankment, and another tower and valve chest on the outer slope, whence the main pipes proceeded to the city. At the commencement, this main was 30 inches in diameter, but it was, subsequently, reduced to 27 inches and, ultimately, to 24 inches. The distribution of the water commenced at 19 miles from Yan Yean, and, including this length of main, there were nearly 104 miles of pipes laid, varying from 24 inches to 3 inches in diameter. A series of Appendices contained Reports of the analysis of the waters, and statements of the rainfall and evaporation in various localities. In the discussion, it was stated, that the method of proceeding adopted in similar cases to that of Melbourne was, first, to ascertain the extent of the drainage area; secondly, to calculate the amount of rainfall, by taking an average of a number of years' observations in the neighbourhood; and, thirdly, to consider the quantity of rainfall that could be collected into any reservoir, which it was practicable to make in the district.

Mr. Mallet, in his experimental inquiry, "On the Coefficients, T_e and T_r of Elasticity and of Rupture in Wrought Iron, in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals," described the difficulty of obtaining very large forgings of a cylindrical form, quite sound, which he attributed to the play of molecular forces. He suggested, that such large forgings should be constructed and worked hollow. Attention was directed to the apparent superiority of puddled steel, for supporting the forces by which the ordinary forged masses of wrought iron were fractured, especially as by the employment of smaller and lighter masses, greater strength in shafts, &c. could be secured. It was thought, that this material would become an important adjunct in the construction of machinery, in the building of vessels of light draught of water, and for artillery of the largest calibre.

Mr. Bessemer, in his Paper, "On the Manufacture of Malleable Iron and Steel," gave an account of his process of converting crude pig-iron into malleable iron, while in a fluid state, by retaining the fluidity of the metal for a sufficient time, to admit of its being cast into moulds, without the employment of any fuel in the process. It was mentioned, that gold, silver, copper, zinc, tin and lead were refined, while in a fluid state, and were then cast into ingots, and there seemed to be no reason why iron should

[1859-60. N.S.]

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remain an exception to the general rule. The form of the converting vessel which had been found most suitable for the purpose, was then described, some details of the processes being given at the same time. As large masses could be cast, of a homogeneous malleable metal, in any desired form, the operation of welding now employed, whenever large masses were required, would become unnecessary. The economy of production for large plates was adverted to, and the facility of forming masses of malleable iron and of steel suitable for ordnance, was also pointed out.

The Library continues to be enriched by the valuable charts published by the Admiralty, and many useful documents, printed by order of the Indian Government; these are transmitted by our Associate, Captain Washington, R.N., the Hydrographer, and Mr. Juland Danvers. Exchanges of proceedings with Foreign and Home Scientific Societies are regularly made, and the number is extending.

The binding of the periodical and other works is progressing, and the re-arrangement of the Library will be proceeded with, in the course of the ensuing year. The Council would again impress upon the Members, the importance of their presenting copies of any Reports made upon works on which they may have been engaged, in order that they may be available for future reference. The Council have pleasure in announcing, that Mr. George Robert Stephenson has expressed the intention of presenting the portrait, by Briggs, of the late Mr. George Stephenson,—that Messrs. Isambard and Henry Brunel have kindly offered a portrait, by Horsley, of their late lamented Father,—and that Mr. Joseph Cubitt has promised a portrait, by Boxall, of your Past-President, Sir William Cubitt. These valuable additions to the collection already on the walls of the Meeting-room, will be received with gratitude, and it is confidently hoped, that they will induce further contributions, so that the series of portraits of Past-Presidents may soon be rendered complete.

The amount of arrears of subscriptions of 1859, due November 30th, is—

	£.	s.	d.	£.	s.	d.
From Members of all classes, residing abroad	51	19	6			
From Members of all classes, residing in the United Kingdom	149	2	0			
				201	1	6
The amount of arrears for 1857 and 1858, is—						
From Members of all classes, residing abroad	32	11	0			
From Members of all classes, residing in the United Kingdom	70	17	6			
				103	8	6
Total				£304	10	0

It will be observed, that arrears of more than two years' standing, are excluded from this statement, the Council having determined to deal specially with all these cases, under the advice of a sub-committee.

The tabular statement of the transfers, elections, deceases, and resignations of Members of all classes, during the years 1857-58 and 1858-59, appears thus :—

—	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1857-58.					
Transferred to Members . .	..	..	9		
Elections	..	11	25	..	36 - 14 = 22
Deceases	1	6	3	..	14
Resignations	..	..	4	..	
1858-59.					
Transferred to Members . .	..	..	4		
Elections	1	16	41	..	58 - 21 = 37
Deceases	1	7	9	..	21
Resignations	..	1	3	..	
Members of all Classes on the Books, November 30, 1859 .}	25	332	523	14	= 894

If the Honorary Members and Graduates are omitted from the calculation, the annual increase of Members and Associates stands thus :—

YEARS.	Members Elected.	Associates Elected.	Total Elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1854	20	37	57	33	24
1855	7	24	31	13	18
1856	10	24	34	24	10
1857	12	57	69	23	46
1858	11	25	36	13	23
1859	16	41	57	20	37

The following Member and Associates, having tendered their resignations, have been permitted to retire from the Institution :—
Mr. George Edwards, Member; Messrs. William Brown, John William Byrne, and Robert Murray, Associates.

The deceases during the past year have been :—Earl De Grey, Honorary Member; Messrs. Isambard Kingdom Brunel, Hugh Ebrington Fortescue, William Hartree, Daniel Mackain, Robert

Stephenson, M.P., Thomas Storey, and Alexander Wright, Members ; James Barrett, Samuel Bennett, Robert Cantwell, George Gardner Donaldson, Robert Barlow Gardiner, Edward Highton, John Houldsworth, Edward Hughes, and George Mills, Associates.

The Memoirs of our late friends will be found in the Appendix to this Report.

Numerically the deceases scarcely exceed the average, but the loss to the Institution of two such Members as Isambard Kingdom Brunel and Robert Stephenson, cannot be adequately estimated. Both have been prematurely removed in the prime of life, and in all the vigour of their intellect. The former died on the eve of the completion of one of his gigantic and original conceptions, after successfully combating great difficulties in the execution of many peculiar constructions ; and the other, when it might have been hoped, that the practical experience of many years in the prosecution of great and successful works, would have rendered him useful to his country, in the House of Commons, and to the Government as an adviser, for which he was eminently qualified, not only by his knowledge, but by the uprightness of his character.

Mr. Robert Stephenson, among other munificent legacies to public bodies, has bequeathed to this Institution the sum of Two Thousand Pounds, the announcement of which, the Council feel persuaded, will be received with kindly feelings analogous to those which prompted the gift. It will be for the succeeding Council to propose the mode of appropriating the interest of this fund, in such a manner as to connect the name of Stephenson, permanently with the Institution.

The financial position of the Institution continues to be very satisfactory. There is an available balance of £1,356. 3s. 1d. against £1,032. 10s. 11d., shown in the Report of the previous year, or an excess in the year of upwards of £300. The Council, considering that the balance at the banker's should not be allowed to remain unproductive, were enabled, in May last, to place £1,000 on deposit at interest, with the Union Bank of London ; this, with the balance in the hands of the Treasurer, amounting to £356. 3s. 1d., makes up the total sum previously mentioned. On comparing the last two years' accounts, it will be seen, that the increase of revenue has arisen from the election of a greater number of Members, and that the larger expenditure has been caused by the second parts of Vols. VII. and VIII. of the 'Minutes of Proceedings,' which were in arrear, having been issued and paid for within the last twelve months. It should be stated, that the Council unanimously resolved, to raise the salary attaching to the office of Secretary from £300 per annum, at which it had remained for

twenty years, to £400 per annum, dating from the 1st of January, 1859. It had long been felt, that the stipend was insufficient for the duties of the office; and it was only because the finances did not, up to the present time, appear to justify an increase, that this step was not sooner resolved upon.

During the year, the series of Minutes of Proceedings up to and including the volume for 1857-8, has been completed, by the publication of Vol. VIII., Part 2, and of Vol. XVII. The Minutes of the past Session, forming Vol. XVIII. of the series, are printed, and will be issued early in 1860. Some delay has arisen from the difficulty in procuring materials for the Memoirs of the deceased Members, and in obtaining the drawings for the numerous plates illustrating the volume.

In the Balloting List for Members of Council, which has already been issued to the Members, it will be seen, that Mr. G. P. Bidder, the senior Vice-President, is proposed for election as President, Mr. Locke's term of office having expired. Two vacancies occur among the Vice-Presidents, in consequence of this nomination and of the decease of Mr. Brunel; Mr. Fowler and Mr. C. H. Gregory are proposed for these offices. The new names submitted for your consideration are Messrs. John Murray, James Abernethy, John Frederick Bateman, and George Robert Stephenson, as Members; and Messrs. William Bird, Captain Huish, Henry Arthur Hunt, and Frederick Marrable, as Associates.

The Council, in resigning their trust, beg to thank the Members for the support accorded to them on all occasions, and would ask for their successors the same kind co-operation they have experienced, without which the Institution cannot continue to make the progress which has, up to the present time, marked its career.

ABSTRACT of RECEIPTS and EXPENDITURE

RECEIPTS.

Dr.		£.	s.	d.	£.	s.	d.
To Balance in the hands of the Treasurer.		£.	s.	d.	1,032	10	11
— Subscriptions and Fees :—							
Arrears		160	13	0			
Current		2,061	8	0			
Fees		182	14	0			
Life		98	3	6			
		<hr/>			2,502	13	6
— Publication Fund					47	19	0
— Council Premium Fund					60	13	6
— Publications :—Sale of Minutes of Proceedings					116	8	3
— Manby Premium					20	15	10
— Telford Fund :—							
Dividends :—6 months, due Christmas, 1858,	} 37 9 7						
on £2,551. 15s. 10d., 3 per Cent. Reduced Consols . . .							
6 months, due Lady-day, 1859,	} 34 8 3						
on £2,342. 17s. 1d., 3 per Cent. Reduced Consols . . .							
6 months, due Midsummer, 1859,	} 37 9 7						
on £2,551. 15s. 10d., 3 per Cent. Reduced Consols . . .							
6 months, due Michaelmas, 1859,	} 33 4 10						
on £2,342. 17s. 1d., 3 per Cent. Reduced Consols . . .							
		<hr/>			142	12	3

£3,923 8 3

from the 1ST DEC., 1858, to the 30TH NOV., 1859.

Cr.		PAYMENTS.		£. s. d.		£. s. d.	
By House, Great George Street :							
	Rent			366	8	2	
	Rates and Taxes			46	6	9	
	Insurance			18	19	9	
							431 14 8
—	Salaries						375 0 0
—	Donation to late Cashier and Collector						50 0 0
—	Clerk, Messengers, and Housekeeper						164 16 0
—	Postage and Parcels :—						
	General			35	0	2	
	Parcels			1	4	11	
							36 5 1
—	Stationery, Engraving, Printing Circulars, Cards, &c.						62 19 10
—	Coals, Candles, Oil, and Gas :—						
	Coals			21	10	0	
	Candles			0	17	6	
	Oil			1	19	0	
	Gas			17	19	3	
							42 5 9
—	Tea and Coffee						28 14 11
—	Library :—						
	Books			5	17	6	
	Periodicals			27	11	10	
							33 9 4
—	Publication :—Minutes of Proceedings						1,239 9 0
—	Council Premiums						27 15 5
—	Watt Medal						4 2 0
—	Manby Premium						11 5 10
—	Diplomas for Members						7 1 6
—	Manuscripts, Original Papers, and Drawings						1 5 0
—	Winding and Repairing Clocks						1 10 0
—	Incidental Expenses :—						
	Gratuities and Christmas Gifts			1	16	0	
	Occasional Assistance			3	4	10	
	Assistance at Meetings			8	15	0	
	Beating Carpets and Sweeping Chimneys			3	4	6	
	Household Utensils, Repairs, and Expenses			32	10	6	
							49 10 10
							2,567 5 2
—	Deposit in Union Bank of London			1,000	0	0	
—	Balance in the hands of the Treasurer			356	3	1	
							1,356 3 1
							£3,923 8 3

Examined and compared the above Account with the vouchers in the Cash Book, and find them to be correct, leaving a Balance in the hands of the Treasurer of Three Hundred and Fifty-six Pounds, Three Shillings and One Penny.—November 30th, 1859.

(Signed) WILLIAM POLE, } Auditors.
HENRY MAUDSLAY, }
CHARLES MANBY, } Secretary

December 5th, 1859.

APPENDIX
TO THE
ANNUAL REPORT.

MEMOIRS.

PHILIP, EARL DE GREY was the elder of the two sons of Thomas Robinson, second Lord Grantham, and of Lady Mary Jemima Yorke, daughter of the second Earl of Hardwicke. He was born at Whitehall, on the 8th of December, 1781. In 1786, he succeeded his Father in the Barony of Grantham, being at the time but five years of age, and in 1833, he became Earl De Grey. His education was completed at St. John's College, Cambridge, where he graduated in 1801. During Sir Robert Peel's short administration in 1834-35, he held the office of First Lord of the Admiralty, on which occasion he was made a Privy Councillor. When Sir Robert Peel again came into power in 1841, Earl De Grey was selected by that eminent statesman, for the high appointment of Lord Lieutenant of Ireland. He discharged the functions of his position impartially, and with much credit, up to June, 1844, when he retired, to the great regret of the people of Dublin; for, as the representative of the Sovereign, the hospitalities at the Vice-regal Court were sustained most liberally, not alone by the Noble Earl, but by his estimable Countess, who gave considerable encouragement to the manufactures of her native country. On his retirement from Ireland, the Noble Earl may be said to have relinquished political life, for beyond an occasional vote in support of the Liberal-Conservative party, he rarely interfered in political matters.

The late Earl having sedulously cultivated a good natural taste for architecture, became President of the Royal Institution of British Architects, in the year 1835. This office he held during the long period of twenty-four years, and he presided at the opening Meeting of the Session, only one week before his death. He took, from the first, the greatest interest in its welfare; it was he, who obtained for it a Charter of Incorporation, and it was mainly through his exertions, that Her Majesty was led to found the Royal Medal for Architecture, annually awarded by the Institution. At the Meetings for the Presentation of Prizes, he had ever words of

encouragement and hope for the younger recipients, warm and hearty congratulations for the elder. In the words of Professor Donaldson, "the Institute owed Earl De Grey a deep debt of gratitude, for much of the success which had attended its operation, and the high position which it held in the public estimation, and in that of all Europe, was to be attributed, in great part, to the warm and untiring interest which he had manifested in its behalf."

He was also President of the Architectural Museum, and took the chair on the occasion of its first public meeting; he was a Fellow of the Royal Society and of the Society of Antiquaries, and was connected with most of the other learned institutions. He was elected an Honorary Member of the Institution of Civil Engineers, on the 4th of June, 1839.

He died suddenly on the 14th of November, 1859, in the seventy-seventh year of his age, and, leaving no male issue, his titles devolved on his Nephew, the Earl of Ripon. The late Earl had been, for many years, Lord Lieutenant and Custos Rotulorum of Bedfordshire, an Aide-de-Camp to Her Majesty, and in 1844, he was nominated a Knight of the Order of the Garter; he was also Lieutenant-Colonel Commandant of the Yorkshire Hussar Regiment of Yeomanry Cavalry, a command he had held upwards of forty years.

MR. ISAMBARD KINGDOM BRUNEL was the only Son of the late Sir Marc Isambard Brunel, whose mechanical genius and originality of conception he largely inherited. Young Brunel was born at Portsmouth, in the year 1806, at the period when his Father was engaged on the block machinery for the Royal Dock-yard. He received his general education at the Collège Henri Quatre, at Caen, where, at that time, the mathematical masters were particularly celebrated, and to his acquirements in that science may be attributed the early successes he achieved, as well as the confidence in his own resources which he displayed throughout his professional career. On his return to England, he was, for a time, practically engaged in mechanical engineering, at the works of the late Mr. Bryan Donkin, and at the age of about twenty, he joined his Father in the construction of the Thames Tunnel, where he attained considerable experience in brickwork and the use of cements, and more especially, in meeting and providing for the numerous casualties to which that work was exposed. The practical lessons there learned were invaluable to him; and to his personal gallantry and presence of mind, on more than one occasion, when the river made irruptions into the Tunnel, the salvation of the work was due. One of his first great independent designs was that selected for the proposed suspension-bridge

across the River Avon, from Durdham Down, Clifton, to the Leigh Woods, which he owed to the fact, that upon the reference of the competing designs to two distinguished mathematicians for the verification of the calculations, his alone was pronounced to be mathematically exact. Want of funds prevented, at that period, the carrying out of the design, which there are now some hopes of seeing executed, by transplanting to that site the present Hungerford Suspension-bridge, which is itself the work of Mr. Brunel.

His introduction to Bristol led to his appointment as Engineer to the docks of that city, which he materially improved. He had been previously engaged in the construction of the old north dock at Sunderland, and subsequently, he was consulted about the design for the Bute Docks at Cardiff.

In 1833-34, he was appointed Engineer to the Great Western Railway, and whilst engaged upon it, he matured his views of the broad gauge, relative to which he sustained one of the hardest-fought engineering contests on record. This work placed his reputation high among Engineers, and henceforth, his mental and physical powers were taxed almost beyond those of any other member of the profession. His attention to all the details of even the smallest works was unremitting; and the Hanwell and Chippenham Viaducts, the Maidenhead and other masonry Bridges, the Box Tunnel, and the iron structures of the Chepstow and Tamar Bridges on the extension of the railway to the west, attest the boldness and originality of his conceptions, his taste in designing, and his skill in the use of various constructive materials. The partial failure at the opening of the line appeared only to incite his inventive faculties, and to afford a field for the exhibition of his great powers. All the physical impediments were met and conquered, and his perseverance was ultimately crowned with success, in attaining a speed of travelling, combined with comfort and security, hitherto unrivalled. In the attempted adaptation of the atmospheric system of propulsion to the South Devon Railway, he was, however, signally unfortunate, in spite of all the ingenuity displayed; but this failure served to bring into view a most pleasing feature of his character, for while he duly paid up all the calls upon the stake he had in the undertaking, he, at the same time, refused to accept the professional emoluments to which he was entitled.

His services were in constant demand in railway contests before Committees of the Houses of Parliament, and he was employed to construct the Tuscan portion of the Sardinian Railways, as well as to advise upon the Victorian lines in Australia, and the Eastern Bengal Railway.

Intimately, however, as the name of Isambard Brunel will ever

be connected with the railway epoch in Great Britain, it is, probably, as the originator of the system of extension of the dimensions of steam vessels, that he will be best known to posterity. The 'Great Western' steam ship was his first innovation. In that vessel, which was much larger than any previously constructed, he had the able assistance of Mr. Paterson, of Bristol, as the shipwright and of Mr. Joshua Field, (Past-President Inst. C.E.), as the constructor of the engines, and in spite of adverse anticipations, even among practical men, the most triumphant success crowned his efforts, and demonstrated the correctness of his views.

His attention was, at that time, directed to propulsion by the screw, a subject on which Mr. F. P. Smith, (Assoc. Inst. C.E.,) had been long and patiently labouring, and the experiments made by Mr. Brunel, in his voyages on board the 'Archimedes,' convinced him of the practicability of the adaptation of the system to large steam vessels. He then designed the 'Great Britain,' an iron ship, of dimensions far exceeding those of any vessel of its period; and if the first essays were not entirely successful, it must be attributed to the fact of the machinery not having been designed by those whose peculiar study it had been, to produce engines of the class required for such vessels. The disaster in Dundrum Bay demonstrated the scientific design and the practical strength of the hull of the ship, and the successful voyages since made, have proved the correctness of his original views. He was appointed the Consulting Engineer of the Australian Steam Navigation Company, whom he advised to construct vessels of 5,000 tons burthen, to run the entire voyage to Australia, without stopping to coal. His counsels, however, were not followed.

The 'Great Eastern' was his crowning effort, and to the design and execution of this gigantic vessel, far surpassing in dimensions any ship hitherto constructed, he devoted all his energies. The labour was, however, too great for his physical powers, and he broke down under the wearying task; leaving to Mr. John Scott Russell, (M. Inst. C.E.,) and Messrs. Boulton and Watt, his co-operators in the construction of the hull and the engines, the actual completion of the work he had so well and so perseveringly brought up to the day of starting on the trial trip. The disasters attending the launch and the trial trip were unfortunate, but they were, perhaps, inseparable from so novel an experiment, on so gigantic a scale, and the ultimate results may be looked forward to with great interest, as whatever they may be, the impulse given by Mr. Brunel to the construction of large-sized vessels is already felt, and must have great influence both on the mercantile marine and on the Royal Navy.

This sketch of the professional labours of Mr. Brunel is, of necessity, brief and incomplete, nor can the details be given of the

numerous scientific investigations in which he was engaged ; but the devotion during two years of considerable portions of his time, to completing the experiments, made by his Father, to test the application of carbonic acid gas, as a motive power for engines, must be mentioned. His special objects of study were mechanical problems connected with railway traction and steam navigation ; and although he was not, perhaps, so sound, or so practical a mechanic as his friend, and at the same time, constant opponent, Robert Stephenson, yet his intuitive skill and ready ingenuity enabled him to arrive at satisfactory solutions. The characteristic feature of his works was their size, and his besetting fault was a seeking for novelty, where the adoption of a well-known model would have sufficed. This defect has been unfairly magnified, whenever the pecuniary results of an undertaking have not reached the preconceived standard, and due allowance has not been made for the difficulties encountered in the prosecution of a new and bold enterprise. It might, perhaps, have been as well, if a uniform gauge had been originally established for the United Kingdom,—and such will, doubtless, be the ultimate result,—but not the less must be admired the indomitable energy and consummate skill, with which Mr. Brunel and his coadjutor Mr. C. Saunders, pushed the broad gauge and its tributaries westward to Bristol, Gloucester, and through Wales, to Milford Haven, then south-west to Exeter and Plymouth, and onwards to the Land's End ; and after invading the north-west manufacturing district of Birmingham, finally arriving at the shore of the Mersey, opposite to Liverpool. This alone would have sufficed for the lifetime of many men, and in truth, the stupendous labours undertaken by Brunel could not be performed, without overtasking the mental and physical faculties, so that eventually, they must break down.

Mr. Brunel was fervently attached to scientific inquiries ; he was a good mathematician and possessed great readiness in the practical application of formulæ. He was elected at an unusually early age, a Fellow of the Royal Society ; he received the degree of D.C.L. from the University of Oxford ; and he belonged to most of the principal scientific societies of the Metropolis, to several foreign societies, and was a Knight of the Legion of Honour. He was an old Member of the Institution of Civil Engineers, which he joined as an Associate, in January, 1829 ; he became a Member in 1837, was elected upon the Council in 1845, and was a Vice-President from 1850 up to the time of his death. A liberal patron, as well as a discriminating judge of art, he was himself devoted to artistic pursuits, and his early drawings as well as his professional sketches attest his feeling for purity of design.

Of his private character those only who were admitted to his intimacy, could alone judge correctly. Brunel was not a demonstrative

man, but there was a fund of kindness and goodness within, which only required to be aroused to stand forth in high relief. It has been well said of him by an old friend :—"In youth a more joyous, kind-hearted companion never existed. As a man, always overworked, he was ever ready by advice, and not unfrequently, to a large extent, by his purse, to aid either professional, or private friends. His habitual caution and reserve made many think him cold and worldly, but by those who saw his exterior only, could such an opinion be entertained. His carelessness of contemporary public opinion, and his self-reliance on his own character and that of his works, were carried to a fault. He was never known to court applause. Bold and vigorous professionally, he was as modest and retiring in private life."

Mr. Brunel was present at the trial of the engines, the day before the 'Great Eastern' left the Thames. His health had been failing for some time previously, but on that occasion, he was seized with paralysis. He was immediately conveyed to his home, and after ten days, he expired on the 15th of September, 1859. He was cut off in his fifty-fourth year, just when he had acquired the judgment which, in such a profession as that of the Civil Engineer, can only be attained by long practice and experience, and when the greatest work of his life had reached the very eve of completion. His remains were interred on the 20th of September, in Kensal Green Cemetery, in the presence of his relatives and friends, and of a large number of members of the profession. At a meeting, in November, under the presidency of the Earl of Shelbourne, it was decided, that a public monument should be erected to commemorate his great abilities, and to demonstrate the high esteem in which he was held by his private friends, and his professional brethren.

MR. HUGH EBRINGTON FORTESCUE, Son of the late Mr. Matthew Fortescue, who, for many years, filled the office of Chamberlain in the Court of his relative, the Earl Fortescue, Viceroy of Ireland, served his pupilage in Civil Engineering under Mr. G. W. Hemans, (M. Inst. C.E.,) and was afterwards employed by that gentleman on the works of the Midland Great Western Railway in Ireland, as Resident Engineer. Being possessed of considerable intelligence and of great energy and skill in field-work, he was afterwards engaged by Mr. Hemans in laying out lines of railway in Spain, and subsequently, in Switzerland, over two ranges of the Alps. In the latter country he also acted, for some time, as District Resident Engineer, under the same gentleman, on the line from the Lake of Zurich to Coire. On leaving Switzerland, he was appointed one of the

assistants to Mr. Doyne, (M. Inst. C.E.,) in the Army Works Corps, in the Crimea, and throughout the many difficulties which beset that corps in its practical working, Mr. Fortescue was remarkable for the efficiency and discipline he maintained among the men committed to his charge. On his return from the Crimea, Mr. Fortescue was employed, with Mr. Bridgeman, (M. Inst. C.E.,) under Mr. Fowler, (M. Inst. C.E.,) in laying out a difficult line of railway in Algeria; and it was chiefly to his labours in that climate, after his previous hard work in the Crimea, that the failure of his health was attributed. His zeal and energy of mind in duties in which he took an interest, led him to make exertions to which his strength was unequal, and in 1859, he fell a victim to consumption, at the early age of thirty-two years. His talents gave great promise for the future, had his life been spared.

He was elected a Member in 1857, but owing to his occupations abroad, he was not able to take any active part in the proceedings, during the short time he was connected with the Institution.

MR. WILLIAM HARTREE was born at Rotherhithe, in December, 1813, and was educated at the Merchant Taylors' School, of which Company he became, subsequently, a liveryman. Having early manifested a decided talent for mechanical pursuits, he became a pupil of Messrs. John Penn and Son, of Greenwich, into which firm, from the abilities and great perseverance he displayed, he was, eventually, admitted a partner, taking, for many years, in that position, a very active and prominent part in the management of those important works, whence have proceeded, not only so many engines for the Royal and mercantile navies of this and other countries, but whence such practical improvements have emanated. Up to within a few days of his decease, he continued his active career, and it was after a trying day's service at Devonport, on board H. M. S. 'Windsor Castle,' that on his journey homewards, he laid the seeds for an attack of pleurisy, which terminated fatally, after only a few days' illness. He died on the 8th of February, 1859, in the forty-sixth year of his age, leaving a widow, (the only Sister of Mr. John Penn, (M. Inst. C.E.,) and five children. Not by them alone was his loss deplored, for it was also most sincerely felt by all who had enjoyed the opportunity of appreciating the frankness and kind-heartedness of his character.

He was much devoted to literary pursuits, and had, at an expense of nearly £10,000, collected a fine and well-selected library. Astronomy was also one of his favourite objects of study, and for its prosecution, he erected an observatory at his residence,

near Greenwich. His connection with the Institution dated from 1849, when he was admitted a Member, but his unceasing professional occupations precluded his taking any very active part in the proceedings.

MR. DANIEL MACKAIN was born at Fortrose, Ross-shire, in the year 1800; and, in consequence of his Father having been an Officer of Militia, he, in early life, joined that service. The inactivity of such an occupation led his energetic mind in search of more active pursuits, and, while still a very young man, he devoted himself to the study of Civil Engineering. After filling, for some time, important professional situations in Leith, he was, about the year 1828-29, appointed Engineer and Manager of the Cranston Hill Water Company at Glasgow. Under his able and energetic supervision, the affairs of the company, then at a very low ebb, greatly improved; and on its amalgamation, about twenty years ago, with the Glasgow Water Company, by Act of Parliament, he was appointed sole Engineer. During this period, the arduous and difficult duty of supplying that great and rapidly-increasing city with water, devolved upon him. Considering that the whole supply had to be forced by engine power from a low level, and that the city had greatly exceeded in population, and in the extent of its commerce and manufactures, what was ever contemplated, at the organisation of the works; and recollecting the many imperfections in the old system which modern science had revealed, and of which no one was more thoroughly aware than Mr. Mackain, it must be admitted, that the success of his efforts to supply upwards of 16,000,000 gallons of water per day, required an amount of energy, foresight, and engineering talent of no ordinary kind.

Unobtrusive and quiet, yet self-possessed, he passed through several Parliamentary campaigns, with singular merit and success. In every case in which the water company was either a promoter, or an opponent, Mr. Mackain was the chief engineering witness before the Committees of the House of Commons; and after the fight was over, Counsel on both sides joined in complimenting him, for his calmness, his intelligence, and his integrity. Perhaps the most trying occasion on which he ever appeared, was on his examination as the principal witness in that which was termed 'The Great Arbitration Cause,' when the value of the waterworks was decided, at the time of the plant and undertaking lapsing, under this valuation, into the hands of the city. His conduct and evidence were admitted to be just, honourable, and impartial by both parties in the cause, by the friends he was about to leave, on the one hand, and by the Loch Katrine Water Commissioners

whom he was about to serve, on the other; and the Lord Advocate, (now the Lord Justice Clerk,) who was final umpire in the arbitration, awarded him the highest praise. When the old company meditated the introduction of water by gravitation, Mr. Mackain explored every glen and rill, and tested the capacity of every loch in the West Highlands, and the result of his observations was the Loch Lubnaig scheme. This was not carried out, on account of the difficulty of raising the capital, but there is little doubt, that it would have answered the purpose intended; and it must be looked upon with respect, as the parent of the great Loch Katrine operations now rapidly drawing to a close. About two years ago, Mr. Mackain was invited to proceed to Portugal, which he did with the concurrence of his Directors, to assist in bringing water to the city of Oporto, and the scheme which he recommended is now being carried out.

One of his most prominent characteristics was a conscientious devotion to the interests of his employers and the public, sparing neither bodily fatigue, nor mental exertion, in the fulfilment of his duties. Naturally of a modest and retiring disposition, he was not much known beyond the circle of those with whom his situation brought him in contact; but he had a few friends who knew his genuine worth, admired his talents, his kind and truly unselfish nature, and who will ever revere his memory.

He joined the Institution, as a Member, in 1840, and his death took place at Dalmarnock, on the 8th of February, 1859.

MR. ROBERT STEPHENSON, the inventor and first constructor of tubular plate-iron bridges, was the only Son of George Stephenson, the 'Father of the Railway System.' He was born on the 16th of October, 1803, at Willington Quay, near Newcastle-upon-Tyne, where his Father was breaksman of a ballast engine. Although Robert Stephenson was born at Willington, he had scarcely any association with the parish, until towards the close of his career, when he contributed a munificent donation to the fund for raising the Stephenson Memorial Schools, which now mark the spot on which stood the home of his Father, and the site of his own birth. Towards the close of 1804, the elder Stephenson removed to Killingworth, a township of Long Benton, and took up his residence at the West Moor Colliery, about five miles from Newcastle.

Having acquired, at the parish school of Long Benton, a rudimentary knowledge of the first elements of education, Robert Stephenson was sent, in 1815, to Mr. Bruce's academy at Newcastle, where he remained during four years, receiving instruction in the usual subjects and in mathematics. On leaving school,

at the midsummer vacation of 1819, he was apprenticed to Mr. Nicholas Wood, (M. Inst. C.E.,) with whom he remained nearly three years, to learn the business of a coal-viewer, and in the performance of his duties, had to inspect the Killingworth colliery, where his father had, several years previously, been the enginewright. He then assisted his Father in the survey for the Stockton and Darlington Railway; and at its completion he was sent, at the close of 1822, to the University of Edinburgh, where for one term, lasting nearly six months, he attended the lectures of the Professors of Mathematics, Chemistry, and Geology. Prizes there were none for him to gain; but he obtained the book which it was the custom of the Mathematical Professor to present, from time to time, to the most meritorious pupil of his class. It was at this period, that he first met, as a class fellow, Mr. George Parker Bidder, (V. P. Inst. C.E.,) with whom, in after years, he was so intimately associated, both professionally and in private life.

Leaving Edinburgh, Robert Stephenson, boy as he was, became the managing partner of the manufactory of engines and machinery of Robert Stephenson and Co., of Newcastle, established in 1823, to meet the demand for locomotive engines which George Stephenson rightly predicted would necessarily ensue, during the course of the next few years. Scarcely, however, was the factory at work, and Robert Stephenson settled in Newcastle, than his health failed, and he accepted an alluring offer, to superintend the working of the gold and silver mines of the Columbian Mining Association, and to report on various engineering works which were, at that time, projected in Columbia. Accordingly, in June, 1824, he left England for South America, where he remained three years, during which time he accomplished his mission with great credit, and he made some investigations and reports which exhibit great foresight and talent. On his way homewards, he visited the United States and Canada, experiencing the perils of shipwreck. It was on this journey that he met with Trevithick, whose splendid dreams of wealth, in Spanish America, had terminated in the stern reality of almost absolute want; and there is little doubt, that the discussions on the steam engine between these original geniuses of such different character, led in the mind of Stephenson, to a closer consideration of the locomotive.

On his arrival in England, in December, 1827, he found the Stockton and Darlington Line in full operation, and the Liverpool and Manchester Railway fast approaching completion. The question as to the best means of traction for the new road was already under discussion, and as the time for opening the line drew near, the controversy amounted to acrimony. Mr. James Walker, (Past-President Inst. C.E.,) and Mr. J. U. Rastrick, [1859-60. N.S.]

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(M. Inst. C.E.), who were employed by the company to investigate the subject, reported, at first, against the adoption of the locomotive so strenuously advocated by Stephenson, and they recommended the use of stationary engines. The Directors, however, determined on giving the locomotive a fair trial, and offered a premium of £500 for that engine which should best fulfil the required conditions. The offer led to the memorable Rainhill contests, at which the 'Rocket,' built by Robert Stephenson, with a boiler on the multitubular principle, suggested by Mr. Henry Booth, and under the guidance of George Stephenson, obtained an easy victory over the other competitors. The success of the 'Rocket' decided the question of locomotive traction. Not content, however, with what he had already achieved, he resolved on effecting further improvements, and the 'Planet,' which virtually gave the type to all succeeding locomotives, was the result of his renewed exertions. From the period of the construction of the 'Rocket,' he still, for several years, persevered in his "endeavours to improve," and such was the success of those efforts, that, as has been justly said by Mr. Nicholas Wood, "to Mr. Robert Stephenson, almost, if not quite, universal assent will be accorded, as having the merit of raising the locomotive engine from what it was in 1829, to what it is in 1860."¹

Between the close of 1827 and 1833, Robert Stephenson was occupied in railway construction, assisting his Father on the Liverpool and Manchester Railway, and laying down some minor lines. The first great work, however, for the success of which he was solely responsible, was the London and Birmingham Railway, an undertaking of high historic interest, both on account of the gigantic difficulties which were encountered in its construction, and of its being the first public iron road into London. The London and Birmingham Line was opened in 1838, and from that time till the close of his life, Robert Stephenson was engaged in a series of achievements which will hand him down to posterity, as occupying the front rank among Engineers, in an era abounding in men conspicuous for mechanical genius. Important works directed by his counsel, or carried on under his personal superintendence, are to be found in every quarter of the globe. Belgium, Switzerland, Norway, Denmark, Tuscany, Canada, Egypt, and India have lines of railway, formed under his direction.

The works by which he will, probably, be best known to posterity are his bridges;—among them may be mentioned the High Level Bridge at Newcastle-upon-Tyne, the Victoria Bridge at Berwick, the Conway and the Britannia Tubular Bridges on the

¹ Vide "Transactions of the North of England Institute of Mining Engineers," vol. viii., p. 66.

Chester and Holyhead Line, the Victoria Tubular Bridge over the St. Lawrence River at Montreal, and the tubular bridges over the Nile at Benha and at Berket-el-Saba, the precursors of that at Kaffre Azzayat, on the Egyptian Railway from Alexandria to Suez. Such are a few of the principal monuments of his genius. But his Parliamentary services, as a witness in the committee-rooms of the two Houses, were, at the time they were rendered, neither less valuable, nor less distinguished, though, at the present date, they may be less generally known. In the two memorable contests of the Battle of the Gauges, and the Battle of the Atmospheric System, he fought, as he had previously fought in the Battle of the Locomotive,—strenuously, indefatigably, and temperately,—opposing the invincible strength of a calm judgment and lofty intellect, to the brilliant subtleties and splendid daring of a worthy opponent.

Throughout his career, Robert Stephenson was as popular as he was successful. Never ambitious of self-aggrandisement at the expense of his colleagues, he had the rare faculty, inestimable in those who occupy places of chief command, of selecting capable coadjutors and subordinates; and he united to this faculty a generous anxiety, that his assistants should receive the full share of fame and of remuneration due to their exertions. He was consequently, from first to last, an object of affection, not less than of admiration, with the members of his own profession, the contractors, and the men of business with whom he acted. In December, 1837, as the labours of constructing the London and Birmingham Line were being brought to a close, the members of the engineering staff under his command, entertained him at a public dinner at Dunchurch, and presented him with a piece of plate of the value of one hundred and thirty guineas. In the same manner he was, in November, 1839, presented with a service of plate, of the value of twelve hundred and fifty pounds, by the “gentlemen who had been engaged as contractors for the construction of railways, or the supplying of permanent materials.” As the subscription of each contributor was limited to five pounds, this demonstration was, in no respect, a mere party movement, but the expression of a general and wide-spread sentiment. On the occasion of the presentation of this testimonial, he was entertained at a very numerously attended public dinner at the Albion Hotel. Besides these and many similar expressions of good-will, unsought honours were poured in upon him. In 1841, he was decorated by the King of the Belgians, with the Order of Leopold; and in 1848, he was presented with the Grand Cross of St. Olaf of Norway. In 1855, the Council of Presidents and Vice-Presidents of the Great French Exhibition awarded to him the Great Gold Medal of Honour, for the invention and introduction of the system

of tubular plate-iron bridges,—First Class Silver Medals being at the same time awarded to Messrs. William Fairbairn, (M. Inst. C.E.,) Eaton Hodgkinson, (Hon. Mem. Inst. C.E.,) and Edwin Clark, (M. Inst. C.E.,) for their respective labours of co-operation,—and he was, at the same time, decorated by the Emperor, with the Order of the Legion of Honour. In 1857, the University of Oxford conferred upon him the Degree of D.C.L. He had also, for several years, been a Fellow of the Royal Society, and he was a Member of most of the other scientific and learned societies of the Metropolis.

His connection with the Institution of Civil Engineers began in 1830, when he became a Member. He was elected a Member of Council in 1845, soon after the first radical change in the constitution of the society, to which he mainly contributed, and he continued in that position till 1848, when he was placed among the Vice-Presidents. At the Annual General Meeting in December, 1855, he was elected President of the Institution, in which capacity he acted during the two ensuing years, 1856 and 1857. It is needless to dilate upon the warm interest he took in everything that concerned the Institution, his assiduous attendance, not only at the Council, but at the Meetings where he so frequently took a prominent part in the discussions, of which the volumes of the Minutes of Proceedings give such instructive evidence. The interest he felt may be said to have continued after his death, for amongst his legacies, he bequeathed the munificent sum of Two Thousand Pounds to that Institution, of which he was so distinguished an ornament.

Entering Parliament in 1847, as Member for Whitby, Robert Stephenson continued to represent that important constituency in the House of Commons, until the period of his decease. A staunch conservative, he voted steadily with his party, but his political conduct was marked by the same generosity that adorned his professional struggles, and the same amiability which endeared him to so many private friends. With the members of all parties he was alike popular, and one of his last acts was to insist on being permitted to subscribe to the testimonial, presented by the liberal members of the House to Sir William Hayter, on his relinquishing the office of 'whip' to their party. In the debates, his voice was not frequently heard; but on the few occasions of his addressing the Speaker, on professional questions, such as that of the Canal of the Isthmus of Suez, and that of the building in Hyde Park for the Great Exhibition of 1851, he was listened to with attention, and acquitted himself with dignity and effect.

A life of severe mental and bodily exertion,—such as that led by Robert Stephenson from early boyhood to the close of his career,—makes decay anticipate old age. For the last eight years

of his existence, his health had, occasionally, manifested symptoms which were calculated to cause great anxiety to his friends. At no time did his mind sustain any loss of vigour; but chronic derangement of the digestive organs indicated the existence of mischief, destined to lay him in the grave, ere he should accomplish the full term of human life. At the beginning of 1859, those symptoms became greatly aggravated, and he was advised to try the effects of change of scene, combined with mental repose. To Robert Stephenson, such a prescription was an impossibility; quiet he could not command. A mind, habituated for nearly half a century to continual action amidst interests, vast, numerous, and diverse, cannot, by an effort of the will, create tranquillity for itself. Moreover, the world would not allow the Engineer that slight amount of rest which he could have commanded, had he been left to shape his own course. Wherever he went, he was followed by those who were anxious for his professional guidance. In September, 1859, however, he broke away from the numerous claimants on his attention, and in his yacht, "that house," as he feelingly described it to a friend, "which has no knockers," made his last voyage to Norway. Yachting was, indeed, the only recreation which he permitted himself, but even then, he combined business with pleasure, performing in that manner his professional visit to several places on the Continent, and to Egypt. At first, he seemed to rally under the refreshing influences of repose and of the sea breezes; but soon the overpowering sense of debility and of depression returned, and the attached friends by whom he was accompanied, justly entertained apprehensions of the worst results. Hastening home from Norway, where he had suffered much, he landed from his yacht at Lowestoft, and was conveyed to London, where he expired at his residence in Gloucester Square, on the 12th of October, 1859, within a few days of completing his fifty-sixth year.

When it is remembered, that Robert Stephenson was a man of varied information, fond of winning others to his opinions, and capable, when he was pleased to make the effort, of writing with singular force and perspicuity, it is a matter of surprise, that he has left behind him very few distinct literary productions. His published Reports on matters connected with his profession are numerous, and well deserving of preservation; but his admirable article on "Iron Bridges," in the *Encyclopædia Britannica*, is, perhaps, his most important contribution to scientific literature.

On the death of Robert Stephenson, it was felt, that Westminster Abbey was his proper resting-place. An application was made to the authorities for permission to place him in that temple, where the greatest of Britain's chiefs have for centuries been gathered, and the permission was promptly accorded. On the

22nd of October, the funeral was conducted with fitting solemnity, his remains being deposited by the side of Thomas Telford, the first President of the Institution, in the presence of several thousand persons, amongst whom were not only his professional and private friends, but also the most distinguished representatives of the literature, science, and art of Great Britain in the nineteenth century; and among them not an eye was dry, when the last remains of their dear friend and coadjutor disappeared. Shortly afterwards, a public meeting, presided over by Lord Llanover, and attended by a numerous body of noblemen and gentlemen, was held for the purpose of taking into consideration the most appropriate mode of testifying the general respect; when it was resolved, that a statue should be erected to his memory in St. Margaret's Gardens, near the Abbey, where the place of his repose is marked by a monumental brass and a window.

The benevolence which had, in early life, formed a prominent feature of Robert Stephenson's character, manifested itself in his later years, in a series of munificent acts towards the inhabitants of Newcastle and the surrounding district, amongst which may be mentioned, his donation of Twelve Hundred Pounds to the Memorial Schools at Willington Quay, Three Thousand Pounds to the Literary and Philosophical Society, and Ten Thousand Pounds to the General Infirmary of Newcastle. The same spirit of enlightened humanity pervaded his final disposition of the great wealth, which a prudent but liberal management of his private affairs had gathered to his keeping, the provisions of his last will, made a short time previous to his last visit to Norway, conferring upwards of Twenty-five Thousand Pounds on charitable societies and scientific institutions. Few professional men have attained such well-deserved celebrity as Robert Stephenson, and his works will remain to attest his well-earned reputation. His memory will long live in the hearts of those who appreciated and loved him for his manly qualities in private, as they admired him for his public acts and high professional attainments.

MR. THOMAS STOREY, Son of an agriculturist, at Makememrich, near Ponteland, in the County of Northumberland, was born at that place, on the 7th of December, 1789. He received his education at Stamfordham, and served an apprenticeship under Mr. Watson, of Willington, whence he removed into Lancashire, and was employed by Messrs. Clark, Roscoe, and Co., as their Mining Engineer in that county, in Wales, and in Shropshire. In 1822, at the request of Mr. George Stephenson, with whom he was connected by marriage, he was released from his engagement under Messrs. Clark and Co., and was employed in

the construction of the Stockton and Darlington Railway, for which purpose, he removed to St. Helens, Auckland, where he continued to reside until the period of his death. He projected and formed the Great North of England Railway, of which he was the Engineer-in-chief, and on his retirement from that line, he was presented with a splendid dinner service of silver plate. He also projected and formed the Auckland and Weardale Railway, and he was engaged on various other lines.

In person, Mr. Storey was tall and athletic, and capable of undergoing great fatigue. He possessed great decision of character, and was deservedly respected for his strict integrity and honesty of purpose. He was as scrupulously just, as an employer, towards those who served under him, as he had been when an agent, to those under whom he served. During the last few years, he lived in retirement, his health not permitting him to undertake any great public work. He died calmly, after a short illness, on the 15th of October, 1859, in the seventieth year of his age. He had been a Member of the Institution for thirty years, having been elected on the 12th of May, 1829.

MR. ALEXANDER WRIGHT, born in Glasgow in the year 1816, was apprenticed to Mr. Cowan, Gas Engineer of that city. On coming to London, he was engaged at several engineering manufactories; he then conducted the business of Mr. Stevens, (Assoc. Inst. C.E.) of Southwark Bridge Road; and ultimately, he became principal foreman at Mr. Edge's gas meter manufactory, in Westminster. His engagement under Mr. Edge terminating in 1844, he established himself as a meter manufacturer, at Hamburg, but not being so successful as he anticipated, he returned to London and carried on the manufacture of meters and gas apparatus, for a short time, in Holywell Street, and afterwards, in Millbank Street, Westminster. During this period, Mr. Wright sedulously devoted himself to chemistry and to the practical details of gas engineering; he built several gas works, and constructed the largest station meter then made. He also invented several instruments for testing the quality of gas, equally adapted to the requirements of the practical gas manufacturer and to those of the scientific experimentalist, among which may be mentioned, an improved apparatus for determining the specific gravity of coal gas, and an instrument for detecting the quantity of bisulphuret of carbon; an alkalimeter, adapted for readily ascertaining the strength of ammoniacal liquor; a registering pressure-gauge for supply mains and for exhausters, &c. He also materially assisted in putting the Bunsen photometer into a working form, and in establishing correct principles for photo-

metric investigations. Mr. Wright had thus attained considerable celebrity as a practical Engineer and careful analyst. He contributed some able articles to the "Journal of Gas Lighting," the most important of which were ;—"The Theory and Economy of Artificial Light ;"¹ "Coal and its Products by Distillation ;"² and "The History of the Gas Meter."³ Unfortunately, however, engagements led him to defer the conclusion of the last, from time to time, and it remains unfinished.

In 1850, Mr. Wright accepted the appointment of Engineer to the Western Gas Light Company, which owes much of its success and present prosperous condition to his indomitable resolution, industry, and judgment. In 1857, he was also appointed Consulting Engineer to the Great Central Gas Consumers' Company, which appointment, from peculiar circumstances affecting that company at the time, offered considerable scope for the exercise of his talents and energies. He continued to discharge his duties to the satisfaction of the directors and shareholders of these two companies, to the time of his death.

Mr. Wright originated and patented, in 1856, a plan for lighting mines with gas. This scheme was successfully carried into operation at the Balleswidden Mine, St. Just, Cornwall, but unfortunately, soon after its practicability had been demonstrated, the mine proved unprofitable to the adventurers, and was almost entirely closed ; this threw a damp on the project, and it has since remained in abeyance.

The Metropolitan Local Management Act came into operation in the year 1855, and Mr. Wright was elected Member of the Board of Works, for the Westminster district, which position he continued to hold to the date of his death, having been re-elected in June, 1859.

The following remarks from the "Journal of Gas Lighting,"⁴ will express the estimation in which Mr. Wright was held by the members of his profession :—

"Cut off at the premature age of forty-three, in the prime of life, in robust health, and in the flood-tide of that prosperity which his unwearied industry, his conciliating manners, his vigorous intellect, his unimpeached integrity, and his enlarged views had justly won for him. His loss leaves a blank in a large circle, the extent of which can only be appreciated by those who knew him as well, and appreciated him as sincerely, as the writer of these lines ; and it is no disgrace to his brethren who survive him to say, that the blank is one which will not be easily filled up. Alexander Wright was, indeed, an honour to his country and his profession. A self-taught genius, he combined acuteness of perception with

¹ *Vide* "Journal of Gas Lighting," vol. i., p. 75, *et seq.*

² *Ibid.*, vol. i., pp. 12 and 69.

³ *Ibid.*, vol. i., p. 114, *et seq.*

⁴ *Ibid.*, 2nd of August, 1859, p. 418.

quickness of apprehension ; a singular felicity in expressing his views, with the most varied knowledge on scientific subjects ; and modesty of demeanour with a frankness and candour which impressed those around him with confidence in his judgment. His contributions to the perfecting of the gas meter were many and important, and his paper on "The History of the Gas Meter," which appeared anonymously in our columns some years since, proves how thoroughly he understood that subject. His self-registering pressure indicator is to be found in every well-regulated gas-work throughout the land, and his photometers, in experienced hands, have relieved photometry from the doubts which empiricism threw over its early practice. As a member of the Metropolitan Board of Works, he entered upon another sphere of usefulness, in which the soundness of his views on the subject of metropolitan improvement soon placed him in the front rank among the members of that body. The main drainage scheme was carried through the opposition it encountered principally by his indomitable perseverance, and he looked forward to the embankment of the Thames as the next great work of the Board.

"Towards the latter end of June Mr. Wright sought relaxation from his labours by a journey in the north of Europe. He returned from Hamburg on the 17th of July, and on the following day was seized with an attack of Asiatic cholera in its most malignant form, to which he finally succumbed on the 23rd. He was interred near two of his children in the Norwood Cemetery on the 27th, amidst the mournful regret of the numerous friends who had assembled round his grave to pay the last honours to departed worth ; and if anything can soothe the sorrow of his family on so trying an occasion, the universal expression of affection for his memory which their bereavement has called forth, is not without value."

Mr. Wright was admitted an Associate of the Institution in 1856, and was transferred to the class of Members, on the 25th of January, 1859, only six months before his death, which occurred on the 23rd of July, 1859.

Mr. JAMES BARRETT was born in Queen Square, Bristol, in the year 1808, and was educated at Brislington, near that city. At an early age he entered the office of the late Mr. H. C. Price, who had introduced a new system of warming and ventilating, known as that of Price and Manby, and Mr. Barrett took an active part for many years, in the application of the system to the numerous buildings in which it has been employed. In 1848, Mr. Barrett became acquainted with the late Dr. Henry Hawes Fox, of Bristol, who had recently originated a method of fire-proof construction now well known as 'Fox and Barrett's'; and, in conjunction with the eldest son of Dr. Fox, he removed to London and established the system which has since been so extensively adopted, and with which his name will always be identified. Dr. Fox dying in 1851, the partnership was dissolved, and from that time, the business was carried on by Mr. Barrett, with the assistance of his Son.

He joined the Institution, as an Associate, in 1850, and was a

frequent attendant at the Meetings. In January, 1853, he contributed a Paper¹ "On the Construction of Fire-proof Buildings," to which a Telford Medal was awarded. His decease, due to an attack of erysipelas in the head, occurred very suddenly on the 30th of April, 1859, in his fifty-first year, to the great grief of his family and of a numerous circle of friends, by whom he was justly esteemed as a very worthy, upright man.

MR. SAMUEL BENNETT was practically educated as a Mechanical Engineer, and at an early age, was employed under his Brother-in-law, the late Mr. Roentgen, (M. Inst. C.E.) in the extensive ship-building yards and steam-engine manufactory opposite to Rotterdam, where he was actively engaged, for many years, in the construction of steamboats, both for sea and river navigation, of sugar mills, and of other machinery. He subsequently removed to Batavia, to take the management of a branch establishment, for repairing machinery, where he died in the year 1859.

He joined the Institution as an Associate, in 1839, but he was precluded, by his constant residence abroad, from taking any active part in the proceedings.

MR. ROBERT CANTWELL was brought up with his Father, who was the founder of the Surveyors' Club, still in existence to the present day, and who, after having realised a handsome fortune, retired from practice many years before his death. The business of an Architect and Surveyor, carried on by Mr. Robert Cantwell, although extensive, was for the most part, of so private a nature as to afford but little material for a memoir of his professional life. He did not hold any public appointments, nor did he execute any important works. His practical knowledge, however, was great, and his integrity was so well known, that he was largely employed in the settlement, by arbitration, of disputed claims. He was, at one period, much engaged upon parochial assessments, and was one of the pioneers of modern views upon the subject. In the course of his practice, he became acquainted with many of the leading Engineers of his day, and ultimately, he joined the Institution as an Associate in 1841. He died in 1859, aged sixty-six years, at his residence in Wimpole Street, London, much respected both by his professional brethren, and by his private friends.

MR. GEORGE GARDNER DONALDSON was born on the 22nd of May, 1801, at Nemphar, near Lanark, where he

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xii., page 244.*

received a sound English and mathematical education. In early life he devoted himself, for some years, with great success to the cultivation of his Father's farm, an occupation very suitable to his taste and talents. He left Scotland in 1835, for Dartmouth, Devon, where he had been appointed land steward to Colonel Seale. He was, however, disappointed in his expectations, and removed, after a short time, to Lancaster, to take charge of some large estates at Wyersdale, belonging to Mr. Garnett, M.P. Whilst there, he published a pamphlet on land drainage, which had a large circulation in the neighbourhood. He afterwards came to London, and was intrusted by the London and North Western Railway Company, with the charge of their landed property between London and Birmingham. He was next employed, during several years, in assisting the late Mr. James Smith, of Deanston, in valuations and land drainage, and in other matters connected with practical engineering. So high an opinion did Mr. Smith entertain of his skill, that he intrusted him with the entire management of the drainage of Sir Robert Peel's estates at Tamworth, and also of those at Castle Ashby, the seat of the Marquis of Northampton. He afterwards became one of the Surveyors under the Metropolitan Commissioners of Sewers, in which capacity the execution of important and difficult works devolved upon him. At the expiration of the Commission, he became Surveyor to the British Land Company, in whose service he died of diphtheria, on the 20th of November, 1859, at the age of fifty-eight years, within a week after his return from surveying an estate in a marsh near the Forest of Dean. His remains were deposited in the cemetery at Norwood, and although they were followed to the grave by few, they were sincere mourners. He has left a widow, by whom his loss is bitterly deplored.

Mr. Donaldson was a man of strict integrity and prompt judgment; and his urbanity and courtesy of manner caused him to be loved by his private friends, and respected by all those with whom he was associated in public life. Many of those who worked with him in a subordinate position, testify to his great kindness of heart, to his conscientiousness in upholding them from injustice, and to his taking every opportunity of promoting the interests of the deserving.

He was elected an Associate of the Institution, in 1856, and was a frequent attendant at the Meetings, occasionally offering remarks when the subject of the discussions in any way related to agriculture, or drainage. He also presented, in 1851, an interesting Paper,¹ descriptive of works at Richmond, designed by him, and of which he superintended the execution.

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xi., p. 407.

MR. ROBERT BARLOW GARDINER, of the Island of Jamaica, began professional life as a pupil of Mr. Tress, the Architect and Surveyor, after which he practised on his own account, for six years, in the Metropolis. He then took charge, under Mr. P. W. Barlow, (M. Inst. C.E.,) of the station buildings and goods warehouses on the South Eastern Railway, for four years; and during the next two years and a half, for Messrs. Jackson, Brassey, and Henfrey, of the building works on the Turin and Susa Railway. He afterwards became, for a short time, a manager for the contractor, on the Pernambuco Line. He was also employed, under Mr. Fowler, (M. Inst. C.E.,) on the surveys of the Great Northern Railway of Portugal. He recently left England for Jamaica, where he was appointed Architect and Engineer for the County of Middlesex, and Commissioner of Roads and Bridges in that island. He died at Spanish Town, on the 14th of June, 1859, at the age of forty-one years, having been an Associate of the Institution only six months.

MR. EDWARD HIGHTON was born on the 13th of August, 1817, at Leicester, at which town he received a classical and mathematical education, first at the grammar school, and afterwards from a private tutor, the Reverend John Foster, of St. Mary's. He then became the pupil of Mr. Stephen Robinson, (M. Inst. C.E.,) of Durham, the Engineer to the Hartlepool Dock and Railway Company. After completing his professional education, and on the contractors failing to perform the excavations required, he was intrusted with the management of the works, and as Assistant Engineer, he superintended, during upwards of three years, the construction of the docks on behalf of the Company. In 1845, he was appointed Resident Engineer of the Taff Vale Dock and Railway; and in 1846, he became Telegraphic Engineer to the London and North Western Railway Company, having, in conjunction with his Brother, devoted himself to the especial study of electric telegraphy, and contributing the whole of the mechanical details and many of the principles of the several patents taken out by them. He read several Papers before the Society of Arts,¹ and he took part in the discussions upon telegraphic subjects at the Meetings of the Institution of Civil Engineers, which he had joined as an Associate, in 1847. In 1849, he received the large gold medal of the Society of Arts, for his inventions in electric telegraphy, for which he also, subsequently, received another medal at the Great Exhibition of 1851. Several of his inventions are still in use by

¹ One of these, 'On Atmospheric Electricity, was published in the "Transactions of the Society of Arts." Supplemental Volume. 4to. London, 1852. Pages 85-112

the British and Irish Magnetic Telegraph Company, who are the owners of the patents.

He was, latterly, compelled to retire from the active duties of his profession, on account of his declining health, which had been much injured by his professional labours and anxieties. He died on the 13th of November, 1859, at the age of forty-two years, greatly beloved by his relatives, to many of whom he had almost acted the part of a father, and towards whom he had always shown the most kind and generous disposition.

He was the author of some poetry of considerable merit, which, however, was only printed for private distribution. He contributed the work on the electric telegraph, published in Weale's Series.¹

MR. JOHN HOULDSWORTH, of Cranston Hill, was born at Whitehall, Glasgow, on the 12th of April, 1807. His Father, the late Henry Houldsworth, of Coltness, Lanarkshire, removed with his Brother-in-law, Mr. William Hussey, upwards of sixty years ago, from Lancashire to Glasgow, where he introduced many improvements in the spinning of cotton, and gave a fresh impetus to what was then a small, but is now a great branch of manufacture in the commercial metropolis of Scotland.

The subject of this memoir received the best education which the institutions of his native city afforded; and when about eighteen years of age, he was sent abroad. He resided in Geneva for upwards of two years, and his being thus early thrown among strangers and new objects, had great effect in developing a liberal and highly scientific mind. On his return to Glasgow, he undertook the partial management of his father's mechanical business, and his natural taste for that profession soon led him to take the foremost rank among the skilled men of the time. He was a very intimate friend and associate of the late Mr. James Smith, of Deanston, with whom he was connected in bringing out some valuable and important improvements in the spinning of cotton. It should also be mentioned, that some years ago, Sir Peter Fairbairn was connected with him in business. About twenty-five years ago, Mr. Houldsworth gave his earnest attention to the development of some of the extensive fields of iron ore in the west of Scotland, and with his Brothers, and some friends of his family, he established the Coltness and Dalmellington Ironworks, situated in Lanarkshire and Ayrshire, in which counties the proprietors have now fourteen blast furnaces, capable of producing about 120,000 tons of pig iron annually. He was, in addition, the senior partner of various establishments for machine making, iron founding, cotton spinning and weaving; all of which were in

¹ Vide "The Electric Telegraph; its History and Progress." By Edward Highton. 8vo. London, 1852; p. 179.

a flourishing condition, and gave employment to great numbers of people. He was likewise connected with several large railway undertakings, and with shipping; his services as a Director having been found very valuable, in consequence of his great experience in business, added to his scientific attainments and general intelligence. He never failed to lend a helping hand to establish any great national, or local enterprise, or to give advice as well as pecuniary assistance, if necessary, to individual genius. His practical and scientific information rendered his advice and judgment of the greatest importance, and his evidence before Committees of the House of Commons, and in legal courts, was of the highest value; in no case was this more remarkable, than during the celebrated 'Hot Blast Trial.'

Only four months before his death, he returned from an excursion to Norway, whither he had gone in his yacht, with a few friends. It is remarkable, that from that time, he, like the late Mr. Robert Stephenson, who made the same voyage about the same period, and under the same circumstances, never enjoyed his wonted health. The weather being exceedingly boisterous, was, probably, instrumental in aggravating, in both cases, diseases, which resulted in depriving society of two valuable members. After a short illness, he died at Glasgow, from a severe attack of liver complaint, on the 18th of October, 1859, in the fifty-third year of his age; and no citizen in a public, or private capacity could be more regretted, not only by the large circle of relatives and intimate friends who enjoyed his munificent hospitality, but by the general public, who fully appreciated the benevolence of his character and the exemplary utility of his life.

He was the last Provost of the Burgh of Anderston, before it was incorporated with the municipality of Glasgow, and at his decease, he was the senior magistrate of the latter city. He had been connected with the Institution of Civil Engineers fifteen years, having joined it as an Associate, in 1844.

MR. EDWARD HUGHES was born in Ireland, in 1819; and after receiving the rudiments of education at the Kildare Place Model School, Dublin, he became, in 1836, through the recommendation of Mr. Irvine, the master of the Kildare School, the junior teacher of writing and arithmetic in the Clergy Sons' School at Edgworthstown. He was, subsequently, through the same influence, appointed, in 1839, to Aubyn's Pauper Model School, at Norwood, then under the superintendence of the Committee of Council on Education. In 1841, Mr. Hughes was named second master of the Lower School of Greenwich Hospital; and in 1844, he succeeded to the office of Head Master of the Royal Naval School, on the retirement of his friend, Mr. Irvine, to

whose care he had, from his earliest boyhood, owed much of his success. While at Greenwich, Mr. Hughes edited and compiled several elementary educational books, principally on geography and arithmetic. Expenses attending the publication of some of his later works, exhausted his means, and greatly harassed and distressed him. His health failed; and after a lingering illness, he died at Greenwich Hospital, on the 30th of July, 1859, in the fortieth year of his age, leaving a very large family in embarrassed circumstances. His mathematical and mechanical attainments led to his election, in 1848, as an Associate of the Institution.

MR. GEORGE MILLS was born in 1796, in London, where he served his apprenticeship to an ironmonger, smith, and stovemaker, with whom he afterwards remained some time as a workman. About the year 1821, he became foreman at a similar establishment; and, in 1827, he undertook the management of a business in Bond Street. He had always a great desire to learn engineering, and between the last two periods, he attended evening classes, in order to acquire a knowledge of mensuration and of mechanical drawing. After a diligent study of many of the engineering works then in progress, he, in 1830, commenced business on his own account, in Warwick Street, as a Mechanical Engineer. Shortly afterwards, he was introduced to Mr. Trevithick, the well-known Engineer, with whom, eventually, he entered into a partnership, which was, however, soon dissolved, in consequence of over-speculation, and of Mr. Trevithick not obtaining from abroad, the remittances which he had expected. He next became the partner of Mr. Dyett, with whom he established an iron foundry at Birmingham, commencing by the construction of engines for the 'Shakspeare,' a vessel which was afterwards sent out to Rio de Janeiro. At this period, Messrs. Mills and Dyett were allowed, for some time, the use of a Government vessel, the 'Falcon,' in which to try their engines. The business not proving successful, the partnership was dissolved, and, in 1839, Mr. Mills returned to London, where he soon afterwards obtained the appointments of Superintendent Engineer of the Herne Bay Steam Packet Company, and of the Thames Steam Towing Company. In 1842, he was appointed Superintendent Engineer of the West India Royal Mail Packet Company, and he removed to Southampton, where he formed an establishment for the repair of the company's fleet. During his connection with this company he displayed considerable energy and ability, and untiring zeal and perseverance in carrying out the service, particularly in the punctual performance of the mail contracts, under

the many disasters which happened to the company, by the loss of so many of their ships. He took great interest in the welfare of marine engineers, and endeavoured, in every way, to advance the interests of those serving afloat. He strongly advocated the introduction of superheated steam; and after the trials of Mr. Wethered's combined steam in the 'Black Eagle' and the 'Dee,' he associated himself with that gentleman, and caused his system to be applied to the company's steamer 'Avon.' That he did so successfully, is proved by the fact, that no better results, as to economy, have been arrived at, from the subsequent use of superheated steam alone, or of combined steam, than those shown by the performances of the 'Avon.' He remained in the service of the company until June, 1857, when he resigned upon a superannuation allowance of £500 per annum, which he did not live long to enjoy. His health had been for some time declining, and he died at Southampton, after a painful illness, on the 17th of January, 1859, in the sixty-third year of his age. After his retirement, he became Chairman of the Risca Iron and Coal Company, in which undertaking he unfortunately invested nearly the whole of his property; and the ample means which, he imagined, he had left to his widow, were almost entirely sacrificed by the failure of the company, one year after his death. He was intimately acquainted with most of the manufacturing engineers and shipbuilders of England, by whom he was greatly esteemed for his strict integrity and his urbanity of manner. He joined the Institution as an Associate, in 1843.

PREMIUMS AWARDED.

SESSION 1858-59.

THE COUNCIL of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, to Michael Scott, M. Inst. C.E., for his Paper, "Description of a Breakwater at the Port of Blyth; and of Improvements in Breakwaters, applicable to Harbours of Refuge."
2. A Telford Medal, to Robert Mallet, M. Inst. C.E., for his Paper, "On the Coefficients, T_e and T_r , of Elasticity and of Rupture in Wrought Iron, in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals."
3. A Telford Medal, to Henry Bessemer, for his Paper, "On the Manufacture of Malleable Iron and Steel."
4. A Telford Medal, and the Manby Premium, in Books, to William Joseph Kingsbury, Assoc. Inst. C.E., for his Paper, "Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction."
5. A Watt Medal, to James Wardrop Jameson, Assoc. Inst. C.E., for his Paper, "On the Performances of the Screw Steam-Ship 'Sahel,' fitted with Du Trembley's Combined-Vapour Engine, and of the sister ship 'Oasis,' fitted with Steam Engines worked expansively, and provided with partial Surface Condensation."
6. A Council Premium of Books to Thomas Sebastian Isaac, for his Paper, "On the use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America."
7. A Council Premium of Books to Matthew Bullock Jackson, M. Inst. C.E., for his Paper, "On the Water Supply to the City of Melbourne, South Australia; comprising a brief description of the Melbourne Gravitation Waterworks."

SUBJECTS FOR PREMIUMS.

SESSION 1859-60.

THE COUNCIL invite communications on the following, as well as other subjects, for Premiums :—

1. A Review of the Plans which have been proposed, at different times, for the Embankment of the River Thames.
2. On the Principles upon which the Works for the Improvement of River Navigation should be conducted, and the Effects of the works upon the Drainage and Irrigation of the District ; including accounts of the Systems of Moveable Dams, (' Barrages Mobiles,') in Rivers on the Continent.
3. On the Effect of Engineering Works in causing injurious Scour, Flooding, or Silting-up, in Tidal Estuaries, or Rivers.
4. On the Main Natural and Artificial Drains of the Country, the extent to which they have been affected by the increasing amount of Agricultural Land Drainage, and the general influence upon the Main River Outfalls.
5. On Reclaiming Land from Seas and Estuaries.
6. On the Results of the Employment of Steam Tugs on Canals, and of other measures for the Improvement of Canals, as a means of conveyance for heavy traffic.
7. On the Methods of constructing Foundations, for large Structures, in deep water.
8. Description of Cast, or Wrought-Iron Cranes, Scaffolding, and Machinery, employed in large works, in Stone Quarries, Hoists, or Lifts on Quays, in Warehouses, etc., especially where either Steam, or Water is used as a motive power.
9. On the Results of Experiments on the Crushing Weights of different materials, particularly as to the resisting powers of Rubble Masonry, set in different limes and cements.
10. The Selection of Sites for the Construction of Docks on the course of Tidal Streams, with reference to communication with Railways, and with Inland Navigation.
11. The Selection of Sites for, and the Principles of, the Construction of Breakwaters, Harbours of Refuge, Piers, Moles, (whether solid, or on arches), Sea Walls, and Shore Defences ; illustrated by examples of known constructions.

12. The Construction of Lighthouses; their Machinery and Lighting Apparatus; with notices of the methods in use for distinguishing the different Lights.
13. On the Mechanical Methods of Boring and of Sinking large Shafts, of introducing the Tubbing and the impervious lining, and of traversing running sand, and other difficult strata.
14. The Results of Contrivances for facilitating the Driving of Tunnels, or Drifts in Rock.
15. The Results of a series of Observations on the Flow of Water from the Ground, in any large district; with accurately-recorded Rain-Gauge Registries, in the same locality, for a period of not less than twelve months.
16. On the Construction of Catchwater Reservoirs in Mountain Districts, for the Supply of Towns, or for Manufacturing purposes.
17. Accounts of existing Waterworks; showing the Methods of Supply, the Distribution throughout the Streets of Towns, and the general practical results.
18. The Comparative Duty performed by, and Improvements in the Construction of, modern Pumping Engines for raising Water, for the Supply of Towns, or for the Drainage of Mines; noticing in the latter cases, the depth and length of the underground workings, the height of the surface above the sea, the geological formation, the contiguity of streams, &c.
19. The Results of the use of Bucket and Rotary Pumps, for lifting large quantities of water to a limited height; as at the Haarlem Meer, or at Whittlesea Mere: with Descriptions of the Machinery employed, and the application of such machinery to the raising of the Sewage of Large Towns.
20. On the Methods in use in various countries, for Raising Water for the purposes of Irrigation.
21. The Drainage and Sewerage of Large Towns; exemplified by accounts of the systems at present pursued, with regard to the level and position of the outfall, the form, dimensions, and material of the sewers, the prevention of emanations from them, the arrangements for connecting the house drains with the public sewers, and the disposal of the sewage, whether in a liquid form, as irrigation, or in a solid form after deodorisation.
22. On Boiler Inspection as practised in this country and on the Continent, with remarks as to the comparative merits of the two systems.
23. On the most Recent Systems of Smoke Prevention, in Stationary, Marine, and Locomotive Boilers; and a discussion of the existing difficulties.

24. On the Causes of the alleged Failure in Economising Fuel, in working Steam expansively, and the probable conditions for insuring success.
25. On the Results of the use of Superheated Steam.
26. On Substitutes for Steam, and the Causes of their Failure.
27. On the Results of the use of Tubular Boilers, and of Steam at an increased pressure, for Marine and other Engines, noticing, particularly, the difference in Weight and in Speed, in proportion to the Horse Power and the Tonnage.
28. On the Best Methods of Reducing the Temperature of the Engine and Boiler Room of Steam Vessels, and of preventing the danger arising from the over-heating of the base of the funnel.
29. The Substitution of Machinery for Manual Labour, for Raising, Lowering, and Reefing the Sails, Weighing the Anchor, &c., on board ship.
30. On Steam Vessels of Light Draught for the Shallow Rivers of India, &c.
31. Description of the 'Great Eastern' Steamer, and of the results of the trial voyages.
32. On the Form and Materials for Floating Batteries, ('Vaisseau bélier'), and the points requiring attention in their Construction.
33. On the Ascertained Duration, and other qualities, of the numerous systems of Permanent Way in use in England and in other countries, with their original Cost and expense of Maintenance.
34. Improvements in the Construction of Railway Carriages and Waggons, with a view to the reduction of the gross weight of Passenger Trains; also of Railway Wheels, Axles, Bearings, Axle Boxes, and Breaks, and of Bearing, Traction, and Buffer Springs; treating particularly of their ascertained duration and their relative friction.
35. Descriptions of the various kinds of Machinery in use in the principal Shipping Ports for the Shipment of Coal; noticing particularly, those in which the greatest expedition is combined with the least amount of breakage of the coal; and also accounts of the means of unshipping and measuring, or weighing the coal, on its arrival in port.
36. On the means of Utilising the products of the Distillation of Coal, so as to make Coke commercially as cheap as Coal; with descriptions of the Ovens, and of the best processes used in Great Britain and on the Continent, in the Manufacture of Coke.
37. The Precautions adopted for guarding against Accidents by Fire-damp and After-damp in Mines.

38. The most Effective Arrangement and Form of Centrifugal and Reciprocating Blowing Apparatus.
39. The Chemical Analysis, and the Application to economic purposes, of the Gases generated in Iron Blast-Furnaces.
40. Description of Modifications of the present systems of Smelting Iron Ores, of Improvements in the Conversion of Cast Iron into the malleable state, and of the Manufacture of Iron generally, comprising the distribution and management of Ironworks.
41. An Investigation of the Causes of Red and of Cold Shortness in Malleable Iron, and other Chemical Characteristics which affect the Physical Properties of Cast, or of Wrought Iron.
42. Improvements in the Manufacture of Iron for Rails and Wheel Tyres, having special reference to the increased capability of resisting lamination and abrasion; and accounts of the Machinery required for rolling heavy Rails, Shafts, and Bars of Iron of large sectional area.
43. On the use of Steel Bars and Plates in Enginework and Machinery, for Boilers and for Ship-Building.
44. The Process of Manufacture, and mode of treatment, of Aluminium.
45. On the Importance of Balancing the Rotating, or Alternating parts of Machinery.
46. On the Forms and Dimensions of Journals of Machine Shafts, Axles, &c.; with the best Composition for the linings of Bearings, and the most approved methods of Lubricating.
47. On the Mechanism of Astronomical Instruments, with suggestions for its improvement.
48. On Machinery adapted for the better Separation of the various substances found in combination with Metallic Productions.
49. On Machinery for Crushing Ores.
50. On the Substitution of Machinery for Manual Labour in Mining Operations; and on Hydraulic Machinery in Mines.
51. On the Improvements which may be effected in the Buildings, Machinery, and Apparatus for producing Sugar from the Cane in the Plantations and Sugarworks of the British Colonies, and the Comparison with Beet Root, with regard to quantity, quality, and economy of manufacture.
52. Accounts of the Improved Systems of Storing, Cleansing, and Drying Corn, and of producing Flour.
53. Description of the Machinery adapted for the Preparation of Indian Cotton.
54. Improvements in Flax Machinery, and in the processes for preparing the Flax for manipulation.

55. The uses of Vulcanised, or Mineralised Caoutchouc; the means of increasing its durability, and the modes of causing its adhesion to Metal.
56. On the Application of Photography to Engineering.
57. The Construction of Clocks to be moved simultaneously by the agency of Galvanic Electricity.
58. On the Form and Construction of Submarine Telegraph Cables, most suitable for certain specified depths; and an investigation into the nature of any new substances adapted for the insulating medium.
59. Memoirs and Accounts of the Works and Inventions of any of the following Engineers:—Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick, William Murdoch (of Soho), Alexander Nimmo, and John Rennie. Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The communications must be forwarded, on or before the 30th of January, 1860, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where copies of this Paper, and any further information may be obtained.

CHARLES MANBY, *Secretary*.

25, Great George Street, Westminster, S.W.,
October, 1859.

NOTICE.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers:

EXTRACTS FROM THE MINUTES OF COUNCIL, FEB. 23rd, 1835.

“The principal subjects for which Premiums will be given are :—

- “1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed; and which shall contain authentic details of the progress of the work. (Smeaton’s Account of the Edystone Lighthouse may be taken as an example.)
- “2ndly. Models, or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.
- “3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering, or Surveying.”

EXCERPT BYE LAWS, SECTION XIV., CLAUSE 3.

“Every Paper, Map, Plan, Drawing, or Model presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary; and the Council may publish the same, in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such Paper, beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary, of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council.”

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and a-half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject, and should be to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication; or enlarged Diagrams may be sent for the illustration of any particular portions.

Reduced Drawings for the illustrative Plates and Woodcuts will be required, as soon as the Papers are accepted.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

[ORIGINAL

ORIGINAL COMMUNICATIONS, DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN JUNE 30, 1858, AND JUNE 29, 1859.

ORIGINAL COMMUNICATIONS.

AUTHORS.

- Amos, C. E. No. 1,002.—On the Government Waterworks in Trafalgar Square.
- Bessemer, H. No. 1,012.—On the Manufacture of Malleable Iron and Steel. With a series of Diagrams.
- Blake, J. No. 996.—On the Construction of Catchwater Reservoirs in Mountain Districts, for the Supply of Towns, and for Manufacturing purposes.
- Brussaut, P. A. de. No. 1,001.—On a New System of Axle Boxes, not requiring Lubrication, and without Liability to Heating. With a series of Diagrams.
- Chadwick, D. No. 1,008.—On Improvements in High-Pressure Water Meters.
- Grantham, R. B. No. 1,005.—On Arterial Drainage and Outfalls. With a series of Diagrams.
- Harrison, T. E. No. 1,011.—On the Tyne Docks at South Shields; and the mode adopted for Shipping Coals. With a series of Drawings and Diagrams.
- Isaac, T. S. No. 990.—On the use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America. With a Diagram, Plan, and Section of the Virginia Central Railroad.
- James, Jabez. No. 1,000.—On the Process of Raising, and Hanging the Bells in the Clock Tower at the New Palace, Westminster. With a series of Diagrams.
- Jameson, J. W. No. 993.—On the Performances of the Screw Steam-Ship 'Sahel,' fitted with Du Trembley's Combined-Vapour Engine, and of the sister ship 'Oasis,' fitted with Steam Engines worked expansively, and provided with partial Surface Condensation. With a series of Drawings and Diagrams.

AUTHORS.

- Kingsbury, W. J. No. 1,004.—Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction. With a series of Diagrams.
- Mallet, R. No. 992.—On the Coefficients, T_e and T_r , of Elasticity and of Rupture in Wrought Iron; in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals. With a series of Diagrams.
- M'Master, B. No. 994.—On the Permanent Way of the Madras Railway.
- Scott, M. No. 991.—Description of a Breakwater at the Port of Blyth; and of Improvements in Breakwaters, applicable to Harbours of Refuge. With a series of Diagrams.
- Sim, R. No. 999.—On the Results of the Employment of Steam Tugs on Canals, and of other measures for the Improvement of Canals as a means of transport for heavy traffic.
- Stileman, F. C. No. 1,009.—On the Construction and Enlargement of the Lindal Tunnel, on the Furness Railway. With a series of Diagrams.
- Stoney, B. B. No. 997.—On the Construction of Floating Buoys and Beacons. With a series of Diagrams.
- Swann, M. No. 998.—On Raising Submerged Vessels.
- Tait, G. H. No. 1,007.—Description of a Swing Bridge at Port Adelaide, South Australia.
- Wethered, The Honourable J. No. 1,010.—On Combined Steam.

CATALOGUE OF PRESENTS.

BOOKS.

- | DONORS. | TITLE OF WORK. |
|------------------|---|
| Adams, W. B. | Road Progress; or, Amalgamation of Railways and Highways for Agricultural improvement, and Steam Farming, in Great Britain and the Colonies. Also Practical Economy in fixed plant and rolling stock for passenger and goods trains. By W. Bridges Adams. Tract. 8vo. Plates. London, 1850. |
| Airy, G. B. | Results of the Astronomical Observations made at the Royal Observatory, Greenwich. 1857. 4to.
[Extracted from the Greenwich Observations, 1857.] |
| ———— | Results of the Magnetical and Meteorological Observations made at the Royal Observatory, Greenwich. 1857. 4to.
[Extracted from the Greenwich Observations, 1857.] |
| ———— | On the Mechanical Conditions of the Deposit of a Submarine Cable. By G. B. Airy. Tract. 8vo. Greenwich, 1858.
[From the Philosophical Magazine for July, 1858.] |
| Alexander, J. H. | An Inquiry into the English System of Weights and Measures. By J. H. Alexander. Tract. 8vo. Oxford, 1857. |
| ———— | International Coinage for Great Britain and the United States. A Note by J. H. Alexander. Tract. 8vo. Oxford, 1857. |
| Allan, T. | Allan's Systems of Inland and Submarine Telegraphy. Tract. 8vo. No place, or date. |
| Anonymous. | Chambers and Champion's Patent Railway Breaks. Tract. Folios. Plate. London, no date. |
| ———— | The Handel Commemoration Festival at the Crystal Palace in 1859. Programme of Arrangements. Tract. 8vo. Plan. London, 1859. |
| ———— | London and North Western Railway. Time-tables for Enginemen and Guards. Southern Division and Branches. Tract. 8vo. London, 1857. |
| ———— | Cataloghi del Museo Campana. 4to. No place, or date. |
| ———— | Plans for a Submarine Communication between England and France. Tract. 8vo. Plates. Dublin, 1858. |

- | DONORS. | TITLE OF WORK. |
|---|--|
| Anonymous. | "Wet and Dry;" or, the Docks of London : being an Inquiry concerning the (proposed) Northfleet Docks. By Capel Court. Tract. 8vo. London, 1859. |
| Architekten und-Ingenieur-Vereins für das Königreich. | Hannover. Zeitschrift. Band IV. Heft 1—4. Folio. Plates. Hannover, 1858. |
| Architectural Publication Society. | The Dictionary of Architecture. Part VIII. Folio. London, 1858. |
| ————— | Illustrations to the Dictionary of Architecture. Parts I. and II. of Vol. for 1857-58. Folio. London., 1858. |
| Armstrong, R. | High Speed Steam Navigation, and Steamship Perfection. By R. Armstrong. Tract. 8vo. London, 1859. |
| Art Union of London. | Report of the Council for the year 1858, with List of Members. 8vo. London, 1858. |
| Bache, Prof., A. D. | Report of the Superintendent of the Coast Survey, showing the progress of the Survey during the year 1856. 4to. Plates. Washington, 1856. |
| Bateman, J. F. | Glasgow Corporation Waterworks. City Piping. Report on the re-arrangement and extension of the Water Pipes in the City. By J. F. Bateman. Tract. 8vo. Plates. Glasgow, 1858. |
| ————— | Report on the means of Deodorising the Sewage of Glasgow. By Thomas Anderson, M.D., and J. F. Bateman. Tract. 8vo. Glasgow, 1858. |
| Baranowski, J. | Patent Automaton Railway Signals, for exhibiting the Danger Signal after the passage of each Train during a given time, (say for five minutes,) or until the Train has arrived at a given distance beyond, (say one mile). 4to. Plate. London, 1858. |
| Beardmore, S. | The Globe Telegraph : an Essay on the use of the Earth for the transmission of Electric Signals. By S. Beardmore. Tract. 8vo. Cuts. London. No date. |
| Belly, F. | Carte d'étude pour le tracé et le profil du Canal de Nicaragua, par M. Thomé de Gamond ; précédée de documents publiés sur cette question. Par F. Belly. 4to. Plates. Paris, 1858. |
| Bidder, G. P. | River Nene. Report of Robert Stephenson, Esq., M.P.; G. P. Bidder, Esq.; and George R. Stephenson, Esq., on the Improvement of the River Nene: with a Preparatory Letter from Mr. Robert Stephenson. 4to. Plate. London, 1858. |

- | DONORS. | TITLE OF WORK. |
|----------------------------------|---|
| Board of Admiralty. | Report on the Teneriffe Astronomical Experiment of 1856. By C. Piazz Smyth. 4to. Plates and photographs. London, 1858. |
| | [From the Philosophical Transactions, 1858.] |
| ————— | Tide Tables for the English and Irish Ports, for the year 1858 ; also the times and heights of High-water at Full and Change for the principal places on the Globe. Computed by J. Burdwood, R.N. 8vo. London, 1857. |
| Boston Library. | Proceedings at the dedication of the Building for the Public Library of the City of Boston. 8vo. Plates. Boston, 1858. |
| Bryson, J. M. | Remarks upon the Drainage of London : shewing the amount of expenditure requisite to carry out Main Culverts, one on each side of the River Thames, in comparison with the amount needful to erect Works upon the Banks of the said River for Deodorising the Sewage, reserving the precipitate for use. By J. M. Bryson. Tract. 8vo. London, 1858. |
| Burn, C. | On the Construction of Breakwaters, for Harbours similarly situated as the one at Dover. By C. Burn. Tract. 8vo. Plates. London, 1859. |
| Calver, E. K. | On the Construction and Principle of a Wave Screen, designed for the Formation of Harbours of Refuge. By E. K. Calver, R.N. Tract. 8vo. Cuts. London, 1858. |
| Calvert, F. C. | On the relative Power of Metals and Alloys to conduct Heat. Part I. By F. C. Calvert and R. Johnson. 4to. Plate. London, 1858. |
| | [From the Philosophical Transactions, Part II. for 1858.] |
| Cambridge Philosophical Society. | Transactions. Vol. X. Part I. 4to. Cuts. Cambridge, 1858. |
| Campbell, D. F. | Enquête sur les moyens d'assurer la régularité et la sûreté de l'exploitation sur les Chemins de Fer. 4to. Paris, 1858. |
| Canadian Institute. | The Canadian Journal of Industry, Science, and Art. New Series. Vol. III., Nos. 15-18 ; and Vol. IV., Nos. 19-21. 8vo. Cuts. Toronto, 1858-9. |
| Cator, G. A. | The National Flax Company, Limited. Explanatory details, opinions of the London press, and commercial arguments in favour of the system proposed to be adopted, for the encouragement of the cultivation and preparation of Flax, under the plans and patented processes of G. A. Cator. Tract. 8vo. London, 1859. |

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| Chadwick, D. | Borough of Salford. Report on the proposed establishment of a Police Superannuation Fund. By D. Chadwick. Tract. 8vo. Salford, 1858. |
| Chesbrough, E. S. | Chicago Sewerage. Report of the results of Examinations made in relation to Sewerage in several European Cities, in the winter of 1856-57. By E. S. Chesbrough. Tract. 8vo. Plates. Chicago, 1858. |
| Colburn, Z., and Holley, A. L. | The Permanent Way and Coal-Burning Locomotive Boilers of European Railways ; with a comparison of the Working Economy of European and American Lines, and the principles upon which improvement must proceed. By Z. Colburn and A. L. Holley. Folio. Plates. New York, 1858. |
| Commissioners of Patents, through Bennet Woodcroft. | Catalogue of the Library of the Great Seal Patent Office. Titles. 8vo. London, 1857. |
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January 10, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

THE following Candidates were balloted for and duly elected :—
ROBERT PEARSON BRERETON, as a Member ; and JOHN TOPHAM,
as an Associate.

Mr. BIDDER addressed the Meeting in the following terms, on taking the Chair, for the first time, after his Election as President :—

GENTLEMEN,

I BEG to thank you for the distinguished position in which your suffrages have placed me. Looking back upon the eminent men who have successively occupied this chair, I cannot but feel anxious, that the high character of our profession, and the efficiency of this Institution, should not suffer any abatement, during the term of my tenure of office, and considering the powers, and high professional position, of my predecessors, this anxiety cannot but be increased ; indeed, it is only in one respect that I can hope to place myself on an equality with those eminent men,—by zeal for your progress, and the ardent desire, I entertain, of conducting our discussions with impartiality and courtesy towards all who may address you. On this I must act, and I am sure you will give me your cordial co-operation and assistance.

Before entering on the main objects of my Address, I cannot but feel, that it would be unbecoming in me not to allude to the recent loss of two of our most eminent brethren, Mr. Brunel, and Mr. Robert Stephenson ; although I am well aware I can add but little to what has been already written and spoken here and elsewhere, and in terms more eloquent than I can command.

With regard to Mr. Brunel, in common with you all, I ever admired the wonderful resources of his mind, his extreme ingenuity, his courage in facing difficulties of every description, and his great tact and resources in overcoming them, so long as he retained his physical power.

It has frequently been my lot to be placed in professional conflict with that gentleman, and I need hardly say that, in common

with every other member of the profession, I found him a very dangerous and most able adversary; but at the same time he was equally high-minded, and above all mean and pettifogging practices for accomplishing his objects. He was one of those men in whose minds private friendship was never interrupted by professional strife; and there never was a time, when if I needed it, I should have hesitated to recur to him for advice, assistance, or sympathy; whilst in private life, I can, from personal knowledge, attest his sympathy for distress, and his unhesitating generosity in pecuniary sacrifices to abate it. In his professional career, it appears to me, that full justice has not been done to the memory of Mr. Brunel;—I allude more especially to his exertions in accelerating the progress of Oceanic Steam Navigation. The ‘Great Western’ was a brilliant example of the correctness of his conceptions on this point. It must be conceded, that he was the first, clearly and practically, to conceive the advantages to be derived from augmenting the size of steamers, with a view to increased speed and to the extension of their voyages. Looking back, therefore, to the period of the construction of the ‘Great Western’ steamer, she must be admitted to have been an absolutely successful experiment, mechanically and commercially, and the names of Brunel, as the Engineer, of Patterson, as the Shipwright, and of Maudslay and Field, as the Constructors of the engines, can never be omitted from the records of Oceanic Steam Navigation. The next step was the ‘Great Britain;’ and so far as regards the construction of the hull, the efficiency of that vessel, even to the present day, bears ample testimony to the skill of the design; whilst her having endured a whole winter’s buffeting of the waves, in Dundrum Bay, testifies to the strength of her construction, and to the powers of resistance of which iron vessels are susceptible. It must not be forgotten, that it was to this vessel, that the screw propeller was first applied on the large scale; and it should be stated, that by Mr. Brunel’s exertions in experimenting upon the ‘Archimedes,’ the introduction of that mode of propulsion was greatly accelerated. The only part of this experiment which was not satisfactory, was the performance of the engines; and this may be mainly attributed to the fact, that instead of confiding their construction to men whose lives had been directed to perfecting that particular branch of engineering, Mr. Brunel took upon himself the responsibility of designing the machines. It may not be unbecoming here to remark, that genius, however great, cannot alone supply the results which can only be attained by a life-long experience in practical details. It is deeply to be lamented, that the life of our friend was not spared, to consummate his conception of the ‘Great Eastern’ steamship. This great experiment has been already partially discussed in this Institution, and there

does not appear to be any reason why she should not be mechanically successful; but all who have had extended experience in our profession are aware, that in all experiments, there will arise certain phenomena, which no human foresight can anticipate. Now seeing that the 'Great Eastern' is six, or seven times the bulk of any existing vessel, and seeing that this, of necessity, involved the application of two sets of engines, two kinds of motive power,—the paddles and the screw propeller,—bearing also in mind, that she was intended to encounter head seas, at a speed never hitherto contemplated, and knowing also the enormous forces which ordinary vessels have to withstand, in heading the waves, however slowly, in heavy weather, it might reasonably be expected, that in many respects her first trial would be somewhat disappointing. I sincerely hope, and I am sure that I carry your sympathies with me, in trusting, that there still remain in this country, sufficient skill, enterprise, and co-operative action, to bring this great experiment to a real test, and thus to complete the most fitting memorial to the fame of our deceased friend.

In alluding to Mr. Robert Stephenson, I cannot but feel, that I am scarcely in a position to take an impartial review of his career and of his character. For upwards of a quarter of a century I have enjoyed his most intimate, and I may add, his most affectionate friendship. Even this term is, perhaps, hardly strong enough, for throughout the whole of this period, his conduct towards me was that of an elder and affectionate brother; he has encouraged me in all he thought right, and has not failed to criticise all he deemed wrong, and had the necessity arisen, he would have applied his whole fortune, to his last sixpence, for my benefit. I have said, that our friendship has endured for upwards of twenty-five years, but our acquaintance extends over a much longer period, as we were in the same class and on the same benches, at the University of Edinburgh. Probably no member of our profession, either past, or present, ever availed himself more earnestly of varied opportunities of acquiring professional accomplishment, than did Mr. Stephenson; his early youth, passed with his father at Killingworth Colliery, his early manhood at Edinburgh, his engagements in the mines of South America, and on his return to England, his occupations in perfecting the Locomotive, and in managing the works at Newcastle, his connection with the early Railways, and added to all these, his pursuit of the studies of chemistry and geology, which continued throughout his life, and even to within a few days of his decease, constituted a substratum of scientific and practical knowledge which few have obtained, and fewer still have the ability properly to apply.

It was one of the distinguishing characteristics of his professional

career, that however bold he was in the conception of an idea, as for instance, the Britannia Tubular Bridge, yet no one, with whom I ever came into contact, watched with more anxiety the completion of these enterprises, than did Mr. Stephenson. His mind was ever occupied in anticipating how, and in what shape, failures might arise, and no doubt, it might appear to many, that the precautions he took were often superfluous. But the experienced Engineer knows well, that if he relies upon the chances turning up in his favour, without due precautions being taken, the enterprise is sure to be attended with some disasters; whilst the mere act of taking due precautions seems to have the effect of averting the consequences they are intended to guard against; in short, the Engineer is never justified in trusting to the favours of fortune, whilst he has the means of guarding against her caprices. Another distinguishing feature in our late friend's career was his treatment of all those who were associated with him in his undertakings. His habit, with those who enjoyed his confidence, was to leave with them the utmost amount of responsibility, which he could possibly lay upon them; and never to interfere, except in cases of emergency, or where his moral influence was required, to prevent undue interference from superior authorities. The consequence has been, that over the whole face of the globe, there are men of his school, who have risen to competency and to eminence, and who live to extol and respect the memory of their revered chief.

Of his successful professional career, his unbounded generosity, the liberality of his views, and the dignity and urbanity with which he filled this chair, you are all witnesses, and it will be long before the place is adequately filled, which his decease has rendered vacant.

In approaching the subjects which ought to be considered the main object of this Address, I would venture to remind you of the custom of our Society, which is, that although we publish all that is said, during the discussions and in the Addresses of our Presidents, yet it is always with the distinct understanding, that the remarks are not intended to represent the collective opinions of the Institution, but only of the individuals who utter them, and that they are not to be entitled to any more weight, than the intrinsic value of the opinions themselves, or that which the position of the speaker may secure for them. I am well aware, that even in my Address, I ought to make every statement without reference to personal convictions; but upon many subjects my opinions are so strong, that I cannot hope to escape developing the bias of my own mind. I trust, therefore, that this will be deemed excusable, bearing in mind the general understanding with regard to the transactions of this Institution.

It will be obvious to you all, how great are the obstacles to giving novelty to each successive Address of your Presidents, and how increasingly difficult it is, to render them interesting and instructive; it is not, therefore, my intention to advert to any of the topics which have been heretofore treated of, on any of those occasions.

The steps in the progress of our profession, measured chronologically, are very unequal, as indeed is the case with all sciences, abstract, or practical. When the mind of man is first released from thralldom and in the early stages of civilisation, it makes rapid and striking advances, until a certain stage has been attained. Indeed, the progress of the human mind, in every branch of knowledge, may be compared to the course of a stream, emanating from a spring in some distant mountain recess; emerging into light, it pursues its course amidst rocks, through woods and over cataracts, affording abundant scope for the poet and the painter, and subsiding at last into the slow, gentle, majestic stream, pursuing its way through the lowlands, in its approach to the ocean. Such is the course of science; and although its latter stages do not present the vivid contrasts which accompany its early course, yet they are not less important, nor less instructive; but the skill which is demanded, to point out their effect and character, is of a much higher order, than is required to indicate the early phenomena. From this task, gentlemen, I shrink, with an innate conviction of my inability to treat the subject as I should desire. The object, therefore, of my Address will be to allude to subjects which have not, hitherto, prominently occupied our attention, or afforded ground for our discussions, with the express intention of inviting your consideration of them, and the design of securing their discussion at our Meetings.

An objection may, perhaps, be raised, that I may be seeking to extend unduly the professional sphere of the Civil Engineer; but I have been long enough in the profession, to see it grow, from a mere craft, or mystery, into a scientific pursuit. This Institution, which may be regarded as representing the objects of the profession, now embraces among its Members, not only those who are engaged in the construction of roads, railways, harbours, &c., but those, also, who are occupied in the construction of engines and machinery, adaptable to every conceivable purpose, in the building of vessels, in the erection of gas and waterworks, in the laying down of electric telegraphs, and in the drainage of towns and rural districts. In short, if I was now called upon to define the object and scope of the profession of the Civil Engineer, I should say, that his particular province is to take up the results discovered by the abstract mathematician, the chemist, and the geologist, and

to apply them practically for the commercial advantage of the world at large; and to diffuse their beneficent influences among all classes of his fellow-creatures.

Among the objects which appear principally to demand our present consideration, are those questions most referable to Hydraulic Engineering. It is in this part of our professional study and practice, I am bound in candour to say, that the least satisfactory progress has been hitherto achieved, and upon these subjects, the discussions in our Society have been the most inconclusive. I believe that it is, in a great degree, owing to the fact of sound hydraulic knowledge being so little prevalent, that so many obstructions have arisen, to the progress of public works. It is impossible, otherwise, to suppose, that the errors, which have been committed in the Health of Towns Commission, would have occurred, or that a Blue Book, outraging all the discoveries of science, would have been published at the expense of Government, had our profession been sufficiently alive to the subject. It is, perhaps, hardly fair to visit some of our public departments with the severity of criticism which has been applied to them, by those to whom they may have been opposed, when it is considered how little unanimity of opinion prevails among ourselves, on some important points connected with this subject; and it must be borne in mind, that the gentlemen in our public departments have nothing to gain, in any way, by sanctioning a scheme, however successful, whilst on the other hand, should injurious consequences result, they might be exposed to grave responsibility.

The points of the utmost importance, upon which to arrive at a clear understanding, are the relative effects of the scour upon our rivers and harbours, arising from the action of tidal, or of land waters. I am free to admit, that I am one of those who attribute the smallest possible effect to the action of land waters, whilst I do attribute the most important effects to the action of tidal scour. This conviction has been forced upon me, by a general view of our rivers and estuaries. Looking, for instance, to the river flowing past our doors, the River Thames, can it be supposed, that the mere dribble of water falling over Teddington Lock, even in seasons of the highest floods, can give any effectual aid to the tidal currents, in preserving the channel from the sea to the Nore, and up to above Gravesend? Looking also to the fact, that when any great change, or improvement has taken place, in any of our rivers, we find them always to result from some new arrangement of the tidal currents, as, for instance, at Lynn, in the Clyde, and in many other cases; on the other hand, where has any marked result attended, either the increase, or the abstraction of the land waters? Upon the solution of this ques-

tion depends the reclamation of large tracts of land, now lying, not only waste and absolutely useless, but, in their present state, exercising a most pernicious influence upon the population of the adjoining districts.

The time has arrived, when the effects of under-draining, now every year more actively pursued, upon the condition of our rivers, should receive most serious consideration. I recently adverted here to some anomalous results arising from under-draining, and showed, that in certain soils and under certain circumstances, the effect of under-draining would be to pass less water to the rivers, than had previously flowed into them. If this view is correct, precautions should be taken to provide for the possible effects of an operation, which is, otherwise, so rapidly augmenting the fertility of our soil.

Another feature in the drainage of towns demands attention ;—the prevailing fashion of subverting the cesspool system and of introducing outfall sewers. One great inducement, hitherto held out, has been the prospect entertained of employing the sewage for the fertilisation of the neighbouring land. Losing sight of the beneficent provisions of Nature, for avoiding pestilence, it was assumed, that the sewage of towns would, necessarily, be of a highly fertilising character, and it is mainly due to the exertions of our Member, Mr. Hawksley, that this delusion has been, to a great extent, dispelled. Recent investigations have shown, that in towns amply supplied with water, the sewage contains very little, if any, fertilising quality ; certainly, none of commercial value. Indeed, a careful consideration of the economy of our rivers might have anticipated the conclusion. Look at the course of the Thames flowing through this great city,—consider the enormous population on its banks, before it reaches the Metropolis,—what would have been its condition, had not running waters possessed that quality of self-purification, which renders the sewage of towns of no practical value ? I trust, then, that this Session will not close, without our having well considered the conditions under which a well-regulated cesspool system can be properly applied ; and under what circumstances towns can be advantageously drained by outfall sewers. Permit me here to express an individual opinion of what appears to me, to be a useful application of the income arising from the bequest of the late Mr. Robert Stephenson. In due course the decision of the Council, upon its application, will be announced ; but in my individual opinion, instead of being divided into a number of small premiums, a considerable portion of it should be devoted, in one premium, at fixed periods, to rewarding Papers upon subjects recommended by the Council, and which require the devotion of considerable time and labour ; and it should

be understood, that although the premium would be given for the best Paper, it should be only awarded, when the Paper possessed the required amount of merit to entitle it to that distinction.

I would beg here to announce my intention of devoting, during this current session, the sum of Forty Pounds, under the above conditions, for the best Paper upon the subject of "the Régime of Rivers;" and I would suggest, as examples, to those who desire to devote their attention to this subject, the changes now taking place in the River Thames,—the condition of the Waveney and the Yare, at Yarmouth,—the harbour of Wells, as an example of the tidal scour alone sufficing to preserve the navigation,—the Ouse, at Lynn, relative to which so many records exist, of the various operations executed there,—and the Tyne and the Clyde,—but, indeed, there is scarcely any river, which, if critically examined, will not afford the most interesting and valuable experience. I need scarcely point out to you, that the works of Du Buat, in extenso, and as abridged by Robison, with his elegant essay upon the history of rivers, combine the most ample, satisfactory, and interesting information on these questions.

There is another branch of the profession, which is now becoming most important:—the extension of the Submarine Telegraph cables, by which our most remote possessions are being brought into almost immediate contact with the Home Government. The experience, up to the present time has, however, been very unsatisfactory, whether we consider the condition of the cables laid across the Atlantic, or of several of those submerged in the Mediterranean, and as regards their duration after being laid down. It was the opinion of the late Mr. Robert Stephenson, whilst presiding over the affairs of the Electric and International Telegraph Company, that a cable could not be anticipated to last more than ten years, and he, therefore, insisted on an annual provision being made for this decay. On the other hand, there are other Companies possessing submarine cables, who will not make any such provision. This anomalous state should not prevail in a commercial community, such as ours. I have much pleasure in stating, that on this subject the Government have taken a very judicious and liberal course, in which I am convinced the opinion of the country will support them. A Commission has been appointed to investigate this question, with the most ample scope for their inquiries. Mr. Stephenson felt a great interest in this Commission, of which I have the honour also to be a member: since his decease the active duties have devolved upon our Associate Member, Captain Douglas Galton, of the Railway Department of the Board of Trade, and it gives me much pleasure to state, that from the indefatigable zeal which he devotes to this inquiry, information of the highest importance will become the common property of the country. The

inquiry has for its object, not only the best form of cable to be laid at great depths in the ocean, but also the electrical condition when laid. It is, no doubt, owing to the want of such a preliminary inquiry, that so large an amount of national capital has been wasted in such operations, and especially in laying that across the Atlantic ;—this subject will, I trust, receive your attention.

There are many questions, which, it appears to me, we may discuss with advantage, in connection with our National Defences. It may be contended, that this subject scarcely comes within the strict limits of our professional pursuits ; but seeing how important a part must devolve upon steam vessels, upon our harbours generally, and especially those of refuge, upon the railway access to the coast, and upon our artillery, the preparation of which has now been admitted to have become part of the duties of our profession,—inasmuch as the recent great improvements have been accomplished by Sir W. Armstrong, Mr. Whitworth, and Mr. Anderson, all civilians and members of our profession,—I do not hesitate to advert to this subject, to which the public attention is so much attracted, especially as I do not know any other arena where such subjects can be so advantageously discussed as in this Institution. There is no assemblage which commands more general intelligence, and certainly, none which contains so much mechanical knowledge. Applying our minds to this question, the first consideration is, what are the peculiar resources which England possesses, and what is most essential to be attained ? As to our resources, they consist chiefly in our enormous and accumulating wealth, our boundless mechanical skill, and the genius to apply them. The object to be attained is the maritime supremacy of the narrow seas. We cannot, indeed, like the Continental nations, maintain large bodies of regular troops, nor have we, like our neighbours, a large reserve of seamen at command for emergencies. Before, however, applying these general considerations, I must advert to the fact of the small amount of novelty and of improvement in naval architecture, which have originated in our own Government Dockyards, especially having regard to the enormous total expenditure recorded. It is the fashion to visit the shortcomings upon the statesmen in power ; but in point of fact, they are as little in fault as we are, who are sitting in this room. In a constitutional government, carried on through the agency of the House of Commons, the Government has not the power of selecting the best mode of carrying on the public departments, but is compelled to adopt that which, under the circumstances, is exposed to the fewest disadvantages ; having reference to the uncertain tenure of office, it is, therefore, unreasonable and useless to complain of statesmen ; the more patriotic course is to suggest practical remedies. The main

reason of so little improvement emanating from the public departments, is the total want of that competition which exercises so irresistible an influence on all our commercial relations.

I cannot help thinking that discussions, at our Meetings, on many of the subjects within the scope of the public departments, will be reflected upon these departments, and will work for the general good. I repeat, why should not the skill, talent, and practical knowledge which has so rapidly improved our artillery, and has been resorted to by Foreign Governments for their navies, be rendered available for our national objects? The Governments of Spain, Portugal, Sardinia, Austria, Turkey, and the Brazils, resort to our commercial shipwrights to form their navies, whilst Russia has recourse to the United States; the British Government alone despising the resources offered by the native genius of the country.

As to our national defences, the all-important point is, as before stated, the maritime supremacy of the narrow seas. It appears that, for this object, three conditions are essential:—

1st. That we should possess the fleetest boats, for conveying intelligence, instructions, and information as to hostile movements;

2nd. The strongest, swiftest, and most powerful rams, or vessels for running down;

3rd. Armed ships of the most efficient description.

As to the fast despatch-boats, they are to be had, in abundance, from our commercial and mail services; especially such as those now constructing for the Holyhead and Kingstown line.

As regards the rams, there are many points demanding serious investigation. The first is, whether they should be constructed simply to act as rams, or be provided with an armament, and combine the two conditions; and thus, whether in attempting to combine both objects in one vessel, the actual efficiency of both may not be impaired. That is to say, whether giving to the ram its adequate strength, may not interfere with its proper armament, and whether the provisions required for the armament may not defeat its object as a ram. It would appear to be obvious, that if a vessel were built solely for running down, and her sphere of action were restricted to the Channel, her form and the system of construction would not be essentially different from that which would be adopted, if her operations were to be more extended. It must also be remembered, that the crew required to work her, solely as a ram, would be very small, as compared with the additional number of men required to work a powerful armament, and upon the perilous service to which they would be applied, we should risk but few lives, which cannot be replaced, in addition to the property which we can so easily re-establish; and thus a powerful Channel fleet could be kept afloat at a small current

charge. These are surely points of sufficient importance to demand careful discussion and development.

The points to be considered relative to the fighting ships are, whether they should not, like the rams, be specially constructed for service in the seas surrounding our coasts. Our men-of-war are now all constructed for carrying the British flag into distant seas, and for this purpose they are adequately masted and sparred, to economise fuel on their passages to their destination. In a general engagement, the spars and rigging not only require the special attention of a large part of the crew, but their destruction endangers the efficiency of the means of propulsion, and thus, on an emergency, not unfrequently leaves the vessel a helpless log at the mercy of the enemy.

Now if a special class of vessels was solely applied to the Channel service, there would not be any object in so fully equipping them, and in burdening them with such cumbersome top-hamper. Neither would such capacity be required for provisions, water, and fuel for long voyages. Under these circumstances, it is worth consideration, whether an entirely new class of vessels might not be constructed, with less draught of water, sharper lines, more power, greater speed, and heavier armament, all essential elements in future warfare, and thus secure, for the nation, a fleet of vessels strictly applicable to defensive purposes, which no other nation would have the means of opposing, and insure, in future, for this country, that which it has hitherto possessed, the maritime supremacy of the narrow seas. Besides these points, there is the question, in what way the mechanical skill of the country and the constructive genius of commercial shipwrights, shall be rendered available for the improvement of our national marine. It may be discussed, whether the best course would not be, after defining the objects of any particular class of vessel required by the Government, to solicit designs from the principal builders; and in furnishing such plans, the builders should not only state the cost at which they will build, but also the speed they will guarantee, combined with the capacity to carry the specified armament, in a manner to insure the efficiency of the vessel; the selections from these designs to devolve upon a commission of independent members. I again repeat, that these may not be the best measures to be actually adopted, but their discussion within these walls must be productive of good.

Another branch of the subject is, the most facile method of concentrating forces upon those points accessible to an enemy. It has been suggested, that a littoral line of railway should be constructed. This proposition could only have emanated from those who were unacquainted with the physical features of our coasts. Shakespeare's Cliff, Beachy Head, the iron-bound coasts to the

west of the Isle of Wight, are familiar to all. But, in point of fact, looking to the existing railways, the problem admits of an easier solution than has been generally supposed. The South-Eastern, the East Kent, the South Coast, the South-Western, with its branch to Dorchester and extension to Exeter, the Great Western, Bristol and Exeter and West Cornwall, the South Wales, and other railways, either directly approach every accessible spot on the coast, or admit of easy connection by branches. The only points remaining to be considered are, the defensive works at those places. It is admitted, that nothing can be more unsatisfactory, than the state of the fortifications around our coasts. Lord Grey has graphically described those at Plymouth; and a short railway journey, and a cruise down the Solent, past the fortifications at Hurst Point, will prove, that neither scientific investigations, nor modern experience, have, as yet, had any beneficial effect upon that department which charges itself with the control of such works.

As a natural sequence to the preceding subjects, we are led to the consideration of the proceedings which have taken place, with regard to what are termed our Harbours of Refuge,—as it must be obvious, that one main object of these works has reference to the operations of our naval forces,—and I believe I am justified in observing, from what transpired during a recent discussion at this Institution, that neither mechanically, nor financially, can they be considered to be in a satisfactory position. According to the present system of conducting such works, it is obvious, that the principle of construction employed at Dover and at Alderney, must necessarily restrict their adoption to a very limited extent. Whether we look to the time, or to the cost, the results are altogether inadequate to the sacrifices required. The protracted time is, to a great extent, owing to the system of voting the funds annually by driblets, the result of which is, that neither the Government, nor Parliament, fairly appreciate, at the commencement of a work, the full extent of the responsibility involved, either as to time, or cost. Can it be supposed, that Government, or Parliament, when adopting the recommendation of the Commission to construct a harbour of refuge at Dover, imagined, that the works would involve an actual cash outlay of five, or six millions, without interest, or of thirty, or forty millions, including interest, and that a hundred years, at least, would elapse, before the full efficiency of the works would be secured; or that after an expenditure of nearly half a million sterling, and the lapse of upwards of ten years, the constructive resources of Great Britain would be exhibited, to the foreigner landing at Dover, in the shape of an incomplete jetty, with two inconvenient landing places? These and other results, of a similar character, may be fairly attributed to the system

[1859-60. N.S.]

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adopted, and must not be laid to the charge of any individual, or department, and certainly not to the eminent statesmen who guide the helm of the nation for the time being; for in matters of this description they possess no interest, political, or otherwise, apart from that of the country at large. No doubt one of the inconveniences of the present system is that of having to apply to Parliament annually for grants, the amounts of which, and the chance of obtaining them, depend upon the financial state of the country, and the temper of the House of Commons, even although the period of the session may be selected, when the Government has the best command of the attendance in the House. No doubt that, having regard to these circumstances, the original plans of the works have often been conceived on a limited and narrow basis, adapted to the proposed expenditure, but totally inadequate to the objects supposed to be attained; the ultimate result, generally, being an extension of the design, an enlargement of the estimates, and a final completion of the works, in a form, or shape which defies investigation to affiliate. Thus money is wasted, time is sacrificed, and full efficiency is not attained.

The remedy for this defective state would appear to be, that antecedent to any application to Parliament, the Government should prepare full and detailed plans of the entire extent of the works intended to be executed, and obtain tenders from competent contractors for the execution, stating the time of completion and the terms and mode of payment. These plans should be deposited, at fixed periods, at the Private Bill Office, for the inspection of all who are interested. Thus, before the vote was taken, there would be ample time for full criticism on all points, and though additional labour might be thrown upon the public departments, in preparing the documents subjected to such investigation, the House of Commons and the members of the State, would have the means of coming to the debate, fully informed on all points connected with these national works.

In a financial point of view the gain would be considerable, because a work which is executed within a reasonable time, is always more economical than one which is extended over an indefinite period; and also for direct financial considerations; which may thus be exemplified. Suppose a work, estimated to cost a million, be made to extend over twenty years, the outlay being restricted by the annual grant, to fifty thousand pounds a year; the ultimate cost of this work to the country, assuming the Government to raise the money at three per cent., involves an additional annual charge of about forty-two thousand pounds per annum; whereas, if the work was executed in five years, by annual grants of two hundred thousand pounds a year, the annual charge to the country would only be thirty-three thousand pounds a year; thus,

irrespective of all other advantages, saving nine thousand pounds a year. These observations only apply to works of real utility, and do not apply to undertakings of so useless a character, that their execution cannot be too long protracted ; such, for instance, as the pier at St. Catherine's, in Jersey, and others of a similar character.

I cannot but feel assured that, were the principle adopted, which I have enunciated, the defects now admitted to exist in the harbours of Holyhead and of Alderney would have been avoided, and the Blue Book mystification at Portland, respecting the expenditure upon the convicts employed on the breakwater works, would not have occurred, and the nation and Parliament would have had the satisfaction of realising, in all these works, the full value of the outlay incurred. Ministers, by taking at once from Parliament a grant for the full amount of the expenditure, would avoid the annoyance of the annual appeal and the recurring waste of the public time, in re-discussing all the features of these undertakings.

I have alluded here to certain defects which will always be inherent in the harbours of Holyhead and Alderney, both of which were, doubtless, originally projected on so limited a scale, on account of the difficulty of obtaining Parliamentary grants ; but during the progress of the works, their total inadequacy for the objects proposed became so obvious, that it would have been absolutely criminal to have persisted in the original designs. Their extension, therefore, became a matter of necessity ; but, alas ! these extensions could only be carried out in such directions, that it is now admitted, that for the same amount of money, the same extent of breakwater might have been constructed, in a form much better calculated to resist the action of the seas, whilst affording more security and nearly twice the amount of accommodation.

Before concluding my Address, I cannot avoid contrasting the progress of Government works with those undertaken by private enterprise. There is, within a short distance, an iron bridge, scarcely even partly completed, across the River Thames. There is no doubt, that this bridge will be substantially and skilfully constructed, but it cannot be said to involve any feature of mechanical difficulty : it is constructed in London, and thus commands, in respect of labour and materials, the resources of the whole empire. Another iron bridge, spanning the River St. Lawrence in Canada, is entirely completed and is opened for traffic : this bridge extends for nearly a mile and a half across a stream, having a current varying from seven to ten miles an hour ; it has to resist the pressure of ice accumulating, occasionally, to the depth of thirty feet, or forty feet ; the severity of the climate is such as to restrict the actual period of working, to a few months in each year ; the ironwork

and the great proportion of the skilled labour were derived from England; and a severe monetary crisis had also to be surmounted, which latter, however comparatively unimportant in Government operations, exercises a formidable influence on private enterprise. Yet this entire work has been executed contemporaneously with the one uncompleted half of Westminster Bridge; thus evidencing what the Civil Engineer can do, when impelled by the pressure of private enterprise, as contrasted with his exertions, when trammelled by the restrictions incidental to the conduct of Government works.

Gentlemen, I am well aware, that the observations I have made are open to the severest criticism. I have advisedly introduced into my Address, subjects and opinions of the most controversial character, because it is my design to induce upon them the fullest and freest discussion. I have endeavoured, on the one hand, and I hope with success, to avoid subjects of trivial interest; whilst on the other, I have attempted to direct my remarks to subjects of national, commercial, and professional importance.

I have now been a Member of this Institution for thirty-five years; during that period I have been a careful and anxious observer of its progress, and the result of my observations leads me to believe, that nothing has tended so much to the steady growth of this Society as the animated discussions, which so frequently occur within these walls. This point may, however, be also a subject of controversy; but, gentlemen, I have only one further remark to make,—upon which I can defy controversy,—that all I have said within these walls, and my conduct, while occupying this chair, has been and will be inspired by the determination, so far as my humble powers permit, to perpetuate the prosperity of this Institution, and to maintain the reputation of the noble profession of which I am proud to be a member.

Being duly moved and seconded, it was resolved:—"That the President be requested to permit his Address to be printed and circulated with the Minutes of Proceedings."

January 17, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

The discussion upon the Paper, No. 1,005, "On Arterial Drainage and Outfalls," by Mr. R. B. Grantham, was continued throughout the evening, to the exclusion of any other subject.

RESTORATION OF CRACKED BELLS BY TIN SOLDERING.

After the Meeting, Mr. S. Alfred Varley exhibited a cracked bell, the metallic continuity of which had been restored, by simply soldering the crack with tin, so that the bell rang as perfectly as before it was injured. It was explained, that tin had the property, when heated above its melting point, to nearly a red heat, of rapidly dissolving copper. If, therefore, the cracked bell, after being soldered, was kept for a little time, at a dull red heat, or nearly so, the crack would be filled up with an alloy of tin and copper, of nearly the same kind of composition as the bell itself, and in absolute metallic union with it, becoming quite as brittle and as sonorous as the other portions of the bell.

January 24, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

No. 1,009.—"On the Construction and Enlargement of the Lindal Tunnel, on the Furness Railway." By FRANCIS CROUGHTON STILEMAN, M. Inst. C.E.

The Author is desirous of laying before the Institution a short description of this work, believing it to be the only instance in which a tunnel, originally constructed for a single line, has been enlarged to receive a second line of railway; the traffic having been maintained during nearly the whole time the works were in progress. In the course of the Paper, reference will be made to the various modes proposed for executing the works, and an explanation will be given of the manner in which they were finally carried out, as well as of the difficulties encountered and overcome.

Allusion must be made, in the first place, to the circumstances under which the tunnel for a single line was constructed. In June,

1847, a contract was entered into with Messrs. Fell and Jopling, for the construction of a tunnel of sufficient width for two lines of way, at a schedule of prices. This contract was annulled, after the works had been in progress about five months, in consequence of the monetary crisis of that period. After a suspension of about twelve months, a fresh contract was entered into, for a single line, which was completed and opened in June, 1851. A great increase in the mineral traffic of the district, due principally to the facilities afforded by the completion of the railway, was the result. Subsequently, an Act of Parliament was obtained for the formation of "The Ulverston and Lancaster Railway," of which Messrs. M^cClean, (V.P. Inst. C.E.,) and Stileman, (M. Inst. C.E.,) were the Engineers. This line forms the connecting link in the chain of coast railways between Lancaster and Whitehaven. It then became doubtful, whether the single line would be sufficient to accommodate the traffic. In August, 1854, therefore, the Directors of the Furness Railway Company instructed their Engineers, Messrs. M^cClean and Stileman, to prepare the contract drawings, &c., for widening the railway, and enlarging, or open cutting the Lindal Tunnel. The question of open cutting the tunnel was entertained, in case that plan might be necessary, to insure the regular working of the traffic, during the progress of the works. The additional cost of open cutting, instead of simply enlarging the tunnel, was estimated at £12,000. The works having been advertised, several tenders were received, from well-known tunnel contractors, by which it appeared, that the expense of the former method would have been more than double that of the latter. Consequently, it was determined to enlarge the tunnel, and the tender of Mr. William Tredwell was accepted. The length of the tunnel to be enlarged was 563 lineal yards, of which 176 lineal yards were in solid rock, and 387 lineal yards in loose material, the latter being specified to be lined with sandstone-rubble masonry. During the execution, the length of the tunnel was reduced to 460 lineal yards, of which 123 lineal yards are in solid limestone rock, and 337 lineal yards in loose material, lined with masonry.

It will be seen by Plate 4, that the tunnel was to be increased in width equally on each side, the level of the rails remaining the same. It was proposed, that there should be two shafts, one on each side of the existing tunnel, so that the mining operations could be proceeded with, and the materials be removed, without interfering with the shell of the small tunnel. This, it was intended, should act as a protection to passing trains, until some lengths of the large tunnel had been completed. In consequence of these conditions, the section of the proposed tunnel is considerably in excess of what is usually allowed for two lines of railway. The time allowed for the execution of the contract was three years,

as it was thought desirable to limit the operations to one, or two faces, or points, so that the miners and other workmen might become experienced in the peculiarities of this particular work.

After the contract deed had been entered into, and all the preliminary arrangements had been made, Mr. William Tredwell suggested, that another single tunnel, parallel with the existing one, could be constructed with less risk to the traffic of the line, than the proposed enlargement. At the same time, he offered to undertake the necessary additional excavation, and to complete the works for the same sum. There were many reasons why this proposition could not be favourably entertained. In the first place, there was no precedent for a work of this description. Again, the great disadvantages in working a tunnel for a single line are well known; the difficulty of properly lifting and packing the permanent way, (the stifling atmosphere, after the passage of heavy trains, preventing the platelayers from working for any length of time together,) and the condensation of the steam upon the rails, practically increase the expense of working. The gradient in this case is 1 in 100. The material to be passed through was known to consist of limestone rock, pinnle, loose gravel, and clay with boulders. The foundations throughout were good; and the difficulty that had been experienced in the formation of the original tunnel, in contending with the water, could hardly be expected to arise in enlarging it.

Before commencing the operations, a code of special rules was arranged for working the traffic, and for watching and signalling the trains. The line was entirely given up to the contractor, between the hours of 9 P.M., and 5 A.M., or for eight consecutive hours. No work was allowed to be carried on at other times, without the permission of the Resident Engineer. Telegraphic communication was made between the stations at each end of the tunnel, and a signalman was placed within the tunnel. Semaphore signals were erected at each entrance, and were connected by an endless wire, inclosed in a continuous trough. The wire was fastened to wheels at various points, having a crank outside the trough. The signalman was thus enabled, by means of a portable lever, to lower, simultaneously, the semaphore signals at each end of the tunnel. As a caution to workmen and others who might be in the tunnel, the signalman, on being acquainted, by telegraph, of the approach of a train, sounded a large gong; and it was only after satisfying himself, that no impediment existed to the passage of the train, that he lowered the signal, thus sanctioning the advance of the trains.

The works for the enlargement of the tunnel were commenced, in June, 1855, at the old shaft No. 3, which was widened, instead of two new ones being sunk, as at first contemplated. The shaft was

divided down the centre, by a strong timber brattice, so that it could be worked as two separate shafts, according to the original proposition.

Top headings were driven for short distances, at the proper levels, above the existing tunnel. The material was found to consist of dry, hard clay and gravel; but it was observed, both in widening the shaft and in driving the headings, that the ground had become set and broken up, from previous mining operations, to a much greater extent than could have been anticipated. As it was probable, that such might be the case, more, or less, throughout, and as it would, when wet, render mining very treacherous, it was thought advisable to make the tunnel for the double line, of less dimensions than at first intended. The crown was kept sufficiently high to allow the mining operations, in getting out the roof, to proceed, without interfering with the original tunnel. Wrought-iron centering was employed, where necessary, and a shield to support the masonry of the small tunnel, whilst a length was being excavated above, which served also as a protection to the railway. The roof of the first length was executed, by placing the cills for the support of the bars, 3 feet above the crown of the small tunnel, on which and on the material forming the sides, they rested. A portion of the masonry of the tunnel between the cills was then removed, and the excavation for the side walls was proceeded with. Working by shafts was afterwards dispensed with, the alteration in the size of the tunnel not permitting the excavation for the side walls to be taken out, before the masonry of the smaller tunnel was removed.

In order to obtain another face, or point, to work at, it was necessary to break through the original tunnel. This operation was commenced by drilling through the soffit of the arch, to ascertain the nature of the material above. If satisfactory, a manhole was made, and the earth was removed, by means of a bar, until the excavation was sufficiently large to admit a miner; the hole was then timbered all round, leaving the top open. Another length of a few feet upwards was excavated and timbered in a similar way; this process being repeated until the level of the top heading was reached. From this upright shaft, the headings were driven, and the ordinary method of tunnelling was adopted. After a few lengths were completed, a regular system of timbering and of working was instituted; little distinction being made between apparently light, or heavy lengths. The bars used were chiefly of larch, varying in size from 15 inches to 18 inches and 22 inches in diameter. They were placed 12 inches to 15 inches and 18 inches apart, round the roof, and were supported at each end by props from the cills, which were of pitch pine, from 20 inches to 22 inches square. A saddle, or half-balk, was placed on the

top of the cills, and fastened to it with wrought-iron glands. The cills were supported from the ground by two upright props, passed through the haunches of the small arch, down to the formation level of the tunnel, by which means, only a small portion of the weight of the roof was thrown upon the small tunnel. After the excavation had been completed to the cill level, and the materials removed to the masonry of the old tunnel, the arch was taken down, the side walls removed, and the excavation at the sides proceeded with. A portion of the small tunnel, from 2 feet to 3 feet in length, was always left in front of the cill, to prevent any materials falling on the railway. The cill was further stayed by raking struts, brought down to the formation level. Small cills were placed about half-way down the side walls, to carry the props supporting the ends of the first cill; and these were again propped down upon the foundations, as the material was removed. In addition to the upper cill, a second, or back cill, was often used, to assist in carrying the crown bars. This was either propped from the bottom, in a similar manner to the one previously described, or from the smaller cills at the sides. A framing, called by miners a 'horse head,' was also frequently used. It consisted of two balks, or bars, placed upright, with a cross piece, or cap, at the top, of sufficient length to take the drawing bars, usually about seven in number. This, when well packed up to the bars, greatly relieved the cills, if placed at the ends, or reduced the length, if placed in the centre. When the ground was more than ordinarily heavy, the lengths of excavation were reduced from 15 feet to 12 feet, to 9 feet, and even to 7 feet. In some instances, it was necessary, after the roof had been timbered, to put in additional bars, called lining bars, between those already placed. These were propped from the cill, or were carried by horse heads. When well packed with the other timbers, they formed a nearly solid timber roofing, 14 inches to 18 inches in thickness, for 12 feet, or 14 feet round, exclusive of the polling boards between the material excavated and the bars.

Four years had elapsed between the completion of the small tunnel and the commencement of the enlargement. This was considered sufficient time for all settlements and runs, from previous mining operations, to have become consolidated. But the displacement of the roof had been very great; and from the nature of the material, the water appeared to have been impounded in the settlements, forming small reservoirs. One of these displacements, or cavities, was met with near shaft No. 4, the two faces being then 95 feet apart. In one heading the materials, which were very wet, consisted of clay, gravel, and large stones; and the whole soon became converted into mud, oozing through the timbers, filling up the heading, and displacing the framing. This continued for some time, and but little progress could be made with the heading. After

a large quantity of mud had been removed, the run subsided, and the excavation became more consolidated. Whilst extending the heading, for another setting, a continuous dropping was heard in advance of the work, giving unmistakeable signs of the proximity of some cavity, from which, no doubt, the mud had been issuing. Special precautions were then taken. On widening out the boundary, a large hole was discovered, the top of which was 70 feet above the rails, and about 28 feet below the natural surface of the ground. The mouth of this hole was timbered, and, as far as possible, the entire place was filled up. Through this ground the work was carried on during the day as well as during the night; but little additional time was gained, or progress made. The old tunnel being so small, the engines which passed through with heavy loads, up a gradient of 1 in 100, so completely filled the tunnel and the headings with steam and sulphurous vapour, that it was impossible for the miners to remain at work. Near this point the greatest difficulty occurred. On the completion of the original tunnel, the shaft No. 4 had been filled up, but the knowledge of its existence, as well as that of the cavity, rendered it necessary to proceed with great caution. Short lengths only were removed, and a large quantity of timber in bars, double cills, horse heads, &c., was used. The excavation for the heading under the cavity improved, whilst that in the heading at the other face began to show broken ground. This was at a distance of about 38 feet from shaft No. 4. The material, though loose, was dry, a vein of fine, clear, washed gravel, about 4 feet, or 5 feet in width, extending from this heading towards the old shaft. On widening out this length, the vein of gravel was cut across its full extent. From the first, it showed symptoms of running; and notwithstanding all the precautions taken by the contractor's agent, and despite the great exertions made by the miners, the length fell in, causing a cessation of the traffic. The mineral and goods' trains were resumed within six days of the fall; but the Directors thought it prudent to limit the working of the line to the goods' traffic only. An arrangement was then made with the contractor, to give up the line to him for ten, instead of eight consecutive hours; he undertaking to complete the work, in less time than was stipulated in the contract. After the fall, it was surmised, that the whole of the ground between the two faces was in motion; and that the cavity and the shaft had united, and had thus caused the accident. A disturbance of the natural surface of the ground was observable; and the material with which the shaft had been filled up, had dropped about 50 feet. The works were soon reinstated, fresh lengths were put in, and the work was completed beyond the shaft and the cavity, without further accident. During the construction of these lengths, the rest of the material in the

shaft fell down to the broken length, thus affording a means of examining the ground from above. It was then discovered, that the cavity and the shaft had not united, as had been supposed, and that the vein of gravel continued past the shaft, towards the cavity. The only explanation which has been offered as to the cause of the accident is, that the bed, or vein, of gravel had run out to, and round the shaft, forming a large hole; thus setting free the loose material with which the shaft had been filled, and allowing the entire contents to drop, at once, 20 feet, or 30 feet, nearly over the heading.

After the tunnel had been completed, and the shaft No. 4, and the ground over the broken length, had been made good, it was decided to examine the cavity from the top, and to ascertain if it had extended. It will be remembered, that, as far as practicable, it had been filled from the work below. This was fortunate, for it was discovered, that it had gradually extended upwards. Before the boring was made, a subsidence on the natural surface of the ground was observed, immediately above the cavity. This was soon filled up and made good, since which time no further settlement has taken place. It has been suggested, that the cavity was not the result of previous mining operations, but that it was a natural reservoir, supplying distant springs, and that the vein of clear gravel, or sand had acted as a conduit.

The masonry, both for the side walls and for the arch, was of fitted limestone-rubble, 2 feet to 3 feet in thickness, set in Aberthaw lime-mortar. The stone was obtained from the adjoining cuttings. During the execution of the works, daily reports were made by the inspectors, of the progress, and returns were given of the number of men employed. It appears, that a length of tunnel of 15 feet was excavated, on the average, by eighteen working sets, or shifts of eight hours, representing one day's work of sixty miners and seventy-five labourers, but some lengths occupied as much as thirty-three working sets, or one day's work of one hundred and three miners and one hundred and twenty labourers. Of this number, eight sets were generally occupied in getting in the crown bars. The amount of excavation in each length was about 300 cubic yards.

The time occupied in building the side walls of a length of 15 feet averaged two sets, and in building and keying the arch, eight sets, employing in all, thirty-two masons and forty labourers, one day each. The time of the masons and labourers was scarcely found to vary; any additional time was easily accounted for, by the difficulty in setting the masonry amongst the extra timbering used in heavy lengths. Setting the ribs, or centres, was generally done by a leading miner and some labourers; it occupied about two sets, employing two miners and ten labourers one day.

The total cost of the tunnel, as it now stands, is as follows :—

	£.	s.	d.
In 1849, the contract price for the small tunnel, per lineal yard, was	6	0	0
In 1854, the additional cost, when enlarged, was	21	4	0
Total cost, per lineal yard, of the double tunnel in rock	27	4	0
In 1848, the contract price for the small tunnel, lined with sandstone-rubble masonry, per lineal yard, was	15	10	0
In 1854, the additional cost of widening, was	38	0	0
Total cost, per lineal yard, of the double tunnel, lined with fitted limestone-rubble masonry	53	10	0

Supposing that the original contract, entered into in 1847, had been completed, the tunnel would have cost :—

	£.	s.	d.
In rock, per lineal yard	21	0	6
In masonry	45	0	0

or £6. 3s. 6d. per lineal yard less when in rock, and £8. 10s. per lineal yard less when in masonry.

That part of the tunnel, 337 yards in length, executed in masonry, was completed in sixteen months. For the first eight months, four faces only were in progress, during which time 87 lineal yards were completed, being at the rate of $2\frac{1}{2}$ lineal yards per week, or less than 2 feet per week at each face. During the remaining eight months, nine faces were proceeded with, and the rate of progress was about 7 lineal yards, or less than 2 feet 6 inches per week at each face. The actual time employed in completing each length of 15 feet, has been stated to be, on an average, thirty sets, or days. If calculated according to the total time that the works were in course of construction, double the actual working time was consumed; it would therefore, appear, that for work of this character, it is necessary to allow the same time for contingencies as for the actual execution. In this particular case, great difficulty was experienced in obtaining workmen, and in keeping them regularly at work. Most of the materials were obtained from the district, but not the workmen.

Mr. Ramsden, (M. Inst. C.E.,) the General Manager of the Furness Railway, has furnished the following particulars as to the number of trains that passed through the tunnel, from the commencement of the works in June, 1855, to their completion in November, 1856 :—7,494 passenger trains carrying 112,050 pas-

sengers; and 2,107 goods' trains carrying 204,566 tons of minerals, &c.: in all, 9,601 trains, exclusive of light engines.

Not the slightest casualty occurred to either description of train, nor any accident, even of the most trivial character, to any servant of the Company. Unfortunately one miner lost his life at the fall of the length, and a second by the firing of a hole whilst charging. Two, or three miners were also injured, from causes incidental to all tunnelling operations.

The Paper is illustrated by a series of diagrams, from which Plate 4 has been compiled.

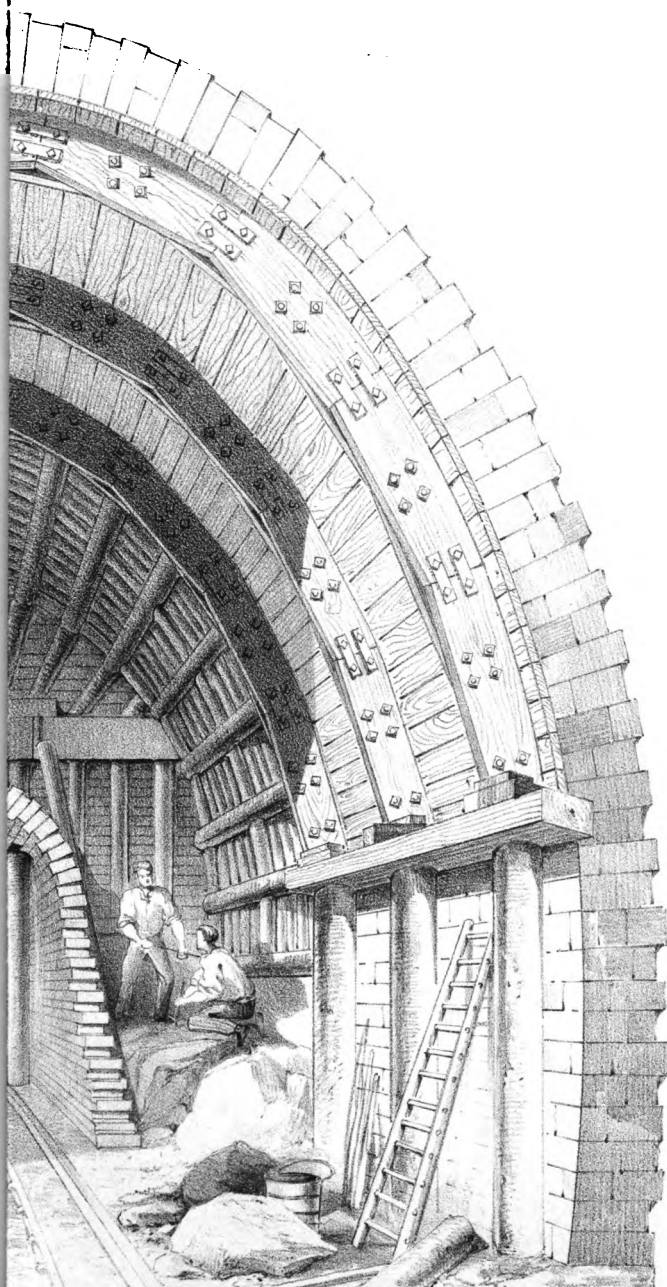
Mr. STILEMAN regretted he was unable to furnish the detailed cost of this work, with which he had hoped to be supplied by the contractor, for this was a case in which labour formed one of the chief items of cost. The original cost of the small tunnel, which, when lined, was 14 feet 6 inches in height and about 12 feet in width, was about £6 per lineal yard of rock work, and £15. 10s. per yard of masonry. The aggregate cost of the tunnel, when completed, was £27. 4s. per yard of rock work and £53. 10s. per yard of masonry. He added, that the contractors who tendered, generally preferred, or proposed to construct a supplemental tunnel, rather than be subjected to the interruptions that must, of necessity, be caused by the trains passing during the operations. The total number of trains given in the Paper, embraced the period from June, 1855, to November, 1856, and averaged about eighteen trains per day.

Mr. HAWKSHAW, V.P., remarked, that the propriety of converting the tunnel of a single line of railway into one for a double line, in preference to the construction of a parallel tunnel, depended very much upon the amount of traffic. When there was little interruption from trains, the plan of widening the existing tunnel would, probably, be generally adopted. In constructing tunnels, he had found, that the larger the drift way was made in the first instance, the cheaper the work could be carried out. The former practice was to sink wide shafts and drive narrow drift ways, but in the many tunnels which he had constructed, he had been satisfied with shafts 6 feet in diameter; he had, however, used drift ways 9 feet square, from which the material could be carried away in the ordinary contractors' waggons. The widening of a tunnel, whilst it was in use for passing trains, was a difficult operation, requiring very accurate arrangement of the timber centering, and the utmost care in the execution. Upon considering the drawings of this work, he thought the design and the execution reflected the highest credit on those who had been connected with the tunnel.

Mr. FOWLER, V.P., had constructed a supplemental tunnel, 3 miles in length, at the Woodhead Tunnel, on the Manchester, Sheffield and Lincolnshire Railway. He saw no reason why the same plan should not have been adopted on the Furness Railway, as no special precaution was required in the execution of the work, and the cost of the second tunnel was from two-thirds to three-fourths that of the first.

Mr. KNIGHT was desirous of knowing how much the construction of the tunnel had cost the contractor, for at £6 per lineal yard, he must have been a considerable loser.

Mr. HAWKSHAW, V.P., suggested that, in this case, the cost of making the approach to a second tunnel through the rock cutting, added to the cost of a second tunnel, would have been greater than



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that of enlarging the existing tunnel. No such general rule could be laid down, as that a second separate tunnel was always the best plan to be adopted.

Mr. WALKER, (Past-President,) as one of the Directors of the Furness Railway, expressed his perfect satisfaction at the manner in which the entire works of the line had been executed; he also thought a single large tunnel preferable to two small tunnels.

Mr. STILEMAN, in reply to questions, stated that the old materials were not used in the construction of the enlarged tunnel. In considering the low price at which the original tunnel in rock was constructed, it should be remembered, that the tunnel was remarkably small, so that, on the average, the price was 6*s.* 2*d.* per cubic yard of solid rock. In this particular instance, the cost of a parallel tunnel would have been the same as for the enlargement; but the chief objection to the former of these methods, was the contracted space of the original tunnel, in which it was difficult for the platelayers to lift and pack the permanent way. The space was so confined, that although the tunnel was only 563 yards in length, it was impossible, during the construction of the works, to remain in some parts of it for any long period.

Mr. BIDDER,—President,—regarded the Paper as one of great value in a practical point of view. It was true, that no absolute rule applicable to all cases, could be laid down, but there were instances in which the construction of a supplemental tunnel would be preferable to enlarging the first; and he concurred in the opinion, that it could be constructed for two-thirds, or three-fourths of the cost of the original tunnel. The cost of the original tunnel appeared, at first sight, extraordinarily small, but of this a sufficient explanation had been given, showing it to have been 6*s.* 2*d.* per cubic yard, which might be considered a fair price, when the material was not excessively hard. Tunnelling, generally, was one of the most interesting features of the profession, from the difficulties which had, in many cases, to be surmounted; the Kilsby and the Box Tunnels were remarkable examples of this, and would form subjects for interesting Papers. The details of those great works would be valuable and useful to the younger Members, and he hoped those who had information upon the subject at their command, would place it before the Institution.

January 31, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

No. 1,015.—“On the means of Communication in the Empire of Brazil; chiefly in reference to the Works of the Mangaratiba Serra Road, and to those of the Mauá, the first Brazilian Railway.”¹ By EDWARD BRAINERD WEBB, M. Inst. C.E.

WHEN Brazil was discovered by the Portuguese, in the year 1500, unlike Peru, or Mexico, it presented neither civilised inhabitants, nor visible wealth. It was entirely destitute of roads, or buildings, and its human inhabitants were as wild as the beasts of its boundless forests.

Notwithstanding its enormous area, equal to twenty-three times that of the United Kingdom, it offered, during the course of a century, but few temptations to the avaricious spirit governing the era of its discovery. Its coasts were, for a considerable period, used for convict settlements, and its only valuable export was the dyewood found in the neighbourhood of the sea. After the arrival of the Jesuits, however, a change took place. The first missionaries were heroic men,—at one and the same time, priests, politicians, and engineers,—and they effected what the sword had failed to accomplish, the civilisation of numerous hordes of savages. Teaching them the art of building, they erected villages and churches, cut and burnt down the forests, preparatory to agricultural operations, cleared paths between the various settlements, and, in later times, built towns and aqueducts. Although the attention of the traveller is frequently called to the former energy and ability of the Jesuits, he meets with no vestiges of ancient roads. He may, now and then, pass a time-worn church, or ‘capella,’ but he never crosses an antique bridge, for up to within a late period, no roads, in the English acceptance of the word, existed.

Brazil has a coast of about three thousand miles in extent. From time to time, at the entrances of the largest bays, and at the mouths of the principal rivers, settlements have been made, some of which have expanded into cities, whilst others have almost disappeared. With so great an extent of coast, and with a limited

¹ The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

number of sites suitable for the construction of seaports, it follows, that they are frequently far distant from each other. Between these coast towns, the communication is by sea. People have penetrated into the interior at right angles to the sea shore, and having arrived at considerable distances inland, have formed junctions to the right, and to the left. Many of these internal lines of communication were, doubtless, first laid out by the 'anta,' or South American tapir, followed up by the Indians, and, ultimately, adopted and widened by the conquerors. The astonishment of an Englishman at the capricious direction of these routes, ought to be modified by the reflection, that they were equivalent to small tunnels driven through massive beds of vegetation; so impenetrable are the primeval Brazilian forests, from the lowest valley to the peak of the highest mountain. Up to within a recent period, these bridle paths were, however, sufficient for the necessities of the inhabitants. They were, occasionally, improved by avoiding a terrific ascent, by the erection of a wooden bridge, and even by the building of a stone culvert. These improvements, however, appeared only when some wealthy proprietor, for his own security, or convenience, executed them upon his own territories. The increase of the population and the development of commerce, led to increased traffic, and as the troops of loaded mules grew more numerous, the yielding paths became more unserviceable. The provincial governments then took the matter in hand, taxing the troops of mules, and repairing the paths by contract. These paths were treated as roads; but being unpaved, and for the most part, extending over a clay surface, with a width only sufficient for two mules to pass each other, they were and still are, at certain seasons, impassable.

The Province of Rio de Janeiro comprises two very distinct regions. A small portion, along the coast, is but little raised above the sea level; whilst the greater part is at an elevation above it, averaging about 2,300 feet. The sea face of this elevated land has, however, a much greater altitude. It is precipitous and rugged, presenting granitic peaks from 5,000 feet to 7,000 feet in height, and is called the 'Serra do Mar.' The roads from the interior to the seaports beneath, pass through the gorges of this Serra, and a few of these descents are now paved, at the cost of the province. The steepness of the gradients, from 1 in 6 to 1 in 9, permits the tropical rains to tear up all unpaved surfaces, trodden by the feet of mules. These animals, loaded generally with about 256 lbs. each, follow one another in single file. Rock gives way beneath such usage, and deep gullies are excavated, down which, during thunder storms, torrents rush with deafening noise. These paved descents of the Serra answered the end in view; but the difficulties inland and over the plains of the coast, continued.

[1859-60. N.S.]

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The deterioration of the existing roads, by the increase of traffic, was marked by a continuous rise in the cost of slaves, mules, corn, and food. It then became apparent to all, that some efforts must be made to remedy the growing evil. At the head of the gorges leading towards the Bay of Rio de Janeiro, a small town, Petropolis, had risen into existence ; first as a German colony fostered by the State, and afterwards, as the residence of the court and the wealthier classes during the hot season. The Government determined to make a carriage road up the face of the Serra leading to this town. It is not well laid out, nor are the works upon it considerable ; it has only recently been macadamised. Its summit level is more than 2,800 feet above the sea, and it has an average gradient of 1 in 16. It was stated, without contradiction, in the Chamber of Deputies, that this road had cost the Government £40,000 per mile, although there were no disbursements for land, or for legal and parliamentary expenses. The first attempt at real road-making in Brazil has, therefore, been of a costly character.

The country between the head of the Bay of Rio and the foot of the Serra, is a sandy plain. The loss and suffering experienced during the passage of this plain, in hot and dry seasons, suggested the idea of a railway, and Senor Ireneô Evangelista De Souza, (now the Baron of Mauá,) obtained a concession for its construction. An Engineer arrived from England in 1851, and the works of the Mauá Railway were commenced during the following year.

Towards the close of 1852, the Author went to Brazil. He was immediately engaged in examining the country northward from the town of Petropolis, and in selecting a route for the continuation of the Mauá Railway ; leaving, however, the Serra ascent intervening. This projected continuation of the Mauá Railway was subsequently abandoned, owing to the Government having decided in favour of a competing scheme, that of the Don Pedro Segundo Railway, the first section of which has recently been executed by Mr. E. Price, (Assoc. Inst. C.E.)

The first and most lasting difficulty met with by the Author, in determining the line of the proposed railway, was the absence of any correct map of the country. Maps there were in name, but they were worse than useless, because some reliance continued to be placed upon them, until their inaccuracy was proved. These maps are little better than itineraries depicted in lines ; the distances upon them having been mainly determined, by the daily, or hourly progress of a saddle mule. A mule's march per day, is reckoned at about a Brazilian league, or four miles per hour ; and the distance between two places is marked by leagues, regulated by hours. If the roads were rectilinear and horizontal, such a

calculation might approach to the truth ; but as they bend in all directions, and at times, ascend gradients of 1 in 4, no true distance can be thus laid down on paper. On the same map, for example, an inch will represent, at one part, a league, and at another, two leagues, or more ; positions of towns will be found interchanged, and rivers running in impossible directions. The Author was, therefore, obliged to discard these maps. All they are serviceable for is to point out a tolerably true line of coast, and to give the names of interior towns, rivers, mountains, &c., in the various provinces.

Soon after his arrival, the Author proposed an arrangement, by which the Government should assist the Petropolis Railway Company, in a triangulation of the country on each side of the valleys through which the proposed line was to be carried. He ascended some of the most prominent peaks, and selected those best fitted for main stations. But the negociation failed ; the Author, therefore, confined himself to the selection and the laying down of the railway route.

It is difficult to convey an idea of the labour of such an undertaking, conscientiously carried out, in a country like Brazil. Gangs of blacks were constantly employed in cutting paths, or headings, through the forests for the chain, theodolite, and level. It often happens, that to bring down one tree, six, or eight others must be felled, so closely do they grow together, and so firmly are their branches united, by ropes of wood. The surveying party lived in tents, and on no occasion desisted from work, on account of the tropical rains, or heat. The survey and levels for the selection of a length of main line extending to thirty miles, were executed in four months and a half. The Author then returned to the plains below, to complete the Mauá Railway, which was already commenced.

This line presented no difficulty, excepting where a deep, unhealthy swamp, from one mile to two miles in breadth, had to be crossed ; there was no rock to be excavated, and no tunnel to be driven. But the prosecution of the works was difficult, chiefly on account of the want of available means. All the ordinary excavations were executed by lines of blacks jerking the earth behind them by means of hoes ; if the weather was fine, the earth, consequently, arrived in the embankment, or spoil heap, in a state of dust. If the earth had to be taken to any distance, it was either carried in small baskets on the heads of slaves, often women, or it was jerked by the hoes upon a bullock's skin extended upon the ground, and drawn lazily by two sleepy oxen to the place of deposit. When rain had moistened the ground, a complete suspension of the operations took place. With the introduction of English barrows and shovels, and of small trucks and rails, a won-

derful improvement was made in the progress. Yet even then, the contrast between the result gained, and what would have been effected by English navvies, was very marked.

The poor native Brazilian is not inclined to work hard; necessity does not compel him to do more than to build a hut of sticks, plastered with mud, and roofed with palm leaves and tough grass. He plants a few banana trees, clears a small patch of ground for the mandioca root, or for the cultivation of black beans and rice, and all he cares for beyond, is to earn a trifle for clothes, rum, and tobacco. Slave labour, at the date to which the Author refers, could alone be depended upon, inasmuch as very little white labour was available.

The importation of slaves having entirely ceased, and all those already in the country being employed in the plantations, it was necessary, in order to obtain a supply, to offer high terms to the owners. The slaves were hired at monthly rates, and were housed and fed by the company. The wages of common blacks were about 1*s.* 4*d.*, and the food cost about 7*d.*, so that ordinary labour amounted to about 2*s.* per day. In 1857, however, after a lapse of four years, the price of labour and food had doubled. The cost of skilled labour was always about double that of the ordinary description.

With one exception, all the bridges were of wood; constructed with rapidity in order to expedite the opening of the line, and with the certainty of a not far distant renewal. Difficulty in obtaining sound and durable timber in Brazil would not, at first sight, be anticipated. Surrounded on all sides by grand, virgin forests, a stranger would imagine, that a large employment of timber in railway structures would be economical. Many circumstances combine to render this assumption incorrect. The Brazilian forests never present considerable areas covered with the same description of good timber, as in the pine forests; a serviceable tree generally stands in the midst of a group of various kinds of no actual value. The labour of dragging the squared balk from the place of its growth, is almost inconceivable. A separate path for each piece of timber has, probably, to be cut, and the log has afterwards to be dragged, by bullocks, down precipices, over ravines, and through swamps. Moreover, in consequence of the great inequality in the character of the timber, it is all but impossible to collect, in one district, a complete supply of one description. As a general rule, the timber is far from durable, when exposed to rain water, or sun.

Contrary to the Author's advice, a large and most expensive wooden pier was constructed for the southern terminus of the railway, in the Bay of Rio de Janeiro. The timber of this pier was selected from stores in the city; but it could not be obtained of

uniform quality, or of regular scantling, and when it came to the works, it varied from 9 inches to 18 inches square. The piles up to high-water mark were sheathed with copper, but before the expiration of three years, it was found necessary to fill up many of the bays with stone, as far as the worms and the sea water had damaged the piles.

Not long before the Author left Brazil, he made an examination of this pier, and he found, that not one pile, and but very few pieces of the superstructure, had remained in a sound state, although they had been in place for only about four years and a half. The copper had been decomposed, and for all practical purposes, had proved useless. All the wooden bridges on the line suffered as much as the pier, and they have recently been replaced by constructions of either iron, or brick. In the wooden bridges not one pile, transom, or longitudinal, could be called sound, and a considerable portion had been reduced to powder. The planking of foreign pitch pine appeared to have escaped with the least injury. The Brazilian pine cannot be used on railways, for it is a very inferior timber, and is a scarce tree along the coast. It is true, that timber exists in the province of Rio de Janeiro, capable of enduring exposure for a great length of time, but it is becoming scarce, and is, for general railway purposes, unavailable.

The rails used were double-headed, weighing 65 lbs. per yard, and they have proved sufficiently heavy for the traffic. They were seated upon Greaves's sleepers, which have answered admirably, in conjunction with very clear quartz ballast. Had sleepers of native wood been employed, the whole line must have been relaid at the end of about three years and a half. The gauge is 5 feet 6 inches, and although it was the first railway structure in Brazil, it did not determine the national gauge. Other Brazilian lines are now being constructed, with a gauge of 5 feet 3 inches.

As to the shape of the rail, it may be remarked, that if the capability of turning the double-headed rail is an advantage in England, it becomes a matter of serious importance in a country so far removed as is Brazil, from the seat of the iron manufacture. Several instances occurred on the Mauá Railway, where rails early showing defects, were reversed in their seats, to manifest advantage; with any other form, those rails would have been thrown aside, and old, or unserviceable wrought-iron may be considered as valueless in Brazil. The double-headed rail may not present the strongest section with a given quantity of metal, and its advantages may be lessened in some localities, where excessive weights cause the chairs to produce indentations; but as neither heavy engines, enormous traffic, nor extreme speed, are likely, for many years, to become features in Brazilian railways, the double-headed rail is, probably, the most appropriate for that country. The rails

do not appear to have been oxidised more than is customary in similar positions in England, nor have the cast-iron sleepers deteriorated.

The district through which the line runs is very swampy, and it proved most unhealthy. All who were engaged in the works, sooner, or later, were struck down by marsh fever. The heat, at times, was excessive; the temperature of the ballast, pure quartz, larger than sand and smaller than ordinary gravel, rose to upwards of 140°. Yet sickness in such situations seems attributable, as much to the impurity of the water consumed by the labourers, as to the excessive heat, or to the vitiated air. A supply of pure water to workmen, in similar positions, would repay a large expenditure for its carriage.

As to the cost of the line, which was single, and of about eleven miles only in length, it is difficult, under the peculiar circumstances of the undertaking, to extract from the total sum expended, that which is absolutely due to the railway works. The company has purchased steamers, slaves, lands, and houses. The works, however, with the rolling stock, may have cost about £15,500 per mile. The traffic on the line shows a continuous increase, and the undertaking will, eventually, offer satisfactory remuneration. It was the first railway constructed in Brazil, and considerable unnecessary expense was, consequently, incurred. It has to compete with an old-established river route, which is still kept open by prejudice and pertinacity; and it failed in obtaining that which promised to be its great source of profit, the continuation northward above the Serra, from Petropolis.

The line has not, like other Brazilian railways, enjoyed a Government guarantee; it paid the penalty of innovations. But it has its satisfactory aspects; it has been in daily use for nearly five years, without the loss of a single life; it remains in excellent condition, and it is worked by an English Engineer, with the most laudable economy and efficiency.

Soon after the opening of the Mauá Railway, the Author was appointed Engineer to the Mangaratiba Serra Road, to which he will now direct attention.

Upwards of one hundred miles to the west of Rio, occurs one of those Serra gorges already referred to. It descends to the port of Mangaratiba, one of the principal spots whence coffee is shipped for the capital. From the summit of the Serra, tracks similar to those already described, branch in various directions; one northerly, towards the interior province of Minas, reaching the great River Parahiba at a distance of about fifty-five miles from the coast, was the route of the projected road.

The land traffic to and from the port of Mangaratiba had con-

siderably increased during late years, and the roads had become less practicable. About 22,000 tons of coffee annually descended to the port, and the cargo mules returned up the mountains with about 10,000 tons of general merchandise, consisting of English and French manufactures, North American flour, and South American dried beef. The Serra ascent had been paved to a width of about 9 feet, at an average gradient of 1 in 9. This pavement sloped inwards to the hill sides, where an open paved drain carried the rain water into numerous dry stone culverts. Inland from the summit, at frequent intervals, the troops of mules had to encounter, in wet weather, pits of muddy clay where the bleached bones of many victims attested the dangers of the road. The difficulties as to the road and the cost of mules yearly augmenting, it was finally determined to construct a carriage road. A concession was granted, and a company was formed.

The contract with the Government, binding the company to certain conditions as to gradient, width of road, time of completion, and amount of capital, was made before any engineering observations had been commenced. It was believed by the promoters, that the first length of twenty miles, in which lies the Serra ascent, was almost ready for carriages; and when the Author pointed out the impossibility of transforming a gradient of 1 in 9 into 1 in 20, (the incline named in the contract,) throughout a rise of about 1,600 feet, he was but imperfectly believed, or scarcely understood.

The work was commenced in May, 1855, by a body of Chinese, a portion of a considerable number contracted with by speculators, in Singapore. They were, evidently, the scum of the population; utterly useless as labourers, they proved a continual source of annoyance and loss, and not one in ten was worth his food. The contracts were, eventually, handed over to the company, and the men were permitted to abscond. Mention is made of these people, because the Brazilian Government contemplated, at one time, the introduction of an almost unlimited supply of Chinese labourers. An Act was passed, empowering the Government to expend £680,000 in the importation of colonists, and they, at first, selected the Chinese.

From the same motives which have induced English labourers to seek homes and employment in the United States, the Portuguese working men have selected Brazil. So considerable was the number of emigrants, that the Portuguese Government deemed it necessary to obstruct the movement. Nevertheless, many thousands have entered the Province of Rio de Janeiro during late years, and the works of the Mangaratiba Road were supplied with them. As the road was set out, small contractors appeared :

with scarcely an exception all were Portuguese, or inhabitants of the various islands belonging to the crown of Portugal. Each of these men brought with him from fifteen to sixty of his countrymen, and the gangs, thus formed, dotted the line of the works with their triangular huts roofed with grass.

The Portuguese labourers are a very hardy race of men, who can endure greater privation and exposure than English labourers. At first, they refused to use the barrow and the shovel; the hoe, their only tool, was not, however, so objectionable along the steep sides of the Mangaratiba mountains, as it was on the plains of Mauá; and in certain localities, from its acting as pick and shovel combined, it was even the best tool that could have been used.

For a great portion of its length, the road is cut out of the solid rock, except where the excessive steepness of the hill sides rendered breast walling necessary. Considerable lengths occurred of nearly, or quite perpendicular rock, chiefly of mica schist. Immense rounded masses of pure granite were met with on the Serra, and occasionally, on the plains below and along the interior. Trap dykes were frequent in the ravines, and dispersed throughout the cuttings, decaying masses of basalt and amygdaloid were to be found, but in no instance was a bed of gravel met with. On account of the general steepness of the hills, and of the heavy character of the rains, the alluvial soil is not deep: beneath the few inches of soil, there is, generally, a bed of red tenacious clay, merging into a substance full of feldspar. After passing through a portion of decayed rock, the solid gneiss, or mica schist, is reached. The solidity of the earth enables the cuttings to stand safely, in most cases, at a slope of $\frac{1}{2}$ to 1. Were it not for this feature, the amount of walling on the Serra would have been immense. Much steeper slopes can be allowed in Brazil than in England, on account of the greater solidity of the material, and the absence of frost.

With the exception of the arched bridges and storehouses, none of the masonry contains lime. All the walling, the parapets, and the culverts are built dry. The abundance of stone and the great cost of lime, in its purchase and carriage, led to its rejection.

The slopes of the embankments stand firmly at 1 to 1. With a little care a rapid growth of a very thick-leaved grass can be produced, and this quickly protects the slope from the destructive action of heavy rains. Before the growth of this grass, however, great damage is frequently done in a few minutes by excessive rain, such as is never witnessed in England.

Simultaneously with the increase in the number of small contractors, the company purchased and hired slaves, so that, in a few months, more than two thousand men were employed. In

default of one single responsible contractor, the works were executed in detail ; and at one time, there were no less than sixty-eight petty contractors at work. The control and direction of the groups created much unusual labour ; for the work could not be handed over to them as in ordinary contracts, as few of them would have properly fulfilled an agreement. The Author, therefore, adopted the following system : a man on presenting himself for employment, stating that he could bring from fifteen to fifty men to the ground, received a length marked out by an Assistant Engineer, and having built his hut, he continued working until the completion of his length, without any engagement for price ; well knowing, from previous examples on the works, that he would be paid according to the quality of his work.

In such a country as Brazil, little selection of workmen can be made. A number of men may be dismissed, or may leave, but they cannot, as in England, be readily replaced. The scarcity of labour places the workmen in a very commanding position.

A most serious consideration is the supply to the men of the necessities of life. The Author had frequent cause to regret his inability to prevent the plunder carried on by the purveyors of food. It is not a mere matter of profit and loss with the contractors, or their men ; the Companies and the Engineers are equally concerned in the cost of living. It is the basis of wages, and it regulates the content, or discontent of the men. It is, nevertheless, too often overlooked ; either because its effects are not considered, or because it is held to be a subject beneath the notice of an Engineer. Yet on accepting the control of works in countries similarly situated to Brazil, he cannot reasonably look for that absence of harassing detail which he expects in England ; he enters upon a foreign campaign, and unless he resolves to undertake, at one and the same time, the heavy responsibilities of a chief, and the minute labours of an assistant, he would act more honourably towards his employers, and with greater prudence in reference to himself, by remaining at home, where no such abnegation of ease, or the amenities of position, are required. It may be suggested, that such details belong to agents and not to Engineers ; the Mangaratiba Road had its agents, but they are to be entered in the list of its difficulties and misfortunes.

The execution and quality of general work in Brazil is not satisfactory. The excavation of rock, for instance, is a tedious and uncertain process, chiefly carried on by blacks, who, in matters of teaching, are frequently not superior to intelligent mules. The masonry proved more satisfactory than almost any other branch of work. The Portuguese masons will make a good dry wall out of inferior materials, and with considerable celerity. The same cannot be said of their stone work in mortar ; if left to them-

selves, the men spend as much time in filling the outer interstices, as in building the wall itself. On the Mangaratiba Road there was only one work worthy of note, in dressed masonry, and notable only on account of its cost. Although the Portuguese dress stone very fairly, their work, as compared with that of English stone cutters, proved in this instance, four times more costly. In a locality far removed from the shore, and, at first, difficult of access, a bridge with a chord of 52 feet, and a versed sine of 9 feet, occupied nineteen months of incessant labour. The coal, steel, iron, and lime, with the supplies of food, were carried to the spot, during many months, on the backs of mules. Timber has been shown to be unadvisable in Brazilian bridge-building, at all events, in Central and Southern Brazil; and the enormous cost of this cut-stone bridge, notwithstanding the most unwearied exertions to diminish expense, proves that stone is not economical. Without doubt, iron is the best material for bridges in similar situations. This bridge did not cost less than £24,000.

The Author, during his connection with the Mauá Railway, and incidentally, with the gasworks at Rio, witnessed the melancholy result of employing English workmen in such a country as Brazil. A certain amount of skilled English labour is, sometimes, indispensable; but the aim should be to reduce the necessity for it to a minimum. For example; five Englishmen were brought to the Mangaratiba Road, to superintend the formation of the macadamised surface: two of them, in a very short time died, one absconded, and two only remained. This will present about an average of the result of such speculations. The strongest constitution will, at times, give way under a complete change of climate, and too often the most temperate men indulge in intoxicating drinks and die of fever, dysentery, or delirium tremens. The existence of slavery is a great drawback, and even the general good treatment of the slaves adds, at times, to the discontent of English workmen.

The comparative scarcity of slaves augments the rate charged for their labour, and tells against the employment of free men; it is yearly becoming more difficult in Brazil to hire slaves for public works. On the Mangaratiba Road it was necessary, at one period, to pay about 3*s.* 6*d.* per day for common slaves, strong and weak, in a mass; and this price, added to the food, brought the cost of a slave's daily labour to 4*s.* 6*d.* Yet notwithstanding this high rate, the Author failed in inducing the greatest slave owner in the vicinity of the works, although he was in the possession of more than three thousand slaves, to let out a single black. If he could have spared only five hundred, he would have received for their hire, free of all expense, from £80 to £90 per day; but his constant reply was, that he had not sufficient hands to keep his own estates in order. The Mangaratiba Com-

pany advertised in the Rio newspapers, offering 3*s.* 7*d.* per day per slave, the company providing food, house-room, and medical attendance, but few owners sent their slaves.

If then, a public company was forced to offer such large wages for slaves, on account of the difficulty in obtaining free labour, what must be the position of those undertakings in Brazil where slave labour is not admitted? Yet when companies were formed in England to carry out two of the Brazilian lines of railway, the British Government insisted upon the exclusion of slave labour in the construction of the works. On one of these railways, a large importation of Italian labourers has been effected, at a continual risk of complete failure. On another line, it has been found necessary to offer most unusual inducements to the free natives to stay on the works, and yet it is almost impossible to keep up a regular force of from fifteen hundred to two thousand men.

The Mangaratiba Road was constructed with care, and has withstood the rains of several seasons. The macadamised surface is 23 feet wide. A flagged drain, 3 feet in width, runs on the mountain side, and on the outer side is a similar drain, 18 inches in width. A bed, 8 inches to 9 inches in thickness, is paved over the 23 feet, and on this pavement is placed a layer of granite metal, 7 inches in thickness. A dry stone parapet, 3 feet high and 2 feet 2 inches thick, runs throughout the whole length of the road. The works have cost about £12,000 per mile. The Serra portions presented great difficulties, and there is no road of the same length in England, with an equal amount of excavation and masonry.

The practical result of the Mangaratiba Road has proved, that animal power cannot be used upon macadamised roads in the general traffic of Brazil, with the same advantage which many other countries have derived from it. Locomotive lines are too expensive for general use, and Brazil ought not, for several years to come, to attempt more than one locomotive line for each seaboard province, with the exception of Rio de Janeiro. These locomotive lines ought to run inwards, at right angles to the coast, for it is the interior that requires, and will most readily repay, the assistance of railways.

With the exception of the Amazon, on the north, and the Paraná on the south, Brazil possesses little internal water-communication: the rest of its rivers are obstructed by rocky rapids inland, and by impracticable bars at their mouths. Neither is it a country generally fitted for canal navigation; it must, therefore, always depend upon roads and railways.

Being convinced, by the experience referred to, that macadamised roads cannot be easily worked in Brazil, and that locomotive

lines are too expensive, except as trunk lines, the Author recommended the employment of tramways, and at the request of the President of the Province of Rio de Janeiro, he drew up a Report advising their use in a certain locality. In his Message last year to the Assembly, the President embodies that Report.

The railways now in progress, or in contemplation, are destined to work a commercial and social revolution in Brazil. They are all single lines. It is to be regretted, that in one instance, that of the Don Pedro Segundo Railway, the benefit which it ought to afford, will be diminished instead of increased, as the line is extended. After reaching a certain position inland, this railway loses its character as a trunk line, and branches to the right and to the left, in lines parallel with, and not far from, the coast; so that points will be reached, where it will be more economical to use common mule tracks for conveying produce to the seaports. On the other hand, had these two lengths formed one line extending into the vast expanse of the interior, the last mile would, in process of time, have become the most valuable.

Of a very different character is the proposed railway in the adjoining Province of San Paulo. Throughout its whole length, it runs in a rectangular direction from the coast. Another feature in its favour, is the means by which the ascent of the Serra is proposed to be effected. Whereas in the Don Pedro Segundo Railway, a route has been sketched out by North American Engineers, with a gradient, for many miles, of 1 in 55, for locomotive engines: on the San Paulo Railway, the Serra has been carefully examined, and a line selected for inclined planes.

There are now five railways in Brazil; the only one completed being the Mauá, a short line, and there are four others in progress. Two of these, the Don Pedro Segundo and the Canto Gallo Railways, run from the Bay of Rio de Janeiro; the third runs from Bahia, and the fourth from Pernambuco. There is one in abeyance, the San Paulo Railway.

Of these five railways, the San Paulo appears to open the most prosperous future. The Pernambuco Line lies nearly under the equator; it is not probable, therefore, that it will be assisted by a great increase of population through the instrumentality of immigration. But in the Province of San Paulo, the climate is similar to that of Spain. With a rich soil, bounded by the prosperous Provinces of Rio de Janeiro, Santa Catharina, and Rio Grande, and by the mineral Provinces of Goyaz and Matto Grosso, San Paulo offers great advantages to emigrants and colonists. It, most certainly, will be covered by an active and an abundant population.

Notwithstanding the stability and prosperity of Brazil, its public works and its agricultural operations are yearly becoming more and more embarrassed, on account of the scarcity of labour.

Hitherto, the supply of labour and the means of colonisation have been considered separately. In a Report upon a proposed road in the Province of San Paulo, and recently, in a document which the Author had the honour of placing in the hands of His Majesty the Emperor, the following system was advocated:—"That the Concessionaire of a public road should seek from the Brazilian Government, assistance in the importation of labourers with families; that the Government should liquidate the expenses incurred in the introduction of the females and younger children; that the enterprise should be charged with the expenses incurred for the male adults, and employ them at certain limits of wages in the formation of the road; that the most eligible sites should be fixed upon, on the borders of the road, for collections of cottages, and that these cottages should be prepared before the arrival of the people. The result would be, that the men, and their elder sons could, immediately after their landing, gain a livelihood. This would last during the construction of the road. In the meantime, the women and the children would cultivate sufficiently large parcels of ground, which ought to be allotted and given to the different families. Gradually, the temporary cottages would be replaced, by the emigrants themselves, by better structures, the children would become acclimatised, and ultimately, these collections of cottages would form the nuclei of future towns."

Public works might thus be made the instruments of populating the districts in which they are undertaken. The Author is informed, that this system, to a considerable extent, will be adopted on the San Paulo Railway. A sum of £10,000 will be set apart for the purchase of land to be given to the workmen.

In conclusion, the Author will refer to the important question of guarantees. Imprudently used, they may defeat the main object in view. Brazil has enjoyed a public credit unexcelled by any other nation, but by an injudicious treatment of the guarantee system, that credit, hitherto immaculate, may be stained.

Two very distinct methods of guarantee are in operation. The shares of the Don Pedro Segundo Railway appear only in the Brazilian market. Upon a stated capital, an interest of 7 per cent. is guaranteed, conjointly by the General and Provincial Governments. The shareholders of this railway have paid up only a small portion of the capital, and one-third of the whole has been raised by loan, in London, in the name of the General Government, at $4\frac{1}{2}$ per cent. This amount has been handed over to the company. The difference between the $4\frac{1}{2}$ and 7 per cent. is to form a sinking fund which will gradually replace the sum borrowed, and the capital of the company will thus, almost insensibly, be reduced by one-third.

The other method, that of guaranteeing foreign shareholders, as in the case of the two English companies managed by boards in London, does not, it must be confessed, owing to most unforeseen and unfortunate circumstances, offer much encouragement. It might have been expected, that with the guarantee of 7 per cent. from a Government whose public credit is so stable, the quotations of its funds on the English Stock Exchange, would not have varied so much as British Consols, and that investments in such undertakings would be eagerly sought after. The shares of each company are, however, at a discount. That company which appears to have caused this state of affairs, suffers the most severely: it has not only damaged a similar undertaking, but has prevented, for the present, perhaps the most legitimate of all Brazilian railway enterprises, from appearing before the British public. If no remedy can be found for the past embarrassments which have fallen upon one, or more of the Brazilian Railways, or no preventive for the future, it would be much more advantageous to the Brazilians to raise all railway money on loan, and avoid the threatened risk of one, or more of their main lines breaking down from financial disorder, when only half completed.

In England, the Empire of Brazil is scarcely better known than that of Japan. The dealers in securities only know, that her engagements are kept with unsurpassed faith; the merchant only knows, that she exports an immense quantity of coffee, and imports a large amount of English manufactures; but in reference to her past and present history, her resources, her people, her fertile lands, her constitution, and her probable future, all but utter ignorance prevails. The railway and other enterprises, now in the course of development, will dissipate much of the ignorance existing on this side of the Atlantic; and notwithstanding present railway misfortunes, it is to be hoped, that ultimately, Brazil, upon a calculation of the preponderance of good and evil, will not have to regret the epoch, when English capital, energy, and engineering skill, assisted her in utilising her own internal wealth.

[Mr. WEBB

Mr. WEBB said, that since the Paper was written, the formation of the San Paulo Railway Company had become an accomplished fact, and the works upon the line were about to be commenced.

Captain W. S. MOORSOM said, that the management of the works exhibited that administrative ability which every Engineer who entered a wild, or a new country must possess, in order to carry out, successfully, a project of that nature. He fully concurred in the observation, that Engineers must, in distant regions, conduct themselves with good temper, and must frequently combine with their own special duties, those of a superintendent, or clerk of the works. Much of the sickness of the labourers was, no doubt, attributable to the nature of the water in certain localities; but there was another circumstance which had a material effect upon the health of persons who worked in jungle countries. Under a tropical sun, where the soil was ferruginous, there was a greater tendency to fevers than elsewhere; those spots should, therefore, be avoided, as far as possible, in the selection even of a temporary habitation. With the single exception of the employment of slaves, and the high price of labour generally, in Brazil, almost all the statistical circumstances related in the Paper, seemed to apply to the tropics on the other side of the globe, where he had been principally engaged, especially in Ceylon. The soil was of the same character, and such facilities as did exist, were equally to be met with in both quarters. But he was astonished at the cost of £24,000, for a bridge which did not appear to have presented any great features of difficulty in construction; he supposed it must have arisen from experimental circumstances connected with it. It had been stated, that large erections had been made without the use of lime. That was a mode of building which he proposed to adopt for upright walls in Ceylon, where there were large quantities of stone, but where lime could only be procured at great expense. In tropical countries, the enormous masses of water, resulting from the sudden heavy rains, passed off with greater facility from dry stone erections, than from masonry built with lime.

Alluding to specimens of Brazilian vegetation upon the table, he remarked of one which resembled a twisted rope, that in Ceylon, it was used by the natives to swing themselves, in the manner of a pendulum, across rapid, or deep streams.

Mr. BIDDER,—President,—referring to the statement in the Paper, that the cost of a bridge with a span of 52 feet, had been £24,000, and that a period of nineteen months was occupied in its construction, inquired how that cost had been ascertained, and the particular circumstances which had occasioned the expenditure of so large a sum. A similar bridge could be constructed in this country, for about £1,500, or one-sixteenth of the price; and there

was no apparent reason why the cost of the cuttings and other works should not have been in the same proportion.

Mr. BRUNLEES observed, that the contents of such a bridge might be estimated at 1,000 cubic yards; it must have cost, therefore, as much as £24 per cubic yard.

Mr. WEBB replied, that the amount was taken from the books, such as they were, kept by the agents of the company. The chief expense was for labour and food. Owing to bad agency, large numbers of the stone cutters frequently remained nearly, and at times, wholly, idle, even for several days together, for want of tools and food, but their wages continued to be claimed and paid. The cuttings and other works had not been attended with the same difficulties.

Mr. Webb, in reply to a question from Mr. Errington, said, that he had purposely avoided discussing, at any length, the question whether the double-headed rail was generally serviceable; he had simply pointed out the advantage to be derived from it in such a country as Brazil. Some rails on the Mauá Railway, for example, having, after a short time, shown defects on one surface, instead of being thrown aside, were turned, and had remained in use to this day.

Mr. EVAN HOPKINS had had considerable experience as to the cost of labour, in carrying on large works in the interior of South America, near the equator. He was much surprised at the cost of the bridge, as he had never paid more than four dollars per cubic yard, for what might be termed ordinary bridges, across ravines, and for culverts, embankment walls, &c., connected with the watercourses and roads for the mines. With regard to the quality of the timber in the lower region of the tropics, it was the same as at Panama, very inferior, and almost useless for permanent works. Although there were large forests of timber, there was, comparatively, little wood near the level of the sea, serviceable for building. Hence, before undertaking great works in that region, it was important to know, that the quality of the timber within the tropics, greatly depended upon the elevation. Timber growing at more than 5,000 feet above the level of the sea, was superior for building purposes to the timber growing below that elevation; hence the cause of the difference of cost in different localities. As he had stated on a former occasion,¹ all the timber required for the Panama Railway bridges, &c., had to be brought from the United States. At the Marmato gold mines, the timber was brought from an elevation of about 6,000 feet above the level of the sea, and was found to be of very good quality. At Santa Anna, which was within 4° of the equator, and only about 3,000 feet

¹ *Vide Minutes of Proceedings Inst. C.E., vol. ix., pp. 77-88.*

above the level of the sea, he employed, and still continued to employ, wrought iron and cast iron for machinery, the wood of the country being unsuitable for that purpose. He had recently introduced the use of sulphate of copper, as a preservative for the framing and the mining timber. Upon his first arrival in South America, in 1834, to take charge of the Marmato establishment, he ordered a quantity of wood for machinery, houses, &c., and he was much struck with the remarks of the natives who had to supply the timber. They said they could not commence cutting it until the decline of the moon, because it had been proved, from time immemorial, that wood cut during the increase of the moon, was attacked by dry rot, and certain varieties would decay in less than three months. Europeans, on their arrival in the tropics, were apt to laugh at such a notion, and he confessed that, at first, he did not believe it, but he soon found, by numerous trials, that such was the fact; that timber cut in the tropics during the increase of the moon, was subject to rapid decay, or decomposition, whereas timber cut during the decline of the moon remained, for years, comparatively good. In the former period it was always full of sap; in the latter, much drier and more compact. Reverting to the subject of the Santa Anna mines, he stated, that iron was principally used for the machinery; but even in that locality, he obtained some timber for the framing which he had put up in 1839, and which had only broken down in November, 1859. Still, there was great difficulty in obtaining suitable timber in those climates at low elevations, and there was great expense attending the conveyance of timber from high elevations. At Marmato, he had paid as much as five hundred dollars, or six hundred dollars for pieces of timber for the axles of the stamping mills, in consequence of the expense incurred in bringing it from an elevation of 6,000 feet, down the mountains and across the ravines, to a spot, 4,000 feet above the level of the sea. He could fully confirm the statement, that the cost of labour was very considerably enhanced since 1847; all these questions should, therefore, be duly considered, before making estimates and undertaking any extensive works in South America.

Mr. ERRINGTON said, the Paper referred to the use of the double-headed rail, in a manner that had led him to ask for further information upon the subject. One advantage of that description of rail was shown to consist in the ease with which it could be turned, and in a country where the cost of materials was so largely increased by the heavy charges for transit, it was, undoubtedly, the best form of rail to employ. He had known these rails to have been in use, on one side, for eight, or nine years; and when they were turned, to have lasted equally long. He had largely employed this description of rail on some of the northern lines, and he could

[1859-60. N.S.]

state from personal knowledge, that upon portions of the South Western Railway, there were rails still in use, which had been laid down twenty-one years ago, and when he last inspected them, they were in very good condition. This was, of course, an unusual period of duration for rails, but those to which he referred, were of excellent quality.

Mr. HAWKSHAW, V.P., remarked, that it was of little value to state the length of time during which rails had been in use, without giving the number of trains which ran over them. Under certain circumstances, rails could be worn out in twelve months; in other cases, the same rails would last twenty-one years, or even more. Of the effect of tropical climates upon timber, he had been enabled to judge, by a residence there of nearly three years. But it was worthy of remark, that timber, when exposed to extremes of temperature, either of great heat, or intense cold, ceased to be durable. Having had some experience in its use, both in hot and cold climates, he had arrived at the conclusion, that it was not desirable to employ that material in either. It was probable, that in India, well-designed iron roads would prove the most serviceable. He did not consider, that rails supported by iron sleepers, were so well calculated for great velocities, as when they were laid upon timber; but speeds of 50 miles, or 60 miles per hour, were not required in those countries, and for all moderate speeds an iron road would be efficient. He was aware that in tropical climates, there were certain descriptions of skilled labour which cost considerably more than in this country; at the same time, it should not be forgotten, that an extravagant sum might be anywhere expended in dressing stone to particular forms, and there could not be any necessity for it, in constructing the bridge to which allusion had been made. Referring to a photograph of a structure with an ornamental arch, he thought the design was such as would make the dressing of the stone very costly in Brazil.

Mr. BRUCE said, it appeared from the Paper, that when the Author first went to Brazil, he found the implements used by the labourers, very crude and imperfect, and he introduced a mode of doing the work which he considered to be more effective. Mr. Bruce was desirous of knowing, whether any economy had resulted from the substitution of barrows and planks, for baskets and skins; for he had found it, in some cases, inexpedient to interfere with the ordinary native methods of doing work. He confirmed the statement in the Paper, that the sickness amongst the workmen was not so much due to the effects of the climate, as to the badness of the water which they drank. In carrying out works in hot climates, it was essential to supply, at almost any cost, good water to the labourers.

Reference had been made to the failure of the guarantee

system, and surprise was manifested, that the guaranteed shares of the Brazilian lines, should be at a discount. It had been said by the press, that so small was the confidence reposed by the British public in English management, that a Government which could, with ease, raise money at $4\frac{1}{2}$ per cent., failed to command it at par, although giving a guarantee of 7 per cent., when that condition was affixed to the undertaking. Now, the fact was this, that the guarantees, though given by the same Government, were altogether different. The Paper had shown the difficulties attending a survey through such a country as Brazil, its inaccessibility, and the unforeseen expenses which might be incurred, in spite of the most careful estimate. Was it, therefore, surprising, that a guarantee on a fixed sum, based upon an estimate made under circumstances where it might be greatly exceeded by the actual cost, so as to reduce the guarantee far below its original nominal value, should not command the same confidence as one not liable to such contingencies? To the difference between the nature of the respective guarantees, and not to any want of confidence in English management, was to be ascribed the different position of the two stocks in a market, where any element of uncertainty operated most injuriously.

Mr. FOWLER, V.P., remarked, that in considering the cost of works of this description, isolated facts were not of much value, without a full statement of all the circumstances connected with them. The Author had recommended the introduction of tramways, alleging that in countries like Brazil, railways would, in many cases, be too expensive. This question could not be discussed, without details of the kind of tramway recommended, its gauge, and the nature of the permanent way.

Mr. EVAN HOPKINS said, that with regard to the use of baskets and barrows, a distinction must be made between temporary and permanent works. It was not till some time after his arrival in South America, that he was enabled to introduce barrows amongst the native labourers, as they were accustomed to carry everything, even very heavy loads, on their backs, and the first barrows that were made were thus carried by the negroes, until they found the advantage of wheeling them. Baskets and bags were, however, often used to great advantage for temporary works in broken ground, not in the interior of South America alone, but also on certain portions of the railway works now carried on in Spain and Portugal; but in permanent works, such as mining, quarrying, &c., there was a great difference in the cost, if they were executed in the native fashion. The native labourers employed in the large establishments of South America, knew now the value of the barrow; they often accepted contracts, and there was very little doubt, that they were capable of adopting the best system of

mechanical appliances, if they were duly instructed by attentive and efficient agents. At the gold mines of St. Juan del Rey, in the interior of Brazil, the engineering and mining works were as well executed, as in any part of Europe.

Mr. WEBB, in reply, explained, that the photograph to which allusion had been made, was that of a drinking fountain built to commemorate a public event. Part of the cut stone had cost about £200, the number of blocks not exceeding eight. With regard to the difference in money value, between the common labour of the country and such labour as was ultimately adopted, he scarcely knew how to arrive at a just calculation. The dilatory manner in which the ordinary works of the country were conducted, precluded any satisfactory account of the cost, as to cubic measure, being kept. The earth was removed in small baskets, holding less than a cubic foot each; the work was carried on without any regularity as to the number of workmen, the hours worked, or the wages paid; the operations were suspended during trivial showers; so that there was no direct means of contrasting the cost of the two systems of labour. It had, certainly, been far from his intention to reflect upon English Engineers generally, with reference to their works in foreign countries: he had a very different feeling, in proof of which he would point to the concluding paragraph of the Paper.

With respect to the bridge of cut stone, which had attracted so much attention, it must be evident, that in bringing this subject pointedly before the Institution, he could have had no other object than to lay before his Fellow Members such information as he possessed, with reference to features which were, unfortunately, too frequently concealed, namely, the failures in works intrusted to their charge, either as regarded cost, or execution. He believed, that many Members would be able to recollect instances, within their own experience, where their calculations had proved erroneous. The calculations and estimates for this bridge were made, at a time when the financial prospects of the company were in a satisfactory condition. Timber was discarded, for the reasons he had mentioned in the Paper. The choice lay, therefore, between stone and iron. Comparative calculations led to the belief, that iron and stone would each cost about the same in that locality; but there was this difference; if iron had been selected, it would have been brought from England at the risk of a sea passage, having afterwards to meet the difficulties inseparable from a transit over rough mountain paths; whereas the stone being on the spot, there was every expectation of completing the work within a given time, so far as the supply of material was concerned. That the bridge should have cost such an enormous sum was not anticipated, and was chiefly due

to the incapacity of agents, and to the imperfections of a commissariat system over which he had no control. The workmen were irregularly paid ; and instances occurred of men working from ten months to twelve months without a settlement, during which time the company supplied food to the men, in addition to their pay. This food, sent from the city of Rio, one hundred and twenty miles distant, was often very bad, and at times, even putrid. The evils attendant upon this truck system, aggravated by the sense of wrong due to irregular and long-postponed payments, very often occasioned strikes amongst the workmen, and the works were either suspended, or the men worked sulkily. This, of course, considerably increased the expense, and protracted the period of completion. Then the river, over which the bridge was built, was subject to sudden and enormous tropical floods, during which the works were unavoidably retarded. Finally, the complete isolation of the locality tended to augment every difficulty and to add to the outlay. After some time had elapsed, it became apparent, that the estimate would, from the causes enumerated, be insufficient ; but the works themselves, and the general preparations, had advanced too far to justify a halt, or to make any great alterations : it was too late, in fact, to recede, and as the less of two evils, it was determined to follow out the original design.

He had brought this matter forward voluntarily ; certainly not for self-gratulation, but as a warning, and in order to show, that the introduction into foreign countries of works, which in England, either as regarded construction, or simple ornamentation, would possess no interest, might, under certain conditions, cause serious embarrassment, even though placed, as was this bridge, on one of the great highways of the empire. He believed, that shareholders might, occasionally, apply similar remarks to some works which had been carried out, even in this country. In confirmation of some of his views, he might be allowed to quote a paragraph from a work by Mr. Hawkshaw,¹ in which it was said, that "it takes a long time for matters at such a distance, to be well understood in England." That remark was frequently applicable, even at the present day, to foreign works.

In conclusion, he would remark, that he who openly and frankly pointed out to others his failures, or errors of judgment, was the most likely person to avoid their repetition.

Mr. BIDDER,—President,—said the object of the practical Engineer was not so much to produce works which should impress the mind, as to accomplish certain purposes in the most economical

¹ *Vide* "Reminiscences of South America, from Two-and-a-half Years' Residence in Venezuela." By John Hawkshaw, F.G.S., M. Inst. C.E. London, 1838. Page 110.

manner. It was not surprising, therefore, that criticism should have been excited by the statement, that a stone bridge with a span of only 52 feet, had cost £24,000. The explanation, however, which had been given, reflected the highest credit upon the Author, and added to the obligation the Meeting was under to him, for bringing the Paper before the Institution.

He believed there was a general feeling, that slave labour could not be profitably employed upon works of this description. Although it might be cheaply obtained, it always proved to be less valuable, than free labour paid for at a much higher price; and the result of his own experience was, that in scarcely any country in the world, could the same amount of work be done at so small a cost, as in England. He concurred in the opinion, that in tropical climates, where wood was subject to rapid decay, it was very desirable, when practicable, to substitute iron; but he did not think, that iron could be used to equal advantage, in extremely cold regions. In many instances, iron sleepers were preferable to those of any other description. On the Egyptian Railway, Greaves's sleepers were used, and the Pacha of Egypt travelled, with his own special engine and carriage, upon that line, at a speed which was scarcely exceeded in England. With regard to the prosecution of railways under guarantee, it was an anomalous plan, and, in his opinion, an unsatisfactory one, for he thought it reflected, to some extent, upon the administrative qualifications of those who took charge of the works. His own conviction was, that if the guarantee, instead of being placed in the hands of directors, had been given to an experienced contractor, the stock of the company would have maintained a higher position.

February 7, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

The following Candidates were balloted for, and duly elected :
THOMAS MASTERMAN HARDY JOHNSTON, EDWARD PURSER, JAMES LAURIE RICKARDS, RICHARD JAMES WARD, FRANCIS WILLIAM ISHERWOOD WEST, AND EDWARD LEADER WILLIAMS, junior, as Members ; EDWARD MIDDLETON BARRY, EDWIN BARTON, FREDERICK ROBERT BROWNING, ANDREW CUTHELL, THOMAS BARNABAS DAFT, ROCHFORD ASTLE SPERLING, and JAMES WILSON, as Associates.

No. 1,017.—“ Description of the Works on the Netherton Tunnel Branch of the Birmingham Canal.” By JAMES RALPH WALKER, M. Inst. C.E.

THE system of inland navigation was introduced into South Staffordshire at an early period. Without the facilities which it afforded for the conveyance of minerals and heavy goods, the mining and manufacturing industry of the district could not have been developed to its present extent. That its advantages have been appreciated may be inferred from the fact, that the Birmingham Canal Company now possesses 157 miles of canal, the ramifications of which reach nearly every colliery and ironwork in the district. Notwithstanding the construction of several railways, on which a large quantity of mineral produce is carried, the traffic on the canal continues to increase. In 1832, the total quantity of coal conveyed was 1,492,000 tons ; and in 1854, it had increased to 3,100,000 tons.

The canal is on several levels, named after the chief towns situated on them. The Wolverhampton Level is $52\frac{1}{2}$ miles in length, and 484 feet 3 inches above low water at Liverpool. The Birmingham Level is $34\frac{1}{2}$ miles in length, and 19 feet $10\frac{1}{2}$ inches below the Wolverhampton Level. The Walsall Level is 20 miles in length, and 45 feet below the Birmingham Level. There are also other levels, 50 miles in length. These levels are connected with each other, and with canals belonging to other companies, by upwards of two hundred locks. The most modern locks are 75 feet 8 inches long between the gates, and 7 feet 3 inches wide between the quoins. The largest boats which navigate the canal are 71 feet 3 inches, or, including the rudder, 74 feet 3 inches

in length, and 7 feet 1 inch in width. Their light draught is about 8 inches, and their loaded draught 3 feet 2½ inches. They carry about 33 tons; but, owing to the system of measurement in use, they pay toll only on about 26½ tons.

The natural features of the country offer considerable difficulties in the construction of canals. Through Rowley Regis, Dudley, and Sedgley, there extends a line of hills, portions of which rise to a height of more than 400 feet above the Wolverhampton Level. This range forms part of the watershed of England; the drainage on the south side being into the Stour, which falls into the Severn, and on the north side into the Tame, and thence into the Trent.

A passage through these hills, whether for a canal, or a railway, rendered the construction of a tunnel indispensable. Accommodation had long been afforded by the Old Dudley Tunnel, but its small size and the increase of the traffic, both conduced to render it insufficient. The object of the works described in this Paper, was to effect such a communication as would meet the urgent requirements of the district. In the year 1768, an Act of Parliament was obtained, for the construction of a canal, on the north side of the hills, from Birmingham to the Staffordshire and Worcestershire Canal at Autherley, near Wolverhampton. This was the first canal constructed in the locality. According to the system adopted at that period, and for some time afterwards, it followed nearly a contour line along the slopes of the hills. The length of the canal, therefore, was 22 miles, although the actual distance, in a straight line, is only 13 miles. In 1824, Mr. Telford was engaged to improve this canal. By cutting off the bends, the length was reduced to 14 miles, and by making a deep cutting at Smethwick, the necessity for three locks at that place, was obviated; the same level being carried from Birmingham to Tipton. A towing path was also formed on each side, and walls were substituted for the slopes, so that the whole width of the canal was made available. A sum of £500,000 was expended on these improvements, between Birmingham and Westbromwich.

Although not immediately connected with the works which form the subject of this Paper, it may be mentioned, that in 1841-43, a canal had been constructed from Toll End to Gravelly Hill, near Birmingham, from the designs, and under the superintendence of Mr. Walker, (Past-President Inst. C.E.) It is called the Tame Valley Canal, is about 8 miles in length, and has thirteen locks. Both from the magnitude of the works and the excellence of their execution, it is the most remarkable part of the Birmingham Canal.

In 1776, a canal had been constructed, by the Dudley Canal Company, on the south side of the Hills, from the Worcester Canal, at Selly Oak, to the Stourbridge Canal, at Brierly Hill.

This canal was on the Birmingham Level, and a communication was effected between it and with the Wolverhampton Level of the Birmingham Canal, at Dudley, by means of a tunnel, having three locks at the south end. In 1846, the Dudley and Birmingham Canal Companies were amalgamated.

The Dudley Tunnel is 3,200 yards in length. In the portions lined with brickwork, it is about 8 feet wide, and its height is 6 feet above the water level. There not being any towing path, the boats are propelled through it, by men lying on their backs and pushing with their feet against the sides and roof of the tunnel; this process is called 'legging.' It is performed by two men, hired for the purpose, who are paid at the rate of three shillings and sixpence for each boat. The time occupied in the operation is, usually, about three hours and a half. As, however, boats cannot pass one another in the tunnel, a certain number can only be admitted, alternately, at each end. Before the traffic was relieved by the construction of the works described in this Paper, the delay at the entrances was very great, as many as one hundred boats being frequently detained there for several hours, and in some cases, even for some days. In dry seasons, when the water in the canal fell below the usual level, boats had to be partially unloaded before entering the tunnel, and the cargoes were thus exposed to pilfering, which was carried on, to a great extent. The tunnel being placed on the summit, or Wolverhampton Level, while all the canals at the south end, and most of those at the north end, were on lower levels, many of the boats had to ascend and descend three locks; this would have been unnecessary had the tunnel been on the Birmingham Level. Notwithstanding these inconveniences, this tunnel continued, for many years, to be the only means of communication between the Birmingham and the Dudley Canals. In 1845, 25,916 boats; in 1853, 41,704 boats; and in 1854, 39,025 boats, carrying 438,000 tons, passed through it. The decrease in 1854 was caused by the dryness of the season, which rendered it impossible to maintain the proper depth of water in the canal.

At length, the complaints of the coal and the iron trades, became so urgent, that the Committee of the Canal Company were compelled to take into consideration a plan which had frequently been pressed upon them by Mr. Freeth, their Secretary. This was the construction of a new canal and tunnel, on the Birmingham Level, from Netherton to Dudley Port. It was shown, that the distance between Netherton and Birmingham might be thus reduced 4 miles, and the ascent and descent of three locks be avoided; while owing to the increased size of the proposed tunnel, the passage of boats through it, could be rendered as easy and expeditious as on any other part of the canal. The highest ground

on the route was 354 feet above the water in the canal. In 1854, Mr. Walker was consulted, and in the following year, an Act authorising the construction of the works was carried through Parliament, and received the Royal assent in July, 1855. The drawings and specifications having been prepared by Messrs. Walker, Burges, and Cooper, the contract for the execution of the whole of the works was let, in November, to Mr. George Meakin, of Birkenhead. The Author was appointed the Resident Engineer, having under him seven inspectors of works, the chief of whom was James Sager. A Committee, of which Sir G. Nicholls, Bart., was the Chairman, had the direction of the undertaking. The first sod was turned by Lord Ward, at shaft No. 7, on the 28th of December, 1855. On the 17th of January, 1856, the sinking of the first shaft was commenced, and on the 19th of March, 1856, the excavation of the tunnel was begun, at shaft No. 15. On the 4th of April, the first brick in the tunnel was laid in the south side length, at shaft No. 15; and on the 25th of March, 1858, the last brick was laid by Mr. Walker, in the arch of the junction length, between shafts No. 7 and No. 8. On the 20th of August, 1858, the whole of the works were formally opened for traffic.

The time occupied in the construction of the tunnel, from the commencement of sinking the first shaft, to laying the last brick, was two years and seven months. The length of canal constructed is $2\frac{1}{2}$ miles, comprising one quarter of a mile of embankment, half a mile of open cutting, and one mile and three quarters of tunnel. There are three embankments, containing, in all, 106,000 cubic yards, the greatest height being 26 feet. The embankments are, generally, 54 feet wide at the water level; but part of embankment No. 3 was made 66 feet wide at that level, to allow of an anticipated subsidence, which has since occurred, from the working of the mines underneath. The slopes of all the embankments were formed with an inclination of 2 to 1. There are four cuttings, from which the total quantity of earth removed, was 136,000 yards. Cuttings Nos. 1, 3, and 4, are 46 feet wide; and cutting No. 2 is 40 feet wide at the water level; the slopes in all cases being $1\frac{1}{2}$ to 1. The materials excavated were, principally, clay and marl, which stood well at that slope, except in cutting No. 2, where an extensive slip occurred, which threatened to carry away a large pumping engine and to damage two coal pits, situated close to the top of the slope. This rendered necessary the construction of retaining walls in that cutting. The width of the waterway of the canal is 30 feet, except in cutting No. 2, where it is 24 feet. A towing path was formed on each side, 8 feet wide in the cuttings, and 12 feet wide on the embankments. The bottom and sides of the canal were lined with puddle, 2 feet thick in the

cuttings and 3 feet thick on the embankments ; the puddle at the sides being carried up to 6 inches above the water level. The puddle was made with clay, spread in courses 8 inches thick, twice cut, and well trodden. The total quantity of puddle, including that used in the tunnel, was 53,000 cubic yards. On the puddle at the bottom, a layer of furnace cinders 6 inches thick was spread, the lower 4 inches being broken so as to pass through a ring 4 inches in diameter, and the remainder, which was mixed with fine ashes, so as to pass through a ring 2 inches in diameter. The thickness was increased at the sides to form a toe for the towing path walls. These cinders were intended to protect the puddle from injury by the boat hooks, &c., which, especially, on embankments, might cause serious damage. On these cinders the towing path walls, 2 feet 3 inches and 1 foot $10\frac{1}{2}$ inches thick, were built of brick ; fine ashes, to the thickness of $4\frac{1}{2}$ inches and 9 inches, being introduced between the walls of the puddle at the sides. The walls were carried up to the water level, and on them were placed iron guards, $\frac{3}{4}$ ths of an inch thick and 9 inches wide, cast in lengths of 12 feet. They were dovetailed into each other at the ends, and weighed 96 lbs. per yard. A lug was cast on each, projecting beyond the back of the wall, against which it was keyed up, by a cast-iron plate, 1 foot 6 inches long, and a wrought-iron key. Where the canal is curved, and where the walls are liable to be struck heavily by boats, the thickness of the brickwork was increased to 3 feet and 2 feet $7\frac{1}{2}$ inches, the guards being made 2 inches thick, and each being fastened down by two bolts, $1\frac{1}{4}$ inch square. These guards weigh from 290 lbs. to 400 lbs. per yard, and on them were bedded the coping bricks, 12 inches by 12 inches by $4\frac{1}{2}$ inches in section, rounded on the edge, and jointed in mortar. The coping is set back $3\frac{1}{2}$ inches from the front of the guard, but in exposed places it is increased to 7 inches, to avoid blows from the raking stems of the iron boats now in use.

The walls of the towing path being placed on new puddle, great care was necessary in their construction. A certain amount of settlement was unavoidable ; but to render it as uniform as possible, the brickwork was built in long lengths, and not more than 18 inches in height at one time. It was then allowed to stand, for some days, before building another course. In order, also, to prevent the walls from being forced forward, by the pressure of the puddle at the sides, the water was, where practicable, gradually admitted into the canal, as the puddle was carried up. Where this could not be done, timber struts were placed from wall to wall, which were not removed until after the admission of the water. These precautions were absolutely necessary, while the walls and puddle were new ; but after the work had set, they were not required. The water

has since been drawn out of several parts of the canal, without occasioning the slightest movement of the walls.

The towing paths were covered to a depth of 6 inches with well-burnt red ashes, from the puddling furnaces in the neighbourhood, which make an excellent and durable horse road.

Open channels were formed at the sides of the cuttings, which drain into the canal, through cast-iron pipes, 3 inches in diameter, provided for that purpose, at intervals of 100 feet. For the accommodation of the collieries and ironworks situated near the canal, seven basins, or docks, were made, varying in size from 300 feet by 33 feet to 75 feet by 24 feet. The construction of these basins is similar to that of the rest of the canal, except that timber wharfing is substituted for the iron guards and coping. This consists of two longitudinal fir planks, 11 inches by 3 inches in section, resting on oak sleepers, 8 feet 6 inches in length and 8 inches by 4 inches in section, placed 6 feet apart, with short sleepers in the intervals. The long sleepers are secured at the end to a T-piece and to two short piles. Instead of using bricks, the walls of two of these basins were built with cinders procured from the blast furnaces in the vicinity, and broken into pieces of convenient size. They were built in a species of rubble work, in courses about 2 feet high, large pieces being placed as binders. The cinders were solidly buried in mortar, and the walls were neatly pointed on the face. This material formed a substantial and durable wall, at about half the price of brickwork. The foundations of many of the bridges were carried up to the level of the ground with this material, and several of the retaining and fence walls were built with it.

Towing-path bridges were built over the entrances of three of these basins, the abutments and wing walls being built on the canal walls, which were strengthened for that purpose. The superstructure consists of two cast-iron girders, resting on stone imposts. The cast-iron covering plates are $\frac{3}{4}$ ths of an inch in thickness, and are furnished with ribs 5 inches deep, secured to each other, and to the girders, by bolts $\frac{3}{4}$ ths of an inch in diameter. The joints are caulked with iron cement. On the girders are built brick parapets 14 inches in thickness, finished with a semicircular brick coping. Four bridges, all of similar construction, were built to carry the roads over the canal. The bridge which carries the Birmingham and Sedgley Turnpike Road has two spans, of 42 feet 5 inches and 8 feet 7 inches, respectively. The pier and abutments are of brickwork, with stone imposts and coping. The girders are of cast iron placed 3 feet 10 inches apart, those for the larger opening being 47 feet in length, and 2 feet 3 inches in depth. Each girder weighs 6 tons 3 cwt., and was tested with a weight of 20½ tons at

the centre, when the deflection was 0·96 inch, and the permanent set was 0·10 inch. The roadway plates are of cast iron, 3 feet 8 inches by 4 feet 6 inches and $\frac{3}{4}$ ths of an inch thick, with ribs cast on them; they are secured to each other by bolts $\frac{3}{4}$ ths of an inch in diameter, passing through the girders. The joints of the plates are caulked with bituminous cement. Brick parapets, 4 feet 6 inches in height above the road and 14 inches thick, were built on the face girders. Six bridges were built at the junctions, to carry the towing path across the canal. The spans vary from 39 feet to 50 feet. The abutments and wings are of brick, with stone quoins and imposts. The girders, which also form the parapets, were each cast in one piece, those for the span of 50 feet being 55 feet long and 3 feet 3 inches deep; each girder weighs 5 tons 8 cwt. The bridge, when put together, was tested with a weight of 26 tons equally distributed, under which the girders deflected $\frac{3}{8}$ ths of an inch. On the bottom flanges of the girder are placed the cast-iron roadway plates, which are $\frac{3}{4}$ ths of an inch thick, with ribs 5 inches deep, and are bolted to each other and to the girders, with bolts $\frac{3}{4}$ ths of an inch in diameter. The joints are caulked with iron cement.

At Tividale, near the north end of the tunnel, the Wolverhampton Level Canal is carried over the new canal, on a brick aqueduct of three arches, two with a span of 19 feet, and the other, of 9 feet 3 inches. The waterway is 30 feet wide and 5 feet 6 inches deep, with a towing path 8 feet 10 $\frac{1}{2}$ inches in width on each side. The piers are 4 feet 1 $\frac{1}{2}$ inch, and the arches are 1 foot 6 inches thick. A layer of puddle, 2 feet thick, was carried over the arches, and the trough of the canal was completed as before described. At each end of the aqueduct, a cill and grooves were placed, to receive stop planks, whenever it may be required to draw the water out of the canal. The cills are of elm, 35 feet long and 1 foot 2 inches by 1 foot in section, bedded on and bolted down to a brick wall, 2 feet high, built for that purpose. The grooves are of cast iron, built into and bolted to the towing-path walls. The bottom of the canal is protected by an apron of bricks, laid on end, in cement, for a width of 8 feet on each side of the cill.

Near Dudley Port, the canal is carried over an occupation road, on a brick aqueduct 81 feet long. The span of the arch is 20 feet, with a versed sine of 7 feet; its thickness is 1 foot 6 inches. Under the Wolverhampton Level Aqueduct, there are two stop locks, each 87 feet long and 8 feet wide, with stop gates, cills, and grooves at each end. The locks are built of brick, with stone cutwaters, quoins, and coping. The gates are 9 feet 5 $\frac{1}{2}$ inches wide, 5 feet 10 inches high, and 9 inches thick. The framing of the gates is of oak, covered with fir planking 2 inches in thickness.

Each gate is furnished with a sluice and an elm paddle 1 foot 6 inches square. The hollow and clap quoins are of cast iron, $\frac{3}{4}$ ths of an inch thick, secured to the stonework with split bolts.¹ The main cills are of oak, 15 inches by 10 inches in section, built into the brickwork. The clap cills, which are of elm, 9 inches by 8 inches in section, are secured to the main cills by screw bolts and plates. The recesses for the gates are covered with cast-iron plates, $\frac{3}{4}$ ths of an inch thick, chequered on the top, and secured to the coping by split bolts. Each cutwater is protected by a strong iron guard, weighing 3 tons, cast in three pieces, and fastened down with bolts $1\frac{1}{2}$ inch square. The top of the pier is paved with bricks, laid on edge, in mortar. As all the boats are gauged in these locks, by toll-keepers stationed there for the purpose, an office was built on the pier, and booms are provided, which can be secured across the lock, to prevent the passage of boats during the absence of the toll-keepers; when not in use, these booms are floated back into recesses. There is also a swing plank to each lock, to enable the toll-keepers and boatmen to cross. These planks are of fir, 11 inches by 2 inches in section, bound with iron; they work on a pivot at one end, so as to swing freely, in either direction, when struck by a boat. Six stop cills were provided, so as to allow the water to be withdrawn from any part of the canal when required. Their construction is similar to those at the Wolverhampton Level Aqueduct previously described.

For the construction of the tunnel, seventeen shafts were sunk; those positions being selected which offered the greatest facilities, on the surface, for the deposit of spoil, &c. The distance between the shafts varied from 164 yards to 200 yards. Of this number, ten were merely intended for use during the construction of the tunnel; and seven were proposed to be left permanently open for ventilation. Four of the temporary shafts were lined with timber, and were 9 feet by 8 feet in the clear. The curbs, or settings, were of fir timber, 11 inches by 10 inches in section, placed 6 feet apart, and close boarded behind; these shafts were afterwards filled up. Six of the temporary shafts were lined with brickwork, the internal diameter being 8 feet. One of these was filled up on the completion of the tunnel, but the others were covered with cast-iron plates, about 5 feet below the surface. The permanent shafts were all lined with brickwork, 9 inches thick; one, which was worked with a horse gin, was 10 feet in diameter, and the others were 9 feet in diameter. The brick lining was supported on the arch of the tunnel by a cast-iron curb, weighing

¹ Cast-iron quoins have long been in use on the Birmingham Canal, and are found to be preferable to those of wood, or stone.

9 tons, in four pieces, strongly bolted together. Skewbacks were cast on the back of the curb, to receive the rings of the arch.

No attempt was made to 'coffer' out the water met with in the shafts. It is received in zinc gutters, nailed to the curbs, and is conducted by a cast-iron pipe, fixed down the inside of the shaft, and in a groove built in the soffit of the tunnel, to the back of the towing path, and under it into the canal. After the completion of the tunnel, the permanent shafts were carried up 12 feet above the surface, and were finished with a moulded brick cornice, and covered with a wrought-iron grating. The whole of the shafts were sunk by the ordinary method. The material having been removed to a depth varying according to the nature of the ground, an oak curb, 9 inches by 3 inches in section, was placed on the bottom, on which the brickwork was built. The excavation of the length below was then proceeded with, the curb being temporarily propped, until under-pinned by the brickwork brought up from the curb below. The brickwork of the shafts was laid in mortar, in alternate header and stretcher courses, the headers being moulded to the proper radius. Cement was only used in places where the ground was very wet. The total depth of all the shafts was 3,083 feet, of which 2,293 feet were lined with brickwork. The greatest depth of any of the shafts was 344 feet 6 inches, and the least depth was 65 feet 9 inches.

The average rate of progress, per day of twenty-four hours, from the commencement to the completion of each shaft, was 2 feet; but counting only the days on which work was actually done, it was 3 feet 4 inches. The ground was, principally, marl and 'bind;' but coal and basalt were met with in several of the shafts.

The tunnel is 3,036 yards, or nearly $1\frac{3}{4}$ mile long, 27 feet wide, and 24 feet 4 inches high in the clear. The waterway is 17 feet wide, 6 feet deep in the middle, and 5 feet at the sides. The height from the water level to the soffit of the tunnel is 15 feet 9 inches. The thickness of the brickwork of the tunnel is, generally, 1 foot $10\frac{1}{2}$ inches in the walls and arch, and 1 foot $1\frac{1}{2}$ inch in the invert; but in the side and shaft lengths, the walls and arch are 2 feet 3 inches thick. In places, also, where the ground was found to be bad, the thickness of the walls and arch was increased to 2 feet 3 inches, and of the invert, to 1 foot 6 inches and 1 foot $10\frac{1}{2}$ inches.

The lengths of the various sections of tunnel as built, were :—

	Ft.	In.	Ft.	In.	Yards.
Walls and Arch	1	10½	Invert	1	1½
"	1	10½	"	1	6
"	1	10½	"	1	10½
"	2	3	"	1	1½
Total length . .					3,036

It was, however, discovered, that in several places, where the foundation was 'blue bind,' or marl, the invert was forced up in the centre, owing to the swelling of the ground. This was not accompanied by any subsidence of the side walls; and although the brickwork was, in some parts, raised 5 inches, it was not broken, or crippled, except at a point immediately south of shaft No. 7. Here the invert having been forced up 8 inches in the centre, and some of the bricks crushed almost to powder, it was cut out and rebuilt 1 foot 10½ inches thick, for a length of 130 feet. This was done in short pieces, of about 6 feet at a time, the side walls being carefully strutted. In rebuilding a portion of this invert, 49 feet long, the versed sine was increased to 2 feet 6 inches.

The trough of the canal in the tunnel was formed in a similar way to that in the cuttings, the puddle at the bottom being covered, with broken cinders, to a depth of 6 inches. The towing-path walls, 1 foot 10½ inches thick, were protected by cast-iron guards, weighing 141 lbs. per yard. Each guard was held back by a wrought-iron tie, 1½ inch in diameter, to a cast-iron plate built into the wall of the tunnel. Sockets, 6 feet apart, were cast on the guards, into which were keyed the standards of the wrought-iron railing for protecting the towing path; this railing is 2 feet 8 inches high. The standards are 1¾ inch by 1¾ inch; the top rail is of half-round iron, 3 inches by 1½ inch, screwed down to the standards, and joined with a lap piece and two rivets. The lower rail is of round iron, 1½ inch in diameter, passing through and keyed into an eye forged in the standards, and joined at the ends by a wrought-iron screw ferule. The towing paths are covered with red ashes, to a depth of 6 inches.

As soon as the sinking of any shaft was completed, the excavation of a bottom heading, in each direction, was immediately commenced, and was proceeded with until it met that driven from the next shaft. The size of the heading was 5 feet by 3 feet, the bottom of it being level with the top of the intended invert. The construction of the tunnel was proceeded with, without waiting for the completion of the heading. The Author is glad to be able

to state, that no part of the tunnel was one inch out of the straight line; and when the water was admitted, the guards were found to be exactly level. This remark does not, however, now apply to a short piece of about 300 feet, at the south end of the tunnel, where, as early as June, 1857, it had been discovered and reported by the Author, that a subsidence was going on, from mining operations. Although these operations were immediately stopped, the sinking continued, so that at the date of opening, the tunnel was, at that place, about 10 inches lower than when it was built. The guard and towing path walls were, necessarily, raised accordingly. Similar depressions, although to a smaller extent, have also taken place near shafts No. 14 and No. 15.

The process of the excavation of a tunnel has been so minutely described by Mr. F. W. Simms, (M. Inst. C. E.,) in his work on "Practical Tunnelling,"¹ that it is unnecessary to repeat it here. The lengths excavated varied from 12 feet to 13 feet, and they were supported by timber in the usual way.

When the construction of the tunnel was proposed, a considerable diversity of opinion existed, as to the nature of the strata to be passed through. On the geological map, a mass of trap rock is shown, about a mile wide, at this point. This, which is locally called 'Rowley Rag,' is extensively quarried on the surface, for road metal and paving. It was, therefore, anticipated, that great expense would be incurred in excavating the tunnel; but in the borings, some of which were close to the summit, no trap whatever was met with. While the excavation of the shafts and tunnel was progressing, a careful record was kept of the strata passed through. With the exception of some apparently unconnected pieces, the only trap rock met with was a wall, or dyke, about 8 feet thick, a little to the north of shaft No. 7. From its inclination and position, this appeared to be the channel through which the trap rock had risen and spread over the surface. On the north side of the dyke, the strata were principally marl, coarse sand rock, and a hard shaly clay, locally called 'blue bind.' On the south side, marl and bind were likewise extensively met with; but coal, bat, ironstone, and fire clay were also passed through in several places.

The brickwork of the tunnel was laid in mortar; that of the side walls being built in old English bond, and that of the arch and invert in half brick rings, with headers where two courses coincided. The skewback of the invert was built with large bricks, moulded for that purpose. Five stop cills were placed in the

¹ *Vide* "Practical Tunnelling, &c." By F. W. Simms. 8vo. 2nd Edition. London, 1859.

[1859-60. N.S.]

tunnel, and one at each end, to enable the water to be withdrawn from any part, when required. The tunnel fronts were built entirely of brickwork, with curved and battering wing-walls. The face of the arch and the coping consist of large moulded bricks.

Nine men were killed, and eighteen were seriously injured during the construction of the tunnel. Of those killed, one fell down shaft No. 11, one was drowned in the sump of shaft No. 7, five were killed by skips, stones, &c., falling down the shafts, and two by stones, or materials falling on them while mining. Of those injured, two were drawn over the pulley at the top of shaft No. 10, owing to the carelessness of the engineman; eight were injured by stones, or materials falling on them while mining; four by skips, or materials falling down shafts on to them; two fell off the scaffolding, and two were hurt by the machinery on the surface.

The mortar used throughout the whole of the works was made with four parts of Hayhead lime, which is strongly hydraulic, measured before being slacked, four parts of sand, and one part of ashes. The lime was ground for twenty minutes under edge stones, during which time the sand, ashes, and water were added. Four mortar pans, driven by an engine of 20 H.P., were erected at Tividale, and two, driven by an engine of 12 H.P., at Windmill End. This mortar was found to set so satisfactorily, that cement was not used even in the tunnel, except where the work was required to set in a few hours. The cill walls, aprons, &c., were, generally, built in mortar, and the coping was set with it. The whole of the brickwork, except in the arches, was laid in alternate courses of header and stretcher on the face; all the inside work being of headers. The courses throughout were horizontal, splayed bricks being moulded for the fronts of the battering walls. Hoop-iron bond was used in some of the more important bridges. The total quantity of brickwork, including the tunnel, was about 75,000 cubic yards. The bricks used in the tunnel and throughout the works, except in the face work of the bridges, were Staffordshire brown bricks. Great care was taken, that only those of the best quality were brought on the works. A Table, showing the strength of these bricks, is given in the Appendix; (page 276). The pressure borne by each brick before crushing, varied from 14 tons to 31 tons, equal to an average of 75 tons per square foot. The bridges and tunnel fronts were faced with the best Staffordshire blue bricks. Some of the coping bricks were of unusual size, those on the tunnel fronts were 2 feet 3 inches by 1 foot 6 inches in section, and were believed to be the largest bricks ever made in Staffordshire. The stone used was principally a sandstone from Duke's Quarry, in Derbyshire.

In order to complete so large a work within the time specified, it was necessary for the Contractor to provide a considerable plant, and to make extensive arrangements for the supply and delivery of materials. A wharf was constructed on the old canal at Tivdale, and another at Windmill End. For the conveyance of materials from these yards to the shafts, a tramway of the gauge of 2 feet 6 inches was laid over the whole length of the tunnel, with passing places and sidings at each shaft. Carpenters', smiths', and fitters' shops were also erected at Tivdale.

The Paper is illustrated by a series of diagrams, and by a section of the strata passed through in constructing the tunnel.

[APPENDIX.

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APPENDIX.

NETHERTON TUNNEL BRANCH, 1858.

EXPERIMENTS as to the power of BRICKS to resist a CRUSHING FORCE, applied by a
HYDRAULIC PRESS.

Place of Manufacture.	Description.	Weight of one Brick.	Size of one Brick.	Surface exposed to Pressure.	Average Pressure when Crush- ing com- menced.	Average Pres- sure, per Square Inch, when Crush- ing com- menced.	Average Pres- sure, per Square Foot, when Crush- ing com- menced.
		lbs.	Inches.	Tons.	Tons.	Tons.	Tons.
Old Hill . . .	Brown	9·78	$9\frac{1}{2} \times 4\frac{1}{2} \times 3\frac{1}{2}$	38·7	31	0·80	115
Tivendale . . .	Blue	8·92	$8\frac{3}{4} \times 4\frac{1}{2} \times 3\frac{1}{2}$	36·09	22·5	0·62	89
Oldbury . . .	Brown	9·25	$9 \times 4\frac{1}{2} \times 3\frac{1}{2}$	40·50	20	0·50	72
Dudley Port . .	Brown	9·58	$8\frac{1}{2} \times 4\frac{1}{2} \times 3\frac{1}{2}$	36·125	16·5	0·46	66
Oldbury . . .	Brown	9·53	$9 \times 4\frac{1}{2} \times 3\frac{1}{2}$	38·25	14	0·37	53
Netherton . . .	Brown	9·78	$9 \times 4\frac{1}{2} \times 3\frac{1}{2}$	38·25	14	0·37	53
Stourbridge . .	Fire	7·25	$9 \times 4\frac{1}{2} \times 2\frac{1}{2}$	40·50	27	0·67	96

NOTE.—The Bricks were tested in pairs, with two thicknesses of millboard between them and the press, and between each other. The Brick was assumed to have commenced crushing, on the first appearance of bursting, or shelling off.

[Mr. LOCKE,

Mr. LOCKE, M.P., (Past-President,) said, this was a valuable Paper, and he wished more of the Members would imitate the example of the Author, and give the Institution the result of their experience. The construction of so extensive a tunnel, although it did not present any peculiar difficulties, was a work in which all must feel great interest. He regretted, however, that so favourable an opportunity had been lost, for placing upon record the entire stratification of the hill, as the great number of shafts afforded sufficient means of obtaining that information, and it would have materially increased the value of the Paper. Having the stratification of each shaft, it would not be difficult to fill up the intervening portions. Among the tunnels constructed under his direction, there was one on the Manchester and Sheffield Railway, longer than the Netherton Tunnel, but it did not present such peculiarities of stratification as were met with in the work under consideration. In the latter there was a superficial stratum of trap, and a small trap vein piercing through from below the tunnel, which, in the opinion of the Author, had been the feeder of the large overflow, or bed of trap, which lay on the surface, and it would have been desirable if the connection between the two had been traced, and exhibited, in section: sufficient data had, however, been given to show, that the assumed presence of trap rock need not deter Engineers, from making a tunnel in the localities where it existed.

The fact, that a tunnel of this extent, with so many shafts, had been constructed with less than an inch of deviation in the line, reflected the highest credit upon all engaged upon it. Although he had had some experience in tunnelling, he could not, in any case, boast of such accuracy as had been recorded in the present instance. In one of the first tunnels he constructed, at Liverpool, there was a deviation of 7 inches; but it was, fortunately, discovered in time to take advantage of the distance between the shafts, and the error was corrected before it was too late. He made this statement, in order that the younger Members of the profession might be induced to spare no pains, so to perfect their lines and levels as to render the chances of error the slightest possible; for where, as was often the case, the masonry of a tunnel had to follow quickly upon the mining operations, if both were not properly attended to, most important and serious consequences might arise.

Mr. J. R. WALKER said, the section was merely a rough record of the strata passed through, in carrying out the works. He did not feel himself sufficiently conversant with geology, to be competent to fill up the vacancies between the shafts; he could only state, generally, that the whole of the ground was very much broken.

In reply to a question from the President, Mr. Walker stated, that the shafts and the tunnel had cost £155,000, and the total cost of the works, including the open canal, was £200,000.

Mr. BEARDMORE suggested, that the section of the hill should be sent to the Museum of Practical Geology, where means would, probably, be found, of filling in the portions between the shafts.

Mr. HEMANS had been particularly struck by the judicious and economical employment of the refuse of the blast furnaces in the foundations of the walls. The same principle might be carried out, where foundations were covered with earth, and protected against water, and that in many cases, hard chips, or rough concrete, such as was used in France, might be adopted with great advantage. Another subject for remark was the successful manner in which a tunnel of that length had been carried out with so flat an invert, considering the great width and the heavy pressure it had to sustain. The weight of the water, if it could be let in at an early stage, would keep down the invert; but he thought, in a tunnel of that nature, that greater curvature might have been advantageously given to the invert, for resisting the pressure. In this case, the invert had given way; for the bottom rose up for some distance, in consequence, as was presumed, of the swelling of the clay below the invert.

Mr. VIGNOLES expressed his high approbation of the great accuracy with which this tunnel had been constructed. Mr. Locke would not have forgotten the great success with which Mr. Purdon had executed the tunnel on the Manchester and Sheffield Line; although three miles in length, with only five shafts of great depth, the deviation was not more than one inch in line, and not a quarter of an inch in the level.

Mr. JAMES COOPER could vouch for the accuracy with which this work had been carried out, having had opportunities of testing it, by frequent inspections, during its progress. There was one point which had not been particularly mentioned, but which would have proved interesting to the Meeting; the difficulties frequently occasioned by the mining operations in the district, which were met with in the continuation of the embankment and the bridges, at the north and south ends. The bridges settled considerably during their construction, and the settlement had increased since their completion; but they were all designed with a view to meet the danger arising from this cause. The materials employed throughout the work, were of the cheapest description consistent with durability, and he considered the work had been very economically executed. Great care was exercised by the Resident Engineer and the inspectors, and great credit was due to them as well as to the Contractor, for the way in which the entire work was carried out. It would, certainly, be very desirable to have a more com-

plete record of the geological stratification of the Rowley Regis Hill, if it could be made with approximate correctness : but there was a difficulty in filling in the strata between the shafts, owing to the fault which had been referred to. The section, exhibited by Mr. Walker, was valuable, so far as it went, as being a faithful record of the strata actually passed through during the operations.

Mr. BATEMAN having been recently engaged in extensive works of the same description, in connection with the Glasgow Waterworks, involving the construction of thirteen miles of tunnels, comprising seventy separate tunnels and from forty to fifty shafts, felt considerable interest in the Paper, and was gratified at the extreme accuracy with which the tunnel had been driven. In the works to which he alluded, there were not less than two hundred junctions, yet it was impossible to tell the points of meeting, except by the different directions of the drill holes, so accurate had been the work, both as to line and level. The great difficulties met with in tunnelling, were those occasioned by water, quicksands, or treacherous material, and the most interesting accounts of that class of operations were those in which they had occurred. A very small amount of water had, it appeared, been encountered in the Netherton Tunnel; and where those difficulties had not to be contended with, tunnelling was a comparatively simple and easy operation, and both cost and time might be approximately estimated. In the construction of a tunnel for the Manchester Waterworks, a shaft was sunk 100 feet through a quicksand; black shale was then met with, through which the shaft was continued to a further depth of 50 feet. More than 1,000,000 gallons of water per day were pumped, for months together, from this shaft. The difficulty and cost attending these operations were also greatly increased, by the peculiar character of the country through which the tunnel was driven. In the Glasgow works no such difficulties were encountered; there it was a mere question of time and labour. In many cases, however, the rock was so hard, that not more than $3\frac{1}{2}$ yards were excavated per month: an advance of 5 yards per month, was considered very good progress. He thought the value of the Paper would be enhanced, if it contained the relative cost of the work through the different descriptions of material. The character of the material was an important element, because where the ground was such, that a tunnel required a great quantity of timber, the cost would be considerably increased, in comparison with that of the tunnel, or those portions of it, where the material was sufficiently substantial not to require timbering.

In answer to several questions, Mr. Bateman said, that the tunnels to which he had alluded, were 8 feet in height, and 8 feet

in width. The aqueduct passed through a great variety of material. Beginning at Loch Katrine, low down geologically, in the mica slate, with beds of gneiss, it passed through the mica slate into clay slate, then across a thin bed of limestone, below the old red sandstone, into the conglomerate beds of the old red sandstone, and through all the upper and softer beds of the old red sandstone, into the carboniferous limestone and the coal measures. As an illustration of the entire freedom from water in the mica slate and clay slate formations, he might mention, that water had, occasionally, to be carried to wet the drill holes. The cost through the mica slate was about £12 per yard: and through the clay slate, £9, or £10 per yard. In the old red sandstone there was sufficient water to retard the progress, and he thought the cost in the lower beds of that stratum was about £10 per yard. The cost through the softer strata would be about £8 per yard, and in some cases, even less. This included the cost of the shafts, except where they were of considerable depth, and formed a heavy item. In one tunnel 2,300 yards in length, there were thirteen shafts, five of them being nearly 500 feet deep; those shafts were not included in the cost of tunnelling. Considerable portions of the tunnels were lined with brick, for in some places the rock, which was, at first, considered durable, was found to perish after exposure to the atmosphere; and the old red sandstone was also lined to a considerable extent. The cost of driving through soft material and of lining was, together, about equal to the cost through hard rock where no lining was required, and which was so compact, that water could neither penetrate nor escape.

Mr. FOWLER, V.P., remarked, that the Paper contained so full a description of the work, and it had been so successfully executed, that it was difficult to find occasion for criticism. He had recently completed a tunnel, commenced by the late Mr. Brunel, on the Oxford, Worcester, and Wolverhampton Railway, in which the stratification was similar to that of the Netherton Tunnel, and where the same means were adopted and nearly the same materials were employed. He differed from the opinion, that greater curvature should have been given to the invert. The proof that it was sufficient, was afforded by the fact, that, in a total length of $1\frac{3}{4}$ mile, a rising of the invert had taken place for a length of only about 120 feet. For a tunnel carried through a variety of material, he thought this invert was judiciously designed, as it was better to make modifications where necessary, than to increase the weight of the invert throughout the whole length of the tunnel. It was desirable to know whether, after the tunnel was built, the spaces left in the excavation were filled in with brickwork, or had been left open.

Mr. J. R. WALKER said, in reply, that the credit for the great

accuracy with which the design for the tunnel had been carried out, was not entirely due to the Resident Engineer, as with seventeen shafts and thirty-four faces at work, it was impossible for one person to see every profile set. The objection made to the flatness of the invert had been already answered; the success of the work justified the design. The higher the rise given to the invert, the greater would have been the quantity of puddle required to be filled in at the top. The rising of the invert occurred at a spot where it was laid upon the 'blue bind,' and was not discovered until some weeks after the invert was built, but no subsidence of the side walls had been occasioned by it. The quantity of water was considerable, in several of the shafts: in some cases it was drawn in buckets, but at shaft No. 8, an engine of 20 H. P. was kept at work. The cost of the tunnel was £50 per yard forward. The sum of £155,000 placed to the charge of the tunnel, included the tunnel faces and the shafts. The cost of the tunnel alone, of that section, would be £39. 5s. per yard forward; with canal and side walls, it would be £45. 5s. per yard. The material was of such a nature as to require, that the arch should be closely timbered throughout. The spaces left in the excavation had been filled up, either by solid brickwork, or by earth rammed in. As to the suggestion of sending the section to the Museum of Practical Geology to have the spaces between the shafts filled up, he stated, that he had already shown it to Mr. Jukes, the former geological surveyor of the district, and had given him all the information he desired upon the subject.

Mr. BIDDER,—President,—had great pleasure in adding his testimony to that which had already been given, as to the practical value of the Paper; it bore evidence of very careful preparation, and would be of great use to many Members who might be engaged, hereafter, upon similar works. But it was to be remarked, that every tunnel had its own peculiar history: and his experience had taught him, that however simple the work might appear at first, however sure the Engineer might consider himself of the material he had to work upon, yet, in execution, difficulties were continually occurring which could not be foreseen in the estimates, and which might ruin the Contractor. There were many present whose experience with regard to the contingencies met with in tunnelling, would be very valuable to the Institution; contingencies which required all the resources of mechanical art, all the experience of Civil Engineers, and all the enterprise of Contractors to bring the works to a successful result. He hoped, therefore, that this would not be the only Paper upon that highly interesting subject. The tunnel which was the subject of the Paper, had been admirably designed and executed, and it reflected the highest credit upon all engaged in it. It was remarkable for its extraor-

dinary freedom from natural casualties; none had occurred, except the rising of a small portion of the invert, attributed to the swelling of the clay below. The cost also of its construction had been unusually small, only £50 per yard, including the canal inside, for which £6 per yard should be deducted. Both the railway and the canal works were subject to the effects of the extensive mining operations carried on in the district, so that the Engineer must determine, either to construct his works in such a manner as to admit of the mines being worked, or submit to heavy exactions from the coal owners. In North Staffordshire, it was not only necessary to purchase the width of land required for the works, but also, thirty yards beyond, on each side, to be secure from the effects of mining operations. On that railway, the bridges were constructed with upright sides and iron girders, so that, in the event of subsidence, they could be easily re-adjusted.

February 14, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

No. 1,014.—“On the Construction of Artillery, and other Vessels, to resist great internal pressure.”¹ By JAMES ATKINSON LONGRIDGE, M. Inst. C.E.

IN bringing before the Institution the subject of the present Paper, the Author wishes, in the outset, to define the limits within which he conceives the Civil Engineer may fairly work, without trenching upon the field of his military brethren.

Not only in the present day, when the profession of the Civil Engineer has risen to an importance second to no other, but even in its infancy, those who followed that and its cognate pursuits, have distinguished themselves by their inquiries and experiments on this subject; and when it is borne in mind, that the names of Robins and Hutton in bygone times, and recently, those of Nasmyth, Whitworth, Mallet, and Armstrong are intimately connected with the mechanism of warfare, the Author feels that he is not going too far, in bringing the subject forward for the consideration of the Members of this Institution.

He does not propose to make a complete survey of the very wide field which contains the science of gunnery; but to confine himself to a small portion of it. Small as that is, it appears to him to be the foundation of the whole; for however perfect may be the theory, and however expert the practitioner, it is the amount of force at his disposal which must limit his efficiency, and unless he can command this force in sufficient quantity and intensity, the results will ever fall short of his desires.

The invention of gunpowder, and more recently of gun cotton, gives a source of enormous power, but unless that power be controlled, its full value can never be utilised; and striving after greater and still greater effects, the probable result may be, that the Engineer will be “hoist with his own petard.”

The first point, then, in the science of gunnery, and that which

¹ The discussion upon this Paper extended over six evenings, but an abstract of the whole is given consecutively.

limits its future, appears to be, the construction of guns of sufficient strength to curb and govern the utmost force of the explosive compound which may be used in them.

So long as gunpowder can burst guns and mortars, so long it is unmanageable, and wanting in that perfect obedience which is the first principle of effective service.

Therefore, leaving aside, for the present, all the other interesting and important questions which meet the Military Engineer on every hand, during his onward way, the Author proposes to limit himself to the investigation of the method of making a gun, which shall give the gunner the mastery over gunpowder;—in other words, a gun which gunpowder cannot burst.

And this is a question, which, in his opinion, no one is more able to deal with than the Civil Engineer of the present day. Exercised in the application of metal to purposes of construction,—with experience still limited and greatly below what is desirable, yet an experience which a few years ago was non-existent,—the Civil Engineer should be more conversant with the properties of the useful metals, than his military brethren. And when, moreover, it is remembered, that structures requiring for their success, an intimate knowledge of these properties, have of late become realities, such as the Britannia, the Victoria and the Saltash Bridges, and the Great Eastern Steamship, there may be fairly claimed for the Civil Engineer, such an acquaintance with the use of metal as to justify him in discussing the question, how to make a strong and effective gun.

The attention of the Author was drawn to this subject early in 1855. He was previously aware of the difficulty, experienced by manufacturers of hydraulic presses, in making cylinders of large size to resist the moderate pressure of 3 tons, or 4 tons per square inch; and in common with others, he knew the explanation thereof, first given, as he believes, by Professor Barlow, (Hon. M. Inst. C.E.,) with the clearness which distinguishes all the works of that accomplished mathematician.

Fully satisfied of the general correctness of Professor Barlow's views, the Author was led to consider, how the inherent defect of any gun composed of material more, or less homogeneous, such as cast iron, or gun metal, could be remedied. He was not long in concluding, that the object to be attained, was to construct a vessel in such an initial state of equilibrium, that when the varying strain caused by the internal pressure should come upon it, the initial strain should be, as it were, complementary to the induced strain, and the sum of the two should be constant throughout.

Supposing the strain caused by the explosion to be some function of the distance from the centre, it was first necessary to

ascertain the nature of this function, and then to find a mode of construction, such that the state of the particles before the explosion, should make up the difference between the strain so determined and the constant tensile force of the material employed.

It was evident, that neither cast metal, nor forged metal in mass could possess the required properties. The Author at once saw, that the best chance was, in putting on layer after layer and giving to each the due initial tensile strain. This he thought might be nearly accomplished, by wrapping the successive layers of wire round an internal core and coiling them on with the proper tension. The facility of execution of such an idea was greatly in its favour, and the Author proceeded, as soon as circumstances permitted, to submit it to experiment. The result of these experiments, which will be hereafter given in detail, was to his mind so satisfactory, that he lost no time in bringing the matter before Lord Panmure, then Secretary at War, and as usual, the proposition was referred to the Select Committee at Woolwich.

The Author submitted his views to that tribunal, as well as he was able, during the short interview he had with it, and left a brass cylinder covered with wire, with the request that it might be fairly tried, as to its power of endurance.

His request was partially acceded to, but other engagements prevented him from being present at the trial, and, as will be hereafter fully explained, the result was, not that the cylinder was burst, but that the end was blown off, owing entirely to the method of conducting the experiment.

It is due to Lieut. Colonel Eardley Wilmot, under whom the experiment was conducted, to state, that he expressed to the Author his opinion, that the result was in no degree decisive as to the principle, and that he felt anxious to see further experiments.

The Author however found it not so easy to accomplish this. He urged upon the authorities the advisability of making further experiments, and offered to construct a gun on this principle, the whole expense of which he would guarantee should not exceed a very limited amount. It was, however, in vain. On the 25th of October, 1855, he was informed that the matter had been referred back to the Select Committee, and that they did not consider it desirable, that further experiments should be made on guns so constructed.

The Author finding no chance of obtaining such a trial as he desired, continued the experiments for his own satisfaction, until he was convinced, that the requirements of the theory were capable of practical realisation.

It was about this time, that he was called upon by Captain Blakely, who had then, and has since, devoted both time and money to the development of the same principle; although, at that period, Captain Blakely appeared to consider the practical solution

was by means of concentric rings, or hoops shrunk, or forced on, in successive layers over a central shell.

At the same time, although unknown to the Author, Mr. Mallet, (M. Inst. C.E.), was engaged in devising and constructing mortars on the same principle, and was assisted in his calculations by the mathematical ability of Professor Hart, of Dublin.

Mr. (now Sir William) Armstrong, (M. Inst. C.E.), was also engaged in the construction of a gun, depending for its strength upon external concentric layers; but the Author believes he did not then attach them under the varying initial tensions, which form the essential feature of the mode of construction advocated in this Paper.

And here it may be stated, by way of saving the time of the Institution, both now and during the discussion which may arise, that the principle brought forward is not simply that of strengthening guns by outer hoops. This mode of construction is probably the most ancient of all, and many specimens of it are to be met with, not only in Europe but in India and in China. It was subsequently abandoned, when the art of casting arrived at greater perfection, and has since only been reverted to as a means of strengthening cast-metal guns.

The principle alluded to is that of building up a gun, layer by layer, and in such manner, that each successive layer, proceeding outwards from the centre, shall be laid on with a tension exceeding that of those below it; so that in fact, the inner layers are in their normal state, in compression. It is to the validity of this principle, that the Author particularly invites discussion.

It has already been said, that the problem to be solved, is to make a gun that cannot be burst by gunpowder.

The first information required, is, therefore, an answer to the question,—what is the ultimate force of gunpowder; that is to say, supposing a close vessel to be filled with gunpowder and the gunpowder then exploded, without means of exit, what will be the pressure within the vessel?

According to Robins, the ultimate strength of gunpowder was valued at 1,000 atmospheres, or nearly 7 tons per square inch.

By Dr. Hutton, it was carried as far as 2,000 to 2,400 atmospheres, or from 14 tons to 17 tons per square inch.

It seemed, however, desirable to the Author, to ascertain, for himself, this important point. It occurred to him, that the most satisfactory way of doing this, was to prepare vessels of certain known strengths, then to fill them with powder, and having plugged them up so as to prevent escape, to fire the powder in the inside. He therefore made application for a quantity of Government cannon powder, and had a series of thin cast-iron cylinders prepared, each 1 inch in diameter, and $\frac{1}{10}$ th of an inch thick. These were bored and turned, so as to be exactly of the same dimensions,

and were purposely made of very hard and brittle iron, so as of themselves to give the minimum of strength. These cylinders were wrapped round with iron wire, the tensile strength of which was ascertained by actual experiment. The number of coils varied according to the degree of strength required, and each coil was laid on with the initial strain, which the Author's calculations led him to believe would, at the moment of bursting, cause all the coils to give way together.

These cylinders were filled with powder and the ends secured, leaving no vent, beyond a touch hole, the size of a small pin, through which the powder was exploded. Several of these, of course, burst, but at length it was found, that a cylinder, as above described, with ten coils of wire upon it, could not be burst.¹

Now the diametral section of the cast iron is $\frac{2}{10}$ ths of an inch, and taking its strength at 8 tons per square inch the result is :—

$\frac{2}{10}$ ths of an inch $\times$ 8 tons per square inch =	Tons. 1.6
There were ten coils of wire, each wire by experiment	
broke with 60 lbs., and was $\frac{1}{8}$ th inch in diameter, there-	
fore the tensile strength of the two sides =	
$2 \times 28 \times 60 \times 10 \div 2240 =$	15.0
Total strength . .	<u>16.6</u>

The internal diameter of the cylinder was exactly 1 inch; consequently it appears, that the ultimate strength of the powder did not exceed 17 tons per square inch.

The Author would, however, wish it to be understood, that he does not hold this to be the maximum effect that may be produced. The explosion of powder is more of an impact than a pressure, and although, strictly speaking, impact is only a pressure of short duration, the question of the length of this duration is generally admitted to have great influence upon the effect produced.

For instance, Professor Rankine states, that "a bar, to resist with safety the sudden application of a given pull, requires to have twice the strength that is necessary to resist the gradual application and steady action of the same pull."²

This being so, it follows, that the more rapid the explosion, the greater is the strain on the gun. Not, probably, that the ultimate pressure is any greater, but that being produced in less time, its effect is greater. This is, probably, the cause of guns being more liable to burst when they get hot. It is not that the iron is

¹ One of these cylinders was exhibited.—EDITOR.

² Vide "Manual of Applied Mechanics," p. 287.

weaker, for Mr. Fairbairn, (M. Inst. C.E.,) has shown, that up to 600° the strength of cast iron is not materially diminished; but when the gun is heated, the gunpowder gets warmed and burns more rapidly, and the force is generated and applied more suddenly.

Therefore, although the Author found, that the bursting effect of cannon powder did not exceed 17 tons per square inch, he is willing to admit, that it may, under peculiar circumstances, exert a greater force. At any rate it seems to him, that if it is sought to make the most of the force of gunpowder, the vessels in which it is employed should be capable of resisting, at least, this strain.¹

According to Professor Barlow's theory, no vessel, however thick, can permanently resist an internal strain greater than the tensile strength of the material. This being so, and the tensile strength of cast iron being about 8 tons per square inch, it is hopeless to look to that material for such strength as is required; and it does seem strange, that the use of this material should be persisted in, and that experiment after experiment should be made, in search of that which is as impossible to be found as the philosopher's stone, viz., a means to make cast iron alone, endure more than its ultimate strength.

It may be true, as was remarked to the Author, by a military officer of high position, that formerly, guns did not burst as they now do. Possibly, guns in those days had not the same amount of work to do? The first rails laid on the Liverpool and Manchester Railway weighed about 35 lbs. per yard, and they did their work well, for a time; but when heavier engines and greater speeds were arrived at, heavier rails were required; and so it is with guns. Much greater care is now taken in testing the purity of the component materials of gunpowder, and therefore, it is probable, if not certain, that the rapidity of combustion must be greater. This, and the increased size of guns, will easily account for the greater number of casualties, without seeking for the cause, either in the assumed deterioration of iron, or the asserted dishonesty of contractors.

The Author is not disposed to think, that either the strength of English iron, or the honesty of English contractors is less, than in what used to be termed the good old days of the war; but he does think, that the strength of powder is greater and the results sought from it much greater, than in former days.

Therefore, without expressing any opinion on the policy of creating Government establishments for construction, he would raise his voice against the assertion, that such were rendered necessary by either the incapacity, or the dishonesty of private firms.

¹ *Vide* Note on the Strength of Powder in the Appendix, p. 322.

It has been stated, that no 68-pounder in the service can be fired, with safety, with a full charge of powder. It is, further, a matter of notoriety that several of the Lancaster guns were burst. Of the Sweaborg 13-inch mortars it is needless to speak. All this ought to prove, that cast iron has been taxed beyond its strength. As this does not seem to be universally admitted, it is necessary, before proceeding with the peculiar subject of this Paper, to say a few words on the causes of failure of cast-iron guns.

In the first place, the actual strength of the interior of a large gun, or mortar, is far below that of the average of ordinary castings, and always must be so, whilst guns are cast solid. So long as this is the case, the outside must cool and solidify first, whilst the interior, cooling more slowly, must be drawn and be rendered less dense, and consequently, *cæteris paribus*, less resisting. This is an operation of nature which no care in selecting material can overcome.

The worst part of this iron, in the chase of the gun, is afterwards bored out; but still the metal around the internal circumference is weakened below the average, and at the bottom of the powder chamber it is in the very worst possible condition. The sudden changes of dimensions, at various parts of the gun, are also sources of weakness, as has been pointed out by Mr. Mallet,¹ who bases his views upon the theory, that the principal axes of the crystals arrange themselves in the direction of the flow of heat outwards, and that whenever re-entering angles, or sudden changes of dimensions occur, planes of weakness are thereby produced.

This explanation depends too much upon, what appear to the Author to be, arbitrary assumptions, to enable him to place much confidence in it. He has examined carefully many cases of fracture of cast iron, but in no instance has he been able to satisfy himself, that the crystals have that definite direction which would justify him in determining thereby, a plane of weakness. They have always appeared to be a confused mass of more, or less, defined crystals, but certainly not so arranged, that he could ascertain any uniform direction of what Mr. Mallet calls their principal axes.

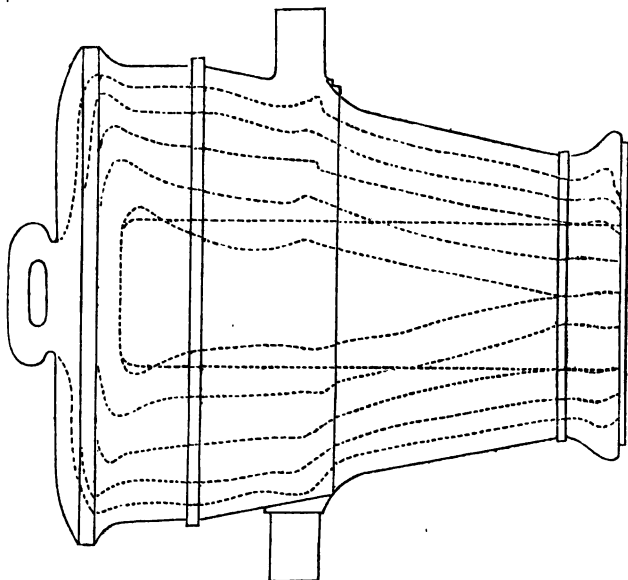
The Author thinks, that without having recourse to this theory, the law of cooling alone will fully account for the source of weakness in the cases in question. Whenever a variation in thickness occurs, a difference in the rate of cooling must also take place. This alone must give rise to a state of varied stress, amongst the particles of the metal, which, without doubt, diminishes its effi-

¹ Vide "On the Physical Conditions involved in the Construction of Artillery." By R. Mallet. 4to. Dublin, 1856.
[1859-60. N.S.]

ciency as a resisting substance. In ordinary castings this is too well understood and admitted, to require further remark. But the same law operates in guns, though, perhaps, to a less obvious extent.

Take, for instance, the accompanying sketch of a gun, (Fig. 1,) distorted in its proportions, for the sake of illustration, and sup-

Fig. 1.



pose it to have cooled down after casting. Although, in the present state of knowledge of the subject, it would be impossible to determine the absolute position of the isothermal lines, at any period of cooling, yet it is certain, they must approximate to the dotted lines, shown in the sketch; and following these lines according to some definite law, would be the lines of equal stress of the particles of the gun, when cold.

When, therefore, the gun is bored out, it is evident, that the inner circumference of the bore must be in a state of varying strain, and that strain is one of tension. Consequently, the internal part of the gun is, throughout, in an initial state of more, or less tension; and as regards its power to resist a tensile strain, it is inferior to the normal, or average strength of the material.

But beyond this, whenever a change of dimensions occurs, the cooling will give rise to varying strains, which may account for fracture taking place, at those particular places.

The Author does not, however, propose to follow this subject further. His main object is to show, that the inner portion of a gun, which has the greatest strain to resist, is by the process of construction, already weakened below the average strength of the material. How much below, he does not pretend to say, but a few well-devised experiments would throw great light on the subject.

The Blue Book recently issued, records the results of the experiments conducted by Lieut. Colonel Eardley Wilmot, at Woolwich. It contains a mass of information respecting the properties of a certain number of irons, but is altogether silent upon this most important element in the question of the use of these irons, in the construction of guns. The Author, therefore, contents himself with the statement of the fact, that the strength of the material next the inner circumference, is below the average strength of that material, as shown by experiments recorded in the Blue Book in question.

The next point to be considered, is the amount of strain to which guns are now subjected. In former days, guns were generally of less calibre, the powder was slower in combustion, and the windage was probably greater. But beyond all this, the modern introduction of the principle of elongated, instead of round shot, and of rifling, has to be taken into account.

A long shot has much more inertia, in proportion to its diameter, and to obtain the full benefit of rifling, it must fit tightly within the gun. Thus there is an increase of inertia and of friction, with a decrease of windage. The result is, that the shot is displaced more slowly, and the pressure of the powder behind is greatly increased; and, as practice shows, it is increased to such an extent, that the guns cannot bear it. Another point, not to be overlooked, is the increase of range, that is, of initial velocity, sought for in the present day. Under the old system, it is well known, the range was necessarily very limited. If the charge of powder was increased, beyond a certain point, the range was but slightly extended, for the simple reason, that as soon as the inertia of the ball was overcome, it moved forward and prevented the back pressure from accumulating; and it often happened, that part of the powder was actually blown out of the gun in an unconsumed state. But with a long tight-fitting, rifled shot, the pressure accumulates, to an extent previously unknown.

Enough has probably been said, to explain why it is, that guns, which formerly stood well, are incapable of resisting the strain now put upon them. The Author will only further observe, that it does seem to him remarkable, that persistent efforts should be still made, to do that which experience had shown to be impossible.

Guns of the ordinary construction have been handed over to mechanics of the greatest ability, to be rifled. The Author

ventures to predict, that utter failure will be the result. They were scarcely strong enough to bear their old work, and must inevitably give way, when a vastly increased strain is put upon them. The fact of cast-iron guns failing has, however, become admitted; but, unfortunately only so far, that the failure has been laid at the door, either of inferiority of material, or of dishonesty of purpose. As a result, a national Gun Foundry has been established, at enormous expense, for the express purpose of making cast-iron guns.¹

The Author does not doubt, that by great care in selecting and manufacturing the best material, results may, perhaps, be arrived at superior to the average under the old system. At the same time he feels, and believes, that many will participate in the feeling, that a new establishment of any description must always labour under disadvantage, when compared with old-established firms, who having obtained a reputation, and having abundant means at their command, are actuated quite as much by the wish to maintain that reputation, as by the desire of making money. Such firms know well, that their power of money-making depends on keeping up their character; and though the former is the essence of all commercial transactions, it is very far from being antagonistic to the production of a first-rate article.

To return to the subject. Cast iron has been tried and found wanting. The initiative, in seeking a new material, has not been taken by Government establishments, but by private individuals, who have devoted much time and money to the subject.

Wrought iron and steel have been tried, and in point of workmanship magnificent results are arrived at, though at enormous expense, as regards large guns. Taking the tensile force of the one at 20 tons and of the other at 40 tons per square inch, and the force of gunpowder, as above stated, at 15 tons, it would appear, that either of these materials would comply with Professor Barlow's requirements. But in practice is it so? Upon this, the Author is not able to pronounce a definite opinion; but the same objections apply, as to guns of cast iron, viz., that the inner part of the gun must be in a state of initial tension. The expense and difficulty of manufacture are, also, very great.

As the finest specimen of that kind of manufacture, the steel gun forged by M. Krüpp, and afterwards bored and mounted in a cast-iron jacket at Woolwich, may be instanced. That gun is stated by Mr. Mallet² to have been bored out to 8 inches, and to have been from 4 inches to $4\frac{1}{2}$ inches thick. Taking the tensile force of hammered cast steel at 40 tons per square inch, the resist-

¹ This was written in November, 1859.—AUTHOR.

² Vide Mallet's "Construction of Artillery, &c.," Appendix, p. 235.

ance would be from 320 tons to 360 tons, which, if the strain had been uniform throughout, would have been equal to between 40 tons and 45 tons per square inch, on the diameter ; yet the gun burst at the first discharge, with 25 lbs. of powder and a 260-lbs. shot.

Mr. Mallet next mentions a wrought-iron 8-inch gun, forged at the Gospel Oak Ironworks, and proved at Woolwich, on the 12th of July, 1855, which burst into several pieces at the first discharge. This gun is stated to have been of very nearly the same dimensions as the established cast-iron guns of the same calibre. The thickness at the breech end was, therefore, about 9 inches ; and taking the tensile force at 20 tons per square inch, the material, provided it had been uniformly strained, ought to have resisted a diametral strain of 360 tons, or about 45 tons per square inch. This gun, which to the eye, presented, both externally and internally, an appearance of entire soundness and perfection of material, burst with a proof charge of 28 lbs. of powder and two spherical 8-inch shot.

The next gun spoken of by Mr. Mallet is that which burst on board the United States frigate, 'Princeton,' in 1842, or 1843. He gives the very interesting Report of the Committee of the Franklin Institute on this gun, and on the material of which it was made. Amongst other experiments, were those made to determine its tensile strength. First, in the original bar ; secondly, in a bar cut from interior of the gun ; thirdly, in a bar made from a portion of the gun, re-worked under the hammer.

The mean tensile strength per square inch of the original bar was :—

1st Bar	46,086 lbs.
2nd „	38,595 „
3rd „	52,521 „

Other experiments made from the same iron gave the following results :—

- “ 1. The average tensile force with which the specimens from the interior of the gun broke, when strained in the direction of the fibre, is less than 32,100 lbs.
2. The specimen from the interior, strained in a direction across the fibre, gave 23,700 „
3. The specimens from the outside of the gun, across the fibre, gave an average of less than 45,333 „
4. Annealed specimens from the interior, strained lengthwise of the fibre, gave an average of 36,067 „

5. The average of all the specimens from the gun, not hammered, is 33,300 lbs.
6. The average of the specimens worked down under the hammer, is 63,475 „

“The general conclusions, from these results, are the same as those from the experiments made by the Committee in Boston, so far as the two series can be compared.

- “1. The average strength of the iron, as it existed in the gun, from both series, is . . 33,586 lbs.
2. The average strength of the iron from the gun, after being drawn down with the hammer, from both series, is 59,824 „
3. The average strength of the original bars from the experiments of the first series, is . 46,950 „ ”

Consequently, taking the original strength as 100, that of the average of the iron, as existing in the gun, was 72, showing a deterioration of 28 per cent. ; and if the tensile force of the interior is taken, when strained in a direction across the fibres, that being the actual direction of the strain in the gun, the proportion to the original bar is as 50 to 100, or a deterioration of 50 per cent.

The Committee state, in conclusion, their “opinion, that, in the present state of the arts [in 1844], the use of wrought-iron guns of large calibre, made on the same plan as the gun now under examination, ought to be abandoned, for the following reasons:—

- “1. The practical difficulty, if not impossibility, of welding such a large mass of iron, so as to insure perfect soundness and uniformity throughout.
2. The uncertainty, that will always prevail, in regard to imperfections in the welding ; and
3. From the fact, that iron decreases very much in strength, from the long exposure to the intense heat necessary in making a gun of this size, without a possibility, with the hammers at present in use in this country [in America], of restoring the fibre by hammering.”

The Author, though dissenting from the views expressed in the last paragraph, inasmuch as he does not believe that long exposure to heat alone will deteriorate the iron, nor that any amount of hammering will restore its fibre, is inclined to agree with the two first reasons, for abandoning the construction of forged wrought-iron guns of large dimensions.

It is true, that the Mersey Iron Company, by great skill, and a thorough knowledge of their trade, and by the appliances at their command, have succeeded in forging the magnificent gun which, with a liberality equal to their enterprise, they presented to the nation. But so far as the Author knows, that gun is as yet only an

experiment; and he has even seen it stated, that already it is beginning to show symptoms of cracking in the interior.

Speaking of wrought-iron guns, Mr. Mallet says:—¹ “The facts [which he has previously stated] are worthy of notice, as indicating the absolute uncertainty that ever must exist as to the trustworthiness of wrought-iron guns, forged in one great mass, although executed without regard to cost, and by parties anxious faithfully to produce a result of the highest excellence. Some of the evils incident to this gun might have been avoided by greater experience and judgment; but the main evil is inherent, and inseparable from every huge forging, and most so where the weldings are most numerous.”

On the other hand it should be mentioned, that Mr. Clay, of the Mersey Iron Works, differs from Mr. Mallet, and very justly observes, that “the several failures in the manufacture of wrought-iron guns should not be a matter of surprise; for it is hardly reasonable to expect immediate success in any new fabrication.”²

Mr. Clay, in the same publication, gives an account of experiments to determine the tensile strength of the iron from which the monster gun was made, and of the same iron, after manufacture into the gun. The results were as follows:—

Experiment.	Description of Iron.	Breaking strain in lbs. per sq. in.	Average.
No. 1.	Original iron of which the gun was made	48,384	49,504
No. 2.	Ditto ditto	50,624	
No. 3.	Cut across the grain from muzzle of gun	41,644	43,390
No. 4.	Ditto ditto	43,904	
No. 5.	Ditto ditto	50,624	
No. 6.	Cut with the grain from muzzle of gun	48,384	50,624
No. 7.	Ditto ditto	50,624	
No. 8.	Ditto ditto	52,864	
No. 9.	Borings from gun re-worked with coal	60,584	61,704
No. 10.	Ditto ditto	62,824	
No. 11.	Borings from gun re-worked with charcoal	76,584	76,584
No. 12.	Swedish iron as imported, $\frac{3}{4}$ inch square	60,584	60,584

Taking the average of the first two experiments, and comparing it with that of the following three, there is a decrease of strength of about 13 per cent., whilst on the other hand, as compared with

¹ Vide Mallet's "Construction of Artillery, &c.," page 239.

² Vide Orr's "Circle of the Industrial Arts," page 331.

the 6th, 7th, and 8th, there is a gain of strength of 2 per cent. These experiments are not, however, so conclusive as those previously quoted, as the iron was cut from the muzzle of the gun, and not from the interior, at the breech, where the thickness is greatest, and the deterioration is, necessarily, the most.

To sum up this part of the question, the Author is, perhaps, justified in saying, that the manufacture of large forged wrought-iron guns is an operation of great difficulty, expense, and uncertainty, and however the difficulty and expense may be decreased, the uncertainty must still remain. Moreover, at the best, it is but substituting for cast iron a material of a higher tensile strength; the radical defect of a homogeneous mass still remaining, viz., the unequal distribution of the strain, from the inner to the outer circumference. The same remarks apply, with still greater force, to guns of hammered cast steel of large dimensions.

The Author has already pointed out the principle, which appears to be the basis of a sound and reliable construction. It is that of manufacturing the gun of successive layers, laid on with an original increasing strain from the centre to the circumference.

The Author claims no exclusive merit for this idea. It appears to have been entertained both by Mr. Mallet and Captain Blakely, and perhaps by others. In 1855, when he mentioned the principle to Sir William Armstrong, and described the method he proposed for carrying it into effect, by means of wire, that gentleman said, Mr. Brunel had also entertained the same idea, and had spoken to him with reference to making a gun on this principle; but finding that the Author was already engaged on it, he had dropped the subject.

Leaving, therefore, aside the generally unimportant and always unsatisfactory inquiry as to priority of invention, the Author will describe his own course of proceeding, commenced in entire ignorance of what others either had done, or were doing.

In the outset, the Author foresaw great practical difficulty in the use of hoops, whether shrunk on, or forced on. Since then, the subject has been investigated mathematically by Dr. Hart, and more recently, at the Author's request, by Mr. C. H. Brooks, as given in the Appendix, (page 329,) to whose results attention is directed.

In the first place, then, there is an objection to the use of hoops from the want of continuity. The special requirement is, that each layer of the gun shall be in a definite initial state of tension, or compression, previous to explosion. If in Fig. 2, (page 297,) A B C D, represent a portion of a section of an 8-inch gun, of which A G B is the inner, and D F C, the outer circumference, the state of tension of any particle between G and F may be denoted by ordinates drawn at the points in question, those above G F representing tension, and those below, compression.

Fig. 2.

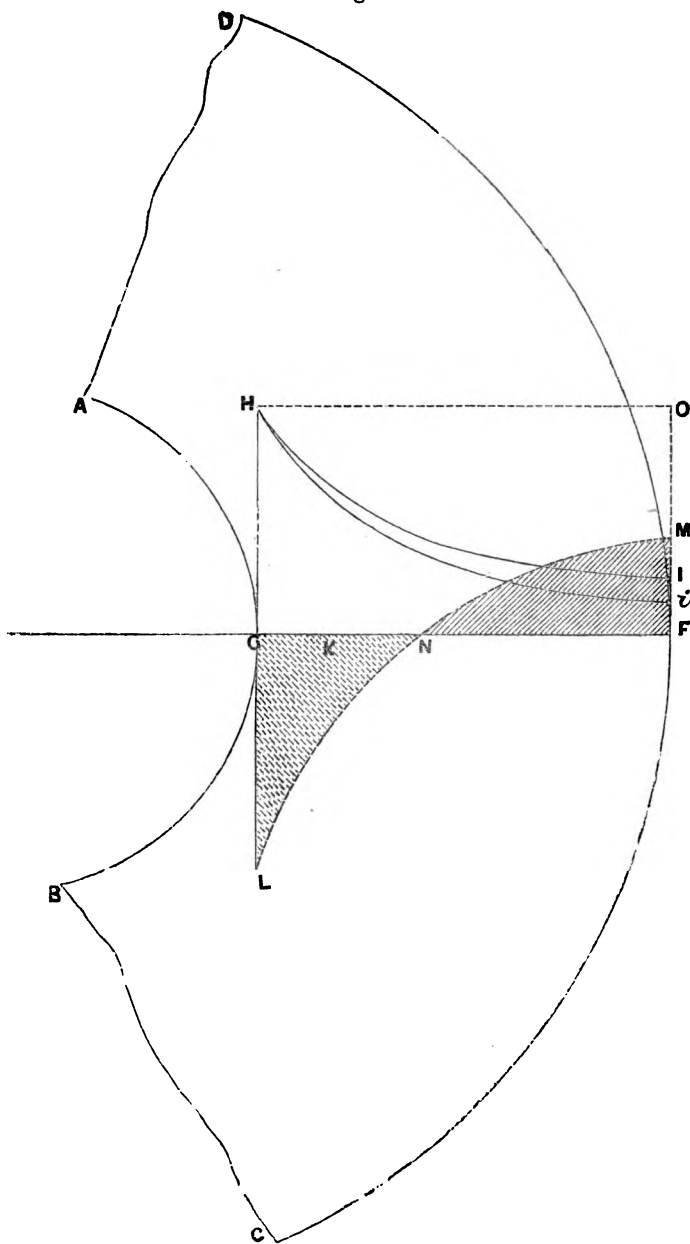


Fig. 3.

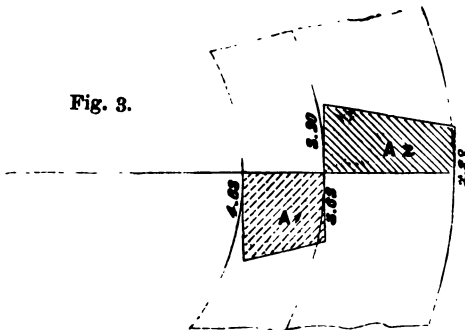


Fig. 4.

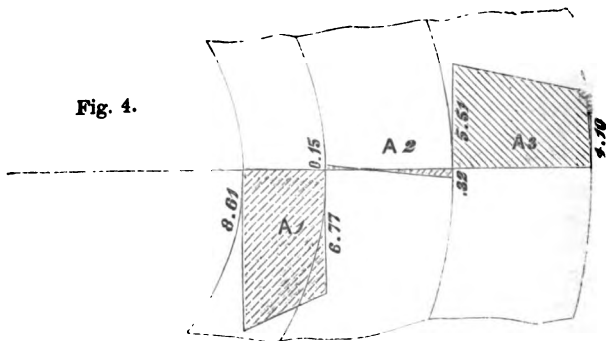
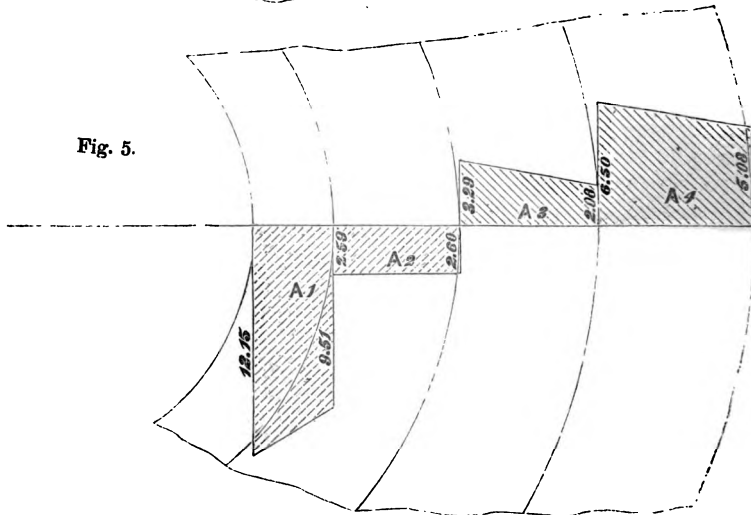


Fig. 5.



If, now, the gun is of any homogeneous material, such as cast iron, the state of tension at the time of explosion, and when the gun is about to burst, will be denoted by a curve HI , or Hi , the former calculated according to Professor Hart, and the latter according to Professor Barlow's formula. Then, supposing the tensile force of the material to be 12 tons per square inch, and the thickness of the gun $6\frac{1}{2}$ inches, when the strain at G is GH , or 12 tons, at F it is $FI = 3$ tons, or $Fi = 1\frac{3}{4}$ ton, according as the one, or the other formula is adopted. The areas of these curves give, of course, the total strengths of the gun at the bursting point, and are found to be $36\cdot72$ tons and $30\cdot871$ tons respectively, instead of 78 tons, which it would have been if uniformly strained at 12 tons per square inch.

Now the object sought to be attained, in the method of construction under consideration, is, that each particle such as K , shall, when explosion takes place, be equally strained with G . In order that this may be so, the initial state of the tension must be such as is represented by the curve $LN M$, those between G and N being in compression, while those between N and M are in tension.

If, now, it is attempted to accomplish this by means of hoops, it will be found impossible, inasmuch as each hoop is a homogeneous cylinder, and follows the same law throughout its thickness, as is represented by the curve HI .

Figs. 3, 4, and 5, (page 298,) represent the successive states of stress of our rings, put on so as that when the explosion takes place, they shall be all equally strained at their inner circumferences.

Fig. 3 shows two rings.

4 " three "

5 " four "

The figures denote the strains, in tons per square inch.

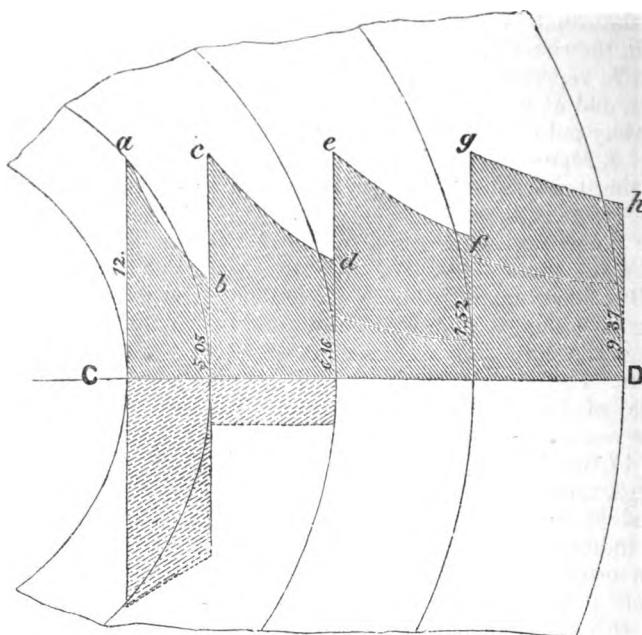
From this it will be seen, that when the four rings are put on, instead of the curve $LN M$ of Fig. 2, there are a series of abrupt changes, the two inner rings being in compression and the two outer in tension.

When the explosion takes place, the state of maximum strain is represented by the next diagram, Fig. 6, (page 300).

The area between the dotted and the full lines, shows the work done by the explosion, and taking the total thickness of the gun, it amounts to $10\cdot1$ tons per inch of thickness; whereas, had the construction been of very thin rings, or of small wire, it would have been represented by the area between the dotted line $LN M O H$, (Fig. 2, page 297,) and would have been = 12 tons per inch of thickness, showing a superiority of about 20 per cent. in favour of the wire, over the hoops.

This is upon the supposition, that the workmanship of the hoops is perfect, which in practice cannot be attained. To afford some

Fig. 6.



idea of the accuracy required, the radii of the several rings, shown in the above diagram, are given in the following Table :—

No. of Ring.	Inner Radius.	'Outer Radius.	Thick-ness.	Differences.
1	4.0000	5.3222	1.3222	$R_1 - \rho_2 = .0031$
2	5.3191	7.2928	1.9737	$R_2 - \rho_3 = .0035$
3	7.2893	9.4633	2.1740	$R_3 - \rho_4 = .0035$
4	9.4598	11.8247	2.3649	

Thus, it appears, that in order to give the requisite amount of initial stress, the external radius of the first ring must be $\frac{31}{10000}$ ths of an inch, or about $\frac{1}{300}$ th of an inch larger than the internal radius of the second: the external radii of the second and third $\frac{35}{10000}$ ths of an inch greater than the internal radii of the rings next to them. Therefore, whilst the whole effect depends upon so small a quantity as about $\frac{1}{300}$ th of an inch, it is evident, that a very small error in workmanship will materially affect the result,

and may tend to the most serious deviations from the proper initial strains.

This is a point of so much importance, that the Author has prepared the following diagrams, (Figs. 7 and 8, page 302,) to show the result of an error in workmanship, of $\frac{1}{500}$ th part of an inch, in the size of the outer ring.

Fig. 7, represents the states of stress of the rings before explosion, and at the instant of maximum strain, when the rings are accurately put on.

Fig. 8, represents the states of stress of the same gun, when the outer ring has been made $\frac{1}{500}$ th of an inch too small.

The result is, that before explosion, the maximum compression of the inner ring is increased from 10·086 tons to 11·244 tons, and the maximum tension of the outer ring from 5·778 tons to 7·823 tons per square inch; whilst at the time of maximum strain, during explosion, the tension of the same ring is only 2·268 tons, although the outer ring is strained to 12 tons, its assumed ultimate strength. The absolute strength of the gun is thus reduced from an average of 10·5 tons to 6 tons per inch of thickness, or about 40 per cent., by an error of only $\frac{1}{500}$ th of an inch, in a ring of about 17 inches in diameter.

Rings, therefore, present practical difficulties, which are entirely avoided by the use of wire, as it may be coiled on with the exact strain indicated by theory.

The method adopted by the Author, was to coil a quantity of wire on a drum, fixed with its axis parallel to that of a lathe on which the gun was placed. On the axis of this drum, there was another drum, to which was applied a break, similar in principle to Prony's dynamometric break, so adjusted, as to give the exact tension required for each successive coil of the wire. The whole apparatus was extremely simple, and the wire was laid on with great regularity. Indeed it is evident, the apparatus might be so arranged, as that the process would proceed with the same ease and regularity, as winding thread on to a bobbin, and at the same time, with the greatest accuracy as regards the initial tension.

No such facility attends the use of hoops. They must be accurately bored, and after each layer is put on, the gun must be placed in the lathe, and the hoops be turned on the outside. Great accuracy of workmanship is indispensable; and not only is the amount of labour much greater, but it must be of a far higher, and consequently, of a more expensive class.

Then, as to accuracy of tension with hoops. The Author looks upon its attainment as almost impracticable. He is convinced, that the process of shrinking on is not to be depended upon. Not only is there a difficulty in insuring the exact temperature re-

Fig. 7.

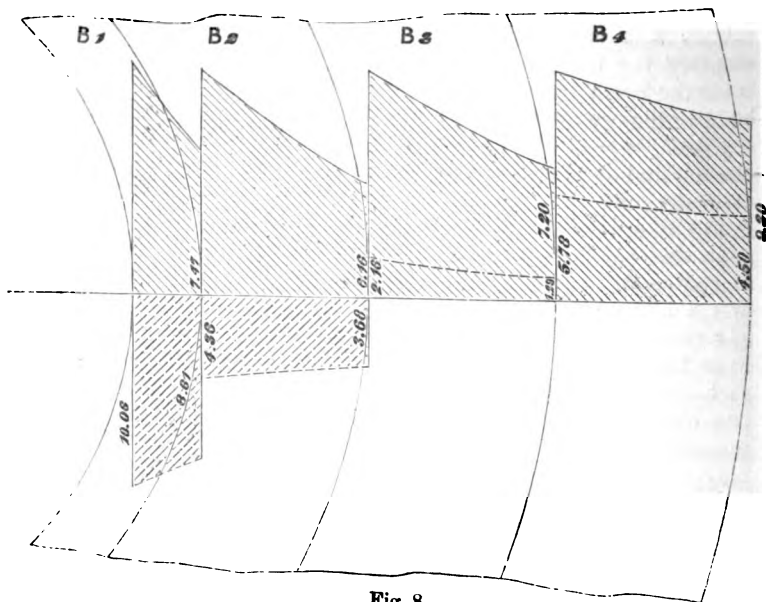
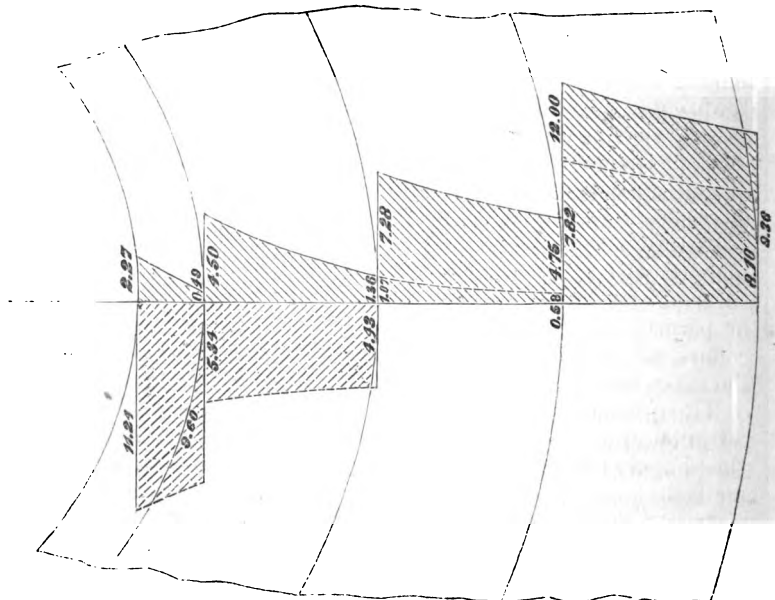


Fig. 8.



The dotted lines denote the state before, and the full lines after, explosion.

quired, but scarcely any two pieces of iron will shrink identically, and when the $\frac{1}{300}$ th part of an inch of contraction would give rise to a great variation in tension, the necessity of perfect accuracy is apparent. But, it has been proposed, and the Author believes it is now solely advocated by Captain Blakely, that the hoops shall be forced, by hydrostatic pressure, on to a gun slightly conical, in longitudinal sections.¹ Here again occurs the practical difficulty of the attainment of extreme accuracy of workmanship, involving the highest class of skilled labour, and the greatest vigilance of supervision.

In the next place, hoops must always possess the defect of want of continuity of substance. However perfect the workmanship at first, the Author feels satisfied, that in large guns, the concussion of repeated firing would, ere long, shake them loose. Those who have had to do with heavy machinery, subject to violent jars, such as rolling mills, and forge hammers, well know how impossible it is to keep iron and iron, however well fitted, working together for any length of time, without shaking loose. The only remedy is to separate the pieces of iron from each other, by a packing of elastic material, so as to take off the jar. Now, the concussions in such machinery are insignificant, as compared with those in a large piece of ordnance, and, therefore, the use of hoops for large guns cannot prove satisfactory.

In the year 1854, Captain Blakely, R.A., laid this method of construction before the Ordnance authorities; but meeting with little encouragement, he took out a patent, in 1855, for a method of making guns. The specification of this patent, sealed 14th August, 1855, and dated 27th February, 1855, contains the following passage:—"I do not claim, as my invention, the method of forming guns, or cannon, by the application of collars, or rings heated, or shrunk upon a cylindrical inner tube, save and except, when the internal diameter of such collars, or rings, are, previously to being heated, so much smaller than the external diameter of the inner tube, on which they are shrunk, that after being cooled, the outer covering, formed by the rings, or collars, is in a state of tension, or permanent strain, similar to that produced, when the rings, or collars, are forced upon a conical surface, as before described, and the inner tube is, in both cases, similarly compressed."

This passage shows, that Captain Blakely clearly appreciated the advantages of the principle of construction which is the subject of this Paper, although seeking for practical results in a different method.

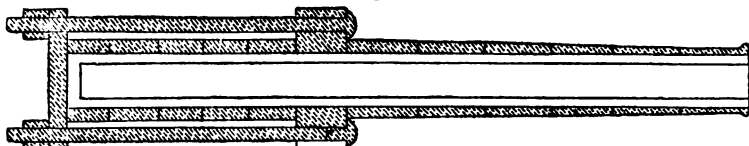
It is, however, due to Captain Blakely to record, that although

¹ In the course of the discussion, it appeared that this was the method now adopted by Mr. Whitworth.—AUTHOR.

he then looked chiefly to hoops, or collars, the idea of spirals, or rods of iron, or wire, was also present to his mind; for in a subsequent part of his specification, he distinctly refers to an outer covering of wire, or rods wound spirally in one, or more layers, for the purpose of strengthening old guns.

In an interesting lecture, delivered by Captain Blakely, at the United Service Institution, on the 21st of January, 1859, he gives an account of his experiments and endeavours to introduce this principle of construction to the notice of the Government authorities. In that lecture were recorded many very interesting facts and Captain Blakely's reasonings thereon; but it is to what was actually accomplished by Captain Blakely, that the Author wishes to direct attention.

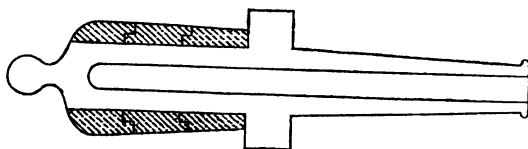
Fig. 9.



Captain Blakely's first gun was an 18-pounder, (Fig. 9,) consisting of one series of wrought-iron rings, shrunk on a cast-iron cylinder, $5\frac{1}{2}$ inches in diameter inside, and $1\frac{3}{4}$ inch thick. The wrought-iron rings were from 2 inches thick downwards. The total thickness of the breech was $3\frac{3}{4}$ inches, that of the ordinary 18-pounder service gun being $5\frac{3}{4}$ inches. This gun was fired frequently and stood well. It was then bored out as a 24-pounder, but not being truly bored, the cast iron was reduced, on one side, to only $\frac{1}{2}$ inch thick. In this state, it sustained, without injury, several hours' firing, with charges varying from one shot and 4 lbs. of powder, to one shot, two wads, and 8 lbs. of powder. At the third round, with this latter charge, it burst. This gun had a thickness of only $2\frac{1}{2}$ inches round the charges, as compared with a service 24-pounder, of 6 inches in thickness.

Captain Blakely next got a 9-pounder turned down, from the trunnions to the breech, and on this part he put wrought-iron rings of such a size as to replace the metal removed. (Fig. 10.)

Fig. 10.



This gun was fired, round for round, with a cast-iron service gun of the same size and weight. The following Table gives the result:—

No. of Shot. Blakely.	Charge of Powder.	No. of Shot.	No. of Rounds Fired.		No. of Shot. Fired from Service Gun.
			Blakely's.	Service.	
4	Lbs.	2	2	2	4
.86	3	1	86	86	86
26	4	1	26	26	26
5	5	1	5	5	5
10	5	2	5	5	10
636	6	2	318	110	Burst 220
3	6	3	1	..	..
4	6	4	1	..	..
5	6	5	1	..	..
6	6	6	1	..	..
7	6	7	1	..	..
8	6	8	1	..	..
9	6	9	1	..	..
1,580	6	10	158	..	..
2,389			607	234	351

Thus, it appears, that Captain Blakely's gun stood 607 rounds, and the government service gun only 234 rounds; the number of shot thrown being 2,389 and 351 respectively, or nearly as 7 to 1.

The subsequent experiments, made by Captain Blakely, are described in his lecture; but enough has been said to show, that he had gone a long way to prove, practically, the truth of the principle. He did not, however, succeed in convincing the Government officials, as may be gathered from his pamphlet, published in 1859. His calculations having been reported upon by Mr. Heather, a mathematician, the system was declared inapplicable to cannon, by the Ordnance Select Committee, in a letter from which the following paragraph is an extract:—

“I am directed by Mr. Monsell to acquaint you, that the Committee, taking into consideration the different expansive powers of wrought and cast iron, are of opinion that guns so constructed could never be considered safe, as they might burst at any time, and the splinters from them would be very dangerous, (as shown in the late experiments,) and the Committee do not therefore recommend further experiments to be made with guns of this description.”

In spite, however, of the opinion thus expressed by the Committee, it must be admitted, that Captain Blakely deserves great credit, for the spirit and perseverance with which he has, at great cost to himself, attempted to introduce a decided improvement into the arm of the service to which he belongs.

It was, however, in entire ignorance of what others were doing, or had done, that the Author arrived at the conclusion, that the construction, by means of wire, offered the greatest probability of

success, and to that construction exclusively he devoted his attention. The first point to be settled was, the amount of initial strain to be put on each coil.

The formula adopted by the Author was one based upon Professor Barlow's investigation, above referred to, and was :—

$$t = T \cdot \frac{x^2 - r^2}{x^2} \quad . \quad . \quad . \quad (1)$$

Since the publication of Mr. Mallet's book, the Author has become acquainted with Professor Hart's investigation, the formula obtained from which is, as given therein :—

$$t = T \cdot R \cdot \frac{x^2 - ry}{x(r + y)}.$$

This, in the case of small wire, is nearly :—

$$t = \frac{T R}{x} \cdot \frac{x - r}{x + r}.$$

These, however, are general formulæ which require modification, according to the varying circumstances of each case, before they can be applied to practice.

Without entering upon any discussion of these formulæ, the Author proceeds to describe the results obtained from his own experiments on cylinders prepared according to formula (1).

The method of conducting them was as follows. A number of brass cylinders were prepared exactly of the same dimensions, viz. :—

Internal diameter 1 inch.
 External diameter $1\frac{3}{16}$ „
 Thickness of brass $\frac{3}{32}$ „

These cylinders were accurately turned and bored, and had a flange $\frac{1}{4}$ inch in depth and $\frac{1}{8}$ th inch in thickness, at each end. Each end was widened out, so as to afford seating to two gun-metal balls, which were accurately ground to fit them. The total content of each cylinder, with the balls in their places, was 300 grains of best sporting powder, which was alone used in this series of experiments. When the powder was put into the cylinder, and the balls were placed at each end, the whole was bound together by a very strong wrought-iron strap, similar to the strap of a connecting rod, with a jib and cotter. The cotter was driven tightly home, and the powder was then fired through a small touch-hole, left in the side of the seating. (Fig. 11.)

The first experiments were to ascertain the effect of the powder on the cylinders, without any wire. They were commenced with charges of powder, beginning at 50 grains, and increasing till the cylinder burst.

After this, cylinders with different thicknesses of iron wire, were tried in a similar manner.

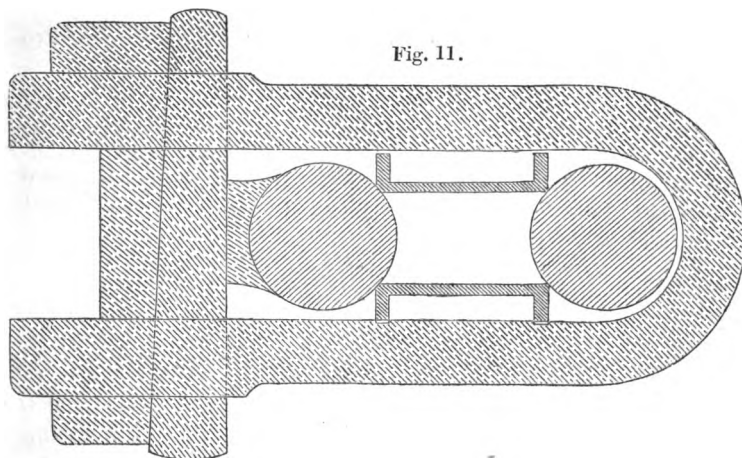


Fig. 11.

The results are given in the following Table :—

EXPERIMENTS ON BRASS CYLINDERS.

No. of Experiment.	No. of Cylinder.	Condition.	Charge of Powder.	Effect.
			Grains.	
1	1	Without wire	50	Slightly bulged.
2	„	Ditto	60	Bulged a little more.
3	„	Ditto	70	Ditto external diameter $1\frac{5}{16}$.
4	„	Ditto	80	Ditto ditto $1\frac{7}{16}$.
5	„	Ditto	90	Burst.
6	2	2 coils of wire $\frac{1}{8}$ inch.	90	No effect.
7	„	Ditto, one end loose . . .	100	Bulged at loose end.
8	3	Without wire	70	Bulged to $1\frac{11}{16}$.
9	4	Six coils $\frac{1}{8}$ wire	100	No effect.
10	„	Ditto	110	Ditto.
11	„	Ditto	120	Ditto, one end of wire came loose.
12	„	{ Same cylinder with one } { coil of $\frac{3}{8}$ wire }	100	{ Burst—the end of the wire being } { badly fastened. Wire not in- } { jured. }
13	5	Two coils of $\frac{3}{8}$ wire	100	No effect.
14	„	Ditto	120	Ditto
15	„	Ditto	130	Ditto
16	6	Four coils of $\frac{3}{8}$ wire	120	Ditto
17	„	Ditto	130	Ditto
18	„	Ditto	140	Ditto
19	„	Ditto	150	Ditto
20	„	Ditto	160	Ditto
21	„	Ditto	170	Ditto
22	„	Ditto	180	Ditto
23	„	Ditto	200	Ditto

The strength of the wire used in these experiments was ascertained, by trial, to be as resisting a dead tension :—

$\frac{1}{64}$ wire	. .	23 lbs.	= 120,000 lbs. per square inch.
$\frac{1}{32}$ „	. .	70 „	= 92,000 „

If now, the expansive force of powder is taken to be inversely as the volume, its ultimate strength may be approximately arrived at from the last experiment. The powder then could not burst the cylinder. Now the strength of the cylinder, supposing all the material to be equally strained, could not exceed the following per lineal inch of cylinder :—

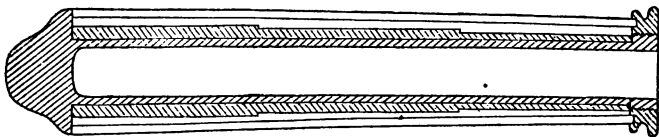
Wire	. . .	17,920 lbs.
Brass	. . .	3,136 „
		<hr/>
		21,056 lbs., or 9·4 tons.

And as the internal diameter was exactly 1 inch, it shows, that the ultimate force of the material in Experiment 23, did not exceed 9·4 tons per square inch. Assuming the law, as above, the ultimate pressure, supposing the cylinder to have been full, could not exceed $9·4 \times \frac{300}{200}$, or 13 tons per square inch.

The enormous strain, to which these cylinders were subjected, is evidenced by the effects upon the gun-metal balls, which were more, or less cut away by the gases, where they touched the cylinders.

These experiments, made on the 17th of May, 1855, were so satisfactory, that the Author proceeded to one on a larger scale. This consisted of a brass cylinder, of nearly the same internal dimensions as a 3-lb. mountain gun, say 3 inches in diameter, and about 36 inches long. The drawing of this cylinder has unfortunately been lost, but it is approximately represented in Fig. 12, from which it will be seen, that the thickness of the

Fig. 12.



brass was $\frac{1}{16}$ inch. At the breech end, it was covered with six coils of steel wire, square in section, and of No. 16 wire gauge, or $\frac{1}{16}$ th of an inch. These coils extended about 15 inches along the cylinder, and were gradually reduced to two coils only, towards the muzzle. Consequently, the thickness of the cylinder was as follows :—

At the breech $\frac{1}{4}$ inch brass + $\frac{3}{8}$ inch iron = $\frac{5}{8}$ inch.
 „ muzzle $\frac{1}{4}$ „ + $\frac{3}{8}$ „ = $\frac{5}{8}$ „

The thickness of the 3-pounder gun, with which it may be compared, being :—

At the breech . . . 2.37 inches.
 „ muzzle . . . 0.75 „

It will be seen, that this cylinder was not mounted as a gun. It had no trunnions. It was cleaded with wood; and the object of the deep steel ring, which was screwed on the muzzle, was simply to cover the ends of the cleading. The cleading had nothing to do with the principle involved, and was only used to screen the construction from general observation.

This cylinder was proved, with repeated charges, varying from $\frac{1}{2}$ lb. of powder and one round shot, to $1\frac{1}{2}$ lb. of powder and two shots. The cylinder was simply laid on the ground with a slight elevation, its breech abutting against a massive stone wall, so as to prevent recoil. It stood the proof without injury, and the Author, on the 19th of June, 1855, addressed a letter to Lord Panmure, then Secretary of War, describing the experiments and the results, and offering the invention to the country.

As was then the fashion, he was referred to the Select Committee, and on 5th of July, 1855, he had an interview with that body, when he explained his views, and exhibited the small brass cylinders as well as the larger one last referred to, which he left, with the request that it might be proved, first as a 3-pounder gun, and then by gradually increasing charges up to bursting.

He remained in London, for some time, hoping to be present at these trials; but other matters called him away, and it was not till the 28th of July, 1855, that the trials were made. Unfortunately as it happened, the Author was unable to be present. The next official communication was a letter from the Ordnance Office, dated the 17th of September, containing a copy of the Report of the Select Committee in the following terms :—

“ On the 28th of July a trial was made with Mr. Longridge’s gun. The gun was clamped on a block of oak with iron clamps, and allowed to recoil on a wooden platform. Two rounds were fired, the first with a charge of 1-lb. powder, 1 shot, (fixed to wood bottom,) and one wood over the shot: the recoil was 7 feet; the gun was found to have slightly shifted its position on the block; a trifling expansion of the wire had also taken place at the breech.

“ At the second round the gun was fired with 2 lbs. of powder, 1 shot, and 1 wad, and burst: the separation took place about 2 inches in front of the base ring; the breech was completely separated from the rest of the gun, and was blown 90 yards directly to the rear. The wire was unravelled to the length of

3 or 4 feet, the brass cylinder burst in a peculiar manner, turning its ends upwards and outwards. It also opened slightly at the centre of the gun ; but the wire did not give way at that point.

"The ordinary proof charge for a gun of this diameter would be $1\frac{1}{4}$ lb., 1 shot, and 1 wad.

"In order to try more particularly the effect of the wire in giving strength to the cylinder, this gun was, after bursting, sawn in two at the centre, and one end of each portion was plugged with a brass plug, which was secured in its place by iron bands and several coils of wire : these guns were then secured to slides of wood as in the former instance ; they were placed opposite the proof butt, and that made from the breech end was loaded with $\frac{1}{2}$ lb. powder and shot. It burst, the breech being blown out and the wire uncoiling to a considerable extent.

"The muzzle portion was then loaded with a similar charge ; it did not burst, but was much shaken by the discharge, and portions of the iron bands gave way. It was then loaded with a charge of 1 lb. of powder and 1 shot, which on discharge burst in two places, the breech being completely separated from the gun and the slide on which it had been fired was rent into several pieces."

Previous to the receipt of the official communication, the Author had, through the courtesy of one of the members of the Committee, been informed of the result obtained. Feeling satisfied that the failure of the cylinder was due to some unexplained cause, he wrote to Lieut. Colonel Eardley Wilmot, begging for some further information, and particularly with respect to the method adopted for firing the gun, during the trials. Colonel Wilmot kindly lost no time in forwarding a sketch, showing the method of mounting, and this sketch at once explained the whole affair. The cylinder had, in fact, not burst at all, but had been torn asunder by the recoil. Fig. 13, which is taken from Colonel Wilmot's sketch, shows how this occurred.

The deep projecting steel flange, at the muzzle, was in fact the *point d'appui*, and the only thing that surprised the Author was, not that it failed at the second trial, but that it stood the first.

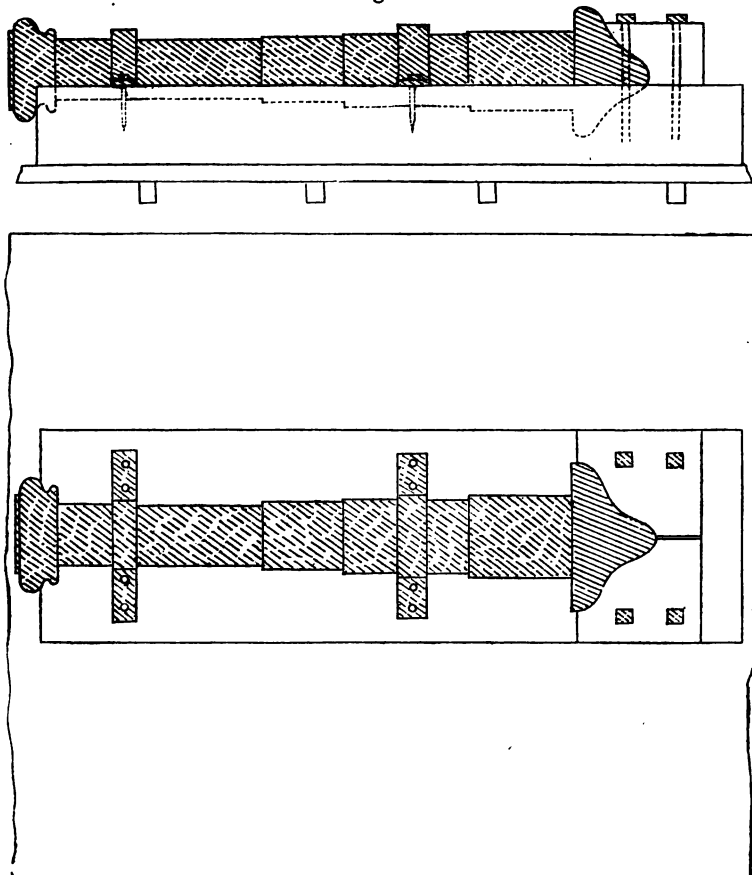
The subsequent burstings, as they are termed in the above Report, were not burstings, but the plugs put into the ends as breechings were simply blown out.

The fragments of the cylinder were, afterwards, forwarded to the Author. Upon examination he found, that the metal was much honeycombed at the breech, where it gave way, and by bad boring had been reduced below $\frac{3}{16}$ ths of an inch in thickness on one side.

The Author, immediately after receiving the sketch, wrote again to Colonel Wilmot, pointing out the cause of failure. To this communication he received a reply stating, that Colonel Wilmot

believed, it was generally thought, that the experiment did not go to disprove the leading idea of his proposition, but that, on the contrary, the blowing out of the breech was an argument in favour of the barrel.

Fig. 13.



On the 21st of September, 1855, the Author again addressed the Ordnance Office, pointing out the cause of failure of the above experiment, and offering to construct a larger gun on the same principle.

In answer to this he received a reply on the 27th of September, 1855, the substance of which was contained in the following words:—"I am directed to inform you, that no further trial of your invention can be made at the public expense."

With, perhaps, some degree of obstinacy, the Author once more wrote to the War Department, repeating his reasons for desiring

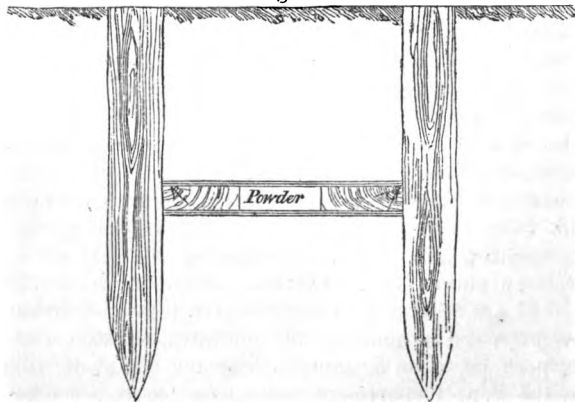
another trial, and pointing out, that what had been done, had been at his expense, and not at that of the public. In answer to this he was informed, that the question was again referred to the Select Committee. Finally, he received a letter from the War Department, dated 25th of October, 1855, to the following effect:—"I have the command of the Secretary of State for War to inform you, that the Committee having referred to the details of an experiment made with it [*i. e.* the Author's invention], consider, that no further trial is necessary, with a gun of this construction."

Thus ended the Author's dealings with the War Department. The result was not encouraging, as regarded the prospect of getting the invention tried by the Government; but the Author had seen no reason to doubt the correctness of the principle. Other affairs imperatively claimed his attention, and the matter lay dormant, as far as he was concerned, for some months, when he commenced a new series of experiments.

Before describing them, he will, however, complete the history of the brass cylinder tried at Woolwich.

Having obtained possession of the fragments, he took a piece of the cylinder, about 2 feet long, and stripped off the wire, with the exception of two coils. It was then a brass tube 2 feet long and $\frac{1}{4}$ inch thick, with two coils of square steel wire, each $\frac{1}{16}$ th inch thick, making together $\frac{1}{4}$ inch of brass, and $\frac{1}{8}$ th inch of wire. In the middle of this, he put $1\frac{1}{2}$ lb. of Government cannon powder, and the ends were filled up with close fitting wood plugs, fixed tightly with iron wedges. A trench 3 feet deep was then dug in stiff clay, and the cylinder was laid at the bottom. At each end a railway sleeper was driven firmly into the clay, and the trench was then filled in with clay, well pounded with a heavy beater. (Fig. 14.) The powder was then fired by means of a patent fuze.

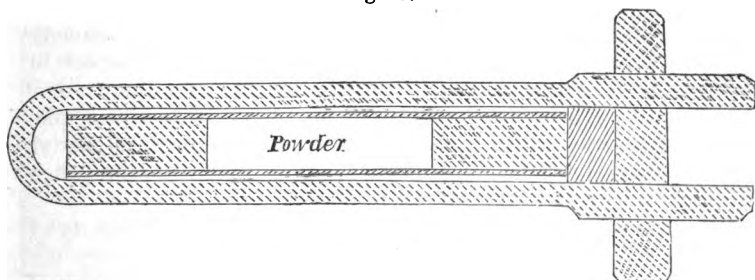
Fig. 14.



The wood plugs and sleepers were thrown out with great violence, and a large mass of clay at each end was blown out, but the cylinder was uninjured.

Determined, if possible, to burst it, the Author next put in 2 lbs. of powder, filled up the ends with close-fitting iron plugs, and bound the whole together with an iron strap, of a sectional area of 5 square inches, as shown in Fig. 15.

Fig. 15.



The powder was then fired, and the iron strap was torn asunder, but the cylinder was uninjured, except at the ends, where from the wire being imperfectly fastened, it uncoiled, and the cylinder was torn open. If the tensile force of the iron strap is taken at 18 tons per square inch, the force of the powder must have been above 13 tons per square inch, and yet this was resisted by $\frac{1}{4}$ inch of brass and $\frac{1}{8}$ inch of steel wire. The diametral strain must have been 39 tons, and taking the brass at 10 tons per square inch, it leaves 34 tons for the steel wire, which divided over the two sides, or $\frac{1}{4}$ inch, would give for the ultimate resisting strength of the wire so employed, not less than 136 tons per square inch of section. This wire, it should be observed, was of the finest quality.

The Author will now proceed to give an account of the second series of experiments made by him in March, 1856.

Many of those to whom he had described the experiments above recorded, whilst admitting the great increase of strength obtained, were yet of opinion, that it would be only practicable to apply the wire, in combination with a metal of a soft yielding nature, such as yellow brass, or pure copper. It was maintained, that it would be impossible to use the wire in combination with cast iron, owing to the assumed brittleness of that material, and it was objected, that the soft brass, or copper, would soon be worn out by the action of the shot, and the guns be rendered useless.

The Author's views were different. He looked on the inner shell simply as a means of confining the gases, and of transmitting the internal pressure to the wire; and knowing that cast iron would resist a crushing force of 40 tons, he was not afraid of subjecting

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it to a strain in a normal direction, which, at the outside, could not exceed the strength of powder, or 17 tons per square inch. But he was quite aware, that no reasoning would suffice. Therefore, in his second series of experiments, which are about to be described, he resolved to use cast iron alone, in its hardest form,—as produced in a thin casting.

Two sets of cylinders were prepared. One set was intended to try the effect of wire, in enabling hard cast iron to resist a bursting strain; the other set, with a view of ascertaining whether it was possible to transmit the force of the powder, through a thin breech of cast iron, to a yielding substance, placed between that breech and the carriage of the gun. The view, taken by the Author, of recoil and its effects, was this. Action and reaction being equal and contrary, it is evident, that the recoil of the gun must increase, when the velocity, or weight of the ball is increased, and the distance of recoil must also increase, if the weight of the gun is diminished. If, therefore, the Author should succeed in throwing a 9-lb. shot, with a gun of the size of a three-pounder, some means must be devised, of providing for the increased recoil. There were two ways of meeting this. The first was by such a disposition of the material of the gun, as would absorb the blow, with the least possible strain upon the gun carriage, and the least internal stress on the gun itself. The recoil is due to a pressure, which begins at the moment of ignition of the powder, increases very rapidly and again decreases, as the ball moves along the chase of the gun. This pressure is, however, so rapid in its generation, that, practically, it is almost like the blow of a hammer. But it is still a pressure of short duration and great intensity, and its tendency is to tear a gun asunder, between the breech and the trunnions, to tear off the trunnions, or to fracture the carriage, and finally, to tear asunder the part of the gun beyond the trunnions, by its own inertia. Thus, in fact, the whole of the recoil induces a tensile force on the chase of the gun.

Now it is well known, that if it is desired to absorb the force of a blow, it is best effected, by interposing a heavy deep mass behind it, and therefore, the Author proposed to concentrate the weight of his gun, as much as possible, behind the breech.

The blow, thus coming, in the first instance, on a heavy mass of metal, would, to a great extent, diminish the jar upon the carriage. Again, the effect of any concussion is greatly diminished, by a yielding material placed between the body striking and the body struck. As it might be desirable, for practical reasons, to separate the gun itself from the mass of material intended to absorb the recoil, the Author wished to ascertain how far it was practicable to transmit the force through a thin breech, or diaphragm of a hard brittle substance, like cast iron, to a soft

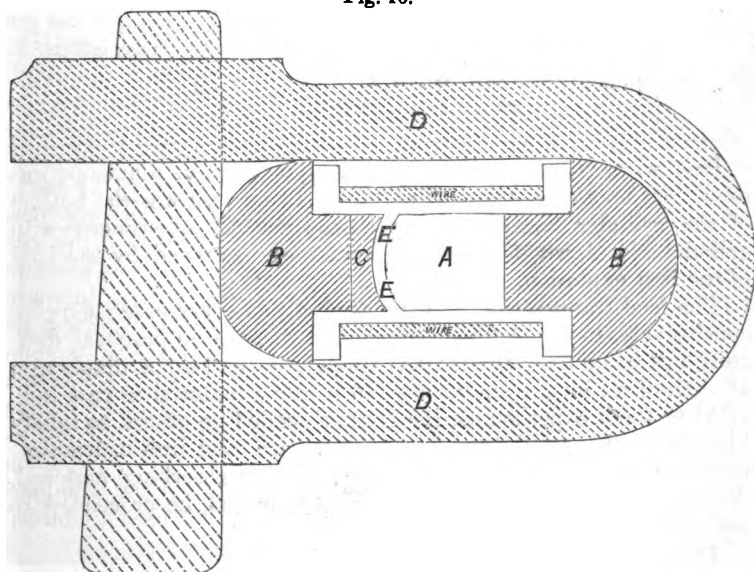
yielding material, like lead, and through it to the absorbing mass behind the breech. He did not expect to diminish the amount of recoil, materially, but to avoid those vibrations, which are so destructive between two hard metals in contact, and which always shake loose any system of bolting, or riveting, however perfect originally.

It was, with this view, that two distinct sets of cast-iron cylinders were prepared.

The first set was intended to try the possibility of transmitting pressure, as just stated, through a thin diaphragm.

The cylinders were of the dimensions shown in Fig. 16, in which

Fig. 16.



A is the powder chamber ;

B and B, cast-iron plugs ;

C, the space between the bottom of the powder chamber, and the plug B, filled up with a soft material ;

D, a wrought-iron strap, with jib and cotter, for keying up the plugs B and B.

The object was to ascertain, whether the diaphragm at E E, would be shattered by the force of the explosion. Six cylinders were thus prepared, and loaded, and fired with charges, varying from 50 grains to 250 grains of Government cannon powder, the total contents of the cylinders being 310 grains.

The following Table gives the results :—

Cylinder.	Wire.	Charge.	Results.	Material behind the diaphragm.
No. 0	2 coils	Grains. 50	No effect.	Lead.
		50	Ditto.	"
		100	Ditto.	"
		120	Ditto.	"
		150	Burst.	"
" 1	4 coils	150	No effect.	"
		180	Top flange burst.	"
" 3	6 coils	180	No effect.	"
		200	Ditto.	"
		220	Ditto.	"
		240	Flange burst.	"
" 6	8 coils	240	Ditto.	"
" 8	8 coils	200	No effect.	Gutta-percha.
		220	Burst.	Gutta-percha, softened by heat.
" 9	10 coils	240	No effect.	Lead.
		250	Flange burst.	

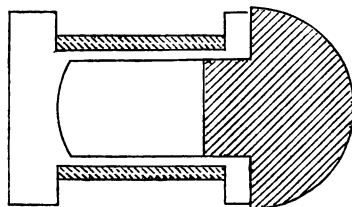
Iron wire, No. 21 wire gauge, or $\frac{1}{16}$ th inch in diameter, was used. Its breaking strain was 60 lbs. In no case was the bottom of the cylinder injured, except in the second experiment with cylinder No. 8, when the gutta-percha was softened by the heat of the first explosion.

The lead transmitted the force perfectly in every case ; showing conclusively, to the Author's mind, that there is no practical difficulty in transmitting the force through even so thin a diaphragm as $\frac{1}{16}$ th of an inch, even when of so brittle a material as cast iron.

After these experiments, the Author needed no others, to satisfy himself of the suitability of even very hard cast iron to transmit the force of gunpowder to wire, or any other absorbing material. As, however, other cylinders had been prepared, he proceeded to try their strength.

These cylinders are shown in Fig. 17.

Fig. 17.



They each contained 305 grains, when full to the plug. The plugs were made to fit accurately, and the powder was fired through a small vent, or touch hole, not larger than a small pin.

The following Table gives the results :—

No. of Cylr.	Wire.	Charge.	Results.	Remarks.
		Grains.		
No. 0	None	40	No effect.	
	Ditto	50	Ditto.	
	Ditto	60	Ditto.	
	Ditto	70	Ditto.	
	Ditto	80	Burst.	
„ 2	4 coils	130	No effect.	
	„	150	Flange burst.	
„ 7	8 coils	200	No effect.	A wrought-iron flange, $\frac{1}{4}$ inch deep, contracted on flange.
	„	220	Ditto.	
	„	240	Ditto.	
	„	250	Ditto.	
	„	260	Ditto.	
	„	270	Ditto.	
	„	280	Ditto.	
	„	290	Ditto.	Hoop on flange shifted.
„ 5	8 coils	200	No effect.	
	„	220	Ditto.	
	„	230	Ditto.	
	„	240	„	Flange cracked.
„ 4	4 coils	200	No effect.	
	„	250	„	Flange cracked.
„ 10	10 coils	310	No effect.	

In these experiments iron wire, No. 21 wire gauge, or $\frac{1}{28}$ th inch in diameter was used. Its breaking strain was 60 lbs.; consequently the actual strength of the material in the cylinder per lineal inch was :—

No. 0 Cast iron $0.10 \times 2 \times \text{tons} = 1.76 \text{ tons}$ 1.76 tons.
Nil.

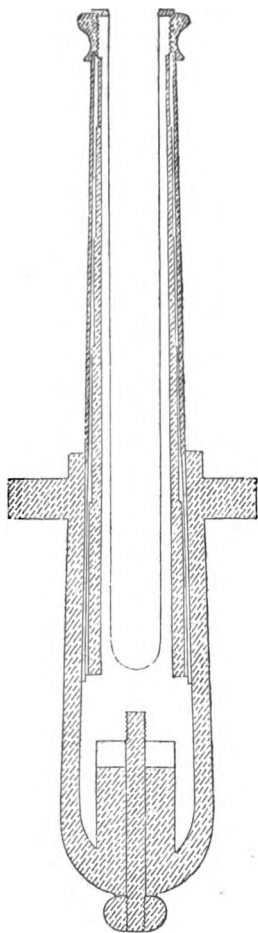
„ 2	{ Cast iron as above	1.76	„	
	{ Wire $4 \times 28 \times 2 \times \frac{60}{2240}$	6.00	„	7.76 „
„ 7	{ Cast iron	1.76	„	
	{ Wire $8 \times 28 \times 2 \times \frac{60}{2240}$	12.00	„	13.76 „
„ 5	Same as No. 7			13.76 „
„ 4	Same as No. 2			7.76 „
„ 10	{ Cast iron	1.76	„	
	{ Wire $10 \times 28 \times 2 \times \frac{60}{2240}$	15.00	„	16.76 „

The enormous force of the expansive gases, in these experiments, was shown by their action on the plugs, which although accurately fitted and of hard iron, were chiselled and grooved out, in an extraordinary manner, as may be seen in one specimen exhibited. The vents, too, were rapidly enlarged.

The results, as regards strength, were so conclusive, that the Author proceeded to construct a small gun, (Fig. 18). This gun

was 2.96 inches in bore and 36 inches long in the clear ; it had on it twelve coils of No. 16 W. G. iron wire, at the breech, decreasing to four coils at the muzzle. The thickness of cast iron was $\frac{1}{8}$ ths of an inch at the breech and $\frac{1}{2}$ inch at the muzzle.

Fig. 18.



The gun was cast hollow, and a recess was left in the thick part of the breech, in which an india-rubber washer, $\frac{3}{4}$ inch thick, was placed. The trunnions formed no part of the gun, but consisted of a strap passing round the breech, with two side rods, extending about one-third of the length of the gun, and terminating in the trunnions themselves. Thus, the whole force of the recoil was transmitted through the heavy mass at the breech, then through the india-rubber, and along the side rods to the trunnions.

The whole was then mounted on a wood carriage, on four roller wheels, about 8 inches diameter.

The weight of the gun and wrought-iron trunnion strap was 3 cwt., and the carriage 2 cwt. 0 qr. 15 lbs., making a total of 5 cwt. 0 qr. 15 lbs.

The shot were cast as nearly the size of the bore as possible, so as to move freely, but with very little windage. The spherical shot weighed $3\frac{5}{8}$ lbs., and the conical shot from 6 lbs. to $7\frac{1}{2}$ lbs.

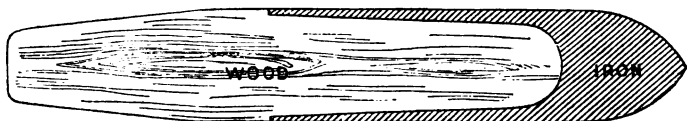
The following are the results with 7° elevation, the powder used being Government cannon powder.

FIRING ON CAMBOIS SANDS, 4TH JUNE, 1856.

No.	Description of Shot.	Weight.		Charge of Powder.	Range to First Graze.
		lbs.		oz.	
9	Round . .	$3\frac{1}{2}$	7°	11	1,400 yards.
4	Elongated . .	$6\frac{1}{2}$	7°	11	1,200 yards.
5	Ditto . .	6	7°	8	1,220 yards.
6	Ditto . .	$7\frac{1}{2}$	7°	11	1,542 yards.
8	Ditto . .	7	7°	11	Lost beyond 1,500 yards.
7	Ditto . .	7	7°	16	Lost beyond 1,800 yards.
10	Ditto . .	$6\frac{1}{2}$	7°	16	1,500 yards.
11	Ditto . .	$6\frac{1}{2}$	7°	16	Lost beyond 1,800 yards.

The variations in the range were due, partly, to not having any very exact means of adjusting the elevations, and partly to differences in the form of the shots. The trials, above recorded, were only intended as preliminary, it being the Author's intention to carry out a more complete series, at another time. Unfortunately this intention was frustrated by an accident, which destroyed the gun, and which the Author now proceeds to describe. He had an idea, that it might be possible to obtain more accuracy of flight by using a shot somewhat on the principle of an arrow, viz., with a long light shaft and heavy head. This shot is shown in Fig. 19. The head was of cast-iron, and weighed about $8\frac{1}{2}$ lbs.

Fig. 19.



The shaft was of fir-wood, fitted tight into the iron head. When fired, by mistake, with a heavy charge of powder, the result was that the wood was driven forward with great force, entering and splitting the iron head. This wedged it so tightly in the chase, that it never left the gun, but tore it asunder about 12 inches from the muzzle; the muzzle and the shot in it were thrown about 15 yards forward, and the wire was uncoiled, but not broken.

This accident, it will be easily seen, was due entirely to the action of the shot, and had nothing to do with the principle of construction of the gun.

Enough however had been done to show, that with a gun weighing only 3 cwt. a shot of $7\frac{1}{2}$ lbs. could be thrown from 1,500 to 1,800 yards,—a result, it is believed, not attainable by any 6-pounder in the service.

So ended the Author's experiments on guns. He had neither time, nor money, at his disposal to carry them further; and although he was thus reluctantly compelled to relinquish the subject, he was fully impressed with the thorough soundness and practical facility of the system, and this in spite of its having been pronounced by the highest authority, unnecessary to make further experiments with a gun of this description.

Another application of the same principle is to the CONSTRUCTION of the CYLINDERS of HYDRAULIC PRESSES. When these are of large size, they are of great weight, and are very liable to be fractured.

Cylinders bound with wire may be made of any size, with the greatest facility, and at considerably less first cost than the unwieldy cylinders now in use.

Taking, for example, a cylinder for a 10-inch ram, with a stroke of 40 inches; the weight of it, when rough, is 46 cwt., and when finished, 31 cwt., and its cost when finished, is about £22.

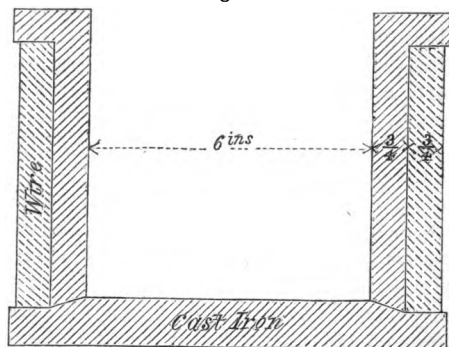
A wire-bound cylinder of the same strength would only weigh 7 cwt., and the cost would not exceed £10.

The difference in first cost, though considerable, is of less consequence than the decrease in the risk of failure, and the vastly increased portability of the wire-bound cylinders. This latter quality is of peculiar advantage in presses intended for exportation to India and to South America, where the means of transport are frequently quite inadequate to the carriage of heavy weights.

In discussing this question, with makers of hydraulic presses, the Author has generally been met with the objection, that the thinness of the cast iron would enable the pressure to force the water through. To try how far this was the case, he constructed a small cylinder, 6 inches in diameter, the metal of which was $\frac{3}{4}$ inch thick, and around it he put twelve coils of No. 16 iron wire, equal to a rim of $\frac{3}{4}$ inch.

This cylinder, represented by Fig. 20, was tested up to a

Fig. 20.



pressure of 6 tons per square inch, without any escape of water. At this pressure it gave way, by shearing the side walls off the bottom plate. The reason for this is obvious. The bottom plate prevented the side walls from expanding, which they were free to do where bound round with wire. The wire was not broken, nor were the side walls shattered.

There are, doubtless, many other useful applications of this principle; but it is to its value in the construction of artillery, that attention is chiefly sought to be directed. There are many questions involved in the construction of an efficient gun, or mortar,

besides that of the absolute strength. These questions have not escaped the Author's attention ; and he believes, that the principle, now under consideration, affords very great facilities, and may be successfully carried into effect, for obtaining every desirable quality in destructive weapons of whatever description, whether for light field-artillery, such as breech-loading rifled guns, or even revolvers, or for heavy guns and mortars for land defences, or for siege purposes ; and he would commence the construction of a 15-inch gun, or a 36-inch mortar, with the utmost confidence in the results. He is quite prepared to meet with objections, and though perhaps the old ones, viz., that these guns would be too light, that cast iron and wrought iron would never work together, that their different rates of expansion would destroy the gun, and so forth, may not now be persisted in, facts having answered them ; still other difficulties may present themselves to the minds of those who have not fully studied the subject, or whose attention is now directed to it for the first time, and although the details of construction and arrangements, which are required to make an efficient weapon, scarcely come within the limits of this Paper, the Author will be glad to hear any objections which may appear to exist, and to reply to them to the best of his ability.

The Paper is illustrated by a series of diagrams, from which the woodcuts, (Figs. 1 to 26,) have been compiled.

APPENDIX.

ANTICIPATING the probability of the extension of the discussion beyond the subject of construction, the Author has prepared the two following Notes;—1°, on the strength of gunpowder; and, 2°, on the causes of deviation in projectiles, and the mode of counteracting the same by rifling. The mathematical investigations referred to in these Notes, as well as the investigation of the strength of hooped, or wired cylinders, by Mr. C. H. Brooks, are given in the latter portion of the Appendix; (page 329.)

1°. FORCE OF GUNPOWDER.

In the foregoing Paper, the initial and ultimate force of gunpowder has been estimated, by the Author, at from 17 tons to 20 tons per square inch. Various authorities have, however, assumed that the force attained was nearly double the Author's estimate.

Unfortunately, no means exist of accurately determining that important datum, owing to the absence of any exact knowledge of the rate at which powder burns in a gun.

It, therefore, still appears to the Author, that the method he pursued is that which is most likely to give reliable results; viz., to construct vessels of certain known strengths, and by actual trial, to ascertain what thickness of metal will resist the full force of powder when no escape is permitted.

The indirect methods are as follows:—

- 1st. From a deduction of the actual volume of gas generated, and thence by an estimate of the force of the gas, when compressed into its original bulk, and at the same time subjected to the great elevation of temperature due to the combustion.
- 2nd. From experiments with the ballistic pendulum, whereby the velocity of the ball leaving the gun is ascertained, and from this velocity the initial force of the powder is estimated.

Both these methods fail, from the absence of correct data. In the former case, the temperature is not known, nor is the index which represents the relation between pressure and volume, when, instead of Mariotte's law, the true law is applied.

In Captain Boxer's "Treatise on Artillery,"¹ the permanent gases evolved from 1 cubic foot of gunpowder, when reduced to ordinary temperature, are stated to be:—

Nitrogen	.	.	.	79.4	cubic feet.
Carbonic Acid	.	.	.	238.0	"
				<u>317.4</u>	"

This, if compressed into the bulk originally occupied by the powder, according to Mariotte's law, would give a pressure of 317.4 atmospheres.

To take in the effect of temperature, Captain Boxer estimates the temperature at 3,000° Fahrenheit; and assuming, that the expansion is $\frac{1}{180}$ th of the volume for each degree of Fahrenheit, he brings the total expanded volume of gases to

$$317.4 \times \frac{3,000 - 60}{480} = 2,154 \text{ feet; which, if compressed to the original volume of}$$

the powder, would give a pressure of 2,154 atmospheres, or 14.4 tons per square inch.

¹ Vide "Treatise on Artillery." 1854, p. 14.

The pressure may, however, be estimated by this law, represented by the equation to an adiabatic curve $p \propto \frac{1}{v^k}$, or $\frac{p}{p'} = \left(\frac{v'}{v}\right)^k$.

Here, p and p' are the pressures before and after compression, v and v' the corresponding volumes, and k the ratio of the specific heat at constant volume to that at constant pressure. In the case of air, $k = 1.41$; and if this be the same for carbonic acid and nitrogen, (which, however, is rather uncertain), the pressure after compression would be = 317.4.

$$\begin{aligned} &= 3,367 \text{ atmospheres.} \\ &= 22.17 \text{ tons per square inch.} \end{aligned}$$

In estimating the initial force of powder from the velocity as ascertained by the ballistic pendulum, the method adopted by Dr. Hutton, and followed by other artillerists, is to find the value of n in the formula:—

$$\begin{aligned} v &= 47.4 \sqrt{\frac{n h d^2}{p + w}} \cdot \text{Log.} \frac{b}{a}; \text{ from which is obtained} \\ n &= \frac{(p + w) v^2}{47.4^2 h d^2 \text{Log.} \frac{b}{a}} \quad \dots \quad (1). \end{aligned}$$

From this, Hutton found the value of n to be from 2,000 to 2,400 atmospheres, or from 13 tons to 16 tons per square inch.

The above formula is, however, based on two erroneous assumptions; first, that the variation of pressure is according to Mariotte's law; and secondly, that the whole of the powder is instantaneously converted into gas. The former assumption may be corrected by adopting the true thermo-dynamical law, and the formula then becomes:—

$$n = \frac{(p + w) v^2}{47.4^2 d^2 \frac{h^k (a^{1-k} - b^{1-k})}{k - 1}} \quad \dots \quad (2).$$

Now in the case of Mr. Whitworth's 80-pounder gun, the velocity of the shot is stated to be 1,300 feet per second, with a charge of 12 lbs. of powder, occupying 20 inches of the barrel. Therefore:—

d = mean diameter of gun . . .	= 5.25 inches.
b = length of gun . . .	= 108 "
a = length of charge . . .	= 20 "
w = weight of shot . . .	= 80 × 16 ounces.
p = half the weight of powder = 6 × 16 "	
v = velocity of shot . . .	= 1,300 feet per second.
h = length filled with powder = 19 inches.	
k = 1.41 (?), as above.	

Whence are obtained the following values of n :—

	Atmospheres.	Tons Pressure.
From (1) Hutton's formula, based on Mariotte's law . . .	2,638	= 17.37
" (2) Hutton's formula, based on the thermo-dynamic law . . .	3,733	= 24.58

These latter results, though probably approaching the truth, must be taken with the limitation involved in the fact, that the burning of the powder is not instantaneous, but is really a work of time. If the relation between the time and the increase of pressure were known, the initial force of the powder, and the maximum strain on the gun, might be determined with greater accuracy.

It may, however, be shown, that the actual strain is always below that given by the formula (2), and that it is less, as the rate of combustion is slower.

It has lately been asserted by the Secretary at War, Mr. Sidney Herbert, (Speech on Army Estimates, 17th of February, 1860,) that "we have been wrong for some time in using powder of so quick a detonating nature for artillery purposes, and

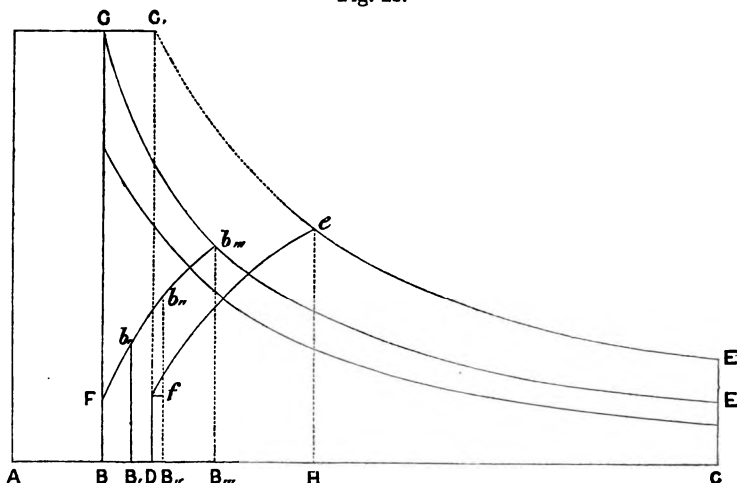
especially for rifled cannon, which require weaker and slower powder than that suited to other arms."

An assertion so extraordinary, coming from such a source, calls for careful examination.

This question may be briefly investigated in the following manner:—

In Fig. 21, let ABC be the chase of the gun, and AB the portion occupied by the powder before explosion. Now as soon as the powder begins to burn, the pressure

Fig. 21.



accumulates in AB , until it is equal to the resistance of the ball. Let this pressure be denoted by BF . The ball then begins to move towards C , and when it arrives at B , B'' , the pressure may be represented by the ordinates B, b, B'', b'' . Let the powder be all burnt when the ball arrives at B''' , and let the corresponding pressure be denoted by B''', b''' . Then the curve Fb, b'', b''' represents the curve of pressure, up to the point B''' . From this point to the end of the gun, the pressure will be represented by the ordinates of an adiabatic curve b''', E , and the total work done by the ball will be represented by the area BFb''', E . This is, of course, on the assumption, that there is no transmission of heat from the gases to the gun. Any such transmission would, of course, decrease the ordinates and the curve area; but the heat, so transmitted, is so small a proportion of the whole heat generated, that it may practically be neglected.

If now the adiabatic curve Eb''' be continued to G , BG would represent the initial pressure, if the powder had exploded instantaneously, and the area BGE the work done on the ball. It therefore appears, that the work actually done is less than the work of powder burning instantaneously, by the area Fb''', GF .

If, then, BGE represents the work done, as determined by formula (2), it is obvious, that to produce the same effect with a slow-burning powder, more of it must be used. If the length of powder is represented by AD , a curve results such as $DfeE, CD$, which must be equal in area to BGE , and the maximum pressure is represented by He . Now eE , must be a portion of an adiabatic curve, descending from G , and G, D must be equal to GB , because each represents the same force, viz., the force of instantaneous explosion; consequently, He is always less than GB .

The result, therefore, is that with a slow-burning powder the strain on the gun is less, but the quantity of powder required is greater; and the necessity of a slow powder, adverted to by the Secretary at War, can only be caused by the

guns not being sufficiently strong to resist the more economical and more powerful quick-burning powder.

In concluding this Note, the Author would take the opportunity of expressing the hope, that a series of experiments may be instituted with rifled ordnance, and all the important appliances of the present day, somewhat similar to those conducted by Dr. Hutton. Such experiments, carefully conducted, could not fail to give results of great value to the science and practice of gunnery.

20. EFFECT OF TWIST.

It is not proposed in this Note on the causes of deviation of projectiles, and the remedy by rifling, to do more than to make a few general remarks on the subject. They, however, appear to be called for by the great variety of opinions existing amongst the rifled-gun makers of the day. The following are the degrees of twist given in three cases :—

Mr. Haddan's	..	1	turn in 100	calibres.
Sir W. Armstrong's	..	1	"	38 "
Mr. Whitworth's	..	1	"	20 "

This great discrepancy in practice is very startling, and it may not be amiss to give some consideration to the subject.

The object of rifling being to diminish, as far as possible, the deviation from the line of aim attendant on ordinary shot, these should be first enumerated, and their causes be described.

They are as follows :—

- 1st. Action of the wind.
- 2nd. Rotation of the earth.
- 3rd. Want of symmetry of the shot around the longitudinal axis passing through the centre of gravity.
- 4th. Position of the centre of gravity before, or behind the centre of figure.
- 5th. Friction of the shot in the air.
- 6th. Want of horizontality of the axis of the trunnions.

The first two of these are incidental alike to all guns, and can only be dealt with by making allowances for their effects in practice ; the third, fourth, and fifth are those with which rifling has to do.

If the material of the shot is not homogeneous, or its form is not symmetrical, the resistance of the air causes the projectile to deviate from the true line of flight. Again, if the centre of gravity is behind the centre of the figure, the shot will turn over. Lastly, if the shot leaves the gun with a rotation arising from striking, or rubbing against the inside of the chase, and is not determined by any specific direction, it will fly off to one side, or the other, according to the accidental circumstances under which it leaves the gun.

In Fig. 22, let A B be a shot projected in the direction of the arrow. Now, if the front end is not symmetrical, but is formed as shown at B C, it is evident, that the resistance of the air will cause the shot to deflect in the direction D E, (Fig. 23,) and that its path, as projected on a horizontal plane, would be a curve to the left of D G. If, however, the shot rotates on its axis, the extent of lateral deviation is limited, and the shot is brought back from E towards the axis D G. Now, it is generally stated and believed, that this retrograde motion goes on, until the shot reaches a point F, as far to the right

Fig. 22.

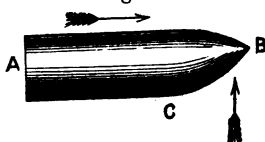
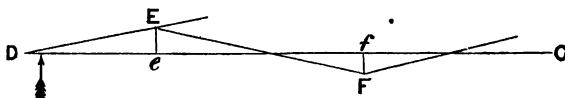


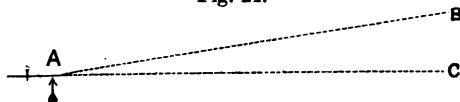
Fig. 23.



of D G as E was to the left, and that, in fact, the shot travels in a spiral around the axis D G, its greatest deviation, at any part of its path, being the distance

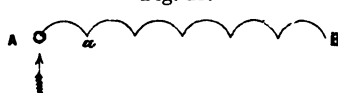
Ee, or Ff. This, however, is not the case. As is shown in the investigation by Mr. C. H. Brooks, (page 335,) the path of the projectile is of a much more complex form, and results in a deviation, increasing uniformly with the distance from the gun, and depending as to its direction, on the direction of the deflecting force, at the moment of its first application. If A be the gun, (Fig. 24,) seen projected on a horizontal plane, and the deflecting force acts on the shot as it leaves the muzzle, in a vertical direction downwards, the general

Fig. 24.



projection of the line of flight will be a line A B, deviating to the right, or to the left of A C, according as the twist is left, or right-handed. If the deflecting force acts in the opposite direction, the shot will be deflected to the right of A C, and whatever be the direction of the deflecting force at the first exit of the shot, the deviation will be a uniformly increasing one at right angles to it. But the line A B is not absolutely a straight line; it is a curve of double curvature, and if projected on a vertical plane at right angles to the axis A C, would consist of a series of cycloidal curves, (Fig. 25,) increasing the distance of the shot from A C, by the

Fig. 25.



length A α , of one of these cycloidal curves at each revolution. The length of each of these cycloidal curves depends upon the amount of the deflecting force, and the number of them is equal to the number of revolutions made by the shot in its flight. The formula for calculating these curves will be found at page 336, and the following Table gives the results as calculated for the several guns therein mentioned, and the aggregate deviation from the line of axis of the gun, at a distance of 1,000 yards, and for a deflecting force, which would have given a deviation of 10 yards to a non-rifled shot, projected under the same circumstances:—

Name of Gun.	Amount of Twist.	Number of Turns in 1,000 yards.	Breadth of Cycloid.	Length of Cycloid.	Total Deviation in 1,000 yards.
Haddan .	1 in 50 ft.	60	$\frac{1}{50}$ th of an inch	$\frac{1}{30}$ th of an inch	2.0 inches
Armstrong	1 in 10 ft.	300	$\frac{1}{250}$ th of an inch	$\frac{1}{750}$ th of an inch	0.4 inch
Whitworth	1 in 5 ft.	600	$\frac{1}{9000}$ th of an inch	$\frac{1}{3000}$ th of an inch	0.2 inch

The aggregate amount of deviation, even with the very slow twist of Mr. Haddan's gun, is very small, and this teaches, that as far as the correction of the deviation, due to want of symmetry, is concerned, the more rapid twists of Mr. Whitworth's and Sir W. Armstrong's are unnecessary.

It is, however, necessary that the rotative momentum be sufficient to keep up the spinning motion to the end of the flight of the shot, and this may require a greater degree of twist, than would be required simply for the purpose of correcting the deviation due to the deflecting force. Experiments are wanting, to show the decrease of rotation due to the friction of the projectile in the air. In Mr. Haddan's projectile, with an initial velocity of 1,300 feet per second, the number of revolutions would be twenty-six per second; and it does not appear likely, that this would be much reduced in the few seconds of the projectile's

The following Table shows the amount of lateral deviation, due to the axis of the trunnions being 1° out of the horizontal line :—

Angle of Elevation.	Azimuthal Error.	Range of Shot.	Lateral Deviation.
35°	42'	8,800 yards	110 yards
10°	$10\frac{1}{2}'$	4,000 „	12 „
5°	5'	2,300 „	$3\frac{1}{2}$ „

When it is considered, how difficult it is to detect, by the eye, so small a deviation from the horizon as 1° , it is evident, that for accurate practice some means must be adopted for accurately levelling the axis of the trunnions.

There may be other causes of deviation, than those above enumerated, but so far as the above investigation goes, it tends to show, that a very moderate amount of twist is all that is generally required, and that the only necessity of increasing the twist arises from the position of the centre of gravity of the shot being such as to make the gyroscopic deviation considerable.

It remains to be considered, what is the amount of force required to impart a certain rotative velocity, and what is the consequent strain on the gun.

Let P = force required at the circumference of the shot.
 r = radius of shot.

ρ = radius of gyration (in a solid cylinder = $r\sqrt{\frac{1}{2}}$).

w = weight of shot.

v' = angular velocity.

v = velocity of shot in direction of axis of gun.

n = length of chase containing one complete turn.

s = total length of chase.

Then it may be shown, that

$$P = \frac{W \pi r}{2 n g s} \cdot v'^2.$$

Now the uniform force which would give the velocity v in the space s , is :—

$$P' = \frac{W}{2 g s} \cdot v^2;$$

Therefore :

$$P : P' :: \frac{W \pi r}{2 n g s} \cdot v'^2 : \frac{W}{2 g s} \cdot v^2$$

$$:: \frac{\pi r}{m} : 1$$

And if m be the number of calibres in which the complete turn is made, $n = 2 m r$,

And $P : P' :: 1 : \frac{\pi}{2 m} :: 1 : \frac{1 \cdot 5708}{m}.$

Comparing the work expended :—

$$W' : W :: P' m 2 r : P 2 \pi r;$$

But

$$P' = P \frac{2 m}{\pi};$$

Therefore :

$$W' : W :: \frac{P 4 m^2 r}{\pi} : P 2 \pi r$$

$$:: \frac{2 m^2}{\pi^2} : 1.$$

Taking Whitworth's large gun, where $m = 20$,

$$W' : W :: 100 : 1 \cdot 236.$$

The force P is exerted tangentially, at right angles to the axis of the shot, and its effect may developed into two others:—

- 1st. A tensile force, tending to tear asunder the chase;
- 2nd. A twisting force, acting by torsion.

These will be found to be:—

$$\text{Tensile force} = P \frac{2 \pi r}{\sqrt{n^2 + 2 \pi r^2}}$$

$$\text{Twisting force} = P \frac{n}{\sqrt{n^2 + 2 \pi r^2}}.$$

Taking Mr. Whitworth's large gun, the following will be, approximately, the forces required to give translation and rotation, when the shot weighs 80 lbs., and the velocity on leaving the gun is 1,300 feet per second:—

Mean force, to give translation	lbs.	306,900
Force, to give rotation	3,784	
Friction of shot in grooves, taken }	3,012	
at $\frac{1}{4}$ th pressure		
		6,796
Total force		313,696

Or, taking the total force at 100, the force to give rotation is 2·16:—
from which it appears, that even with the rapid twist of Mr. Whitworth's gun, the amount of force expended on the rifling, scarcely exceeds 2 per cent. of the total force of the powder.

INVESTIGATIONS BY MR. CHARLES HENRY BROOKS.

CONDITIONS OF STRESS OF A CYLINDER BUILT UP OF CONCENTRIC RINGS.

In a homogeneous cylinder of any material, let R_1 and ρ_1 be the external and internal radii respectively, and let f_2 be the normal, or fluid pressure on the exterior, and f_1 , that on the interior surface. Then it is shown in Rankine's "Applied Mechanics," Article (273), that the tension per square inch of the internal surface is:—

$$T = \frac{f_1 (R_1^2 + \rho_1^2) - 2 f_2 R_1^2}{R_1^2 - \rho_1^2} \quad (1)$$

and in the same way it may be shown, that the tension of the external surface is:—

$$\tau_1 = \frac{2 f_1 \rho_1^2 - f_2 (R_1^2 + \rho_1^2)}{R_1^2 - \rho_1^2} \quad (2).$$

To apply the above to the case of a cylinder composed of four concentric rings:—

Let	f_1 = normal pressure on the interior surface.				
	f_2 =	"	"	between the 1st and 2nd rings.	
	f_3 =	"	"	2nd 3rd "	
	f_4 =	"	"	3rd 4th "	

Also let R_n and ρ_n be the outer and inner radii, respectively, before it is built up in the cylinder. When a ring is expanded, the greatest tension will be at its inner surface; hence, and in order that the cylinder may bear the strain in the best way, the inner surface of each ring must be strained to some tension T , not exceeding the tensile force of the material.

Then equation (1) being for the first ring, there will be similar equations for the second, third, and fourth rings; but with all the subscript numerals increased [1859-60. N.S.]

by one, two, and three units respectively; let these be denoted by (1.), (1..), and (1...), and let these four equations be denominated group (1).

Also, for the outer tensions, τ_2 , τ_3 , and τ_4 of the other three rings, there will be equations similar to (2), but having the subscript numerals increased by one, two, and three units respectively; let this group of equations be (2.), (2..), and (2...),

Now if t be the tension at any radius x , and κ the modulus of extension, then the extension of that radius is $\frac{tx}{\kappa}$, and as the outer surface of the first ring is in contact with the inner surface of the second ring :—

$$R_1 + \frac{\tau_1 R_1}{\kappa} = \rho_2 + \frac{T \rho_2}{\kappa} \quad . \quad . \quad . \quad (3)$$

Similarly :

$$R_2 + \frac{\tau_2 R_2}{\kappa} = \rho_3 + \frac{T \rho_3}{\kappa} \quad . \quad . \quad . \quad (4)$$

And

$$R_3 + \frac{\tau_3 R_3}{\kappa} = \rho_4 + \frac{T \rho_4}{\kappa} \quad . \quad . \quad . \quad (5).$$

Thus there are eleven equations containing five f 's, or normal pressures, four τ 's, or outer tensions, four R 's, or outer radii, and four ρ 's, or inner radii; but of these seventeen quantities there may be assumed any particular values for five of the radii, and also one of the normal pressures, say f_1 , or f_5 may be taken, so that the unknown quantities being reduced to eleven, can be determined as follows :—

Subtracting (2) from (1), the result gives $\tau_1 = T - f_1 + f_2 \quad . \quad . \quad . \quad (6).$

And in like manner, from the corresponding equations of groups (2.) and (1.) are formed the other members of group (6.), viz. :—

$$\tau_2 = T - f_2 + f_3 \quad . \quad . \quad . \quad (6.)$$

$$\tau_3 = T - f_3 + f_4 \quad . \quad . \quad . \quad (6..)$$

$$\tau_4 = T - f_4 + f_5 \quad . \quad . \quad . \quad (6...)$$

Substituting in (3), the value of τ_1 from (6), and reducing :—

$$\rho_2 = \left(1 - \frac{f_1 - f_2}{T + \kappa}\right) R_1 \quad . \quad . \quad . \quad (7)$$

Similarly :

$$\rho_3 = \left(1 - \frac{f_2 - f_3}{T + \kappa}\right) R_2 \quad . \quad . \quad . \quad (7.)$$

And :

$$\rho_4 = \left(1 - \frac{f_3 - f_4}{T + \kappa}\right) R_3 \quad . \quad . \quad . \quad (7..)$$

Let, now, R_4 and ρ_4 be assumed of any given value, and let the external pressure $f_5 = 0$:—

Then from (1...):

$$f_4 = T \frac{R_4^2 - \rho_4^2}{R_4^2 + \rho_4^2} \quad . \quad . \quad . \quad (8)$$

And from (7...):

$$f_3 = (\kappa + T) \frac{R_3 - \rho_4}{R_3} + f_4 \quad . \quad . \quad . \quad (9)$$

in which equation R_3 must be assumed;

Then from (1.):

$$\rho_3 = R_2 \sqrt{\frac{2f_4 + T - f_3}{T + f_3}} \quad . \quad . \quad . \quad (10)$$

Also from (7.):

$$f_2 = \frac{(\kappa + T)(R_2 - \rho_3)}{R_2} + f_3 \quad . \quad . \quad . \quad (9)$$

in which R_2 must be assumed;

Then from (10.): $\rho_2 = R_2 \sqrt{\frac{2f_2 + T - f_1}{T + f_2}} \dots \dots \dots (10)$

Then from (7), assuming a value for R_1 :—

$$f_1 = \frac{(\kappa + T)(R_1 - \rho_2)}{R_1} + f_2 \dots \dots \dots (9)$$

And then from (1): $\rho_1 = R_1 \sqrt{\frac{2f_2 + T - f_1}{T + f_1}} \dots \dots \dots (10).$

Having determined the radii and normal pressures by the seven last equations, the outer tension can be obtained from group (6).

EXAMPLE.—Let T = the greatest amount to which the material is to be strained, be = 12 tons per square inch.

κ = modulus of extension = 12,000 tons.

R_4 = outer radius of the 4th shell = 10 inches.

ρ_4 = inner " " = 8 "

Then from (8) f_4 = 2.634 tons per square inch.

Let R_3 = 8.003 inches.

Then from (9) f_3 = 7.114 tons per square inch.

" (10) ρ_3 = 6.1644 inches.

Let R_2 = 6.1674 "

Then from (9) f_2 = 12.953 tons per square inch.

" (10) ρ_2 = 4.4934 inches.

Let R_1 = 4.500 "

Then from (9) f_1 = 17.213 tons per square inch.

" (10) ρ_1 = 3.7873 inches.

And from (6) τ_1 = 7.740 tons per square inch.

τ_2 = 6.161 " "

τ_3 = 7.520 " "

τ_4 = 9.366 " "

In this example the internal radius is 3.7873 inches, but it is evident from the form of equations (8) to (10), that the pressures are not altered by taking any multiple of all the radii; and hence, if it were required, that the internal radius should be n inches, all that is necessary to be done is to multiply all the other radii, by the ratio $\frac{n}{3.7873}$.

Suppose, for instance, that the internal radius was 4 inches, then multiplying the above radii by $\frac{4}{3.7873}$, they become :—

ρ_1 = 4.000 R_1 = 4.7526 $\therefore$ thickness of 1st ring = 0.7526

ρ_2 = 4.7510 R_2 = 6.5137 " " 2nd " = 1.7627

ρ_3 = 6.5106 R_3 = 8.4523 " " 3rd " = 1.9417

ρ_4 = 8.4492 R_4 = 10.5614 " " 4th " = 2.1122

And for the original differences of the radii of the surfaces in contact :—

$R_1 - \rho_2$ = 0.0016

$R_2 - \rho_3$ = 0.0031

$R_3 - \rho_4$ = 0.0031

From this example, part of Fig. 7, (page 302,) has been prepared.

When three rings are put together, equation (5), and consequently (21), (24), and (27), do not exist; hence making $f_4 = 0$ in (26):—

$$f_3''' = - \frac{NP + S}{PL + Q} \quad \dots \quad (29)$$

then from (25):—

$$f_3''' = Lf_2''' + N \quad \dots \quad (30).$$

For four rings put together, equating (26) and (27) will give f_3'''' and then f_2'''' and f_4'''' from (25) and (26). In all these cases the values of the inner and outer tensions are found by (11) to (18).

For example, taking the case already given—

$$\begin{aligned} a &= - \frac{2 R_1^2}{R_1^2 - \rho_1^2} &= - 6.857 \\ b &= \frac{R_2^2 + \rho_2^2}{R_2^2 - \rho_2^2} &= 3.2726 \\ c &= \frac{2 R_2^2}{R_2^2 - \rho_2^2} &= 4.2724 \\ d &= \frac{R_3^2 + \rho_3^2}{R_3^2 - \rho_3^2} &= 3.9173 \\ e &= \frac{2 R_3^2}{R_3^2 - \rho_3^2} &= 4.9172 \\ g &= \frac{R_4^2 + \rho_4^2}{R_4^2 - \rho_4^2} &= 4.5556 \\ L &= \frac{b\rho_2 - 1 + a R_1}{c\rho_2} &= 2.1373 \\ N &= \frac{\kappa(\rho_2 - R_1)}{c\rho_2} &= - 0.99902 \\ P &= \left\{ 1 - \left(\frac{1-c}{d} \right) \frac{R_2}{\rho_3} \right\} \frac{d}{e} &= - 1.4625 \\ Q &= \frac{1-b}{e} \cdot \frac{R_2}{\rho_3} &= - 0.4624 \\ S &= - \frac{\kappa(R_1 - \rho_3)}{e\rho_3} &= - 1.1876 \end{aligned}$$

Hence, from equations (28), (29), and (30), the following values are obtained:—

NORMAL PRESSURES DURING CONSTRUCTION.

1 Ring	$f_1' = 0$	$f_2' = 0$	$f_3' = 0$	$f_4' = 0$
2 Rings	$f_1'' = 0$	$f_2'' = 0.4674$	$f_3'' = 0$	$f_4'' = 0$
3 Rings	$f_1''' = 0$	$f_2''' = 0.9944$	$f_3''' = 1.1264$	$f_4''' = 0$
4 Rings	$f_1'''' = 0$	$f_2'''' = 1.4713$	$f_3'''' = 2.1456$	$f_4'''' = 1.270$

Also from (11) to (14) and (15) to (18), are found the tensions of the inner and outer surfaces, the accents denoting, as before, the number of rings put together.

	Inner Surfaces.	Outer Surfaces.
2 Rings.	$T'' = - 3.205$ $T_2'' = 1.5297$	$\tau_1'' = - 2.7376$ $\tau_2'' = 1.0623$
3 Rings.	$T_1''' = - 6.819$ $T_2''' = - 1.557$ $T_3''' = 4.411$	$\tau_1''' = - 5.825$ $\tau_2''' = - 1.425$ $\tau_3''' = 3.285$
4 Rings.	$T_1'''' = - 10.086$ $T_2'''' = - 4.355$ $T_3'''' = 2.161$ $T_4'''' = 5.778$	$\tau_1'''' = - 8.615$ $\tau_2'''' = - 3.680$ $\tau_3'''' = 1.285$ $\tau_4'''' = 4.508$

From the latter portion of this Table, part of Fig. 7, (page 302,) has been formed.

If in the example, (page 331), R_1 had been taken = 4.501, instead of 4.500, the value of f_1 would have been found = 19.8917, and $\rho_1 = 3.3827$, the other radii and forces remaining the same, excepting τ_1 , which becomes $12 - 19.8917 + 12.953 = 5.051$; and if, as before, the inside radius is increased to 4 inches, the radii will be as under :—

Inner.	Outer.	Thickness.	Differences.
$\rho_1 = 4.000$	$R_1 = 5.3222$	1.3222	$R_1 - \rho_2 = .0031$
$\rho_2 = 5.3191$	$R_2 = 7.2928$	1.9737	$R_2 - \rho_3 = .0035$
$\rho_3 = 7.2893$	$R_3 = 9.4633$	2.1740	$R_3 - \rho_4 = .0035$
$\rho_4 = 9.4598$	$R_4 = 11.8247$	2.3649	-

With the above radii and value of τ_1 , and with the values of $\tau_2 \tau_3 \tau_4$ from page 331, Fig. 6, (page 300,) was constructed.

Proceeding as before, the following values are obtained for the normal pressures and tensions during construction :—

NORMAL PRESSURES.

2 Rings	$f_1'' = 0$	$f_2'' = 1.0095$	$f_3'' = 0$	$f_4'' = 0$
3 Rings	$f_1''' = 0$	$f_2''' = 1.8851$	$f_3''' = 1.4082$	$f_4''' = 0$
4 Rings	$f_1'''' = 0$	$f_2'''' = 2.6458$	$f_3'''' = 2.6314$	$f_4'''' = 1.4272$

TENSIONS.

Inner Surfaces.	Outer Surfaces.
$T_1'' = - 4.6394$ $T_2'' = 3.3037$	$\tau_1'' = - 3.6299$ $\tau_2'' = 2.2942$
$T_1''' = - 8.6637$ $T_2''' = 0.1529$ $T_3''' = 5.5163$	$\tau_1''' = - 6.7786$ $\tau_2''' = - 0.3240$ $\tau_3''' = 4.1081$
$T_1'''' = - 12.1596$ $T_2'''' = - 2.5837$ $T_3'''' = 3.2900$ $T_4'''' = - 6.5018$	$\tau_1'''' = - 9.5138$ $\tau_2'''' = - 2.5981$ $\tau_3'''' = 2.0858$ $\tau_4'''' = 5.0746$

From which Figs. 3, 4, and 5, (page 298,) were formed.

If in the example, (page 331,) the value of ρ_1 had been taken = 8'4472, instead of 8'4492, the inner and outer tensions, when the four rings are put together, would be as follows :—

$$\begin{array}{llll} T_1 = -11'244 & T_2 = -5'339 & T_3 = 1'364 & T_4 = 7'823 \\ \tau_1 = -9'604 & \tau_2 = -4'473 & \tau_3 = 0'577 & \tau_4 = 6'104 \end{array}$$

In the case where $\rho_1 = 8'4492$, the internal force (f_1) necessary to stretch all the rings at their inner surfaces to 12 tons tension, was found to be 17'213 tons, (page 331); but in the case where the value of ρ_1 is too small by '002 of an inch, the inner surface of the outer ring will be strained to 12 tons by an internal force = 9'908 tons, and the several tensions will be as follows :—

$$\begin{array}{llll} T_1 = 2'268 & T_2 = 4'534 & T_3 = 7'28 & T_4 = 12'0 \\ \tau_1 = 0'492 & \tau_2 = 1'570 & \tau_3 = 4'752 & \tau_4 = 9'362 \end{array}$$

These are represented by Fig. 8, (page 302).

In the preceding investigation, R and ρ have been taken to denote the original radii of the rings, before being built up in the gun. In reality, however, they denote the expanded radii, and by treating them as such, a different and neater method of investigation would result; but the method here given is preferred, as being that by which the calculations for the diagrams in the body of the work were made.

ON THE EFFECT OF ROTATION IN CORRECTING THE DEVIATION DUE TO WANT OF SYMMETRY OF THE PROJECTILE.

The unsymmetrical form will cause the resistance of the air to have a preponderating effect on one side of the shot. Let the component of this effect perpendicular to the line of flight, be denoted by f ; then, this force f may be considered as acting always upon one determinate side of the shot, and consequently, it revolves at the same rate. Setting aside the parabolic form of flight, and supposing that the velocity of the shot, and consequently, the force f are constant, take two rectangular axes perpendicular to the line of flight, the origin in that line, and let the axis of x coincide with the initial direction of the force f , and at any time t , let it make an angle θ with the axis of x .

Then if w = weight of shot, the accelerating force on it will be $\frac{fg}{w} = a$ suppose.

Hence :—

$$\begin{aligned} \frac{d^2 x}{dt^2} &= a \cos \theta \\ \frac{d^2 y}{dt^2} &= a \sin \theta. \end{aligned}$$

But θ increases uniformly. Let $\theta = nt$, which substitute in the above and integrate, making the initial velocity, zero :—

$$\begin{aligned} \frac{dx}{dt} &= \frac{a \sin nt}{n} \\ \frac{dy}{dt} &= a \frac{(1 - \cos nt)}{n}. \end{aligned}$$

Integrating again, so as to make x and y vanish with t :—

$$x = \frac{a}{n^2} (1 - \cos nt) \quad \dots \quad (1).$$

$$y = \frac{a}{n^2} (nt - \sin nt) \quad \dots \quad (2).$$

Equation (1) shows, that at the end of each revolution, the point of application of the force f has made no progress in the direction of that force; but from equation (2), the progress at right angles to that direction is $\frac{2a\pi}{n^2}$, and after

m revolutions the amount is $\frac{2am\pi}{n^2} \quad \dots \quad (3).$

Draw the great circle ZCN , then the path of the ball will be in that plane, and the angle CZB , or its measure Bn , will be the azimuthal error.

Let $Bn = a$, $BC =$ elevation of gun $= \theta$:—

Then, in the spherical triangle BCn :—

$$\cos CBn = \tan Bn, \cot BC,$$

which gives

$$\tan a = \sin \theta \tan \theta. \quad (1.)$$

There will also be a small error in altitude. The altitude at which the gun really is set to is not BC , but nC ,

and

$$\sin \text{true alt} = \sin \theta \cos e \quad (2).$$

EXAMPLE.—Let the tangent slide be set to 10° elevation, and let the trunnions have an accidental error of $2''$. Then (1) gives the azimuthal error $= 21' 9''$, and by (2), the actual altitude would be $9^\circ 59' 38''$, being an error of $22''$; and it is this small error which is generally believed to be the only one.

The following approximate rule is easily deduced from (1). Multiply together the degrees of elevation of the gun and the degrees of inclination of trunnions to the horizon, the product will be the minutes of azimuthal error, to which the horizontal adjustment of the sight may be arranged; or else allow half a yard per mile of range for each minute, and aim that amount to the side which has the most elevated trunnion.

EXAMPLE.—Let a gun be fired to the west, at an elevation of 10° , on a hill sloping $2\frac{1}{2}^\circ$ to the south; then the azimuthal error would be $10 \times 2\frac{1}{2} = 25'$; and if the range were two miles, the gun should be aimed 25 yards to the north of the object fired at.

Mr. BIDDER, —President, —said he felt it was hardly necessary to ask the Meeting to express its acknowledgments, to the Author, for this highly interesting Paper, which touched upon so many points of great importance, and introduced such a variety of matter, requiring careful discussion. As it might be difficult, upon any future occasion, to bring together so many gentlemen whose attention had been directed to the different branches of this great question, which was now exciting so much public interest, it appeared desirable to take advantage of this opportunity, for eliciting information upon the whole subject. The Paper treated, principally, of the construction of artillery; but he hoped some observations would be made upon the best mode of rifling, upon the most effective projectiles, and upon other details connected with the science of gunnery. He also thought, that some attention should be given, to the means of defence against the destructive weapons now being introduced into modern warfare.

Several statements made in the Paper had rather surprised him. The tensile pressure evolved by the explosion of gunpowder was said to amount to from 2,000 to 2,500 atmospheres, or from 14 tons to 17 tons per square inch. He was not prepared to learn, that the tensile force was so great; but the Author had confirmed the statement, by ascertaining the amount of powder required to burst a cylinder of known strength. The President had tested it by the velocity which must be communicated to the projectiles in being urged forward, and the result at which he had arrived, went to show, that the tensile force was rather under-stated than otherwise. Indeed, he believed, the pressure of the gases evolved by the combustion of gunpowder, might be taken at 20 tons per square inch.

Mr. LONGRIDGE remarked, that it might be thought strange, that in the year 1860, he should bring forward the results of experiments which were carried out so long ago as 1855. It had been originally his intention to have laid the subject before the Institution at an earlier period; but on talking over the matter with one of the Past-Presidents, now deceased, that gentleman thought it was hardly advisable to do so, because as Mr. Longridge had taken out a patent for the principle, it might appear that he was making an unwarrantable use of the Institution, as a means of forwarding his own views. Recognising the propriety of the suggestion, he refrained from taking any further steps in the matter at that time. It might be said, that the same objection still applied; but he hoped the Members would acquit him of any such intention. He was aware of the vast amount of time, patience, and money expended by highly intelligent individuals, in endeavouring to effect improvements in weapons of war; and after all that expenditure, there was great probability of their exer-

tions not being attended with success. He had, therefore, long since given up the idea of bringing the matter forward, commercially ; and it was only after the bursting of so many cylinders of hydraulic presses, at the launching of the 'Great Eastern,' that he determined to prepare the present Paper. Having done so, he hoped it would induce a good discussion. It might be thought strange, that he should have made no allusion to what had been done by Sir William Armstrong, Mr. Whitworth, and Mr. Mallet. He had avoided doing so, solely because he was not in possession of that accurate information, which the Papers presented to the Institution ought alone to contain. He could not, of course, apply directly to Sir William Armstrong, for he knew the official reserve which in that gentleman's position it was proper to maintain ; and he was averse to obtaining such information in an indirect manner. Since the Paper was written, there had appeared in a public journal, a description of the Armstrong gun. There were some portions of that description which led him to think, that the person who wrote it either was not, or did not wish to appear versed in the technical details of the matters he described. At the same time, there was a general description of the process of manufacture, which he presumed the writer had witnessed, and which gave a tolerably clear idea of the leading features of construction. The principle adopted seemed to be the construction of artillery by a series of superposed concentric rings. The bar of iron was coiled round in a spiral form and welded. The same process had been very successfully applied in France, many years ago, for the manufacture of the tyres of locomotive wheels. As regarded guns, Mr. Longridge had formerly tried the system ; and he exhibited a piece of a gun so constructed. There was, however, a difficulty in making perfect welds. With the appliances which Sir William Armstrong had at his command, this difficulty had probably been overcome. At the same time, the chief strength of the cylinder so made, was circumferential. The trunnions were shrunk on the gun ; consequently, the whole of the recoil was transmitted through the hoops to the trunnions. He doubted, whether it would be possible, in guns of large calibre, constructed upon that plan, to make the welds hold perfectly. He considered, that the transmission of the force of the recoil to the trunnions, should be through iron laid longitudinally. If some plan of that kind were not adopted, the hoops of the guns would shake loose and give way, although smaller guns made upon that plan had been successful. He had read the article in the journal with pleasure, because it convinced him, that a step was at last being taken in the right direction.

With respect to Mr. Whitworth's proceedings, he appeared to be directing his attention rather to the best modes of rifling,

than to making a strong gun. As regarded Mr. Mallet, his was an endeavour to carry out the principle of hoops upon a large scale. Mr. Longridge did not like to call it a failure; he would rather say it was an unsuccessful experiment. The principle Mr. Mallet had in view was the correct one; it was a step in the right direction; but it was not successful, because sufficient attention had not been paid to the accuracy of dimensions and of workmanship, which the system of rings involved. Mr. Longridge had written to Mr. Mallet for particulars as to the size of the rings; but as that gentleman professed to be preparing a Paper upon the subject, for the Institution, he naturally preferred to retain the information, until such time as he could bring it forward himself.

Before the discussion commenced it might be advisable to explain the objects exhibited, and also to call attention to the diagrams of tension; (Figs. 2, 3, 4, 5, 6, 7, and 8, pages 217, 298, 300, and 302). He would first allude to the brass cylinders referred to in the Table, (page 307,) and to the method of using them shown in Fig. 11. One of these cylinders, without wire, was bulged by a charge of 60 grains of powder. If firing had been continued with the same charge, no doubt the cylinder would have been burst. Another cylinder, with four coils of wire, was tested with 200 grains of powder, and was fired repeatedly, without any effect being produced. Another cylinder, with two coils of wire, was fired first with 90 grains without effect. The wire at one end was then loosened, and 100 grains of powder were put in; when the cylinder became curiously bulged at one end.

With respect to the cast-iron cylinders, Fig. 17, (page 316,) represented the last cylinder mentioned, with ten coils of wire. It was filled with powder, the end was plugged up, and the powder was fired repeatedly, without producing any effect upon the cylinder. The flange had been since accidentally broken off, when it was found, that the side of the cylinder had been sheared off from the top flange. The top flange was not able to expand; but the part of the side, covered with the wire, did expand, and was sheared off. That, however, did not affect the principle, as applied to artillery. He would mention the extraordinary effect which the powder had upon the cast iron. The plug was the exact size of the cylinder when made. After being fired six, or seven times, the plug was grooved in more than $\frac{1}{8}$ th of an inch, by the action of the powder, and the recoil from this, on to the flange, caused a groove in the opposite direction.

When the Paper was written, he had not been able to find any information respecting the actual amount of deterioration, which cast iron, in the interior of a gun, underwent by cooling; nor had he yet been able to do so. But the results of some experiments made by

Captain (now Colonel Sir H.) James, R.E.¹, (Assoc. Inst. C.E.), for the Commissioners on the use of iron for railway structures, bore somewhat upon the point. Captain James took a small bar of cast iron, $\frac{3}{4}$ ths of an inch square, and then cut a bar of the same size out of the centre of a bar 3 inches square. Those bars were then tried as to their resistance to a crushing force, and also as to their transverse strength. The reduction in resistance of the latter bar to a crushing force was 43 per cent., and in transverse strength 42 per cent. Mr. Longridge felt confident, that in a mass of metal, such as was required for a 68-pounder gun, the loss of strength would be at least 50 per cent. When that was combined with the loss of strength due to a homogeneous cylinder, it easily explained the bursting of the hydraulic presses, to which allusion had been made. If the tensile strength of cast iron was taken at 8 tons per square inch, and Professor Barlow's formula was used, the pressure which would burst the cylinder of a hydraulic press 10 inches in diameter, would be 5.54 tons per square inch. But inasmuch as the tensile strength in the interior was reduced from 8 tons to 4 tons, the pressure at which it would burst would be 2.77 tons. If the more accurate formula of Lamé was employed, afterwards deduced by Dr. Hart, in his calculations for Mr. Mallet, and by Mr. C. H. Brooks, in his investigation for the Author, and also arrived at by Professor Rankine, by another method,² the bursting strength would be $3\frac{1}{2}$ tons. Mr. Longridge believed this last formula was the most accurate yet discovered. In the Paper, before the Institution, Professor Barlow's formula was mentioned, because he was the first to point out the cause of weakness in hydraulic presses. But he did not think that Professor Barlow was quite accurate in the investigation, the chief error being in the assumption, that the area of the section of the cylinder remained a constant quantity. Now inasmuch as the iron, by the force of the pressure, became compressed, that must be taken into account in the equations.

In Fig. 2, (page 297,) the line H I represented the state of tension of the particles of a homogeneous cylinder, strained by an internal pressure, according to the true formula. The line H $\dot{i}$ represented the same, according to Barlow's formula. Consequently, the absolute resisting strength was the area of the curve G H I F, or G H $\dot{i}$ F, as one, or the other formula was employed. Now the object to be attained was, that when the particle at G was strained to the extent denoted by G H, the particles at K and F should be equally strained at the same moment. The only way to accomplish that, was to put the particles from G to N

¹ Vide "Report of Commissioners on Railway Structures, 1849," page 257.

² Vide "Manual of Applied Mechanics," page 293.

into an initial state of compression. The strain of the particles, before explosion, was represented by the curve $L N M$. What took place when the explosion occurred, might be thus described:—

L was raised to H : and every point from G to F was raised up to the tension denoted by its projection on the line $H O$. The total strength was represented by the area $L H O M N L$, which was equal to the rectangle $G H O E$. That was the way to get, theoretically, the strongest gun. With reference to the system of construction by means of hoops, referring to Fig. 3, (page 298,) as soon as the second hoop A_2 was put on, with proper tension, it brought the inner one A_1 into a state of compression; the parts shaded below the diametral line representing compression, and those above exhibiting tension. But at the junction of the hoops there was an abrupt change. When the third ring A_3 was put on, the inner ring A_1 was still more compressed. The second one A_2 was brought down almost to the normal line, while the third A_3 was in a state of tension. When the fourth ring, A_4 was put on, the first ring was put in a still greater state of compression, as also the second A_2 , and the tension of the third A_3 was reduced. When the pressure was brought on the inside, it ought to raise the tension of the whole of the rings to their ultimate tensile force. But as was shown in Fig. 6, (page 300,) it only did so as regarded the inner surfaces of the rings. The inner one was raised 12 tons, so that the inner surfaces were strained to 12 tons uniformly, but the outer surfaces could not be so, for each ring, being homogeneous, must follow the law shown in Fig. 2, (page 297). The state of tension was represented by the series of curves a, b, c, d , &c. &c., (Fig. 6); therefore the aggregate strength would be less than the rectangle $C a \times C D$, by the area of all the spaces $a b c$, $c d e$, &c. That would be the case, if a gun was constructed with rings accurately made, according to theory; but supposing the fourth ring to be $\frac{1}{300}$ th part of an inch too small,—in the case of an 8-inch gun, the result was shown in Figs. 7 and 8, (page 302). The initial tension of the outer ring B_4 was increased, whilst that of the second ring was decreased, and the initial compression of the inner rings was increased. When the internal pressure was brought on, the inner surface of the outer ring was strained to its full tensile force; the next was strained about one half, the next one third, and the inner ring was scarcely strained at all. Thus there was a great reduction of strength, from even an error of $\frac{1}{300}$ th of an inch. This example showed, that if the strength of a homogeneous cylinder of wrought iron was 100, when rings were applied in a proper manner, the strength would be raised to 191. But the error of $\frac{1}{300}$ th part of an inch, would reduce the strength to 110. If, on the other hand, all the rings had been brought up to the full tension, then the strength would be 218, or

nearly two and a quarter times the strength of the homogeneous cylinder. This was what Mr. Longridge had been trying to do with wires, which were in every way equivalent to very numerous and thin rings, so that every point could be brought almost up to the ultimate strain which the wire would bear. He would also state, that not only could wire be applied, with the greatest facility, exactly in the way indicated by theory, but it was the strongest material known. A piece of iron which would bear a tensile force of 20 tons per square inch in the bar, would bear 40 tons per square inch, when made into small wire; and steel wire had borne from 120 tons to 130 tons per square inch. Although the experiments he had made had been on a small scale, he hoped they would be regarded as valuable, in confirming what theory pointed out. He had so strong a faith in this theory, that he should have no hesitation in working upon it.

The present question reminded him of the course of events in reference to the construction of girders. In the first instance simple beams of cast iron were used. Tredgold then suggested the double T form, which gave greatly increased strength. Mr. Eaton Hodgkinson, (Hon. M. Inst. C.E.,) followed, and brought out the best form of beam, theoretically considered. Subsequently, the new and stronger material of wrought iron was introduced, and was carried to a high state of development in the Britannia Bridge. In all this the indications of theory had been followed, and he hoped the same would occur with regard to guns. He looked upon the Armstrong and Whitworth guns, as steps in the right direction. Hoops were used, but it was at present doubtful, whether they were being applied with that care, with respect to tension, which theory demanded. Still, it was a step in the right direction, and he had no doubt further improvements would be made, and that before many years, the value of the system of construction now advocated, and the applicability of wire, would be fully recognized.

Mr. ALFRED LONGSDON stated,—through the Secretary,—that he was desirous of explaining the circumstances in connection with the bursting of Mr. Krüpp's gun, at Woolwich, in 1853, alluded to in the Paper. This explanation was essential, in justice to Mr. Krüpp, as, if the cause of the bursting was not made apparent, an erroneous idea of cast steel and of its application to ordnance might be the result. The gun which burst at Woolwich was designed for an ordinary 68-pounder round shot, but during the proof a shot weighing 259 lbs. was used. It was, moreover an expanding shot, having a wrought iron ring, of a V shape in section, fitted on to the end. When the explosion of the powder took place, this ring was broken, and was forced along the body of the shot, cutting up the cast iron to the extent of from 6 inches to 8 inches. The pieces of the shot, thus cut off, together with the

broken ring, completely wedged the shot in the gun, at about the second reinforce, and the natural consequence was, that the gases having no means of escape, burst the gun. The shot was not forced through the gun, but when the bursting took place, it was carried, with the muzzle of the gun, forward to the butt, and was jerked out at the broken end, and thrown over the butt into the convict sheds. The shot was, evidently, the whole and sole cause of the bursting, and no blame could be attached to the metal of the gun. That cast steel was specially adapted to the purposes of ordnance had now been proved by other Governments, and Mr. Krüpp had made a very large number, particularly of rifled guns, without one having burst. As a proof of the tenacity of the steel, it might be mentioned, that a 12-pounder howitzer gun was sent, by Mr. Krüpp, to Woolwich, for the purpose of being tested, as severely as it could be, and notwithstanding that the gun was completely filled to the muzzle with powder, shots, and broken shells, it could not be burst, and it was returned with the cascable knocked off by the recoil; the gun having been thrown high up into the air by the force of the explosion.

Mr. C. H. GREGORY, V.P., said, having been for two, or three years a member of the Select Committee of Ordnance, he begged to offer a few observations upon the Paper before the Institution. If he differed from the Author in one, or two points, both as to his practical details, and as to the implied incompetence of the Ordnance Select Committee, he could not withhold his testimony to the excellence of the Paper, in which was developed, as he believed, one of the most important principles, in the manufacture of large guns. He agreed with the views expressed, that it was impossible, in a large gun, to get the ultimate strength out of a homogeneous material, such as cast metal, or wrought iron forged in large masses; and he believed it was an important improvement to build up large guns, on the principle which had been so well explained. But with regard to the manner in which that principle was to be practically applied, he did not quite agree with Mr. Longridge. Perhaps he could best illustrate his views, by referring to one, or two cases which had come before him officially, as a member of the Ordnance Select Committee. Soon after the commencement of the war with Russia, the civil element was introduced into the Committee. Besides himself and another Engineer, the Professor of Mathematics at the Royal Military Academy, the Chemist to the Ordnance, and another gentleman distinguished in physical science, were made members. There was, at all events, it might be imagined, sufficient of the civil element to assist the military members of the Committee in coming to a right conclusion. The Select Committee was now, however, composed exclusively of military members.

The idea of constructing guns by hoops laid upon bars was not a new one. Some of the oldest guns were made in that way; although no doubt in ignorance of the principles elucidated in the Paper, and without any attention whatever being paid to those principles. If he did not quite agree with the Author, that the Civil Engineer was more qualified to deal with the designing of guns than Artillery Officers, it might in some measure be, because this principle first came to his knowledge through an Artillery Officer, Captain Blakely, who, he thought, had dealt with the matter more practically than Mr. Longridge. The form of Captain Blakely's first gun was shown in Fig. 9 (page 304). When Mr. Gregory first saw it, he ventured to predict, that it would fail at the breech; and he suggested, that it would be better for Captain Blakely to make a gun with the probability of the breech being preserved, rather than expose himself to the risk of failure. The breech of that gun did blow out. He admitted that the Select Committee did not, at the time, understand the principle of that gun, as their report showed; but they afterwards became sensible of their mistake, and, he thought, were disposed to recognise the merits of the principle. If the officer who brought it forward, had not received that encouragement which might have been expected, it had been owing to the belief on the part of some members of the Select Committee, that the principle was not new. But the question of priority of invention was not now before the Institution, and he would, therefore, only say, that whoever first introduced it, in a practical way, deserved the utmost credit, and, some solid reward from the country. Whilst Captain Blakely's gun was before the Committee, Mr. Longridge showed and explained to him a drawing of the model, Fig. 12 (page 308). He then pointed out the probable failure that would ensue, from the want of means to keep the breech on, and the absence of longitudinal strength; and where a gun had to be severely tested, these were important considerations. It had been stated, that the gun burst because it was not properly tested, and that the breech of the gun should have been placed against a solid bearing; but he submitted, that guns should bear due proof without such support. While recognising the excellence of the principle, he had told Mr. Longridge, that the same principle, in a more practical form, was already before the Select Committee. He pointed out, that the mode in which the principle was applied, though theoretically more perfect than that of Captain Blakely, would be liable to objection, as there would be no certainty in coiling on the wire with the proper tension, and that theoretical perfection could not be insured. He considered, also, that there would be a difficulty in securing the wire from injury, for if the end were detached, or one wire were broken, there did not seem to be anything to prevent the whole coil from

unravelling. The mode of shrinking on hoops, or tubes, one over the other, though not so perfect theoretically, was less liable to irregularities of manufacture, or to subsequent injury. Where wire was used, there would be a difficulty in effecting longitudinal strength, and in securing the breech, which were essential conditions to the safety of a gun. When hoops, or tubes were employed, upon a shell, or core, the breech could be made more a part of the gun itself, and longitudinal strength could be better attained. That view had received confirmation, from the Armstrong gun, which had a strong and secure breech. Owing partly to the descriptions which had appeared in the journals, and partly to the statements of Sir William Armstrong himself, the particulars with regard to that gun were no longer secret. It was, therefore, no breach of confidence to intimate an opinion, that the construction of that gun was based, with some variations, upon the principles of construction brought forward by Captain Blakely; and the very ingenious combinations of the Armstrong gun had produced a strong gun with a secure breech. Mr. Mallet's gun, known as the 'Monster Mortar,' was partly made upon the same principle; but here again had occurred the difficulty of fastening on the breech. Mr. Mallet seemed to under-rate the enormous power of the explosive gases from gunpowder. There was a series of rings, and the breech was held on to the muzzle piece, by a number of longitudinal wrought-iron bars, which appeared to be inadequate for the explosion of a full charge. Mr. Whitworth's guns seemed, by the description in the journals and the statements in the House of Commons, to have been built somewhat similarly to those of Sir William Armstrong. Therefore, there were three, or four of the most celebrated modern guns, in which the value of the principle advocated in the Paper had been practically recognized.

Mr. Longridge had alluded to several rifled guns having burst. It must not be forgotten, that some of those guns had been bored out to a larger chase than the blocks were originally intended for, and so far, the test was unfair. Some of the Lancaster guns had burst; while the shells from those guns sometimes attained great precision, and at other times they flew wide. These results, he thought, might have occurred from a want of concentricity in the axis of the shell and the axis of the gun, in which case, there was a tendency to jam and burst the gun. With regard to the guns which had burst after being bored upon Mr. Whitworth's principle, he believed that the hard metal shot was made to be a close fit to the polygonal rifled bore. This arrangement might answer very well, so long as the bearing surfaces were as clean as those of a piece of machinery, and the work was done with the precision of Mr. Whitworth's tools. But if inferior work were used, or when the bore became foul, he thought a hard metal shot, fitting close to a rifled

bore, would have a tendency to burst the gun. He did not say this might not be overcome, with a gun built upon Captain Blakely's principle: at the same time it was rather a hard tax upon cast iron, which might be capable of standing its work with a smooth bore.

It was not necessary, that he should defend all the acts of the Select Committee. He believed they had done good service, and had helped good inventions, rather than thrown impediments in the way, as some disappointed inventors seemed to think. When he first became a member of that Committee, about thirty inventions were submitted for consideration every week. This involved a large amount of work; and if occasional errors of judgment had occurred, that must be the excuse. If Sir W. Armstrong's gun was not recommended, with all the promptitude which some considered due to it, it should be remembered, that without careful experiment, the Committee would have incurred grave responsibility in suggesting such a revolution. It was felt, that in so important a matter, the change should be gradual. After seeing the wonderful practice with that gun, the Committee had, he considered, given it due encouragement, although it was not the Select Committee who advised its adoption, to the extent to which it was now decided to be used.

As a Civil Engineer, he was not likely to undervalue the powers of his own profession, but he must say, that he thought the artillery officer who used the guns had some qualifications for the successful designing of guns, which even the Civil Engineer could not possess. He did not think an artillery officer would have proposed such a projectile, as that alluded to by Mr. Longridge, as having caused the fracture of one of his guns. Those who used guns would often think of some important point, which would escape the attention of civilians, however scientific, or practical.

With regard to the Select Committee, he hoped it was no breach of official propriety to say, that inventions were repeatedly referred back, because some influence was used with the Government, to set aside the recommendations of the Committee. He believed it could be shown, that thousands of pounds,—he might perhaps almost say, hundreds of thousands of pounds,—had been squandered, in trying, at the public expense, inventions which the Committee had pointed out to be utterly valueless, and which afterwards proved to be failures. In the desire to avoid a waste of the public money, and in the multitude of inventions upon which they were called upon to decide, the Select Committee might sometimes have committed errors; but many important improvements had been encouraged and developed, and he believed the Committee had merited the confidence of the Government and the thanks of the country.

Captain BLAKELY, R.A., while appreciating the kind mention which had been made of his efforts to improve the construction of guns, thought undue weight had been attached to the circumstance of his having preceded Mr. Longridge by a short time, in the introduction of his principle before the Government authorities. It was well known, that about the same time (1855), Mr. Mallet brought the same general theory of the matter before the Royal Irish Academy.¹ Mr. Mallet and Captain Blakely took a slightly different view of the mode of carrying out the principle, to that adopted by Mr. Longridge. As the method of using wire had been already fully described, he would confine his remarks, chiefly, to the views entertained by Mr. Mallet and himself. They wished to build up a gun of concentric cylinders, each slightly compressing that within it, thus only approximating to the theoretical perfection, which, doubtless, could be gained with wire, better than with any other material. Mr. Mallet and Captain Blakely only seemed to differ on one point, and that an unimportant one. The former proposed wrought iron throughout, whilst the latter had thought steel, or cast iron, more suitable for the interior of the gun. He was now speaking of a method of construction proposed six years ago, when only iron shot were fired. The introduction of a leaden coating to projectiles, somewhat lessened his objection to forged iron, as a material for the interior of cannon. The barrel of the Armstrong gun was an example of the mode of construction recommended by Mr. Mallet. Any person following the instructions contained in his treatise on artillery,² could scarcely fail to make a barrel like that of the Armstrong gun. Captain Blakely had made some experiments with cast iron for the centre of the gun. The first had already been alluded to, as having had the breech blown out. It was made as an 18-pounder gun, and was very thin, and it was intended to fire about 3 lbs. of powder, with the 18-lbs. shot. A long time having elapsed, before he received an answer to his application to have the gun tried at Woolwich, he tested it personally, with the assistance of the staff of the Butterley Iron Company. He then found it to be an excellent light 18-pounder. Although weighing only 15 cwt., it was safe to fire with 4 lbs. of powder and an 18-lbs. shot. It was afterwards bored out to the calibre of a 24-pounder, (Fig. 9, page 304,) when the cast iron was not more than a quarter of an inch thick. In thus increasing the size of the bore, the true proportions were necessarily lost, but he wanted to ascertain how far the thickness of the metal could be safely reduced. The gun was in this state, when, at length, permission

¹ *Vide* "Transactions of the Royal Irish Academy," vol. xxiii., part I., page 141. 4to. Dublin, 1856.

² *Vide* "On the Physical Conditions involved in the Construction of Artillery, etc." By R. Mallet. 4to. Dublin, 1856.

was granted to have it tried at Woolwich. There it was fired several times, first with 4 lbs. of powder and a 24-lbs. shot, the maximum charge he expected it to bear, then with gradually increased charges of powder, and ultimately, for three rounds, with 8 lbs. of powder and a 24-lbs. shot. It burst, of course, as was intended, and exactly where Mr. Gregory had predicted. Whilst this experiment was going on, the gun, (Fig. 10, page 304,) was being made. It was simply a cast-iron gun, cylindrical from the breech to the trunnion, having three wrought-iron hoops shrunk on it, with a tension not very accurately ascertained. Yet that gun was proved to be one of the strongest ever made. For the sake of comparative experiment, the Ordnance Select Committee had a cast-iron gun and a brass gun of the same size fired, round for round, with this gun. This experiment was made at Shoeburyness in 1855 and 1856, and lasted over a period of nineteen months. The result showed, that his gun was more durable than the cast-iron gun, in the proportion of about 7 to 1, and than the brass gun, by about 3 to 1. The Table, (page 305,) showed the exact number of shot fired. Guns made on that model would be of simple construction and be useful for many purposes, particularly for naval rifled cannon. The result of the experiment just alluded to, caused Lord Panmure, the then Secretary of State for War, to order a 68-pounder and a 10-inch gun to be made, at Woolwich, further to test the principle, and now, he was happy to say, large numbers of similar guns were being made for the Royal Navy. Whilst advocating this system, however, Captain Blakely wished it to be understood, that he fully agreed, that greater strength could be obtained by the use of wire, than in any other manner. Indeed if monster cannon were wanted,—mortars to throw shells of several tons weight, to a distance of several miles, for example,—recourse must be had to wire. He believed that such guns could be made by that system; but he doubted if they could be manufactured in any other way.

Mr. BASHLEY BRITTEN said, one of the reasons assigned in the Paper, for its being necessary to discover a better method of making guns, than that which had previously existed, was that for rifled guns, with elongated projectiles without windage, cast iron would not stand. It had recently been asserted, that all the cast-iron guns rifled in England had, without a single exception, been burst, before the experimental trials were concluded. This statement was calculated seriously to mislead. At the same time it was remarked, that the French had succeeded in rifling a great number of old iron ordnance. This fact proved, that cast iron was a better material than it was generally considered to be. He adverted to this point, because, for many years past, he had been endeavouring to improve the efficiency of the existing stock

of guns, by converting them into rifled cannon. He had made a considerable number of experiments, during the last six years, at Shoeburyness, and would state, generally, the facts elicited. He had, altogether, tried seven guns, made entirely of cast iron. Five of these were ordinary service guns, not strengthened in any way. They had been put into a lathe, and five shallow grooves, each $\frac{1}{16}$ th of an inch deep, had been cut down the bore. Two of these were 9-pounder field-guns, weighing 17 cwt.; two were 32-pounders, weighing about 56 cwt.; and one was a 68-pounder, weighing 95 cwt. There had been fired from the 9-pounder guns fifty-four rounds; from the 32-pounders, one hundred and eighty-one rounds of heavy shells, with heavy charges of powder; and from the 68-pounder, twenty-six rounds of shells, weighing from 90 lbs. to 100 lbs. each, and capable of containing nearly 8 lbs. of bursting powder. Up to this time, no gun to which this system had been applied, had been burst, or injured. The rifling of these guns had enabled conical instead of round shot to be used, and the projectiles were, generally, about 50 per cent. heavier than the service solid shot; whilst the conical projectiles were shells, possessing a capacity for a bursting charge three times as great as that of the spherical shells. With these shells and the rifled guns, an increased range of several hundred yards had been obtained, at 10° elevation, beyond the range of similar guns, before they were rifled. The results of some experiments with the 32-pounder guns, as smooth bores, and the same guns when rifled, were given in the following Table:—

RIFLED 32-POUNDER CAST-IRON SERVICE GUN, (Unstrengthened).							SMOOTH-BORE 32-POUNDER CAST-IRON SERVICE GUN.						
Weight 55½ cwt., bore 6·41 inches. Weight of projectile 49 lbs., diameter 6·33 inches. Charge of Powder 6 lbs.							Weight 56 cwt., bore 6·41 inches. Service solid shot, weighing 32 lbs. Charge of Powder 10 lbs.						
Elevation 4½°.			Elevation 10°.			Recoil.	Elevation 5½°.			Elevation 10½°.			Recoil.
Range, first graze.	Deviation from line of aim.		Range, first graze.	Deviation from line of aim.			Range, first graze.	Deviation from line of aim.		Range, first graze.	Deviation from line of aim.		
Ft. In.	Yards.	Yards.	Ft. In.	Yards.	Yards.		Ft. In.	Yards.	Yards.	Ft. In.	Yards.	Yards.	
9 7	2,026	In line	8 9	3,530	3 left		9 9	2,030	6 left	9 0	2,768	24 right	
9 7	2,125	½ right	8 9	3,556	5 right		9 8	1,962	8½ right	9 0	2,761	34 right	
9 9	2,100	2 left	8 10	3,690	6 left		9 5	2,021	9 right	9 6	2,802	22 left	
9 4	2,078	2 right	8 10	3,560	4 right		9 5	1,885	10 left	9 5	2,676	17 right	
9 3	2,063	½ left	9 1	3,665	In line		9 4	1,980	36 right	9 3	2,665	14 right	
			9 2	3,570	1 right		9 6	1,980	In line	9 6	2,768	40 left	

It would thus be seen, that at an elevation of $10^\circ 22'$, the smooth bore, with a range of only 2,724 yards, varied in accuracy to the average extent of 23 yards from the line of aim, while the rifled gun, at 10° , varied at a range of 3,562 yards, only $3\frac{3}{4}$ yards.

These facts afforded a practical refutation of the assertion, that

the cast-iron guns were incapable of being rifled. He believed, that at Woolwich, on shipboard, and at the various home and colonial stations, there were not less than fourteen, or fifteen thousand of these guns. If they could not be improved up to something like the new standard now looked for in artillery, no doubt they must be sacrificed, at any cost, and others of a more elaborate and expensive workmanship be substituted. He ventured to assert, however, not only that these guns might all be rifled, but that they did not positively require strengthening for this purpose. They could be strengthened in the manner that had been suggested, and perhaps it might be advisable to do so, because if stronger, heavier projectiles could be employed. But he thought they should first be rifled, and then, if desirable, they might be adapted for heavier work. The rifling need not cost more than about thirty shillings for each gun, and the operation could be effected with portable, hand-labour rifling machines, either on board ship, or wherever the guns might happen to be. It was not necessary that they should all be brought to Woolwich. He was convinced, that these guns did not absolutely need strengthening previously to being rifled, because he contended, that the recoil of a gun afforded a comparative indication of the strain from within; and the superior results, he had mentioned, were obtained with less recoil than was usual with the service charges. The average recoil of a 32-pounder gun, on the platform at Shoeburyness, with the service charge of 10 lbs. of powder and a 32-lbs. solid shot, was 9 feet 3 inches. The rifled gun, with a 50-lbs. shell and 6 lbs. of powder, only recoiled 8 feet 11 inches, and with 5 lbs. of powder, only 7 feet, or 2 feet 3 inches less than the usual recoil. This fact was inconsistent with the idea, that the rifled gun was endangered by additional strain. He was aware that several attempts to rifle cast-iron guns had failed; and it was not surprising, that frequent failures should beget mistrust. But he believed these failures had arisen, because the guns were tried in such a way as to involve an immense amount of unnecessary strain. If the bore of a gun was converted into a female screw, having a sharp pitch, and the attempt was then made to drive through it a hard iron shot with a velocity of 2,000 feet per second, the friction on the sides of the gun would be so enormous, that the gun must have extraordinary strength to withstand it. This, he imagined, was the case with the cast-iron 95-cwt. guns, having bores only about 5 inches in diameter, rifled and burst by Mr. Whitworth; and it was the same, though in a less degree, with the Lancaster gun. The fact of its having been found necessary to make the Lancaster shells of wrought, instead of cast iron, proved this. The shot was liable to get jammed in the bore, and then, if the gun was not of great strength, it burst. It should not,

however, be argued from those failures, that Mr. Britten's system must also prove abortive.

In considering the question of additional strain on rifled guns, the character of the projectile was a most essential point. He used a compound shell, on the principle of the Enfield bullet. The body of the projectile was of cast iron, and a band of lead was secured firmly to the iron, so that no disruption could take place. The soft metal was placed just where it was calculated to expand, to fill the bore, and to take the rifling. By examining the shells which had been fired, it would be seen, that the lead only extended for about 2 inches up the sides, where the marks of the rifling showed itself. All the hold of the rifling was on the five thin projections of soft lead, $\frac{1}{16}$ th of an inch thick. It was impossible they could offer sufficient opposition to the egress of the shell, to cause the gun to burst. Some of these shells had been fired with such heavy charges of powder, that the lead had been entirely sheared away by the rifling, but this was all that could happen. The shot could never get locked in the bore.

For field artillery, he was certainly of opinion, that cast iron was unsuitable. Small wrought-iron, or steel, guns could be easily made, having the important advantage of superior lightness. But as the size of forgings increased, the expense was so great as to become a serious question; and the saving of a few cwt. in ship guns could not in itself be worth the outlay. Some idea of the comparative cost of cast and wrought-iron guns might be formed from the fact, that the Armstrong 12-pounder 3-inch gun, weighing 8 cwt., cost, it was said, £250, while the value of the cast-iron 9-pounder, weighing 17 cwt., was less than £20. With one of these 9-pounder guns, he had obtained a range, at 10° elevation, of 3,250 yards, with 1 $\frac{3}{4}$ lb. of powder and a shell weighing 14 lbs. It had recently been stated in the House of Commons, that the range of the Armstrong 12-pounder field gun, fired at 7° elevation, was about 2,480 yards, and at 9° elevation, 3,000 yards, which Mr. Britten had equalled in 1855.

So much had been recently said about long ranges of five miles, that it might seem trifling to talk of only two, or three thousand yards. But he gathered from the opinions of practical artillerists, that a range of five miles was, in itself, of comparatively little use. At that distance, it could never be expected to hit a moving object like a ship. To do so, the exact position of the object must first be determined, and then the elevation must be calculated, so that the shot might be sent up into the sky, and be literally dropped from the clouds right down upon the deck. It seemed to him, that some great authorities on rifled cannon were engaging in a contest about a minor point, in constructing guns of small bore,

with the single object of enormous length of range. There was no doubt, that a small bore would give great range, at high angles of elevation, but it did so at the sacrifice of that which was of far more value, great capacity of shells. Small holes, caused by shot only 3 inches, or 4 inches in diameter, through the sides of a ship, would never sink her. But a shell, containing 8 lbs., or 10 lbs. of powder, bursting between decks, would so rend everything asunder, that a few such shocks would sink the largest line-of-battle ship afloat. Such shells as these he had fired from a common cast-iron 8-inch rifled gun; and at the practicable distance of two miles, they might be so fired, as scarcely ever to miss an object the size of a gun boat. It might be advisable to have on board all ships of war, a few small-bore guns, for skirmishing at long ranges, but they would never decide actions. Battles would be fought and won at nearer ranges; and directly the distance was shortened to within two miles, all the advantage of the expensive wrought-iron guns ceased, and the cheap cast-iron ordnance would then be just as effective,—indeed, far more so, if of larger calibre.

The performance of different guns should not be compared for range alone. The charge of powder, the size of the bore, and the resistance of the air to the larger projectiles, and the probable efficiency and actual results should all be taken into consideration. That was the most perfect instrument, which used to the best advantage the power applied to it. He contended that no results, hitherto obtained, with any breech-loading cannon had, when all these points were considered, established any superiority in breech-loaders over the far more easily constructed, less complicated, and less delicate guns which were loaded from the muzzle. Whenever screws formed a portion of a gun, there was, necessarily, considerable liability to injury from rust and other causes; and bearing in mind the rough work that guns were subjected to, involving long-continued exposure to damp and wet for sea and garrison service, he could not but think, that this was a serious objection. It might be true, that men would not be so much exposed at port holes when loading breech-loaders. But the introduction of rifled guns would cause actions to be fought at long ranges; and when, for instance, ships were engaged only half-a-mile apart, it would be impossible to see whether men were exposed, or not, during the process of loading.

Mr. Britten considered there was a great deal of misconception, as to the advantages to be obtained by the employment of small-bore guns and projectiles of great length. At very high elevations, such projectiles, undoubtedly, had longer range, because from their greater weight and smaller area of transverse section, they were less impeded by the air, and maintained their velocity during a longer time of flight. But it was a mistake to suppose, that at low