

Mr. PREECE, in reply, observed, that he thought there could scarcely be any difference of opinion as to the necessity of the Paper. The discussion had been very full and free, and an amount of information had been gathered, which might not otherwise have been obtained. He regretted the narrow views which had characterised some of the speakers, who appeared to be so impressed with the importance of their own systems, as to ignore the general questions that had been raised. If he had failed to place Mr. Tyer's and the needle systems in the foremost rank, he had given reasons for not doing so; and if he had not considered the South-Eastern bell-system as the best, it was because he believed it to be the worst. When the Paper was perused dispassionately and quietly, he was convinced it would be found, that he had described, fairly and correctly, every system referred to.

He would now take a broad view of the subject, and would deal rather in generalities than in particularities. The first great question that arose out of the Paper was, the advantage of the general adoption of the telegraph in the working of railways. He was gratified to find, most of the railway managers who had spoken confirmed the opinion, that the telegraph was chiefly valuable as an auxiliary agent, and that its use should never be resorted to, until experience had shown its employment to be imperative. Mr. Eborall alone had advocated the adoption of the 'block' system. Mr. Preece believed that this subject had not been thoroughly considered, nor had Railway Companies arrived at any definite conclusions, as to the point of demarcation, where it was necessary to abandon the 'time' system and to seek the aid of electrical signals. The South-Eastern Railway Company used the 'block' system on their branches, where trains were few and far between; while a contiguous railway, the South-Western, continued to work the traffic on a very busy portion of their line (the Richmond branch) without the aid of the telegraph. The London and North-Western Company worked the length between London and Rugby by the aid of the telegraph, while between Manchester and Liverpool, where the trains were much more frequent, there was no electrical signalling system at all.

But it was upon single lines that the adoption of the telegraph was most urgently needed, and on this point he regretted to be at variance with Captain Huish, who advocated the use of the train-staff, to the exclusion of the telegraph. Captain Huish preferred delay, to the probability of accident from mistakes in messages. Captain Tyler had also supported the train-staff system, but Mr. Heamans had pointed out its failure on the Irish lines. The experience of the staff on the South-Western Railway was by no means in its favour. It frequently happened on the Epsom and Leatherhead line, that a man had to be sent on horseback, or by carriage to the other

end of the line to obtain the staff. Wherever human agency was employed, there was always a liability to error; and it had even happened that an engine-driver had left without the staff. The telegraph was unquestionably liable to mistakes, but by the system employed on the South-Western Railway, it required three different persons to make three similar mistakes before any chance of accident could occur. The train-staff system might be very good in theory, but experience, which after all was the true test of theory, had shown it to be impracticable. The Board of Trade had issued a code of instructions, prepared with considerable care, for the use of the train-staff; but no such regulations had ever been circulated for the proper working of the electric telegraph.

Having thus determined that, in certain localities and under certain circumstances, a system of electrical signalling was essential, the question arose, as to whether that telegraph was to be dependent upon the organs of sight, or upon those of sound. It seemed scarcely necessary to those who were in the habit of using apparent signals, to argue this question; but when the South-Eastern, the London, Chatham, and Dover, and the North-Eastern Railway Companies employed bells, it was essential to inquire into the matter. Now the only argument advanced against the use of visual signals was that adduced by Mr. Walker, who contended that the deflection of a needle contained a contradiction in itself; as in reply to the question, 'May I send a train?' it said, 'Yes, you may not.' Nothing could be more absurd than this. The lowering of a semaphore was not a contradiction, and every engine driver who whistled down a signal considered it to be an intimation that he might proceed; and the deflection of a needle was taken to imply, 'Yes, train may proceed; line is clear;' and could not possibly be misinterpreted, as had been suggested. Mr. Walker himself had been obliged to resort to the use of indexes upon his recent bells. Several facts were instanced, exemplifying the confusion arising from the constant repetition of the same sounds, and he thought that a signalman in a small hut, surrounded by bells continually ringing, would be likely to get confused, and to neglect his duty. The London, Chatham, and Dover Railway required twelve beats of the bells to signify 'all clear,' and ten to indicate 'danger.' Such elaboration and repetition might conduce to safety, but only at the expense of simplicity. He contended that the weight of the evidence was in favour of visual as against aural signals.

The next point to be determined related to the advantage of producing these visible signals, either in a permanent, or in a transitory manner. As the use of transitory signals necessitated the employment of record books, he believed them to be disadvantageous, inasmuch as record books could never be trusted. Captain

Tyler remarked, in his report upon the collision between two trains near the Victoria (Pimlico) station "These entries [in the record book] would, if they were to be relied upon, confirm in a satisfactory manner the evidence."¹ Record books were undoubtedly useful, but they should be avoided as much as possible. Distant signals required no such entries, and electrical signals were nothing more than distant signals. Mr. Culley had instanced a case where the signalmen themselves had resorted to an expedient to obtain this permanent effect; and as experience had thus shown its utility, practice should confirm its necessity.

To determine the question, whether these permanent signals should be obtained by the use of continuous, or by momentary currents of electricity, it was necessary to refer to various natural and artificial phenomena which disturbed the correct working of telegraphic circuits. The first and greatest enemy to be contended with was the effect of atmospheric electricity. A flash of lightning might itself directly enter the wires, and completely destroy any telegraph instrument through which it passed; and in this respect every instrument which had been described suffered alike. But its most frequent effect was one resulting from the inductive action of a cloud charged with electricity, which might be passing at a distance even of several miles. Such inductive effect invariably took the form of a current, at one time so strong as to reverse the magnetism of the needles it traversed, at another abstracting the magnetism out of the needles, and at other times acting simply like an ordinary current, as though transmitted from a battery. Such effects were comparatively harmless on the semaphore, were easily remedied upon the needles, but were highly dangerous, as giving false signals, on Mr. Tyer's and other instruments worked by momentary currents. The liability of Mr. Tyer's instrument to be affected by lightning had been denied; but in a letter he had received from an inspector who had made inquiries on a line running out of London, it was said 'that they were sometimes affected by lightning.' Mr. Gilbert, the Telegraph Company's inspector on the Great North of Scotland Railway, also wrote as follows, on the 21st November, 1862, in reference to Mr. Tyer's signal system:—

"During the prevalence of lightning the permanent magnets sometimes lose the whole of their magnetism, and sometimes only that of one pole. In the former case the needles drop between the two poles of the magnets, and are useless for any signalling purposes. In the latter,² the needles adhere to the poles of the magnets in which magnetism exists, and if shifted by the line current to the opposite pole, will not remain but fly

¹ Vide "Reports of the Inspecting Officers," &c., 1860. Page 89.

² Mr. Gilbert is evidently in error in this. A magnet cannot be deprived of one pole alone. The effect is due to residual magnetism,—a peculiarity of electro-magnets alluded to by Mr. Fleeming Jenkin.—W. H. P.

back. These defects are well known to the station agents, and when existing, they are guided by the beat of the bell or gong. Thus, if A has a train for B, he gives two beats on B's bell, which is tantamount to the question, 'train waiting, can it come on?' If line clear, B returns one beat on A's bell, and at the same time directs his own and A's needles to 'train on line.' The beat of the bell is therefore a guide, in the event of the needles being affected by lightning. If both bell and needles fail, as is sometimes the case, or any doubt exists, the trains are signalled by needle telegraph. It rarely happens that the poles of the magnets are reversed. Deflections, when strong, shift the needles and ring the bells, particularly in the old make of instruments: In the new instruments this defect is lessened, but still exists. The system is too complicated to allow of any local remedy being applied, in any case of interruption; thus a considerable time must elapse in the setting right of only a few stations. On a line like the Great North of Scotland, where the trains are few and far between, and where a needle telegraph exists to fall back upon, these defects are of comparatively little moment; but on a crowded line, where illiterate pointsmen are employed, and where no needle telegraph exists, confusion must arise, and I cannot see how any such line could be worked with safety. The system works well in the winter, and is, perhaps, then preferable to any other; but in the summer our own system is far safer, and I would give it a decided preference."

He thought this evidence was conclusive, as to the liability of these instruments to derangement from atmospheric electricity.

Another natural phenomenon—that commonly termed 'deflections' or 'earth currents,'—seriously affected circuits worked by momentary currents. At certain times and seasons, immense masses of electricity passed through the crust of the earth, from the equator to the pole and vice versa, traversing the telegraph circuits in their course, and causing great annoyance and trouble. In the needle and semaphore instruments, such currents produced little effect, as they rarely if ever equalled in force the usual working currents; but upon instruments worked by momentary currents, such effects produced a complete stoppage. The signal in Mr. Tyer's instrument in place of remaining at 'train on line,' would instantly fly back and remain at 'line clear.' Mr. Gilbert's letter afforded evidence of the effect of these earth currents.

There were also interruptions arising from accidental and artificial causes. The wires might be brought into temporary contact by the wind, or, as they frequently were, by the long levers of the platelayers; and cases had been known where birds alighting upon wires had produced similar effects. Such accidents would produce false signals on instruments worked by momentary currents, while those actuated by continuous currents would remain unaffected. An accident which occurred on the London, Brighton, and South Coast Railway, near the Victoria Station, on October 16th, 1860, was believed by the Author, who investigated it shortly afterwards, to be due to this cause. Capt. Tyler said, "There is

¹ Vide "Reports of the Inspecting Officers," &c., 1860. Page 90.

no question in this case of any irregularity in the working of the instruments or of the needle having been pushed over accidentally at the Victoria Junction, (which might possibly have happened under other circumstances in consequence of the instruments being as yet unprovided with glass covers,) because the statements of Bicknell and Agent are to the effect that they both saw the needle go over, and both heard the bell ring at the same time, though they could not be sure as to whether it rang three times or not." This was an illustration of the danger of depending upon sound.

False signals were also produced on Mr. Tyer's instrument, by a defect which was pointed out by Mr. Fleeming Jenkin, whereby a signalman, to make the same signal had at one time to push one button, and at another time the other button. Evidence of the occurrence of such a false signal was given in a letter he had received from a late inspector of his, who said:—

"The wrong signal that was given on Tyer's instrument at * * * the other day was caused by the man pressing the wrong piston, and was likely to have been very serious in its consequences; but the affair has been hushed up; and Mr. * * * seemed very reluctant in giving me any information about the instruments, but said they are sometimes affected by lightning."

He therefore contended that, judged by the liability to accident from natural and other phenomena, instruments actuated by momentary currents were decidedly inferior to those worked by continuous currents.

The question of the superiority of the various systems was consequently reduced to the relative merits of Mr. Clark's and of the semaphore. Presuming the defects of each to be equal, as a telegraphist, Mr. Preece would as soon use the needle as the semaphore, but as his object was to produce uniformity in signalling, he believed the semaphore to be fully equal to all the requirements of a railway. It had been contended that, inasmuch as the semaphore was a mechanical arrangement, it was defective; but all telegraph instruments were more or less mechanical arrangements, and while the construction of the semaphore was visible, if the interior of most of the instruments which had been described were examined, it would be found that they were considerably more intricate than the semaphore. It was absurd, in the present day, when mechanical construction was brought to such perfection, to object to an instrument on account of its construction, unless it was unduly complicated. In the instrument in question, there were only two pivots, one lever, and a rack and pinion. It was questionable whether any other instrument was so simple. Moreover, the simplicity of its construction rendered it peculiarly suited for the hands of uneducated signalmen, who fully and completely comprehended it, from their acquaintance with the construction and

working of the out-door semaphores, with which it was assimilated in every particular. The intelligence of signalmen had been much underrated, as Mr. Newman had pointed out, and experience had fully shown, that when an instrument which they understood was placed in their hands, it received as much care and attention as if the men were skilled mechanics. It was infinitely preferable to place such an instrument in the hands of signalmen, than to give them an instrument kept invariably under lock and key.

Again, it was contended, that the semaphore arrangement was not new. If he had felt any curiosity before the commencement of this discussion, it was to know how many claimants there would be for the invention of the semaphore. He had, therefore, been agreeably surprised to find there was only one such claimant. He did not conceive the mere inventor of a useful article to be the only one entitled to credit; those who brought it into general use surely merited some notice. It was not Mr. Cooke who invented the telegraph, but he introduced it, and was therefore deserving of the reward he had received. He willingly accorded to Mr. Walker any reputation that might accrue from originating such an instrument, but of which Mr. Preece had been perfectly ignorant when he brought out his own; but if such a really useful thing had been allowed to lapse for a period of nine years, it certainly should not now be brought forward, in order to attempt to detract from the credit due to its introducer. The idea conveyed in the two instruments was similar, but their mechanical construction was totally different; and while Mr. Walker's was a simple needle, in no way differing from an ordinary needle instrument, but with its defects magnified, Mr. Preece's was to all intents and purposes a practical railway signal, based upon a totally different principle. Both Mr. Walker and Mr. Preece had, however, been anticipated by Mr. Ward, who, in 1847, invented and patented a semaphore worked by electricity; but he went beyond either by fixing the semaphore visibly before the driver on the line. It was not however the mere invention of the semaphore that Mr. Preece claimed; it was the assimilation of the electrical to the ordinary line signals of the particular railway upon which they might be fixed, the method by which electrical signals were simply worked as distant signals, and the reduction of the whole system to one uniform plan. This had never been attempted before. Allusion had been made to the effects of decreasing battery power. Now, upon no instrument was the failing strength of the battery shown more clearly than upon the semaphore, the arm of which rose with greater or less rapidity, according to the strength of the current. It had also been stated, that five wires were necessary to work this system in its complete form. This was an error, as only four were required. In practice, however, three wires were used for a double line and

two wires for a single line, as in the case of Mr. Clark's system. A single line could be worked by the semaphore system on one wire alone, but he deprecated the use of a single wire. It must also be observed, that in the event of derangement from any cause, either to the wires or to the instrument, the arm immediately showed the danger signal, and thus warning was at once given, and security obtained. In conclusion, he expressed a hope that the time might come, when all the great railways of the kingdom would be worked on one plan for the manifest advantage of all.

Mr. HAWKSHAW,—President,—said the discussion of this subject showed that electricians were still a long way from uniformity; and he was not sure if, at this stage of the inquiry, uniformity was desirable. It had been objected, on the score of safety, that there were too many trains on railways. He was afraid that objection would not be obviated, for, in his opinion, the number of trains would increase, as the growth of population, and the tendency of people to live near railways, must lead to the multiplication of trains. He felt that whatever science and vigilance could accomplish, to ensure greater safety on railways, should be done; and he thanked Mr. Preece for having brought forward a Paper which had elicited a great variety of opinions, as to the best mode of applying telegraphs to railways. He placed a high value on the opinions of Captain Huish, who had had such long experience on this subject; but he could not agree with him on one point. Theoretically, no doubt, the train-staff led to greater safety than any other mode of working. But persons might be preserved from railway accidents by not going upon a railway at all; and the train-staff system was an approach to doing away with railway travelling. As a system, it simply meant that, provided a Company confined itself to one staff, it would also limit itself to one locomotive; and so long as only one locomotive at a time ran upon the line there could not be any collision. But it was obvious that, under that system, trains could not be started from the same end of the line at short intervals of time; as when the staff was at the other end, it must be brought back, and this necessarily involved delay. He considered the train-staff system was wholly inapplicable to any railway on which the traffic was large. Neither could he concur with the remark, that a great mistake had been made, in not more generally adopting single lines of railway; or that, with the use of the telegraph, proper superintendence, and due vigilance, a single line of railway could be made as useful as a double line. If an accident happened upon a single line, the traffic of the whole system was stopped. Therefore, although there were cases in which single lines were proper, inasmuch as the district might not afford sufficient traffic for a double line of rails, yet he should not wish it to be understood, that one line of rails could ever answer all the purposes of two lines.

As to this particular question, he concurred with those who thought, that every one engaged on railways should always be on the alert, and that nothing should be done to diminish, or to relax, the vigilance of the engine driver, in looking out for the signals during his journey; but, so far as he knew, he did not believe the tendency of telegraphic arrangements had produced that effect.

With regard to the electric telegraph, he had on previous occasions expressed his opinion of its great utility. It was adopted about the same time that railways were introduced; and to those who aided in its establishment, society at large owed a great deal. There was one point of view from which the telegraph became very important: whatever time might be saved by railways, the telegraph carried that reduction still further. Here the train-staff failed. If, for instance, A wanted something from B, by employing the telegraph, B could be instantaneously informed of this want; whereas without the telegraph a message must be sent by an engine to B, to bring back what A required. The same advantage would be conferred upon steam-boat communication by the electric telegraph. Whatever might be gained by the time saved in transit by steamers, the telegraph would double the saving. Merchants requiring goods could ask for them by telegraph, and the steamer could be loaded and dispatched at once. Without the telegraph, the steamer must go one way to announce the want, and return back again to supply it. Although it had not been proved, whether Mr. Tyer's, or Mr. Preece's, or Mr. Walker's system was the best, he believed that all were calculated to be of advantage to railways. The telegraph would be of great service, and must ultimately become essential in working railways, though clouds charged with electricity might occasionally demagnetise the needles; and he hoped those gentlemen who had undertaken that branch of science would continue their endeavours to eliminate, as far as possible, every source of error.

January 20 and 27, 1863.

JOHN HAWKSHAW, President,
in the Chair.

The discussion upon the Paper, No. 1,079, "On Railway Telegraphs, &c.," by Mr. W. H. Preece, was continued throughout these evenings, to the exclusion of any other subject.



RAILWAY BREAK.

After the Meeting a model of a Railway Break was exhibited by Mr. W. G. Creamer, of New York. This plan was stated to embrace, first, an arrangement of compensating, or balanced breaks, worked by one lever, and distributing the pressure equally on all the wheels, with a small expenditure of power. Secondly, an attachment of reserved power to the breaks of every carriage, in combination with a non-elastic signal rope, so as to enable the driver instantly to apply every break in case of danger; or on the separation of the train, or any part being thrown from the line, the breaks would apply themselves automatically, as each carriage was entirely independent of all the others, and the breaks were available wherever they were placed in the train.

February 3, 1863.

JOHN HAWKSHAW, President,
in the Chair.

The following Candidates were balloted for and duly elected :—
EDWARD FILLITER, and ARTHUR SIDNEY ORMSBY, as Members ;
THOMAS EDWARD DUNN, JAMES ROBERT FURNISS, Captain JAMES
GRANTHAM, R.E., JOHN JACOB HOLTZAPFFEL, STEPHEN LANCELOT
KOE, ALFRED STANSFIELD RAKE, LEONARD ROBERT ROBERTS,
ROBERT OWEN WHITE, and HUGH WILSON, as Associates.

No. 1,048.—“On the Woods used for Sleepers on the Madras
Railway.” By BRYCE M^CMASTER, M. Inst. C.E.

OF all the questions relating to the construction of railways in India, there is not one of greater importance, and few have of late years received more consideration, than that of the substructure of the permanent way ; and most deservedly so, for it has a material influence on the cost of maintenance of the line. The native wood sleepers having hitherto been found, for the most part, deficient in durability, attention has been turned to an iron substructure for the permanent way ; and as the resources of India seem inadequate to meet the demand, the question has arisen, whether sleepers of cast iron, or of creosoted timber, must not be sent from England ? This is so important, that it is desirable to inquire into the causes of the failure of the native woods, with a view to ascertain whether these causes can be overcome, and the vast resources of the country be rendered available.

On the Madras Railway between 30 and 40 per cent. of the sleepers have annually required renewal. This has been due to two causes : first, to the employment of woods unfit for the purpose ; and secondly, to the sleepers being cut from young trees, which would have been good if allowed to stand till old enough. With reference to the first of these, it was to determine which woods ought to be rejected as unfit for sleepers, at whatever age they might be cut, that the Author, in the year 1858, commenced a form of examination which should discover and record the annual deterioration of the sleepers. It may appear a simple matter to

[1862-63. N.S.]

R

note the names of the woods as they were removed, and to discontinue the use of such as were found to be unsuitable; but experience showed that, in the majority of instances, the sleepers decayed so rapidly and so completely, that it was impossible to determine, with any degree of accuracy, the names of the woods. The nature and appearance of the woods were often entirely changed, and all brands, or other marks made on the sleepers when new, were effaced. In practice the Author prepared a list of upwards of thirteen hundred sleepers, on a portion of the line convenient for the purpose, and numbered these sleepers from certain fixed points. They were examined carefully twice, at an interval of twelve months, and the state of each sleeper, at the date of the examination, was recorded. When decayed sleepers were met with, it was easy, by reference to the list, to discover what the woods were. The Author's sudden departure from India prevented a third annual examination, and his observations are, therefore, less calculated to prove the length of time good sleepers will last, than to show those which should not be used at all in a plain state,—a point on which, as far as he is aware, no system had previously been adopted, and the want of which information had caused many woods to be used for sleepers, which were proved by the Author's first examination not to be capable of enduring a single year.

The sleepers examined were variously placed—some on embankments and some in cuttings. Advantage was also taken of the opportunity to test the effects of different forms of ballasting, regarding which there had been some discussion amongst the Engineers on the line. The system usually adopted on the Madras Railway was to cover the sleepers entirely with ballast; which, outside the rails, was on a level with the tops of the keys, and between the rails was about 4 inches over the sleepers. This was drained in the ordinary way, by cross drains at intervals. The other system, which was adopted by the Author on the division under his charge, was to leave the sleepers as much as possible uncovered. In the middle, between the rails, the ballast was raised about 2 inches, and it was sloped off so as to throw the water under the rails; the sleepers from the rails to the outer ends being uncovered.

The annexed statement gives the Tamil and the botanical names of the woods which came more particularly under observation, with the state of the sleepers at the end of the second year :—

Tamil Name.	Botanical Name.	Uncovered.			Covered.		
		Good.	Serviceable, but beginning to get bad.	Useless.	Good.	Serviceable, but beginning to get bad.	Useless.
		Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
Chella woonjay	Acacia odoratissima	63	29	8	55	33	12
Vel vengay . .	Ditto speciosa . .	37	36	27	17	36	47
Dud eloopay . .	Bassia longifolia . .	60	25	15	64	25	11
Vella naga . .	Conocarpus latifolia .	47	29	24	20	..	80
Miladi	..	6	6	88	..	..	100
Margosah . . .	Melia Azadirachta .	43	43	14	..	25	75
Kurkuttah . .	Zizyphus glabrata .	..	31	69	20	10	70
Kurrah murdah	Terminalia glabra .	66	28	6	35	31	34
Palay (red) . .	Mimusops hexandra	75	25	..	38	62	..
Kotvoye	Acacia speciosa . .	46	8	46	7	30	63
Maroothy . . .	Terminalia alata . .	13	28	59	29	15	56
Coombaderie . .	..	22	22	56	7	11	82
Auray	..	..	9	91	9	12	79
Karavalum . . .	Acacia Arabica . .	80	20	..	56	22	22
Necanee	Conocarpus latifolia	11	22	67	..	..	..
Cadookoy . . .	Terminalia chebula .	..	..	..	11	16	73

From this table it appears, first, that only five woods—the Chella woonjay, Eloopay, Kurrah murdah, Palay, and the Karavalum—were sound at the end of two years, and that the other eleven species would not last as sleepers for that time. Secondly, it is evident, that where the sleepers were uncovered, decay was much less rapid than where they were completely buried in the ballast. The last two woods in the list were not found in the two systems of ballasting; of the remaining fourteen it will be seen, that in ten the advantage is decidedly in favour of the uncovered sleepers, while in the other four, the difference in favour of the covered sleepers is extremely small.

The system of leaving the sleepers as much as possible uncovered has many advantages. It effects a saving of about 9 cubic yards of ballast per chain of line, and there is proportionately less labour in opening out the road for examination, or repairs. It allows the platelayers to detect at once any defects in the substructure of the road, which, when the sleepers are buried in ballast, can seldom be done, until the effects are visible in a depression of the rails; and by throwing off wet more rapidly, it keeps the sleepers drier, and induces their better preservation.

The objections urged against the system were, that the heat of the sun would split the sleepers, and cause the keys and trenails to shrink. Further, that the road would not be sufficiently bedded

in the ballast to prevent its twisting when the rails expanded, or on the passage of trains.

Regarding the splitting of the sleepers, the following statement, referring to the whole of the sleepers examined, shows the effects of the two systems:—

	Good.	Beginning to split.	Beginning to rot.	Useless; split.	Useless; rotten.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Uncovered .	47	19	8	2	24
Covered . .	38½	12	13	.	36½

It thus seems that, while amongst the uncovered sleepers there is a larger proportion 'beginning to split' or 'useless from being split,' there is, on the other hand, amongst the covered sleepers, a still larger proportion 'beginning to rot,' or 'useless from being rotten;' and the per centage of good sleepers amongst the covered is less than amongst the uncovered. On the whole, therefore, it appears to be decidedly better not to bury the sleepers in the ballast, as has generally been done. As regards the trenails, the Author found that where the sleepers were rotten the trenails were almost invariably rotten too, on which account uncovered sleepers seem to be preferable. On the other hand, he never found that trenails whose heads were exposed to the sun were loosened by shrinking. Keys, if not properly seasoned, will shrink in India. No system of ballasting which would protect them from the sun would be admissible, as it would effectually prevent the platelayers from tightening them up. Besides this, the Author found, that where the ballast touched the keys, whether of English, or of native wood, they were generally soft, and covered with fungus, and, where the line was not opened for traffic, in many instances they were eaten by white ants. With reference to the last-named objection, that the road would be more liable to twist and buckle if the sleepers were not buried in the ballast, the Author can only state, that he never knew this to be the case on 40 miles of line thus ballasted and opened for traffic, on the division under his charge.

Trenails made in India cost from £2 10s. to £4 per thousand; the price varying with the difficulty of getting wood and labour. The woods generally used for the purpose were the Vengay, Kurrah murdah, Erool, Porasa or Satin wood, and Trincomalee. These trenails appeared excellent, but the Author left India before he had an opportunity of observing their durability. He is, however, convinced, that they are equal to any trenails sent from England. Trincomalee wood in particular seems deserving of more attention

for the manufacture of trenails. Keys were also extensively made in India, of the Vengay, Kurrah murdah, Erool, and Teak. These keys were considerably longer than usual, so as to allow of their being driven up, when they got loose. Teak keys seemed to be the best, and as their cost did not exceed £6 per thousand, it would be worth while to have them supplied in India. The other woods named, if properly seasoned, would doubtless be found as durable as, and cost less than, Teak.

From personal observation and inquiry, the Author thinks the following twelve woods will make really good sleepers, to be used plain :—

TAMIL NAME.	BOTANICAL NAME.
Teak	<i>Tectona grandis</i> .
Saul	<i>Vatica robusta</i> .
Sissoo	<i>Dalbergia sissoo</i> .
Pedowk	<i>Pterocarpus Indicus</i> .
Kurrah murdah	<i>Terminalia glabra</i> .
Aucha	<i>Hardwickia binata</i> .
Vengay	<i>Pterocarpus marsupium</i> .
Chella woonjay	<i>Acacia odoratissima</i> .
Erool	<i>Inga xylocarpa</i> .
Karavalum	<i>Acacia Arabica</i> .
Dud eloopay	<i>Bassia longifolia</i> .
Palay	<i>Mimusops hexandra</i> .

The previous list contains the names of eleven woods which should, in the Author's opinion, be rejected as unfit for sleepers, if used in a plain state.

It is deserving of notice, that of the sleepers 'beginning to rot' 19 per cent. of the whole had begun under one, or both chairs. In many of the sleepers which were so rotten as to be useless, it was impossible, from their state of decay, to determine where, or how the decay had commenced. Speaking, therefore, only of those previously alluded to as 'beginning to rot,' the additional fact was observed, that in the uncovered sleepers 24 per cent., and in those covered 18½ per cent., decay had begun under the chairs. The Author believes that the cause of this decay is the retention of moisture under the chairs, in the hollows of the castings. The rarefaction of the air within this hollow would be greater when the chair was not protected by ballast from the heat of the sun: when rain fell, this air would be sooner cooled, and the water would have freer access to the interior, than where ballast intervened. It may be said, that under any circumstances the quantity of water so retained must be extremely small. Nevertheless for many hours after the rest of the sleeper was perfectly dry, damp was observed all round each chair, the water within being slowly expelled, as the chair was again heated. The large proportion of sleepers shown to have been affected by this damp, and the fact that many sleepers had to be removed, because they were rotten

under the chairs, while the rest of the sleeper seemed perfectly good, are sufficient proofs that this subject deserves consideration. It is believed that if the seats of the chairs in the sleepers were well tarred, it would go far to remedy this evil; although the Author had not an opportunity of witnessing the effects of what he recommends. It cannot be said that the chairs had, in any instance, been crushed into the sleepers, for at the date of the second and last annual examination, nothing heavier than a platelayer's 'trolley' had passed over them.

With regard to the second cause of failure,—the woods being used too young and unseasoned,—the list already given, of the state of the sleepers at the end of the second year, does not show the actual expenditure of sleepers on the Madras Railway up to that time. Large as the renewal is there seen to be, it was even yet larger in reality. For as the main object of the investigation was to discover what woods were good and what bad, so in the record made of the results of this investigation no notice was taken of the decay of sap wood, which unfortunately formed a considerable portion of many sleepers; its decay, which took place always before the end of the first year, leaving so little of the original sleeper as to necessitate its renewal. In such cases when the heart wood was found to be sound and good, the sleeper was recorded under that head.

The circumstances under which the sleepers were supplied were such as to account, in some measure, for the great loss from this cause. In the first place, until sleepers were actually required for the railway, there had not been any demand for them from any quarter. The jungles were unknown to all but a few native wood-cutters. A commencement was made by some of the civil servants of the Government, who rendered valuable assistance to the Railway Company, by working the jungles in their neighbourhood. The example thus set was followed by natives possessed of capital, who entered into contracts with the Railway Company for the supply of sleepers. These men sublet the work to 'wudders,' a peculiar tribe accustomed to wood-cutting in the jungles. But this arrangement was speedily found to fail. The native contractors took little interest in the work, and exercised little supervision over the wudders. They secured themselves by throwing upon the wudders, a poor ignorant race of men, all the loss caused by sleepers being rejected by the Railway Company's agents. The want at that time of any supervision in the forests, (now ably exercised by the Forest Department), tempted these wudders, and the rude appliances at their command forced them, to leave untouched large trees from which really good sleepers might have been cut, and to satisfy themselves with felling only the smaller and young trees. They also frequently lopped off the branches of large trees, and left fine

trunks standing. Of course a large proportion was rejected by the Engineers of the Railway Company, but the supply was so scanty and irregular, that at last, when the permanent way was being laid, sleepers had to be obtained by any means, and many sleepers which would have been rejected at first were bought up eagerly at last. In fact instances occurred, in which sleepers rejected by one Engineer, who could afford to pick and choose, were taken immediately to a less fortunate neighbour, (the marks of rejection branded on them being carefully removed), and by the latter they were bought and used. Under these circumstances it is not to be wondered at, that so many inferior sleepers were used. The appointment of Conservator of Forests was made in December 1856, but some time elapsed before the arrangements could be completed for an efficient supervision and systematic working of the forests. It was not, for instance, until July 1858, that an establishment was sanctioned for the working of the Salem Jungles, from which a large portion of the railway was supplied with sleepers. Things continued in this state until May 1858, when the system of giving large contracts for sleepers was discontinued, on account of the utter inability of the contractors to fulfil their engagements, and the Engineers received permission to purchase sleepers direct from any one who should offer them for sale. This change had many advantages. The middle-men being done away with, the Engineers had direct access to the wood-cutters. In many cases the price of the sleepers was reduced, but where it remained the same, the wood-cutters who brought the sleepers direct to the Railway Company received a larger profit, than when they had to work for contractors who were not remarkable for liberality, nor even for honesty in their dealings with the poor, ignorant labourers. But many of the disadvantages of the old system still continued. The different establishments of the Forest Department were at first unable to superintend and control the numerous parties engaged in all directions in felling timber, and the wood-cutters were still no further advanced in the knowledge of the good woods, or the means of obtaining proper appliances for felling any but the smallest trees. The results were, therefore, although in a less degree, the same as before. Sleepers were used green and unseasoned. The supply of good sleepers was far short of the demand, and timber of inferior quality had to be bought at last, to complete the laying of the permanent way.

From what has been said, it will be seen that the sleepers which have failed on the Madras Railway may be divided into two classes:—those which are of perishable woods, and those which, although of good woods, have been cut from young trees. The existence of the first is to be attributed to want of experience of the nature of the Indian woods; and of the second to want of a

proper system in working the jungles. It is of importance to consider how far these evils may be remedied. As regards the first, experience is being gained every day of the woods suitable for, and actually used for sleepers, and if those who have opportunities of witnessing their durability would record the result of their observations, much useful knowledge would be gained, and economy might be effected in the construction and maintenance of Indian Railways. It is indeed hardly possible to suppose that, after so many years' experience, there has not been much information obtained in all parts of India, regarding the nature and qualities of its timber; but it is to be regretted, that hitherto no means have ever been taken to collect such information, or if collected, to disseminate it, so as to render it useful to the Railway Companies.

The two systems of procuring sleepers, through native contractors possessed of capital, and by purchase direct from the wood-cutters, or others, having been found to fail, the question arises, What can be done to secure a plentiful supply of good sleepers? The Author is persuaded, that this will be accomplished when, but not until, the Railway Companies send their own agents, with sufficient establishments, into the jungles, to cut down the wood themselves, to furnish the wood-cutters with proper appliances, and personally to superintend their operations. This was done on the Madras Railway, in one or two instances: in particular in the Paulghaut Jungles, where Mr. Ross, the Resident Engineer, (afterwards the Chief Engineer of the Madras Railway,) worked the jungles systematically. The result was, that Mr. Ross was able to furnish from his own resources nearly eight districts; while on portions of the line where the other systems were in operation, the supply required for one district (of 25 miles) could not be obtained from some scores of suppliers. In the case of a new line of railway, it would be highly desirable, as soon as it is settled that the line is to be made, to send establishments into every jungle, and to commence felling really suitable timber. Then by the time the sleepers were required, the logs would be tolerably well seasoned, and they might be cut up into sleepers and be conveyed to the works. There is no doubt that the cost of these establishments would be money well spent; for besides the immediate advantage of a large supply, and the ultimate advantage of the sleepers being of good and seasoned woods, it is certain that the cost of the sleepers might be reduced, as large profits seem to have been made by the native contractors. The present practice is to push on the earth-works and masonry; and too often when these are ready to receive the permanent way, there is not a sufficient number of sleepers, and the Engineer is obliged to buy any timber he can get. Directors and shareholders are satisfied for the time, and when, after the first year, they hear of the extravagant cost of renewals,

the Indian jungles are condemned as unfit to yield the required supplies, and England is resorted to for a substitute, without sufficient thought being given to the want of experience and system which must operate at first.

So far, reference has only been made to such Indian woods as may be expected to answer if used plain, and to the means of obtaining them. But the Indian jungles abound in woods which are of too perishable a nature to allow of their being used in that state. The Author thinks that the sleepers should be creosoted, or otherwise prepared, on a much larger scale than has yet been attempted; so as to render available many of the woods which would otherwise be useless. In a previous Paper,¹ allusion was made to the creosoted sleepers sent from England to Madras, and an opinion was given of their value. Shortly before his departure from India, the Author examined some thousands of these sleepers, both of the rectangular and the triangular cross section, which had been laid for four years, and the impression then formed was, that they were admirably adapted to the country. An exceedingly small number had been renewed. They had been laid, mixed with native wood sleepers, of the description usually supplied, and while the native wood sleepers had in two, or three years become so rotten as to be, with few exceptions, unfit for use, the creosoted sleepers were as good as when they were originally laid. It may be stated, that the cost of an English creosoted sleeper conveyed, say, 100 miles by rail and 50 miles by road, would be nine shillings and sixpence, while the average price of native wood sleepers used plain and delivered on the works was six shillings each. The English creosoted sleepers are liable to get too dry from exposure to the sun, especially those of a triangular cross section, which are apt to be broken at the edges in being laid. All creosoted sleepers should be constantly protected from the direct heat of the sun, until actually required, and care should be taken in laying them. It is because English creosoted sleepers answer so well in India, that the Author recommends that native wood sleepers should be subjected to the same process. It is true that some sleepers have been so treated, both on the East Indian and on the Madras Railways, and possibly elsewhere; but as far as the Author is aware, the experiment has not been fairly tried. Saul, Teak, Soondry, Sissoo, and such other woods as have been creosoted, or otherwise prepared, and to which the experiment appears to have been limited, are all hard, durable woods, and so close-grained as to make it a difficult matter to force the solution into them. Why should the most expensive woods in first cost and those most diffi-

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xviii, pp. 417-422.*

cult to creosote, be selected, when there are many others more plentiful and more easily obtained, lighter and more open-grained, and therefore more easily creosoted? Establishments and apparatus for creosoting, or otherwise pickling, might be erected in convenient positions near each extensive jungle, and such establishments would be more, or less permanently useful. Sleepers of common light woods might easily be procured at an average price of four shillings and sixpence each, delivered on the works; and, judging from what has already been done in India in this way, the cost of creosoting, including the expense of the apparatus, would probably be less than one shilling each. There is every reason to believe, that sleepers thus prepared would last as long as those sent from England, at one-third less cost.

Having thus attempted to explain the chief causes of failure in the native wood sleepers, and how these may be overcome, in order that the resources of the country may be made available, the Author will now endeavour to show, that these resources are likely to prove sufficient to meet the demand. Taking, for example, one forest, that near Salem, out of probably twenty in the Madras presidency:—It is stated, in the Report of the Conservator of Forests for the official year 1859-60, that from the Salem jungles alone two hundred and forty-six thousand sleepers, or sufficient for 133 miles of railway, were cut during that year. Of course, a large number were rejected, and of those actually bought many were found to be very perishable; but the figures show what one forest can yield. As might be expected, it was not without considerable anxiety that those interested in the conservation of the forests saw the vast drain required to supply the railways. In the Report alluded to, the Conservator of Forests calculated that, for 1,150 miles of railway, sanctioned, or contemplated for the Madras presidency, an annual supply of two hundred and fifty-three thousand sleepers (say thirty-five thousand trees) would be required for renewals alone, allowing each sleeper to last on an average eight years. Arrangements have been everywhere made for planting good trees to meet this demand and to keep up the supply. With twenty forests from which to draw the supply, the demand on each would average about one thousand sleepers per month; and this does not appear above what may be expected from the supply. Railway Companies and other bodies likely to require large supplies of timber are recommended to plant on their own lands trees suitable to their requirements, a plan which, if followed, would much increase the sources of supply. But it will be many years before there are 1,150 miles of railway requiring an annual supply of sleepers, and the numbers given above are sufficient to allow of a renewal annually of about 25 per cent. of sleepers for some time to come.

The Author cannot discover, in the Reports of the Conservator of Forests, any information regarding the largest amount of timber that may annually be obtained from the Madras forests. Probably the short time the Department has been in existence, the limited number of assistants, and the immense amount of work they have had to perform, as well as the still unexplored state of many parts of the forests, have tended to prevent this information from being obtained, and without it no correct calculations can be made. But as a supply from each jungle of two thousand sleepers per month would provide for the construction of 500 miles of railway within the next five years, and for the same period would allow a renewal of 33 per cent. of the sleepers already laid, it may be confidently anticipated that the supply will not fail, if means are taken to make the naturally perishable sleepers last a reasonable time.

An analysis of the two hundred and forty-six thousand sleepers already stated to have been cut in the Salem jungles during the year 1859-60, may be useful, as exemplifying the waste of timber and the great expenditure of sleepers that then prevailed; and further it will be seen, how large is the number of sleepers which can be obtained, if artificial means are used for preserving those of a perishable nature. The sleepers referred to may be divided as follows:—

	Good.	Bad.
Known to be good	82,000	..
Known to be bad	..	96,000
Not known, of unsanctioned woods, and probably rejected. }	..	46,000
Ditto, of sanctioned woods, allow one-half to be good . }	11,000	..
Ditto, of sanctioned woods, allow one-half to be bad . }	..	11,000
Totals	93,000	153,000

It therefore appears, that of these two hundred and forty-six thousand sleepers about 62 per cent. were practically useless. Surely then, when, of the sleepers which could be cut under ordinary circumstances, two-thirds cannot be used plain, no stronger proof is necessary of the importance of at once taking steps to turn these to account, in the only way in which it can be effected.

But after all, the great argument will always be, the comparative cost of each description of way; and the Author will therefore, before concluding, show the probable cost of one mile of

single line of four different kinds of permanent way in the Madras presidency. In questions of this nature the cost of 'leading' should always be taken into consideration. In the following estimates, the cost of conveying the materials 25 miles up the country has been added:—

No. I.—WITH CAST-IRON SLEEPERS.

	£.	s.	d.
Rails, fish-plates, bolts and nuts, cast-iron sleepers, wrought-iron tie bars, gibs and cotters, and keys, delivered at Madras, per mile	2,065	0	0
Conveying 25 miles by carts, 262 tons at 6d. per ton per mile	164	0	0
Total cost per mile	<u>£2,229</u>	<u>0</u>	<u>0</u>

No. II.—WITH CREOSOTED SLEEPERS SENT FROM ENGLAND.

Rails, chairs, fish-plates, bolts and nuts, delivered at Madras, per mile	1,439	15	0
Conveying 25 miles, by carts, 164 tons at 6d. per ton per mile	102	10	0
Keys and trenails, native made, and carried 25 miles, per mile	47	0	0
1,584 English creosoted sleepers, delivered at Madras, each 7s. 1d.	561	0	0
Conveying ditto 25 miles by carts, per mile	100	0	0
Total cost per mile	<u>£2,250</u>	<u>5</u>	<u>0</u>

No. III.—WITH NATIVE WOOD SLEEPERS, USED PLAIN.

Materials and carrying as before, per mile	1,589	5	0
1,584 plain native wood sleepers, each 6s.	475	4	0
Total cost per mile	<u>£2,064</u>	<u>9</u>	<u>0</u>

No. IV.—WITH NATIVE WOOD SLEEPERS, CREOSOTED.

Materials and carrying as before, per mile	1,589	5	0
1,584 native wood sleepers creosoted, each 5s. 6d.	435	12	0
Total cost per mile	<u>£2,024</u>	<u>17</u>	<u>0</u>

From this comparison it appears, that English creosoted sleepers make the dearest, and native creosoted sleepers would make the cheapest road. It has already been stated, that as the creosoting, or otherwise pickling, of native timber has never been attempted on a large scale, it is impossible to say what the actual cost of sleepers thus prepared would be. The reason of a less price being allowed in these estimates for creosoted native sleepers than for plain native wood is that, to insure the duration of plain native sleepers for a sufficient length of time, a high price must be given for hard woods, whereas common soft woods for creosoting might be obtained at much cheaper rates. Owing to the heavy cost of carriage, the native wood sleepers present an advantage over the two systems in which English sleepers are used;—that is to say—an advantage in first cost, for, as regards the durability of the different materials, all the information gained in India up

to this time is negative rather than positive. It is known that certain woods will perish within a certain time; but it is not known how long the best hard woods, or those artificially preserved, will last. No satisfactory comparison can therefore be drawn between the different systems of permanent way, as regards the cost of maintenance. It appears, however, that while the defects hitherto discovered in the native wood sleepers are pretty generally known and often dwelt upon, it is too frequently the practice to imagine that a cast-iron way in India possesses all the advantages claimed for it in England. In addition to the cost of freight and carriage, the cast iron 'pot' sleepers are not only liable to breakage on the voyage out, but also while being landed, and in their carriage up the country; and owing to the carelessness of the native workmen in unloading and in laying them, they are very liable to further casualties. The Author has observed many cast-iron sleepers broken for want of proper packing, and from settlement of the ballast in wet weather, or otherwise. It should likewise be remembered, that the broken sleepers have not the same value in India as old metal that they have in England, as there are not at present in India the same facilities for smelting and re-casting.

In conclusion, the Author would recommend that a fair trial on a new footing be made with the native wood sleepers;—that all woods now known, or hereafter found, to be good be used plain;—that proper care be taken in the selection, felling and seasoning of them;—that the sleepers be tarred in the seats of the chairs; and that they be laid in the driest ballast, which should be raised slightly in the middle and sloped off so as to direct the water under the rails. He would also recommend, that all woods which will not last plain, be creosoted, or otherwise prepared.

The main object of this Paper has been to give some facts relative to the resources of India, as regards timber for railway purposes, and to draw attention to what appears to have been passed over without sufficient consideration—the possibility of turning to account the native woods hitherto believed to be useless. At the same time, the general want of experience on these subjects, and the great importance of more knowledge regarding them, must be admitted. In India it is difficult for an Engineer to profit by another's experience. The distances are so great, and personal communication is so rare, that it is not easy to obtain accurate information beyond the immediate neighbourhood. Each individual has to struggle against the same difficulties, to try the same experiments, and to encounter the same failures. As has already been remarked, if those in whose power it lies would collect the experience of the agents of the different Railway Companies in India, and would then generally communicate the infor-

mation so collected to the agents, a saving would be effected to Railway Companies in the cost of construction and of maintenance, and, possibly, by the discovery that native wood sleepers might be used with advantage, would secure for India all the good which must follow the use of so large a quantity of her own products.¹

¹ The following extract from 'The Times' confirms the statements in the foregoing paper :—

" Calcutta, Jan. 8, 1863.

" If I were asked what is at the present moment the most pressing of India's wants, I should say, the want of timber. It is as difficult to realise this fact in a country one-third of which is supposed to be covered with forests, as it was lately to believe that our Eastern Empire is so under-populated as to render the immigration of Chinese and others desirable. But the want of wood is more and more felt every day, and the country is scoured by contractors eager to supply railways and other public works. Take the one item of railway sleepers. India is a country where damp, dry-rot, and white ants consume the best sleeper in six years. For the past ten years all over the country we have been busy in laying down new lines, and all attempts to use iron or stone sleepers have proved unsatisfactory. We have still nearly 2,000 miles to complete, besides the numerous feeders and branches which are being constructed. Creosoting has been tried, but it is doubtful if that is of any advantage. At this moment the railway might be open to within 12 miles of Delhi right through from Calcutta, instead of only to Agra, if sleepers could be procured. And what will Government and the shareholders say to the cost of renewing the sleepers, which, on the Calcutta and Delhi line alone is estimated, at present prices, at £130,000 a year? Except in Burmah, where Lord Dalhousie strictly shut up the forests, so that now, under a good system of conservancy, they yield perennial supplies, we have cleared the forests away wherever we have gone. Indeed, the old rules for grants of waste land insisted on a certain extent of clearing every year under pain of forfeiture. The result is, that wood is not to be got in our own territories, unless in very inaccessible places, and timber from the north of Europe begins to figure largely in our imports. Not only so, but by clearing away trees, especially on the sloping ridges of hills, we have made the climate in some places rainless, and in others, because there is no belt of wood to catch and keep the periodical rain, the district has become barren, just as Palestine is, and from similar causes. With some degree of thoughtlessness, Lord Canning gave away to Sir Jung Bahadoor, of Nepaul, our finest forests, which he has closely shut up as a hunting ground; and in another case, after the late Viceroy had promised a district, containing our next best forests, to a Mussulman chief for loyalty in 1857, he had to submit to the humiliation of asking it back when he found that there was no other well-wooded tract in the North-Western Provinces."

[Mr. BURT

Mr. BURT said, he was not prepared to hear so favourable an account of the sleepers first sent out to India,—because they were of the triangular form, cut from blocks 9 inches square, and therefore having a sectional area of only 40 inches, and because the same care was not taken in the selection of the timber, nor was it so thoroughly impregnated with the coal-oil, as was now found to be necessary. From the commencement of the establishment of railways in India, in 1854, down to the present time, timber sleepers had been supplied from this country, and a large portion of them had passed through his hands. The sleepers latterly used were of the rectangular form, with a sectional area of 50 inches; the timber was of a superior quality, and great improvements had been made in the process of creosoting. The minimum quantity of creosote generally required to be absorbed was about 10 lbs. per cubic foot; but it was possible, with well-seasoned wood, to make it take up even more than that quantity. Formerly, in the winter time, creosoting operations were partially suspended, as it was found that, at a temperature below 40°, the creosote coagulated to such an extent as to render it almost impossible to force the preservative material into the timber. At present, by raising the temperature to 120°, and applying a pressure of 120 lbs., and maintaining both, so that all the time the timber was under pressure it was kept at a uniform temperature, the process was so effectually carried out that failure was nearly impossible. After an experience of twenty years, during which time he had sent about one million and a half of sleepers to India alone, besides having prepared many thousand loads of timber for other purposes, he could safely assert that the instances of failure had been rare and isolated. In those cases where decay had taken place, it had been found on inquiry to be due, either to the operation not having been properly performed, or to the timber having been cut and framed after being prepared. As a collateral proof that this mode of preserving timber was considered satisfactory, he mentioned that the process was now more extensively employed than at any former period, and that he had contracts in hand for the supply of nearly half a million sleepers.

The Author of the Paper recommended, that creosoting establishments should be formed in India; but he did not appear to be aware of the late Mr. Rendel having already tried that experiment upon an extensive scale, without success. A large apparatus was sent out, complete in every respect; but the heat of the climate rendered the process so dangerous for the workmen, and the cost of conveying the creosote from this country was so great, owing to the risk of fire, that the attempt was abandoned. The Author had estimated that sleepers might be creosoted in India at a cost of about one shilling each. Mr. Burt however calculated,

that, supposing the oil to cost in this country from threepence to fourpence per gallon, and that one gallon was used for each cubic foot of timber, and taking into account the expense of transit in iron tanks, and the difficulty of carrying out the operation in India, the sleepers could not be properly prepared for less than three shillings and sixpence each.

A question had recently arisen, as to the possibility of supplying sleepers to India from Australia. An experienced agent had been sent out to collect timber suitable for shipbuilding and for railway sleepers; and a cargo of timber was despatched from Australia, but unfortunately both the ship and the cargo were lost on the passage. From the information he had obtained from various sources, Mr. Burt had arrived at the conclusion, that a supply of wood for sleepers could not be relied upon from that quarter of the world, at all events not as a profitable commercial speculation. There was great difficulty in getting freights from the western part of Australia to India; added to which the Jarra wood was so heavy, that the expense of inland transport would be a serious item. This wood weighed 64 lbs. per cubic foot, so that the weight of a sleeper would amount to 1 cwt. 3 qrs. 15 lbs., or nearly three-quarters of a hundredweight more than if of ordinary timber. It was also very hard, so that the conversion of it would be costly, and when used in a hot climate, it was liable to 'shakes' and to split. Other Australian woods which had been tried had not been found to answer so well as had been at first expected.

Mr. GEORGE BERKLEY said he had sent out creosoted sleepers to India; but, chiefly on account of the difficulty and the cost of conveyance to Bombay, preference was given to the process of kyanizing, as applied to the native jungle woods. It was the opinion of the late Mr. Robert Stephenson, that almost all the systems of saturating timber with essential oils, or with mineral salts, for the purpose of preserving it, would, if well done, be more or less efficient, and in that opinion Mr. Berkley entirely concurred. Teak was the best kind of native wood for sleepers, and its cost was about the same as that of creosoted timber sent from England. There were, however, many descriptions of native woods which were considerably less expensive. He was not at present prepared with any facts, as to the relative durability of native wood and of English creosoted sleepers; but on some future occasion, he hoped to be in a position to state the results of the comparative value of the different descriptions of sleepers used on the Great Indian Peninsula Railway.

Mr. JAMES WALKER, Managing Director of the Madras Railway, conceived that the Author was, from his position and experience, well qualified to give correct information on this important subject. It might, however, be broadly stated that the native woods

of that part of India had generally proved unfit for the purposes of railway sleepers. The late Resident Engineer-in-chief of the line was engaged, at the time of his death, in preparing a Report upon the native woods. In the draft of that Report, Mr. Ross stated he had been gradually brought to the conclusion, that with the exception of Teak, Erool, and Vengay, none of the woods of that part of India were to be depended upon for sleepers. He believed most of the Engineers who had experience in India coincided with that opinion; and the result was, that the use of native woods had been in a great degree abandoned. Iron sleepers were now being resorted to, and he thought they would ultimately be used on all the Indian railways. With regard to creosoted sleepers, he agreed that wherever the essential oil penetrated, the preservation of the wood was complete; but the difficulty was to insure thorough penetration. If the heart of the timber was not completely saturated with the creosote, it decayed, leaving a hollow which would sooner, or later be crushed in. With respect to the Jarra timber of Australia, he might state that a trial of that wood was made on the Madras Railway, and as far as durability was concerned, it had proved satisfactory; but it was found, as had been stated, that it was very liable to shakes, and as in the case of Teak, the high price of the timber prohibited its use.

Mr. COCKBURN CURTIS, having been employed under the Department of Public Works of the Madras Presidency, prior to the establishment of Railways in India,—had had some opportunity of observing the effect of the climate upon the different kinds of woods in use in that Presidency, and hence could form some estimate, as to their probable duration when used as railway sleepers. The woods of the Madras Presidency were naturally divided into two broad classes,—those of a light spongy character, manifestly unfit for the purpose, and those of a heavier and denser kind. Of the denser, with the exception of Teak and one or two other woods of a similar oily character, he was unaware of any which could successfully stand the test of exposure; and even those woods required a free current of air, and the most careful periodical examination, to prevent the accumulation of moisture in the joints, or other parts of a structure where the wet might be liable to lodge. He also considered that it would be found very difficult to prepare the denser kinds of wood by any of the ordinary modes of injection, and that upon after-exposure to the moist heat of the rainy monsoon and the desiccating heat of the dry monsoon, it would be found that the outer part of the sleepers would crack, as they did in their natural state, and they would thus let the water into the centre, and more rapidly promote its decay. He therefore feared that the Author's praiseworthy exertions, to render the natural resources of the Madras Presidency available, and to afford increased

[1862-63. N.S.]

s

employment to the natives, would be unattended by the success which they so decidedly merited.

It was probable that some of the woods found at Singapore might be suitable for railway sleepers. The Chinese, who were not bad judges of wood, were in the habit of exchanging the masts and spars which they brought in their vessels from China for others of Singapore woods.

Mr. SHEILDS stated, from his experience in the use of Australian woods, that it was the custom in that country to cut down the timber as it grew, to convert it into the required shape, and to use it without any kind of seasoning, or preparation. It was not to be supposed that timber, under such conditions, would, when exposed to the burning sun of India, endure for any long period. He believed that when properly seasoned, as all timber required to be, by the use of some simple means of preparation, such as immersion in water, or exposure, under cover from the sun, to a current of air, Australian timber would be found as durable as that of any other country : and he knew of none in any part of the world which was equal to it in strength, or tenacity. It approached inferior wrought iron in tensile strength, and possessed excellent properties, if it was subjected to fair treatment. He thought more might be done with Australian timber than had been the case hitherto, and he considered the use of it should not be abandoned without further trial.

Mr. COODE said, as reference had been made to the difficulty of impregnating with creosote the denser woods of India, he might state that eight, or nine years ago he had tried an experiment upon Saul wood. The result was that at the first trial only about 2 lbs. of oil per cubic foot were injected. The wood was then laid by, and from the evaporation which took place in the course of a fortnight, or three weeks, about half a pound in weight was lost. On a second trial this half pound was again injected. The process was frequently repeated with the same result ; the piece recovering only what it had lost in weight subsequent to the last trial. The experiment, though on a small scale, was sufficient to corroborate what had been stated, as to the difficulty of impregnating the denser woods with any considerable quantity of creosote.

Mr. A. BRYCE remarked, that from his experience in the use of Indian jungle wood for sleepers, he believed the resources of the jungles, under a proper system of working and organisation, would be equal to supply all the demand that was likely to be made upon them. In the case of the Madras Railway, the sleepers were in the first instance supplied in small parcels by native contractors ; but they were found to contain a great deal of sap wood, which decayed in the first, or second year. That was,

however, entirely owing to the jungles not having been worked under proper direction and superintendence. If that were done he thought an immense quantity of fine timber, available for sleepers, if for no other purpose, could be delivered at any part of the Madras Presidency at a price of six shillings each sleeper, which was less than their cost, if they were sent out from England. As to the question of durability, he believed more extended experience in the use of the native woods was required, before a satisfactory opinion could be formed upon that point. He agreed with the Author, that the generality of the woods of India were of too dense a nature to be submitted to creosoting, and that they would with difficulty be rendered more durable by that process.

Mr. JENOURE remarked, that the deodara cedar, which could be procured in some parts of India, and which was stated on good authority to be very durable, when constantly exposed to the weather, as bridges constructed of it had lasted five hundred years, was omitted from the list of the native woods enumerated. He doubted the policy of any artificial application to young and green timber. It was acknowledged that young timber was the best for creosoting, but it was an established fact, that natural productions of all kinds used before their arrival at maturity were deficient in lasting qualities. He urged the importance of selecting timber of a proper quality and age, of felling it at the proper time, and of paying close attention to its due and gradual seasoning before it was used ; and he believed, that much of the failure attributed to the native woods arose from neglect of these essential considerations. Numerous examples of the durability of timber, as prepared and used long before the days of creosoting, kyanizing, or any other patent process, were to be found in old English wooden houses which had stood for centuries.

Colonel SALE remarked, as the result of his experience in Bengal and the north-west provinces, that he believed there was no necessity to go beyond India to procure wood suitable for sleepers and for other railway purposes. As regarded Teak, Saul, and Soondry, if these woods were cut down in a ripe and sound condition, no artificial process was required for their preservation. The process of injection was beneficial when the timber was young, but when it had a good sound heart, it was not necessary, as it would be as durable in its natural state as the inferior woods when artificially prepared. In buildings, the wood was not so much exposed to the action of the elements as it was in the case of railway sleepers ; but he had known Saul wood last for twenty-five years without requiring to be renewed.

Mr. CHARLES GRAVES said, upon the subject of the relative value of wood and iron in the construction of the groundwork of Indian

railways, he could confirm the opinion as to the great inferiority of wood. It still remained a question, whether the creosoting process could be beneficially, or at all, applied to the hard-grained woods of India; but the majority of the woods of that country were so full of moisture in their growth, were of so perishable a nature from the effects of wet and dry rot, and wasted, shrunk, and diminished so much under exposure to sun and air, after the saturation they suffered in the wet monsoon, that a duration of three, or four years was the utmost that could be expected. There were a few descriptions of wood of an oily nature. Teak particularly partook of that character, and was unquestionably the finest wood of the country. Saul somewhat resembled it, but was harder and heavier; it was a very strong and serviceable wood, but would be expensive for sleepers. The wood universally used for building purposes in Calcutta was Saul, for all beams, cills, door-frames, rafters, &c.; whilst for ship-building Teak was as invariably employed; but masts were sometimes made of Poon wood, from Singapore and the Straits of Malacca. The way in which European woods were affected by the action of a tropical climate would surprise any one who had not witnessed it. The strongest English woods, when exposed, unpainted, first to wet and then to the heat of the sun, lost their coherence and strength; just as willow, or poplar did in this country. Saul timber, until it was very thoroughly dried, was heavier than water, and notwithstanding its hardness and strength, nearly resembling African oak, it was very liable to the attacks of white ants. For these reasons and for many others, which several years' residence in Bengal, in active practical work, had taught him, he was strongly in favour of the use of cast iron, as by far the cheapest material for any work intended to last twenty years. No doubt the jungle woods could be made to absorb creosote, and their durability would be to some extent increased, but the practice of the natives was sufficient evidence, that they were only of use for the most temporary purposes.

Mr. C. H. GREGORY, V.P., was glad to hear the observations which had fallen from Colonel Sale, for if they had not been made, the Meeting might have lost sight of what he believed to be the fact, that it was the condition in which the native woods were used, added to the want of a proper selection of them, which had mainly led to their being condemned. The use of unsuitable native timber on some of the Indian railways was naturally explained by the large and sudden demand for sleepers. It had been his duty to investigate the character of the Ceylon woods, and their fitness for railway sleepers, and having obtained the best information he could, from the records of the Government Departments, and from other sources, he found that there were certain hard woods of

Ceylon, akin to those of India,—such as Satinwood, Millille, Ironwood, Jack, Gal-mendora, Ebony, and Paloo, which were extensively used for the public works in Ceylon, and which, in respect of durability, had given great satisfaction. In dealing with this question, all the woods of India ought not to be condemned, unless it could be satisfactorily shown, that the best woods which the country afforded had been selected, and had been used in a proper condition.

February 10, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,053.—“Description of the Drainage of the Borough of Dundee.”¹ By JOHN FULTON.

THE borough of Dundee, which is situated on the north bank of the estuary of the river Tay, contains a population of nearly one hundred thousand persons. Its police boundary includes an area of about 6 square miles, and the value of its assessed rental is not less than £218,000. Its docks cover an area of 30 acres, and the annual registered tonnage of shipping entering and leaving the port is 288,557 tons.

Previous to the year 1851, the town of Dundee was in a very defective condition, in a sanitary point of view. With the exception of three, or four streets, it was wholly undrained, and the sewage flowed on the surface of the streets and ‘closes,’ or it was discharged into cesspools, having no other outlets than the surface channels. There existed few places of convenience, and the scavenging was imperfectly performed. The consequences were a prevailing high ratio of deaths from typhus fever, and several outbreaks of cholera, not to speak of numerous minor evils, all traceable to the same cause.

In the year 1851, by the vote of a majority of the ratepayers, the town was brought under the powers of the General Police Act for Scotland, which somewhat resembles in its provisions the Health of Towns’ Act for England; but although other sanitary measures were then adopted, such as improved paving, cleansing, &c., owing to a defect in the drainage clauses of the Act, which had to be amended by Parliament, the sewerage of the town was not commenced until the year 1856. It has, however, progressed steadily, year by year, since that date, and, with the exception of a few minor details, it is now completed. The work has been five years in progress, and has cost the sum of £52,000, which is only £2,000 in excess of the estimated amount.

The site occupied by the town is slightly embayed. The substratum on which it rests is for the most part composed of trap rock; but at the east end of the borough, this merges into sandstone. These rocks are generally found near to the surface, and in some places they project above it; this occurs more particularly

¹ The discussion upon this and the following Papers occupied portions of two evenings, but an abstract of the whole is given consecutively.

in the centre of the town, where at a not remote period, the fort, or castle of the town, occupied one of these eminences near the river, and about 50 feet above its level. Surrounding the castle rock for some distance, and extending at a right angle from the river about 1,000 yards, the substrata are clay, silt, and water-rolled gravel. The clay contains many indications, such as branches, leaves, nuts of hazel, &c., of having been deposited in water; and the fact of this portion of the surface being very flat, and only slightly elevated above the sea level, tends to prove that it was at one period an inlet of the river. The ground extending inward from this basin, or level tract, rises rapidly, the gradient of several streets being 1 in 7. The highest portion of the town has an elevation of 300 feet above the mean tide level; but the 'law,' or hill immediately behind the town, rises at a still steeper slope to an elevation of 570 feet, and forms a prominent object in the landscape.

The town was at one period surrounded by a wall, and that portion is closely built, with narrow and crooked streets. The houses are crowded into courts and passages, and many of the latter, not more than 6 feet in width, have houses on each side, three, or four stories high. In both the old and newer portions of the town, the houses are almost without exception built of sandstone, the walls being of great thickness and weight. The public works, such as mills and factories, are also stone erections; the chimney stalks alone being built of brick. These particulars are given merely to illustrate the nature and difficulty of the work under consideration.

It has been stated, that three, or four sewers existed, previous to the commencement of the works here described. One of these, which was constructed by the Harbour Trustees to intercept the drainage of the town and to prevent it from entering the docks, or the tidal basins, extends the whole length of the harbour, about 1,600 yards, and runs for the greater part of its length nearly parallel to the river. It has a fall of 1 in 400, and its average depth is 15 feet. Its discharging end is 21 feet below the surface level of the quay, or 8 feet below the level of mean tide. It is built of substantial rubble masonry, and is of rectangular form, its dimensions being 7 feet in height, by 3 feet 9 inches in width. This sewer forms the chief outlet for the drainage of the town, including the sewage and flood waters. The entire surface drained by it has an area of upwards of 1,000 acres. The sewage discharged by it, in dry weather, measures 2 feet in depth, and during storms 6 feet. The velocity in the former case is 65 feet per minute, and in the latter 116 feet per minute. There are two other outlets, one of which drains a suburb containing a population of about 4,000 persons; the other is required for flushing purposes, and

acts as a relieving sewer during floods. They measure respectively 3 feet 6 inches by 2 feet 3 inches, and 4 feet 6 inches by 3 feet, and, in section, are of the egg form.

A line of railway extends along the river margin for several miles above and below the town, which effectually deprives the population of any use of the stream for bathing. But one redeeming feature of this evil is, that it permits the sewage to be discharged at once into deep water, and thus prevents a nuisance.

In designing the drainage under consideration, one primary object kept in view was the application of the sewage to some useful purpose. Accordingly, the whole drainage, so far as was practicable, has been carried to one point, the outlet first referred to. It is proposed to form a well near the junction of this outlet with the river, and from this by steam power to lift the sewage and force it through cast-iron pipes 12 inches in diameter, to the sands of Barry, a district on the shore of the estuary, about 7 miles below Dundee, and there to apply it in the liquid form as at Edinburgh. The Dundee and Arbroath Railway runs in almost a straight and level line between this outlet sewer, and the tract of land in question, the improveable portion of which is not less than 2,000 acres; and as it is of a level character, the formation of embankments through it, for conducting the sewage, would not be expensive. This land is on the estate of Panmure, the property of the Earl of Dalhousie, and it would be for his interest to carry out this scheme to completion, as the return from it could not fail to yield a handsome profit, the land at present being comparatively valueless. The sewage of the town is in the meantime allowed to flow directly into the river, and is thus lost. This is, however, the utmost extent of the evil, as it causes no nuisance, being speedily dissipated in the stream, which is upwards of a mile in width opposite the town; and the point of discharge of the chief outlet sewer is more than 400 yards from any dwelling.

The drainage has been carried out by a combination of brick sewers and salt-glazed, fireclay, socket-pipes, of dimensions suitable for the discharge of the sewage and the flood waters together. The brick sewers, which are all of the egg-form, are confined to the leading thoroughfares: their dimensions are respectively, 3 feet by 1 foot 10 inches, 3 feet 6 inches by 2 feet 3 inches, 4 feet by 2 feet 9 inches, and 4 feet 6 inches by 3 feet. The diameters of the pipe sewers are, 9 inches, 12 inches, 15 inches, and 18 inches. The leading thoroughfares converge to a point in the centre of the town, and, as already explained, this has been taken advantage of in regard to the main outlet. The streets drained by tubular sewers are chiefly those at right angles with the river, which are the steepest, and therefore the most suitable for tubular drains. The joints of all the tubular sewers have been made with clay.

The average depth of the sewers is 12 feet, which was considered necessary in order to secure proper drainage of the cellars. The surface levels being very irregular in many places, the depths of the cuttings consequently varied, the smallest depth (which was in trap rock) being 7 feet and the greatest 21 feet. The deepest cutting in trap rock—19 feet—occurred in the centre of the town, across the base of the Castle Rock.

The total amount of rock excavated was 24,000 cubic yards. The greater portion of this had to be removed by means of gunpowder ; and although in most cases the work was done in narrow and crowded lanes and streets, no serious injury occurred to persons, or property. It was even found necessary, in some cases, to use gunpowder inside dwelling-houses, in the formation of branch drains, but by proper precautions, such as the selection of cautious and intelligent workmen, using only small quantities of gunpowder to each shot, and carefully covering and loading the rock, casualties were prevented. The contractors were paid for excavating this rock by measurement as it occurred, and as an extra, per schedule price. Running sand occurred in many places, and occasioned much trouble and expense. In one lane not more than 9 feet wide, with ponderous buildings on each side, having their foundations near the surface, a bed of this sand was found at the depth of 9 feet. The sewer was in this case of large dimensions, and 12 feet in depth, but by shoring the buildings, and using cofferdams, all injury was prevented. It was, however, found requisite in this and many other instances to leave nearly the whole of the timber lining in the trench. The sums paid to the contractors on this account have consequently been very heavy, the total amount being £3,600 ; but this includes the timber used for supporting gas and water pipes. In several streets, where the strata were sufficiently solid, tunnelling was resorted to ; but this was found unsatisfactory, and was soon given up, because of the uncertainty of securing thorough consolidation of the spaces having to be filled up over the arches, or pipes.

The numerous gas and water pipes were a source of great annoyance. In the older portions of the town, more particularly, these were found to occupy the centres of the lanes and streets, which, as already stated, are for the most part narrow and crooked. There being, moreover, three Companies having distinct mains and branches, and in some cases two sets of pipes, the difficulty may be conceived, and indeed the danger of constructing any kind of drain under such circumstances. It was found absolutely necessary in some instances to remove several of the pipes for a time, or permanently, and the cost of this, as well as of the unavoidable breakage of pipes and loss of gas, has been very considerable—the total amount claimed by the Companies being upwards of £1,100.

The contractors, being held liable for all damages, have paid the greater portion of this amount; the Commissioners of Police having only borne the expense of the alterations of the mains. Ample allowance was, however, made to the contractors for timber supports to these pipes. Many of the pipes were found to be in a frail condition, and their contents escaping into the houses caused considerable injury to persons and property.

The leading, or intercepting sewers have been made from 12 inches to 18 inches deeper than the lateral and branch drains, with the view of preventing the ends of the latter from silting. This has been found to be a wise precaution, as in those sewers possessing little fall, sand speedily accumulates. The quantity of sand, and the time in which it is deposited, are, however, materially influenced by the quantity of water passing through the sewers, and up to a certain point it may be, and is, entirely prevented by a proper system of flushing. This point commences with a fall of 1 in 600, the earthy and more soluble matters being then carried off by the ordinary rain-fall and sewage; but a deposit of coarse sand is left behind in all sewers having no greater fall than this. It is not apprehended that much annoyance will arise from this source, as none of the sewers have a fall of less than 1 in 700.

Manholes with brick walls 9 inches thick have been carried up to the street level, from both the brick and the pipe sewers. They have been placed at the junctions of the leading and lateral sewers, and at intervals of 40 yards along each sewer. They are provided with covers of cast iron, having frames 8 inches deep to suit the paving stones of the streets, and grooved lids hung on wrought-iron axles. Projecting bricks are built on opposite sides of the manholes to serve as ladders, and they answer this purpose very well. In the pipe sewers the manholes are extended on each side, to give room to the workmen when cleansing the sewers. The use of these manholes will be explained in describing the sewer-cleansing apparatus.

The junctions for the house drains and gullies were built into the sewers, as the work proceeded. They consist merely of the ordinary socket pipes, with bevelled ends to suit the form of the sewer. A flat stone is placed on the exterior end of each pipe, until it is required for use, to prevent earth, or sand, from falling through into the sewer. In the case of tubular mains, socket junctions, having an acute angle, were placed at intervals, or where they were required for branches, or gullies, and their positions were defined by marks made on the walls of premises at right angles from them; and in addition, a register of all branch junctions is retained in the surveyor's office, describing their depths as well as positions, and the nature of the strata to be excavated.

The brick sewers are all provided with invert blocks of glazed fireclay, 2 feet 6 inches in length, and have walls and arches 9 inches thick, the latter being turned with two rings of half brick. Where the sub-strata were of a wet, or yielding nature, it was found necessary to prepare a bed of concrete for the reception of the invert blocks; and where the sewers were subject to the influx of the tide, the side walls were built in Roman cement. The form of the brick sewers is shown in Fig. 2, page 10.

The gully drains are placed at intervals of from 30 yards to 60 yards apart, the steepest streets having them closest together. They are for the most part made with faucet pipes, 6 inches in diameter; the streets in the lower, or level portion of the town having pipes 9 inches in diameter.

The gases of the sewers are prevented from escaping through the gullies, by valves made of stone, hung with copper links, on one side of a small cesspool (Fig. 1). The bottoms of the cesspools are 10 inches below the lower sides of the valves; by this means all heavy matters, such as sand and stones, are prevented from entering the sewers. These gully drains are meant for the reception of rain water only; the cesspools being cleansed weekly by the scavengers, during the prevalence of wet weather. This form of gully has been found very suitable in Dundee. A few water traps were at one time in use, but owing to the constant flow of hot water through the sewers, from the spinning mills and other works, they soon dried up and became useless. The valves on the contrary meet all contingencies. They freely pass the flood waters, and the cesspools retain all the heavier particles of road detritus.

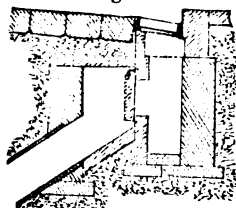


Fig. 1.

Gully Drain.

The branch drains, where they are connected with the sinks and water-closets in houses, have no other traps than those of the syphons which are placed in immediate contact with the sinks or water-closets. These are found to answer every purpose, and anything additional would be superfluous. Many persons are under the impression that more than one trap on a drain is requisite, a cesspool being considered by them indispensable. It will be found by experience, that cesspools, on drains of this kind, create rather than remove a nuisance, and that there is in reality no nuisance to remove, as one trap only, if properly constructed and applied, is perfectly sufficient to prevent the escape of all emanations from sewers. This trap ought always to be placed as near the sink, water-closet, or grating used for the reception of soil water as possible, and in such a position as to be easily accessible for cleansing, or for repair. Another reason against the

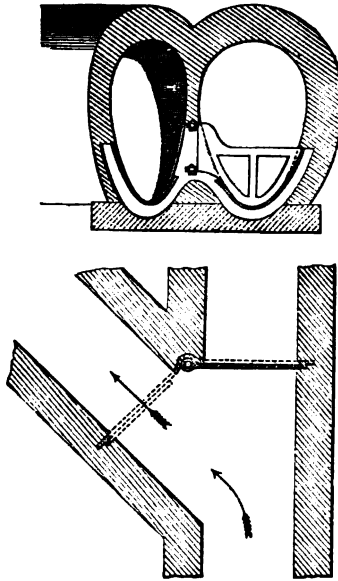
use of cesspools, except as now recommended, is that they retard the flow of the sewage in the drain, and cause it to become choked. The branch drains have in all cases been made with glazed stoneware, or fireclay socket pipes, from 4 inches to 12 inches in diameter. In back courts and passages, and for the use of the working classes, stone basins, with gratings of cast iron, containing water-traps, have been provided, and where many tenants use one basin, an additional grate is placed over it, to prevent its misuse. It was found in several instances, that the branch drains were choked by the tenants lifting the gratings, and throwing into the basins ashes, fish offal, and other unsuitable matters; but this has been entirely prevented by an additional grate of wrought iron, 12 inches square. The total number of house drains made, up to December, 1861, is one thousand eight hundred: many of these branches drain passages and courts serving a numerous population.

The town is supplied with water on the principle of gravitation, by a Company established by Act of Parliament; and this Company has received, as one of the effects of the drainage operations, a considerable addition to its income, in the form of water rents. The owners of property, having in many places no means of getting rid of waste water, had neglected to provide their tenants with any water supply, and they were consequently under the necessity of purchasing it in small quantities, as sold at stated intervals by the servants of the Company from their hydrants, or of begging from their more fortunate neighbours, or what was too frequent, they were compelled to use water taken from the street channels and open water courses, for washing their clothes, for which it was quite unsuited. This state of matters no longer exists, as in nearly every case where a branch drain has been constructed, a branch water pipe has been laid, and the requisite tap been provided.

The water supply being in the hands of a Company, it was needless to think of flushing the sewers from this source, as the expense would have been too great. This led to the adoption of the only other mode of flushing available, which was to intercept the sewage at any suitable point, by means of a cast iron gate, and to turn it into any sewer, or special series of sewers. The various levels have been taken advantage of for this purpose, and by means of a series of gates of this description placed at the junction of the sewers, Fig. 2, and immediately under manholes, giving ready access to them, the greater portion of the sewers have been rendered self-cleansing. As already explained, it is found, that in sewers having little fall, say 1 in 600, there is a tendency to the accumulation of sand, and in pipe drains with even greater fall than this, where the ordinary house drainage only exists, sand

also accumulates. This occasioned the invention of a cleansing apparatus to be hereafter described. The flushing gates are only

Fig. 2.



Plan and Section of a Sewer at a Junction.

15 inches deep, and they answer the purpose of overflow weirs, preventing the sewers, during floods, from being subjected to pressure, by allowing the surplus contents to flow into subsidiary outlets, and thus equalizing the flow of water. It has been proposed by some Engineers to provide two separate lines of sewers, the one for rain water and the other for soil water; but it is suggested, that the above particulars prove the impolicy of such a system, as without rain water, unless with very steep gradients, the sewers would soon silt up. This is only one objection out of many that will readily occur, such as the great additional cost, the difficulty of providing two sewers in narrow lanes, and of gaining access to them, &c. It has also been proposed to use tubular drains under pressure; but this is believed to be a fallacy, as stoneware, or fireclay tubes will only bear a limited amount of pressure, and the Roman cement joints would bear still less. Again, if drains of any kind are to be put under pressure, how can their contents be prevented from rising through the branches into the cellars, or other places drained into them, and how are those cellars to be drained? These questions must be satisfactorily answered, before

any attempt is made to apply a general system of 'head' pressure to sewerage.

The whole of the sewers within the borough are provided with manholes, or entrances carried up perpendicularly from the arch of each sewer, and at intervals of 40 yards. When a sewer is to be cleansed, a windlass containing about 45 yards of iron chain is placed over each of two adjacent manholes; a series of rods each 4 feet in length extending to 40 yards, and composed of iron tubes (for lightness), with screwed ends fitting into each other, is then put together at the bottom of the manhole, and is pushed by hand to the next manhole, where the rods are again unscrewed as they are drawn through. The chain being attached to the last rod is by this means carried along the sewer, and affixed to the cleansing tool in connection with the other chain and windlass. Horizontal and vertical bars of iron with clamping screwed-slides to suit any size of sewer are then fixed, the vertical bars having iron pulleys on their lower ends with hinged openings through which the chain is passed. As the matter to be removed from the sewer usually consists of hard sand, a tool is first attached to the hooks of the chain, in order to plough, or break it up. When this has been sufficiently done, a scraper is next drawn through. This scraper is formed of strong plate iron, and is furnished with small wheels, on moveable axles, on its lateral and lower edges. It has usually to be drawn backward and forward several times before the required cleansing is complete. The stuff removed is taken to the surface in buckets by the windlass, or by hand-ropes.

The cleansing of tubular sewers is somewhat different. In this case the manholes are enlarged underneath, to give room to the workman, and also to admit of the pulley bars being properly secured. The jointed rods require to be forced through the sewer, by the aid of the windlass and chain and a strong pair of pincers; and they are removed from the next manhole in a similar manner, or are carried farther into the sewer, as may be requisite. The scraper for pipe sewers does not require wheels; but to prevent its adhering to the end joints of the pipes, it is provided with fenders composed of rods of wrought iron passing over its edge, and terminating in a ring at each end.

The cost of cleansing sewers by this mode is on an average:—For tubular sewers, one penny, and for brick sewers, two pence per lineal yard.

No sewer has hitherto required to be cleansed oftener than once in twelve months; and those sewers requiring this service are chiefly such as have not, from their shortness, a sufficient flow of water to keep them clear of silt.

Under-ground cellars near the level of high tide, or the water-

run of the public sewers, and having branch drains into the latter, have in all cases been provided with self-acting flap valves of polished stone, similar to those used in the gully drains. These valves, when properly constructed and applied, are excellent safeguards against the flooding of cellars by storms, or by high tides. The stones used in their construction have a fine grain, and this, with an overlap of 2 inches on the opening, properly polished and adjusted, resists a considerable head pressure, and remains perfectly water-tight. The brickwork surrounding the valves (which are placed at the entrances of the drains) is in all cases built in Roman cement. These valves are only meant for occasional use, as if they were constantly closed by head pressure, the drains on which they are placed would be of no service.

The ventilation of sewers is a subject which has been much discussed, and apparently to little purpose. But as this Paper is merely meant to convey a description of a work actually accomplished, and not an essay on what might be done, it will only be necessary to state, that no ventilation whatever has been applied to the sewers in Dundee, and farther, that none is contemplated. No complaints have been made of bad smells issuing from the drains, nor are they likely to be made, as owing to their form of construction, the smallness of the dimensions, and the mode of flushing adopted, there cannot be any generation of gases from putrid matters retained in the drains, as all such matters are carried rapidly through them to the river, and thence to the sea. It is not denied that gases do to some extent exist in the sewers; for it is known that, irrespective of any other source, the mains and branches of the gas companies contribute their quota by their ordinary leakage, and the sewage must exhale noxious vapours in its passage through them. But the gases are not present in such volume as to overcome the ordinary traps, and they are carried off frequently by the flood waters. The only deposit habitually left in any of the sewers, or drains, is sand. This, on being taken up, emits no perceptible odour, and when closely examined, has all the appearance of ordinary river sand. It is only where sewers are badly constructed, as regards their form and water-run, that putrid matters are retained in them to poison the surrounding atmosphere, and to bring disgrace on the very name of drainage. No sewer under 10 feet in perpendicular dimensions ought to have an invert greater than 9 inches radius, and 6 inches is quite large enough for the radius of the invert of any ordinary sewer. When the sewage is confined to such a small compass as this, its scouring power is very great, and if care be taken to have the invert block laid in a straight line, with such fall as may be available, it will be found that, although the fall be slight, little silting will take place, and that it will consist of sand only. No ventilation is, therefore,

requisite with well-constructed sewers. It is only where the scouring effect of the sewage is lost, by constructing sewers with flat bottoms, that such is needed.

The proportion of brick sewers constructed, to that of tubular sewers, is as one to two, the total length of the former being 10 miles, and of the latter 20 miles; and their cost is nearly as one to three, the average of the former being thirty-three shillings, and of the latter thirteen shillings, per lineal yard.

There being an abundant supply of excellent sandstone in the immediate vicinity of Dundee, it was at one time contemplated to build the larger sewers of this material; but on calculations being made, it was found that, unless with a very coarse description of rubble-work, the cost would be greater than that of brick-work, and that the work could be much more expeditiously carried out with the latter than the former; also, that the streets being narrow, they would not well admit of wide trenches to receive the thick walls required for masonry.

The drainage of the town having been so recently completed, sufficient time has not yet elapsed to judge of its effects on the health of the population; but it may be stated that, so far as can be ascertained, a decided decrease in the rate of mortality, as compared with former years, has taken place. One beneficial result of the work, however, is apparent; this is a general tendency of the people to more cleanly habits than formerly prevailed. Drunkenness and crime have diminished to a considerable extent; but this may be owing partly to other causes, which need not be mentioned here.

The Paper is illustrated by three drawings, from which the woodcuts, Figs. 1 and 2, are taken.

No. 1,064.—“Description of the Sewerage and Drainage Works, of Newport, Monmouthshire.”¹ By ALFRED WILLIAMS, Assoc. Inst. C.E., F.G.S.

THE borough of Newport, Monmouthshire, which now has three thousand six hundred and ninety-five houses, and a population of 23,248 persons, extends over an area of 950 acres. It is situated on the River Usk, which discharges itself into the Bristol Channel about $3\frac{1}{2}$ miles below the southern extremity of the borough. A portion of the old town is built on the hill of Saint Woollos, crowned by the parish church, the base of which is 174 feet above high water. This hill is of the old red sandstone formation, but a very large proportion of the borough is on the flat alluvial deposit through which the river channel passes, the natural surface being about the level of high water of ordinary spring tides. The portion of this surface occupied by houses has been raised artificially with ballast, &c., the largest owners of building land,—the Tredegar Wharf Company (under the liberal management of Mr. Samuel Homfray,)—having persevered in carrying this out. Many of the cellars of the town are several feet below the level of high water at spring tides.

Newport being one of the principal shipping ports of a large and wealthy mineral district, is intersected in all directions by passenger and mineral railways, which cross the streets on the level. Within the borough there are about 5 miles of railways belonging to Public Companies, exclusive of innumerable branches to wharves, &c. The Monmouthshire Canal runs through the town for about $1\frac{1}{2}$ mile to the dock, which occupies an area of 12 acres, with an entrance lock 220 feet long by 61 feet in width. The principal part of the trade, however, is carried on at the river, where the wharves extend for upwards of 2 miles along the western, or right bank. The river, at the upper part of the town, is 450 feet wide at high water spring tides, and has a sectional area of about 12,000 feet; at the lower part of the town it is 900 feet wide, with a sectional area of about 26,500 feet. The rise of the tide in the river, at ordinary springs, is about 35 feet, and at extraordinary springs about 40 feet, and occupies only five hours, the current being necessarily very rapid. High water of extraordinary spring tides is 1 foot, and of ordinary springs 6 feet, below the coping of

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

[1862-63. N.S.]

the dock, at the entrance lock. High-water of ordinary neap tides is 17 feet below the same coping.

The town is efficiently supplied with water by a Company, the works for which were executed in 1847 and 1848, under the direction of Mr. James Simpson, Past-President of the Institution. All the water, excepting that for the very high part of the town, is supplied by gravitation.

Before the construction of the Sewers, which form the subject of this Paper, several miles of sewers and drains had at different times, during a long series of years, been constructed by Local Commissioners, landowners and others, on the western side, or right bank of the river, where nearly all the town stands. These for the most part were of rude design and rough material; many of them were small and square, and others were merely a rough stone arch over a ditch, without any invert. In many cases they were built to preserve the old watercourses and field ditches, without regard to the intended street lines, or to the buildings subsequently to be erected over them; consequently they often passed obliquely under houses and gardens. Some of the old sewers were, however, found to be substantially constructed, and with suitable falls, although they had not been laid out on any general system of levels. The later works were egg-shaped brick sewers, constructed where most urgently required, under the direction of the Author, in some cases with the sanction of the General Board of Health, and all arranged with a view to more extensive works. Many of the houses over, or near the old sewers, drained into them, but in the larger portion of the town cesspools were necessarily used. These old sewers, which varied in height from 1 foot to 4½ feet, discharged also a great portion of the land and surface water, the remainder running direct into the river, canal, dock, &c. There were nine open outlets into the river, varying in level from 5·4 feet to 12·9 feet below high water of ordinary spring tides; and the tide flowed up the sewers, and sometimes flooded the cellars and basements.

In 1856, the Author was instructed by the Local Board of Health to prepare "An efficient plan for the drainage of the borough, with estimate of cost of same, using, where possible, existing drains and outlets, with a view to a sound practical and economical system." In accordance with these instructions a carefully considered scheme was prepared, which received the sanction of the General Board of Health, and (with the exception of the cleansing and repairs of old sewers) was executed. The Plan of Newport which accompanies this communication, taken from that submitted for approval to the General Board of Health,

shows generally the direction, &c. of the existing and proposed sewers.

The design was so arranged :—1°. That the outlets were to be reduced from, nine to four, by intercepting sewers, (necessary for the drainage of the districts through which they pass); power being retained to use the abandoned outlets, without additional works, should circumstances require it. 2°. That the sewage of two-thirds of the town might be brought to the lowest outlet down the river, near the extremity of the borough; and by a further expenditure, if events should justify it, the greater portion of the remaining third might be brought to the same outlet. This was a new one, selected at a suitable point for the distribution of the sewage matter in a liquid form, or for its conversion into solid manure. 3°. That the gradients were generally favourable, considering the level of the great portion of the district, the flattest inclination of any new sewer being 1 in 488 near the lowest outlet, and nearly half the entire length of new sewers being steeper than 1 in 100. 4°. That no cost would be incurred in works, or for water for flushing; the plan being laid out so as to take advantage, for cleansing purposes, when required, of the land-water and the waste-water from the canal, and from ponds, feeders, &c. in the town, and water being also obtainable, on an emergency, from the waterworks, at any point.

In an aqueduct for supplying the dock with water from the Ebbw, constructed shortly before the new sewers, by arrangement with the Dock Company's Engineer, iron invert, with openings, were inserted at two points over the sewers, so that water might be obtained for cleansing them: other provisions were also made in different parts of the town. For a considerable portion of the sewage, a choice of two, or three outlets is provided, which may be useful in case of cleansing, &c.; the only work necessary for altering the course of the water, or the sewage, being the use of a few moveable doors, or gates.

In a Report to the Local Board before the execution of the works, further details are given, but generally they are only of local interest.¹

The general plan comprised about 7 miles of new brick sewers, varying in height from 14 inches to 4 feet 6 inches,—all above 14 inches being egg-shaped and narrow at the invert—with outlet works; a sufficient number of entrances with ventilating shafts; and street gullies; the contract for which was let to Mr. John Phillips, and by him successfully executed, under the direction of the Author. The plan also included the cleansing and repairing

¹ A printed copy of this Report is appended to the Paper.

of some of the old sewers which were to be retained, and a considerable extent of new sewers, which the Author was instructed to make for the owners of land not yet built on.

As regards the objection, which will no doubt suggest itself, to the course determined on by the Local Board of Health, (but to a considerable extent modified by the Author,) of using numerous outlets into the river within the borough, it must be observed, that the case of Newport is an exceptional one; the size of the river and the extraordinary rise of tide rendering the amount of sewage matter discharged into it comparatively insignificant. If, however, any present, or future discovery should prove sewer water commercially valuable at Newport, the objection will be still further weakened.

Of the four outlets necessary to the present system, two are old outlets, where a large quantity of land-water is discharged: for the remaining outlets, two points were selected which were suitable for the utilisation of the sewage, (if that should be found profitable,) and not near any houses; where the sewage water would have a short and steep run into the stream at low water; and where only short lengths of pipes would be required, should they be found necessary. The levels of the cills of the new outlets are 9·8 feet and 12·6 feet, and of the old outlets 8·8 feet and 12·6 feet, respectively, below high water of ordinary spring tides. When the outlets are closed, the sewers have for a time to act as reservoirs; but no practical inconvenience is found to arise from this, as means of ventilation are provided. The outlet valves were made by Messrs. Burton, Sons and Waller, of Southwark. The valve is formed by an iron disc, suspended loosely by chains, but when the tide rises it fits closely against a raised and planed surface on the iron work which is fixed in the masonry of the wall, the opening in most cases being smaller than the sewer. These valves are found to answer well; and although at extraordinary spring tides, there is a rise of about 17 feet above the cills of two of the outlets, and 6 feet above some of the lowest floors and cellars, no inconvenience is complained of, and the houses and cellars remain dry.

The sizes of the sewers were arranged to suit the quantity of sewage and water to be carried through them, as well as the rates of inclination, and other circumstances of the locality; regard being had to the advantage of making them sufficiently large for a man to pass through, where it could be done without an unjustifiable outlay.

In approving the design, the General Board of Health called attention to the successful working of stoneware pipes for sewers at "Salisbury, Sherborne, Southampton, Gloucester, Woolwich, Manchester, Carlisle, Rugby, and many other towns;" but the

Author considered it unadvisable to use them as main sewers in Newport, having regard to all the circumstances of the town, the existing works, the relative cost of brickwork and pipes, the quantity of debris washed from the roads into the sewers, as well as the difficulty of preventing improper interference after their construction, &c. In Newport all the roads are macadamized, the extent of private streets not repaired, or cleansed by the authorities, being considerable; and where the clearing of gully cesses is neglected, crushed stone and other matters pass into the sewers. The sewers have often been broken into, without the knowledge, or consent of the Local Board of Health, and if the labourers employed to do such work were to break a pipe, the probability is that the trench would be filled, and nothing would be said about the matter, until its effects became apparent on the house drainage of the neighbourhood. The danger of such an occurrence as this would be much increased, if the system of 'back drainage' (where pipe sewers are carried for considerable distances through private courts, gardens, &c.) were adopted. The cost of brick sewers, as compared with pipes, in Newport, may be thus stated. Brick sewers 14 inches diameter, and $4\frac{1}{2}$ inches thick, and 10 feet deep, under the Newport contract, with radiating bricks specially made, and a junction pipe inserted for every house, cost complete 7s. 7d. per lineal yard. This is about the same as a pipe 12 inches diameter, well laid, with junctions, would cost. Sewers 2 feet 6 inches by 1 foot 10 inches of brickwork $4\frac{1}{2}$ inches thick, similarly constructed, with junction pipes, and large enough for a man to pass through, at the same depth, cost 11s. per lineal yard. Excepting for small sewers under 12 inches in diameter, brickwork is, in Newport and in many other localities, cheaper, as well as more permanent, than pipes. The Author has found, in practice, great advantages in dealing with sewers constructed large enough for a man to pass through, if necessary; and although from time to time he has carefully weighed the advantages and disadvantages of pipes, he has most frequently constructed and recommended brick sewers, not less than $2\frac{1}{2}$ feet high, for all important lines, excepting where the fall is very great. He has generally confined the use of pipes to house drainage, for which they are admirably adapted, to short branch sewers on steep inclinations, and to conduits for fresh water. In the district of the Christchurch Local Board of Health, which was drained by the Author, several hundred yards of pipes were laid parallel to one of the brick sewers, to convey fresh water for the use of a few houses.

The subjoined Table will, with Plate 4, show generally the sizes, thickness, and cost of the Newport Sewers, all excepting the first being egg-shaped:—

No. of Figure.	Internal Dimensions.		Thickness of Brickwork.	Quantity of Brickwork per Lineal Yard.	Average Depth of Cutting.	Cost per Lineal Yard, including Junctions.
	Height.	Width.				
	Ft. In.	Ft. In.	Inches.	Cubic Ft.	Feet.	s. d.
1	0 14	Circular	4½	5½	10	7 7
2	2 6	1 10	4½	9	10	10 11½
3	2 6	1 10	6	12½	10	13 10
4	3 0	2 2	4½ in. with 9 in. inverts	14½	10	15 0
5	3 0	2 2	All 6 in.	14½	10	15 6
6	3 0	2 2	6 in. with 9 in. inverts	17	10	17 2
7	3 0	2 2	All 9 in.	23½	10	22 0
8	4 6	3 0	9 in. excepting crown 6 in.	27½	12½	28 1
9	4 6	3 0	9	32½	13½	31 5
10	4 6	3 6	9	33½	15½	35 0

The prices of the sewers up to, and including, 3 feet by 2 feet 2 inches are given for an average depth of 10 feet, for the purpose of easy comparison, though many of them were laid deeper. The depths of the sewers 4 feet 6 inches in height are the average of excavations actually made, the greatest depth being about 20 feet. The cost of the brickwork in mortar was 18s. per cubic yard for 9-inch work, 18s. 6½d. for 6-inch work, and 19s. 1½d. for 4½-inch work; the earthwork cost about 1s. 4d. per cubic yard. A copy of the quantities and of the form of tender, which the Author arranged carefully, and found very useful in preventing trouble and disputes in the settlement of the contract accounts, is appended to the communication.

The brickwork was generally laid in mortar, composed of blue lias lime and clean sharp sand, in the proportion of 1 of lime to 1½ or 2 of sand, well mixed with water in a mill, and used fresh. The external surface of the crown of the sewers was coated with mortar about half an inch thick. Cement was used in some places for the brickwork and concrete for the foundations.

Before selecting the bricks for the work, a close, and in some cases a chemical, examination of the bricks obtainable was made; and it was ultimately arranged to procure machine-made bricks from the works of Mr. Tuckett, of Shirehampton, near the mouth of the River Avon, below Bristol, the samples of these having stood well the examination and tests of analytical chemists. They are made by machinery, (the clay having been previously passed through a pug mill,) some by steam and others by hand power; and they have a small longitudinal hollow, which reduces the thickness of the clay, and without materially weakening the brick, causes it to become more dense and be more easily burnt. For the 6-inch brickwork, radiating bricks 12 inches long 6 inches deep and 3½ inches thick, on an average, including the hollow, were burnt without difficulty; and were found to effect a large saving

in many of the sewers, where otherwise two rings of $4\frac{1}{2}$ -inch work would have been used. The bricks for the 6-inch and $4\frac{1}{2}$ -inch rings were all made to radiate, to suit the invert, sidewalls, and crown of the several sized sewers; and in order to distinguish readily the different radii of the bricks, as well as to afford a key for the mortar, grooves varying in shape and number were made in the sides of the bricks, to indicate the radii for which they were intended. The inner and outer surfaces of the bricks were curved, to suit the respective radii, so that, when well put together, a very accurate sewer was formed. Some bricks of a similar character were made, for the side walls of the sewers, at Mr. Henry James's Court-y-bella Brick and Tile Works, Newport.

The sewers are connected by curved junctions, or bellmouths, the curves being laid at a steeper inclination.

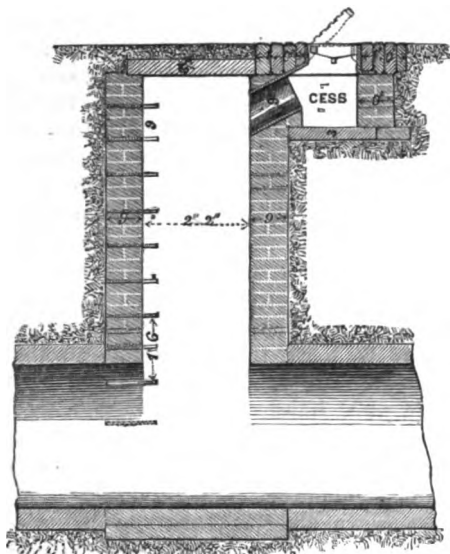
The subsoil through which the sewers in the higher parts of the town had to be laid is marl, rock, &c.; but in the flat part, where most of the new sewers were required, it is a level deposit of mud, or clay, more or less hard, naturally about the level of high water of ordinary spring tides, and 4 feet or 5 feet below high water of extraordinary spring tides, but covered, for a depth of about 6 feet, with ships' ballast—stones, gravel, and sand—or with clay from the excavations for the docks, &c. In some parts, at a depth of about 10 feet from the natural surface and 16 feet from the present surface, a layer of peat 6 inches or 9 inches thick was found; and in places, where the brickwork would have rested on it, the peat was removed and concrete was substituted. The construction of sewers in this flat district was found to be easy, where the ground was dry, and the brickwork could be executed immediately on the completion of the trench, which was cut by a template exactly to the shape; but where the trenches were acted on by land, or tidal water, difficulties necessarily arose, which had to be overcome in various ways. Generally, owing to the looseness of the ballast, and the water it contained, the trenches had to be well strutted and lined with planks, which were driven down vertically as the workmen removed the ground, while other men were employed in baling, or pumping the water, which ran in from the ballast, or the old drains, and sometimes from the river at high tide. In one of the large sewers, which was constructed to a point near the river, before the outlet works were completed, the contractor for some time used a syphon to discharge the water into the river, when the tide would allow. The sewer along Church Street, which is 573 yards in length, and from 3 feet to 10 feet below high water of spring tides, running nearly parallel to the river and only from 33 yards to 90 yards from it, is in difficult ground. The street, for a considerable distance, is only 14 feet wide, with houses on one side, and a railway carrying heavy mineral traffic on the other, the rails being only

18 feet from the houses. The sewer is from 8 feet to 15 feet below the surface in a soft clay. There are several imperfect old sewers and drains across the line of this sewer, and these, added to the loose character of the ground, for several feet below the surface, and in some parts below the range of the tide, rendered it difficult to keep the trenches clear, and in shape. The most effectual plan was found to be to prosecute the work promptly and vigorously during neap tides, which scarcely affected the trenches; and in order to save the houses, of which the foundations were in some cases on the ballast, only a little below the surface, the contractor was allowed to tunnel portions of the work. In filling the trenches, the clay required careful ramming, to prevent the settlement of the adjacent buildings. The greater part of the work being in open cutting, and the remainder in tunnel, the gas and water pipes which ran along this narrow street, near to, or over the sewer, were broken by the unequal subsidence of the ground. As a rule, tunnelling and building brickwork at night were forbidden, the Author having found, in numerous instances, that, when underground, or working at night, bricklayers would, without the knowledge of their employers, put in very rough work,—bricks without mortar, or even one ring of brickwork instead of two. In one case the Author found a bricklayer laying the crown of a sewer in a tunnel, under a passenger and mineral railway, in bricks without mortar, although the mortar yard was but a short distance from the spot; and several instances came to his knowledge, where one ring of brickwork was inserted instead of two. In sewer works where the sizes are not large, and the work is progressing simultaneously at a great many places, it would be vain to attempt to watch every brick put in, if tunnelling and night-work were allowed; and the Author has consequently found it desirable to have, as far as possible, open cuttings and brickwork executed by daylight.

As previously referred to, the sewers near two of the outlets, have, for a period of about three hours at spring tides, to act as reservoirs, and ventilation is then more than usually important, to prevent the noxious gases from being forced up through private drains into the houses, where the house drains are not properly trapped. The ventilation of the sewers is effected, and means of access to them is secured, by a large number of manholes and ventilators combined, which are placed in open parts of the centre of the roads and streets. These consist of a square shaft carried up from the sewer to near the surface, and covered by a flagstone, and then by a thin layer of the macadamized metalling of the road. Close to the shaft a small cess is constructed of brickwork in cement, with a flagstone bottom; and a stoneware pipe, 9 inches

in diameter, is laid from the side of the cess, 6 inches above the bottom, through the brickwork to the shaft: a strong iron grating weighing 1 cwt. 3 qrs. 7 lbs., hinged and with a notched surface, being fixed over the cess (Fig. 3). By this arrangement any

Fig. 3.



Manhole and Ventilator combined.

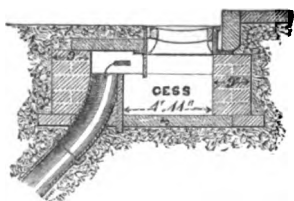
rubbish falling through the grating is caught in the cess, and may be removed without difficulty; the grating also indicates exactly the position of the manhole. Ladder irons are built in the brickwork of the shaft, to facilitate ingress and egress. These combined manholes and ventilators are found economical, costing £4. 10s. complete, and are suitable to such towns as Newport.

During the construction of the sewers glazed stoneware inlet pipes, 9 inches, or 6 inches in diameter, were inserted in the side walls, for connecting house and street drainage; these pipes were specially made, so that when fixed obliquely in the brickwork, with a proper fall, the socket end was outside the sewer, and the other end was flush with the inner face of the brickwork. They were generally placed opposite every house, or at points fixed on by the Engineer's inspector. In a large number of cases the house drainage was carried on simultaneously with the sewers; in others, marks were made to indicate the position of the pipes, and the house drainage was effected subsequently. Usually a separate drain, 6 inches in diameter, was constructed for each house, or a drain

9 inches diameter for two, or more houses, belonging to the same owner. Cesspools were cleared and filled up, and all sewage matter was allowed to pass through pipe drains into the sewers; water traps being placed at the commencement of the drains and in the closets to prevent the rising of effluvia. The junction pipes not used for house drainage, although partially stopped with a slate, or tile, afford an inlet for water, and thus drain the land several feet below the level of the cellars.

The gully grates for street drainage (Fig. 4) are of cast iron,

Fig. 4.



Gully Grate and Drain.

21 inches by 17 inches at the surface, hinged and slightly concave in the line of the bars, with a vertical flange which, with the stone and brickwork in cement of the cess for catching the silt, over which it is placed, forms a water trap to prevent any effluvia from rising from the sewer. The casting weighs $2\frac{1}{4}$ cwt. A pipe 6 inches diameter is laid at a steep inclination

into the sewer. The gully grate, cess, and drain complete cost £3.

The Author's estimate for the works was £13,838, and the tenders, nine in number (the highest and the lowest being from London contractors), ranged from £11,893 to £16,797: the lowest was accepted, and the contract was closed at £11,862, that sum paying for 12,500 lineal yards of sewers, with manholes, ventilators, gullies, and outlets; instead of 11,900 yards as in the contract. This saving was effected by reducing the thickness of the brickwork in many cases, after ascertaining the nature of the ground, by using mortar instead of cement in the inverts, and by otherwise carefully economising the construction. The works were completed at a cost about 14 per cent. under the Engineer's estimate, which latter was less than the average of the tenders: but these facts are not mentioned with the view of encouraging the practice, so disastrous in its results, often adopted by Local Boards, of accepting the lowest tender, without due regard to the capability of the contractor to perform his engagements. In this case the reputation and experience of the contractor justified the course pursued, and on the completion of the contract, the Local Board of Health passed a resolution expressing their perfect satisfaction with the works.

During the execution of these works 1,250 yards of sewers with manholes, ventilators, gullies, &c., were constructed for the Tredegar Wharf Company, under the direction of the Author. Sewers were also made by him for other landowners, in ground about to be built upon; and subsequently works have been con-

structed by Mr. Conyers Kirby, Surveyor to the Board, on plans prepared by the Author, for the drainage of a small portion of the borough on the east side of the river where the population is increasing.

The Local Board has only partially carried out the repairs and cleansing of the old sewers, which formed part of the original plan ; and in some instances the new sewers now receive from the old, which are defective, quantities of rubbish of almost every description, including stones, pieces of iron and tin, boots, &c. ; but notwithstanding this, Mr. Kirby states, that the new sewers, most of which have now been in use about four years, act well, and cost the Board and landowners almost nothing in repairs and cleansing.

The rate of mortality in Newport has decreased from 30·3 in a thousand, before the Public Health Act was applied in 1850, to rather less than 20 in a thousand, for two years ending Michaelmas 1861, which latter rate is below the average of England and Wales ; and no doubt this very large decrease of deaths is, under Providence, to a considerable extent due to efficient drainage and water supply, the prevention of overcrowding, and other sanitary measures.

The Paper is illustrated by a Plan of the town of Newport, and by a series of diagrams, from which Plate 4 and woodcuts, Figs. 3 and 4, have been compiled.

[Mr. FULTON

Mr. FULTON stated, through the Secretary, that after upwards of an additional year's experience, since writing the Paper, and after a practice of eighteen years in sanitary engineering at Liverpool, and in Dundee, he was fully convinced, that with properly-constructed sewers, no ventilation was requisite. This might seem a startling assertion, but having had a length of not less than 30 miles of main sewers, and nearly as many miles of branch drains, all closely trapped, in use for several years, without a single complaint being made regarding foul emanations from them, was a proof of the correctness of his position. The sewers were kept free of all silt, except sand, by the flow of the ordinary sewage and rainfall, regulated by flushing gates, so that their perfect cleanness, so far as any sewer could be called clean, was insured; or, to put the matter in another form, no putrescent substances were retained in the sewers, or drains, to fill them with deleterious gases, and to poison the inhabitants. Therefore, there did not exist the slightest necessity for the ventilation of such sewers and drains.

Mr. A. BASSETT remarked, through the Secretary, that being well acquainted with the district of Newport, and particularly with a large extent of wharf and other property, on the River Usk, belonging to Lord Tredegar, he had opportunities of forming an opinion on the utility of the drainage scheme executed by Mr. A. Williams, and it afforded him much pleasure to state, that the works had proved to be most satisfactory, both as regarded economy and efficiency. He had never heard of any complaint having been made with reference to the discharge of the drainage water into the River Usk. The large river area, coupled with the rapid flow of the tide, precluded any ill effects arising from this mode of drainage.

Mr. THOS. C. THORBURN (Borough Surveyor, Derby), observed, through the Secretary, that he did not think the drainage works of Dundee would be found to work satisfactorily, without efficient means of ventilation. He was persuaded that the light sewer gases would force themselves through the inlets, or imperfections of the pipe-joints, at the higher levels, which would in most cases be under houses, and therefore would be doubly objectionable in a sanitary point of view. The arrangements for flushing, at Dundee, appeared to be ingenious, but they must involve considerable expense in labour. Such complicated works as town sewers generally were should be arranged on the most simple principle, and be made, as far as possible, self-acting. The flushing of town sewers was absolutely necessary if they were to be kept clean, without resorting to the old method of breaking up the surface of the roads, or sending men up the sewers to clear them by hand. At Derby the whole of the sewers were kept clean by



Fig. 1

Brickwork, per Lin. Yd. 57s C. Ft.
Cost . . . 7/7



Fig. 2

Brickwork, per Lin. Yd. 9 C. Ft.
Cost . . . 16/11 1/2



Fig. 3

Brickwork, per Lin. Yd. 12 3/4 C. Ft.
Cost . . . 16/11



Fig. 4

Brickwork, per Lin. Yd. 14 3/4 C. Ft.
Cost . . . 17/-

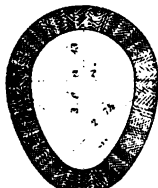


Fig. 5

Brickwork, per Lin. Yd. 14 3/4 C. Ft.
Cost . . . 16/11

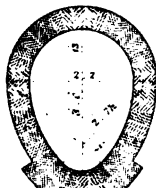


Fig. 6

Brickwork, per Lin. Yd. 17 C. Ft.
Cost . . . 17/2

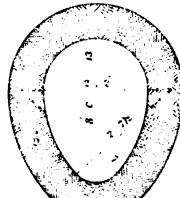


Fig. 7

Brickwork, per Lin. Yd. 23 3/4 C. Ft.
Cost . . . 22/-

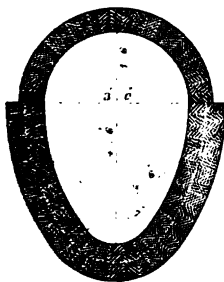


Fig. 8

Brickwork, per Lin. Yd. 27 3/4 C. Ft.
Cost . . . 28/4

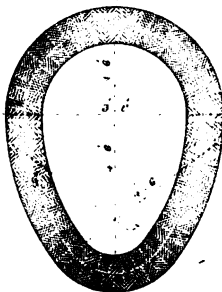


Fig. 9

Brickwork, per Lin. Yd. 32 3/4 C. Ft.
Cost . . . 33/6

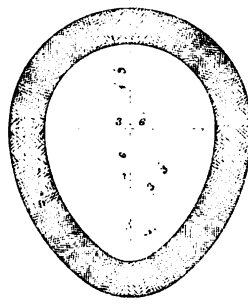


Fig. 10

Brickwork, per Lin. Yd. 33 3/4 C. Ft.
Cost . . . 34/-

The above Prices include Cuttings 10 Feet deep in Figs 4 to 7, 12 1/2 Feet in Fig. 8, 13 3/4 Feet in Fig. 9, and 15 1/2 Feet in Fig. 10.

flushing, by penstocks fixed at the river side above the weirs, and by numerous cisterns constructed at the upper end of the collateral and branch sewers, filled with water from the mains of the Waterworks Company. No doubt this involved expense; but, on the other hand, labour was saved, and he believed the public were fully compensated by the more efficient working, and by the sewage being carried completely away from the town to the outlets. In other respects the arrangements for the drainage of Dundee, if carefully carried out, would probably work satisfactorily.

Mr. Williams appeared to have designed the works of drainage at Newport with great discrimination, and if they had been executed with care, they would no doubt act well. He did not, however, entirely agree with the Author in the limit to which he recommended the use of stoneware pipes, for house-drainage, as long experience had convinced him that they might, with advantage and economy, be used for collateral sewers, and for the upper ends of main sewers, where the flow of sewage was small, and adequate means of flushing were provided. He did not, however, recommend the use of stoneware pipes for sewers of any description, without sufficient power for water-flushing being in every case provided, especially where debris was liable to be washed from the streets and roads into the sewers.

Mr. R. RAWLINSON said the description of the works at Dundee was clear and full; but there were some remarks which deserved special notice. He would direct attention, in the first place, to the amount of sewage discharged by the outlet sewer, which was stated to measure, in dry weather, 2 feet, and, during storms, 6 feet in depth; and that the velocity of the discharge was in the former case 65 feet per minute, and in the latter 116 feet per minute. He had looked over the calculations, and thought there must be a mistake; unless there was some element which did not appear in the Paper. He believed the velocity would be much higher for the gradient given, and the depth of water in those sewers; at least he had found it to be so in sewers he had constructed.

The principal point, however, to which he wished to call attention was, that although it was stated that the sewers at Dundee had been designed to act entirely without ventilation, and the Author asserted that ventilation was not required; yet, with apparent inconsistency, in another part of the Paper, he had spoken of having trapped certain gullies, to prevent the sewage gases escaping into the streets and houses. Mr. Rawlinson had a large experience in sewer construction, and he contended that it was dangerous to lay down a system of sewers over an entire town, without in the first instance providing, as part of the scheme, for the fullest and freest ventilation, at all parts of a town; but it was

generally most necessary at the upper and higher levels. Sewage gases, being lighter than atmospheric air, flowed upwards, while the sewage itself flowed downwards, and as the velocity of the discharge of sewage water downwards would be in proportion to the gradient of the sewer, the flow of sewage gases upwards would also be in proportion to the gradient. Therefore, a town having a naturally steep gradient, required the fullest means of ventilation; and so far from its being easy to sewer such a town, he held, if proper means were not taken to provide for ventilation, the Engineer was liable to leave that town worse than he found it. Within his own knowledge, disease had broken out in well-sewered districts, which was traced to a connection of house drains with unventilated sewers; and in those cases the highest portions of the towns suffered most severely. He thought the authorities at Dundee should not rest satisfied with what had been already done, nor until the work was completed by a proper ventilation of the sewers. Mr. Fulton seemed to infer, that sewers which wanted ventilation had been badly constructed. Mr. Rawlinson, on the contrary, held, that if such sewers were sweet, they must have been badly constructed; and that there were joints and crevices which allowed the gases to escape; because, with a perfectly tight sewer, the gases must make their way to the upper extremity, and have a tendency to find exits into houses through the house drains. The method of cleansing sewers, proposed by Mr. Fulton, was very similar to a system invented by the late Mr. Richard Blades, and used by him at Liverpool; it had also been introduced to the notice of the Metropolitan Board of Works. He thought it right to mention this, because credit ought always to be given to those who had the priority in any useful invention.

Mr. Alfred Williams had presented an able description of good and useful works executed at Newport, Monmouthshire, where ventilation had been adopted. He did not quite understand what was meant by the remark, that it was not considered advisable to use stoneware pipes as main sewers, but that it was preferable to adopt a sewer of sufficient size for men to traverse. He thought any Engineer in sewerage a town, ought to banish from his mind, at once and for ever, the necessity of constructing sewers sufficiently large for a man to pass through, unless those dimensions were required to discharge the sewage flowing into them, and should rather endeavour to design such a form of sewer as would be absolutely certain to discharge the contents derived from the upper extremities and from all the tributaries, and to keep the sewers clean and sweet. He could mention instances, in his own practice, where sewers had been constructed so as to act in the most efficient manner, without incurring the additional cost of making them larger than was necessary, merely

for the sake of saying at the conclusion of the work, "that they had a sewer large enough for a man to go through." He could point to dozens of miles of sewers which had been in operation a sufficient length of time to subject them to the severest test, without any instance of failure from choking up, or requiring hand-cleansing. The sections of the Newport sewers (Plate 4) were certainly of the most approved forms, and the bricks employed there were well adapted for the construction of such sewers with economy. Looking at the section, Fig. 8, Plate 4, it appeared that the internal dimensions of that sewer were 4 feet 6 by 3 feet, and that the brickwork of the invert and of the sides consisted of a double ring, 9 inches in thickness, while in the crown there was a single ring only, 6 inches in thickness. He did not know what plan had been followed at Newport, but in his own practice he should have set the two top courses of the thicker part of the work as 'headers,' so as to bond the two lower rings together, and to give a fair start for the single ring. In fact, in every instance where there were two rings of brickwork in the invert and sides, he insisted that there should be two rows of 'headers' at, or about the springing, so as to bond and tie the work together, where the arch commenced. The method of ventilating a sewer at Newport was good as far as it went; but he thought it was imperfect in this respect, that the manhole shaft was not available, without removing the flag which covered it, and thus breaking up the street.

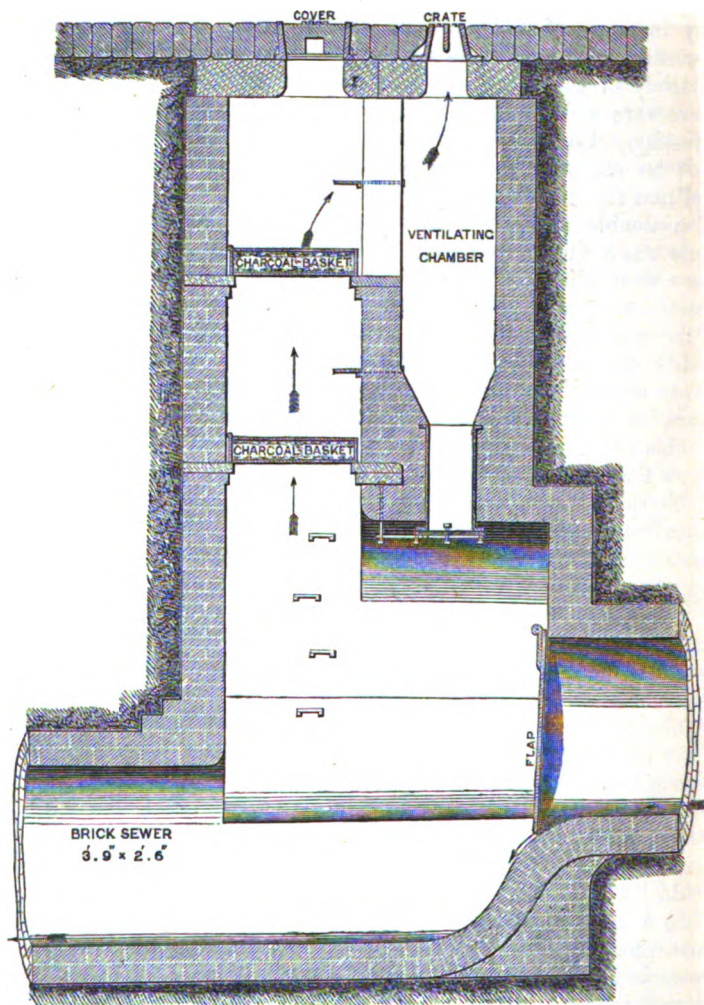
The system of ventilation he had adopted was shown by Fig. 5, page 288. There was a side chamber; but instead of covering the manhole shaft with a flagstone, which was difficult and expensive to remove, when access to the sewer was desired, it was finished with a manhole cover, which formed the street surface, and did not allow air to pass out; so that the sewer gas was compelled to rise through two, or more charcoal screens, or filters, before passing into the side chamber, or ventilating shaft. Any dirt from the street, falling into the ventilating chamber, was caught in an iron box, at the bottom of which there was a slide, so that the dirt could be readily removed whenever necessary.

In a hilly town the whole system of sewage should not be so connected together as to permit of the accumulation of the sewage gases in the higher parts of the district. Where the gradient was steeper than 1 in 200, and a sewer was, say, one mile in length, it should be divided by steps, or falls, and there should be a flap valve upon the upper, or higher discharging end of the sewer; with at least two ventilating grates at that point, so as to insure thorough ventilation.

It was to be remarked, that the systems of sewerage, both at Dundee and at Newport, discharged into rivers. It was fre-

quently necessary to carry the outlet of a sewer to a river, having a low summer level, and a high, or flood level. It was

Fig. 5.



Manhole, Tumbling Bay, and Double Ventilating Arrangement.

neither advisable, nor always practicable, during flood times, to carry the whole of the sewage, if the quantity was considerable, down below the summer level. Figs. 6 and 7 (p. 289) showed the arrangement he had executed at Windsor Castle, where formerly

Fig. 6.

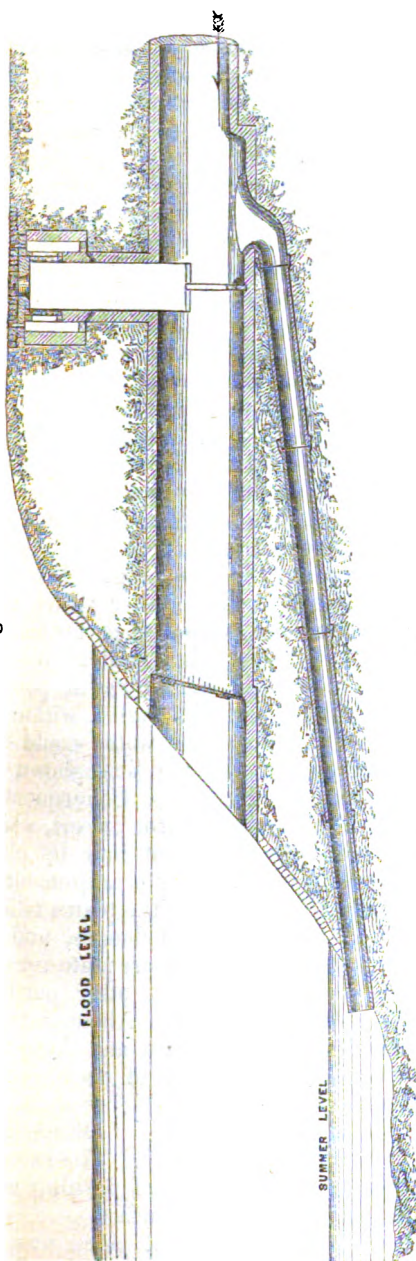
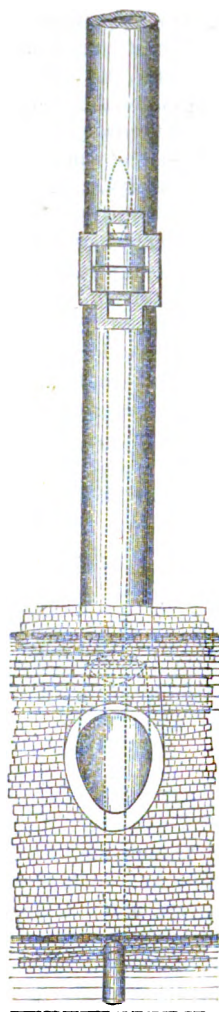


Fig. 7.

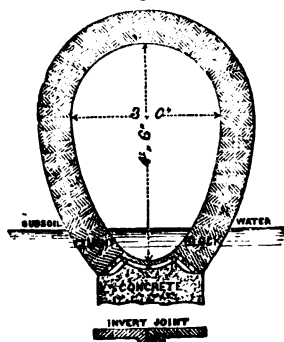


Dry Weather River Outlet, at Windsor Castle.

a large brick sewer discharged itself into the Thames, close to the Queen's private walk, and was a source of nuisance. By fixing a cast-iron pipe at the bottom of the sewer, and putting a slight dam in front of the junction, all the ordinary sewage was discharged by the iron pipe below summer level, so that the sewage was never thrown into daylight. The brick sewer above took away all excessive storm waters, and there was no danger of bursting, or other difficulty. He found a sewer 4 feet high and 3 feet wide might be required for flood, or storm waters; but that an iron pipe 12 inches diameter would probably discharge the ordinary flow of sewage for three hundred days out of the year, and when there was anything more than the pipe would take off, it would be in extreme dilution, and the river itself would be in flood, so that there would be a minimum amount of nuisance.

The main outlet sewer at West Ham (Fig. 8) was 4 feet 6 inches in height by 3 feet in width. It had a cast-iron invert,

Fig. 8.



Main Outlet Sewer, West Ham.

which was laid for about half a mile, at the level of low water of spring tides, and then for $2\frac{1}{2}$ miles with a fall of 3 feet per mile. Of course the outlet was obtained by pumping. The surface of the ground, under which that sewer was laid, varied from 10 feet to 12 feet below high water in the Thames, and the subsoil was so porous, that with a portable engine within 10 feet of the work, the water could not be pumped below the line shown on the section (Fig 8). Consequently, he had to devise an iron invert, which the workmen could put into its place in the trench under water, by feeling only. The arrangement of the joint was such that there was a certainty of the plates falling into place, and each could be raised by the side flanges, and be rammed below with gravel, or clay. Upon this invert plate cement blocks were laid to above the water line, and the other portions of the sewer were built in the ordinary manner. About 3 miles of that sewer had been in use for nearly two years, and there was no difficulty in keeping it clean. The velocity of discharge in that sewer, which had its invert on a level, was higher than that which had been given in the Paper on the Drainage of Dundee, for a depth of 2 feet of water and a gradient of 1 in 400. The velocity was due to the surface gradient, or head. Means of flushing were provided, and the only fall was the grade of the surface.

The mode of forming sewer junctions by bent pipes was, he thought, defective. A better plan was at the option of the Engi-

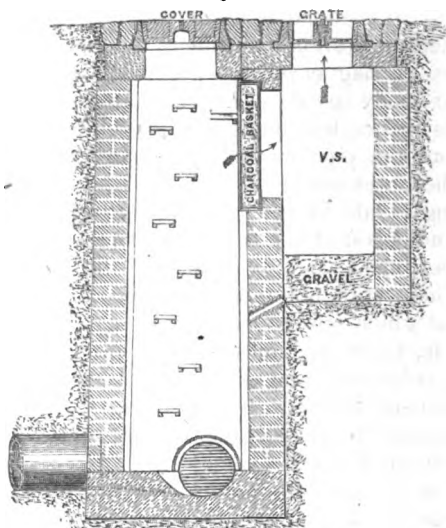
neer, and he had requested Mr. Doulton to send specimens of side junctions, suitable both for 9-inch and for $4\frac{1}{2}$ -inch work, which, he explained, formed part of the brick sewer, whatever size it might be; the blocks being built in with the work wherever junctions were anticipated. He also directed attention to an earthenware disc plate, which might be secured either with clay, or cement, and was intended to be put on the openings as the sewer proceeded, to prevent extraneous matters from being introduced. Slate, or flag coverings were neither so cheap, nor so perfect, nor so handy to use. The ordinary invert block afforded great facilities in accelerating the work, and in use, secured the scouring action of a pipe having that diameter, whatever the dimensions of the sewer might be.

The drawing (Plate 5) gave the particulars of various sewers, their forms and sizes, the number of bricks, and of the cost of each section per lineal yard, together with the prices of the various materials. These were not merely assumed figures, but were the actual prices at which sewers had been executed, at Berwick-upon-Tweed, Carlisle, Chorley, Lancaster, and other places. It might be useful for reference, and in every instance it would be seen, that double courses of bonding bricks were put in at, or near the springing, to insure the rings being tied together.

As the question of town sewerage was of daily increasing importance, he had been at some trouble to bring these matters forward, because he wished to give the fullest information in his power; and he thought young Engineers would do well to pay attention to the subject in all its bearings. He had adopted several leading principles, which he would briefly refer to. In the first place every sewer should be laid out in an absolute right line from point to point. He laid stress upon that, because in examining old lines of sewers, he found they invariably took the course of the streets under which they were constructed. To set out a sewer in a straight line surface sight rails were necessary, so as to 'bone' the invert level. The main sewer at Brighton, built within the last ten years, by a former surveyor, under the old Commissioners, was proved on examination to be most irregular both in line and level. This he apprehended must have arisen from the sewer having been built in short lengths, and without sight rails, or any proper levels. Then again at every change either in line, or in gradient, there should be a manhole, or a lamp-hole, to afford the means of access to the sewer from the surface. At all manholes, and at many of the lamp-holes, means of ventilation should be provided, such as he had explained. A chamber should be formed at the side of each of these ventilating shafts, to catch detritus from the roads; and the ventilating grate should be over it, and not directly above the crown of the sewer.

Between the side chamber and the shaft, charcoal filters should be fixed, so as to deodorise the foul gases, before passing into the streets. Care must be taken, that ventilating openings should not be direct down into the sewer, as was the case with the great part

Fig. 9.



Manhole and Ventilating Shaft.

of the sewers of the Metropolis, where shafts were carried up direct from the crown of the sewer, and the ventilating grate was put directly above it, thus admitting foul gases into the streets without deodorisation, and allowing stones and mud from the macadamized roads to fall into the sewer below, and to form an obstruction upon the invert, which was a cause of great mischief. The sooner this state of things was remedied, the better it would be for the Metropolitan drainage. It was impossible to carry out the grand scheme of intercepting drainage beneficially, if the tributaries were left in an imperfect condition. He ventured to mention his views on this subject, as he thought the first effect of the operation of the intercepting sewers would be, that water would be abstracted from the sewers which were now diluted with it; the washings of macadamized roads, which formed a good disinfecting material, would be taken away with the flood water, and in the intermediate districts, where there were great lengths of foul tributary sewers, there would be deposits of putrid matters; and with the ventilating grates opening directly into the streets, one of the first effects, during a hot and dry summer, would be to raise

SECTIONS OF BRICK SEWERS.

Fig 1^a

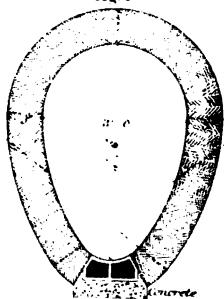


Fig 1^b

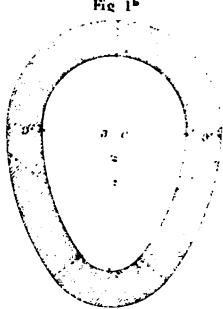


Fig 2^b

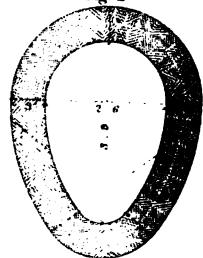


Fig 2^c

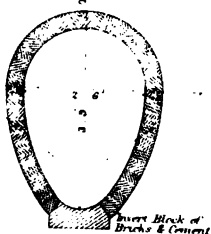


Fig 2^d

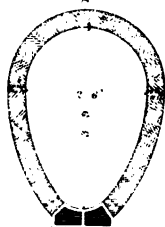


Fig 3^b

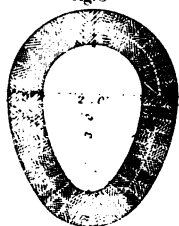


Fig 3^c

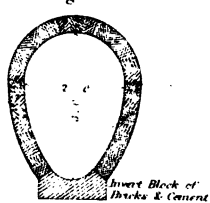


Fig 3^d



Fig 4^b

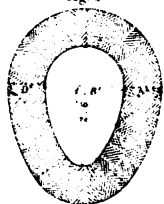


Fig 4^c

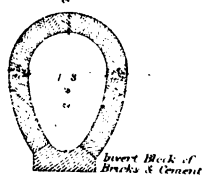


Fig 4^d



Fig 5^b

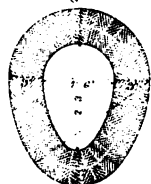


Fig 5^c

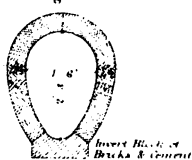


Fig 5^d



the rate of mortality. The Registrar-General would find it out, and record it in his Reports on the State of the Metropolis, unless some prompt precautions were taken, as it would be a serious evil to abstract the flood water which now diluted the foul matters in the sewers, unless provision was made to counteract such effect.

His reason for laying out sewers in right lines, was because he had found in practice, that to insist upon straight lines of sewers, and an absolutely true gradient, was more than equivalent to putting an inspector on the work. He would defy a contractor to scamp work if it was required to be true in line, both vertically and horizontally. Practically he never allowed the curves of junction to exceed $22\frac{1}{2}$ degrees.

Sewers of unequal dimensions should never be level at the inverts. It was safer, as a rule, that they should be even at the crown,—that the tributary drain should have an extreme fall at its junction with the main sewer. The fact of one sewer being made larger than another, implied that the former would have more work to do; and if the sewers were joined with level inverts, the large sewer would dam back the sewage in the smaller tributary, and prevent its being flushed out. He had found that where pipe drains were brought into a sewer with level inverts, the pipes became rapidly choked up, as the sewer water was dammed back for one-half, or two-thirds of their diameter, and sediment which had poured into them had no opportunity of getting out. But if the invert was raised above the ordinary flow of the main sewer, the solid ingredients might be diluted, and be flushed out, without still-water lying in the tributary drain. A tributary sewer would be better with less gradient and a free delivery. Sewers might be made to discharge large weights of material which had passed through the gullies. As an illustration of this he might instance the Birmingham sewers. The amount of sediment at the outlets of those sewers was not less than 500 tons per week, or 25,000 tons per annum, which was almost equivalent to the weight of the metal put upon the roads, as Birmingham was macadamized throughout all the streets, and there were only very few paved channels. Whenever there was a heavy fall of rain, large quantities of the ground-up materials of the roads were carried into the sewers, which passed through them, and collected at the outlets.

At Carlisle, the main sewer had a fall of 1 in 700, for a length of a mile and a quarter; it was liable to be flooded frequently in the course of a year, and at times the freshets and floods rose 18 feet, or 20 feet above the level of the invert, and 10 feet, or 12 feet above the surface of the ground where the sewer was built. That sewer had been in operation for six, or seven years, without requiring any outlay for hand-cleansing, and without any

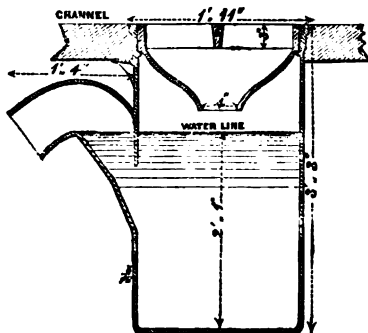
extreme power for flushing, but simply by due attention being paid to the arrangements at the manholes. At every manhole there was a groove in the brickwork to receive a stop plank, by which the sewers could be flushed out in sections, either by accumulated sewage, or by the admission of water from the Waterworks.

The question of fouling of rivers, by allowing undiluted sewage to pass into the nearest available water courses, was a matter of serious importance. It was a practice which the legislature should be called upon to put a stop to; but in saying this, he hoped that advocates would not arise for the abolition of the system of sewerage, because certain rivers had been fouled, and injuries done, for which apparently there had been no remedy up to a certain time. That which was of the greatest value in the consideration of this question was that greatest blessing to any community,—healthy human life. Modern civilization had been the means of massing populations together in towns: a town population could not exist and enjoy good health without some efficient, constant, and unceasing system of removing all the soil refuse from the midst of that mass of human beings. Schemes had been propounded for the sanitary inspection of water-closets, and house-to-house visitations; and various plans had been devised, to save what was conceived to be a valuable manure, in a form other than its being passed away in water. But his experience led him to the conclusion—that the cheapest element to remove soil refuse was water, and that the readiest method of doing it was by a proper system of sewers. It was quite possible that this could be done without committing any injury whatever; because chemistry could be brought to their aid. If it was not worth while commercially to pump the fluids and the solids, for the purpose of appropriating them to agricultural uses, then the solid matters should be removed by deposition and filtration, and the liquids should be deodorised, before being discharged into the rivers and water courses. In the year 1859, the River Thames, within the Metropolis, became a foul stinking stream, and the rivers in the vicinity of Manchester were foul beyond the powers of language to describe. That was also the state of some of the rivers in the manufacturing and thickly populated districts of the West Riding of Yorkshire. It must not, however, be thought, that because these evils existed, the sewers were in fault. They were only imperfect appliances at present, but were still a great improvement on the old cesspool system. He believed they were on the eve of a satisfactory solution of this problem. The land, beyond all question, was the place to which the soil refuse should go, and if the authorities of a town could not dispose of it at a profit, so as to obtain a return for their outlay, they ought to be

compelled to incur the necessary expenditure, for carrying it to some place, whence it could be beneficially applied, without creating a nuisance, and pay the necessary cost.

Mr. J. NEWTON contended that no system was perfect which permitted accumulations in the sewers; for if the velocity of the flowing sewage was insufficient to prevent the deposit of sand, grit, or other insoluble substances, such matters ought not to be allowed to enter the sewers, and by suitable gully traps and cesspits this might be easily accomplished. At Dundee, the main outlet sewer had a fall of 1 in 400 only, whereas some of the other mains had gradients varying from 1 in 600 to 1 in 700. As the scouring power was in proportion to the velocity, and the velocity, with like gradients, was in proportion to the amount of flow, this outlet might, with advantage, have been made much flatter than 1 in 400, and the fall, thus economised, have been used for augmenting the fall of the subsidiary mains. The gradient and the section of a sewer at the invert ought to be carefully adjusted to the probable average flow of sewage through it; and when this was done, it would very rarely be found that silting occurred, or even that flushing was necessary. In regard to street gullies, he directed attention to one entirely of cast iron which he had adopted (Fig. 10). It weighed 4 cwt. 2 qrs. 14 lbs., and, at six shillings and three-

Fig. 10.



Street Gully, as used at Preston.

pence a cwt., cost £1. 9s. A smaller size, weighing 3 cwt. 1 qr., cost at the same rate, £1; whilst the expense of fixing, or of removal did not exceed two shillings each. The efficiency, cheapness, and durability of this form of gully had induced him to use it exclusively, and during the last five years, he had fixed upwards of sixteen hundred of them in the borough of Preston.

There was still a diversity of opinion amongst Engineers, as to the proper size of sewers. His own experience showed, that in purely urban districts a rainfall of 1 inch in half-an-hour ought to

be provided for. Thus, on the 29th of July, 1857, he registered at Preston $\frac{3}{4}$ of an inch of rain in thirty-five minutes, and on the 8th of October, 1861, nearly the same depth in thirty minutes. On the latter occasion an egg-shaped brick sewer, 4 feet 9 inches high by 3 feet 2 inches wide and 300 yards in length, with a fall of 1 in 156, carried away this water from a closely built and densely populated district containing 117 acres. In another part of the town, which was also built upon and which contained 85 acres, a sewer 3 feet 6 inches high by 2 feet 4 inches wide, with a fall of 1 in 75, carried off these storms, without causing any damage, or without the water rising in the cellars, which were generally from 1 foot to 2 feet above the soffit of the arches. In both cases, however, the sewers were under pressure, as on the first occasion the water rose 18 inches, and in the other case 1 foot in the manhole shafts. These examples showed, that the sewers of Preston were not too large, and as most of the tributary mains ran nearly full on these occasions, and had never proved insufficient, they indicated the sizes required generally under similar circumstances. Almost all the rainfall, in the districts alluded to, flowed direct into the sewers, every house being drained, and but few receptacles existing for retaining the water. The sewers were constructed in straight lines, or on easy curves, and all branch drains were connected with the mains at angles of 45° . In ordinary town districts, calculating upon a maximum fall of rain of one inch in half-an-hour, and that it all passed directly into the sewers, he believed the following proportions would prevent silting, if the district was thickly populated, and the house drains were connected with the sewers:—

Diameter of Sewer.	Inclination.	Drainage Area.
Inches.		Sq. Ft.
6	1 in 50	200
9	1 in 100	400
12	1 in 150	650
15	1 in 200	1000
18	1 in 250	1400
21	1 in 300	1800

In intercepting sewers, where the ordinary flow was greater, and in large mains, an ordinary velocity of 1 foot per second would be amply sufficient to scour the invert, without any artificial flushing. As a general rule, he preferred the egg-shaped section for sewers, but where the inclination was such, that the velocity of the flowing sewage would not allow of silting, the circular form was preferable, because its discharging power was greater, when the flow was a maximum, and the cost of construction was less.

The form and construction of the brick sewers at Newport appeared to have been well considered ; but there were many places in which a smaller tube than 14 inches in diameter would have sufficed. In such cases a 6-inch, or a 9-inch pipe would have effected a considerable saving in expense ; in fact, at least one half might have been saved, and the efficiency of the system would have been improved. Although the advantages of good sewers, both in a moral and physical point of view, were undoubted, it was desirable not to be too sanguine in anticipations as to the results. Mr. Williams stated, that the mortality of Newport had been reduced from 30 per 1,000, in 1850, previous to the adoption of the Public Health Act, to less than 20 per 1,000 in 1860 and 1861. On reference to the Registrar Generals' Report he found that in—

1851, the mortality was	23·1	per 1000.
1852, " "	25·5	"
1853, " "	22·6	"
1854, " "	26·2	"
1855, " "	25·2	"
1856, " "	26·4	"
1857, " "	23·3	"
1858, " "	33·3	"
1859, " "	24·1	"
Average . . .	<u>25·5</u>	"

Mr. Williams might, therefore, with equal accuracy and reason, have said it was reduced from 22·6 per 1,000 in 1853, to less than 20 per 1,000 in 1860 and 1861. The mortality of a district was influenced by so many causes, and fluctuated so much, that conclusions should not be drawn from a short period of time: nevertheless he was satisfied that much good must necessarily arise from such works.

Mr. W. MERRY remarked, that some of the observations which had been made reminded him of the dogma of twelve, or fourteen years ago, that certain specific rules might be laid down to apply to every town in the United Kingdom. He dissented from that doctrine, and he regretted to find that such notions should still be entertained ; because experience had shown that every town must be dealt with on its own merits. It was necessary to take the local circumstances into consideration, as there might be a variety of peculiarities appertaining to one town which did not exist in another. There were general principles which should be discussed before entering into the details. In the first place, with reference to the drainage of provincial towns,—it was said that the work was done at less cost than in the metropolis. The great

point, in the system adopted at Dundee, appeared to be, that a length of 30 miles of sewers had been in use for years, without provision having been made for ventilation, and that no complaint was made of nuisance. It should at the same time have been stated how many houses in that borough had water-closets, what number of these drained into the sewers, and what proportion had 'middins.' He believed it would be found, that not more than one-third of the filth of the town got into the sewers. He had visited several large provincial towns which were drained upon this system, at probably one-half the cost of similar works in the metropolis, and he found that there were only water-closets in the first-class houses,—the houses of the middle and lower classes having 'middins,' the contents of which were removed periodically by the dust contractors, and were used upon the land. In such cases there was plenty of room in the rear of the houses for ventilation; but that system would not answer for London. This was further evident, by reference to the quality of the sewage, which in London might be compared to treacle in consistency, whilst in the country it was simply dirty water. At Paddington, which was considered an aristocratic part of London, there were about 800 acres of land on which there were 10,000 houses and 80,000 inhabitants, or an average of 100 to the acre. In other parts of London there were from 1,500 to 2,000 persons per acre. Recently plots of land at Paddington were covered with six-roomed houses; and on one estate, called Hall Park, containing an area of 3 acres, 235 six-roomed houses had been erected, with a water-closet to each house, the population amounting to 2,649 inhabitants. The sewers there, had a gradient of 1 in 480, and yet they required flushing, notwithstanding it had been stated that 1 in 600 was self-cleansing. Before arriving at conclusions on this subject, it was necessary to know the number of houses, the number of the inhabitants, the amount of the water supply, and whether each house was furnished with a water-closet which drained into the sewers.

Mr. RAWLINSON stated that Professor Way, who had analysed many different sewage waters from all parts of the country, found the analyses as nearly alike as possible. It was a mistake to speak of London alone as being a water-closeted town. At Alnwick, with 7,000 inhabitants, there was not a house without a water-closet. There was no necessity to provide duplicate sewers for surface flood water, in a system of sewers in provincial towns. The special features of every town should be studied, and the works be laid out with due regard to local peculiarities. Rules for sewers in the metropolis, or at Preston, or elsewhere, would not apply, except under similar conditions. In the town of Alnwick, having an area of 2,000 acres, the outlet sewer was 18 inches

in diameter, with a fall of 1 in 400. It had been in use for ten years, although all the down spouts, yard grids, and street gullies communicated direct with the pipe sewers. Alnwick Castle, with several acres of area, was sewered by a 12-inch pipe, and that effectively. The town of Worksop was sewered by a 15-inch pipe outlet. In each case the flood water of heavy rain flowed over the surface, as it did before any sewers were made.

Mr. J. GRANT remarked that, the main sewers on the south side of the River Thames were all provided with ventilating shafts and side catch pits, each capable of holding about a cubic yard of matter, which prevented stones and mud from entering the sewers. Between each ventilating shaft and catch pit there was a semicircular opening, all the openings being of the same diameter throughout, to admit of frames filled with charcoal, or other deodorising material being afterwards fitted; and through these frames of charcoal the foul gases would have to pass, before being allowed to enter the atmosphere. In confirmation of the statement, as to the advantage of a supplementary pipe outlet to discharge at low water, he mentioned that he had carried out a similar arrangement, at Battersea, eight, or ten years ago, and subsequently at four, or five other outlets of the main sewers on the south side of the River Thames. He laid large iron pipes to below low-water mark, having flaps, or penstocks, to prevent the tide from entering at high water. This plan had been adopted at London Bridge, and at Waterloo Bridge, as well as at other places. He concurred in the opinion that, in laying out a system of sewers, every town must be dealt with according to the local circumstances and the peculiar features of the case. The character of the outlet, the rate of inclination, and the nature of the surface of the ground, the rate and the amount of the rainfall, the number of houses draining into the sewers, the extent of the population, and other things, all required consideration.

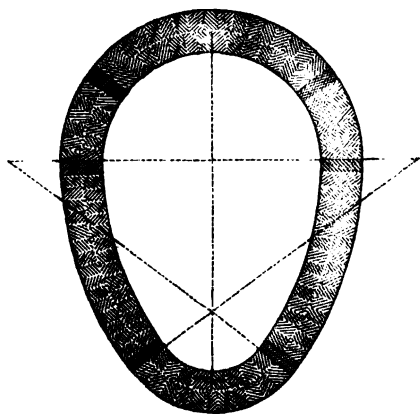
With reference to the question of cleansing sewers, he thought that the method adopted at Dundee was complicated and expensive; and that the plan pursued in the metropolis, which he had first practised at Richmond, was simpler and cheaper. In the pipe, or sewer a flap valve was fixed, which could be kept closed until a head of water accumulated. By this means the water could be backed up to any height that might be fixed upon; and when the valve was opened, the rush of water would clear away any deposit, including macadamized matter and stones.

Mr. RAWLINSON inquired whether the system of ventilation alluded to had been adopted at the west-end of London.

Mr. GRANT replied, that he believed it was likely to be adopted. It was simple, and effectually prevented stones and road mud from getting into the sewers.

Mr. COCKBURN CURTIS said, that, the extension of the main sewerage works of the city of New York afforded an instance of the application to a particular case of the results arrived at, after a calm consideration of all the facts and arguments which had been recorded on either side, in the numerous blue books which had been published in England during the Administrative Contest popularly known as the 'Small Pipe' and 'Back Drainage' Controversy. In extending the sewerage of New York, the section adopted for nearly all the main sewers was similar to that shown in Fig. 11. As it appeared to be a well-established fact, that the

Fig. 11.



Section of Sewer adopted by the Croton Aqueduct Department.

maximum amount of rain which had fallen upon Manhattan Island, upon which New York was situated, had never exceeded one inch in an hour, the capacity of the sewers was adjusted to provide for that amount of flood water, in addition to the prospective maximum house sewerage flow of the several districts proposed to be drained. The material adopted was brick laid in cement, and the inner bottom of the sewer was plastered with cement, to make a uniform surface for about a foot in vertical height, or the lower courses were laid dry, according to the necessities of the locality. In keying the crown of the arch, no headers were allowed to be used, except when bricks were furnished of a particular shape, made expressly for that purpose. In all other cases, the inner and outer courses of stretchers were carried over separately, and each was keyed with slate, after the arch was turned. The streets in the modern part of New York were laid down in straight lines, and the main sewers were laid down as nearly as possible in the middle of the streets, but with confluent junctions,

having radii suitable to the peculiar circumstances of each locality. Receiving basins for the road detritus, with trapped culverts for passing the surplus water into the sewer, were fixed at the corners of the streets, or in other suitable positions. These receiving basins were from time to time cleared out by manual labour. In most cases there was a good natural fall. Each length of sewer was laid down from end to end, on an uniform gradient. In almost all instances it was found, that these arrangements were sufficient to keep the sewers free from any permanent deposit.

As regarded the example which had been adduced, of a sewer constructed with a dead level bottom, Mr. Curtis considered generally, that such a mode of construction was objectionable, on account of its decreasing the hydraulic mean depth at the outfall, where it was most needed. In most similar cases an easy gradient would be preferable, as affording a greater sectional area at the outlet for the passage of the sewage, or the flood waters, and as occasioning less danger of regurgitation. He did not think the question of priority of invention could be entertained, in reference to the mechanical cleansing of sewers, inasmuch as similar systems had been used for cleansing out the supply and discharge sluices of the tanks in India, probably for the last thousand years.

Mr. LOVEGROVE said, what appeared to be the most remarkable circumstance about the two Papers was, that in one case brick sewers seemed to have been mainly adopted, whilst in the other tubular drains, or pipes, had been more largely employed; but as no drainage areas had been given, the relative merits of the two systems could not be compared. At Dundee, the sewerage had been laid out, so as to avoid the necessity of purchasing water from a public Company. To accomplish this, the sewers had been constructed at such relative depths, as to admit of the sewage being turned from one channel into another, and this, doubtless, caused the gradients to be kept as low as 1 in 600 and 1 in 700, which would favour a deposition of silt. Then there was the expense of shafts at every forty yards, and the application of mechanical arrangements for the purpose of cleansing. It was a question, whether it would not have been better and more economical, to have paid the Water Company for a proper supply of water, and have depended upon that for the scouring power, rather than to have reduced the gradients sufficiently to enable the water to be turned from one channel to another. With a series of sewers constructed on rising ground at different levels, it was easy to intercept the sewage at various points, and to make use of the several sewage currents as a scouring power. If, however, the land was level, and the sewers were about the same relative vertical height, the intercepting sewers must be nearly on a dead level,

thus reducing the scouring power of the system to a minimum. He thought, that if a greater fall had been given to the sewers at Dundee, and an occasional supply of water had been obtained from the Water Company, the expense would have been less than that incurred in the original construction on this plan. There must be nearly a thousand shafts, solely for the purpose of removing the deposit, and their cost could not be calculated at less than £5,000 or £6,000; added to which the expense of manual labour would have been decreased by 50 or 60 per cent. if the other plan had been adopted. The form of street-gully was also objectionable, as it would allow of large quantities of road detritus entering the sewers. The cess-pit below the grating was about 10 inches in depth, and would contain about one cubic foot. When the cess-pit was filled, and while water passed through the hanging flap-valve, the sediment would escape into the sewer. Such a cess-pit, he thought, was not large enough for protection against the intrusion of road detritus. There were certain principles which should be observed in the construction of gullies. They should be so made as to prevent road detritus from entering the sewers, and to arrest the escape of noxious effluvia, while at the same time they should provide for the admission of a downward current of air, to aid in the ventilation of the sewer. With untrapped and imperfect gullies this downward current existed, but they also permitted the foul air to escape through the same channel. The gullies in Preston were an instance of this, as unless there was a sufficient quantity of water there could be no trap, for as soon as the water was evaporated below the syphon dip, the gully was no longer trapped, and the sewer was in direct communication with the outer air. The same state of things existed in Derby and in Leicester. He had noticed many instances, in those towns, where the water had evaporated below the syphon dip, and where a direct current of foul air escaped from the sewers, through those defective gullies. In many cases these gullies were placed within two, or three yards of the windows and doors of the dwelling-houses. With reference to the direction of the air passing through sewers, it had been asserted, in the course of the discussion, that the more powerful the current of water passing along a sewer, the more powerful would be the current of air in the contrary direction; while in one of the blue books issued by the General Board of Health, it was stated, that there was always a flow of air in the direction of the sewage current. He had tried some experiments as to the direction and temperature of the air in sewers, but he had not found any relation between the flow of the water and the direction of the air. The latter was sometimes with, and sometimes against, the sewage flow, and did not appear to be governed either by the velocity, the temperature, or the direction of the sewage; but to be determined by the

various points of ingress and egress, and by the number of gullies and ventilating shafts.

Mr. Lovegrove then directed attention to a model of a vertical inspection shaft designed to facilitate the cleansing and ventilation of small sewers, and described its principal effects with regard to ventilation. Also a form of gully trap combining the three principles before adverted to ; to prevent the escape of noxious effluvia from the sewers, to protect the sewers from the entrance of road detritus, and to aid in the ventilation of the sewers, by providing for the admission of air, as a downward current. These subjects he proposed to bring more prominently before the Institution on a future occasion.

Mr. WILLIAMS said, in reply upon the discussion, the principal objection to the Newport works had been, that he had carried brick sewers too far, and that a saving would have been effected by using pipes. He thought by referring to the prices given on Plate 4, it would be seen, that there would have been little saving by adopting pipe drains in any part. The smallest brick sewers, 14 inches in diameter, were built at a depth of 10 feet, at a cost of 7*s.* 7*d.* per lineal yard, including the junction pipes for the house drains ; and according to his estimate and experience a pipe drain 12 inches in diameter would have cost that sum, or rather more. The only other prices that had been given, were those relating to the works at Dundee, where the average cost was—brick sewers 33*s.*, and tubular drains 13*s.* per lineal yard ; whilst he had constructed sewers large enough for a man to traverse at 11*s.* per lineal yard, and these with radiating bricks, specially made for the purpose, samples of which were shown. He thought that a sewer of those dimensions would be preferred to a pipe drain, through which a man could not pass.

With regard to what had been said, as to the rate of mortality, he might state, that the average of several years before 1850 was 30·3 per 1,000. He had taken the figures very carefully from the returns of the registrar of Newport, inasmuch as at the time he had no opportunity of obtaining the Registrar-General's Report ; and probably there was some difference in the boundaries of the districts over which the averages had been taken. But, in confirmation, he read a letter from Mr. W. Downing Evans, the Registrar of Newport, dated the 13th of February, 1863, which said, " the number of deaths I registered last quarter was 128, chiefly from diseases of the respiratory organs ; there was not one case of fever. The mortality of Newport became much reduced immediately upon the formation of the drainage, and I estimate it to be now 22 per 1,000."

Further, in the Report, for the last three months of 1862, of Dr. Davies, the Medical Officer of Health for the borough, it was

said, "not one death has been recorded from continued fever, which is a most remarkable immunity among so large a population, and is, no doubt, chiefly to be attributed to our excellent and thorough system of drainage."

Mr. HAWKSHAW, President, concurred in the opinions which had been expressed, as to the necessity for the thorough ventilation of sewers. The fact seemed to be overlooked, that a sewer was an inverted receiver, and could not with safety be hermetically sealed. If the gases were not allowed to go out into the streets, they must pass into the houses. Those who constructed sewers should be bound to provide frequent inlets and outlets, at given distances. He believed the best way to render sewer gases innocuous was by a large admixture of atmospheric air. He agreed, that not only must the gases be let out, but air should also be admitted into sewers; he did not, however, quite concur in the suggestion as to charcoal filters, through which gases had to escape, not because he did not wish the gases to be purified, but because in proportion to the extent to which that plan was adopted, would the ingress of atmospheric air into the sewer be obstructed. He believed, that if the sewers of London had ventilating shafts at every 100 yards, by which air could have entrance and exit, the metropolis would be in a much better and healthier state; and when he heard of sewers being constructed wholly without ventilation, he felt thankful he did not live where such plans were adopted. With reference to the sample of earthenware invert for sewers, having at one time filled the office of a Metropolitan Commissioner of Sewers, he had paid some attention to the subject, and he believed that this plan of invert was a mistake. It was well known, that the bottoms of the sewers were subject to the greatest wear, and the inverts, to which he referred, had a thickness of only an inch. It was along the invert that the grit and other triturating matters passed, and it formed the pathway for the men, who used their shovels upon it, when cleansing the sewers, and an invert, only one inch in thickness, was the weakest and worst thing that could be applied.

With regard to the fouling of rivers, no doubt by vastly increasing the local burdens upon trade and manufacture, means might be provided for depositing the heavy matters, and for deodorising and disinfecting the fluid portions of sewage; but such nuisances were, to some extent, the penalty incurred for concentrating the population in dense masses, and it was hopeless to expect, that the rivers in the neighbourhood of large manufacturing towns could ever be restored to their former state of purity.

February 17, 1863.

JOHN HAWKSHAW, President,
in the Chair.

The discussion upon the Papers No. 1,053, "On the Drainage of Dundee," by Mr. Fulton, and No. 1,054, "On the Sewerage of Newport," by Mr. A. Williams, was continued throughout the evening, to the exclusion of any other subject.

February 24, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,063.—"American Timber Bridges." By JAMES ROBERT MOSSE, M. Inst. C.E.

IN presenting the following description of American Timber Bridges, the Author desires to direct attention to some designs, which, though they may afford only feeble interest to Engineers in England, are practically the only works available in new and comparatively poor countries, where the cost of more permanent structures cannot be supported, but where timber is abundant and cheap.

The magnitude of the rivers in the United States early required extensive bridges, even for the common roads. Viaducts of considerable length, in spans of from 150 feet to 200 feet, are often met with, although the financial means of the country had always an inverse ratio to the work to be performed. Hence structures of timber are more frequent than those of iron, or stone; and the expense of skilled labour in America has still further necessitated the erection of cheap and expeditious works. Indeed, considering all the circumstances of the early struggles, the rapid growth of the country, the past state of the finances, and the value of money, always worth at least 6 per cent. per annum, it was evident economy to erect a bridge, costing, say £5,000, even if it had to be rebuilt in twelve, or fifteen years, rather than to construct one at an expenditure of £10,000, which would not require renewal.

In the order of introduction, the first design to be noticed is the
[1862-63. n.s.]

x

LATTICE BRIDGE. The earlier common road bridges, for spans of 100 feet and upwards, were generally built on the lattice plan. The sides and the top and bottom chords were formed of planks, usually 12 inches wide by 3 inches thick, fastened together by oak trenails 2 inches in diameter. For road traffic, with moderate spans, this bridge answered tolerably well; and several of the earlier railway bridges were thus constructed. But the lattice design, having proved insufficient for heavy trains, has long since been abandoned. Heavy railway traffic has shown "that, owing to the great number of joints, the shrinking of the timber in seasoning, and the absence of any heavy continuous piece of timber, distributing the strains of passing trains over the whole bridge, and then on to the abutments, the settlement of these lattice bridges was certain and rapid, so much so as, in some instances, to assimilate to a wooden suspension-bridge. The joints of the chords tear asunder below, the lattice pieces split, and the top buckles until the bridge becomes unsafe, or impassable." To maintain these bridges, it has always been found necessary to add some new element of strength, frequently in the form of a queen-post truss, but more usually by the addition of arched ribs, on each side, without which many American engineers consider "no railway timber bridge safe, or efficient." They state also, that the arch has "answered admirably, wherever used either to strengthen a failing bridge, or as embodying the main principle of strength in a new one." Attention has thus been drawn to the defects of the lattice plan, because it has been erroneously supposed in England, to be the usual style of American bridges.

After one, or two other designs, which need not be particularly mentioned, the **HOWE BRIDGE** (Plate 6, Fig. 1) became extensively used for railways in the United States. The earlier bridges of this class were usually from 100 feet to 150 feet span; but arches are now generally added, when they approach, or exceed the latter dimension. For spans of 100 feet this design stands well. It is light, cheap, and very simple in construction. The ordinary price for a single line, including erection, is from £4 to £5 per lineal foot; and for spans of 150 feet, with arches, from £5 to £6 per lineal foot.

The Howe bridge was the first design in which any camber could be easily given by means of the tie-rods; and counter-braces were introduced, by which, when keyed up, the bridge could be so stiffened, that a passing load was said to produce no additional strain upon it. Especial care was also taken in forming the bottom chords, so as to resist, as much as possible, the tensile strain. As now constructed the panels are generally from 10 feet to 11 feet wide, and the bottom chords, four in number on each side, are from 40 feet to 44 feet long, and 6 inches by 12 inches in section. The bottom chords thus extend over four panels; and they are so arranged, that there

shall be only one joint in the chord pieces, in any one panel. Oak splicing-pieces, 6 feet long, are inserted at every joint, and oak keys, 12 inches long by $2\frac{1}{2}$ inches wide, are let in $\frac{3}{4}$ inch between each chord piece, at intervals of 5 feet; and the whole of the chords are bolted together by numerous bolts, in order to keep them from stretching. There has always been difficulty in preventing the extension of the bottom chord, and in rendering the bridge rigid. The former is obviated by the manner in which the chord is made solid by the oak keys and bolts; and the latter is obtained by keying up the counter-braces, so as to prevent the undulations which the trains would otherwise cause. The main braces increase from the centre to the abutments; but they are sometimes found insufficient for the strains coming on them in the first and second panels. The angle blocks at the top and bottom of the braces are sometimes of oak, but generally of cast iron. The vertical rods, usually three in number in each panel, but sometimes only two, vary from $1\frac{3}{4}$ inch diameter at the abutments to $1\frac{1}{4}$ inch diameter at the centre. The joists, 6 inches by 12 inches in section, rest on the bottom chords, at distances of 2 feet 9 inches from centre to centre; and upon these are placed the longitudinal pieces, which carry the rails.

Plate 6, Fig. 1, is an ordinary Howe bridge of 121 feet span, built over the James River, at Richmond, on the line of the Danville Railway. The principal dimensions of this bridge are—Length, about 1,800 feet; general span, 121 feet; number of trusses, 2; number of spans, 11; width of panel, 11 feet; total depth of truss, 20 feet; and width of bridge outside, 18 feet.

The upper chords consist of two pieces 9 inches by 12 inches, and four pieces 5 inches by 9 inches, having a total sectional area of 396 square inches. The bottom chords consist of four pieces 6 inches by 12 inches, and four pieces of 5 inches by 12 inches, having a sectional area of 528 square inches. The area of the bottom chord is always greater than that of the upper chord, on account of the numerous joints in the former. The end main braces—eight in number, four at each end of the bridge—are 8 inches by 9 inches, giving a sectional area of 576 square inches. The counter-braces are $7\frac{1}{2}$ inches by 7 inches; the tie-rods at the abutments are $1\frac{3}{4}$ inch diameter, and have a sectional area of 2 square inches, while those at the centre of the bridge are $1\frac{1}{2}$ inch diameter, with an area of $1\frac{3}{4}$ square inch.

These bridges are always built of the best white pine. The usual quantity of timber in them is about 30 cubic feet per lineal foot. This, at 35 lbs. per cubic foot, is equal to 1,050 lbs., and, adding for ironwork 120 lbs., gives the total weight as about 1,170 lbs., or little more than half a ton, per lineal foot. Assuming a load of 2,000 lbs. per lineal foot to be uniformly distributed over

this bridge, or say 3,000 lbs., including its own weight, then, by the ordinary calculation,¹ the strains are—

On the upper chords, compression,	729 lbs. per square inch.		
„ bottom chords, tension,	547	„	„
„ end braces, compression,	735	„	„
„ end tie-rods, tension,	15,125	„	„

It may be interesting to give the ordinary dimensions for a span of 150 feet, built without arches, on the Portland Railway. Span in the clear, 150 feet; whole length of chords, 164 feet; number of trusses, 2, each 19 feet in height; and number of panels, 14, each 10 feet 9 inches long. The width of the bridge between the trusses, if the rails are placed on the top of the bridge, is 12 feet; and if on the bottom chord, 14 feet. Two of the lower chord pieces are 6 inches by 13 inches, and the other two are 7 inches by 13 inches, with a total sectional area of 676 square inches for both sides. The whole of the lower chord, when packed, measures 13 inches in depth by 30 inches in width. Two of the upper chord pieces are 6 inches by 10 inches, and the other two are 7 inches by 10 inches, with a total sectional area of 520 square inches for both sides. The whole of the upper chord, when packed, measures 10 inches in depth by 30 inches in width. The main braces, for three panels from the abutments, are $8\frac{1}{2}$ inches by $10\frac{1}{2}$ inches, the rest of the main braces being 8 inches by $10\frac{1}{2}$ inches. The counter-braces are 7 inches by 9 inches. The main tie-rods are $1\frac{1}{8}$ inch diameter; three panels from the abutments having three rods each, and the other panels two rods each. The diagonal braces are 6 inches by 7 inches, and the bolts through these diagonals are $1\frac{1}{4}$ inch diameter. The splicing bolts through the chord pieces are always $\frac{3}{4}$ inch diameter.

Assuming the same weight, 3,000 lbs. per lineal foot, to be equally distributed over this structure, the strains are—

On the upper chord, compression,	901 lbs. per square inch.		
„ bottom chord, tension,	694	„	„
„ end main braces, compression,	750	„	„
„ end tie-rods, tension,	18,750	„	„

¹ In the case of the upper chord,			
$\frac{121 \times 3,000 \text{ lbs.} \times 121}{396 \text{ (area)} \times 8 \times 19}$	=	729 lbs. per square inch.	
In that of the bottom chord,			
$\frac{121 \times 3,000 \text{ lbs.} \times 121}{528 \text{ (area)} \times 8 \times 19}$	=	547 lbs.	„ „
The strain on the last main brace is,			
$\frac{121 \times 3,000 \text{ lbs.} \times 21 \text{ feet diagonal}}{8 \text{ braces} \times 8 \text{ in.} \times 9 \text{ in.} \times 18 \text{ feet height}}$	=	735 lbs.	„ „
The strain on the end tie-rods is,			
$\frac{121 \times 3,000 \text{ lbs.}}{12 \text{ (No.)} \times 2 \text{ inches area}}$	=	15,125 lbs.	„ „

It will be observed, that in this case the strains are considerably greater than in the first example, of 121 feet span, and that the compression of 901 lbs. per square inch on the upper chord reaches the limit of a safe strain. It is not likely, however, that this bridge will ever be loaded to the amount assumed. At the same time it should be remembered, that the pressures above mentioned are those resulting only from the dead weight, and that they do not include the strains caused by the concussion of trains.

It will be evident from what has been stated, that for the increased weight of trains and the enlarged span of railway bridges, it was afterwards found necessary to strengthen the Howe Bridge, by arches on each side of the truss. This IMPROVED HOWE TRUSS, as it is called, for several years came into general use. Plate 6, Fig. 2, gives one of the best examples of this bridge, built for a double line on the Philadelphia and Reading Railway, where it is subject to the heaviest traffic in America. The principal dimensions are, span 160 feet in the clear. The trusses are three in number, and 23 feet deep; the upper chords are composed of four pieces, each 15 inches deep, and together 27 inches in width. The bottom chords are also of four pieces, each 20 inches deep by 27 inches in total width, keyed and bolted together in the manner described in the first example. The sectional area of the upper chords is, therefore, $3 \times 15'' \times 27'' = 1,215$ square inches, and that of the bottom chords is $3 \times 20'' \times 27'' = 1,620$ square inches. The arches, six in number, one on each side of each truss, are formed of the best pine, in pieces about 24 feet long by $4\frac{1}{4}$ inches wide and 15 inches deep. There are four such pieces in each arch, making together $8\frac{1}{2}$ inches wide by 30 inches deep, and giving a sectional area of 255 square inches. These pieces are made to break joint at every 6 feet. Timber arches have not unfrequently been built of pieces 6 inches square; but they are very rarely constructed of laminated 3-inch planks in the manner formerly practised in England. The thicker pieces are found to be a convenient size, and are considered preferable, as there are fewer joints by which water can penetrate. Care is always taken that they break joint in the most approved method. The sectional area of the arches is, therefore, $6 \times 8\frac{1}{2}'' \times 30'' = 1,530$ square inches. The main braces are 8 inches by 10 inches; the counter-braces being 8 inches by 8 inches. The width of each panel is about 10 feet 3 inches, and the vertical tie-rods are $1\frac{1}{2}$ inch diameter.

Referring to this bridge, Mr. G. A. Nicolls, the Chief Engineer of the Railway, states that "it is composed of a combination of the Howe truss and arch, and is susceptible of having the strain borne by each, either exactly equalised, or as much thrown upon either

truss as may be desirable. . . . No other combination of bridge possesses the strength and efficiency of this plan. We have had loaded coal-waggons, which got off the rails on a grade above this bridge, in a train weighing 700 tons, brought up, all standing, inside the bridge after knocking out, or breaking, several of the main braces of the Howe truss, thus leaving the whole bridge and train suspended by, and depending upon, the arch alone, while trains were passing on the other line of rails."

As before remarked, this bridge affords an excellent example of a timber structure subject to very heavy loads; for the coal traffic which passes over it is unusually large, amounting to fully $1\frac{3}{4}$ million tons per annum, or more than 5,000 tons daily, besides the ordinary passenger and goods trains.

It appears, by calculation, that the strength of this bridge is considerably in excess of what may be deemed necessary. For, supposing the bridge to be covered on both lines with locomotives, or say 3 tons per lineal foot equally distributed, including the weight of the structure itself, then if the load be borne equally by the upper chords and the arches, the compressive strain on the former is 292 lbs., and on the latter 237 lbs. per square inch; and supposing the load to be sustained by the arches alone, the pressure, even then, only amounts to 468 lbs. per square inch, while practically the bridge is never likely to be loaded to this extent. About 900 lbs. per square inch is usually considered by American Engineers to be the limit of safe compression on timber framing.

The following are approximate quantities of the materials in this bridge, exclusive of the roof. Timber 10,554 cubic feet; wrought iron 22 tons, and cast iron 7 tons; or, per lineal foot of bridge, 58 cubic feet of timber, 270 lbs. of wrought iron, and 76 lbs. of cast iron: the total weight being a little over one ton per lineal foot. The cost of this bridge, for a double line, with three trusses, "exclusive of the masonry and roof, but including all materials, timber, iron, castings, kyanizing, mechanical work and erection, while the full business of the railway was passing at the same time, amounted to £1,868, or £10. 3s. per lineal foot. Under ordinary circumstances it is believed the bridge could have been put up for £100 less, as the passage of numerous trains interfered greatly with the workmen."

These bridges are usually built with about 12 inches of camber, and as regards deflection, Mr. Nicolls states "that a well-built timber bridge in America would not settle more than $\frac{1}{4}$ or $\frac{1}{8}$ inch under a heavy engine and train;" and that "on the Philadelphia and Reading Railway one of these bridges settles only $\frac{1}{4}$ inch under an engine of 28 tons hauling a train weighing 0.64 ton per lineal foot." The Author presumes this deflection was measured shortly after the bridge had been erected; for heavy trains, and

the decay of the timber at the joints, tell upon these structures so much, that they soon deflect, and do not last in good condition more than from twelve to fifteen years. This heavy wear and tear results, in a great measure, from the unseasoned state of the timber when it is framed. It is generally very difficult to get seasoned timber anywhere in America, and much more so on a railway; and timber put into framing green from the woods, say within two, or three months after being cut, cannot be expected to stand. To obviate the effects of the shrinkage, which will necessarily take place, much greater care and attention are requisite, than are generally bestowed; so that these causes combined, readily account for the short duration of timber bridges. It is the custom to cover these structures with a roof, and to close in the sides with boarding 1 inch thick; and when thus protected from the weather and cared for—any shrinkage of the braces being immediately remedied—it is believed these bridges will remain in good condition double the usual time, or about twenty-five years.

There are, on the other hand, Engineers in the United States, who do not approve of the arch in combination with the truss. They hold that a structure composed of two systems, neither of which is strong enough by itself, is defective in principle, and they state it to be very difficult, if not impossible, so to proportion the weight upon each system, as to make each bear its proper share. Practically the best mode of obtaining this combined action, seems to be, the removal of the scaffolding before the suspension-rods from the arches are secured to the joists, and then by tightening these rods to make the truss rise slightly. These Engineers are of opinion, that the better plan is to follow one system; either to place in the truss the material used in the arch, thus making the truss sufficiently strong by itself, or to depend entirely upon the arch, and use a light truss merely to stiffen the roadway. There is also a minor objection to the combination, viz. that in a climate varying 150° in temperature, the rods which suspend the roadway from the arch, being of unequal lengths, will expand and contract considerably and unequally, and thus give much trouble in keeping them somewhat, not to say uniformly, adjusted. The arched bridge has likewise the disadvantage of requiring the piers to contain at least twice the quantity of masonry which would be sufficient for a truss bridge, having no horizontal thrust.

The piers of American truss bridges are generally well built, of solid granite ashlar masonry, but they are remarkably slight. When from 60 feet to 80 feet in height, the piers are usually 5 feet thick at the top, but many are only 4 feet thick. They are generally built with a batter of $\frac{1}{2}$ inch to the foot at the sides, and ordinarily stand well. Granite being abundant in all the Eastern States, brick piers are comparatively rarely built. On a railway in Vir-

ginia, on which the Author was engaged, a viaduct 2,000 feet in length and averaging 80 feet in height, was carried on brick piers of the following dimensions, built hollow, and not filled with concrete, but having a centre cross wall :—Height 80 feet, width of the pier at the bottom 26 feet 8 inches, and at the top 20 feet. The external breadth at the bottom was 13 feet 8 inches, and at the top 7 feet. The thickness of the walls at the bottom was, two walls each 3 feet 4 inches, making 6 feet 8 inches, and at the top, two walls each 2 feet 4 inches, making 4 feet 8 inches. For 8 feet below the top of the pier, the brickwork was solid, so as to receive and distribute the concussion caused by the trains. These piers are said to have stood satisfactorily.

With reference to the great height of some timber piers, it may be interesting to mention, that on the Buffalo and New York Railway, a truss bridge has been erected across the Genesee River, supported on trestles of timber framing 190 feet high, the total height from the bed of the river to the rails being 234 feet. This viaduct is 800 feet long, and has nine piers each about 190 feet in height. It was commenced in July 1851, and was finished in August 1852. It is still in use, and has never failed in any particular, except by the natural decay of the timber, which is so framed without mortices, or tenons, that any decayed pieces can be easily replaced. This work contains,—timber 133,500 cubic feet ; ironwork, bolts, &c. 108,862 lbs. ; masonry in cement, 9,200 cubic yards.

Timber-bridge building has become an especial branch of Engineering in the United States, and there are several firms who devote their whole time to this subject. The large number of bridges required for 30,000 miles of railway has necessarily given great field for experience, and many designs having been tried, the plan of bridge now the most general, becomes of course the more valuable. Of the firms alluded to, one of the most eminent is that of Mr. D. C. McCallum, an Engineer of high standing, who was for several years the manager of the New York and Erie Railway, a length of 460 miles, exclusive of branches. The INFLEXIBLE ARCHED TRUSS being now probably in more general use than any other bridge, Mr. McCallum has, at the request of the Author, furnished the plans shown in Plate 6, Figs. 3 and 4. The Author would remark, in passing, that he believes the first mention of this bridge, and of Mr. McCallum's admirable system of working trains by the electric telegraph, will be found in Captain Galton's Report on the Railways of the United States.¹

Plate 6, Fig. 3, is a railway bridge, for a single line, 200 feet span ; several of which have been erected in the States of New

¹ Vide "Report on the Railways of the United States." By Captain Douglas Galton, R.E. Folio. London. 1857.

York, Ohio, and Mississippi. The principal dimensions are : length, 210 feet ; span, 200 feet ; depth of the truss in the centre, 26 feet, and at the ends, 21 feet. The arched top has two pieces, 7 inches by 11 inches, one piece 16 inches by 11 inches, and one piece, 7 inches by 11 inches, together giving a sectional area of 407 square inches, or for both sides, of 814 square inches. The bottom chord is composed of four pieces, each 7 inches by 14 inches, but which only afford an available clear sectional area, excluding notches and scarfs, of 234 square inches, or 468 square inches for both sides. The main braces, which project 32 feet from the pier, are each 11 inches by 16 inches, and give a sectional area of 704 square inches on each side. The posts, of which there is a double row, inserted between the chords, vary from 9 inches by 13 inches at the abutments to 9 inches by 6 inches at the centre. The counter-braces are 9 inches by 6 inches throughout.

It is desired to direct special attention to the manner in which the bottom chords are scarfed, by long splicing pieces and by combination keys, let 1 inch into each chord, at every 4 feet, or 5 feet, and by numerous bolts, so as to prevent them, as much as possible, from stretching. It will also be noticed, that the spur-arch braces transfer the load directly on to the abutments ; therefore the braces at the ends of the bridge are relieved from a large portion of the strain which would otherwise fall upon them, and the span becomes practically reduced, so far as the strain on the truss is concerned, to 136 feet. This bridge contains 7,360 cubic feet of timber, 6,958 lbs. of wrought iron, and 5,997 lbs. of cast iron. It cost, including erection and every expense, £5. 4s. per lineal foot ; the rough timber being taken at one shilling per cubic foot, delivered on the site of the work. The total weight, including the permanent way, is 109 tons. When loaded with 205 tons in addition, or say 314 tons equally distributed, the pressure on the arched top will be 862 lbs. per square inch, and the tension on the bottom chords will amount to 1,500 lbs. per square inch.

Mr. McCallum has informed the Author, that this bridge, when loaded with locomotives and tenders, the whole weighing 195 tons, "or very nearly one ton per lineal foot, deflected about $\frac{3}{4}$ of an inch previous to any adjustment of the counter-braces ; that while the load was upon the bridge, the counter-braces were screwed down, and when the load was removed, the structure rose slightly, due to the compression of the counter-braces, but leaving a permanent deflection caused by their action of nearly $\frac{3}{8}$ of an inch." In the calculation as to strains, "the strength has been considered as a truss simply, without taking into account the arch brace system, which of itself is sufficient to sustain both the bridge and the load."

As bearing on this point, Mr. Gardner, the Superintendent of Bridges on the Ohio and Mississippi Railway, states that "on the

12th of March, 1858, an engine was thrown off the rails 100 yards distant from a McCallum bridge of 94 feet span. The train was running at high speed, and before it could be stopped, the engine had reached the centre of the bridge with all its wheels off the rails, and upon it were piled, one baggage van and two passenger carriages. The concussion broke the lower chords of both trusses of the bridge, together with six posts, twelve braces, and thirty floor beams. The engine, after having passed through the floor timbers, was arrested in its course by coming in contact with the longitudinal rail pieces and the lateral rods. The lower chords being broken, the whole train was prevented from falling into the stream, by the sustaining power of the arch and arch braces alone."

It will be remembered that a similar accident, exhibiting the strength of the arch, has been previously mentioned respecting the Improved Howe Truss,¹ which formed the last example; and that the deflections of both these bridges were not only very slight, but were nearly identical.

In Appleton's 'Mechanics' Magazine and Engineers' Journal,' 1st April, 1852,² it is stated that, on the 29th January of that year, a McCallum bridge, 190 feet span, built over the Susquehanna River, was tested by a number of engineers and bridge-builders, by running from one to four locomotive engines and tenders over it at different rates of speeds. "Upon placing, first, one engine and tender upon the centre of the bridge, and noting the deflection; then bringing on successively the second, third, and fourth, and arranging them as near the centre of the bridge as possible, the deflections were found to be as follows:—

	Gross Weight.	Deflection in Feet.
One engine and tender . .	37 tons	0·02
Two " " . .	85 "	0·04
Three " " . .	125 "	0·06
Four " " . .	167 "	0·06

"On removing these engines from the bridge, it was found that the truss had entirely resumed its original level, showing that the elasticity of the timbers was unimpaired." Referring to this bridge, Mr. Post, Chief Engineer of the New York and Erie Railroad, stated, in a letter dated May 15th, 1858,³ that it had "been in use nearly seven years, without having cost one cent for watchmen, adjustment, or repairs, except a coat of paint last year, and

¹ *Vide ante*, p. 309.

² *Vide* "McCallum's Inflexible Arched Trust Bridge." Explained and Illustrated. By D. McCallum. Tract 8vo. Plate and Cuts. New York. 1859. Page 41 *et seq.*

³ *Ibid.* p. 46.

is now in perfect condition." Mr. Post also states, that there are on that railway one hundred McCallum bridges, on the aggregate nearly 3 miles in length, subject to passenger trains of 100 tons, at speeds of from 25 to 50 miles per hour; that the average weight of the goods trains passing over these bridges is 262 tons, at speeds of from 15 to 20 miles per hour; and that there are about ten trains of each class daily, besides those employed in ballasting, moving wood, and the other supplies of the railway. As regards the durability and economy of these bridges, Mr. Post speaks of them in the highest terms, preferring them to "any other in use for railroad purposes."

The Author is informed by Mr. McCallum, that "there are at present nearly 15 miles in length of these bridges upon different railways, in spans varying from 30 feet to 260 feet in the clear, and in no case have they been so unfortunate as to have a failure." The spans of 260 feet here referred to, the largest yet constructed on this principle, are those built on the New York and Erie Railway, over the Delaware River; but Mr. McCallum expressed to the Author, a few months back, his entire confidence in erecting similar spans of 300 feet in the clear.

Plate 6, Fig. 4, is a design for a railway swing bridge, having two openings of 150 feet each, to be erected over the Mississippi River at Clinton, in Ohio. Several railway swing bridges, with spans of 120 feet each, have been already constructed on a similar plan, with complete success; and although, owing to the present condition of America, the particular bridge in question has not yet been erected, Mr. McCallum, from previous experience, has perfect confidence in its feasibility. The principal dimensions are—length, 335 feet; length over turntable, 30 feet, and diameter of turntable, 29 feet; clear span of each opening, 150 feet; depth of the truss at the centre 34 feet, and at the ends 10 feet. The arched top is composed of four pieces, each $6\frac{1}{2}$ inches by 10 inches, giving a sectional area of 260 square inches on each side. There are also three pieces of straining beams, about 8 inches square, which extend in different lengths from the centre towards the ends, to strengthen the top when the bridge is open. The principal spur braces, 8 inches by 14 inches, extend on both sides, about 80 feet from the turntable. It will also be noticed, that in addition to the ordinary posts and diagonals, this system of spur bracing pervades the whole structure. The bottom chord is formed of four pieces, each $6\frac{1}{2}$ inches by 12 inches, scarfed and stiffened by combination keys and numerous bolts, the sectional area being 312 square inches on each side. The quantity of timber in this bridge is about 12,600 cubic feet, of wrought iron, 18,973 lbs.; and of cast iron, 17,845 lbs. The total weight may be taken at 200 tons, or, not including the central portion, 90 tons for each span. If to this weight a load of

1 ton per lineal foot be added, making 240 tons equally distributed over each opening, the strains will be—

On the arched top, compression, 808 lbs. per square inch.

On the lower chord, tension, 1,077 lbs. „

When the bridge is swinging open, there will be,—

On the arched top, tension, 1,218 lbs. per square inch.

On the lower chord, compression, 609 lbs. „

In the above and previous calculations respecting the bridge shown in Fig. 3, which are quite independent of the spur brace system, the tension has been taken on the available sectional area of the bottom chord; in other words, usually on the area of three of the chord pieces instead of four, as one of these pieces having a joint in every panel is seldom included in such estimates. If the spur braces should take the whole of the weight of this bridge when open, they would be subject to a strain of from 600 lbs. to 700 lbs. per square inch. In order to prevent any sinking of this bridge at the ends, the truss can be adjusted by means of the counter-braces, and provision is also made to bring the spur braces into action, so as to obviate that tendency. The bridge swings on a turntable 29 feet in diameter, and it is said will require only two men to turn it. The cost of this structure, including the turntable and erection, will be about £10 per lineal foot.

With reference to the deflection of railway timber bridges after several years' use, Mr. McCallum informs the Author that, "the earlier bridges were constructed of timber in every condition, from perfectly green, or wet to nearly seasoned; that spans from 150 to 200 feet were cambered in the chord from 6 inches to 10 inches according to the state of the timber; and that very few, if any, of the bridges have deflected below a straight line."

Plate 6, Fig. 5, is a McCallum common road bridge of 150 feet span,—a dimension in more general use than any other. This design is similar in principle to that shown in Fig. 3, though built with only a single row of posts, and with timbers of light scantling. The following are its principal dimensions, length, 155 feet; span, 150 feet; width in the clear, 20 feet; depth of the truss at the centre, 20 feet 6 inches, and at the ends, 16 feet 6 inches. The arched top is composed of two pieces 7 inches by 10 inches, and of two pieces, 6 inches by 8 inches, giving a sectional area of 236 square inches. In the bottom chord, there are two pieces 7 inches by 12 inches, making a sectional area of 168 square inches on each side. The braces are 8 inches by 10 inches at the abutments, and 6 inches by 10 inches in the centre. Taking the weight and load of this bridge to amount to 1 ton per lineal foot, the strains will be, on the arched top, with a sectional area of 472 square inches, 685 lbs. per square inch;

on the bottom chord, with a sectional area of 336 square inches, 961 lbs. per square inch. The quantity of timber is 23 cubic feet per lineal foot; and the entire cost of the bridge, including erection, amounts to only £3. 2s. 6d. per lineal foot, the rough timber on the ground being estimated at ninepence per cubic foot.

Plate 6, Fig. 6, is a simple adaptation of the Howe Truss to roofs of considerable span, a very common construction in the United States. The span of this roof, erected at the Dunkirk Station of the New York and Erie Railway, is 80 feet, though similar roofs are frequently found of greater width. The top and bottom chords are formed of the following scantlings:—two pieces, each 5 inches by 7 inches, giving a sectional area of 70 square inches; and one piece 6 inches by 7 inches, with a sectional area of 42 inches, together amounting to 112 square inches. The braces diminish from 5 inches by 7 inches at the walls, to 5 inches by 4½ inches at the centre. The counter-braces, 5 inches by 3 inches, remain the same throughout. This roof is chiefly remarkable for the lightness of the scantlings, only two pieces of timber being as large as 6 inches by 7 inches, and most of them being about 5 inches by 7 inches. A principal of this roof contains 280 cubic feet, and at the ordinary price for timber framing, would cost, including erection, about £35.

In concluding this slight sketch of American Timber Bridges, the Author feels it to be unnecessary to go more into details, even if the limits of a single Paper did not preclude his doing so. He avails himself of this opportunity to record his best acknowledgments to American Engineers, for the courtesy they have invariably shown, in taking him over their works, and in affording him every information and assistance in their power.

The Author believes that these bridges have been accurately designed in proportion to the strains coming on the timbers in the several parts; but whatever may be their merits, or their faults, they have produced good practical results and will bear investigation. This Paper is presented in the hope that these specimens of timber work, the result of many years' experience, and the adaptation of the only available resources of a new and comparatively poor country, may be found interesting to the Members of the Institution of Civil Engineers.

The Paper is accompanied by three drawings, from which Plate 6 has been compiled.

[Mr. ZERAH COLBURN

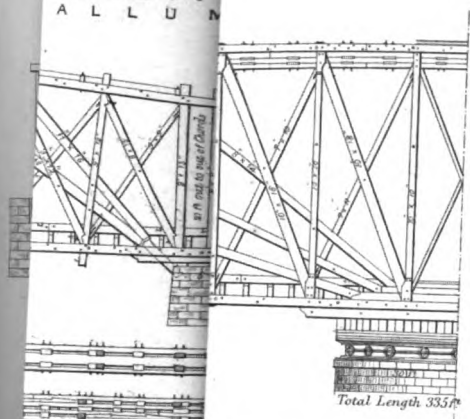
Mr. ZERAH COLBURN thought the Paper gave a very complete account of the construction of American Timber Bridges, but it hardly contained sufficient information to lead to a correct judgment as to the relative merits of timber and of iron. Timber had been almost exclusively used in the States, for railway bridges, chiefly because iron was beyond the means of the Railway Companies, and partly, no doubt, because its application was not so well understood. American Engineers had perhaps made a virtue of necessity, but Mr. Colburn thought there were but very few among them who would not prefer iron, or stone to the best timber bridges ever built. Whatever form of truss was employed, timber bridges were very perishable, and they were always liable to destruction by fire. The Report, for 1857, of the chief Engineer of the Pennsylvania Central Railroad, contained the following remarks :—

"The bridges have all undergone a thorough examination, and many of them found to be much decayed. This examination leads to the conclusion, that about nine years is as much as can be calculated upon for the duration of an uncovered wooden superstructure; and when the liability to fire and the expense of watching are taken into consideration, shows most conclusively that economy, as well as safety, is in favour of iron structures."

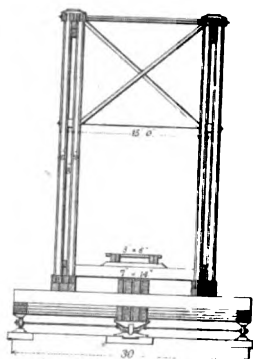
The following classification of bridges was given by Mr. Post, formerly chief Engineer of the New York and Erie Railroad, one of the most important lines in the States, in his Report on that line for 1857 :—

"A represents bridges of the first class on this, or any other railroad. Their superstructures, composed principally of white pine, white oak, and iron, have been constructed in the most substantial manner from the best materials, and remain in every way sound and in perfect condition. When first put together, the joints were thoroughly inlaid with white lead and oil paint, and as soon afterwards as the timber became perfectly seasoned, their external surfaces were well painted, the season checks cemented, and other exposed points protected, so that the timber is almost completely secured from the effects of the weather and preserved from premature decay. If kept properly painted, these bridges will, unquestionably, with very little other repair, perform their offices well, and with perfect safety, for twenty years, or more. B represents bridges of the second class on this road. They were built of inferior timber, with little, or no mechanical skill, and are, generally, of too slight proportions to be of long duration. The greater number of them have been supported with 'bents' from the beds of the streams, &c., or strengthened by other expedients. They may probably be made to last, from the time they were built, about fifteen years. C represents bridges of the third class on this road. They are built of inferior timber, but are generally of good workmanship. Their most general defect is the weakness of their lower chords, which were not made up with strength enough to resist the tensile strain to which they have been subjected. With but a single exception, these bridges have failed, so as to require supports beneath, or to be strengthened by applying additional thickness of timber to the chords. There have been already expended, for repairs on these bridges, from five to six and a

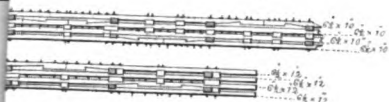
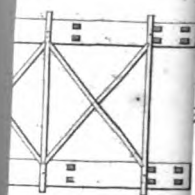




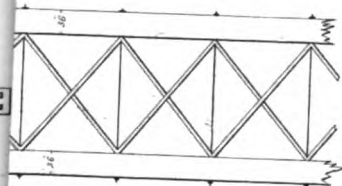
Total Length 335 ft



SECTION AT CENTRE.

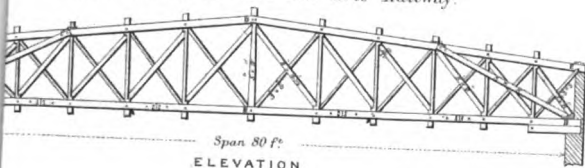


BRACING.

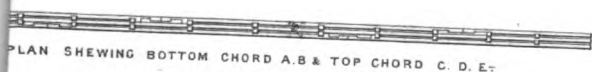


BRACING.

Fig. 6.
HOWE TRUSS ROOF
Dunkirk Station, New York and Erie Railway.



ELEVATION.



PLAN SHEWING BOTTOM CHORD A.B. & TOP CHORD C.D. E.

75 FEET

half dollars per lineal foot, and many of them require renewal this year. The average wear will not probably exceed ten years. E represents bridges of the fourth class, or trestle bridges. They cost, aside from their foundation masonry, about eight dollars per lineal foot for single track, and will give about six years' service with small repairs—say at an average cost of twenty-five cents per foot per annum. Many of these have already been renewed. D represents bridges of the fifth class, or stringer bridges. They cost, independent of their masonry, about five dollars per lineal foot, and will last altogether about eight years. Many of them have been renewed."

Mr. Colburn stated that the New York and Erie Railroad Company was then expending £9,000 yearly in the repairs of timber bridges, exclusive of costly renewals. As an instance of what these renewals sometimes were, might be mentioned the Cascade Bridge, a timber arch of 276 feet clear span over a ravine 185 feet deep. This bridge was put up in 1848, and cost £9,000. In 1860, from fears of the failure of the bridge, the line was diverted so as to cross the stream higher up, and on an embankment over a stone culvert. The cost of this deviation was £21,000. The bridge was taken down immediately afterwards, and many of the timbers were found to be in a rotten state. Indeed timber bridges were always rotting. In 1858 a short bridge broke down under a passenger train on the New York Central Railroad, and nine passengers were killed. It was found that some of the timbers were so decayed that a walking-stick could be pushed through them. In 1860 a bridge broke down on the Albany Northern Railroad, and a number of passengers were killed. In this case, too, the timbers were much decayed. A bridge broke down about the same time on the Great Falls and Conway Railroad, in New Hampshire, and some time previously a large railroad bridge fell near Easton, Pennsylvania. One of the railway papers, the 'American Railway Times,' had a leading article, stating that there were great numbers of railway bridges just as unsound as the Great Falls Bridge and the Albany Northern Bridge. The article stated, that the editor could name ten bridges which were likely to fall in a fortnight, twenty bridges which might come down any time within six months, and forty bridges which were not safe for more than a year. Mr. Colburn could not say whether any of these bridges had yet broken down, but he had just received a copy of the 'American Railway Times,' from which he read the following extract:—

"On Monday, December 1st, the Howe Truss Bridge over the West Fork of White Lick Creek, gave way while a freight train was passing, and a portion of the train fell with it, killing a brakeman, Isaac Pratt, and a stranger, who was standing on the east abutment. The bridge had been well protected from the weather, and the timbers were all sound. Every precaution had been taken to guard against such an accident."

In very many cases American bridges were built of unseasoned

timber, and they were not always painted. There was sometimes a deficiency of skill in the distribution of the material. The top and bottom chords, and also the diagonals, were often of the same scantling all the way through, even for large spans. Besides the decay of the timbers, the joints worked loose after a time, and in this way timber bridges finally became very shaky. Mr. Colburn believed this was the case with the very best forms of truss, and the inferior kinds began to go very soon. There was a large lattice bridge of nineteen spans of 153 feet each, and nearly 100 feet high, over the James River, at Richmond, Virginia. This was erected about the year 1835, and when Mr. Colburn was living in Richmond, eleven years ago, it was considered to be very weak, even for light trains crossing at a slow speed. Mr. Colburn was connected with locomotive works there, and the Railway Company objected to their heavy engines being taken over the bridge when they were being sent southwards. It was a rule, on most American railways, to cross long timber bridges at a slow speed, and on highway bridges there was almost always a notice, that a fine of five dollars would be imposed for driving a horse over faster than a walking pace.

Fires were very frequent among timber bridges. Mr. Colburn could mention a dozen within his own recollection. The White River Bridge across the Connecticut River, about twelve years ago,—the Coosa River Bridge on the Alabama and Tennessee Railroad, about eight years ago,—the Mohawk Bridge on the New York Central Railroad,—the Orwigsburg Bridge on the Reading Railroad,—the Salmon Falls Bridge on the Boston and Maine Railroad,—the Valley Creek Bridge on the Philadelphia and Columbia Railroad (the first bridge was built here in 1837, and the third was now standing on the same site),—the Lackawaxen Bridge on the New York and Erie Railroad,—the Conewago Bridge on the Lancaster and Harrisburgh Railroad (the first bridge was built here in 1837, and the fourth was now standing), besides bridges on the Pittsburgh, Fort Wayne, and Chicago Railroad, the railway bridge over the Middlesex Canal at Lowell, and others. A roadway bridge over the Schuylkill River, at Philadelphia, a single span of 340 feet, and one of the best examples of this class of construction, was also burnt.

All long bridges required watchmen, generally day and night. The Baltimore and Ohio Railroad paid £1,600 yearly for watching bridges. Large tubs of water were kept on the bridges, the water being saturated with salt, to prevent its freezing in winter. There were cases of incendiary fires. Many attempts had been made to burn the great bridge across the Mississippi River at Rock Island. The Michigan Central Railroad had several bridges burnt at one time. Since the beginning of the present

war many bridges, of course, had been destroyed, and chiefly by fire.

Mr. Colburn then gave the cost of a number of American timber bridges, as follows:—The Bedford Bridge, on the Cleveland and Pittsburgh Railroad, a Howe bridge with an arch, had a clear span of 243 feet, was for a single line, and was 20 feet high: it cost 30 dollars per foot. A single line, Howe span of 230 feet, without an arch, and 24 feet high in the truss, erected, in 1853, on the Rochester and Lockport (now part of the New York Central) Railroad, cost 35 dollars per foot. A Howe bridge without an arch, of 250 feet clear span, on the Washington county road, in Texas, cost 60 dollars per foot. An arched Howe bridge over the Connecticut River at Bellows Falls, having two spans, each 250 feet in the clear and 23 feet high, cost 35 dollars per foot. The bridge over the Mississippi River at Rock Island had five spans of 250 feet each, and three spans of 150 feet. The wider spans cost 52 dollars per foot; the spans being Howe's truss, with arches, and the timbers all planed. The Miami Bridge on the Ohio and Mississippi Railroad had six spans of McCallum's truss, each 210 feet, and cost 33 dollars per foot for a single line. The Delaware Bridge on the New York and Erie Railroad had two of McCallum's spans of 262 feet each, and cost 42 dollars per foot. The Susquehanna Bridge on the same line, with 188 feet spans, cost 35 dollars per foot. The Clinton Bridge on the Galena and Chicago Railroad had seven McCallum spans of 200 feet, and cost 28 dollars per foot.

Mr. C. H. GREGORY, V. P., considered that the remarks of Mr. Colburn tended to confirm the prices given by Mr. Mosse for the constructions described in the Paper. Of course the cost would vary according to the character of the work, the locality, and the convenience of transport of the timber. Mr. Mosse's opinion of the durability of these bridges was not inconsistent with what had just been stated; for the Paper no doubt alluded to bridges which had been well and carefully constructed: but when roughly executed, of inferior materials, such bridges could not be expected to be durable. The Paper would be a valuable addition to the records of the Institution, as affording instances of the most approved forms of timber bridges, derived from the large experience which had been gained in those parts of America where timber was readily obtained, and where other circumstances had led to its extensive employment on public works. Of course English Engineers preferred, if possible, using the most permanent materials; but there might be circumstances where a limited amount of capital, or a high rate of interest for money, might render it more economical to put up a cheap and temporary structure, to be renewed in a certain number of years. Any English

[1862-63. N.S.]

Engineer who had travelled in America, would agree with the remark, that many of the timber-trussed bridges were not put together in a way to answer the description which had been given of the well-executed structures referred to in the Paper, and he would observe that a cheap and rough description of work was not limited to timber bridges, but that it extended to the permanent way of railways, in which it was no uncommon circumstance to find ballast entirely omitted in the first construction : and although there might be rules for limiting the speed of the trains in passing timber bridges, his own experience was that the general custom was to travel without checking the speed, even over timber bridges of very doubtful security.

He agreed that one great fault in the timber bridges used in America was their liability to destruction by fire. Numerous instances of such destruction had come to his knowledge when travelling in Canada and the Northern States of America ; and although he had not seen many watchmen in charge of timber bridges, he had noticed the evidence of contemplated risk in the frequent presence of water-tanks near the bridges. This risk of fire was perhaps in America the most serious objection to the use of these large timber bridges ; and it was difficult to estimate the evils which might arise, either through loss of life consequent on the destruction of a bridge by fire, or the unavoidable and serious interruption of traffic, after a bridge had been so destroyed. In 1857 he had examined and reported on the Grand Trunk Railway of Canada, where the bridges executed by the Company were all of a character as permanent as those of an English railway, but on the line between the Atlantic and the St. Lawrence, which had come into the Company's possession, the numerous large river bridges were almost invariably of one, or other of the forms which had been described ; and having reference to all the circumstances of the case, to the increased facility in the introduction of iron, and to the fact that a large number of these bridges, however good in design, had not been executed with that care which was essential to make them safe structures, and considering also the great risk of fire during the hot and dry summers of that country, he had thought it his duty to recommend, in every case, the substitution of wrought-iron girder bridges, at the earliest possible period.

At the same time he thought Engineers were too apt to look upon structures of wrought-iron as being of an absolutely permanent character. There was always a deteriorating action going on in them to a greater, or less extent ; and where box girders were used, or any structure not of the simplest form, and perfectly accessible for repair, and for protecting all parts, by paint, from atmospheric influences, this deteriorating action might, in a few years, reduce to a most temporary character, and even to a dan-

gerous condition, some bridges which were considered as being necessarily durable, because they were made of iron: and whilst many wrought-iron bridges were undoubtedly monuments of genius, ability, and courage, he thought the time would come when, if wrought-iron bridges were not looked upon as being 'pro tanto' as temporary as wooden ones, they would not be adopted by English Engineers, in some of their present forms, so generally as was now the case.

Mr. A. S. ORMSBY stated, that he had been informed by the President of the Richmond and Petersburg Railway, that the expense of the insurance of the bridges on that line, which were all of wood, amounted to 15 per cent. upon the cost of each bridge.

Mr. COCKBURN CURTIS observed, that when employed upon railways in Spain he had some opportunity of witnessing the great expense, annoyance, inconvenience, and interruption to the traffic, which arose from the employment of timber bridges and viaducts. To effect a saving of first cost, many of the bridges of the lines, in the central portion of Spain, had been constructed of timber. But the subsequent outlay for repairs and renewals certainly could not have been less than that stated by Mr. Zerah Colburn in reference to the American lines. Another drawback to their employment in Spain was their liability to be burnt in the pronunciamientos and insurrections, to which that country, unhappily, seemed chronically liable. While Mr. Curtis was in Spain the large bridge across the River Turia, near Valencia, had been so destroyed, and owing to the cost and danger of using timber, the leading lessees and empresarios of the main lines, in the central portion of Spain, had determined upon substituting iron girders for the original timber structures.

Mr. SHEILDS thought some additional information was required as to the details of construction. Every one dealing with framing, whether of wood, or iron, knew that the method of joining the separate pieces, or parts together was the most critical point to be considered in the design. He had known failures occur from a bolt, passing through two timbers, tearing a piece of its own width out of the end of the wood, and from other causes, while the middle part of the timber was generally secure. Some details as to these points would therefore be valuable to those who had to use framings of timber, or of iron and timber in combination, and he was rather disappointed at not finding them fully given in the Paper. The whole of the structures which had been described, appeared to have been designed upon the principle of diminishing the strain upon the top and bottom, by using framings of very great depth; and this principle seemed to be carried to such an extent as to make them top heavy, and he thought it was alto-

gether a form of construction which Engineers in this country would scarcely venture upon. The only other point was as to the cost. The first cost per lineal foot appeared to be from one-half to two-thirds of the cost of wrought-iron bridges in this country: and there was no doubt, looking at it in a commercial point of view, and even irrespective of the danger from fire and other such circumstances, that the balance of economy would be much in favour of iron structures, owing to the want of durability in the timber bridges, and the heavy outlay required for their maintenance.

Mr. A. GILES said, there was one point which had not been touched upon, viz., the difficulty of repairing wooden bridges of large span, on single lines, without stopping the traffic. In case of fire the stoppage of the traffic was inevitable. This was one of the principal objections to wooden bridges: another was the expense of watching. He had examined and reported on a line in Canada which had nearly 4 miles of wooden bridges, and which cost for watching above £2,000 a-year; yet even that was not always effectual. He had recommended the large spans to be reduced, wherever it was practicable, so that in case of accident or decay, the renewal of the bridge could be more easily executed.

Captain MOORSOM said, that after what had fallen from the previous speakers relative to wooden bridges in America, the journey to Plymouth ought to be regarded as wilful seeking of danger, on account of the numerous timber structures on the line; yet he had to go very frequently over it, and he had done so in safety for many years past: and going further on into Cornwall, such structures were even more numerous than in Devonshire, over which many thousands of passengers had passed in safety. He therefore thought the experience of these structures in England was not so generally adverse to them as appeared to be the case in America.

He exhibited a sketch, by one of his assistants, of a lattice bridge of 90 feet, or 100 feet span, which had been built under his direction between 1837 and 1840. On the Birmingham and Gloucester Railway he had erected at least a dozen of those bridges. Having left that line, and not being interested in the maintenance of it, he took no trouble to inquire about these bridges till the year 1854, when they had been at least fourteen, or fifteen years in use. He then wrote to the Resident Engineer to know what had been the cost of repairs, and the answer was that the Company had been at no expense, except that of repainting them from time to time. The timber in all those bridges had however been subjected to some preservative process. So far, therefore, as he might quote that experience, these bridges might be used with advantage in certain cases. This description

of bridge had been erected by him usually on common roads, where economy was necessary, as the traffic was but small, and also in localities where they might be dispensed with hereafter at the fancy of the landowner. He thought in such cases the timber lattice bridge might be adopted with advantage. Mr. Mallet had erected for him a large lattice bridge in 1847 at Thomastown, over the River Nore,¹ and he believed it was still standing, without objection having been made against it. He would therefore express his decided conviction, contrary to the opinion of those who had spoken of the destructibility of the American bridges, that if timber bridges, and especially lattice bridges, were properly constructed, as they had been in this country, they might be adopted in many cases with perfect safety, and with great advantage in point of economy. Captain Moorsom added that he had found one great advantage of the lattice bridge to consist in the facility for repairs, and that he should have no difficulty in repairing a lattice bridge with a single track, while the trains were passing, provided it was of the ordinary character.

Mr. MALLET said the Paper did not give any information, as to the particular sort and quality of timber used in these structures in America. Practical men knew that there were three important elements which chiefly determined the durability of any timber bridge;—the quality of the timber, the way in which it was put together, especially the extent to which the joints were water tight, and the climate to which it was exposed. He was rather surprised at the very short life assigned to American timber bridges by Mr. Colburn, whose facts were nevertheless, he did not doubt, worthy of full acceptance in point of accuracy. It must, however, be borne in mind, that the climate of North America tried timber very severely; in addition to which he suspected, that the timber used was probably unseasoned, and not in all cases of the best quality. Upon these points, and whether due regard had been paid to the exclusion of moisture lodging between the opposing surfaces, he should deem it very desirable to have further information. The large annual expense for repairs and the short durability mentioned, did not quite coincide with European experience of wooden bridges. In the east of Germany, for example, it was well known that there were many wooden bridges, whose durability had been so great, that they were now actually objects of antiquity. The original bridge of Schaffhausen had stood, he believed, for more than forty years, before it was burnt by the French. The Germans and the Swiss, however, employed excellent timber, and they well understood how to put it together. In the case of the River Nore Viaduct, on the Waterford and Kil-

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xi., pp. 426-434.*

kenny Railway, alluded to by Captain Moorsom, Mr. Mallet's firm had been the contractors for the erection of that structure; the timber used was of admirable quality, the wales being pitch pine and the lattice bars choice crown memel. That viaduct was still standing, and was, he believed, sound, after being in use for fifteen years. He had passed over it last year, and it appeared to stand well. He had heard, however, that since Captain Moorsom had ceased to have charge of the line, piles and struts had been put in, forming a centre pier, and dividing the original long span of 200 feet into two spans of 100 feet each nearly. This appeared to him to be perfectly unnecessary—though it was only another example of a case that too frequently occurred, in which advice given by a second Engineer subsequent to the completion of a work by his predecessor, was based upon an assertion of original insufficiency.

February 24, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,088.—“On the Reconstruction of the Dinting and the Mottram Viaducts.” By WILLIAM FAIRBAIRN, F.R.S., M. Inst. C.E.

IN the early period of railways, the passage of rivers and deep ravines was frequently effected, to save expense, by timber viaducts and bridges, instead of by more substantial structures of stone, brick, or iron. This has been demonstrated, by experience, to be a mistaken economy; and although, with a limited capital, the Engineer has to adopt measures in accordance with his means, yet at the present time, considering the facilities afforded by wrought iron, there does not appear to exist any inducement for the introduction of a perishable material into structures intended to be of a permanent character. Previous to the application of wrought iron, in the tubular girder and other forms in which it is now employed, there might have been some reason for the use of timber, in order to reduce the first cost. But it is now generally acknowledged, that it is safer and more satisfactory to increase the estimates, than to incur the necessity of frequent repairs and renewals, the risk of accident, and the danger arising from the use of a material subject, like timber, to rapid decay. In the construction of works in which strength and durability are required, the Engineer is justified in availing himself of the material best adapted for ensuring permanency. For bridges and viaducts of great width and span, wrought iron is, probably, the most suitable. A wrought-iron girder, when properly proportioned, contains within itself the elements of lightness, with great powers of resistance to strain; and although, like all other materials, it is liable to oxidation and decay when exposed to the action of the atmosphere, it may nevertheless, with a little trouble and attention, be preserved for many years, in a state of perfect security. These considerations have more or less guided Engineers for the last fifteen years; and hence the immense increase in the use of iron for road and railway constructions.

The experiments for determining the strength and form of the Britannia and Conway tubular bridges led to a new era in bridge building. They developed an entirely novel principle of construction, which has been most successful. The many advantages resulting from the application of a tenacious, but flexible, material like wrought iron, both in plates and bars, may be estimated by the numerous structures of this class in almost all parts of the world.

From what has been already accomplished, it is probable, that, in bridge building alone, the use of this material will confer on Engineers the power of crossing rivers and deep ravines with spans up to 1,000 feet; and the time is, apparently, not far distant, when even greater spans may be possible, by the employment of a quality of steel possessing a much higher degree of strength and uniformity in its tensile character than iron, so as to enable nearly one-half the weight of the present constructions to be dispensed with. It may, therefore, be reasonably anticipated, that the improvements in progress in the manufacture of steel and iron will still farther extend the solidity of works, in every department of the useful and the industrial arts.

The Dinting¹ and the Mottram viaducts, on the Sheffield and Manchester Railway, were erected in the year 1843-44, under the direction of the late Mr. Joseph Locke, (M.P., Past-President Inst. C.E.) In the former there were five arches of 125 feet span, and in the latter, one of 150 feet and two of 125 feet span, all constructed of timber ribs on the laminated principle. At the springing of the arch, the ribs were fitted into cast-iron shoes, let into the masonry of the piers and the abutments. There were four main ribs in each arch of the Dinting viaduct (Fig. 1), and three in each arch of the Mottram viaduct; and these ribs were stayed by diagonal and cross braces. The uprights and diagonals in the spandrels were also stayed, and were morticed into longitudinal beams supporting cross joists, on which the permanent way was laid, at a height of 100 feet to 120 feet above the level of the river.

As is generally the case with similar structures, after a few years the ribs became twisted, and the entire structure of the Dinting viaduct was so insecure, that it had to be trussed diagonally with iron rods to retain it in line, and to prevent it from bulging over in a lateral direction. Within ten or twelve years after erection, the timber in both the viaducts was so much decayed as to endanger their security, and the Author was consulted as to the best means of reconstructing them in iron. The late Mr. Jee, then the Resident Engineer, undertook however, to render them secure, and after much trouble and expense this was considered to have been accomplished. But this did not last long, as, in 1858, they were again in such a state as to alarm the passengers and the people in the neighbourhood, who drove and travelled several miles to avoid crossing either bridge. Under these circumstances it was finally determined to renew them with iron, and the Author being again

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. v., p. 216, for "A Description of the Dinting Vale Viaduct," by the late Mr. A. S. Jee. Also, *Ibid.* p. 219, for a Paper, "On the Arched Timber Viaducts on the Newcastle and North Shields Railway," by Mr. B. Green.

Fig. 1.

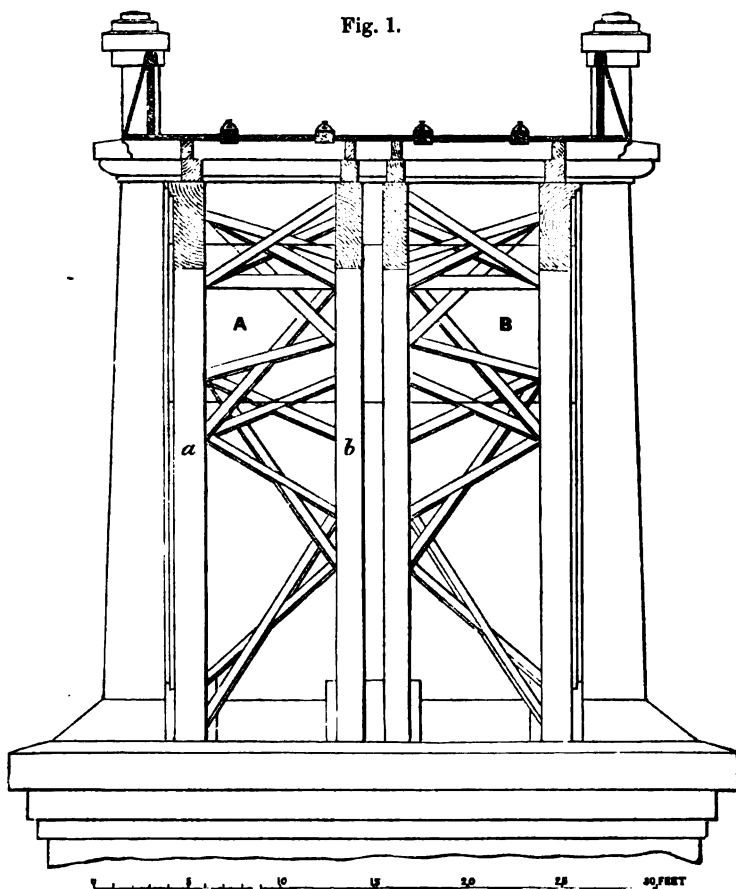


Fig. 2.

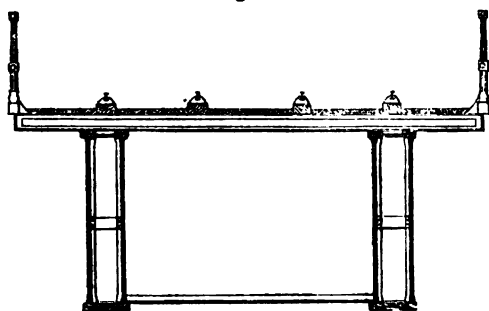


Fig. 1 shows the Dinting Viaduct as originally constructed ; Fig. 2, as restored.

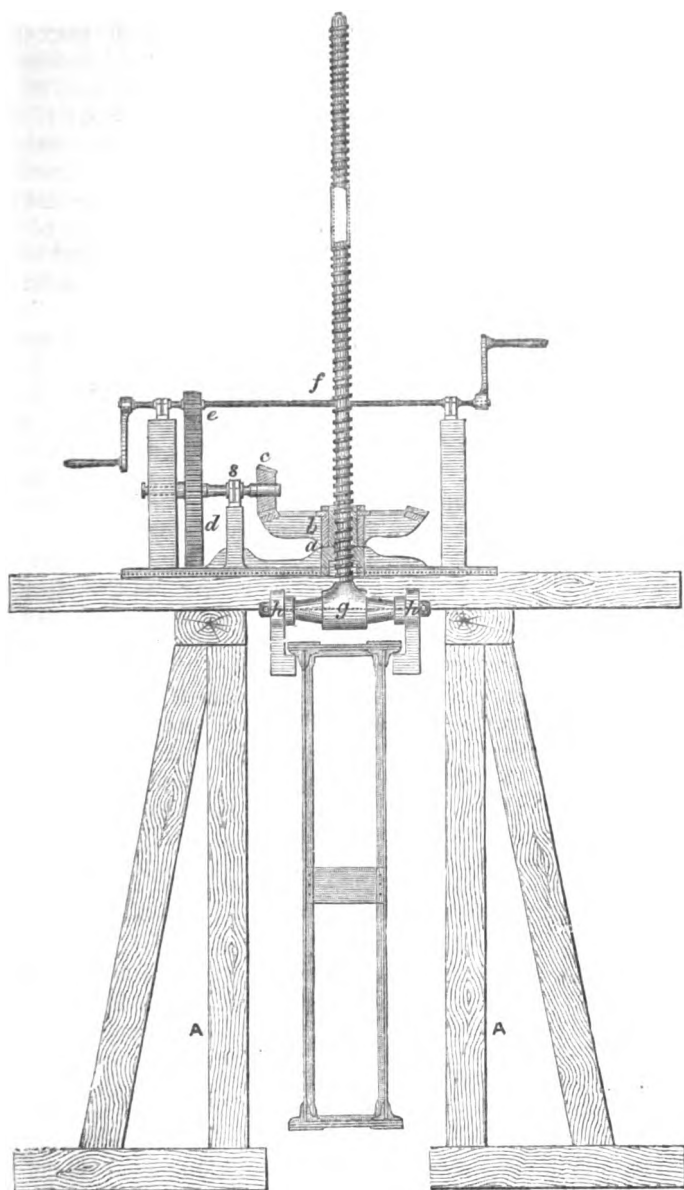
referred to, the designs, now submitted for the consideration of the Institution, were subsequently executed.

There is nothing novel either in design or construction, the chief peculiarity being in the mode of erection, and the manner in which the substitution of iron for wood was effected. The restored portions consist of two longitudinal tubular girders (Fig. 2) extending from the abutments on each side, and resting upon the piers, which were cut down to the proper depth to receive them. The girders are uniform in depth, in both the Dinting and the Mottram viaducts, being one-thirteenth of the span; and the areas of the top and the bottom flanges are in the proportion of 7 to 6, the breaking weight, equally distributed, amounting to 12.58 tons per lineal foot. The girders are riveted and united by covering plates over the piers, and are thus rendered continuous from one extremity to the other. They are fixed to the two middle piers in the case of the Dinting viaduct, and on one pier of the Mottram viaduct, and are free to expand and contract in the direction of the abutments. On the top of the girders iron cross-beams are riveted to the flanges, at intervals of 4 feet, and to these are attached the longitudinal sleepers for supporting the rails. The cross-beams project 3 feet 7 inches beyond the longitudinal girders, and upon their extremities the hand-rails are raised. The spaces between the longitudinal sleepers and the railing on each side are covered with planking $3\frac{1}{2}$ inches thick, and upon this is spread a depth of from 3 inches to 4 inches of macadamized ballast, constituting the roadway of the bridge.

The principal condition insisted upon by the Directors was, that the traffic should not be interrupted during the progress of the works. This was agreed to, and it is satisfactory to state that, although there were from sixty-eight to seventy trains per day, no stoppage, even of a single minute, occurred, and that the whole of the work was accomplished without accident. In the prosecution of this undertaking, the Author incurred heavy responsibilities, and he was not free from anxious thought as to the results, and as to the best means to be employed. In this duty he was ably and cheerfully assisted by the Company's Engineer, Mr. Charles Sacré, and to that gentleman he is indebted for many useful suggestions.

As already stated, there were four ribs in the width of the Dinting viaduct (Fig. 1), but only three in the Mottram viaduct, the centre one of which was proportionally stronger. It was at first determined, in the case of the former, to construct one line of girders between the two ribs on one side at A, leaving the other side, B, untouched for the passage of the trains. But this could not be accomplished, as it was found that the space was too confined to permit the men to work; and the rickety state of the structure was such as to render the removal of any part dangerous,

Fig. 3.



Apparatus for Raising and Lowering the Tubes.

and there was considerable risk of the whole falling into the river below. It was then proposed to remove two side ribs, *a* and *b*, but that idea had to be abandoned, on account of their being the only support, as lateral stays, to the others, which were distorted and out of the perpendicular, as well as out of line. Finally, it was resolved to construct the girders on the top of the old existing platforms, to cut down the piers and the abutments, and, by a simple mechanical apparatus, to suspend the girders at each end, and lower them into their places. This arrangement was successfully carried out, and answered every purpose, as it not only allowed the old structure to be retained intact, but it enabled the contractors to finish their work on every girder, without obstruction to the riveters and their assistants.

The apparatus for raising and lowering the girders was exceedingly simple. A strong wooden frame, *A A* (Fig. 3), about 16 feet high, was erected on the pier at each end of the girder. On the top of this frame there was a cast-iron plate *a*, with a hole in the centre, through which a square-threaded screw, $4\frac{1}{2}$ inches in diameter, was passed. On this screw there was a bevil wheel *b*, having a brass bush, and resting on the plate *a*, which was increased in thickness to 4 inches round the hole; the meeting surfaces being covered with plates of steel and brass, carefully turned, so as to diminish the friction, when the girder, which weighed 80 tons, had to be lifted. Into the wheel *a* the pinion *c* worked, and received motion from the spur wheels *d* and *e*, the shaft *f*, and the crank handles on each side. On the lower end of the large screw was forged an eye, to receive the cross bar *g*, and at the extremities of this bar there were two links *h, h*, which hooked under the angle irons at the sides of the girders, at each end. From this description it will be seen that the operation was exceedingly simple, and with six men at the handles, the girders were raised, and lowered into their places, in the course of one hour from the commencement to their final settlement on the piers. When one line of girders was completed, and connected together over the piers, temporary wooden cross-beams were laid on the girders, in such a position as to allow of the permanent iron cross-beams being afterwards inserted between them; the temporary beams being partially supported on one side by the old centre arches, which had to be firmly stayed to the new girders. On these temporary cross-beams longitudinal bearers for supporting the rails were placed, and the permanent way having been fixed, the traffic was transferred to this side, during the operation of constructing and erecting the second line of girders. As soon as these were finished, and lowered into their places on the piers, the iron cross-beams were introduced between the temporary wooden beams, and when in place they were riveted to the main girders on the open side.

The longitudinal timbers were then bolted to the flanges of these cross-beams, the rails were permanently laid on that side, and the whole of the traffic was again transferred to it, until the other side was completed in the same manner. It will thus be seen, that there was no interruption of the traffic during the whole time of the reconstruction; and the last process was the riveting of the cross-beams to the line of girders first finished. The work of reconstruction of both viaducts was accomplished without accident, to the entire satisfaction of the Directors and of the public.

The communication is illustrated by three diagrams, from which Figs. 1 to 3 have been compiled.

[Mr. BATEMAN

Mr. BATEMAN said, it appeared to him that the most remarkable part of this work, was the manner in which the traffic of the line was maintained during the time the iron girders were being constructed and substituted for the wooden arches. He did not think the Paper described with sufficient clearness how that was accomplished; how in fact two iron girders could be made to take the place of four wooden arches, whilst the trains were running.

Mr. FAIRBAIRN said, his object in bringing forward the Paper was to show the way in which iron girders had been substituted for wooden arches, without obstruction to the traffic, or danger to the public, during this difficult and critical operation. The Dinting and the Mottram viaducts had been erected about twenty years, and had undergone repeated repairs. When he examined the Mottram viaduct, one of the arches was so much decayed, as to cause the timbers to rise and fall from 3 inches to 4 inches during the passage of the trains; and in his opinion it was in so precarious a state, that it would have tumbled down within eighteen months, or two years. In fact, the passengers became so alarmed, that it was seriously proposed to run an omnibus to a distant station, in order to avoid crossing over the viaducts. It was necessary that the main girders should be constructed, be fixed in their places, and be made continuous, before the removal of any portion of the old wooden arches; and as it was found that there was not sufficient room to effect the reconstruction between the arches without danger, it was decided to build the girders on the top, at the same level as the rails. During the progress of the works the old timber arches were strengthened by the introduction of tie-rods and bolts. The traffic both ways was conducted first on one line of rails, while the girders were being erected for the other, and on their completion, it was transferred entirely to the second line of rails. This was effected without the slightest stoppage or interruption of any kind, during the whole process of reconstruction. The girders were originally constructed completely at the works, and were then taken to pieces in sections, reconstructed as separate girders, and when in place, were riveted together, so as to make them continuous from abutment to abutment. They were fixed on the central piers, and there were rollers on the abutments at each end to allow for expansion and contraction. The extent of expansion from the freezing point to summer heat, was about $\frac{3}{4}$ of an inch; and as the movement was in both directions, from the centre to the extremities, it was not considerable. In the Britannia bridge the possible movement would be about $2\frac{1}{2}$ inches. Cutting out some of the cross braces to get the girders down was a delicate operation, owing to the want of lateral braces, the old ones being totally inoperative. It was feared that the new bridge might be ugly; but on the contrary, it had a very light and symmetrical appearance,

even more so than ordinary arches, and was not without harmony in its general outline. The apparatus employed for raising and lowering the tubes was simple and effective in every respect. The diameter of the screws was $4\frac{1}{2}$ inches, and the weight of the girder was 40 tons at each end. The pitch of the screw was about $\frac{3}{4}$ of an inch. In his opinion there was no economy in the erection of timber bridges in this country, when iron bridges could be built at so moderate a cost. The expense of the iron work in these viaducts did not exceed £20 or £22 per ton, including erection, and the cost was not increased by the peculiarities of the situation, or the circumstances under which the girders were erected. It was true that a certain deterioration was constantly going on in iron structures, particularly wrought iron, which oxidised more rapidly than cast iron; but with care and attention, a riveted plate, or lattice bridge of wrought iron, if occasionally painted and looked after to prevent oxidation, should last not only a hundred years, but for five hundred years.

Mr. HAWKSHAW, President, said the personal explanations which Mr. Fairbairn had given, in reply to questions from the Members, would he was convinced render this interesting work more fully appreciated. Every one must have been struck with the ingenuity which had been displayed, and the care which had been evinced, throughout the successful operation.

March 3, 1863.

CHARLES HUTTON GREGORY, Vice-President,
in the Chair.

The following Candidates were balloted for and duly elected :—
ALEXANDER BRYCE, JOHN FRASER, EDWARD HARRIS, FRANCIS
CHARLES MIERS, GEORGE PADDISON, and GEORGE KENT RADFORD,
as Members; GEORGE OSBALDESTON BUDD, Colonel GEORGE
CHANCELLOR COLLYER (Royal Madras Engineers), JOSE MANUEL
FARFAN, JOHN BARRACLOUGH FELL, WILLIAM PARSEY, HENRY
PRINCE, STUART RENDEL, M.A., DOUGLAS SUTHERLAND, and
WILLIAM MARSTON WARDEN, as Associates.

No. 1,074.—“The Perennial and Flood Waters of the Upper
Thames.”¹ By the Rev. JAMES CHARLES CLUTTERBUCK, M.A.

THE water-shed of the Thames comprises, and may be divided into, three geological districts,—the tertiary, the chalk, and the oolitic strata. A great portion of the first of these was subjected to a close investigation in 1851, when it was proposed to supply London with water from “the soft springs of the Surrey sands.” The second was the subject of communications to the Institution in 1842 and 1843.² It is the third, though not strictly confined to its limits, that is the subject of this Paper. Geographically it is that portion of the water-shed, north of the range of chalk hills, bounding the vales of Aylesbury and of White Horse, and it extends to the Cotswold Hills, bounding the vale of Evesham and the valley of the Severn; and it has a computed area of 1,500 square miles. The river is spoken of as the Thames, the name it bears from its very source in Saxon records, and by which it is known to the inhabitants of the district through which it flows.

The subject is a complicated one, but it will be simplified by describing the tributaries in the order in which they join the main stream, which rises from the great oolite at Thames Head, about 4 miles west of Cirencester, near the Tetbury road station, on the Gloucester and Cheltenham Branch of the Great Western Railway. The Thames within 3 miles of its source passes from the oolite to the Oxford clay, over which it flows till it cuts through a

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

² *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 155, and (1843), p. 156.

gap in the coralline oolite at Sandford, below Oxford. It then passes to the Kimmeridge clay, turns the escarpment of the lower green-sand at Culham, touches the gault clay at Long Wittenham, whence it passes over a shelf of the lower green-sand, and returns to the gault above its junction with the Thame stream, the limit of the district now under consideration.

Thus the Thames runs over a clay bed, and is the mere carrier of waters derived from its tributaries. Those which run from north to south and from north-west to south-east—as the Churn, the Coln, the Leach, the Windrush, the Evenlode, and the Cherwell,—carry their perennial waters from oolitic sources. Those flowing from south to north have their sources in the chalk hills, from the escarpment of which they receive the back drainage, slightly augmented by that of the upper green-sand, and then pass over the gault and the Kimmeridge clays, either to the main stream, as the Ray and the Cole,—or as affluents of the Ock and the Thame, which are the main sources of the waters carried by these tributaries into the Thames. The Swill Brook is a sluggish stream, little more than the carrier of the flood water from the surface of the Oxford clay, on each side of the Cheltenham Railway, between Purton and the Cirencester branch. With this may be classed several brooks of the same character, which receive an insignificant quantity of perennial water from the oolite, though, from the extended surface of clay they drain, they carry large quantities of flood waters into the Thames above Cricklade. Thus, the river is a carrier of flood water immediately below its source.

The Churn rises just within the escarpment of the oolitic hills near Cheltenham; the geological condition of its sources is a type of most of the streams which derive their head waters from these strata. The inferior oolite, capped to the west of the Evenlode by the great oolite, and the great oolite to the east of that river, rest on the upper or lower lias clay and intervening marlstone. The water falling on the surface sinks into these strata, till it meets with the lias clays forming the bottom of the numerous valleys by which the district is furrowed. The springs often issue at so high a level above the foot of these valleys, that the villages are supplied with water led by pipes into tanks and troughs. It is from the aggregation of such streamlets, augmented frequently by springs from the marlstone, where its surface is exposed, or where it is thinly covered by the upper lias clay, that the Churn, the Coln, the Windrush, the Evenlode, and the Cherwell derive their headwaters; which may be termed perennial when sufficient in volume to drive a mill. As they approach the river, they intersect the upper strata of the great oolite, of which they receive the drainage, often thrown out at various levels by the frequent bands of clay found in these strata,—such as the fullers' earth and the clays of the

forest marble; which prevent an accumulation of subterranean water sufficient to produce copious springs. The Churn with its affluents comes within this general description. It has one of its chief perennial sources in the well-known Seven Springs or Wells, about 4 miles south of Cheltenham. It drives the first of several mills about 2 miles from this source; thence passes Cirencester, and carries a considerable body of perennial water into the river near Cricklade; though in dry seasons its volume is reduced, in a remarkable manner, as it passes from the lias clay to the oolitic strata. This phenomenon, which occurs in other tributaries flowing from and over the same strata, requires further investigation.

The Ray receives its water from a different source, and is a type of the streams flowing from south to north. It rises in the escarpment of the chalk range, whence it flows over a band of the upper green-sand, the gault, and the lower green-sand, then runs over a large surface of Kimmeridge clay, cuts through the coralline oolite, (from whence, by its branches, it receives a small addition of perennial water,) then passes to the Oxford clay, and reaches the river near Water Eaton, between Cricklade and Lechlade. The volume of perennial water it receives from the chalk is shown by several mills near its source. It is the carrier of a considerable amount of flood water, from the surface of the Oxford clay in the neighbourhood of Swindon.

The head-waters of the Coln rise in a valley of which the geological condition is much the same as the Churn. From the ridge which separates Charlton Abbots from Brockhampton, the water flows into the Severn to the north, and into the Thames to the south. The first mill is at Syreford, which receives its chief power from a spring at its head. It brings down but little flood water to its junction with the river, immediately below the first lock of the Thames and Severn Canal. The Cole is of the same character as the Ray, rising under the escarpment of the chalk, driving several mills near its source, and carrying a considerable amount of flood water to the river. The Leach and several small streams spring from the oolite.

The two principal remote sources of the Windrush are in a valley at Cutsdean, and near the old jockey stables at Spring Hill. The several branches form one stream above Burford, and supply water-power to important manufacturing mills at Witney. Though rapidly augmented by heavy rains, this river does not bring down much flood water.

The Evenlode differs in some important respects from the streams before described. The head-waters of its north-west branch are found to the west of Moreton-in-the-Marsh, situated in a flat, the lower lias clay forming the surface. The perennial waters are mere threads, issuing from the oolitic hills above; their chief drainage falls into the Windrush. It is not until the

waters of this branch of the Evenlode are augmented from the oolitic strata flanking the valley, through which it descends, that they are sufficient to drive a mill. The extended surface of lias clay throws off much flood water, which is carried down by this branch of the Evenlode. The branch from Chipping Norton, though it brings down much land drainage, is of a more perennial character. The Glyme, which it receives as a tributary below Blenheim Park, derives its water chiefly from the oolitic strata, and for this reason brings down little flood.

The Cherwell drains the most northern portion of the watershed of the Thames. Its perennial waters are derived from the oolitic rocks, augmented by the drainage of the marlstone, a large surface of which is exposed in the district. The Oxford canal runs through the valley of the Cherwell, and is supplied, at its summit and at various points, by its waters. The gaugings of the Boddington reservoir, from which the summit level of the canal is sustained, afford a good indication of the character of the supply to the river. This reservoir receives a certain quantity of perennial water from the strata above the lower lias clay, and its area, of 65 acres, is sometimes raised, by heavy rain, more than a foot in twenty-four hours. It has never failed to supply sufficient water for the summit level of the canal. Soon after passing the outcrop of the Oxford clay the Cherwell receives the waters of the Ray, the northern branch of which drains the country round Bicester. The eastern branch serves as the carrier of the flood water of a large and very flat district of the Oxford clay, known as Ot Moor. The bed of this branch has frequently been dry, though it drains a water-shed of about 30 square miles. There are not any mills on either branch. The Cherwell is one of the chief sources of flood water to the neighbourhood of Oxford. A small stream, issuing from the coralline oolite near Headington, drives an overshot mill, and may be reckoned among the sources of perennial water. Those received by the river between Oxford and Abingdon are inconsiderable. The next tributary is the Ock, running from west to east on the Kimmeridge clay, near the margin of the outcrop of the coralline oolite, from which it receives a portion of its perennial water on the north. Its chief sources are from the foot of the escarpment of the chalk hills flanking the vale of White Horse to the south. The stream which flows from two heads at Letcombe to the south-east of Wantage is the largest of these; it drives several mills scarcely a mile from its sources. One streamlet from the north, rising in the oolite, drives a small mill at Sandford. Several smaller brooks running from this source in the same direction sink, by swallow holes, into the rock; the water rises again to the surface, when the overlying Kimmeridge clay is pierced, by artesian borings, as at Abingdon. As the gault and Kimmeridge clays are not

separated in the vale by the usually intervening lower green-sand, a considerable body of flood water is thrown from their surfaces. From the flatness of the strata, and consequently little fall in the river, there are but three mills above Abingdon, just below which town the Ock falls into the Thames, close to the termination of the Berks and Wilts canal, to which it runs parallel through the vale. A small stream rises at Betterton, to the east of Wantage, also from the chalk. It drives a mill at Ardington within a mile of its source, and its waters are slightly augmented by the drainage of the upper green-sand; through the undulations of which it flows diagonally in its passage to the river at Sutton Courtney; between which place and Ardington it drives several mills. These streams are rapidly replenished by heavy rain, much of which is readily absorbed and re-delivered by the upper green-sand, but they carry little flood water. A few brooks and streamlets bring down small quantities of perennial water from the upper green-sand to the south, and the lower green-sand here found to the north. The flood water from the surface of the gault, which is exposed to a larger extent than elsewhere near the Didcot Station, is considerable, and drains away slowly from the little fall from this spot to the river.

The last of the tributaries is the Thame. The geological condition of its water-shed is, with some exceptions, the same as the Ock, though its course is in the opposite direction, flowing from east to west. Its bed is principally on the Kimmeridge clay, but it passes to the gault, at the point where these two clays run together, before it reaches the Thames near Dorchester. It receives the drainage of detached patches of the lower green-sand and Portland oolite, strata which are absent in the vale, but are found in situ above and below the Kimmeridge clay respectively. None of these streams are sufficient to drive a mill. The chief source of its perennial water is, as in the case of the Ock, the escarpment of the chalk hills, and the upper green-sand. There is much flood water from the extensive clay surface of the water-shed, and the river bed is choked and grown up at many points, thus seriously obstructing the passage of the waters. The mills on the main stream are few.

Such are the tributaries of the Upper Thames. The geological condition of the source of the main stream is worthy of especial notice. The oolitic strata at the Thames Head crop out from beneath the Oxford clay: as the junction of these strata is covered with oolitic gravel and debris, it is difficult to determine its exact point. The water falling on the oolitic rock sinks into, and accumulates in these strata, and is restrained from escaping below a certain level by the overlying clay. As the water rises in the oolite it shows itself above ground, where the surface is de-

pressed ; and it is in such a depression, which appears to have been further artificially excavated into a shallow well, now nearly filled up, and overgrown with the ash and hawthorn, indigenous to the valley, that the Thames is reputed to rise in Trewsbury meadow, about 10 feet below the summit level of the Thames and Severn Canal. In its normal condition it was probably a perennial source, whose volume was regulated by the elevation and depression of the water level in the surrounding oolitic rock, which rises to a considerable elevation on the opposite side of the canal. Augmented in its course by kindred springs, it carried a river of considerable volume over the outcrop of the Oxford clay, from whence it could receive no increase of perennial water, except a small quantity of soakage from the bed of gravel by which the clay is covered, at and below the outcrop of the oolitic rock. Thus, it is not without reason that there is, in a Charter of Caedwealha, 19th August, A.D. 688, this description of a boundary at Kemble, of lands given to St. Aldhelm, "*usque famosum amnem qui dicitur Temis.*" Besides, it lies further to the west than any other considerable source ; and it may be, that its naturally intermittent character caused it to be honoured by a superstitious people. In 1852, and again in the spring of 1862, the water flowed in a large volume from this source, and even higher up the valley it showed itself above ground. The Thames and Severn Canal was formed in 1789. When the natural sources fail, a large quantity of water is lifted into the summit level of the canal from a well on its brink about half a mile below Thames Head. The well is 14 feet in diameter, and is sunk 63 feet below the surface of the canal, or about 50 feet below Thames Head. At the bottom two adits, said to be about a quarter of a mile in length, are driven east and west, that to the west in the direction of the head, that to the east to a spot whence another source usually springs. The engine works a pump with a length of stroke of 9 feet, and has a cylinder 33 inches in diameter. In September 1862, it was making an average of eight strokes per minute, with a decreasing depth of 14 feet of water in the well ; then no flowing water was to be seen in the bed of the stream above Ewen, a mile and a half below the engine, or 2 miles from the head. The mills below were deprived of nearly all their water, and though the Thames receives the contributions of the Swill and other brooks before spoken of, it carries very little perennial water to its junction with the Churn at Cricklade.

As the bed of the river is on the Oxford clay from Somerford Keynes till it passes the coralline oolite at Sandford, below Oxford, and as there is little difference in its physical, or geological condition between these places, it may be described in general terms. The whole natural bed of the river is an excavation in the Oxford clay,

flanked to the south by the escarpment of the coralline oolite, which rests on a ridge of the clay. As a rule, the lower levels of the valley, including also in many places the oolitic rock, outcropping to the north at a very slight angle beneath the Oxford clay, are covered with drift gravel. Wherever the floods have extended, sand, silt, or argillaceous loam, has been deposited on this gravel; and this action is still going on, governed by the number and character of the floods. Thus, the bed of the river is as a rule gravel, and the banks a warp, the accumulation of ages. As the set of the current wears away the face of the bank at one point, a deposit is made elsewhere; the silt and warp settle in the eddies, and flags and rushes grow upon it, and a (so-called) *flam* is formed. If this should cause an obstruction to the ground-ice in its passage down the stream, the stones and other substances raised by it from the bottom add to the accumulation; which gradually rises as a bank to the river, and then receives the heavier portions of the sand and silt in floods, the lighter or argillaceous particles of the warp being carried inland. At length the whole assumes a level surface, with a slight inclination from the river to a point, usually on, or under, the level of the navigation high-water mark. There are instances of the change of bed to the extent of several chains in width; and indeed there appears to be no limit to these deviations, but the physical features of the valley. These facts have an important bearing on any improvement, so much needed, in the drainage, or condition of the Thames Valley.

The perennial waters are either used for mills or for navigation. The mills on the tributaries are numerous. Between Thames Head and Cricklade they are, as already shown, virtually deprived of water. That on the parent stream near Cricklade is said to be short of water; another close at hand on the Churn is assisted by steam power. It may be, that the Churn is affected by the pumping-engine near Thames Head. Therefore no gaugings of these streams would be a guide to the natural yield of water from the district which they drain. Between Cricklade and Lechlade the water is not applied to any economical use; and again from Lechlade to Wolvercot, three miles above Oxford, there are no mills. Above Wolvercot a portion of the water is diverted to Wytham, and this, together with the main river, is broken into a perfect network of mill and other streams in and about Oxford, which unite at Kennington above Sandford, where there is a large paper-mill. There is a corn-mill at Abingdon, and another paper-mill at Sutton Courtney, the last within the district ending with the confluence of the Thames and the Thame stream.

It has been shown that the Thames is merely the carrier of water, whether perennial or flood, brought into it by its tributaries; therefore the gaugings of these tributaries, where they join the main

stream, would give the aggregate of water that it carries. As, however, such observations have been neglected, there are no available existing data on this point. The tributaries are so numerous, and their water-shed so varied, that any estimate of their volume at different seasons would be difficult. The effect of rain-fall on streams issuing from the chalk stratum, for instance, is made a matter for calculation. Not so the waters of any one of the tributaries of the Upper Thames, most of which are immediately affected by heavy rains and subject to flood; but for this reason, as connected with land drainage, supposed to tell upon the flooding of rivers. On the accompanying map (Plate 7), those streams only are marked which have sufficient volume to drive a mill. Those rising in the chalk stratum have this power from their source. This is some guide to their volume, which might be easily gauged periodically; but as, in their passage to the main stream, they receive water from other sources, often suddenly augmented by summer rain and winter flood, the gauging of these streams would require incessant observations. This remark applies even in a greater degree to streams from the oolitic rocks, where the interlacing of clay with pervious beds is so marked a feature, and makes the discharge of water very complicated. The gauging of the main stream is beset with other difficulties, as the height and passage of the water is divided between the mills and the navigation, controlled indeed by stringent legal enactments, but too often disregarded.

Though the object of this communication is rather to draw attention to the nature of the water-shed, than to deal with absolute quantities derived from the various sources; the following gaugings are given, taken at a point on the river well fitted for observation, and will yield, if carried on in other places, valuable results. There are no mills for thirty miles above Wolvercot, and the navigation, though 'flashes' are still sent down, has virtually ceased. The manager of the mills at Wolvercot, has found, as the result of several years' observation:—That in the summer months, the branch of the river supplying Wolvercot mill has a mean velocity of 58 feet per minute, and a yield of 8,120 cubic feet per minute; at the same time, there is a further quantity of 3,500 feet passing in the Wytham stream, giving a volume of 11,620 cubic feet for the main river.¹ This is exclusive of the additional quantity brought down twice a week by 'flashes,' which last two or three hours, and are difficult to estimate. During the winter months, in fine weather without frost or rain, the river has a mean velocity of 94.9 feet per minute, and taking the sectional area as 181.5 square feet, this gives a volume of 17,224 cubic feet per minute; to this must be added, on account of the Wytham branch,

¹ This quantity was reduced to 6,849 cubic feet in the summer of 1864.—J. C. C.

5,400 cubic feet, making the volume of the main stream 22,624 cubic feet per minute. In moderate rainy weather, without floods, the total quantity of water passing through the mill, lashers, and weirs in connection with it, is 28,189 cubic feet per minute. With this quantity, the level of the river reaches the high-water navigation mark, but it does not at any part overflow. In floods, the river rises from 6 inches to 18 inches over the banks, and extends over a large area of flat meadows, so that the yield cannot then be ascertained at this part of its course. At the end of December, 1862, gaugings were taken of the whole stream at a period coinciding with the last example, namely, moderate rainy weather without flood. The total yield was then 35,498 cubic feet per minute, of which 27,986 cubic feet may be taken as representing the quantity passing through the mill, &c., at Wolvercot, given in the previous example as 28,189 cubic feet, and the remaining 7,738 cubic feet, as the water passing from the main stream to Wytham. These data suggest the necessity of adopting a standard at various stations, so that the results may be compared with the rainfall when the gaugings are taken, and also of fixing on localities where the flood waters of the tributaries and of the main stream may be gauged. This obviously must be a work of time, and requires patient and repeated observations. When these latter gaugings were taken, observations of a similar character were made on the river below the influx of the Cherwell and the Ock, which gave 50,995 cubic feet per minute, a difference of 15,497 cubic feet per minute as compared with Wolvercot. Of this quantity, it was estimated that 7,689 cubic feet per minute were brought into the main stream by the Cherwell, and the remainder by the Ock and smaller perennial streams. The verification of the quantity in the Ock was prevented by a fall of rain of 0·48 of an inch, or nearly half an inch in a few hours. At the expiration of thirty-six hours, the volume of the Thame stream was doubled, and about 30 per cent. was added to the volume of the main river. At Wolvercot, on the 5th January, 1863, after about 1 inch of rain, the increase was from 27,986 to 48,418 cubic feet per minute.

The rainfall from the 1st to the 7th January, 1863 inclusive, produced a flood in the Thames under circumstances peculiarly favourable for observation. The rainfall recorded during that period was at—

	Inches.
Oxford (Central) . . .	1·74
Banbury (North) . . .	1·30
Cirencester (West) . . .	1·50
Hartwell (East) . . .	1·28
Wittenham (South) . . .	2·27

This gives an average of 1·61 inch over the whole water-shed.

Dalton's gauge at Hemel Hempstead, for the same period, showed a total fall of 1·52 inch, the percolation being 1·10 inch. The gaugings of the main river at Wolvercot then amounted to 82,500 cubic feet per minute, and at Clifton Hampden, below Abingdon, to 181,832 cubic feet per minute. Of this latter quantity, 44,755 cubic feet, or an increase of 37,066 cubic feet as due to the flood, were delivered by the Cherwell, 24,864 cubic feet by the Ock, and 29,713 cubic feet by the many smaller streams, water-courses, and land-drainage outfalls, issuing into the river between Wolvercot and Clifton Hampden, from a computed water-shed of 80 square miles. The latter quantity was on this occasion much increased, by the rainfall on the southern part of the district being in excess half an inch; the brooks and water-courses bringing down the drainage from the gault clay were consequently much swollen. These gaugings show the quantity of flood-water from some of the tributaries, which issue into the river between Wolvercot and Clifton Hampden, a distance of about 20 miles by the river, with an average fall of 2 feet per mile. The gaugings of former floods cannot be given, but the following comparison of floods is not without interest:—

Date.	Rainfall.		Dalton's Gauge.		Rise of Flood above H.W. Mark.
	Duration.	Quantity.	Rainfall.	Percolation.	
	Days.	Inches.	Inches.	Inches.	Inches.
1852, Nov. 16. .	27	5·25	..	..	81
1862, March 29 .	27	3·09	3·90	2·70	62
1863, Jan. 10 . .	7	1·62	1 52	1·10	42

When gauging stations have been fixed on, the quantity of flood or perennial water flowing down the river may at any time be ascertained; but up to the present time there is no available information on this interesting subject.

The navigation of the Thames is of very ancient date. A toll of salt fish (herrings?) was levied by the Abbey of Abingdon before the Conquest, on boats passing from Oxford through a new cut made for their accommodation. From that time it has been the subject of frequent legislation. It is now under the control of Commissioners, and is divided into six districts, of which that between Lechlade and Oxford is the sixth. It was a remark of the late Dr. Buckland, that no lines of inland communication could flourish, except they ran transversely to the lines of strata, as their variation ruled the products, and the internal commerce of the country. This is fully exemplified in the sixth district of the Thames navigation, which runs on one stratum, the Oxford clay. From this and other causes it has virtually ceased to exist. The physical

condition of its bed, and its easy gradients, offer facilities for navigation. The whole fall from Lechlade to Oxford, 31 miles, is only 51 feet 3 inches, or about 1 foot $7\frac{1}{2}$ inches on an average per mile. Some of the pound locks belonging to the Commissioners are in a hopeless state of dilapidation. The weirs, chiefly the property of individuals, and of a construction little improved since the days of the Saxons, are almost exclusively used for fishing purposes; often to the injury of lands near or adjoining the river, and of little profit to those who own or rent them. The shutting tackle, as it is called, consists of a cill fixed at the bottom of the river, upright posts, called rimers, fitting at given distances to the cill, and removeable; there are also two sets of moveable flood gates, called ground gates, and overfalls, the one fitting above the other in the spaces between the rimers; also two cross-beams parallel with the cill, against which the rimers, and the handles of the flood gates rest, and are kept in place by the force of the stream. One of these beams swings like a lock gate on a pivot, to allow the boats to pass, when the weir is drawn, and the rimers on one side are removed. On the passage of every boat or barge, the water on either side of the weir is drawn nearly to a level. There are eleven such weirs still in existence between Lechlade and Oxford, two having lately been removed. There are but three pound locks. It would now be very difficult for a boat to pass the whole distance at the time of low water. Flushes, or flashes, are still paid for, by a sort of tariff, levied by the owners of the weirs as far as Langley weir, above Eynsham, to enable boats to travel below. From Oxford, the flashes are arranged, during seasons of low water, for two days in the week, beginning at Oxford on Monday and Thursday, and reaching the district below on the following days. Under these regulations the interests and convenience of the navigation and of the mills are necessarily at variance. The economical use of the water, when most needed by the mills, is sadly interfered with, by suddenly sending down an excess on 'flash' days, and by penning it back, to replenish the vacuum above, when the flash has passed. The rising and falling of the water, with an alternating wet and dry surface, tends to the disintegration of the banks, and in various ways inflicts injury on the mills and on the landed property. The present depressed state of the navigation forbids the hope of any improvements by the Commissioners. The first step towards any general change for the better must be, the abdication of their power, or the refusal to interfere in any case between Lechlade and Oxford. From Oxford, the perennial waters are not only used for navigation, which has been greatly improved of late years, but these waters drive many important corn and paper mills. Notwithstanding the extended and varied water-shed of the Upper Thames, its waters have often fallen very short, as in 1858. But

for the heavy rainfall in the spring of 1862, a similar defalcation would have occurred in the summer of that year.

It has been shown, that the Thames is a river of floods almost from its source, increased by flood and land drainage brought down by the Ray and the Cole, and other smaller water-courses above the navigation. The lower oolitic rock cropping out from beneath the Oxford clay in the Thames valley to the north and the coralline oolite from beneath the Kimmeridge clay in the valley of the Ock, rise at so slight an angle from beneath those clays, that in wet seasons, these strata become so gorged with water as to throw it from their surface, either as flood, or by land drainage. Thus these pervious beds assume the drainage character of retentive strata, added to which, in the higher levels, the frequent bands of clay in certain localities, produce the same effect, and augment the flood water from the exposed surface of the lias clays in the valleys of the Windrush, the Evenlode, and the Cherwell, from the large tract of Oxford clay in the watershed of the Ray, a tributary of the Cherwell, and from the Kimmeridge and gault clays in the valleys of the Ock and Thame. This geological condition at once accounts for the large body of flood water thrown into the Thames. It must be noticed, that in many localities these clays are covered with drift gravel, of which the depth is often so considerable, that the water sinking into it issues in springs, and so becomes perennial. These complications make it impossible to identify the respective sources of flood and perennial water, or to limit them to certain strata.

As the volume of flood water depends not only on the amount of rain, or snow, but on the circumstances under which it falls, it requires close and constant attention to determine the probable flood from a known quantity of rainfall. It has been observed, that it requires from 2·50 to 3·00 inches of consecutive autumnal rainfall to replace the summer evaporation. The highest recorded floods on the Thames since January 8, 1734, are January 17, 1764; March 10, 1774; and January 27, 1809, the highest on record, caused by the sudden melting of snow, by which bridges were swept away, and much damage sustained at Maidenhead, and other places; December 21, 1821, nearly as high as that of 1809; January 1842, owing to a sudden thaw; and November 16, 1852, caused by long-continued rainfall, amounting to 5·50 inches on twenty-six previous days, after an unusually wet autumn. There was also a very considerable flood March 29—31, 1862, to which the following observations apply. As the relative quantity of rainfall varies on so large an area as the water-shed of the Upper Thames, with tributaries flowing in opposite directions from its extreme limits, the records of rain-gauges at three stations, Hartwell, near Aylesbury (east), Banbury (north),

and Cirencester (west)—are given for the months of March and April, and part of May, in Table I. The records of Dalton's gauge, communicated by Mr. John Evans (Assoc. Inst. C.E.), are added, because it may be presumed, that the water of super-saturation, which in permeable soils sinks to the subterranean water-level, in impermeable soils flows from the surface, or is discharged by land drainage.

TABLE I.

—	Hartwell.	Banbury.	Cirencester.	Dalton's Gauge.	
				Rainfall.	Percolation.
	Inches.	Inches.	Inches.	Inches.	Inches.
March	4·19	4·21	4·70	4·04	2·87
April	2·95	1·88	2·22	2·52	1·52
May 1st to 19th . . .	2·32	2·51	2·30	2·73	0·87
Totals	9·46	8·60	9·22	9·29	5·26
Average	9·09				
Level above the sea, } in Feet	250	350	446		

The whole period has been divided into four portions, marking the alternations of the flood, Table II., and as it is known, that the direction of the prevailing wind affects the volume of the flood-water, this is stated.

TABLE II.

Date.	Hartwell.	Banbury.	Cirencester.	Wind.	Excess of Rain at
	Inches.	Inches.	Inches.		
March 5 to 11 . . .	1·24	0·98	1·40	Var. S. and S.W.	Cirencester.
" 12 to 28 . . .	1·69	2·85	2·55	Var. N.E. to S.E.	Banbury.
" 29 to . . .	2·10	1·75	1·38	N.E.	Hartwell.
April 11 . . .	1·92	2·47	2·30	Var. S.E. to S.S.W.	Banbury, and Cirencester.
May 5 to 16 . . .					

The first period brought down little flood water, as the rainfall scarcely sufficed to replace the evaporation of an unusually dry February, in which only 0·49 of an inch of rain was registered, against an average of 1·53 inch.

In the second period, the river had sunk to high-water navigation mark on the 16th of March, and the flood attained its greatest height at Long Wittenham, between Abingdon and the junction of the Thames and Thame stream, on the 29th of March, at 4 P.M. It there occupied a sectional area of 2,546 square feet, of which 1,796 square feet may be accounted flowing water, with a central surface velocity of 240 feet per minute, and a mean depth of 11

feet. The periods at which the flood attained its greatest height at other points were as follow.—

ON THE TRIBUTARIES.

Witney (Windrush) . . .	March 29th, NOON.
Somerton (Cherwell) . . .	„ 28th, P.M.
Heyford „ . . .	„ 28th, 3 to 5 P.M.
Islip „ . . .	„ 28th, 4.30 P.M.

ON THE MAIN STREAM,

St. John's Lock, Lechlade .	March 29th, 6 A.M.
Newbridge	„ 30th, 12 NOON.
Eynsham	„ 31st.
Wolvercot	„ 28th and 30th.
Port Meadow, above Oxford	„ 30th, 12 P.M.

The variation at Eynsham is due to the influx of the water of the Evenlode, which, as has been shown, brings down a large body of flood-water from its source, due to the geological condition of its watershed. The water at Eynsham was thus penned back.

The record below Abingdon is as follows :—

Abingdon,—the mouth of the Ock	March 29th, NOON.
Abingdon, main stream	„ 29th, 2 P.M.
Long Wittenham	„ 29th, 4 P.M.
Crowmark Mill	„ 29th, 6 P.M.
Wallingford	„ 29th.
Streatley	„ 30th, 3 A.M.
Caversham, Reading	„ 30th, 8 A.M.
Henley	„ 30th, 3 A.M.
Marlow	„ 30th, P.M.
Windsor	„ 30th, P.M.

It will be seen, that the rise of the flood maintained a regular progression in its passage from Abingdon downwards. The excess of rain with a north-east and a south-east wind was from Banbury and Cirencester. Thus the flood encountered no obstruction from the waters of the Thame stream. The influx of the waters of the Loddon above Henley accelerated the rising of the flood at that point, five hours in advance of the increase at Caversham.

In the third period, from the 29th and 30th of March to the 11th of April, the flood fell, with slight pulsations of rise. The total rainfall on the 9th, 10th, and 11th was 1.40 inch. The wind during this period was from the north-east, and the fall of rain with the wind in this quarter was unusually great, the excess of rain being registered at Hartwell. The flood in the Thame

stream attained a greater height than during the-previous period, and in the main stream it was about 7 inches lower where measured.

During the fourth period, from May 5th to 10th, the wind was variable from south-east to south-south-west, with heavy and partial storms. The excess of rainfall was at Banbury and Cirencester. The flood in the Cherwell, and in the extreme west, rose higher than in the former periods. There are no generally available data, as to the volume of flood-water as compared with the rainfall. Any steps towards the improvement of the Thames valley should be accompanied by a well and regularly conducted series of observations on the volume of the perennial as well as of the flood waters. The latter can only be relied upon, when the volume of the flood requires the removal of all the shutting tackle at the various weirs and locks, so that free passage be given to the water throughout its course.

The action of land drainage on flood water is an important question. Land drainage yearly increases in area and in efficiency. Much information on this point might be obtained from large landed proprietors, who in some localities have drained thousands of acres; but the mere knowledge of the area drained would be no sure guide, without the quality of the work was also ascertained. Another question arises, are the perennial waters augmented, or diminished, by land drainage? It is universally admitted, that the floods in the main river and in its tributaries rise more rapidly than heretofore. In some localities there has been an advance of twenty-four hours in seventy-two hours within the last twenty years. There is a difference of opinion as to the subsidence of the water, and as to the total relative amount of flood.

As to the perennial water: On the escarpments and undulations of the lias and oolitic strata, where the sand or rock outcrops above the clays, the water often exudes so slowly, that it evaporates from the surface of the soil over which it is diffused. This is frequently the case, where these springy places are covered with a peat deposit, the accumulation of a long period. When deep drains are cut into such spots, the water is gathered into a small stream, and sometimes becomes perennial. This more than counterbalances the loss, where too free an outlet is given to sources already perennial, and by which their periodical exhaustion is accelerated. This remark applies to the drainage of the upper and the lower green-sand, and in some cases, to the water issuing from the escarpment of the chalk, and the drift gravel, resting on the various clays: the last are frequently laid quite dry by artificial drainage; at other times, when the water in them is tapped, they become perennial. As yet, land drainage has pro-

duced little apparent practical effect on the volume of the flood, or perennial waters of the Upper Thames; though it is probable that floods will be diminished, inasmuch as land drainage promotes winter evaporation, and increases the absorption of rain water by the soil.

There is great scope for improvement in the valleys of the Thames and its tributaries, especially the Thame, the Ock, the Cherwell, and the Evenlode. The antagonism in the interests of the mills and the navigation is an acknowledged difficulty. These are guarded, or restrained, by very definite laws, which also protect the landowners, though their provisions are seldom enforced, and are too often disregarded. Much might be done by the landowners, without affecting the rights or privileges of the mills or of the navigation, by a united and well-matured determination of purpose. After the great flood of 1852, a committee was formed, of which the late Mr. Pusey was the Chairman. A report was published, stating the amount of injury inflicted by the floods, but no action was taken upon it. During the year 1862, an application was made to the Home Office, by an influential Committee, headed by the Duke of Marlborough, to issue a Commission to inquire into the whole question; but as yet nothing has resulted from the interview with Sir George Grey. Under the powers of an Enclosure Bill, with the concurrence and assistance of several landowners, Mr. Bryan Wood has carried out some important works, by which the injury inflicted by the floods has been restrained. These works are based on a different system from that previously suggested. Mr. Wood separates the local drainage entirely from the flood. In describing the physical condition of the river, it has been shown, that in the gradual deposition of the warp covering the natural bed of the valley or vale, by the continued action of the floods, the surface has assumed an inclination from the river to a point at or under the navigation high-water mark. First, all communication with the river is cut off by embankments on both sides, a sufficient area being left within the river bed to carry off the ordinary flood water. Inside these embankments, channels are cut parallel with the course of the river, and of sufficient size to take the adjacent land drainage, as well as the surface drainage of the meadows. The water collected in these channels is then led down, and delivered into the river at a lower level. In the spring of 1862, the crops of hay on the unprotected land were spoiled in growth, or were carried away when cut, by the flood. At the same time, and close at hand, the hay crop on the protected meadows was cut and safely secured, whilst the flood water passed between the embankments, which were 2 feet or 3 feet above the surface of the land. As the winter floods are known to benefit the meadows, if the water does not rest too long upon them, the embankments

are fitted with hatches, by which the flood can be admitted at will. In proof of the injury inflicted on the meadows by a protracted flood, it may be mentioned that, in the spring of 1840, the surface of a large tract of meadow (at the very spot where these improvements have been made) was covered by a substance of macerated vegetable matter resembling a felt of cotton wool. It was in many cases made into garments, and was worn by the farmers, to show the toughness of the material, and as tokens of the effect of a protracted flood. If, by some such system as that adopted by Mr. Bryan Wood, the floods were brought under control, and water prevented from remaining stagnant on the land, two great objects would be accomplished; the improvement of landed property, and of the sanitary condition of the Valley of the Upper Thames.¹

The communication is accompanied by a series of diagrams, from which Plate 7 has been compiled.

¹ Works are now in progress, executed at the expense of the Rev. R. Greswell, calculated to free part of Port Meadow, belonging to the freemen of Oxford, from stagnant water, by leading it to a large outfall.—J. C. C., Nov. 1864.

UPPER GEOLOGICAL MAP

PLATE 7 VOL. XXII

ston in the
Marsh

The Retentive Strata

Lower Lias Upper Lias Kimmeridge

▼ River Gauges

Chipping Norton

Burford

Witney

Langley We

Hartwell

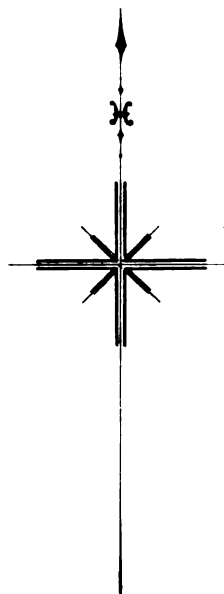
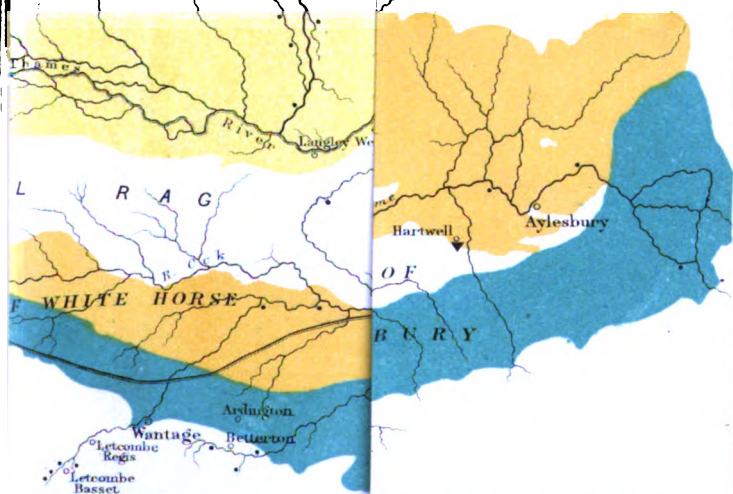
Aylesbury

Aslington

Wantage

Letcombe Regis

Letcombe Basset



The Rev. J. C. CLUTTERBUCK said, there were many points to which he wished to direct special attention, both as regarded the nature and varied character of the water-shed, as well as to the question of the navigation and the mills. Some persons went so far as to say, that the navigation of the Thames must be discontinued, and the mills be removed, before any real improvement could be effected in the valley of the Thames. It was true that, as at present regulated, there was an antagonism in the interests of the mills and the navigation, and that by this rivalry damage was sometimes inflicted on the owners and occupiers of land, whilst the sanitary condition of the valley was affected. Now, he believed that, under proper regulation, both the navigation and the mills might be retained, not only without mutual injury, but also with benefit to the public. With respect to the sanitary condition of the valley, he begged to refer to the elaborate and valuable Memoir of Dr. Acland, on the Cholera at Oxford¹ and to the Report of Mr. T. Macdougall Smith, addressed to Mr. (afterwards Sir) W. Cubitt.² Referring to the geological rather than the engineering character of the Paper, he remarked that numerous failures in schemes for obtaining supplies of water had arisen from a want of sufficient knowledge of the geological condition of the strata whence water could be procured. It was now more than twenty years since he stated, that the aggregation of causes would produce some great effect upon the pumping under London. The bearing of agricultural drainage on water supply was a subject of growing importance, from the increase in the population of towns, and the large quantities of water now required by the inhabitants. The water-shed of the Upper Thames presented a great extent and every variety of agricultural land drainage. Though at first sight it might seem a contradiction in terms, yet he believed that winter evaporation was promoted by agricultural drainage. Evaporation depended on the condition of the atmosphere, and on that of the surface of the soil. There was little evaporation from the surface of water, but very much from a rough surface exposed to the air. This might be shown by a simple experiment. If two shallow vessels were filled with water, and into one a piece of brick, or some such substance, was introduced, then from this latter four or five times the amount of water would be evaporated in a given time, than from a surface of water alone; of course by the addition of the brick the surface would be increased, but not sufficiently so as of itself to account for the augmented

¹ "Memoir on the Cholera at Oxford in the Year 1854. By Henry Wentworth Acland, M.D., F.R.S.," &c. J. H. Parker, Oxford. London: J. Churchill, Burlington Street.

² "University and City of Oxford. Report of Sir William Cubitt upon the Sewerage and Water Supply." Amersham: W. Broadwater.

[1862-63. N.S.]

evaporation. Thus, on the falling of winter rain, there would be a greater absorption of water on the drained surface; consequently, winter floods would be diminished by agricultural drainage. He had applied the recorded readings of Dalton's rain-gauge in a novel manner, by presuming that the quantity of water which flowed from the surface, or was discharged as flood by land drainage, was represented by the water of super-saturation percolating the gauge. The interest felt in this subject, especially at Oxford, was very great. Heretofore it had only attracted attention after unusual and disastrous floods; but he trusted that this spasmodic action would give place to some well-devised and determined action, and it was with this view that he desired the subject to be thoroughly sifted, by those who were best able to cope with the various difficulties that it presented.

Mr. ALDERMAN TOWLE concurred in the opinion, that this subject was of immense importance to the inhabitants of the valley of the Thames. Having formed one of Mr. Pusey's Committee, consisting of six members, to which reference had been made in the Paper, having resided for many years at the lowest part of the Upper Thames, and having had the advantage of attending the practical discourses, delivered on the spot, by the late Dr. Buckland, he could claim to possess some acquaintance with the questions at issue. At Sandford, where all the streams met, there was a gorge, in form like the letter V, the rising ground on the east, which was in Sandford churchyard, approaching very close to that on the west at Bagley Wood. At this point an embankment had been thrown up, which was the only cause of the continuous floods round Oxford; for he contended, that no mill could cause a flood; it would simply divert the water from its course, throw it upon the neighbours, and soon after passing out of the river, it would flow in again. But in this case the mill produced a flood, because the valley, and not the river only, was dammed up. The highest fall in the Thames was upon the flat country, which here inclined towards Oxford. He looked upon this point as the grand mistake of the Thames Valley, and without it was altered, the drainage could not act, as all the disputes originated with the flood at this spot. This great evil arose from the lock at the entrance of the Sandford mill pond having been placed too high, in order, as it was supposed, to raise the high-water level. Before this alteration was made, barges of 160 tons could navigate this portion of the river, whereas now it was impossible for craft exceeding 30 tons to pass the same point. This was the gist of the whole question. It had been lost sight of by Engineers, in the general treatment of the Thames Valley, and had been got rid of in some way by the Thames Navigation Committee and other interested parties.

Mr. ALDERMAN RANDALL said, though he had no pretensions to scientific knowledge on this subject, he could bring the observation of many years to bear upon it. He was well acquainted with the peculiar features of the whole district of the Thames above Oxford, and could speak particularly as to the water being now brought down more quickly than formerly. Agricultural drainage had materially aided this, but he thought that larger operations had caused those sudden floods, with which the neighbourhood of Oxford had specially to contend. Above Oxford, there were some thousands of acres of meadow land, which formerly used to act as natural reservoirs, holding the water in suspension, as it were, and supplying the river by percolation through the summer. Across these meadow districts wide and deep channels had been cut, so that the water was no longer retained on the land, but was at once passed from the marshy grounds into the river; and any heavy rain-fall was, in like manner, conveyed more suddenly to the narrow part of the valley at Oxford, sometimes thus producing summer floods. At the large brewery of Messrs. Hall & Co., close to the old Castle Tower, at the back of which there were several low lying meadows, once belonging to the White Friars, there was formerly, as he was informed, considerable notice of a coming flood by the gradual rise of the river; whereas now the whole of the meadows were sometimes under water within a few hours. There could not be a more practical proof of the suddenness of the flow of water from the Upper Thames on to this district than was furnished by these facts, confirming as they did the opinion that the recently-made large cuttings, as at Aston Mead and at Standlake Common, across marshy districts, were instrumental in producing the evils described by Mr. Alderman Towle, as arising to the locality abutting on the narrow gorge of the river near Sandford. Besides this, however, it should be noticed, that it was at Oxford that the Cherwell flowed into the Thames, and the waters of that tributary were similarly swollen from the drainage of Otmoor Common. Prior to the systematic drainage of this extensive flat, it generally presented, through the winter months, the appearance of a large lake, from the hills, near Bicester, to the Beckley Hills, near Oxford; while now it was rare to witness such a flood after a heavy rain-fall. Even assuming that the natural autumnal fall had been to some extent taken up, by the lands being more thirsty than prior to the adoption of systematic drainage, the Cherwell, from the free influx of the surplus water through the deep channels intersecting the Otmoor district, would become more suddenly charged, and the mischief around Oxford would thus be aggravated, and the probability of flood be increased.

The Author had described the many sources of the perennial

waters of the Thames, as well as the causes specially producing flood water. These sources and causes appeared as existing largely above the gorge at Sandford, which held back the water upon Oxford in flood time, owing, as he believed, to the natural formation of the Valley of the Thames at that point, and not to any other cause. Much weight was to be attached to the remarks in the Paper, as to the changing deposit of gravel and soil in the bed of the river. He had himself witnessed a special illustration of the bad consequences of this below Sandford Mill. In 1862 he inspected, in company with one of the University Professors, the state of the river, then swollen by flood water, from Oxford to Abingdon. At the lower pound gate at Sandford, the water was nearly 3 feet above high-water mark. On the same reach, with no works of any sort to intercept the flow, and nothing but the old island at Nuneham legitimately to break the course of the stream, on proceeding to Abingdon, just above the pound gates, it was found to be only 5 inches above the high-water mark. On an after-inspection of the course of the river on this reach, the cause of this was soon discovered, as the manager at Mr. Norris's mill at Sandford had anticipated. The channel was materially affected in many places by such deposits as had been alluded to, but especially opposite Nuneham Park, where, at the fork of the river formed by the old Island at the cottages, within the last few years the deposit had formed in the centre of the stream a new island, now planted with trees. Under such a state of things, it must be evident, that there would be considerable difficulty in the escape of the water from the upper and narrower part of this reach, and the singular difference in the respective heights of the water at its two extremes was easily accounted for. Remedies, however, had been suggested for the relief of the Oxford district, and rough plans of them had been placed in influential hands. These were suggested by an inspection of the measures adopted at Abingdon, for the discharge of the waters there, from the reach just spoken of, where, by means of a paved towing-path at high-water mark, the swelling waters were passed on as soon as they reached that level. The late Mr. Treacher, for many years the surveyor of the Thames navigation, pointed out, at Sandford and at Ilfley, spots exactly suited for the application of similar means of relief. It was right to mention that at Sandford, Mr. Norris, the owner of the mill and of the land at the required spot, expressed his readiness to help forward this or any other reasonable plan, if his interests were protected, and means were provided for keeping in repair the projected works. Mr. Norris also added the reasonable request, that if the water was brought to the mill tail, the channel should be opened to Abingdon to relieve it. The drawings for long lashers, like paved towing-paths, 150 feet each at high-water

level, both at Sandford and at Illey, were placed in the hands of the Dean of Christchurch, to submit to the judgment of an eminent Engineer. He trusted that the efforts now being made would result in a well-devised measure, which, without prejudicing the landowners' interests, or injuriously affecting the navigation of the river, might improve the land throughout the whole of the valley, and benefit the sanitary condition of Oxford and its vicinity.

Mr. J. H. TAUNTON said, with regard to the early sources of the Thames in Gloucestershire, the springs at Thames Head, which had been spoken of as the principal feeder of the Thames and Severn Canal, rose at a level of about 330 feet above the sea (taking the Ordnance datum); and their volume was usually from 350 to 400 cubic feet per minute. He had never known them to afford less than 200 cubic feet per minute.

He did not understand whether the Author considered that these springs issued from the Oxford clay, or from the lower clays of the great oolite series.

Mr. CLUTTERBUCK said, the water at Thames Head issued from the oolite, which was overlapped to the south by the Oxford clay; thus it received no additional water after it passed the junction of these strata. In September 1862 no water flowed from the head, as he had stated in the Paper.

Mr. TAUNTON proceeded to remark that, in his opinion, the Oxford clay had nothing to do with the out-throw of the Thames Head springs. From borings made in the locality many years ago, he believed that these springs issued from a bed of blue clay, probably the fuller's earth, 27 feet in thickness, at Thames Head, and which was under the great oolite. It was in consequence of that alone, that these great springs were brought to the ground. Below this point, there were the Ewen Springs, the average yield of which might be taken at 150 cubic feet per minute; so that the whole of these springs gave, on an average, fully 500 cubic feet per minute. The River Churn, the next feeder, rose in the Cotswold Hills, at Seven Springs, near Cubberley, about 6 miles from Gloucester. The stream there was inconsiderable, but before it had passed the lias bed, the volume was increased. Gaugings which he took, in the autumn of 1849, just below Colesbourn, showed that the flow there was 420 feet per minute. After passing Colesbourn, the flow was diminished, some of the water being lost in passing the inferior oolite. The principal source of the River Coln was at Syreford, near Andoversford, and it also received a supply from a great number of springs which proceeded from the oolite. Gaugings taken at Fairford Bridge, on 22nd March, 1854, showed its volume to be 4,700 cubic feet per minute. He had calculated the

drainage areas of these different gathering grounds, and found that of the Thames Head Springs and of Swill Brook to be 75 square miles, that of the Churn Valley was 64 square miles, and of the Coln 86 square miles, while that of the South Ampney Springs was 25 square miles, making a total area of 250 square miles. Now, a rainfall of 12 inches over that area would give a volume of upwards of 13,000 cubic feet per minute. It was stated, in the Paper, that at Wolvercot the summer flow was 8,120 cubic feet per minute, and the winter flow 17,224 cubic feet per minute, with a velocity in the former case of 58 feet per minute, and in the latter of 95 feet per minute. The mean of these quantities would be 12,672 cubic feet per minute, and assuming the drainage area at Wolvercot to be only 600 square miles, that result would be produced by 5 inches of rain, whereas the rainfall in that locality averaged about 30 inches a year. He therefore thought that the average flow of the river at Wolvercot must be much larger than had been stated, and that the sectional area of the river at that point must be greater than 140 square feet.

With regard to the navigation of the Thames, he thought there were other causes, than those generally assigned, for its present state. In reference to the remark attributed to the late Dr. Buckland, "that no lines of inland navigation could flourish, except they ran transversely to the lines of strata, as their variation ruled the products, and internal commerce of the country," he considered it empirical, and that the London clay traversing the greater part of the course had not much to do with the question, except so far as that it did not contain minerals. The interests on the Thames were distinct and separate. The right of the river belonged, in the first place, to the weir or millowner, and consequently the weir also. He had the right of pounding, and no boats could pass without he chose to pound, and he would not do so unless he was paid for it. At every weir there was a separate right. In addition there were the Thames Commissioners, who made the locks to pass the weirs. These different authorities must be made to accord before any real improvement could be effected; but there were so many weir and millowners' rights, and so many who took no interest in the navigation, that it was a difficult matter. With regard to the floods, the right of the weir or millowner extended to the fishing, and that right was most valuable in the early period of the flood. The eels began to pass just when the flood commenced to overspread the banks. It was at this time important to keep all the sluices down, except the one through which the eels were to pass. On some occasions, as the flood set in, as many as 4 cwt. of eels were caught. That was just the critical time when the flood should be let off; but the millowner had the right of pounding to what was called the old

'flash' mark, and that right he strictly preserved. He cared nothing for the flood, but he sought to catch as many eels as he could.

Mr. JOHN TAYLOR stated, that a survey of the River Churn, one of the principal tributaries of the Upper Thames, had been made under the direction of Mr. Simpson (Past President Inst. C.E.), in the dry period of the autumn of 1859. The gaugings of the volume of water, and other particulars then obtained, showed some extraordinary circumstances, with reference to the loss of water, by percolation, through the bed of the River and the Fish and Mill Ponds upon it. The flow from the Seven Wells, (the springs forming the source of the river in the Cotswold Hills) was ascertained to be 11 cubic feet per minute. At one-eighth of a mile below this point, the quantity had increased to 21 cubic feet per minute, and thence the increase continued, somewhat in proportion to the drainage area, as would be seen by the following Table:—

At $\frac{1}{4}$ mile below the springs the flow was 31 cubic feet per minute.				
$\frac{1}{4}$	"	"	"	61
1	"	"	"	73
2	"	"	"	105
$2\frac{1}{2}$	"	"	"	165
$4\frac{1}{2}$	"	"	"	312
$5\frac{1}{2}$	(estimated as the maximum)			320

At this point, however, the volume of the river, instead of increasing, began to diminish, for,

At $6\frac{1}{2}$ miles from the spring the flow had decreased to 290 cubic feet per minute.				
7	"	"	"	235
$7\frac{1}{2}$	"	"	"	179
8	"	"	"	113
$8\frac{1}{2}$	"	"	"	45
$9\frac{1}{2}$	"	"	"	33
$12\frac{1}{2}$	"	"	"	30

and at $14\frac{1}{2}$ miles the quantity had actually become reduced to 10 cubic feet per minute, or less than the original flow of the Seven Wells. From thence to the junction of the river with the Thames at Cricklade, 22 miles from the source, the flow again gradually increased up to 110 cubic feet per minute. Thus, in a length of less than 8 miles of the course of this river, there was a measured loss of 300 cubic feet of water per minute, or 2,700,000 gallons per day. But even this was less than the actual loss, as, of course the stream would continue, under ordinary circumstances, to increase in proportion to the drainage ground, and allowing for this, the estimated flow at Cricklade ought to have been 450 cubic feet per minute, instead of being 110 cubic feet as gauged, thus showing a loss to the mills on the lower parts of the stream of 340 cubic feet per minute, or upwards of 3,000,000 gallons per day.

As to the geological character of the River Churn, the stream was derived, principally, from the drainage of a considerable area

of the inferior oolite, and was thrown out by a fault at Seven Wells; the upheaval of the impervious beds of the upper lias clay preventing percolation in the direction of the dip of the strata. The stream then took its course through a valley of denudation, where the upper strata had been swept away in some convulsion of nature, forming in parts a deep narrow ravine, surrounded by the Cotswold Hills, which were composed chiefly of the porous and fractured rocks of the oolite. It thence passed over the impervious beds of the upper lias clay for nearly 6 miles, from the source at Severn Wells, to Maresden Farm; next over the porous beds and fractured freestone of the inferior oolite for $3\frac{1}{2}$ miles to a little below North Cerney Mill, by the Rendcomb fish-pond and the mill-ponds and courses of Rendcomb and North Cerney Mills; afterwards flowed over the impervious beds of clay known as fuller's-earth, continuing past Perrot's Brook and Trinity Mill to the mill-pond at Baunton, a distance of about $2\frac{1}{2}$ miles; and then it traversed the porous rubble freestone of the great oolite for 1 mile, by Stratton mill-pond. At this point commenced the tenacious clays of the forest marble formation, which, partly overlaid with the gravel and detritus of the oolite, passed under Cirencester, Barton, and New Mill Ponds to the head of Preston Mill; the only remaining porous strata being a short length at Preston and Seddington Mills, where the rubbly rock of the cornbrash formation outcropped in the bed of the stream. Thence the course of the river, from Seddington Mill to its confluence with the Thames at Cricklade, a distance of 7 miles, was entirely over the impervious beds of the Oxford clay. Such being the bed of the river, there was no doubt, the vast quantity of water which continually disappeared, percolated through the fissures and fractures of the rocky bed, and through the porous strata in the bottom of the mill and fish-ponds; and sinking below the impervious beds of fuller's-earth, never rose again in the valley of the Churn, but was completely lost to that river, and possibly even to the River Thames. Certain remedial works, chiefly such as puddling the bottoms of the ponds, were advised to be done, at a cost not exceeding £3,000, which would probably have prevented the loss of all this water; and it was estimated that this outlay would have resulted in a saving of nearly £1,400 a year in water-power.

Mr. S. C. HOMERSHAM said, it was now generally well understood, that rain falling upon different geological formation produced different results. Thus, upon chalk, the rain was immediately absorbed, even to the extent of 2 inches or 3 inches in depth in an hour, as sometimes happened over an area, say, of 100 square miles; whilst upon the primitive formations, it at once flowed off the ground, into the neighbouring valleys. He believed that

the effect of draining clay lands directly into rivers, or into ditches that communicated with rivers, was, by removing the rain more rapidly, to increase the severity of the floods of the district. There were, however, hundreds of square miles of country, which for the last seventy or eighty years had been drained in a different way. For instance, where there was chalk, or other absorbent strata covered by clay 16, 18, or more feet in thickness, the drainage was effected by sinking in suitable situations, what were technically called dumb wells, from the surface through the clay for a few feet into the chalk, then filling the dumb wells with broken flints or stones, and conveying the water through drain tiles in the usual manner from the clay land into them. The effect was, that the rain, instead of flowing through various surface channels into the rivers and causing floods, was absorbed into the body of the chalk, and escaped underground into the sea. Floods in districts thus drained were much rarer than they used to be.

Allusion had been made to the gauge used by Mr. Dickinson, still incorrectly called a Dalton Gauge. On a former occasion, Mr. Homersham had stated¹ that the two were not alike, and he had shown in what respect they differed. Dr. Dalton's gauge was made with a view to register both the proportion of the rain which penetrated the ground, and also that which flowed off the surface. Accordingly, there was an overflow pipe, with a bottle, or vessel, to catch the water that passed off without entering the ground, as well as a vessel to catch the water sinking through the earth. The sum of these two quantities, deducted from the total rain-fall, would leave as a remainder the quantity that was evaporated. Now Mr. Dickinson avowedly employed only one vessel, or bottle, and this collected the water which percolated through the soil, but it gave no record of that which flowed off the surface. The consequence was that, for this and other reasons, the records of these gauges could not be depended upon; and for himself he did not hesitate to say, that having had occasion to make himself fully acquainted with them he placed no reliance upon the records of these gauges. It had been said that Mr. Dickinson was in the habit of regulating his contracts, as to the amount of paper he could manufacture, by the indications afforded by these gauges. Now Mr. Homersham doubted that, for at all Mr. Dickinson's mills in Hertfordshire, steam power, as well as water power, was applied for driving the machinery; the former being greater than the latter. Besides, there was an inexhaustible supply of water, from small wells, with bore-holes sunk in the bottom of each, at all these mills, from which, in the driest seasons, more water could be obtained than was ever required for the manufacture of paper.

¹ Vide Minutes of Proceedings, Inst. C.E., vol. xiv., p. 82.

During the last twelve or fifteen years, numerous wells had been sunk into the chalk, for the purpose of obtaining water, without a single failure, so far as he was aware. At the present time the same thing was being done with the greatest success. Only a few years ago, the town of Hull was entirely supplied with water from the river: now it had sufficient for its whole supply from wells and bore-holes sunk into the chalk. Again, a large district of London was now supplied by the Kent Waterworks Company with from 4,000,000 to 5,000,000 gallons of water a day, obtained from wells sunk in the chalk, while for more than a century before, their whole supply had been taken from the River Ravensbourne. The wells not only yielded water abundantly, but the level of the water had not been lowered by the pumping. Therefore, he thought the Author was not justified in his views, as to the impolicy of sinking wells to procure large supplies of water from the chalk; and personally he had no confidence in any statements, with respect to the permanent lowering of the surface of the water in wells sunk in the chalk.

Mr. J. F. BATEMAN remarked that the facts and figures given in the Paper were not sufficiently numerous or minute to enable many deductions to be drawn from them. The area was not mentioned from which the water was collected, nor were there any particulars as to the quantity of water per acre, per minute, or during any other period of time. His acquaintance with the Thames was confined to the upper and lower ends; but of the main valley he had very little knowledge. He was, however, able to furnish some measurements of the flow of water in other streams in different parts of the country, showing the large amount of flood water that came off the land under certain circumstances in some districts, and the comparatively small amount which came from other districts under different circumstances. There was no doubt, that all the information that could be obtained, as to the amount of floods, the manner in which they rose, and the causes to which they were attributable, was valuable in an agricultural and engineering point of view. During the years 1833, 1856, and 1857, he had the means of ascertaining, with great accuracy, the quantity of water flowing off the ground, in a given time, by the River Medlock at Manchester. That river was a short stream, running through the city of Manchester, and draining only about 12,000 acres, principally of clay land. The maximum quantity of water passing off in those years was equal to a depth of 4 inches, 5 inches, and 6 inches respectively every twenty-four hours; that was, the volume of the floods when at their maximum was such, that those would have been the depths of water flowing from the ground had the floods continued at the same height for twenty-four hours consecutively. At the Manchester Waterworks, during the flood

of February, 1852, which might be remembered as the time when the Bilberry Reservoir, near Holmfirth, in Yorkshire, was carried away, the water which came down from a district of 15,400 acres, was measured either in reservoirs, or through discharge pipes and gauges. The flow, when at the highest, was from 3,600 to 4,000 cubic feet per second, or 25 feet per second for each 100 acres, or 15 cubic feet per acre per minute, being at the rate of between 6 inches and 7 inches in twenty-four hours; and the mean flow during the same period was 1,520 cubic feet, or $2\frac{4}{7}$ ths inches per second. In 1856, the quantity of flood water flowing into the Woodhead Reservoir, of the Manchester Waterworks, from an area of 7,000 acres, was equal to 2,100 cubic feet per second for seven hours forty minutes, or a depth of $2\frac{1}{2}$ inches, being at the rate of 7 inches in twenty-four hours. This quantity was equal to 18 cubic feet per acre per minute. In 1849, during the early progress of the work, a flood occurred at Woodhead which, at its maximum, amounted to 50 cubic feet per second for every 100 acres, or 30 feet per acre per minute, being at the rate of 12 inches in twenty-four hours. He had also some further measurements of the flood of May, 1862, at the Woodhead Reservoir, from the same district of 7,000 acres. For a period of two hours and a half, the flow was equal to $22\frac{1}{2}$ cubic feet per minute per acre; for seven hours it amounted to $14\frac{8}{10}$ ths cubic feet per minute per acre, and for thirteen hours to $9\frac{1}{3}$ rd cubic feet per minute.

At the Glasgow Waterworks, in October, 1854, the flood from Loch Lubnaig, Loch Voil, and Loch Doine, (the water surface of the lochs being about $\frac{1}{3}$ th of the total drainage area of 44,600 acres,) was equal to 328,000 cubic feet per minute, or a depth of 3 inches flowing off in twenty-four hours, and $7\frac{1}{2}$ cubic feet per acre per minute. On the same day the volume of the flood flowing out of Loch Venachar, from a drainage area of 45,800 acres, but where the surface of the lochs was $\frac{1}{11}$ th of the whole, the flood only amounted to 150,000 cubic feet per minute, not one half of that which flowed from Loch Lubnaig, from about the same area and the same rain-fall. This showed the regulating effect of large lakes, or sheets of water. The quantity stored in and discharged from Loch Katrine in twenty-four hours was equal to nearly 4 inches, while in two days it was equal to 6 inches of rain over the whole drainage area. The surface of Loch Katrine formed $\frac{1}{8}$ th of the whole drainage ground of 23,300 acres.

In the River Clyde at Carstairs, in the winter of 1856-57, from a drainage area of 190,000 acres, the flow of water was equal to 20,000 cubic feet per second, or 6 feet per acre per minute; and of that quantity only 9,000 feet passed down the river channel, the remainder sweeping over the flooded land.

From a Table of the measured maximum quantities of water

in various parts of the extensive valley of the Shannon, he would instance the measurement at Killaloe: Here the drainage was from a total acreage of 2,560,000, and the quantity of water in flood was 1,600,000 cubic feet per minute. The discharge of various large rivers into the basin of the Shannon, from actual measurement in flood, varied from 0.76 to 1.54 cubic foot per acre per minute, the latter being a maximum. That contrasted very strikingly with the quantities he had given from mountain districts in England and Scotland, where they amounted to 6, $7\frac{1}{2}$, $9\frac{1}{3}$, 15, 18, and in one case 30 cubic feet per acre per minute. He gave these measurements for the purpose of drawing attention to the great differences which existed, in order that one river might not be taken as a guide for calculations upon another, except when the circumstances were similar.

Mr. FREDERICK BRAITHWAITE remarked that, from the statements which had been made, it was evident a large quantity of the flood water which was supposed to fall into the Thames, did not reach the tidal part of the river below Teddington Lock. Of late years, in dry seasons, there had at times been so little water flowing over the lock, that the salt water had nearly reached as far up as Hammersmith. Moreover it was stated, that from ninety to one hundred million gallons of water per day were now being taken from the river above Teddington Lock for the supply of London; and as, by the main outfall intercepting sewers, the whole of that quantity, together with the rain falling on the area so drained, would be conveyed beyond the metropolis, to Barking Creek and to Erith, it was important to ascertain, what would be the probable effect of the abstraction of so large a body of fresh water from the tidal part of the river. It was manifest that it must lead to the intrusion of a still larger quantity of salt water. Dr. Letheby had recently stated,¹ that the mixture of a large proportion of salt water with the fresh water was likely to be attended with unhealthy results, as noxious exhalations would arise from the mud on the banks, in dry weather.

The Author had referred to the subject of evaporation, both from the earth and from a surface of water, stating that in the latter case the amount was very small; and citing in proof of this opinion, the case of two vessels both filled with water, but in one of which a brick was placed, and that the evaporation was much greater in the vessel containing the brick than in the other. Now, all evidence went to show, that the amount of evaporation from water was 30 inches per annum. He could readily understand, that if a porous substance was put into a vessel of water, the sur-

¹ Vide a letter in "The Times," March 16, 1863, p. 10, headed "The Water of the Thames."

face of evaporation was increased, and also the amount of capillary attraction which assisted the evaporation.

Some observations had been made, in which he did not concur, with regard to Mr. Dickinson's rain-gauge. He thought that the overflow pipe of the rain-gauge had nothing to do with evaporation; and that the absorption was dependent upon the nature of the soil. There were some descriptions of soil which would variously absorb from 20 per cent. up even to 60 per cent.; therefore it was unphilosophical to generalise, nor could it be done with any approach to accuracy.

Mr. R. B. GRANTHAM said, the map which had been prepared for the Salmon Fisheries Committee, by Colonel Sir Henry James R.E. (Assoc. Inst., C.E.), a copy of which he then presented to the Institution, gave some interesting details of the water-shed of most of the principal rivers in England, amongst the rest, of the Thames, and was a most important document for all who were interested in the drainage of the country. The areas of the catchment drainage of two hundred and four rivers and their length were enumerated, from which he had extracted the following particulars relating to a few of the principal rivers:—

	Area in Square Miles.	Length in Miles.
Thames	5,162	201 $\frac{1}{4}$
Ouse (Yorkshire)	4,207	59 $\frac{1}{2}$
Trent	3,543	167 $\frac{1}{2}$
Severn	4,437	178
Nen	1,055	99
Great Ouse (Cambridgeshire)	2,894	156 $\frac{1}{4}$
Mersey	1,706	68
Tyne	1,053	35
Witham	1,052	89
Medway	997	69
Humber	1,229	37
Wye (Herefordshire)	1,655	148

It would be extremely useful if this inquiry could be extended, so as to include the catchment basin of the minor rivers.

The Valley of the Upper Thames did not appear, from the description, to differ materially from the formation of the valleys of other rivers, except from its magnitude. It consisted of a series of large and flat areas, at places throttled by the hills, and by the undulations of the country closing upon and narrowing the valleys. It was at those places, he believed, where the gorges occurred, that the greatest improvements might be made, and to which the attention of Engineers should be directed, to draw off the floods. But the Paper, though interesting in a geological point of view, as showing Engineers the sources whence water was derived,

gave no suggestions as to the mode of treating the Valley of the Thames, so as to improve its drainage.

Mr. GRAVATT said, he should not have been induced to make any remark, had it not been stated, that the present condition of the Thames Navigation and Drainage rather implied a low state of Engineering skill in such matters. He had had to do with Navigations, Mills and Drainage for many years; amongst others with the Calder and Hebble navigation, and he was old enough to have actually constructed a Canal, called the Longport navigation. The Calder and Hebble works were originally laid out by Smeaton for a 3-foot navigation; and, as an instance of Smeaton's foresight, when the depth had to be increased to 5 feet, there was only one lock-cill that had to be altered, and that lock, Mr. Gravatt found, had been built by another Engineer, to avoid a local opposition. The real difficulties were not at all of an engineering character, but they arose from the supposed difference of interests, between Navigation Proprietors, Drainage Commissioners, and Millowners. Where these parties agreed, the Engineering difficulties almost vanished. As one instance out of many, already known to several Engineers, he mentioned that when the proprietors of the Calder and Hebble Navigation bought the Mills, there was no further difficulty. The Navigation proprietors, who had been before subject to continual lawsuits, completed their works, at a moderate expense, and the rents of the Mills actually increased. The power of half ruining a navigation, or of flooding large tracts of land, for the sake of a few hundred-weights of eels, was a legal power possessed by many persons; but the difficulties that arose from such a source could not seriously be called engineering difficulties. He thought sufficient had been said to show, that the present state of the Upper Thames was not to be attributed to any fault of Engineers, or their works.

Mr. FREDERICK KING said, as a resident, for upwards of forty years, upon the banks of the Upper Thames, he had witnessed the most prosperous trade in the navigation, the many abuses practised upon the stream for the monopoly and misuse of the waters, and subsequently its decline and fall. For more than twenty-five years he had endeavoured to suggest remedies for the evils existing in this, the most fertile valley, and perhaps the most abused in England. He had been engaged as the valuer under several enclosures of meadow districts, between Oxford and Lechlade, subsequently followed in the same district by the late Mr. Woolley, one of the Enclosure Commissioners, and since by Mr. Bryan Wood. All had encountered the same difficulties, that whilst cuttings and drains could be made, no proper outfall could be obtained, for the system of economising the water in former days was such, that the whole valley was submerged, and the land a perfect swamp,—the habi-

tation of wild-fowls. This was considered, though erroneously, to be necessary by many, when the only means for the transport of coal, corn, timber, slate, stone and heavy goods was by navigable streams, and more recently by canals, and when water was almost the only motive power for grinding corn, and working the rude machinery of bygone days. He feared that the way in which Dr. Acland had taken up this subject was calculated still further to complicate it, by not keeping it separate from that of the disposition of the Sewage of Towns, a question which must have its issue first in London, when the main drainage works were completed.

The Paper was interesting, as it professed to show the source whence the water was derived which had to be dealt with. He believed that both in an agricultural and in a sanitary point of view, nothing more was required than the perfect drainage of the now water-logged valleys, so as to convert the swamps which now disgraced them into fertile vales, by which the health of the inhabitants of the numerous towns and villages situated on the course of all navigable rivers would also be improved. The plan formerly adopted, for securing the largest supply of water for navigation purposes, was to place a lock, or weir, immediately below a great outlet of land drainage, or of tributary streams running into the main river, by which, when the locks, or weirs were closed, instead of filling the river, (itself sufficient for all the purposes of navigation, if properly fed,) thousands of acres of rich land were unnecessarily submerged, or partially so. It was a fact that at the present time, not one boat passed annually down the Upper Thames from Lechlade to Oxford, and yet the water was still impounded. Even in hay-time, in dry summers, the water was dammed up to a depth of 3 inches to 6 inches amongst the hay, the herbage being water-plants, instead of nutritious grasses fit for animal sustenance. This occurred now, he believed twice a week, when the water was impounded for the purpose of sending down the unnecessary semi-weekly 'flashes.' If the river were made a perfect canal, and the land drainage was allowed to fall into the main stream immediately below a lock, mill, or weir, as the case might be, instead of immediately above it, this state of things would be remedied. Any increase in the tail water, tending to diminish the motive power, would be compensated by the head-water being raised in a corresponding degree, by the admission of the land drainage into the river at a higher level.

The observations in the Paper went to show that the great evil in the level of the Upper Thames was occasioned by the narrow gorge at Sandford, where the coralline, or coral rag, overlapped the Oxford clay. One of the consequences above Oxford of this great natural obstruction was that the levels of Wolvercot Mill,

King's Weir, and Wytham Mill Streams, had all been raised, within the time named, by the improper addition of new cills on the old ones, by which many acres of land had been flooded nearly a foot deep. This was only one of many similar abuses. Thus the damming up of Shire Lake Ditch at the top of Godstow, and of Swift's Ditch at the bottom of Godstow Liberty, had ruined Port Meadow, improved Binsey, and swamped Oxford. The treatment of all navigable valleys was a national question, affecting the production of food for cattle, and consequently of food for the people, and this could only be properly done by the application of Parliamentary Powers, the preliminaries of which in his opinion were, forming each valley into an elective drainage district, or districts, giving one-tenth of the proprietors of any area requiring a combined system of drainage, power to apply to the Enclosure Commissioners, to constitute such lands into a separate elective drainage district, with a saving clause as to the consent of existing Commissioners of Sewers, Town Councils, Local Boards of Health, or Improvement Commissioners. Upon receiving this Petition, the Commissioners should appoint an Inspector to make local inquiry as to the propriety of the boundaries of the areas proposed to be drained, &c. In the event of the proprietors of one-third of the land comprised within the area dissenting, within a given time, the Commissioners should dismiss the Petition. He suggested that the area to be dealt with was the alluvial strata of the whole valley, as laid down on the Geological Maps of the Ordnance Survey.

The Rev. J. C. CLUTTERBUCK said, in reply upon the discussion, that though he had had access to much information from landowners, he found it impossible to ascertain the extent of agricultural drainage, or to make any calculation of the drainage area of each tributary stream. It must be remembered that the whole area, 1,500 square miles, comprised every variety of soil, involving most complicated geological conditions. Thus, the water was thrown to the surface, in some districts, by the underlying lias clays, in others by the fuller's-earth, in another by the clay beds of the forest marble, and then from the extended surfaces of the Oxford, Kimmeridge, and gault clays. He had described the geological condition of districts drained by each tributary, and must refer to the Paper for all the information he could give. The accuracy of the gaugings had been questioned, the minimum flow at Wolvercot being deemed too small. Certain gaugings at other points were brought forward; but to show that these latter could not be relied on, it was only necessary to refer to the case of the Churn, a very considerable tributary, which decreased in its course from 320 cubic feet to 110 cubic feet per minute. It had also been stated that the Thames Head seldom yielded any water to the river. Averages of rain-fall afforded no guide

to the minimum flow of rivers, which could only be ascertained by actual observation. Personally he had great confidence in the gaugings at Wolvercot, as they were taken by a man of experience and an accurate observer. Mr. Treacher, the late surveyor of the Thames, had informed him that, in 1855, the perennial flow in the Thames was so much reduced, owing to the rain-fall in the previous eighteen months only amounting to the yearly average, that all the flood-gates at the Pangbourn Lock were opened at one time, a fact without example in his long experience. With regard to the capacity of the river for the discharge of flood-water, when the river at Clifton Hampden, between Abingdon and Wallingford, ran 'flash' high, the flood-gates at the lock being shut, the velocity was 134 feet, and the discharge 51,000 cubic feet per minute. In January, 1863, when the flood attained its height, on the flood-gates below being drawn, the velocity was increased to 265 feet, and the discharge to 182,000 cubic feet per minute, though the area occupied by the flood was only doubled. He believed that Mr. Bryan Wood's system of confining the flood by low banks would be generally adopted, in executing the so-much-needed improvements of the Thames Valley.

With regard to the objections to the experiments on evaporation, experience would show, that the increase of winter evaporation from drained soils would tend to diminish winter floods. He believed that the amount of evaporation from a surface of water, or the wet surface of the soil, was over-estimated. In corroboration he could refer to the dew-ponds on the downs, which, when once filled, were never without water: he repeated his belief that the extension of agricultural drainage would tend to decrease floods. As to the remark that in Dalton's gauge no account was taken of the overflow from the surface of the soil, on looking to the daily records of that gauge, he observed that when rain commenced, only 1 inch out of $1\frac{1}{2}$ inch was recorded, showing that the $\frac{1}{2}$ inch went to replace the previous evaporation. If the rain continued, as in January, 1863, the whole of the next inch would percolate to the lower receptacle, and there would be no waste by overflow. As to what had been said about the water supply to be obtained from the chalk, it should be remembered that the London wells alone had been alluded to, in the Paper; and he believed that the decrease in the level of the water in many of the wells of the large breweries in London confirmed his view. At the same time he could confidently affirm, that many towns depending for their supply of water from chalk wells might draw too heavily upon the quantity of water at command.

Mr. HAWKESMAW, President, in thanking the Author for his useful communication, which he regretted not to have heard read,
[1862-1863. N.S.]

would only observe, that as far as he had considered the matter he thought it probable, that extensive agricultural drainage might have the effect of decreasing floods.

At this Meeting it was resolved unanimously :—

“That in consequence of the marriage of H.R.H. the Prince of Wales having been fixed for Tuesday, the 10th of March, there should not be any Meeting of the Institution on the evening of that day.”

March 17, 1863.

JOHN HAWKSHAW, President,
in the Chair.

The discussion upon the Paper No. 1,074, on “The Perennial and Flood Waters of the Upper Thames,” by the Rev. J. C. CLUTTERBUCK, occupied the whole evening to the exclusion of any other subject.

March 24, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,075.—“Description of the Lydgate and of the Buckhorn Weston Railway Tunnels.” By JAMES GRANT FRASER, M. Inst. C.E.

IN introducing a Paper on so important a subject as Railway Tunnels, the Author feels considerable diffidence, on account of their long existence, and the extensive knowledge already possessed by Engineers relative to their construction. Yet the paucity of recorded information of a practical character, in the Minutes of Proceedings of the Institution, or elsewhere, on this interesting branch of Civil Engineering, would furnish an excuse, if one was required, for hazarding a Paper on such well-known structures.

The late Mr. R. Stephenson, M.P., in his address as President, delivered January 8th, 1856, stated,¹ that nearly 70 miles of tunneling had then been formed in Great Britain. It may not, therefore, be inaccurate to assume 80 miles as representing the length of tunnels now daily traversed by railway trains in the United Kingdom; and supposing that they have cost, on an average, £45 per lineal yard, the capital expended in their construction will have amounted to the enormous sum of about six and a half millions sterling. Up to the present time, communications referring to a length of only 3 miles of tunnels, constructed at a cost of about one-quarter of a million, or one twenty-sixth of the total expenditure, have been read at the Institution, so that it is manifest this class of work has been inadequately chronicled. Each tunnel has its own peculiar history; the variety of strata, the springs of water, &c. all require different treatment, and have demanded a greater amount of forethought, and probably occasioned more anxiety to the Engineers, than any other description of work. Kilsby, Box, Woodhead, and many other tunnels, remain as bold illustrations of conquered difficulties, but their histories are still untold. If particulars of all important Engineering works were, either during their construction, or immediately after their completion, transmitted to the Institution, for the information of the members, more effectual remedies might in many cases be practised, with advantage to public economy.

¹ *Vide Minutes of Proceedings Inst. C.E.*, vol. xv., p. 125.

In selecting instances for this Paper, the Author will confine himself to descriptions of two tunnels that have been executed under his immediate superintendence, upon lines of which Messrs. Locke and Errington were the Engineers-in-chief.

The Oldham branch of the London and North-Western Railway commenced by a junction with the main line at the Greenfield Station, and terminated at the Oldham Station of the Lancashire and Yorkshire Railway. Its length was 3 miles 64 chains, and it was constructed at a cost of £35,000 per mile, exclusive of the purchase of land.

The Lydgate Tunnel on this branch was driven through the coal measures. The accompanying longitudinal section (Plate 8, Fig. 1), prepared from measurements taken during the progress of the works, illustrates the geological details. Faults are common in this formation; sometimes severing it in the line of the dip, at other times in the line of the bearing. Several of these distortions were met with in this work. Plate 8, Fig. 2, exhibits the singular manner in which one of these presented itself, one half of the tunnel being in strong shale and rock in veins, whilst the other half was in a mass of wet and loose shale. The lengths of the different strata cut through were,—

Clay and loose shale	210 lineal yards.
Strong shale	335 "
Strong shale, interspersed with bands of rock	474 "
Rock, with veins of shale	135 "
Rock	130 "
Limestone	13 "
Fire-clay	30 "
Coal	5 "
<hr/>	
Total length of the tunnel	1,332 "

Five shafts were required for completing the tunnel within the time specified: their total depth amounted to 289½ lineal yards, and the average rate of sinking each was 11 yards per month. Four were left for permanent ventilation, the space between them being about 230 yards. No. 1^a had formerly been a colliery shaft, and had not been used for many years. It was reopened by the Contractor, and from it a cross-heading was driven into the tunnel, the centre of which was 40 feet distant. Great care had to be exercised in fixing the centres through the portion lined from this heading (24½ lineal yards), as part was on a curve, and part on a straight line. Fortunately perfect accuracy was secured. The proximity of the shafts checked much inconvenience arising from foul air. Where it occurred, fans were

fixed on the surface, and a volume of air was forced down, and conveyed through pipes, fastened along the tunnel. A sufficient supply was thus transmitted, to enable the miners to form a junction between the headings. In the neighbourhood of the old coal-workings, which ran across the tunnel, a considerable amount of choke-damp was met with. To overcome its effects, a bore-hole was sunk from the surface, and was lined with an iron pipe, down which fresh air was forced.

The sinking of the shafts was carried on in the usual manner, by excavating through soft material, and drilling and blasting through rock. After attaining the average depth of 60 feet, the material was raised by engine power. The four permanent shafts were lined with 9-inch brickwork, or about 12 inches of masonry, except where in rock. They were finished at the soffit of the tunnel with ashlar curbs about 2 feet 3 inches deep. Where water penetrated, iron shields, with a gutter round the edge, were suspended, and the water was conveyed by a pipe, down the side of the tunnel, into the regular channels. The shafts were carried up 12 feet above the surface of the ground, and were completed with an ashlar coping. They were circular in plan, their diameter being 9 feet in the clear; this size was, however, found to be insufficient to allow of the skips ascending and descending simultaneously, which occasionally caused a short delay. A slight increase in the diameter would have prevented this. A steam engine of 9 H.P. was fixed at shaft No. 1^a, and locomotive engines between shafts Nos. 1 and 2, and shafts Nos. 3 and 4, each locomotive working two shafts.

The following table gives the depths of the shafts and the rate of sinking, which averaged 11 lineal yards per month:—

No. of Shaft.	Commenced.	Completed.	Depth to the Formation Level.	Rate per Month.
			Lineal Yards.	Lineal Yards.
1 ^a	August, 1854 . . .	October, 1854 . . .	27½	..
1	Ditto . . .	November, 1854 . . .	53½	13
2	Ditto . . .	February, 1855 . . .	80	13
3	Ditto . . .	February, 1855 . . .	75½	12½
4	Ditto . . .	January, 1855 . . .	53	5
		Total . . .	289½	43½

With the exception of the faces worked from each cutting, and amounting to 141 lineal yards, through which a bottom heading was driven, the tunnel was 'mined' by a top heading, 6½ feet by 4½ feet, being first made. The shafts furnished ten faces, and 1,191 lineal yards out of the total length, were worked from them, each face averaging 17·26 lineal yards per month. The open ends gave four faces, and both equalled 9 lineal yards per month. The

lengths mined from the different shafts are given in the following table :—

No. of Shaft.	Lengths Driven.		Total.	Time occupied.	Rate per Month.
	East.	West.			
	Lineal Yards.	Lineal Yards.	Lineal Yards.		Lin. Yards.
1 ^a	138	107	245	1854, Oct., to 1856, March	15
1	157	126	283	" Dec., "	19
2	100	96	196	1855, March, "	16
3	95	108	203	" " "	17
4	119	145	264	" Feb., "	19
Faces	95	46	141	" Oct., "	9
		Total	1,332		95

There was no peculiarity in the mode of excavating in this case, rock and strong shale being blasted by means of powder, and the softer material, clay and loose shale, being displaced by the pick-axe. When the top heading had been driven for the full distance of each length, the crown was protected by poling boards and bars of larch, which description of wood is almost universally adopted for bars, on account of its strength, combined with its elasticity. After the ground was secured, it was widened out to suit the shape of the tunnel, and the same description of timbering was continued to 9 feet, or 10 feet above the formation level; the distance between the bars being gradually increased. The earth was removed in iron skips, (capable of holding half a cubic yard each), which were placed on light 'trolleys,' and were pushed along tramways laid between the work and the shafts. They were there raised by engine power, and tipped on the spoil-banks on the surface of the ground. The contract price for this, without distinction, was 4s. 6d. per cubic yard, including all the timbering.

Where expedition is an important element in the construction of tunnels, the common mode of sinking shafts and multiplying the number of faces presents many advantages; and it is doubtful whether mechanical contrivances will ever bear comparison with manual labour, when it is possible to get several points simultaneously under the miners' operations. Another system, occasionally followed, is driving a heading near the rail, or formation level, and at intervals forming a 'break-up.' This becomes, in fact, the shaft of the former method, and presents the working faces. But it can be easily understood, that one opening for a number of men and a quantity of materials is not so successful in rapidity, as the system of sinking shafts, each of which affords a free channel for supplying all the requirements of the labourers. Again, no progress can be made with this heading, until the cuttings, or their gullets, are

run up to the faces of the tunnel, and there are frequently obstacles to this being done, as the gradients do not always admit of the drainage being preserved. A bottom heading likewise necessitates a much longer exposure of the sides to the action of the atmosphere, which, in clays and marls, loosens the ground, causing weight to follow, and in rock opens the fissures. As a rule, in tunnel construction the masons, or bricklayers, should commence lining the ground prepared by the miners, as soon as possible after it is ready.

The lengths mined, before lining with masonry, varied according to the nature of the ground; averaging in loose shale 3 lineal yards, through strong shale 5 yards, and through rock 8 yards, and in some instances 10 yards. The prices paid to the miners varied from £8 to £18 per lineal yard, according to the material; nearly one-half of the total length of the tunnel amounting to £12 per lineal yard, or less.

The centres consisted of skeleton ribs, placed about $1\frac{1}{2}$ yard apart. At the leading end two sets were fixed close together for greater security. This description of centering is very suitable for this kind of work, on account of its lightness, its non-liability to be injured by the masses of rock scattered about after blasting, and the facility with which it can be readjusted to the true contour line when distorted in the work. The price allowed for setting the centres was 8s. per rib.

The masonry used in building the side walls was coursed rubble, the beds of the stones being punched with a hammer. The footings were not less than 18 inches below the formation level, and the walls were carried 7 feet 3 inches above the level of the rails; the tunnel being 24 feet 6 inches wide at that point. The arch for about 632 lineal yards was turned with fitted rubble, but from the scarcity of good bedded stone, 700 lineal yards of arching had to be built with brickwork. The contract price throughout for masonry was 20s. per cubic yard. The time the masons and labourers were allowed for building, with the cost, was as follows:—

Side walls, 2 feet 6 inches thick, and 12 feet in length,	
4 masons, $1\frac{3}{4}$ shifts of 8 hours = 7	at 5s. 6d. £1 18 6
9 labourers " " = $15\frac{3}{4}$	at 3s. 6d. 2 15 $1\frac{1}{2}$
Arch, 2 feet thick, and 12 feet in length,	
4 masons, 3 shifts = 12	
2 ditto, extra, for key, 1 shift = 2	14 at 5s. 6d. 3 17 0
11 labourers, 3 shifts = 33	
3 ditto, for key, 1 shift = 3	36 at 3s. 6d. 6 6 0
	<hr/>
	£14 16 $7\frac{1}{2}$

or about 4s. 9d. per cubic yard.

The mortar was composed of barrow stone lime, mixed with coal ashes, in the proportion of 2 to 1, ground by heavy iron rollers, and used fresh. Its setting power was most satisfactory.

Where much weight showed itself, by the bars either sagging, or springing, the crown bars were built in, and the spaces between, called the 'mid-feathers,' were filled with brickwork. The ordinary practice is to draw the bars after the arch is keyed, and then to pun in earth, filling the mid-feathers with masonry. One of the most important features in tunnel building is the prevention of any motion in the ground, as when it occurs there is always great expense in overcoming it, and many failures may be traced to this as an originating cause. In cases where water was met with over the crown of the arch, the tunnel was covered with zinc, terminating in a gutter to convey the water to some convenient point, where a pipe was built through the masonry, for its discharge into the proper drains.

There was considerable variation in the thickness of the masonry. In shale, the strength of work was as shown in Plate 8, Fig. 3; whilst in rock, the section Plate 8, Fig. 4, was adopted. The following table gives the lengths of each thickness built:

Length.	Thickness.		Earthwork, per Lineal Yard.	Masonry, per Lineal Yard.	Total Masonry.
	Side Walls.	Arch.			
Lineal yards.	Ft. in.	Ft. in.	Cubic yards.	Cubic yards.	Cubic yards.
10	3 6	2 6	84	20	200
30	2 9	2 6	82	18½	547
16	2 6	2 6	81	17½	280
30	2 6	2 3	79½	16½	490
120	2 6	2 0	78	15½	1,890
119	2 0	2 0	76	14½	1,725
62	2 0	1 9	74	13½	827
24	2 0	1 6	72½	11½	282
500	1 9	1 6	71	11½	5,667
421	1 6	1 6	70	10½	4,526
1,332	..	..	..	..	16,434

The average quantity of masonry per lineal yard was $12\frac{1}{2}$ cubic yards.

The total length of the tunnel was 1,332 lineal yards. The first length was keyed in on the 27th October, 1854, and the last was finished on the 21st March, 1856, a period of seventeen months, or about 80 lineal yards per month, irrespective of the shaft-sinking. The tunnel was on a straight line for $47\frac{1}{2}$ chains in length, and for 13 chains on a curve of 74 chains radius. The width of the tunnel was 25 feet, and was so continued to 3 feet above the level of the rails. The height to the soffit was 20 feet above the level

of the rails, and the footings averaged 3 feet 6 inches below the rails. For 7 feet on each side of the crown the radius of the arch was 10 feet 6 inches, then for 9 feet the radius was 14 feet 8 inches, and for the succeeding length of 7 feet 7 inches, the radius was 26 feet 6 inches. The drainage was carried down channels formed of dry stone pitching along the face of the side walls. The ballast was composed of broken stone, 2 inches diameter, for 1 foot in depth, covered with ashes to the level of the rails.

The contract price for the tunnel through rock was £26 per lineal yard, and through shale £35. 16s. per lineal yard, the average price being £30 per lineal yard.

The Buckhorn Weston Tunnel on the Salisbury and Yeovil Railway was constructed through Kimmeridge clay, intersected with veins of loose rubbly rock, as shown in the geological section. (Plate 8, Fig. 5.) These veins acted as conduits for a large quantity of water, which flowed into the tunnel, for nearly one-half its length. The vein that principally affected the work is marked 'loose rock and water' in the section. The main difficulty to be overcome was the evil effects arising from this volume of water, amounting to about 90 gallons per minute, which being confined to the crown, instead of a general 'shedding,' was a source of expense as well as of delay. It was eventually remedied by driving a heading, 5 feet by 5 feet, for 200 yards in length, above the tunnel, and about 10 yards beyond it. A pipe 12 inches in diameter was laid in this; the remainder being filled up with loose stone. The water was thus intercepted, and carried away from the work. This heading is shown in the longitudinal section (Plate 8, Fig. 5).

It was originally intended, in executing this tunnel, only to sink two shafts, and to form a bottom heading for waggons from the cutting at the west end, the gradient falling in that direction, so that drainage could have been obtained. This heading was driven for 200 lineal yards, when the action of the atmosphere caused the sides to bulge so much that double timbering had to be resorted to. As this failed to check the swelling, the plan was abandoned, and a smaller heading was substituted. The waggons were consequently prevented from entering the tunnel, and three additional shafts, making five in all, had to be sunk. As they were not intended to be permanent, the sides only were timbered, but in a very strong manner, on account of the treacherous nature of the ground. These shafts were 8 feet square in the clear, and their cost amounted to £1. 10s. per lineal yard of tunnel. The earth was raised by horse gins, kept in constant operation. The average price for mining and tipping was 4s. 6d.

per cubic yard. The lengths mined from the different shafts are given in the succeeding table :

No. of Shaft.	Lengths driven.		Total.	Time Occupied.	Rate per Month.
	East.	West.			
	Lineal Yards.	Lineal Yards.	Lineal Yards.		Lin. Yards.
1	63	45	108	1858, Oct., to 1860, Jan.	7½
2	64	88	152	" " " Feb.	9½
2*	29	29	58	1859, July, to " Jan.	10½
3	89	106	195	1858, Sept., to " Feb.	12
4	70	62	132	1859, July, to " "	16½
Break-up	..	..	73	" " " "	10½
Face	..	..	21	" Oct., to 1859, Dec.	10½
		Total	739		77

The mining was conducted in a similar manner to that of the Lydgate Tunnel, a top heading being first driven from each shaft. The shafts furnished ten faces, and 645 lineal yards were worked from them, averaging 56 lineal yards per month. The 'break-up' and face gave three additional faces, and 94 lineal yards were mined from them, equal to 10½ lineal yards per month. This, under the circumstances, is a favourable return. The lengths mined, before lining with masonry, ranged from 3½ lineal yards in heavy ground, to 5 lineal yards in favourable strata. The average cost of mining per lineal yard was £30, exclusive of the shafts.

The bars were of larch of large scantling, the crown bars being 18 inches diameter, and fixed about 18 inches apart (Plate 8, Fig. 6). The centres were strongly braced, each rib containing 35 cubic feet of timber, and 285 lbs. of wrought iron in bolts and straps. The centres were fixed about 1½ yard apart, and the cost of setting came to 6s. per lineal yard of tunnel.

As side pressure was anticipated at the commencement of the work, the first ten lengths were built with an invert, which contained 4 cubic yards of brickwork per lineal yard (Plate 8, Fig. 7). Further experience, however, and a more accurate knowledge of the material, justified the abandonment of the invert. The pressure at the crown of the tunnel, occasioned by the water, rendered it necessary to construct a length of 390 lineal yards, with seven rings of brickwork, or 2 feet 8 inches in thickness. The remaining length of 350 lineal yards was favourable, the water-line having dipped gradually, as is shown in the longitudinal section. Through this distance the section, Plate 8, Fig. 6, was adopted. The tunnel was built throughout of brickwork; upwards of six millions of bricks being used. The neighbourhood was totally un-

provided with sharp sand, and as a substitute, burnt clay, fine sand, (the material of the locality) and broken bricks, were ground together, and mixed with Bridgewater hydraulic lime, in the proportion of 2 to 1. The result was perfectly successful. Great caution was exercised in packing behind the brickwork, to prevent subsequent settlement of the surrounding ground. Many of the bars were left in, and the spaces between were filled solid with brickwork. Throughout the heavy ground three bars in each length were on an average bricked in.

After the completion of the work, a large quantity of water continued to percolate, which was conveyed by pipes into the regular channels. The discharge of water was gauged at the completion of the works, when it was not found to have abated, since the time of its being tapped upwards of eighteen months previously.

The following table gives the lengths of each thickness built:

Length.	Thickness of Work.	Earthwork, per Lineal Yard.	Masonry, per Lineal Yard.	Total Masonry.
Lineal yards.	Ft. in.	Cubic yards.	Cubic yards.	Cubic yards.
4	3 5	110	27·25	109
41½	2 8	95	24·38	1,008
	with invert.			
335½	2 8	85	20·56	6,908
178½	2 3	80	18·22	3,250
178½	2 0	77	14·88	2,657
737½	..	..	..	13,927

The average quantity of earthwork per lineal yard was 80 cubic yards, and of brickwork 20 cubic yards. The total length of the tunnel was 739 lineal yards. The first length was keyed in on 6th October, 1858, and the last on the 17th February, 1860, giving sixteen months for completing this work. The width of the tunnel was 24 feet 6 inches at the level of the rails, widened out to 25 feet at 3 feet above. The height was 20 feet above the rails. The crown of the arch in this case was more pointed than in the Lydgate Tunnel, the radius being 9 feet 3 inches for 5 feet on each side of the centre; then a radius of 14 feet 3 inches for 7 feet 6 inches, and for the remaining length of 11 feet 9 inches the radius was 21 feet 9 inches.

The total cost of this tunnel was £53,000, or £72 per lineal yard, of which detailed particulars of every item are subjoined:—

Description.	Total Cost.	Cost per Lineal yard of Tunnel.			Cost per Cubic yard.
		£.	s.	d.	
Mining and tipping	13,300	18	0	0	4 6
Headings and shafts	3,070	4	5	0	..
Timber	3 400	4	15	0	..
Iron and steel	2,250	3	0	0	..
Powder and grease	1,040	1	9	0	0 4½
Horsework	4,300	5	16	0	..
Bricks, coal, and sand	13,650	18	10	0	18 6
Lime and sand	1,732	2	7	0	2 4
Bricklaying	6,003	8	0	0	8 0
Setting centres	225	0	6	0	0 3½
Temporary roads and buildings .	1,095	1	10	0	..
Management and plant	2,650	3	10	0	5 per cent.
Faces and drain	400	0	10	0	..
Total cost	53,115	71	18	0	..

In conclusion, it is satisfactory to be able to state that in neither of these tunnels has any failure been perceptible. The Author trusts that this description may be the means of eliciting from other Members of the Institution further information on this subject.

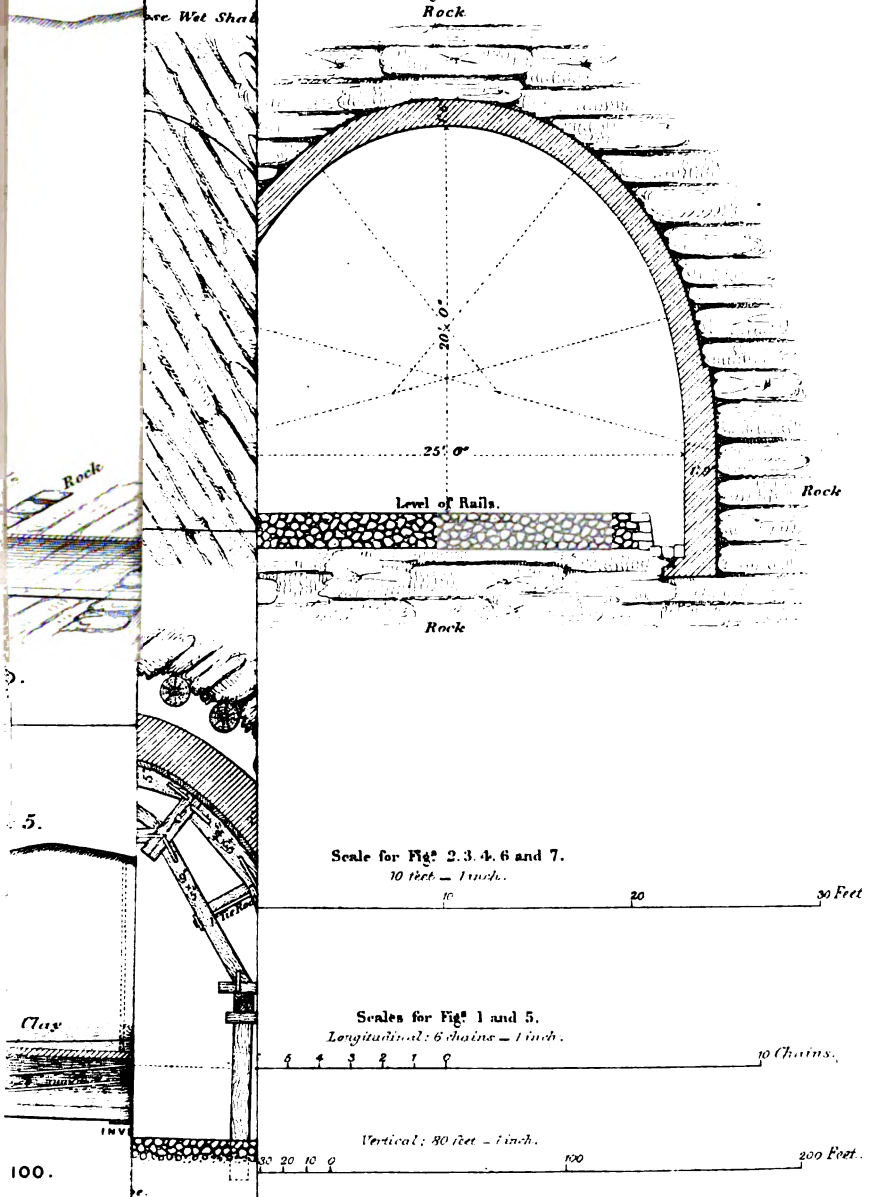
The Paper is illustrated by three Drawings, giving longitudinal sections of the strata passed through, as well as cross sections of the tunnels at different points, from which Plate 8 has been compiled.

[Mr. FRASER

No 2.

Fig: 4.
Rock

PLATE 8. VOL. XXII



KELL, BRON LITH^g. CASTLE ST. HOLBORN

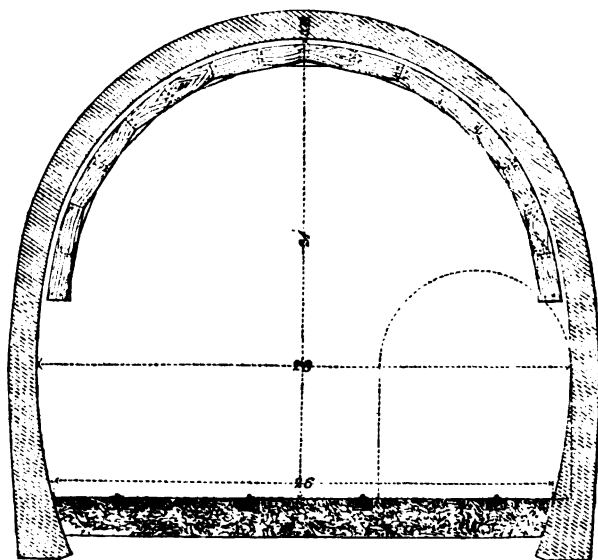
Mr. FRASER thought the following summary of the cost of railway tunnels, constructed under the direction of Messrs. Locke and Errington, might be found to possess some interest, not only as a record of actual experience, but also as indicating, to some extent, the relative expense of piercing different strata :—

Name of Tunnel.	Name of Railway.	Length.	Strata.	Cost per Lineal Yard.
		Lin. Yds.		£.
Guildford . . .	London and South-Western.	965	Chalk . . .	30
St. Catherine's . .	Ditto	191	Sand . . .	40
Petersfield . . .	Portsmouth	484	Chalk . . .	30
Salisbury . . .	London and South-Western.	440	Chalk . . .	30
Honiton . . .	Ditto	1,350	{ Red marl and green sand }	50
Lydgate . . .	London and North-Western.	1,332	Coal measures	30
Buckhorn Weston	Salisbury and Yeovil. . .	739	Clay . . .	72

Mr. C. B. LANE gave a description of a tunnel executed by him in the years 1843 and 1844, as resident assistant to the late Mr. Brunel, on the Bristol and Gloucester Railway, Fig. 1, p. 382. The tunnel was situated at Stapleton, about 3 miles from Bristol, and was carried through the shales of the coal measures, locally called 'duns.' The ground, from the fact of an old tunnel (shown by dotted lines on the cross section) having been carried through the same place, and also from some old coal workings, was in a very shaky condition. The tunnel was constructed for a double broad-gauge line, its east side being occupied by the old tunnel, which was about 9 feet wide and 12 feet high, through which the traffic on the Coal Pit Heath Railway, leading from Bristol to Westerleigh, was originally carried. The work was commenced in 1843 during a dry summer, and there being no appearance at first of the pressure that afterwards exhibited itself, the arch work was carried on with only four rings of brickwork in mortar. When the autumnal rains set in, the ground began to press heavily, so much so that the whole line of the tunnel could be traced along the surface; and it pressed all the more heavily from the fact, that the greatest depth over the arch was not more than 40 feet. On the 10th November, 1843, a length of the tunnel fell in, and it was found necessary to proceed with the centering as rapidly as possible, to prevent the whole of the work, so far as then constructed, from falling; and before completion, upwards of 200 lineal yards of the arch had to be taken out and rebuilt. After this accident the dimensions of the brickwork were considerably increased, and Roman cement was employed. The late Mr. Robert Stephenson the highest authority the profession had had on practical questions, —had said, that more was to be learned from failures, than from

successes, and it was on that account that Mr. Lane ventured to bring forward the facts relating to this tunnel, as a warning to Engineers not to incur unnecessary risks in tunnels. During the progress of the work, some little embarrassment was caused by the necessity of keeping the small tunnel open for traffic; but no interruption occurred until the accident of which he had spoken, and that casualty was happily unattended with loss of human life. He had at first used such centres as were employed in the Buckhorn Weston Tunnel (Plate 8, Fig. 6); but he thought it scarcely possible to devise a more inconvenient centre for a tunnel: subsequently skeleton ribs were used of the kind shown in Fig. 1. There were

Fig. 1.



Stapleton Tunnel, Bristol and Gloucester Railway.

great objections to the use of timber centres in a tunnel, and he preferred wrought-iron centres, like those used in the construction of the Metropolitan Railway, which must be pronounced most valuable contrivances. The total length of the Stapleton Tunnel was 514 yards. It was 26 feet wide at the level of the rails, 28 feet at the springing, and 24 feet high. The side walls were built of sound-fitted rubble work, of Pennant sandstone; and the arch of brickwork was laid in lias lime mortar up to the time of the accident, after which Roman cement was chiefly employed. At the conclusion of the work the arch stood thus:—

Brickwork in Cement :—	
6 rings thick	122 lin. yards.
5 " "	280 " "
Brickwork in Mortar :—	
6 rings thick	10 " "
5 " "	48 " "
4 " "	47 " "
Coursed rubble in mortar, 2 feet thick	7 " "
<hr/>	
514 yards.	
<hr/>	

The work was executed in one hundred and thirty lengths, the greatest being 16 feet, the least 6 feet, and the average about 12 feet. Where there was much lateral pressure an invert was put in.

The total quantity of oak bars and props broken, or otherwise destroyed, in timbering the excavations was 6,715 feet, or 13 feet per lineal yard of tunnel. The quantity of poling boards unavoidably left in amounted to about 50 superficial feet per lineal yard of tunnel. The greatest number of bars used in one length was thirty-four, and the greatest number broken in one length twenty-three. From eight lengths only was all the timber saved. The average for the labour for brickwork in cement (the three rings next the soffit being laid header and stretcher) was 1 bricklayer and $1\frac{1}{2}$ labourer to 1.8 cubic yard of brickwork; for the masonry, 1 mason and 1 labourer gave $2\frac{3}{4}$ cubic yards on the average per day. The price allowed for centre setting, including the profiles, was 10 shillings per rib. Bristol bricks were delivered for 29 shillings per thousand, and Keynsham lime for about fourpence a bushel. The Roman cement was gauged with ashes in the proportion of 2 to 1, and gave an average, including all waste, of about 2 cwt. 3 qrs. per cubic yard of brickwork. The oak bars cost eightpence per lineal foot, and elm poling boards 16 shillings per 100 square feet. The contract price for ordinary excavation in the tunnel was 3s. 6d. per cubic yard, and for rock 7s. The brickwork in mortar was 25 shillings, and in cement 30 shillings, the rubble masonry in mortar 15 shillings per cubic yard, and ashlar 2 shillings per cubic foot. Mr. John Pritchard was the contractor.

Mr. HAWKSHAW, President, trusted that because the Paper did not elicit much discussion, it would not be considered the less valuable. The fact was, a plain and accurate description of important works was perhaps the most useful kind of communication that could be laid before the Institution. The discussions were doubtless very interesting, but the most valuable permanent records for the

'Minutes of Proceedings' were drawings and descriptions of works of magnitude, and the detailed experience of those who had superintended them. He therefore felt personally obliged to Mr. Fraser—and he was sure the Institution joined in that feeling—for the Paper he had laid before them. It related to a class of work which often presented great difficulties ; and he was quite sure if carefully-prepared accounts were brought forward, of all those modes and processes which Engineers had recourse to in constructing the tunnels in this country, it would afford, especially to the younger members of the profession, most important and valuable information.

No. 1,089.—“Public Works in Pernambuco, in the Empire of Brazil.” By WILLIAM MICHAEL PENISTON, M. Inst. C.E.

THE object of this Paper is to describe a few of the Public Works of one of the most extensive, productive, and yet the least known empires of the world. There are difficulties, however, to be met with at the outset, in the want of statistical information, the absence of correct maps, and the uncertainty as to what are called standards of measure in Brazil. Pernambuco is one of the principal, but by no means the largest, of the twenty provinces of which the empire consists. It has an area about equal to England, whilst its population is estimated not to exceed one million. It is so directly in the course of sailing-vessels bound to Australia, the Cape of Good Hope, and Cape Horn, that most of them sight the coast of Pernambuco on their way out. The Royal Mail steamers for Brazil and the Rio Plata leave monthly from Southampton, and make two stoppages for coal, at Lisbon and at St. Vincent's, on the voyage out. At the latter place there is a detention of two, three, or even four days, arising from the great demand at this mid-ocean depôt, and the want of adequate arrangements. The distance from England is a little above 4,000 miles. The mail steamers make the passage out in nineteen days; and on each of the three trips the Author has taken, leaving Southampton on the afternoon of the 9th, the arrival at Pernambuco has never varied an hour from 8 A.M. on the 28th of the same month.

The appearance of the town of Pernambuco from the sea is not imposing; being built on a low, sandy, flat, only a few feet above the level of the ocean. This flat is surrounded, at a distance of from 3 miles to 5 miles, by an amphitheatre of hills, the rising ground on the north side being extremely beautiful, and on it was built the original capital of the Province Olinda, so named from the exclamation of admiration uttered by the first discoverers of South America, “O! linda bellissima!” most beautiful place. The commercial capital was soon after removed to its present position, on account of the natural harbour formed there by a Reef, or in Portuguese, Recife, which is the true name of the capital, although Europeans generally speak of the town as Pernambuco, which properly only applies to the province. This reef runs for hundreds of leagues parallel to, and at only a short distance from, the coast. A little further south it is reported to be of coral; but in the immediate

[1862-63. N.S.]

neighbourhood of Recife it is composed of soft, calcareous, and silicious sandstone, the sand of which is similar to that found on the adjoining beach, intermixed with shells of existing species. The reef is here about 100 feet wide and 3 feet above high water; it is stratified, and dips to the east, on which side it has a long, flat slope; but on the side next the harbour it is nearly vertical. The width of the channel increases considerably, between the town and the opening in the reef which forms the entrance to the harbour from the Atlantic Ocean; and at the widest part, just inside the entrance, a shoal, or bar, is formed, which has, until very lately, prevented any vessel entering which drew more than 16 feet of water. The Government are now, however, extending the quay walls of the Marine Arsenal towards the entrance of the harbour, thus equalising the channel area; and by the use of a dredger on the shoal, (which is of no great width), there has been already excavated a channel which admits vessels of 18 feet draft. This channel does not present, as yet, any indication of a tendency to refill.

In consequence of the absence of quays with sufficient depth of water for vessels to come alongside, all cargoes have to be shipped and discharged by means of lighters, the owners of which enjoy a practical monopoly. The usual charge for lighterage is one milreis per ton, to be paid by the ship, and one more by the receiver of the goods, or 4s. 6d. per ton in all. Occasionally this charge has amounted to ten milreis, or 22s. 6d. per ton, although the distance to the shore does not exceed half a mile.

The number of foreign vessels entering the harbour annually is about three hundred and fifty, averaging 250 tons each. The coasting trade is carried on principally by the Pernambucana Steam Boat Company, which enjoys a grant from the Government, covering all the working expenses, but has not yet been able to pay a dividend. There is a fair trade carried on by Barcassas, or sailing barges, of from 15 tons to 25 tons, which run up the mouths of the smaller rivers, to receive and discharge their cargoes. The 'Jangada,' or Raft, (of which a model is exhibited,) although not available for the carriage of cargo, is used to a great extent for fishing, and as a passage-boat, for hundreds of miles along the coast. The same craft, without its sails and shelter, is used at all ferries in the rivers of the interior.

There is properly no river navigation in Pernambuco; but the São Francisco, which rises among the hills, in the rich mining district at the back of Rio de Janeiro, flows northward from Minas Geraes till it enters the Province at its south-west angle. It there precipitates itself over the Falls of Paulo Affonso, a depth of nearly 200 feet, whence it takes its course through a rocky rapid channel for nearly 200 miles to the sea. Above the Falls of Paulo Affonso, the São Francisco is navigable to the Falls of Pira Póra,

a distance of from 600 miles to 800 miles, and it is to this, as a feeder, that the railways from Recife and Bahia are both directed.

Nothing can exceed the richness of the soil in the valleys in the interior, which are principally devoted to the growth of sugar. This in general is very poorly cultivated, and the manufacture is worse conducted, only from 50 to 75 per cent. of the saccharine being extracted from the cane. The produce is sent on horses' backs from 70 to 100 miles to the port. In the height of the sugar season, eight thousand horses so laden usually arrive daily; the quantity annually exported from Recife varying from 60,000 to 70,000 tons. Cotton is occasionally found growing wild; and is cultivated only in the far interior. It is also sent to the port on horses' backs from distances varying from 200 to 500 miles; the annual export being from 20,000 to 25,000 bags of 170 lbs. each. Hides, rum, dye and fancy woods, with cotton and sugar, form the principal exports; but tobacco, coffee, rice, Indian corn, mandioca, and beans are cultivated largely for home consumption.

The principal imports are manufactured cotton goods, hardware, dried fish from Newfoundland, and dried beef from Buenos Ayres and from Rio Grande do Sul. The duty chargeable on imported goods varies from 2 to 60 per cent., averaging say 30 per cent.; while the duties on exports are only about 8 per cent. All articles required for the construction, or the working of a railway are allowed to pass free. But the number of forms to be gone through involves delays and annoyances, which will be much lessened by adopting the courtesies of the country.

The base of the currency of Brazil is the real, one thousand of which are a milreis, equal to 2*s.* 3*d.* English. Large amounts are reckoned by contos, or one thousand milreis, equal to £112. 10*s.* The milreis has been stated to be equal to 2*s.* 3*d.* English; but it is subject to constant fluctuations, according to the rate of exchange, 27*d.* being taken as par. In 1858 and 1859 it was so much below par, that the salaries of Englishmen, estimated by the milreis at par, required an addition of 8 per cent. Whilst on some occasions in times past business has been done at 24*d.*, advices by the last mail show that it had risen to 30*d.*, an exceptional case, it is presumed, for a paper currency. Wages are usually reckoned by parts of the milreis, called by the native workmen patacas, the milreis being equal to 3 patacas. Thus men are spoken of, as well as wages, as being from 3, 3½, 4, 4½ or 5 patacas—the usual limits of range, or from 2*s.* 3*d.* to 3*s.* 7*d.* The Government rate of interest is 7 per cent. The banks give 8, but 10 and 12 per cent. are easily procurable on very good security; and 1½ per cent. per month is by no means an unusual interest for the senhors to pay for money advanced on the security of the crops.

The ordinary measure of weight is the arroba, equal to 32 lbs.

English, or 70 to the ton. The cubical measure for dry goods is the alqueire. This varies considerably at different places, nearly every town having its own standard. At Recife, the capital of the province, the standard alqueire measures 2·93 cubic feet; whilst at Villa do Cabo, within 20 miles, the standard measures only 2·18 cubic feet. The national standard of length, the braça, or fathom, was defined, in 1852, to be the $\frac{1}{3000}$ th part of a league of eighteen leagues to the degree, without specifying where the degree was to be taken. By the law of 1857, it is fixed that the braça is to be equal to 22 decimetres, or 7·218 feet; and the league is sometimes estimated at 3,000 braças and sometimes at 2,400 braças. The palmo, or hand, is one-tenth of the braça. Besides these two national measures, the French metre is frequently used. Most small dimensions are given in polegados, or inches, and here a further difficulty arises, owing to the difference between the Portuguese and the English inch, both of which are used, the Portuguese being to the English as 1·000 to 1·082.

If it were not for the occasional outbreaks of yellow fever, the climate of Pernambuco would be most enjoyable; but so sudden and sweeping are the attacks of that malady, that panics are frequently created, and the dread of it operates, long after it has disappeared, to prevent the full enjoyment of the climate. It is, however, rare that fatal cases occur with men of good constitution, of cleanly and regular habits, and who take frequent and active exercise. People of sedentary habits, sailors, navvies, mechanics, and all who give way to a dirty, loose mode of living, are its usual victims; but it is a curious fact, that at a time when nearly every vessel in the harbour of Recife was losing numbers of its sailors by fever, vessels alongside with creosoted sleepers on board never lost one. Occasional outbreaks of cholera have been very fatal amongst the slave population, whilst small-pox has made great ravages with the natives; but these complaints are confined almost exclusively to those classes. The healthiness of Pernambuco may be gathered from this, that although all seek to avoid the city of Recife as less healthy than the country, yet in the city with a population of 120,000 persons, until lately without a single closet, or any drainage whatever, and with a daily consumption of water of only $\frac{3}{4}$ gallon per person, the rate of mortality is only $1\frac{3}{4}$ per cent. per annum.

The variations in temperature are considerably less, and the regularity at any hour much greater, than in this country. For the five, or six summer months, the temperature does not vary more than 4° above, or below 82° at 9 A.M. in the shade, nor 4° above, or below 78° at the same time for the winter months. The mean maximum temperature in the shade for the year 1861 was 84·4°, and the mean minimum in the shade for the same year 68·8°. December was the hottest month, viz. 90° in the shade.

July was the coldest month 85.75° in the shade. During the night, the average lowest temperature was 64.5° in September, and the average highest was 71.75° in April. The highest temperature in the shade was 92° in June, and in the sun it was 148° in November.

The total fall of rain in . . .	1860 was	67.20 inches.
" " " "	1861 "	123.75 "
For the first six months in . . .	1862 "	53.64 "
The wettest month in . . .	1860 "	June.
" " " "	1861 "	January.
" " " "	1862 "	March.

The extreme recorded rain-fall was 7.25 inches in twenty-four hours, of which upwards of 4 inches fell in six hours; this was in January 1861. The highest floods in the valleys crossed by the Recife and São Francisco Railway vary from 15 feet to 25 feet; but they rise very rapidly, as frequently the river is in its usual quiescent state in the evening, and in the morning is a raging torrent.

The coast of Pernambuco is peculiarly free from storms; the winds being as regular as they are proverbially uncertain in this country. The prevailing winds are from the east, veering a little to the south when the sun is in the northern hemisphere, and a little to the north of east when the sun is in the southern hemisphere. Towards evening a land-wind springs up, which falls again in the morning; and for the hour, or two after the land-breeze has fallen, and before the sea-breeze sets in, the heat is more sensible than at any other hour of the day. The regularity of the wind on the coast of Pernambuco has directed the Author's attention to it as a motive power, there being no water-power to compete with it, and the cost of fuel being a serious objection to the use of the steam-engine.

The geological character of the province is chiefly of the Plutonic type, the base being almost invariably granitic, or metamorphic. The most prominent hills are of granite at their summits; but the smaller hills are generally of decomposed schist or gneiss, the decomposed material still retaining the appearance of the rock, though perfectly soft. In some instances the section represents an intermixture of boulders and coarse water-worn gravel, entirely decomposed and quite soft, working like the oolitic sands. There are several indications of trap rock, from St. Antônio in the south-west to Ilha, near Recife; and the island of São Aleixo, near Serenhaem, on the eastern coast, is of the same class of rock.

The waterworks for the supply of Recife consist of a natural reservoir among the hills, about 33 feet above and 9 miles from

Recife, to which the water is conveyed by a main 12 inches diameter, and is distributed by thirteen stand-pipes and fountains in different parts of the town, and sold at the rate of about a halfpenny per cubic foot. The ships in the harbour and the villages in the suburbs are supplied by lighters and canoes at the same rate. The works have been very ably executed, under the direction of Mr. Bowman, an English Engineer long resident in Recife. They cost less than the estimate, and yield about 15 per cent. per annum to the proprietors.

The gas-works of Pernambuco are of so late a date, that they have not yet been completed, as regards the accommodation to be rendered to the suburbs and the adjoining villages. They have been very well carried out by Messrs. Bellhouse, of Manchester, under the direction of Messrs. Law and Blount, Civil Engineers. There are now 1,100 public lights, and 2,800 private lights, supplied by about 30 miles of main and service pipes, from two gas-holders, 100 feet diameter and 18 feet deep, with a gas-making apparatus, consisting of sixty retorts, hydraulic mains, two vertical condensers, two dry-lime purifiers, a scrubber, exhausters, steam-engine and boiler, station-meter, governor, &c.

Up to a recent date there was no drainage, or sewerage, whatever in the town of Recife. The Government has now granted a concession to M. Cambronne, who undertakes to put a water-closet into every house, so constructed that all liquid matter is to pass into a system of pipe-drains, and all solid matter into a closed barrel, which is to be removed once a week to an establishment outside the town, where the contents are to be converted into a dry manure. A regular rate has been fixed at which the closets are to be supplied, and a fixed annual sum is to be paid by each householder, for the service of emptying the barrels.

The streets of the city proper, where the traffic is heavy, are pitched, or very roughly paved, with stones of any size, or shape, consisting mainly of granite taken out of vessels in ballast from Europe. The streets being extremely narrow, the traffic is usually worked over them by long, low trucks, from 6 feet to 8 feet in length, about 2 feet in height, and 2 feet 6 inches wide, hauled by a single bullock. These trucks suit the goods which form the principal traffic very well, as this consists of sugar in bags of about $1\frac{1}{2}$ cwt. The side streets and the thoroughfares in the suburbs are sand tracks in summer, and frequently watercourses in winter; but this is being altered, under the direction of Mr. W. Martineau (M. Inst. C.E.), the Government Engineer. Outside the town there are four principal roads, about 20 to 25 miles in length each from the capital, leading south towards Rio Formoso, south-west to Victoria, or São Antão, west to Paó D'Alho, and north to Iguarassu. The total length of road passable during the greater

part of the year for wheeled carriages throughout the province is about 130 miles. Of this about one-sixth only is metalled. It is considered that, in clay districts, metalling alone is available to make a passable road; but in districts where the soil is favourable and the drainage is good, a fair road may be made by a proper admixture of clay and sand, provided it has a sufficient rise in the centre. This mixture soon gets beaten hard, and endures a good deal of bad weather before it gives way.

In some districts the roads made by the Government are practically useless, from the want of bridges across the rivers; in others timber bridges have been built. These usually have brick abutments, and piers of timber piles 'wriggled' in, the use of the pile-engine being almost unknown. On the piles so driven, cap-sills are fixed, and two, three, or four longitudinals, according to the width, which is ordinarily 15 feet, are laid throughout from abutment to abutment. On these, cross timbers from 6 inches to 8 inches square are laid side by side, and these form the road on which the wheels run. The want of sufficient bearing in the piles, and the rapid decay of timber in that climate, makes these bridges a constant source of trouble and expense. Therefore for the bridges on the new roads now being made iron has been adopted. The São João bridge, on the Paó d'Alho road, consisting of four spans of 60 feet each, is a fair example of the class of structure now being introduced by the Government Engineer. Besides these public road bridges, there is a new iron bridge in the town of Recife, erected from the designs of Mr. Edwin Clark (M. Inst. C.E.), of which Messrs. Horace Green and Co. were the contractors.

In districts adjoining the capital, and in bad clay, or for heavy traffic, the road is metalled with broken granite, mostly brought from Europe as ships' ballast, to a width of from 12 feet to 15 feet and about 9 inches in thickness, wide spaces being formed on each side for horse traffic, as the horses are never shod.

The cost of these roads has been, in times past, almost fabulous, exceeding that of European railways. But according to the latest contracts, the cost has been under £3,000 a mile, including the bridges, but exclusive of the metalling, which latter a short time back amounted to upwards of one pound sterling per cubic yard, when broken and spread in place. It may be noted that these roads were generally made from a sketch map, the distances being plotted approximately by the time occupied in walking from one place to another. The preparation of the survey followed the completion of the work.

Next in order to the public roads come the bullock tracks, made and repaired by some proprietors through their own estates, where carts can travel during the summer months; but these are little used, and indeed are scarcely available, for public traffic.

The main traffic of the country is at present carried on by pack horses, on tracks barely wide enough for two horses to pass each other, and pursuing a course so devious as to lead one to speculate what could have been their origin; certainly not to take the most level course, for they frequently mount the highest hills, apparently only for the purpose of descending them again. In winter, the constant working of the horses' feet, each following in the leader's track, works these roads into a series of ridges and furrows, which run with the greatest regularity across the track; and it is not at all unusual for the horsemen's feet, or the horses' girths, to be touching the tops of the ridges between the furrows, or trenches, in which the horses walk. The pack horses as a rule are not larger than English ponies, or cob horses, carrying from 250 lbs. to 300 lbs., a distance of from 20 to 25 miles per day, at a charge of from 6s. 6d. to 11s. 3d. Neither the horses nor the drivers are at present available for any draught work; and for railway purposes it has been found necessary to introduce English horses and English drivers. The system of feeding is not conducive to hard work, being ordinarily grass of the country, called 'capim,' with molasses and water.¹

On the estates adjoining the Government roads, and for the work of the Engenhos themselves, bullock carts are used for transport. These consist of a pair of cheese wheels, 4 feet diameter, keyed on to a wooden axle. The bed of the cart is framed on to the wooden pole, and seated on the axle, by means of two wooden bearings, or plumber blocks. To the pole are generally attached three pair of oxen, whose daily duty is about 10 miles, the average load not exceeding 15 cwt. The charge per day for a pair of bullocks varies from 9s. to 13s. 6d.

To render this state of affairs more apparent, imagine, if possible, the following parallel case. Suppose England to be part of an empire extending from the Straits of Gibraltar to the North Cape in the Arctic Ocean, which is exactly the extent of the sea-board of the Brazilian empire. That London, as the capital, had one road, partly formed, but not metalled, to Staines; a second road partially metalled to Reading; a third formed, but with bridges incomplete, to Watford; and a fourth just completed to Barnet. That none of these roads could take more than lightly-laden carts, and that all beyond and between was wild country, with horse tracks alone; such was the condition of Pernambuco before the railway was commenced. But in justice to Brazil it is necessary to carry the case a little further, and suppose, as is the fact, that this vast empire only obtained its constitution in 1825, and

¹ This only applies to the district within a hundred miles from the sea-coast; in the interior horses regularly working are fed chiefly on 'milho' (Indian corn) during the dry season.—W. M. P.

was only firmly established as an empire in 1831, on the accession of the present Emperor, and the surprise will be not that there are no detailed records, or statistical accounts, of public works, but that there are any public works at all to compare with those existing in the old-established countries of Europe.¹

The absence of river navigation, the inefficiency and great cost of public roads, and the horrible character of the common roads of the country, led very naturally to the consideration of a railway, which was brought forward by the Messrs. de Mornay, English Engineers engaged in Brazil, who, whilst executing some improvements in sugar machinery, became acquainted with the urgent wants of the district. Their project was to carry a line through the entire length of the province, from Recife, the capital, to the Falls of Paulo Affonso, on the Rio São Francisco. This being well recommended to the Government, received its sanction, and a concession was granted for the whole line, with a guarantee of 5 per cent. from the Imperial Government and 2 per cent. from the Provincial Government, upon the estimated cost of completing the first portion of the line, from Recife to the River Una, a distance of about 75 miles. Besides the guaranteed interest, it was conceded, that there should be no other line within 20 miles; that Government land should be supplied free of cost, and the right of working, or letting the minerals for 20 miles on each side; that there should be powers of deviation for a mile on each side; that native labourers on the works should be exempt from impressment in the National Guard; and that all materials required from Europe should be admitted free of duty.

The original estimate was for a line on the North American system at £540,100. By the advice of the late Mr. R. Stephenson, M.P. (Past President Inst. C.E.), the late Mr. Borthwick (M. Inst. C.E.), went out to examine the line. He recommended considerable alterations and revised the estimate, which was increased to £875,123. Further improvements were afterwards introduced, and the capital was increased to £1,200,000, to which amount the guarantee on the part of the Government was extended; but even this has not sufficed to complete the line, and the Brazilian Government have now agreed to a further extension of the capital, to cover the amount actually expended on the works.

The inspection and control of the Government have been confined to examining and reporting on the character and mode of execution of the works. This duty has been performed by Engineers-

¹ At Rio de Janeiro there are some very good roads, one of which is equal to the best macadamized roads in England, and is upwards of 100 miles in length, extending from the terminus of the Mauá Railway, near Rio de Janeiro, to Juiz de Fora in the Province of Minas Geraes.—W. M. P.

Fiscal, generally Brazilians resident in Recife, assisted occasionally by the Engineer to the Province, Mr. Martineau, and subject to periodical inspection by the Consulting Engineer to the Imperial Government, Mr. C. B. Lane (M. Inst. C.E.). It would be unreasonable to expect, that public works, like railways, could be carried on without giving rise to differences of opinion between Engineers representing interests sometimes at variance; yet it is a bare act of justice to state, that the Government Engineers have performed their duty with a fairness worthy of the liberal Government they represent.

The character of the country traversed by the first portion of the Recife and São Francisco Railway, from Recife to the River Una, presents a great uniformity in its physical features. It consists of a succession of narrow valleys, with hills from 100 feet to 150 feet in height, the sides being very thickly wooded, composed almost without exception of rock of a granitic character, varying from a state of perfect decomposition to its natural hardness, the proportion of soft ground to hard rock being at least 10 to 1. It was decided, by the Concession, that the curves should not be sharper than 20 chains radius, or the gradients steeper than 1 in 80, nor longer, at that inclination, than 2 miles. The character of the country may be gathered from this, that in no case has the specified gradient approached the limited length, and in two cases only has it exceeded 1 mile in length.

One tunnel only has been required, and that under 500 feet in length. A short tunnel like this for a single line, through easy ground, and with very inexpensive, unornamental fronts, would require no particular description, were it not that its position rendered it desirable to effect a communication through it, for the conveyance of materials to the upper portion of the works. When, therefore, the small trial heading had shown that the ground was favourable, as the materials for the permanent tunnel were not at hand, and there was plenty of timber on the ground adjoining, it was decided to enlarge the heading sufficiently to take an engine through, minus the chimney. This was effected without difficulty, and a constant stream of materials passed through, during meal times, without interfering with the work. With the like objects, of keeping up the supply of materials and of not delaying the tunnel, the mode of execution was varied to the following extent; as soon as the end lengths had been completed in the usual manner, a surplus stock of materials was sent through so as to last for a few days; the road was then broken up, the invert was built throughout, and the road was re-laid; after which the tunnel and the supply of materials went on without interfering one with another. The size of the large heading was 9 feet 6 inches wide at the bottom, 8 feet wide at the top, and 10 feet high. The invert and

arch of the tunnel were of brickwork, with side walls of rubble masonry, and the cost was 13s. 6d. per yard for labour only.

The earthworks of the heaviest 20 miles have amounted to about 800,000 cubic yards, or 40,000 cubic yards per mile; which is about double the other parts of the line. The highest embankment and the deepest cutting have been about 40 feet. The dimensions usually adopted are, for cuttings a width at the formation level of 20 feet, which includes a 2-foot drain on each side, the slopes varying according to the ground. In rock cuttings the width is reduced to 10 feet, with a drain down the centre. The width of the embankments at the formation level is 16 feet, with slopes of about $1\frac{1}{2}$ to 1. The formation surface is trimmed 6 inches lower on the outside than in the centre, and is kept 18 inches above the level of the highest known floods. This gives, usually, a preponderance to the quantities in the embankments, as most of the valleys are subject to floods. The balance of quantities has been further disturbed by its having frequently been found preferable to make up the shallow banks in part from side cutting, rather than from a long 'lead,' and then to complete them to the full dimensions, after the rails were laid. It is necessary to bear this in mind, or the section, however carefully taken, will not represent the quantities actually to be executed.

There are eight principal bridges, all of iron, in the length of about 75 miles. They vary in height from 15 feet to 25 feet, and are of the following spans:—No. 1 has five 60 feet spans, No. 2 six 60 feet spans, No. 3 three 60 feet spans, No. 4 two 60 feet spans, No. 5 one 80 feet span and one 50 feet span, No. 6 one 80 feet span, No. 7 two 60 feet spans, and No. 8 two 90 feet spans.

The smaller streams are carried under the railway by open culverts where practicable, small iron girders being used to carry the railway across them, when their spans exceed 4 feet. Where this mode has not been possible, the usual form of brick culvert has been adopted.

The fencing found to answer best is a ditch and bank, the latter being planted at the proper season with the native thorn. This fencing serves its purpose very well; but the real difficulty is to keep people from trespassing along the line, which not only the people of the country, but those in subordinate authority, think they have a perfect right to do.

The permanent way, for the first and second divisions, consists of a double-headed rail, weighing 80 lbs. per yard, with creosoted larch cross-sleepers laid at intervals of 3 feet, on the average. The rail is fixed in cast-iron chairs, weighing $24\frac{1}{2}$ lbs. each, the joint chair being 39 lbs. weight. Each chair is fixed to the sleeper by two spikes $\frac{7}{8}$ th of an inch diameter. The rails were at first laid without fish plates, but these have since been added, and the weight of the rails, on the remaining portion of the line, has been reduced

to 72 lbs. to the yard. About 10 miles of the permanent way have been laid, as an experiment, with Greaves' 'pot' sleepers. They have answered very well generally, but in a wet bottom, or on high embankments, the line, so constructed, does not remain in such a good condition as when cross-sleepers are used. An experiment is being tried with sleepers of native timber, of which there are in the woods adjoining the line nearly a dozen different kinds, that are understood to be sufficiently durable for the purpose. These are Sapucaia de Peilão, Paó d'Arco, Aroeira, Coração de Negro, Maria Preta, Sedro, Amarella, Paó Ferro, Emberiba, Murici, and Visgeira. The price at which these can be delivered is one-third that of creosoted sleepers. The only question is whether such caution can be exercised in the selection of the timber as shall insure its being of the right sort. They possess this advantage, that when the chair is once well spiked to them it becomes a matter of great difficulty, in fact almost an impossibility, to draw the spikes. There have been instances of failure in the creosoted sleepers sent out from England, but they have stood much better than the compressed keys, which have had to be entirely replaced. There are several kinds of native timber available for this purpose. Those now being used are made of wood called 'Oiticica,' or of 'Sicupira.' They are steeped in creosote for about three months, there being at present no means of putting them under pressure. The ballast for the whole of the first division, or 20 miles of the line, is composed exclusively of sand. For about 9 miles of this distance the line passes through a series of small sand hills. On the second division the ballast is composed partly of decomposed granite, 'topped' with the sand from the first division; but the upper part of this division, and the whole of the third and fourth divisions, are ballasted with a coarse sand found on the adjoining river banks.

The stations and line arrangements are of the simplest description. The station at Recife is at present a temporary one, on the understanding that the line, which now terminates at the suburb of Cinco Pontas, will be advanced to a more central situation in the city. The intermediate stations each consist of a booking-office 12 feet square, and a passengers' waiting-room of the same size, with a porch between them. These stations, twelve in number, are provided with sidings only; but there are three larger stations where goods sheds are provided, and two have running sheds for the engines. There is not the slightest attempt at ornament in any of the buildings, which have been executed in the simplest way, with the best materials, and with a view to the extension of the accommodation as the traffic increases.

The locomotive engines, carriages, and part of the goods waggons were manufactured in England; the engines by Messrs. Robert Stephenson and Co., the passenger carriages by Messrs. Wright & Co., and the goods waggons by Messrs. Brown, Marshall, and Co.

The engines have done, and are doing, their work in that first-rate style for which Messrs. Robert Stephenson and Co. are celebrated. The passenger carriages are from the designs of Mr. Edward de Mornay, the original Concessionaire of the line, whose ideas have been ably carried out by Messrs. Wright & Co. They have succeeded in building a carriage reputed to be one of the best for tropical climates. It has one peculiarity, however; the projection of the double roof gives a total width of 12 feet, and necessitates a middle track, or space between the rails, of 7 feet 6 inches, instead of the ordinary width of 6 feet. The goods waggons generally have been made in Brazil, and for this purpose, as well as for the ordinary uses of the line, the Company established workshops at Barbalho, near the upper end of the first division.

It was originally proposed that the engine-shed and repairing shops should be built on waterside property, adjoining the harbour of Recife; but about the time they were to have been commenced, there occurred an outbreak of yellow fever, which carried off several of the English foremen and mechanics, and frightened away so many others, that it was decided to establish the locomotive depôt at Barbalho, about twenty miles up the line, as this had the reputation of being a much healthier place. The general arrangement of the workshops and men's quarters is that of a hollow square, but only such portions were executed as were required from time to time. On one side, abutting on the line, are the shops and running shed;—on the second side are the married men's cottages; at the back are the single men's quarters;—and on the further side, on a mound overlooking the whole, is the locomotive superintendent's house and offices. The workshops cover a space of 180 feet by 160 feet, and consist of one central space of 30 feet with a traversing frame running through the centre of the shops, by which engines, or carriages, can be brought in from the line, and be placed in either of the side stalls, which are all 20 feet wide. The roof, of which the tie-beam is 15 feet from the rails, is supported internally by pillars of native timber, and externally by brick piers 3 feet by 2½ feet at the sides, and the end finished under each principal with arches. The spaces on each side of the traversing frame are again divided into four nearly equal areas. One of these serves as a general fitting and repairing shop for engines; and opposite this, on the other side of the traverse, are the forges, lathes, iron planing machine, &c., whilst the space devoted to waggon building and carriage repairs is situated opposite to the saw benches, wood planing and morticing machines. In a detached building adjoining the running shed, is a small foundry, capable of producing all the ordinary small castings of iron, or brass, usually required for rolling stock and repairs. The following is the list of a tools fixed in the different shops:—25 H.P. engine and boiler; wheel

turning lathe; lathe with 17-inch centres; ditto with 8-inch centres; screw cutting lathe with 10-inch centres; screwing, slotting, planing, and vertical drilling machines; 6 fan blasts for smiths' hearths, and 2 ditto for the foundry; 6 smiths' hearths; crane; 2 double-throw pumps; with the necessary shafting, pulleys, drums, &c. In the wood machinery shop are the following: planing, tenoning, morticing, rebating and drilling machines; 3 circular saw benches, and a self-acting saw bench; vertical saw sweep; turning lathe; grindstone, circular oil stone, with shafting, drums, pulleys, &c. This establishment has at present proved amply sufficient for the purposes of the line.

The first concession from the Brazilian Government was dated June 1852; the last in December 1855. The actual work was commenced in May 1856. The first division of about 20 miles was opened in February 1858; the second on the 16th December 1860; the third and part of the fourth on the 26th May 1862; and the whole of the first section to the River Una was finally opened in November 1862.

The best evidence that the working arrangements have been well carried out is, that during the five years the line has been in operation there has not been an accident to a passenger. The want of any railway experience on the part of the officials connected with the traffic, who, excepting the traffic-manager, are all natives, threw a much greater amount of duty and responsibility on the locomotive superintendent and the engine-drivers than is usual in this country. The line was opened as a single way without a station-master, or a native official who could give a correct signal, so that the engine-drivers were obliged to judge for themselves; each acted every journey under written instructions from the locomotive superintendent, in whom was vested the sole authority to regulate the motions of the trains. The same plan was adopted on parts of the line under construction, and has been attended with perfect success, even when five engines have been at work at the same time on a length of 20 miles of single line.

The maintenance of the permanent way has been carried on by native labourers,—a gang of six of whom, under a Brazilian, or a Portuguese ganger, takes charge of three-quarters of a league, or nearly three English miles; the whole being under the inspection of English foremen, each of whom takes a district of about 20 miles.

The labour question is one of the most vital importance to the future of Brazil; for upon it will depend not alone the conditions on which Public Works can be executed, but however favourably they may be carried out, their ultimate success is contingent on the extension of trade and agriculture, which again are absolutely dependent on the supply of the requisite amount of labour Agri-

cultural operations have heretofore been conducted exclusively by slaves, as has also, mainly, the work of porters and lightermen about the ships, and the harbour and warehouses of Recife, where the absence of all mechanical appliances renders these operations of more relative importance than in England. The laws, however, against the further importation of slaves having been strictly enforced for some years past, the number has gradually decreased, and as the concessions for the prosecution of public works now prohibit the employment of slaves, that class of labour may be excluded from further consideration in this Paper. Liberal concessions have been granted, from time to time, by the Brazilian Government, for the promotion of colonisation, but with no commensurate success;—one or two unimportant German colonies being the only result. Attempts have been made to introduce coolies, and lately to import a large body of Germans for one of the public works of Pernambuco, which has resulted in a most signal failure. No positive conclusions can be drawn from these endeavours, as it is well understood that in the former instance failure arose from the business being transacted in too speculative a spirit, and in the latter from the want of the exercise of proper judgment in the selection of the men. Portuguese, and men from the western isles supposed to have been colonists from Portugal, succeed very well in Pernambuco. There are a few instances of Frenchmen and Piedmontese standing the climate better than Englishmen,—but all that can be reasonably obtained would not more than suffice for foremen and leading men for the public works of the province, leaving the main labour to be performed by the natives.

Experience has proved that, both in the province of Pernambuco and in the adjoining provinces, there is an ample supply of manual labour for any public works, or extension of agricultural operations at present probable. Although men are to be found in the country, as they can easily maintain themselves, in their simple way of living, without work, they must first be persuaded, not only that it is to their advantage to work, but to leave their homes and families and to walk 200 or 300 miles to obtain employment. Then the native Brazilians are naturally a proud race; and as heretofore work has only been done by slaves, the free man considers it 'infra dig.' to be on terms of equality with them in this respect. Even when these difficulties have been overcome, the native Brazilians must be treated with such consideration, that it requires more tact, temper, and discretion, than are ordinarily to be found in an English ganger, or foreman, to keep them on the work. No consideration, whatever, pecuniary or otherwise, will prevent them from returning home, when the season arrives for looking after their little crops. This however generally happens about the rainy season, when their presence is less required on public works; and

if treated kindly, and any hopes are held out of their being employed again, they will almost invariably return to the work. It is but right to say, that the consideration and courtesy the native workmen expect to receive from an Englishman, they pay to one another; and it is ridiculous to hear them in argument, and occasionally to find them in writing, addressing each other as 'Illustrissimo Senhor.' A gang of native labourers, on their first arrival from the interior, is always accompanied by a 'Cabo,' or keeper, who receives double their pay, and without whom they will not work. His duty is nominally to superintend the work, but in reality he sits listlessly by, smoking a cigar, and however irregular the workmen, the Cabo indignantly resents any interference, or remonstrance. For a long time all attempts to alter this system were vain; but the introduction of piece-work is gradually bringing about a better order of things. The only work that the native workmen are accustomed to is ditching, and the only tool is the hoe, with which he digs and scrapes the earth into a bank at the side. Specimens of this work may be found, in the boundary fences of the Engenbos in the interior, that for line and uniformity of slope could not be surpassed anywhere. This work costs on the average about 6*d.* or 7*d.* per cubic yard. The ditch varies from 6 to 10 feet wide, and 4 to 5 feet deep. The first lesson is to induce a native to give up the hoe, and take to the pick and shovel. Their want of order and discipline prevents them from working a barrow road properly, and they dread the operation of tipping a waggon; but a light hand-cart they work very well, and fill a set of ballast waggons in much less time than might be expected, but they will not continue their exertions. Four men will, in light dirt, excavate and fill a set of five-yard waggons in twenty-five, or thirty minutes, and on certain occasions they have been known to do it in twenty minutes. Their delight is then to run out with the waggons and engine to discharge the load, when they will jump about the waggons, and shout like madmen, or boys wild with excitement. It is scarcely possible to conceive a greater contrast than the present mode of working offers to the only one formerly adopted by the natives. An engine with twenty trucks carrying 100 cubic yards of dirt, or ballast, and eighty, or one hundred labourers will now run 2 or 3 miles and back again, in less time than they would, formerly, if left to themselves, have loaded about a barrow full of dirt on a distended ox-skin, and have drawn it by two oxen from 200 to 300 yards. Filling waggons, as above, costs 9*d.* to 10½*d.* per cubic yard, exclusive of road-laying and repairs. Men's wages vary from 3*s.* to 3*s.* 9*d.* per day, the latter pay being for picked men in all cases.

Although the difficulties are great in getting the native labourer into order, temper and perseverance will overcome these with time;

but with the native artisan the difficulties are greater still, as there are even in the principal towns, scarcely sufficient mechanics for the ordinary work, so that they are even more independent than the common labourer, and are infinitely more conceited and wedded to their own ways. It becomes, therefore, almost indispensable, that works of art should be executed by foreigners, with such assistance from the natives as can be obtained. The native country carpenter is not available, except with the assistance, and under the immediate inspection, of Europeans. He has but one tool, the incho, or hand adze, and with this he will, if left to himself, hew a piece of timber, 14 inches by 8 inches, to get a scantling of 6 inches by 4½ inches, rather than use the saw. When he does use the saw, he requires, even for common work, the aid of another man, who catching hold of the point of the saw with his fingers, helps the down cut. He can make a Brazilian roof, or rough door and shutter, (there are no windows in the interior); but he is entirely ignorant of staging, scaffolding, pile driving, or waggon building, and not having the slightest idea of square, or line, all his work must be set out. For such duty as the native carpenter can perform, he is paid from 4*s.* 6*d.* to 5*s.* 9*d.* per day. The bricklayer is also the mason, the plasterer, and the tiler, and of such men as are available for public works in the province, the same remark holds good as for the carpenters. They have not the remotest idea of bond, line, or level, and not only has the work to be set out, but sometimes two English workmen, one at each quoin, can scarcely keep the native workmen right between them. In consequence of the action of the atmosphere on the native bricks, it is usual to plaster all exposed work; and of this, as well as of the plastering of the interior of the houses, the native mason makes very tolerable work. He is also very handy in placing the native tiles, and at both these operations may be trusted by himself, with ordinary instruction and supervision. Brickwork and masonry cost, for labour only, from 9*s.* to 14*s.* per cubic yard, according to the thickness and the height. The wages vary from 4*s.* 3*d.* to 6*s.* 6*d.* per day. Native smiths have turned out better than any other mechanics; their wages vary from 5*s.* 6*d.* to 6*s.* 9*d.* per day. Fitters who can be trusted with engine repairs are not to be found, and, at present, have been difficult to be formed. All the waggon building, and the repairs, both of waggons and carriages, are executed by Europeans. Native painters are very scarce, and decidedly bad, with wages varying from 4*s.* 6*d.* to 9*s.* per day.

From this description of the capabilities of the native workmen, it will be readily understood, that foreigners must be imported for all the higher orders of work. It may be remarked, that Brazil supplies an immense number of young gentlemen of good family, and of good Brazilian education, who, in the absence of any other

[1862-1863. N.S.]

2 D

occupation, are anxious to get employment on public works; but although all are convinced that they know everything necessary to become 'administrators,' or 'superintendents,' they are found, on examination, to be wanting in all the essential requisites. As numerous applications for employment were received, advertisements were inserted in the newspapers, offering an engagement to any applicant who could draw, level, survey, speak or write English, keep accounts, or who had any previous experience on public works. During six years, there were not six applicants who could fairly comply with either of the terms of the requisition. As a consequence, all the foremen and most of the interpreters are English, as are also the engine-drivers, fitters, waggon-builders, painters, miners, platelayers, founders, horse-drivers, watchmen, and storekeepers. These are generally engaged for a term of years, at wages varying from £12 to £20 a month, their passage being paid out; they are also supported whilst sick, and sent home free if invalidated.

As a rule, the native carpenter depends on his 'incho' for all work; but in and about the larger towns, sawyers are to be found, whose tools and mode of work are most amusing. Instead of the easy swing of the English sawyer, they jerk their little frame-saws up and down, with a good rest at the top and the bottom of the stroke. The result is very unsatisfactory; as the work comes from the saw rough, irregular, and winding, involving much labour before it can be brought into shape. Their wages are very high, and their habits uncertain, so that when there is a saw bench within 10 miles, their services on public works are not likely to be required.

The native Brazilian boys can swim and dive almost before they can walk, and amongst the men are everywhere to be found divers whose services may be made available in examining foundations and works under water. The rapidity with which they recover any small tool, bolt, or washer that has been dropped into the water is astonishing.

Pernambuco produces, in common with most of the provinces of Brazil, very superior timber, and of infinite variety; but as twenty trees may have to be cut down, and cleared away, before the one wanted can be obtained, and as there is a complete absence of roads, and of all ordinary means of transport, foreign timber is cheaper than native, at the sea-ports, and at all places at any distance from the forests. Again, the difficulty of transport leads to reduction in the length, and diminution in the scantling of native timber. At the same time the hardness of four-fifths of the native timber renders it difficult to work; whereas pitch pine, which is not subject to the attacks of the white ant, may be got from the United States, in any

length, or scantling at a less price, and may be wrought with much greater facility. In the interior the use of native timber is compulsory, and there it can be obtained of good quality and of any scantling; but for particular qualities, such as large scantlings, or great lengths, the price rises. The most serviceable and most reasonable sizes are from 6 inches to 9 inches square, and from 25 feet to 40 feet long. These may be delivered at from 1s. to 1s. 6d. per foot, and if 10 inches, or 11 inches square, at from 1s. 6d. to 2s. per foot, whilst round timber, up to 10 inches diameter, costs about 6d. per foot. Accompanying this Paper are samples of upwards of one hundred kinds of timber, most of which would be available for temporary purposes, but not more than a score would do for any permanent work. According to the best local authorities, *Maçaranduba* (red), and *Sapucaia* (light red), are both very good woods, resisting the attacks of white ants, as well as the effects of wind, or water; *Barubú* (purple, hard) also possesses the same qualities. *Sapucairano* is lighter and not so good, but both it and *Mangabevia de viado* resist the white ant.

The mode of felling and dressing timber for the market is peculiar. In consequence of the difficulties of transport, the logs of timber are seldom rendered of a greater length than from 25 feet to 30 feet. The greater part, indeed, of the timber that is brought to the capital is considerably less, and is generally hewn out of the round to a scantling of from 12 inches by 6 inches to 16 inches by 8 inches, except at one end, where a bit is left on to which the rope is made fast, after being passed through a hole in the end of the timber; the use of timber hitches, or timber dogs, being quite unknown to the natives. Mr. Mansfield, one of the most intelligent writers on Brazil, referring to the enormous field open for mercantile speculation, proposes to construct rafts of timber, forgetting that nine out of ten of the species of woods will not float. The small quantities of durable timber now brought down the rivers, from the interior, can only be sent when the rivers are surcharged by the winter floods, and they are lashed to the *jangada*, or raft wood, previously referred to, to render the logs sufficiently buoyant.

There are besides numbers of woods valuable for dyeing purposes, and for furniture. The *Paó d'Arco*, besides being a useful timber for construction, forms one of the most attractive features of the Brazilian forests. There are several varieties, generally larger than the English elm, the place of leaves being supplied by bright beautiful blossoms, one kind being pink, another yellow, and a third violet. There is another tree the peculiarity of whose butt led the Author to send a sample to this country to accompany this Paper. One of this kind was measured giving a spread to the foot of 12 feet, and a height to the circular trunk of

20 feet, whence it ran up with very little taper and straight for a length of 70 feet without a branch, and then threw out its branches, showing a beautiful head about 30 feet higher.

There are but few varieties of native stone, and these are so difficult to obtain and to work, that Europe has heretofore supplied Recife with what is required. Thus from Lisbon is sent nearly all the ashlar dressings used in the public buildings, and in the best-finished private houses. The sandstone of the reef is not in general sufficiently durable for building purposes, even if it were not preserved by the authorities for the protection of the harbour. The island of St. Aleixo, on the coast to the southward of Recife, produces trap rock, and this has occasionally been brought up by small coasters to Recife. The same rock appears inland, adjoining the railway at Ilha, where a quarry has been opened and worked successfully. This stone was used for the tunnel fronts. Granite is to be found everywhere, and of every degree of hardness: in some few instances it has been found possible to make tolerable coursed work of it. The absence of limestone proper has been supplied by the use of coral, obtained from the reef on the coast. This is burnt for lime for building purposes, whilst shells from the beach, or oyster shells,¹ are used as a flux in the foundries.

The native bricks are of the rudest description, and are used in all stages, from the simply sun-dried to that of sound kiln-burnt; but so little pains are taken with the burning, that only about one-half those ordinarily sold are available for any work subject to much pressure, and even with the best the action of the atmosphere renders it necessary to plaster the whole surface exposed. When this is not done, the bricks moulder away, like badly-burnt bricks in England after a frost, leaving the mortar joints standing as a bead. The bricks are made by placing a couple of moulds, 12 inches by 6 inches by 2 inches, on the sanded floor of the brick shed, into each of which is thrown a lump of clay, trodden in by a boy. The surplus clay is then struck off, the mould removed, and the brick allowed to remain on the floor for a day, or two, when it is placed in stack ready for burning. When the railway works were commenced, an attempt was made to introduce the ordinary system of English brick-making; but although successful in a few instances the result on the whole was not satisfactory. A brick machine, by Messrs. Bradley and Craven, was subsequently sent out. It answered capitally, and turned out some first-rate bricks, upon which neither the weather, nor the atmosphere has produced any effect. From the general character of the buildings and the country, paving bricks are greatly used in Brazil.

The Brazilian, or Portuguese, tile is almost invariably used for

¹ Oysters are found attached to the trees, on the river banks.

covering roofs, and although attempts have been made to introduce corrugated iron and other materials for roofing, nothing is so good, where ventilation is so important, as the ordinary tile of the country; and as a rule, those who live with a tile over their heads dwell in a pleasanter atmosphere than the few who reside in rooms with ceilings. The place of the ordinary rafters for English roofing is supplied by what is called a 'caibro.' This is a straight stick of timber, forming the underwood of the native forest. These sticks are generally straight, and run to a height of from 30 to 40 feet, from 3 inches to 4 inches diameter. The lath is supplied by what is called the 'ripas,' which is reft off the outer part, or what is really the sapwood of one of the native trees, and is called 'emberiba.'

In addition to the building materials already alluded to, the country produces, for some miles round Pernambuco, and amongst the valleys and river beds, sand, which is available for ballast; but no gravel is to be found in that part of the province traversed by the railway.

The materials required to be imported into Brazil for the construction and carrying on of public works are iron for rails, chairs, bridges, rolling stock, and repairs; steel, coke, and coal; glass, oil, turpentine, tallow, tools, doors, windows and general stores.

Reference has been made in the early part of this Paper to the want of all statistics in the province, and to the difficulty of obtaining information. The Author thinks it right, therefore, to say he is indebted for the data as to the harbour, roads, &c. about Recife, to Mr. W. Martineau (M. Inst. C.E.), Government Engineer and Director of the Public Works of the Province. Those relating to the railway have been supplied by Mr. John Whitfield, the representative in Brazil of the Engineer-in-chief, during his absence, Mr. James Fforde, the Resident Engineer, and Mr. G. O. Mann, the Locomotive Superintendent.

In Appendix A. will be found a list of the standard dimensions of the Recife and São Francisco Railway, and of the principal structures upon it, of many of which, as well as of the rolling stock, drawings and photographs are exhibited.

Appendix B. contains a table of the wages of the different classes of labourers and artisans.

Appendix C. gives the prices of materials, and of the cost of various kinds of work and of transport; whilst a numerous collection of samples of building materials and geological specimens is shown.

Appendix D. shows the actual cost, per mile per annum, of the maintenance of the way and works of the Recife and São Francisco Railway, on an average of four years.

[APPENDIX

APPENDIX (A.)

SOME trouble has been taken to secure uniformity of dimensions throughout the Recife and São Francisco Railway, and the following general results have been arrived at:—

	Ft.	In.
Gauge of line	5	3
Middle space	7	6
Cuttings (viz., formation width 16 ft. + 2 ft. + 2 ft. drains)	20	0
Ditto in rock	10	0
Embankments, formation width	16	0
Ditto, above the flood level	1	6
Bridges, minimum headway	14	6
Ditto ditto width	14	0
Tunnel, minimum headway	14	6
Ditto ditto width	16	0
Station platforms, above rails	2	3
Ditto, clearance from ditto	2	9

CARRIAGES AND WAGGONS.

All the wheels and axles are uniform, the waggons being provided with buffers and spring drawbar, and the tyres of the wheels being of Low Moor iron.

	Ft.	In.
Diameter of wheels	3	6
Distance from centre to centre of wheels	9	10
Length of axles to centre of journals	7	1½
Length of journals	0	8
Diameter of journals	0	3½
Height of buffers	3	4
Distance between the centres of the buffers	4	6
Carriage, width of roof	12	0
Ditto ditto body	9	0
Ditto ditto steps	10	6
Turntable for engine and tender	42	0
Ditto for carriages	15	0

LOCOMOTIVE ENGINES.

	Ft.	In.
Diameter of cylinder	0	14
Length of stroke	0	20
Diameter of coupled wheels	5	6
Ditto of leading ditto	4	0
Distance between the coupled wheels	7	5

APPENDIX (B.)

TABLE OF WAGES.

	s.	d.	s.	d.
Native labour, before the railway works began	1	4	to	2 3 per day.
" shortly after ditto	2	3	"	3 0 "
" when the works were in active progress	3	0	"	3 9 "
" at present, and for the past year	2	3	"	3 0 "
Native, or Portuguese Gangers	4	6	"	9 0 "
" Timekeepers and clerks	6	9	"	9 0 "
" Carpenters	4	6	"	5 6 "
" Woodmen	3	9	"	4 6 "
" Bricklayers and masons	4	6	"	6 9 "
" Smiths	5	6	"	6 9 "
" Strikers	3	0	"	3 9 "
" Fitters	6	9	"	9 0 "
" Turners				
" Painters				
English Sailors	4	6	"	6 9 "
" Foremen	13	6	"	18 0 "

English workmen are usually engaged for three years, at a salary rising each year; their passages being paid home on the expiration of their engagements, or if invalidated before that period.

Watchmen, stable-keepers, and horse-drivers	£ 8 to £10	per month.
Smiths, carpenters, bricklayers, and masons	£12 to £14	"
Foremen, platelayers, and engine-drivers	£14 to £16	"

APPENDIX (C.)

PRICES OF MATERIALS.

NATIVE.		£.	s.	d.	£.	s.	d.	
Timber delivered at the workshops on the line	} per cubic foot.	0	1	3	to	0	1	9
Caibros		each.	0	0	9	"	0	0
Ripas	} per 100.	0	6	9	"	0	9	0
Rough logs, for sleepers, not sawn, 9 feet long and 12 inches diameter		each.	0	3	3	"	0	4
Bricks, hand-made	} per 1000.	8	0	0	"	4	10	0
Ditto, machine-made.		"	2	0	0	"	3	10
Ditto, paving	"	5	0	0	"	5	10	0
Burning bricks, fuel only	"	0	9	0	"			
Tiles	"	8	10	0	"	6	0	0
Lime	per alqueire.	0	1	3	"	0	1	6
Building stone, exclusive of carriage	per cubic yard.	0	6	9	"	0	8	6
Iron castings at the foundry, in Recife	per cwt.	1	8	0	"	2	10	0
FOREIGN.		£.	s.	d.	£.	s.	d.	
Pitch pine, from the United States.	per cubic foot.	0	2	3	"	0	2	9
Baltic yellow deals	"	0	2	6	"	0	3	0
Coal	per ton.	1	16	0	"	2	5	0
Coke	"	3	0	0	"	5	0	0
Oil, rape	per gallon.	0	5	8	"			
Tallow	per cwt.	2	14	0	"			
Turpentine	per gallon.	0	8	5	"			
Waste	per lb.	0	0	3	"			

COST OF WORK.

		£.	s.	d.		£.	s.	d.
Earthwork, ditches	per cubic yard.	0	0	8	to	0	0	11
" getting and filling waggons	"	0	0	8	"	0	0	11
" in foundations	"	0	0	11	"	0	1	1½
" " if run 50 yards	"	0	1	1½	"	0	1	4
" rock, exclusive of powder and drills	"	0	6	9	"	0	9	0
Brickwork in heavy abutments	"	0	10	0	"	0	11	0
" in walls, from 18 inches to 2 feet 6 inches thick	"	0	11	0	"	0	13	6
Masonry in abutments	"	0	9	0	"	0	10	0
" in walls, 2 feet thick	"	0	10	0	"	0	13	6

COST OF TRANSPORT.

		£.	s.	d.		£.	s.	d.
Four bullocks and man and boy, from the workshops to the wood, about 2 miles	per trip.	0	11	3				
Bullock-cart, with three pairs of oxen, carrying from 15 to 20 cwt., going about 10 miles per day	per ton per mile.	0	5	0				
Bullocks for draught purposes	per day.	0	9	0	to	0	12	0
Pack-horses, carrying from 256 lbs. to 320 lbs.	"	0	6	9	"	0	8	0
Sawing timber, hard or soft	per 100 feet.	0	4	6	} total	0	9	0
Loading, unloading, and shop expenses	"	0	4	6				
Building covered goods-waggon, complete	..	22	10	0				
Sawing timber for goods-waggon, painting, wheeling, &c.	..	11	5	0				
Labour in making barrows, complete	each.	0	6	9				
Permanent way, cost of laying.	per lineal yard.	0	1	9	to	0	2	3
" lifting, boxing, straightening	"	0	1	0	"	0	1	3
Laying points and crossings	..	8	0	0	"	11	0	0

APPENDIX (D.)

COST OF THE MAINTENANCE OF THE WAY AND WORKS OF THE RECIFE AND SÃO FRANCISCO RAILWAY, per mile, per annum, on an average of Four Years.

	£.	s.	d.
Repairs of permanent way, lifting, packing, &c., per mile per annum	158	10	1
Ballast, and purchase of gravel	"	"	1 5 11
Repairs of bridges, culverts, tunnel, &c.	"	"	0 7 10
" stations and appurtenances	"	"	12 7 11
" signals and waterworks	"	"	0 0 3½
" gates, fences, and ditches	"	"	5 19 3½
Salaries of engineers, and inspectors, with office expenses	"	"	39 12 0
Total average cost per mile per annum	£218	3	4

[Mr. PENISTON

Mr. PENISTON said, he was glad to avail himself of the opportunity that was afforded him of collecting a few facts for the information of the Institution. Although physically unable to take part in the discussion himself, fortunately those who had assisted in the collection of the facts were present, as were also the representatives of several large establishments connected with works in Brazil, who were well qualified to take part in any discussion that might arise. He should also be happy to supply any further particulars which it might be in his power to do.

Mr. E. DE MORNAY, as one of the Concessionaires of the Pernambuco (Recife and São Francisco) Railway, would avail himself of this opportunity to state, although he had not then with him the details of the survey, so as to enable him to give the exact length of the lines to which the estimates referred, that the line estimated by Mr. Borthwick was divided into four sections, and that the estimate of the concessionaires related to the first three sections only. The concessionaires considered, a railway might be made in Brazil upon the American principle, involving only a moderate outlay, with immense advantage to that country; and although it had not been carried out upon that principle, he wished to explain why they had advocated that view. In the first place a return of 7 per cent. was, during construction, to be secured to the shareholders; and it was thought as that guarantee of interest was made good at the expense of the shareholders' capital, it would be of great advantage that the line should be cheaply constructed, and that the works should be completed within the shortest period of time. Instead of that the line had been many years under construction: and it was for those who were more able to do so than himself, to calculate how far the capital subscribed for the railway ought to be expended in the payment of interest to the shareholders. Under those circumstances it was considered important by the concessionaires, that the line should be made at a low cost. It had always appeared to him, that an expensive railway in a country like Brazil would be a calamity rather than a benefit; and in his opinion the only lines that could return a fair interest to the shareholders, and conduce to an extension of the railway system in Brazil, would be those which were constructed at a moderate amount of expenditure.

Mr. C. B. LANE said, so many topics had been referred to in the Paper, that it was difficult to speak upon them without previous consideration. He would, however, in the first place allude to the question of the employment of native timber. When he first went to Brazil, about ten years ago, as the Government Engineer, he made a point of studying carefully the various building materials of the country; and the conclusion he arrived at, after two, or three years, was, that if railways were to be con-

structed in that country, upon the alleged economical principle of using the native timber, as it was found, it would be better not to make them at all. Timber employed in railway bridges and in viaducts was destroyed so rapidly, in that inter-tropical climate, that their maintenance and renewal would more than eat up the receipts which should go to diminish the onus of the Government guarantees. Although he fully agreed in the advantages of reducing the first cost, yet economy was a relative term. The first railway in Brazil was opened in 1854. It was a short line, leading from Mauá, in the Bay of Rio de Janeiro, to the foot of the great 'Serra' of Petropolis. It passed for a considerable part of its length over a low muddy swamp, full of mangroves—a most uninteresting spot, the only thing to enliven the scene being an occasional alligator. Various water-courses were crossed, for which timber was employed; the best timber no doubt available, at that time, having been selected for the purpose. About two years after that line had been opened, he inspected the water-passages and bridges: for after that short time it had become necessary to rebuild them with other materials. He could not more graphically describe the condition of the timber, than by stating that in one case upon giving a transom under the railway a moderate kick, his foot was buried in it up to the instep. With the timber in that condition, after two, or three years, it was manifestly better not to make railways than to use such materials in their construction. He did not doubt, that in Brazil there was a great abundance of valuable timber: but as yet there were no certain means of getting at that timber, or being sure of its quality and properties when it was obtained. There was also abundance of gold, copper, and other valuable minerals in that country; but the time had not yet arrived when they could be made available. It was the same with regard to the timber. It would be cheaper to send from Brazil to Liverpool for a stick of timber, even though it was first imported from America to Liverpool, than to cut one in Brazil half a dozen miles from where it was required to be used. All the timber he had seen in Brazil—though good for many other purposes—was inapplicable for railway sleepers; the quick-growing woods being too perishable, and the hard woods too brittle. There was a specimen of timber upon the table which felt like a piece of porcelain, and yet after five years' immersion in the waters of Rio Bay it was completely riddled by the teredo. It was totally unfit for railway sleepers, being too brittle. On an inspection he made of the Pernambuco Railway, three years ago, he found that the wear and tear of the imported creosoted sleepers on the first section had not amounted to more than about 1 per cent. during the two years that the line had then been open for traffic. He could not state exactly the amount of depreciation of the

sleepers of native wood laid on other sections of that line; but from what he saw he had no doubt it would turn out to be equal to that which was stated in a Paper by Mr. M'Master¹ read before the Institution a short time ago, to have occurred from using native timber on the Madras Railway,—that was, to 33 per cent. in the first year, or two. This in the matter of sleepers was a very heavy item in the maintenance of a railway of small traffic. On the Bahia Railway it was stipulated in the concession that only native timber should be employed: but very soon after the works were commenced, it was found impossible to procure suitable native timber for sleepers: upon which the Engineer, Mr. Vignoles (M. Inst. C.E.), and the Company petitioned the Government to have that particular clause of the concession altered: and under his (Mr. Lane's) advice it was altered, and creosoted North of Europe timber was substituted. He had given that advice in the full belief, that there was great difficulty in finding proper native timber, and also that the creosoted timber offered as a substitute was a very superior material. In advocating his views relating to the employment of other material than native timber in bridges and viaducts, he had encountered much opposition from parties interested in the execution of some of the lines of railway; but he had ultimately succeeded in having the correctness of these views duly recognized, and the rule now was, that all such railway structures should be constructed of "stone, brick, or iron, singly or combined." Greaves' 'pot' sleeper had been introduced on about 10 miles of the Pernambuco line. It was also used on the Mauá Railway, and was being employed by Mr. Brunlees (M. Inst. C.E.) on the San Paulo line. He believed it would be found to answer well in Brazil, India, and in other inter-tropical countries, with the present amount of traffic; but he felt convinced that if the time ever came when such heavy trains were run and at such high velocities as prevailed in England, the iron 'pot' sleeper would have to be relinquished, as it was too rigid for high velocities.

The labour question was no doubt a very important one. As far as his own experience went, he thought, under the best circumstances, it would be found that the labour of Europeans in an inter-tropical climate was very nearly that determined many years ago by the well-known French philosopher and Engineer officer Coulomb, who in employing French Sappers and Miners in the Island of Martinique, where the thermometer was seldom below 77°, and similar troops in France, stated the efficiency of their labour to be less than one half in the tropical climate: and in the inter-tropical portions of Brazil with which he was acquainted, the thermometer was seldom below 77° during the day.

¹ *Vide ante*, page 241.

With regard to the mason work, his own experience (which was chiefly at Rio de Janeiro) differed from that of Mr. Peniston. In employing Portuguese, as masons, the work was done extremely well, and he had rarely seen men work a quoin more truly; but they were slow as compared with English workmen, in England. The worked stone brought from Lisbon, referred to by Mr. Peniston, must he thought be only that for ornamental purposes, because the neighbourhood of Lisbon supplied beautiful marble which was not found in Brazil.

Mr. JAMES T. WOOD remarked, that the engineering part of the subject had been so fully discussed in the Paper that he would not further touch upon it. He would therefore direct attention to a few circumstances, which five, or six years hence would be more interesting than they were at the present moment:—that was to the development of the traffic of a country where land was of small value, and where labour was scarce—to trace what would be the result in a few years of increased facilities of transit throughout the country. One great result he thought would be, the bringing of the population and the changing of estates, to localities in the immediate vicinity of the railways, in consequence of the proprietors of slave labour migrating, and clearing the lands adjoining the line, in the same way as the borders of navigable rivers, in all parts of the world, had been selected for cultivation. When he was in Brazil he took a journey of above 70 miles from the coast. He there met a most intelligent man, the schoolmaster of the district, who gave a history of the large number of farms and estates that had been brought into cultivation, by cutting down the trees in the neighbourhood of the line, and in anticipation of the present terminal station. He thought that five, or six years hence, if the statistics could be obtained, they would be of great interest, as showing the movement of the population towards the localities where improved means of communication were provided.

Another point, which was a most material one, was that which had reference to labour. As far as his experience went, a labourer who could read and write was very scarce in the Province of Pernambuco. During the period of slavery there, certain acts of labour were performed solely by slaves, even down to the carrying of a parcel; and the main distinction between the people was those who were slaves, and those who were not, the latter being too proud to do slave work. The railway was consequently deprived of the useful class of men from which the porters in this country was obtained. During the last twenty years that feeling had been going out, and in the course of time it might be possible to find intelligent men amongst the labouring classes of the country, who could read and write, and whose services would be of the greatest value to the country. It was his opinion, that the

gradual extension of the line, say at the rate of 20 miles a year, might be executed. But it was of importance that the surveys and the exact direction of the extension should be judiciously and accurately prearranged, so as to give time and opportunity for the adjoining land to be brought into cultivation, during the progress of the railway works. He also considered there was ample field for branch feeders to be made; but as the traffic on these branches could not pay any company an adequate return for the capital expended, they should be made at the expense of the proprietors whose estates would be benefited. He was happy to bear testimony to the excessive kindness and hospitality to Europeans, which prevailed all over the country.

Mr. E. B. WEBB said, about three years ago, he had the honour of reading a Paper before the Institution, "On the Means of Communication in the Empire of Brazil,"¹ and he referred, in that Paper, particularly to the use of timber, and to the cost of labour upon the works. Since that time professional engagements had caused him to revisit South America. He had traversed the greater part of the eastern coast of that continent, and had visited all the railways which were in course of construction. The opinions he expressed three years ago in reference to Brazilian public works had been confirmed. He had an opportunity of inspecting timber structures, which, when he left Brazil, in 1858, were apparently in a sound condition, and he found them, last year, in ruins. The specimen of timber laid on the table by Mr. Lane, was a portion of a pile driven under his direction in the Bay of Rio de Janeiro, in 1854. That piece of timber was removed about the year 1858. It was a fair sample of the material in a pier of some magnitude; and the destruction caused by the 'teredo' was complete. He had no hesitation in saying, that all timber, taken in large quantities from the forests of Brazil, and driven in the littoral waters of that country, would, in a short time, be reduced to a similar condition.

With reference to sleepers of native timber, he was of opinion that, on the ground of economy and convenience, their use was most imprudent; because scarcely any timber, that could be obtained in sufficient quantity, size and condition, would endure the wear and tear of the climate much longer than two years. The loss and annoyance resulting from an early decay of sleepers, would be felt by the Companies and not by the contractors. In the Brazilian forests there were countless varieties of timber, and specimens might be produced by the hundred; but the difficulty of selecting, collecting and transporting to the works a sufficient supply of durable timber, could only be correctly estimated after

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xix., p. 240.*

an experience in the country itself. The forests of Brazil, unlike pine forests, never presented a number of trees of the same description in one spot; and serviceable timber was very limited. It was frequently necessary to make a selection of one tree only in the midst of several hundreds of no value whatever. In fact an Engineer, standing in the magnificent primeval forests of Brazil, might paraphrase the words of the Ancient Mariner, and exclaim—

“Timber, timber everywhere,
And not a stick to use!”

When visiting the Brazilian railways last year, he was sorry to find that native timber was being largely used as sleepers. He saw, for instance, on the San Paulo Railway, large piles of native timber sleepers. These sleepers were made up of many varieties of timber, more or less durable; they were of irregular scantling, and being exposed to the sun and weather, they were splitting freely. He believed that the greater part of those sleepers, after being down for two years, would be found to be decayed; and long before the lapse of two years the spikes would become loosened, on account of the tendency of the timber to split. The result of his experience, in the use of timber in Brazilian soil, made him regard its employment as something like putting “ashes to ashes.” He knew of no instance of any attempt to creosote the native timber, which, when worth anything at all, was hard, and had a tendency to split. On the same railway timber telegraph posts were being erected. Now he knew for a fact, that on the Dom Pedro Segundo Railway (Rio de Janeiro) three several sets of timber telegraph posts had been put up; and the Company, after having incurred very great expense and annoyance, were now erecting posts of iron, notwithstanding that their line passed through some of the most magnificent forests on the face of the globe. Considerable experience induced him to draw the general conclusion, that the use of native timber sleepers in all such countries as Brazil, was very unadvisable, first on account of the difficulty in selection, and secondly on account of the trouble and expense in keeping the permanent way in a proper state of repair. In such countries, for years to come, high velocities would not be required; and with moderate speeds iron sleepers were safe and economical, and they might be considered as indestructible.

Mr. F. W. SHELLDS said, four, or five years ago he went to Brazil to lay out works of some magnitude. At that time he inspected the works on the Pernambuco Railway, with the view of applying the experience gained upon that line, to a railway at Bahia, then about to be commenced. The conclusion he came to was, that all works of art in Brazil would be more safely estimated and more satisfactorily carried out, upon the supposition that the materials should be designed and be prepared in

England, in such a manner that they could be put together, with the least trouble and labour, after their arrival in Brazil. He was led to this conclusion, not only on account of the perishable nature of the timber, and the generally inferior quality of the masonry, but also because, in a hot climate, little reliance could be comparatively placed upon the labour of even the English workmen sent out there, as their nervous system was generally debilitated by the effects of the climate. It was therefore far safer, as a general rule, to design works of art, in the simplest form, with English materials and have them erected in the country, no matter in what part it might be. He might add, that in the course of his explorations, he examined some rude bridges which had been erected about three years, and on breaking the surface of the timber, which he could easily do with his foot, he found the interior of the timber filled with white ants. This satisfied him that the use of native timber was generally to be avoided in permanent works. With regard to iron work, it appeared to him, that the use of corrugated iron, so much employed here for roofing, would in a country like Brazil be a great mistake. The native tiles laid upon the rafters, with no ceiling underneath, formed the best kind of roofing for that country, as, although it made a heavy roof, it was not only the best protection against the heat of the sun, but it also afforded the best means of ventilation. In a large railway viaduct, which had been intrusted to him to design, and to arrange for the execution of, cast-iron piles were required to be used, at a considerable depth in sea water. It was for some time a question, whether the salt water and other elements would not have a very deteriorating effect upon the cast iron; but he had recently received a report stating, that immediately upon the iron being put down into the water, it became so thickly encrusted with marine shells, as to form a complete protection against the action of the salt water, so that there was every probability that these cast-iron piles would endure for a long period. In using wrought iron, in situations exposed to the atmosphere, in these climates, care must be taken effectually to protect it, by thorough painting. Such a construction as a bridge, with wrought-iron girders, must be constantly painted and carefully protected from the influences of the climate, which possessed the peculiarity of an excessive degree of heat, combined with much moisture, the corroding effects of which, upon wrought-ironwork, were remarkably rapid.

Mr. J. WHITFIELD, in reply upon the discussion, for the Author, said with regard to timber, there was a great variety of wood in Brazil which would be useful and would endure for a long time under any circumstances; other descriptions under the most favourable circumstances would not endure for twelve months. There were some varieties of timber the outside of which was ex-

ceedingly perishable, but the interior would last for a long time. He had known instances of timber, which had been in use for fifty years, both in and out of water. That was proved to be the case in some old buildings he had examined ; and he found that some descriptions of timber would last sound for a long time. It was quite true that wrought iron when put under sea water rapidly became encrusted with marine shells, which protected it to a great extent : but wrought iron when exposed to the atmosphere, near the coast, if not kept well painted, was very quickly corroded and destroyed. In the interior of the country, where the atmosphere was drier, ironwork properly painted would last as long, if not longer, than in England. It was a great mistake to suppose that the whole of Brazil was like that part of the country, near to the sea-coast. The hygrometric state of the atmosphere had a powerful effect upon materials near to the coast ; but it was different in the interior. Some materials of construction might therefore be usefully employed in one situation, which would perish rapidly in another locality.

March 31, 1863.

JOHN FOWLER, Vice-President,
in the Chair.

No. 1,082.—“Structures in the Sea, without Cofferdams ; with a Description of the Works of the new Albert Harbour at Greenock.” By DANIEL MILLER.

OF late years a revolution has been going on in nearly all the branches of engineering practice. The application of scientific principles, the adoption of new constructive materials, and the development of modern wants, by the expansion of trade and commerce, have in some cases much altered the formerly received modes of construction, and in others rendered necessary the introduction of entirely novel methods.

Although harbour and dock engineering has participated in this change, there is no doubt still scope for improvement, in the scientific and economical construction of these works. And when it is considered how much the prosperity of a great maritime and commercial country depends upon the extent and efficiency of its docks and harbours, few subjects are deserving of greater attention.

The more immediate object of this Paper is to treat of the various methods of constructing the foundations of quay-walls, piers, or breakwaters, for the formation of docks and harbours in deep water ; to describe works of this kind carried out on principles different from those usually practised ; and to point out the further application of these principles to other works of a similar nature.

The formation of these works has usually required the adoption of very expensive means ; and an easy and economical mode of building such structures, so as to combine the various conditions necessary to insure solidity and capability of resisting the mechanical forces to which they are subjected, and also the destructive action of exposure to the elements, the boring of marine worms, or the corrosive action of salt water, has been hitherto a desideratum.

Several methods of founding works in deep water are at present practised ; but there are objections to most of these systems, arising either from their expensive nature, or from defects in the dura-

[1862-63. N.S.]

2 E

bility of the structures. The plans which have chiefly prevailed are—

Founding on piling carried up to about the level of low water ;

Constructing within caissons or cofferdams ; or,

Building under water by means of diving apparatus.

The first method has serious defects, both in deficiency of strength and of durability, as the piling is often insufficient to resist the lateral pressure from behind the wall, and the heads of the piles being exposed to the alternate action of air and water soon decay, when the weight of the wall above rapidly completes the failure of the whole structure. Of course where there are marine worms this mode is quite inapplicable. Instances of the failure of such works will occur to many. Referring to the River Clyde, for example, nearly all the older quay-walls of the harbour of Glasgow were built on this principle, and have given way from the decay of the piles, or have required very expensive repairs to keep them up ; and at Port Glasgow Docks, the walls, which were also built on that system, gave way from the lateral pressure forcing them out, shortly after completion, greatly to the injury of that port.

The most usual mode adopted, where works of great solidity are required, is to resort to cofferdams, and to pump out the water from the enclosed space, so that the foundations and the walls may be constructed as on dry land. This is certainly most effectual, but it is at the same time generally expensive, and it is often not unattended with danger. In many cases, too, from the nature of the strata, it is almost impossible to form an effective cofferdam. The construction of cofferdams, moreover, frequently requires great engineering skill, besides involving vast expense ; and when it is considered that they are only wanted for a temporary purpose, it must be conceded that it is an object of great importance, to devise some mode by which their use can be obviated, and solid and durable works can be executed without their aid.

The system of building under water by means of diving-bells and diving-dresses has been practised to a considerable extent, and the improved apparatus now used gives great facilities for this kind of work ; but it is only applicable under particular circumstances, and it is also costly, besides being liable to cause delay in the progress of the work. The Dover Breakwater, at present in course of construction, is an example on a large scale of this mode of construction, but it is also an instance of the vast sums which may be expended on this system.

In bridge building, a great innovation has been made in the construction of the piers without the aid of cofferdams, and the

French engineers have been, until lately, in advance in this mode of constructing such works. The plan they pursue was introduced by Vicat in 1813; it consists in forming enclosures of close piling, or 'caisses sans fonds,' of the shape of the pier, up to about low-water level, and filling in with hydraulic concrete, or *béton*, on which the upper part of the piers is built in the usual manner. Some important bridges in France, and many of those across the Seine at and near Paris, such as the Carrousel, Jena, Austerlitz, Alma, and Asnières, have the piers formed in this way without cofferdams. These works of the French Engineers, however, being in some instances a combination of timber and concrete, cannot be said to possess substantiality and durability, and a change was necessary, in order to enable them to compete with stone structures built in the usual manner. The modes recently adopted in constructing the piers of the Westminster and the Chelsea Bridges without cofferdams, have effected this, and these works are instances of successful departure from stereotyped rules, and of the application of scientific principles in the practice of bridge building.

APPLICATION OF CONCRETE.

In these modes of construction, *béton* or hydraulic concrete has played an important part, and it also forms a leading feature in the plans for marine works afterwards to be described.

This valuable compound, though employed in Roman and mediæval times, was allowed to go out of use, and since then, it has not, until recently, been much recognised as a constructive material by the Engineers of this country, who have, for marine purposes, placed their faith chiefly in works of cyclopean masonry, constructed within cofferdams, or built under water by the diving-bell. The French Engineers deserve the credit of having been, for a longer period in modern times, alive to the value of *béton*, as an important auxiliary, in hydraulic works.

For some time, however, its value has been more appreciated in this country as a substitute for masonry, and it has been employed in some important works. Still, its use is chiefly confined to forming a homogeneous and monolithic bearing stratum for foundations, and not, properly speaking, as a constructive material, to which latter purpose it is more especially the Author's object to direct attention. In particular, there are but few examples of the application of liquid concrete, deposited and allowed to set in the water, in the construction of submarine works.

There are three modes in which concrete may be applied for constructive purposes,—building it in mass, and allowing it to set before water has access to the work, as has been adopted in the construction of the walls of the Victoria Docks, by Mr. Bidder,

and in those of the London Docks, by the late Mr. Rendel ; preparing it first in blocks, and allowing it to harden before being used, as employed by the late Mr. Walker at the Dover Breakwater, and by Mr. Hawkshaw for the new sea forts, for protecting the arsenals of Plymouth and Portsmouth ; and depositing it in a liquid state, and allowing it to set under water, as practised upon a gigantic scale by M. Noël, in the construction of the large government Graving Docks at Toulon. In the latter case hydraulic concrete has been deposited in a liquid state, in the sea water, at a depth of about 40 feet, forming a vast rectangular trough of béton about 100 feet wide, of the length of each dock respectively, and with walls and bottom about 16 feet thick. After the béton had set, the water was pumped out from the interior, an inner lining of masonry to form the altars, stairs, and floor was built, the caisson put into its place, and the concrete side of the trough at the entrance having been removed, the dock was complete.

The facilities for making béton or hydraulic concrete, which has the invaluable property of setting under water, and of thus forming an artificial rock or stone, are very great ; as it may be formed either from the naturally hydraulic limes, the artificially hydraulic limes or cement, or from the rich or non-hydraulic limes, rendered hydraulic by the admixture of other substances, such as pozzuolana, minion, or iron-mine dust.

The béton made from the naturally hydraulic limes, which are found extensively in this and other countries, is the most to be depended upon. The blue lias in England, the limestone of Arden (found near Glasgow) in Scotland, and that of Theil in France, are good specimens of their kind, possessing in an eminent degree the property of setting under water. Of the Arden lime, the Author and his partner have had abundant experience, in the dock works at Glasgow, Greenock, and other places. As to the blue lias, its extensive employment in the docks at Liverpool, London, and other important works throughout the kingdom, is proof of its good properties. The hydraulic limes of France have been still more severely tested, by their application for the formation of the large concrete blocks, used for the protection of the seaward side of the French breakwaters. It may be useful to mention, for comparison, the proportions of some of the concretes made from these various limes. The Arden lime concrete, employed by Messrs. Bell and Miller for the foundations of the large Graving Dock at Glasgow, was composed of one part of ground Arden lime, one part of iron-mine dust, one part of sand, and four and a half parts of gravel and quarry chips. The lias concrete, used at the recent extension of the London Docks by Mr. Rendel, consisted of one part of blue lias lime to six parts of gravel and sand. The proportions adopted for the blocks of the Mole at

Marseilles, were two parts of broken stones to one of mortar, the latter being composed of three parts of Theil lime to five of sand.

A knowledge of the mode of composing artificial hydraulic limes is of great importance, in situations where natural hydraulic limes are not easily procurable. Smeaton was the first to point out, that it was to the clay or silicate of alumina in the composition of the hydraulic limes, that they were indebted for their peculiar property. Subsequently the able researches of Vicat showed, by actual experiment, how all the rich or non-hydraulic limes might be rendered eminently hydraulic, by burning them with a certain proportion of silicious clay. Indeed, to Vicat is due the credit of having reduced the knowledge of limes to a system, and of having shown the practical application of concrete as an eminently constructive material. The excellent artificial cements now manufactured are most valuable to the Engineer; and the concrete made with Portland cement can hardly be surpassed. That used at the new Westminster Bridge, is harder and more compact than the greater number of building stones, even where put down in the bed of the Thames, and where it is exposed to the running stream. Portland cement concrete is also extensively used for the artificial blocks, weighing from 6 tons to 10 tons each, which form the hearting of the breakwater at Dover and that at Alderney, the proportions being one part of cement to ten parts of shingle.

Some substances, such as pozzuolana—a volcanic production found chiefly in Italy—have, in consequence apparently of silicate of alumina being predominant in their composition, the property of giving hydraulic qualities to the rich or non-hydraulic limes. It is of these that the concrete is made, which has long been used for marine works on the shores of the Mediterranean; and, indeed, the piers at some of the Italian ports have been constructed almost entirely of hydraulic concrete. The Author had lately an opportunity of examining, at Genoa, the extension of one of the moles of the harbour, the inner side of which has a vertical wall. The latter was in process of being constructed under water entirely of pozzuolana concrete simply thrown into the sea, from baskets carried on men's heads, a boarding confining it to the shape of the wall. In a short period, it set quite hard, so as to enable the upper part of the wall, which is of stone, to be built upon it. The outer side of the mole, which had been previously made, was formed by stones deposited 'à pierre perdue.' Though the depth of the quay wall was not great, this shows the confidence which the Italian Engineers have in concrete applied under water in a soft state. The piers of the new basin constructed by the Austrian Government at Pola, in Istria, are also formed, in a similar manner, of concrete confined between rows of timber piling.

But perhaps the most striking application on a large scale of pozzuolana concrete, is in the great mole which protects the port of Algiers. To form the mole, blocks of *béton* of immense size, so as to be immovable by the force of the sea, were employed. Some of these were formed in situ, by pouring the concrete into large timber cases without bottoms, sunk in the sea in the line of the mole. Other blocks of a smaller size, though upwards of 30 tons in weight, were made on shore, being moulded in strong wooden boxes. After the *béton* had set, the boxes were removed, and the blocks were launched into the sea to find their own level. The *béton* for the blocks in situ was composed of one part of rich lime in paste, two parts of pozzuolana and four parts of broken stone; that for the blocks made on shore, was formed of one part of lime in paste, one part of pozzuolana, one part of sand, and three parts of broken stone. These blocks set sufficiently hard in twenty-four hours, to resist the shocks of heavy seas, and the mole now stands firmly, instead of being, as it was when formed of loose blocks of stone in the time of the Moors, nearly destroyed every winter.

The French Engineers have shown great boldness and skill in the application of *béton*, as exemplified in the Pont de l'Alma over the Seine, the arches of which, as well as the piers, are formed of rubble concrete; in the new Graving Dock at Toulon, before alluded to; and in the formation, or protection of breakwaters, by enormous artificial blocks of *béton*, as carried out at Marseilles, Cherbourg, La Ciotat, Cette, Vendres, Cassis, and Algiers. A short time ago, when the Author inspected the mole, or breakwater which encloses the Harbour of Marseilles, he found the huge rectangular concrete blocks, weighing upwards of 20 tons each, by which its seaward side is protected on the '*pierre perdue*' principle, perfectly entire and sharp in their outline, though they had been exposed for many years to the action of the sea. Any one standing upon that mole, and witnessing in a gale the heavy seas breaking with tremendous force on these concrete masses and recoiling harmlessly, could have no doubt as to the efficiency of concrete as a constructive material.

Hydraulic concrete, to be effective, requires care and attention in its manipulation, and in the regulation of the proper proportions of its materials. Any failures must have arisen from inattention to these, or similar points, as there is ample experience to show that, when properly made, every confidence may be placed in its strength and durability. Even where stone is abundant, this material may be often employed with economy and advantage; but where stone cannot be obtained, the importance of being able to form an effective substitute, out of materials of so little value, and so widely distributed, can hardly be overrated.

CONSTRUCTION OF DOCK AND QUAY-WALLS WITHOUT COFFERDAMS.

Though so much has been effected in bridge building, little has yet been done in founding and constructing quay walls, piers, or breakwaters in deep water, of a solid and durable character, without the aid of cofferdams, diving apparatus, or other means equally expensive. The Author has, for a considerable period, devoted his attention to this subject; but it is only recently that he has had a favourable opportunity of putting his ideas into practice upon a large scale.

In sea water the Engineer has to encounter enemies which do not exist in fresh water, or at least only to a trifling extent. The 'teredo navalis' and other worms, quickly destroy timber, and the corrosive action of the sea water, and other peculiar properties, have a prejudicial effect upon iron. In consequence of these deteriorating influences, these materials have not hitherto been much employed in sea works, where durability is essential. There is no doubt, however, that they may be employed with advantage, if protected from the destructive action alluded to; and whatever materials may be used, it is desirable that the surfaces exposed to the sea should be of continuous stone work, or other material capable of resisting its effects.

As Engineers-in-chief for the Albert Harbour at Greenock, the Author, and his partner, Mr. Bell, have had an opportunity of introducing the new system there adopted for the construction of sea-walls and quays in deep water, without the aid of cofferdams, by which a large saving is effected, and works of great solidity and durability have been secured.

The accommodation for the loading and discharging of the shipping of Greenock consists of three open tidal docks or harbours, the most recent having been constructed by the late Mr. Locke, M.P. Extensive schemes for wet docks have been proposed at different times by several Engineers, particularly by Rennie, Telford, and Walker and Burges, but hitherto, no wet docks have been constructed, as it has been considered that the moderate range of the tide—from 8 feet to 10 feet—does not render them indispensable, and the trade is found to be efficiently worked by the present system. In the additional accommodation in progress, the system of harbours is adhered to, though provision is left for conversion into wet docks, by the addition of locks and gates, should this at some future period be deemed advisable.

The new works (Plate 9, Fig. 1) are situated on the west side of the town, and in order not to interfere with valuable shore ground, they have been projected almost entirely beyond the high-water line into the sea. The depth of water at the outer line being

considerable, the amount of excavation required in the interior is comparatively little. The outer sea pier, according to the plan proposed by the Engineers, will enclose a large extent of shore as well as the Bay of Quick, and when carried out to the full extent, will be upwards of 3,000 feet in length. Within this area there will be space for two harbours, each 1,000 feet in length, 15 feet deep at low water, or 25 feet at high water, with entrances 100 feet wide. There will also be ample room for the construction of graving docks, for the storing of timber, and for the erection of sheds. Connecting the two harbours is shown, in dotted lines, the position for a lock 350 feet in length, by which one of the harbours can be converted into a wet dock, with a depth of 25 feet, when required; and at the west end is shown the site for a graving dock, such a work being also in contemplation. It is only intended, however, in the meantime to execute about one-half of the sea pier, and to form one harbour or tidal dock, the Albert Harbour, leaving the prosecution of the other works till the growing trade demands further accommodation. This from the present rapid increase of shipping will be at no distant period.

The depth of water along the line on which a cofferdam must have been constructed, had such been contemplated, is in many places nearly 30 feet at high water; and taking into account the length, and that it must have been of strength sufficient to resist the storms of winter, it could hardly have cost less than £50,000. Besides the great cost of a cofferdam, there was another difficulty, as, owing to the line of the proposed new pier being close to the edge of the deep-water channel, it would have been necessary to project the cofferdam so far into the channel, as to have formed a serious interruption to the traffic. In consequence of these difficulties, and from considerations of economy, it had been the intention of the Trustees to use timber for the outer piers of the harbour, and the Engineers were instructed to make their plans accordingly. It was the opinion, however, of the Author and his partner, that in a situation where the sea worm is very destructive, the work ought not to be constructed of such a perishable material, and that it was quite possible to build a solid structure, so as to avoid the difficulties referred to, in an economical manner. In order to effect this, they proposed to construct the outer pier and quays forming the seaward side of the dock, without cofferdams, so that the pier might itself serve as a cofferdam for the interior operations in the harbour which would afterwards be required. This seaward pier is 60 feet wide at the top, having quays on both sides.

The mode in which the work was designed was, to form the walls under low water of a combination of cast-iron guide-piles in the front, with a continuous stone facing, slid down over and

enclosing these, and of concrete backing deposited in a soft state, all of which could be easily accomplished from above the water line. Timber bearing-piles were to be used in the body of the walls where required, and the upper part of the walls from the low-water line was to be carried up of masonry in the usual manner. (Plate 9, Figs. 2 to 7.)

This plan was felt to be so novel, particularly with regard to the application of the concrete, that though the Trustees as a body had the greatest confidence in the Engineers, they considered it to be their duty before proceeding with the work, to fortify themselves by having the opinion of another Engineer. Accordingly, Mr. Thomas Page (M. Inst. C.E.) was consulted, who fully satisfied them as to the efficiency of hydraulic concrete applied in the manner proposed, and otherwise confirmed the soundness of the principles upon which the works were designed. At his suggestion, granite from the Ross of Mull was substituted for freestone, for the stone facing under the low-water line, as it could be obtained in large blocks at a moderate price; he also recommended that the timber piling should be dispensed with, but the nature of the bottom has hitherto not allowed this to be carried out to any great extent.

The first operation in the construction, when the water is not sufficiently deep, is to dredge out two parallel trenches to 17 feet below low water, for the foundations of the walls. A staging of timber piles is afterwards erected in the line of the pier over the whole breadth, for carrying the tramways, travelling cranes, and piling engines. Cast-iron guide piles are then driven from the staging, with great precision, 7 feet apart in the line of the face of each quay-wall. These piles are driven till their heads are near the low-water line, and they form guides for putting down the stone facing. They are connected at the top transversely by wrought-iron tie-rods stretching through the pier, cottered into sockets and binding the heads together. At first it was thought that there would be some difficulty in driving the iron guide-piles with the required exactitude, but this was overcome by pile engines of peculiar construction, devised by Mr. William York, one of the contractors. (Plate 9, Figs. 8 and 9.) These travel on the rails of the scaffolding, and are furnished with long arms projecting downwards, strongly stayed by diagonals, and forming a trough, into which the pile is placed, and from which it is driven by the pile engine in the manner of an arrow from a cross-bow, being obliged to go down perfectly straight.

The ground is very unequal, the hard substratum, or red 'till,' being in some places 20 feet below the bottom of the wall, the upper strata being mud and soft sand. In such cases timber piling, driven to the same level as the iron piles, is used to form a platform for sustaining the part of the wall above low water; but

where the ground is firm this is not required. When the proper depth has been dredged out and the piling driven, a bed of hydraulic concrete 3 feet thick, and 20 feet wide, is deposited in the trenches, to form a base for the wall to spring from, and to give a large bearing surface. Into the grooves formed by the flanges of the iron piles, large granite slabs, from 18 inches to 2 feet thick are slipped, the bottom one resting upon the concrete base, and on a projecting web cast on the piles: not more than three stones fill each compartment between the piles 16 feet in height and 7 feet in width. These stones slip into their places with the greatest ease, and form the face of the wall under water. Behind this facing hydraulic concrete is lowered under the water in large boxes having moveable bottoms, and is discharged in mass to form the body of the wall. To confine this at the back before it has set, loose rubble stones are deposited and carried up simultaneously with it. The hearting of the pier, consisting of hard 'till' stones, and gravel, is deposited afterwards, and the whole carried up to the level of low water.

The entire mass, piles and stone facing, concrete backing and hearting, is allowed to consolidate for a sufficient time; after which the heads of the iron piles and the granite facing blocks are capped at the level of low water by a granite blocking or string course, and the upper portion of the walls is carried up in free-stone ashlar, and rubble. The remainder of the hearting between the walls is then filled in, and the whole is finished with a granite coping and causeway. The walls are 36 feet in height from the foundations, $11\frac{1}{2}$ feet thick at the concrete base, and they diminish to 5 feet thick at the top.

Particular care is taken with regard to the hydraulic lime. It is burnt at the quarries, but is brought from thence in the 'shell' by the railway in covered waggons, so as to preserve it from wet. It is ground at the harbour works, for which purpose, and for mixing the mortar, there have been erected four vertical double-roller mills and two sieves, driven by an engine of 20 H.P.

In the part of the pier which has been already executed, the stone facing under low water being made to slip into the groove formed by the flanges of the iron piles, the outer flange is left exposed to the action of the salt water, which no doubt will in the course of time exert an injurious effect upon the iron. (Plate 9, Figs. 4 and 7.) To remedy this, it is intended in the remainder of the work to reverse this plan, and to make the grooves in the stone facing, into which the outer iron piling will fit. (Plate 9, Figs. 2 and 5.) The stone blocks will therefore overlap the iron piles, and form a continuous stone facing, so that no part of the iron will be exposed to the action of the salt water. The grooves will be filled from the top with cement, which will enclose the iron flange, and effectually preserve it.

When the whole extent of the seaward pier is completed, the

interior operations for the harbour will be proceeded with. This pier will serve as the principal cofferdam, and the entrance will be closed by a short cofferdam about 100 feet in length, and then the water will be pumped out from the enclosed space; after which the excavation, and the construction of the interior walls surrounding the harbour will be commenced. It is not intended to describe these operations, as they do not possess much novelty.

The cost of the outer or sea piers, 1,200 feet in length and 60 feet wide, constructed in the manner described, will be £63,000.¹

The concrete employed is formed of Arden hydraulic lime, iron-mine dust, sand, gravel, and stone chips,—the lime and the mine dust being well ground, under edge stone mills, before being mixed with the other materials. The proportions are by measure:—one part of ground lime, half a part of mine dust, one part of sand, and three parts of gravel and stone chips. Immediately after being mixed, and when brought to a proper consistency with water, it is conveyed to where it is to be used, is let down under water in the discharging boxes, and in a short time sets very hard. The boxes used are either of iron or of wood, and contain one cubic yard each. Those of iron are found to be preferable, as the buoyancy of the wooden ones renders them somewhat unmanageable in a tideway, after their contents have been discharged.

The works of the Albert Harbour are being executed under the immediate superintendence of Mr. John Thomson, C.E., as resident Engineer, the contractors being Messrs. W. and J. York.

This mode of constructing walls in deep water without cofferdams has proved very successful, and a sea-pier of great solidity and durability has been formed at a comparatively moderate cost.

In constructing quay-walls on the foregoing principles, different modes of forming the stone casing may be employed; and particu-

* It has recently been decided to increase the area of the Albert Harbour, by building the south quay 90 feet further back than is shown on the plan (Plate 9, Fig. 1), the necessary land having been acquired. In connection with the harbour works, and to dispose of the materials from the excavations, amounting to nearly half a million cubic yards, it is intended to form an esplanade, or embankment, 100 feet wide, along the shore of Fort Matilda. This will be faced on the seaward side by a substantial wall, 6,000 feet in length, with landing-stairs opposite the principal streets, and the wall will be surmounted by an iron balustrade. The cost of the several works will be—

Albert Harbour and Albert Quay	£150,000
Sea-wall and roadway of esplanade	20,000
Land	50,000
Cranes, rails, &c.	10,000
Total	<u>£230,000</u>

larly where stone of a softer nature than granite, such as limestone or freestone, is used, a still more efficient outer casing may be obtained. (Plate 9, Fig. 6.) In it, blocks of stone, having orifices or holes cut in them, are strung or put down over the iron piles, so as completely to enclose them. These blocks have also grooves or projections on their sides, in which are slid down intermediate slabs or blocks of stone, having corresponding grooves or projections. A continuous facing of stone, having all the stones locked into each other, is thus formed, and the iron piling is effectually enclosed. It was on this principle that the facing under low water was intended to have been formed at Greenock, previous to its having been suggested to employ granite instead of freestone. Still further to protect the iron from the action of the salt water, the holes round the piles would be filled up from above with cement well-rammed down, so as to fill up all the joints, and to unite the stone and iron together. This plan admits of the iron piles being kept further apart than when single blocks connect the piles. Concrete backing may then be filled in, and the structure be completed as previously described. Temporary sheet piling or boarding, instead of loose stone, may be employed to keep the concrete in its place until it has set. In many cases, blocks of béton, which can be easily moulded into the shapes required, may be advantageously substituted for stone in the facing, as it has been proved by experience that, when properly made, they possess the requisite strength and durability.

The range of different purposes to which this system of founding marine structures is applicable is very extensive, and works such as the formation, re-facing, or re-construction of quay-walls; the formation of docks or tidal basins on sites covered by the sea; embankment walls along the shores of seas or rivers; the foundations of lighthouses, beacons, or forts which may require to be made in the sea; the construction of breakwaters enclosing harbours of refuge; may be effected with a speed, facility, and economy not hitherto attainable.

The applicability of this system to the construction of breakwaters, and the necessity for some mode by which the cost of these works may be lessened, seem to the Author so important, as to deserve further remarks.

APPLICATION TO THE CONSTRUCTION OF BREAKWATERS AND HARBOURS OF REFUGE.

Although various Royal Commissions and Parliamentary Committees have elicited much valuable information on this subject, the main object of diminishing the enormous cost of these works, and of providing a durable and substantial, and at the same time economical, barrier to the force of the sea, is as yet a desideratum.

So important, indeed, has this become, that in 1860 a Select Committee of the House of Lords was appointed to inquire, how far it might be practicable to adopt some plan, for the construction of breakwaters and harbours of refuge, less costly than the system of solid masonry then in use. Various plans were discussed, and amongst them floating breakwaters; but the investigation failed to establish any effectual substitute for the present modes of construction.

The plans about to be described will, in the Author's opinion, have a material effect in filling up this want. Before proceeding, however, it will be necessary to refer, briefly, to the principal modes of construction hitherto adopted, and to consider the peculiar phenomena by which such structures are affected.

The most common mode of forming breakwaters is the 'pierre perdue,' or 'long slope' system. This is simply the deposit in the sea of a vast amount of loose rubble stone, rising to about the level of high water, allowing it to take its own level, and to be acted upon by the sea, until its section assumes the permanent form which this action gives it. The seaward side obeys the laws of ordinary sea beaches, and forms itself into a long sloping shore, involving the employment of an enormous amount of material before the mound reaches the height to give the required protection. Such a system is only applicable where stone is abundant, and can consequently be deposited at a cheap rate. Of this system, the Plymouth, Cherbourg, and Holyhead breakwaters may be taken as examples. (Plate 10, Figs. 1 and 2.)

In situations where stone is not abundant, the opposite principle, called the 'vertical system,' is adopted. In this mode the walls are built upright from the bottom; and as all the material below low water is put in place by diving apparatus, and is of an expensive nature, the cost of a work executed in this way is very great. The Dover Breakwater, in course of construction, is the most prominent example. It is built up solid from the bottom of the sea, the exterior facing being of ashlar granite blocks rebated, or checked into each other, and the hearting of rectangular blocks of concrete, built in the same way as ashlar masonry up to the level of high water, above which it is filled in with liquid concrete. (Plate 10, Fig. 7.)

Besides these systems, which may be taken as the extremes, an intermediate form of section, combining both to a certain extent, is adopted. It consists in carrying up a rubble mound to within a certain depth below low water, and upon this, building the remainder of a vertical construction. The Alderney Breakwater may be taken as representing this system to a partial extent. (Plate 10, Fig. 10.)

It has been a subject of discussion, as to whether the 'long slope,'

or the 'vertical wall' was the better section for breakwaters, and as to the relative force of the sea exerted upon them. The observations which have been made on waves may be said to have settled this point in favour of vertical walls, as it has been clearly shown that waves in deep water are chiefly oscillatory in their character, the fluid having little progressive motion in itself, and consequently exerting but little force on objects opposed to it; but in shallow water, waves assume an entirely different character, as they acquire a progressive motion, becoming waves of translation, in which the fluid is carried bodily forward in a horizontal direction, and in consequence it strikes any body opposed to it with great percussive force. Vertical walls, therefore, which rise from the deep water, being only subject to the oscillatory movement of the waves, are least exposed to the destructive effects of storms. The evidence taken before the Royal Commission in 1859 seemed to be conclusive on this point, and the opinions of the Commissioners, as developed in their Report, may be considered to have set this subject at rest. But whatever difference of opinion there may still be upon this matter, there can be no question as to the vast saving of material by vertical walls, and of the great economy which would result, provided a simple and easy mode of construction could be adopted. The vertical system has, besides, the great advantage of being applicable in many cases as quays for vessels lying alongside to load and discharge, which may be turned to valuable account both for commercial purposes, and, in times of war, for the rapid shipment, or debarkation of troops, stores, and other material.

The experience, however, derived from the formation of the great breakwaters on the 'pierre perdue' or 'long slope' principle, such as Plymouth, has been very valuable. The examination of the sections which the materials assume, shows that the great disturbing action of the sea, or conversion of the waves of oscillation into those of translation, does not extend to any considerable depth; as it is found that the long sloping beach terminates generally at from 12 feet to 15 feet below low water, after which the inclination becomes much steeper, the materials assuming nearly the form due merely to the natural angle of repose, as if unacted upon by any force except that of gravity. The inclination on the seaward side within the tidal range, and to the depth of 12 feet or 15 feet below low water, is generally five or six horizontal to one vertical, but below that depth it is only from one to one and a quarter horizontal to one vertical. It is the long slope which these breakwaters assume to a certain depth, that causes the enormous absorption of material; but it appears that a mound of rubble may be deposited to within a certain distance of low water which will not have this long slope,

and consequently will only require a comparatively small quantity of material. The consideration of these facts shows, that in the generality of cases, the vertical and 'pierre perdue' systems may be combined with advantage and economy, by first depositing a rubble mound to about 15 feet below low water, and from that point carrying up the remainder of the breakwater by vertical walls.

A great improvement in the facility of constructing these breakwaters, when such an immense quantity of material has to be deposited, was the introduction, by the late Mr. Rendel, of timber staging carried on piles in advance of the work, and sustaining lines of rails, by which the material can be brought down and be deposited in the sea with a rapidity before unattainable. The consumption of timber is, no doubt, very great, as much has to be left imbedded in the work, and there is considerable destruction besides; but this is amply compensated by other advantages. By this system, an average of about a million tons of stone a year have been deposited at Holyhead, and a similar plan is pursued at Portland.

Massive staging is also employed at the vertical breakwater at Dover, for facilitating the building operations. Indeed, staging may now be considered essential in the generality of cases for the economical construction of such works.

The breakwaters of the French Engineers are generally formed 'à pierre perdue,' but upon a different method from that pursued in this country. Thus, at the Plymouth Breakwater, only large blocks of rubble stone were deposited, the small being thrown aside, and at Holyhead and Portland, the large and the small rubble were deposited promiscuously; while the French Engineers usually employ the small rubble for the core, and reserve the larger blocks for the outer coating. Furthermore, they protect the seaward side by blocks of *béton*, thrown in to take their own position, and of such a size, (generally from 20 tons to 30 tons), as effectually to resist displacement by the utmost force of the waves. These blocks assume a slope as steep as one to one under the water line, so that the mass of material in a breakwater thus constructed, is considerably less than where smaller materials are employed for the seaward face. The moles of La Joliette and Napoleon which enclose the harbour of Marseilles, are excellent examples of this mode of construction. (Plate 10, Fig. 3.)

Having thus glanced at the general principles which affect breakwaters, and described the modes of construction usually adopted, the conclusion to be arrived at appears to be, that the vertical system is that which best resists, or rather averts, the destructive action of the sea, and requires the smallest amount of material. However, both systems, the 'long slope,' and the 'vertical,' as at present carried out, are very expensive, the

former from the quantity of material which is required, the latter from the costliness of the material and the mode of construction. The one system may be characterized as involving the maximum in quantity, and the minimum in cost of material; the other, on the contrary, the minimum in quantity and the maximum in cost of material. The object sought to be attained by the system about to be described, is to effect a minimum, as far as possible, both in the quantity and in the cost of the material.

According to circumstances, breakwaters on this system would be constructed either wholly vertical, extending from the bottom, or partially vertical springing from a rubble mound. For the sake of comparison, the mode proposed by the Author (Plate 9, Figs. 10, 11, and 12,) is designed to suit the conditions usually prevailing; say a range of tide of 15 feet, and a depth at low water of 6 fathoms, being about the same as at the Plymouth Breakwater, and as at Hartlepool, Filey Bay, and the entrance of the Tyne, where the most important harbours of refuge have been recommended by the Royal Commissioners. The section (Plate 10, Fig. 6,) represents a breakwater with a parapet, but this is not indispensable to the main object of a breakwater, and is only required in certain cases, as where the inner side is to be used for commercial purposes. Where the parapet can be dispensed with, the top of the breakwater may be capped by large blocks of *béton*, or stone, of such a weight as not to be displaced by the heaviest seas. (Plate 10, Fig. 5.)

The principal feature of the new plan is a framework of iron, formed of piles, or standards, and ties, which serves as the staging for all the constructive operations, and afterwards becomes an essential portion of the structure, by binding together a strong casing of stone or other sufficiently durable material, which encloses and forms the facing of the breakwater, allowing the interior to be filled up with loose rubble, or other cheap materials, which may be cemented into a solid mass by means of liquid *béton* or concrete. It will be preferable for breakwaters to make the standards of wrought-iron, and in the generality of cases it will not be necessary to drive them into the ground, but simply to set them in place.

The mode of proceeding is to erect the iron staging in advance of the work, which may be done, either by driving, screwing, or guiding the piles, or standards, from a machine placed on the platform, and travelling along as it progresses. This machine will have long guides firmly stayed and set accurately in position, into which the iron piles will be placed, and then driven in a similar manner to that pursued at Greenock. When two piles are erected in place, they are connected transversely by iron ties, and by the temporary platform at the top for bearing the rails, and the piling machine is then moved on to drive the next set, and so on. Fol-

lowing this operation come the wagons depositing the material to form the rubble mound, which collecting round the lower part of the standards, firmly fix them in their places, and give stability to the staging. When the mound has risen to the required height, say 18 feet below low water, the cranes from the staging above commence lowering the casing blocks for the facework. These are made to enclose the iron standards, and are formed so as to be arched or locked into each other, and thus to resist any pressure arising from the backing. They can be made to break bond, or to slide down without breaking bond, as may be considered desirable; but the former plan permits the standards to be kept at a greater distance apart, and the blocks to be of less dimensions, and at the same time, of greater strength.

Simultaneously with the building of the casing, the hearting of the work, rough rubble, or other suitable material, is to be deposited from the wagons on the staging, filling in from the centre, while backing of béton, or hydraulic concrete, will be lowered down in large boxes, and discharged behind the stone casing, consolidating and cementing together the rubble hearting, as it is filled in and falls down.

It will be observed, that the whole of the facing is rendered continuous; and by all the blocks being arched, or grooved into each other, it is impossible that any individual block can get out of place. This is a danger greatly to be feared in structures of this kind built in the ordinary way, as the action of the compression of the air in the joints of the masonry, by the pressure of the waves, and the after-expansion when the waves retire, is sometimes so great as to blow out the stones, thereby endangering the whole structure.

By this system the Author believes great solidity and strength may be obtained, as the whole structure is bound firmly together by the iron framework; while the manner in which the stones of the facing are locked into each other, and in which the concrete will penetrate and solidify in a short time the whole mass, will realize as nearly as possible the idea, which should be the object of attainment in such structures, of a monolith, or solid rock in the bed of the ocean.

The cost of such a structure, under ordinary circumstances, and of dimensions suitable for Hartlepool, Filey Bay, or the entrance of the Tyne, may be taken at £190 per lineal yard without a parapet, and at £200 per lineal yard including a parapet wall, according to the following estimate, in which the same prices are taken as were assumed by Mr. John Murray (M. Inst. C.E.) in a previous discussion at the Institution.¹

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 104.
[1862-63. N.S.]

Estimate of the quantity of material in a bay of 15 feet of a breakwater, with 36 feet depth at low water and 15 feet range of tide.

		£.	s.	d.
150 cubic yards rubble in outer coating of mound	at 4s. 6d.	33	15	0
550 cubic yards rubble in body of mound (deducting one-fifth for interstices)	at 3s. 6d.	96	5	0
2,970 cubic feet béton blocks in facing under low water	at 1s. 8d.	247	10	0
2,250 cubic feet ashlar facing above low water	at 1s. 6d.	168	15	0
547 cubic yards rubble hearting (deducting one-fifth for interstices)	at 3s. 6d.	95	14	6
70 cubic yards concrete backing	at 10s.	35	0	0
83 square yards causeway	at 10s.	16	10	0
119 cwt. wrought-iron standards (100 lbs. per foot)	at 30s.	178	10	0
22 cwt. wrought-iron transverse ties (3 inches diameter)	at 30s.	83	0	0
5 cwt. wrought-iron longitudinal ties	at 30s.	7	10	0
<i>Parapet.</i>				
907 cubic feet ashlar facing	at 1s. 6d.	68	0	6
9 square yards causeway	at 10s.	4	10	0
30 cubic yards concrete	at 10s.	15	0	0
		<hr/>		
		£1,000 0 0		

£1,000 ÷ 5 = £200, the cost per lineal yard of breakwater with parapet wall; and making deduction for parapet and addition for capping blocks, £180 per lineal yard would be the cost without parapet wall.

The blocks forming the casing under water may be either of stone or of béton. When the former cannot be conveniently procured, the latter may be used with advantage, particularly as it can be so easily moulded into the required shapes, and almost of any size. The power of such blocks to resist the action of the sea for an indefinite period is now fully confirmed. These may at least be generally adopted for the inner walls of breakwaters. Indeed concrete blocks, built in the ordinary way, have been already used by Messrs. Walker and Burges at Alderney for the inner facing.

The great economy of this system of constructing breakwaters would arise from the smallness in quantity and the cheapness of the bulk of the material. The quantity of material in this breakwater compared with that in the Plymouth Breakwater on the long slope principle, in the same depth of water will be about as one to four, and the disparity of cost is not less striking, the Plymouth Breakwater having cost nearly £900 per lineal yard.

In comparing with any other mode of construction, the iron framework may be allowed to go for nothing, as staging of some kind must be used for the speedy and economical construction of any kind of breakwater. This framework of iron standards will not cost more than timber staging, and, indeed, far less than in cases where an immense quantity of staging requires to be used for the deposit of the enormous mass of material of long slope breakwaters, such as at Holyhead; while it will be far more secure,

in consequence of its inherent strength, the heavy nature of the material, and the small surface presented to the action of the waves. The buoyancy of timber staging is an element which causes its own destruction, as is exemplified at Holyhead, where it is admitted that for every piece of timber another piece is required to make up for the loss.

Another important advantage is the great speed with which it may be constructed, from the mass of the material being of a nature easily deposited, and from the facility with which operations may be carried on upon a long stretch of the work at one time. In situations where the materials for the construction of ordinary breakwaters cannot be obtained, the advantages of this system would be still more striking. Dover may be taken as an example, there being no stone in the neighbourhood suitable for depositing 'a pierre perdue,' or building vertically in the usual modes of construction. By the system proposed the harder chalk from the cliffs, and shingle, could be used for the hearting, as in a structure so firmly bound together these materials concreted with *béton* would serve the purpose quite as well as any other. In forming the rubble mound, the example of the French Engineers might be followed with advantage, by forming the core of smaller and inferior materials, and for this the chalk and shingle would be quite suitable. This would be protected by a thick layer of rubble, and on the seaward side by a layer of concrete blocks, of such a size as would not be disturbed by the sea. The vertical superstructure would be constructed of chalk, or sandstone rubble, concreted by *béton* for the hearting. A breakwater upon this construction (Plate 10, Fig. 8.) the Author estimates could be built at Dover for £290 per lineal yard. The present breakwater for the same depth of 45 feet at low water is contracted for at £1,245 per lineal yard, so that there would be the enormous saving of upwards of one million and a half sterling per mile. The difference in the cost of construction, vast as it is by this system, is not the whole saving, as the time occupied is an important element, affecting the final cost of such a work, the interest on the outlay being lost until the harbour becomes available. There can be no doubt of the solidity and durability of the Dover Breakwater, but considering its enormous cost, and the distance into the future before its completion will render it available for commercial or for war purposes, the wisdom of prosecuting it upon the present mode of construction may be well called in question. Upon the construction proposed, the breakwater could be completed and be available as a Harbour of Refuge for the naval and commercial fleets of the country in less than five years, at a cost of little over £1,000,000.

Breakwaters and piers have been frequently made of timber

framing and casing, confining a mass of rubble. Extensive piers on this principle are in existence at Boulogne, Calais, Dunkirk, and other ports; but it is evident that such a system, from the timber being exposed and the consequent want of durability, and from their liability to sudden destruction when once the casing gives way, must prove very expensive in the end. This system has been revived, though upon more scientific principles, by Mr. Abernethy (M. Inst. C.E.) and Mr. Michael Scott (M. Inst. C.E.).¹ In these plans a structure, composed of a casing of timber, is formed of timber frames, standards, or piles and planking, and this casing is afterwards filled with rubble. But as the casing cannot be expected to possess much durability, it is proposed subsequently to enclose this structure by solid walls of masonry or composite blocks, for which the first structure will afford a convenient and substantial platform, for bearing the rails and cranes necessary for executing this part of the work. There are two distinct operations necessary, therefore, to complete the work upon this mode in a permanent manner; first, the formation of the inner structure with its timber casing; and, second, the formation of the outer structure, for the purpose of making a casing of a durable character. The economy of making breakwaters of a durable construction on these modes has not been fully made out, chiefly arising from the great quantity of timber required, and the necessity of employing two distinct casings, one of which must be superfluous.

The system which the Author has proposed, will he thinks secure all the objects which appear to have been aimed at by these plans, but with greater simplicity and economy.

It is not essential that the standards employed in the system proposed by the Author, should be of iron, as they may be of timber, but enclosed, as has been already described in the case of iron standards, in a casing of blocks of stone or of béton. The Author, however, would not recommend this, except for small piers, or breakwaters where great economy is necessary.

APPLICATION TO THE FOUNDATIONS OF MARINE FORTIFICATIONS.

The general application of steam to ships of war, the improvements in artillery, by which the range and weight of projectiles have been vastly extended, and the system of coating ships with defensive armour, have entirely changed the relations of works of defence on shore to those of offence from sea, and rendered the supervision of the system of fortifications which defend the naval arsenals and seaports, a question of vital moment. The present

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xviii, p. 72; vol. xix., p. 644; and vol. xxi., p. 322.

defences have been found to be quite inadequate to cope with the new forces which can be brought against them, and in particular, a necessity has been felt for the construction of advanced works, which shall keep the enemy without the range of bombarding the places they are intended to protect, or at least subject them to severe punishment while attempting it. In some cases, these can only be constructed in the sea, and in others, this is the most effective situation for them. It is in this way that Cronstadt is protected, and it forms an important part of the general scheme of the new works for the defences of Plymouth and Portsmouth. There are many considerations that will render sea-forts of great value, which need not be entered upon in this place. Suffice it to say, that it is probable the use of such advanced works will be much extended, and many situations could be pointed out where forts could be more advantageously placed in the sea than on the land, for the protection of seaport towns. The difficulty, however, in the way of executing such works, is the expense and delay in constructing the foundations. The Author is of opinion, that the principles already described for works of a different nature, would admit in this case also of successful application for the works under low-water level. The casing might be of granite, or the greater part of large concrete blocks, capped near the low-water line, where exposed to shot, by a massive blocking course of granite. The manner in which the filling in of concrete in the interior would set in a solid mass, and in which the whole structure would be bound together by the iron standards and tie-rods, would, the Author apprehends, form as efficient a foundation for the purpose as could well be devised, while the rapidity and economy with which such a work could be put down, would certainly be advantageous.

In developing the foregoing system for constructing the submarine works of breakwaters, piers, quay walls, lighthouses, fortifications, and other similar structures, it must not be understood that it is advocated as being applicable in all cases, as the mode of construction of any engineering work must be determined greatly by local circumstances. But the Author considers that it will admit of general application, and that the following advantages may be fairly claimed for it:—

- Great economy, combined with strength and durability ;
- Facility and rapidity of execution ;
- Adaptability to situations where the present modes are inapplicable.

It is to be expected that there will be considerable doubt and diversity of opinion regarding the various operations involved ; such as the accuracy with which the guide-piles or standards can be

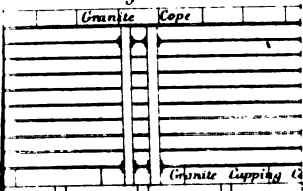
driven, the facility with which the stone facing can be put in place, or the depositing and setting of the concrete in open sea-water; but it must be recollected that all these have been tested and found successful in works upon a large scale at Greenock.

The various examples which have been given, to show the different applications of this system, must be merely understood as intended to illustrate the subject generally, as, of course, the details will admit of variation, according to the views of different Engineers.

The Paper is illustrated by a series of Diagrams, from which Plates 9 and 10 have been compiled.

[Mr. MILLER

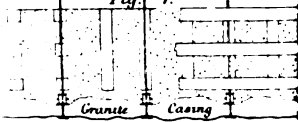
Fig. 4.



Granite

ELEVATION OF PART OF PIER

Fig. 7.

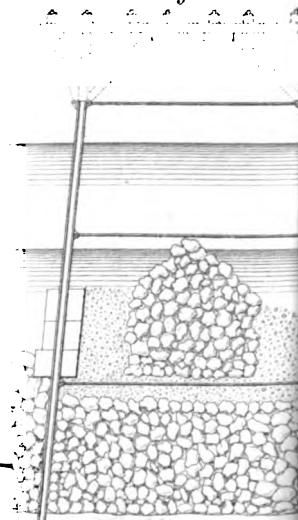


Granite

Casing

N OF PART OF PIER AT LOW WATER

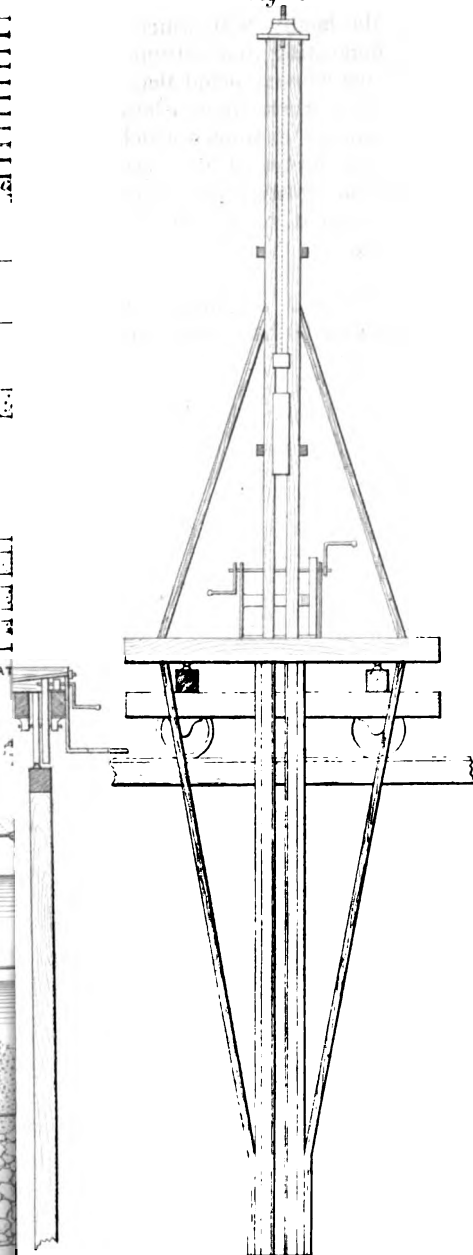
Fig. 12.



SECTION OF PERMANENT FRA
AND TEMPORARY PLATFOR

Scale for Figs. 10, 11, & 12

Fig. 9.



S.

Harbour Face
 H W Ordinary Springs
 L W Ordinary Springs

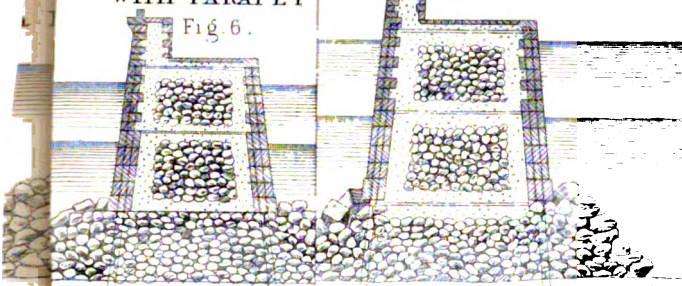


WATERS

PROPOSED
 NEW MODE FOR DOVER

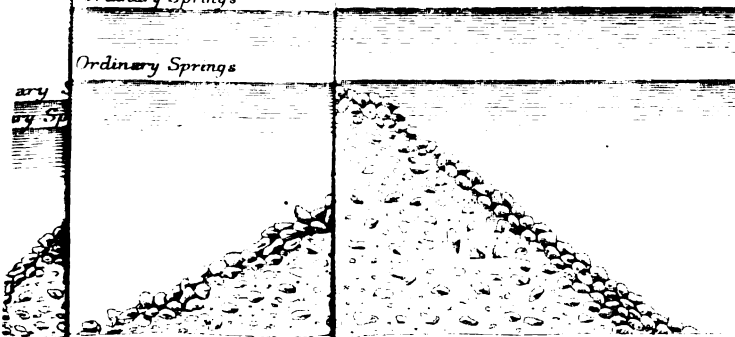
WITH PARAPET
 Fig 6.

Fig 8.



Ordinary Springs
 Ordinary Springs

Harbour Face



140 120 100 80 60 40 20 0 Feet

MacLure & MacLure, Sec

Vol XXII Session 1862-63

Mr. MILLER stated, in reply to questions, that the contract for the pier at Greenock, complete in every respect, 1,200 feet in length and 60 feet in width, had been taken for a sum of £63,000, being at the average rate of £157. 10s. per lineal yard. As yet only about 300 feet in length of the pier had been completed. No difficulty whatever had been found in getting the concrete to set, and to become thoroughly consolidated, even under water 15 feet or 20 feet deep at low water; and although occasionally there were strong northerly winds and heavy seas in that part of the Clyde, yet the concrete was as solid as rock, and so hard that iron bars would not enter it. Much depended, of course, upon the quality of the materials used in forming the concrete, and upon the mode of preparation. The Paper would be found to contain detailed information on this branch of the subject.

Mr. JOSEPH MITCHELL remarked, that the water at Greenock was generally very quiet. From his experience he apprehended that, with rough water, there would be difficulty in getting the concrete to set firm. In some cases he had found that the lime and the sand were washed out by the water, and only the large gravel remained. That appeared to him as likely to arise in depositing concrete in boxes, in the way which had been described.

Mr. GREGORY, V.P., observed, that there could be no doubt as to the structural advantages of concrete, if it was allowed to set, and if the materials of which it was composed were not washed away. But concrete generally required a casing to protect it: and while he gave full credit to the Author for the ingenuity of the construction of the casing, which carried out the same idea as that which had been adopted in the piers of Westminster Bridge, he feared that, where exposed to a heavy sea, it would be found that there was not sufficient bond between the casing and the body of the work. It was well known that water would often penetrate through the joints of masonry, and whatever might be the precision of the work, he apprehended there would be a risk of the water finding its way behind the casing, and along the line of the bolts, which appeared to be the only means by which the casing was held to the body of the work. He thought that when such a structure was exposed to a heavy sea, damage might from this cause occur to the casing, and incidentally to the whole mass. When using concrete as the hearting for a wall, he had frequently adopted counterforts and bond courses running back from the casing walls, so as to unite them with the mass of the work. It was possible that while in rivers, or estuaries, where there was no great run of sea, the system described might, under certain circumstances, be adopted with advantage, it was necessary to pause before using it for walls which required to be well bonded, when they might be exposed to the action of the sea in harbours or breakwaters.

Mr. J. F. BATEMAN thought the Author did not mean it to be supposed that the outer casing was in itself completely watertight, so as to form a close coffer-dam. He had no doubt that concrete, when properly made, would set as hard as the old red sandstone conglomerate; but there was the risk of the water sucking out the lime before it had become set, and leaving only the gravel behind. In the structure under discussion, there was certainly a want of bond, as had been already pointed out; and he feared that, in a heavy sea, the whole of the veneer-like facing would be stripped off, leaving the rubble backing and the concrete hearting entirely exposed. That, however, would not be of much consequence, if sufficient time had elapsed to enable the hearting to become consolidated, and if the primary difficulty, of preventing the water from sucking out the lime and depriving the concrete of its cementing property, were overcome. If the concrete was of good quality, then the plan described would, no doubt, if successful, ensure a very economical kind of work, and in that view it was deserving of consideration. At the same time he thought more experience was required to enable its intrinsic merits to be fairly judged of. It would be necessary, in order to give every chance of success, that the concrete should be composed of excellent hydraulic lime, and sharp stones, with little or no sand, so as to possess no particles which could easily be removed, and that the whole of the work should be well bonded together. Although Portland cement, undoubtedly, made the best concrete, where rapid setting was required, a good concrete could be obtained without the use of cement. For instance, he had frequently employed the Halkin Mountain lime, and the concrete in which it was used set as hard as rock. The character of the concrete depended upon the quality of the lime, and the proper apportionment of the lime to the broken stone or shingle. When lime was used the concrete would not set so quickly as with Portland cement.

Mr. F. J. BRAMWELL said, it appeared to be assumed that cast-iron was an improper material to be used in the sea. He should like to know, whether that had been satisfactorily tested in English waters, and also whether the applicability of that material did not depend, very much, upon the quality of the cast-iron; in other words, whether different results had been obtained from using grey or white iron.

Mr. BEARDMORE fully agreed with the concluding observation of the Paper, that everything must have its own special application. With regard to the adaptability of this form of construction to breakwaters, he remarked that the term itself implied a structure requiring such prodigious strength, that it was necessary carefully to consider the circumstances under which that form of construction was to be adopted. He had occasion to inspect the works at

the Albert Harbour somewhat critically, and he thought that, regard being had to the local conditions, the plan was well chosen. In the Clyde at Greenock there was but little sea exposure, a heavy sea being in fact very rare. The worst evil that had to be contended with was a rather strong current; but when the first piece of work was finished, a cover was afforded against the current, as far as any washing effect was concerned. The foundation of the pier, generally speaking, was in the very strong 'till' usual in that part of Scotland, and was as good a foundation as could be desired; it was situated also advantageously for the excavation of a trench suitable for the reception of the basement bed of concrete. From his examination of the process of manufacture, he considered that both the hydraulic lime and the manufactured concrete were very good. The plan he had found to succeed best in the manufacture of concrete was, first to make a mortar of lime and sand, and then to mix and incorporate this mortar with the coarser material. With ordinary Thames ballast, for instance, a far superior concrete was made, by first sifting out the sand and blending it into mortar, and afterwards mixing with the remaining coarse material, than by making the concrete at once, by incorporation of the original gravel with the same proportion of lime. The former operation greatly improved the concrete, and economized the use of lime, or cement, especially if the ballast and sand were washed before they were used. He had examined the concrete at Greenock at dead-low water, where the surface of lime was being washed by the tide, and it appeared to be perfectly hard and sound. Even with an iron bar, he could not detect anything like softness; in fact, in that situation he doubted whether there would be any wash at all, so as to affect good hydraulic concrete deposited in large masses. This part of the work was well below the level of dead-low water, where the water was comparatively quiescent, and was subject only to the motion within itself. The rise and fall of the tide in the Clyde was very small, and there was scarcely a variation of 2 feet in four or five hours. In some cases, the extent of tide created the necessity for a high vertical wall, so that great strain was thrown upon the work, as at Liverpool, where the difference between the neaps and springs was as much as the whole rise of the tide at Greenock.

If he might give his opinion fairly upon this work—which he presumed was the object of the discussions at the Institution—he certainly looked with suspicion on the want of bond. On this point he would strongly advise the Author to be cautious. In the construction of a work like Westminster Bridge, there were two faces tied together, and intimately connected by cross ties; in fact the piers formed a wall with two faces; but in the pier at Greenock there was a mass of material 40 feet in width that might settle

between the two walls, and the power that would be exerted on the ties by a small settlement would be very great. Therefore, not only was the strength of the ties important, but also the strength of the grooved iron piles, as they became in fact girders for sustaining the weight of the materials forming the hearting, and for conveying the pressure to the thin facing stones. The solidity of the structure in reality depended on the cast-iron piles, which should be very strong, and on the wrought-iron ties, which should be more numerous than might be deemed strictly necessary by mere theoretical considerations. With regard to the deterioration of iron in sea-water, his own experience did not lead him to anticipate much danger. No doubt, wherever there was sulphuretted hydrogen in the water, there would be a tendency to the decomposition of iron; but such cases were rare, and it was more frequently found, that the iron was completely protected by incrustation, particularly when entirely under water. Iron exposed to the tidal wash, and alternately wet and dry, was under another condition, and where it was above half-tides it would waste to some extent, unless it was well protected. The chief difficulty in this plan of construction was, that the work was not open to inspection as it progressed. In the old-fashioned system of laying course after course, either by a diver, or from a bell, perfect bond was attained, and everything was seen. There certainly was the apprehension, that the concrete might not set thoroughly solid; but he supposed that in this case the concrete was tried at different depths. It would, however, be necessary to make up for the want of seeing what was going on under water, by giving great extra breadth and strength to the structure.

He thought there was little chance of any settlement in the portion of the work he had seen. A length of between 300 feet and 400 feet was finished, and it looked good, sound work; if there had been any disposition to settle there would have been some signs of it then. It was a proper application of the plan for the situation, but he should hesitate to adopt it generally. It was to be hoped that there would be an improvement in the mode of carrying out similar large structures, as at present a great heap of spoil had to be run out, unless vertical walls could be adopted; but that must be regulated entirely by the situation, and by the judgment of the Engineer in charge of the works. If the proposed plan were generally followed, he would recommend a greater number of ties, so as to afford a substitute for bond; because the plan meant the abandonment of bond, in the old-fashioned sense of that term.

He had used, somewhat extensively, Kentish rag-stone, and also brickwork, as a veneer, with a backing of concrete, formed of ballast and Portland cement, in the proportion of about six to one.

He had recently occasion to pull down a wall, built in that manner, about nine years previously, but he found that the work was too strong to be broken up, so that he let the rough concrete remain as the lower part of the wall, and trimmed off a face, and then underpinned several feet in depth with brick piers, with concrete forced in behind. In regard to the use of concrete in large foundations, it ought never to be forgotten, that the heavier and larger the mass put in, the greater was its power of consolidation and chance of absolute and permanent setting into hard rock. When good hydraulic concrete was used, in large masses, the general mixture with, and surrounding of, water was a great aid to the soundness of the work.

Mr. F. W. SHEILDS said, he had known a mass of concrete 9 feet square, when taken up, after having been deposited six or seven months, to be quite soft, although made with the best lime. It hardened, however, almost immediately on exposure to the air. He thought Portland cement was much preferable to Roman cement, and should be used wherever a first-rate concrete was required. He had found ordinary masons' chippings an excellent material for concrete, and superior to gravel alone. When they could be procured in sufficient quantity, and were mixed with gravel and with a due proportion of Portland cement, a very reliable material was obtained. He had put in the foundations of the tall water-towers at the Crystal Palace in that way with the best results. He quite agreed that the want of bond was a very doubtful feature in the walls constructed upon the plan described in the Paper.

Mr. COCKBURN CURTIS said, the principal thing to be regarded, with reference to the more extended application of the mode of structure advocated in the Paper, was the situation in which the works were to be placed, more particularly if proposed to be applied to harbours of refuge. The most important point in the construction of harbours of refuge was the 'lead' of sea, and, especially where concrete was concerned, the rise and fall of the tide. He thought it would be sufficient to say, that the works under consideration, and which were proposed as a model for others of a larger character, were situated in a place completely land-locked, and between 40 miles and 50 miles from Ailsa Craig, so that the 'lead' of the sea was inconsiderable, not exceeding $3\frac{1}{2}$ miles. The rise and fall of spring tides was only 12 feet, and the difference between spring and neap tides only 8 feet. This showed, to those conversant with the subject, that this form of structure, looking to the want of bond and other particulars previously noticed, could not be applied in exposed situations, such, for instance, as at Alderney.

Mr. W. A. BROOKS said, with regard to the form of breakwaters,

the Author had expressed the opinion, that the vertical wall was the best, for resisting the destructive action of the sea, and that it took the least amount of materials. This opinion was entertained by many persons, and appeared to be based on the belief, that a deep-sea wave had only an oscillatory movement. He thought that was an erroneous supposition; because it was known that, in a gale of wind, there was a pressure of from 30 lbs. to 40 lbs. per square foot, blowing for hours in one direction, and therefore the waves must have a progressive motion. It was found, also, that when the wind shifted from one quarter of the compass to another, the sea went down directly. If there were only an oscillatory motion of the waves in deep seas, there would be no occasion for ships to lay to for fear of being 'pooped.'

The piers of the deep-water harbour at Kingstown were constructed with long slopes of 5 to 1, and the cost of the granite used there did not exceed eighteenpence per ton. Those acquainted with quarrying knew, that with a 'lead' of only 2 miles or 3 miles, any rock might be quarried and put into the sea at a shilling per ton. No doubt when the wall could be executed at that cost, breakwaters, or piers, with long slopes were the best, both as regarded strength and economy. Many millions of money might have been saved to the country, if the Engineers of the last twenty years had followed the excellent rules laid down by Smeaton, Telford, and Rennie. In the recent harbour works, it was proposed to build them with vertical walls; but there was no work, except the Admiralty pier at Dover, in which that principle was really adhered to. At Alderney the pier was a compound of the worst forms. The substructure aided the progressive motion of the waves, while the vertical wall gave them a back sweep, which must in time destroy the rubble foundation and carry away the stones. Nothing could save the superstructure, or vertical wall, but an immense addition to the foreshore, eventually making the Alderney Pier a long-slope work. It was stated that the stones on the rockwork slope were converted into boulders, rounded from being tossed up against the facework of the masonry by the action of the waves. That showed a bad system of construction. A great mistake had been committed, in treating certain small harbours in Ireland, as being formed of piers with long slopes, whereas they were not more than $2\frac{1}{2}$ to 1, or 3 to 1. If all had been 5 to 1 or 6 to 1, no objection could have been raised to long slopes. The late Sir W. Cubitt had stated, in one of his Reports, that he deemed Kingstown Harbour to be the best and cheapest work of the kind in the British dominions, in proportion to its size and extent. That opinion certainly did not favour the system of construction that was now adopted for public harbour works. He had heard with regret, that no refuge harbour works for the north-east coast

of the kingdom would be assisted by the Government until the public harbours, now in course of construction, were finished. Hundreds of lives would, therefore, continue to be lost, before anything was done, in places where those works were so greatly needed.

Mr. J. JENNINGS thought, as the method of construction then under consideration appeared to be greatly dependent upon the iron ties, that the question of their durability was of the utmost importance, as well as the extent to which iron bond might be advantageously made use of in concrete work, and, whether in the form of hooping, or of rods. When he had cut into work where iron had been used in concrete, he had found the iron decayed to a considerable extent; but, at the same time, a hard metallic compound had been formed round the iron, which might lead to the supposition, that it would not decay throughout its whole thickness. With regard to the manufacture of concrete, recent experiments tended to show, that if made with a much smaller quantity of water than was usually employed and sufficiently punned, as hard and compact a substance as limestone would be formed in a short period. This, of course, was a point to be determined by experience. It was said that a labourer could only produce two or three yards of concrete on that principle in a day; but although such an amount of labour would cause an increase in the cost, yet this would be compensated for, by the better quality of the material. He had used Roman cement for concrete twenty years ago, and the result of his experience was, that concrete formed with that cement was very satisfactory and stood perfectly. The setting of the concrete was as perfect as could be desired, although the tide came over it within a quarter of an hour after it was deposited.

Mr. JOHN WRIGHT said, in reference to the use of concrete, in large masses, when deposited under water, that some years ago he had built a wall which was 5 feet or 6 feet under water at low tide. That wall had a facing of brickwork 18 inches thick, and the backing was entirely composed of Portland-cement concrete. The turn of the tide was exceedingly quick and strong, and it washed over the concrete shortly after it was laid. The concrete he referred to was made of eight parts of Thames ballast mixed with one part of Portland cement, and it was deposited in the water immediately after it was made. It was not mixed by machinery. Three or four years afterwards, when it was requisite to take down a considerable portion of that wall, he had an opportunity of testing the quality of the concrete. It was then found to be as hard as solid rock, so that the removal of the wall was a most difficult operation, and an enormous quantity of gunpowder was consumed in blasting it. Therefore he was sure that well-

made concrete was a very suitable material for works of construction, whether under water or not. Where there was not a great depth of water, he had found it an excellent plan, as soon as a face could be established against the water, to force in the concrete at the back, and keep pushing the face on. In this way, the concrete at the back did not come in contact with the water, and the surrounding water was not even coloured. When the water was charged with silt, mud or dirt would be deposited upon the concrete, so that the next layer would have a tendency to slide upon it, and would not bind with the mass below, unless the surface was cleaned. As a further illustration of the efficiency of concrete in large masses, Mr. Wright referred to the sea-walls he had built at Brighton. Some parts of those walls were 70 feet in height, and had already stood between twenty and thirty years, without at present giving any indications that they would not endure many years longer. The composition of the concrete in that case was lime and sand, in the proportion of three to one, made into mortar in the usual way, and one barrow load of that mortar was mixed with a barrow load of beach shingle in the pug-mill, after which the concrete was immediately pressed into the cases. As the result of his own experience, he felt convinced that concrete was generally made too dry. He believed that it should be used when in a fluid state, so that every particle might settle perfectly and then set, and that the sooner it was deposited, after being made, the better would be the result.

The Paper opened a wide field for discussion, as to building under great depths of water. On this subject he should endeavour more fully to express his views upon another occasion.

Mr. J. BRUNLEES called attention to a design, made by him two years ago, at the request of Captain Vetch, R.E. (Assoc. Inst. C.E.), for a breakwater and pier at Point de Galle. It would be seen that that design was almost identical with the system of construction now under consideration.

Mr. PARKES had found great difficulty in ascertaining whether concrete, deposited under water, had properly set. Although it might appear hard, when tried with iron rods, yet, in some cases, if pieces were brought up out of the water, they were discovered to be soft and 'crumbly.' He did not mean it to be inferred that he had any doubt that concrete deposited under water might, in the majority of instances, turn out very well, for he had formed foundations in this way entirely to his satisfaction. But he did not think that, at present, the theoretical knowledge of the action of hydraulic limes and cements under water was perfect. It was known, practically, that certain limes and cements would set in water, but not under all circumstances. What were the conditions necessary to insure success did not seem to be fully known. In

any particular case, therefore, involving new conditions, there was a possibility of some essential precaution being omitted, and after the concrete had been deposited, it would be uncertain whether it was good, or not. It therefore seemed to him, that more than ordinary care was required before such a system as that practised at Greenock could be generally adopted. That such precautions could be taken as would ensure success, he had not the least doubt : but these would differ in each particular case.

With regard to the section of the pier at Greenock, an objection had been raised, as to the want of bond between the granite face and the concrete. It was in his opinion a fault, that there should be two distinct walls instead of only one to support the superstructure, one for the face and another for the backing, but he did not think that the two could be bonded together—that a concrete backing could be bonded with a granite facing. The concrete would either swell or shrink, and in either case the virtue of the bond would obviously be destroyed. The most natural course to have adopted would have been, instead of making the face-work an integral part of the wall, and allowing the superstructure to bear partially upon it, to have made it a mere shell, so as to protect the surface, and to allow the whole superstructure to rest upon the concrete. If the concrete set well, it would be quite as good as second or third class masonry ; if not good, then it ought not to be there at all. It was contrary to first principles, that the superstructure should rest upon two substances so different in their composition as perfectly dressed granite and concrete. The piers of the new Westminster Bridge had been cited as a precedent for this principle of construction ; but in that case there was an entirely different feature introduced, as the whole interior of the superstructure of the pier rested upon bearing piles, the concrete merely filling in the spaces between the piles. He believed it was part of the original design to use bearing-piles at Greenock, but that this was afterwards abandoned, and although they were shown on one section (Plate 9, Fig. 3), he understood the work had been executed according to the design shown on the other section, so that the outer edges of the pier rested upon the casing, formed of granite slabs, and the interior upon the concrete. No doubt the Author would be able to explain, why he had adopted a facing of granite of, he believed, 2 feet thick, rather than a shell, which might have been made of cast-iron plates ; or even wooden sheet piles would have been sufficient for the purpose, which was only a temporary one, if the concrete were really good.

Mr. MILLER, in reply, said many opinions had been expressed as to the *béton*, and instances were cited of its setting hard, like solid rock, and requiring blasting afterwards to remove it, while in other cases failure had resulted. He was astonished that so

much misapprehension should still exist as to this material. He could only account for it by supposing, that the compounds in prevalent use for common purposes, and also called concretes, were confounded with the *béton*, or hydraulic concrete, as applicable to marine construction, and he attributed the failures to the bad materials of which the concrete was composed. The many occasions in which concrete had been successfully employed in works of this description were sufficient to establish its value. Of course, in the preparation of *béton*, certain precautions must be observed. The materials must be properly selected, thoroughly manipulated, and duly proportioned to the work for which the *béton* was required. If those conditions were attended to, he considered that *béton*, whether made from the naturally hydraulic limes, or from artificial cements, such as Portland, or even the rich limes rendered hydraulic by the mixture of other substances, such as pozzuolana, would, as certainly as there was such a principle as chemical combination, be successful, and would set like solid rock; and that any cases of failure must have arisen from the want of attention to these principles. Many examples might be adduced of the deposit of hydraulic concrete in sea-water with perfect success; but it was unnecessary to go beyond the Greenock Sea Pier. The *béton* used in that work was made from materials obtained within a few miles of the spot, and it had set hard in a short time. It had been doubted whether the whole mass was consolidated throughout; but the answer to that was, that it had been often tested, by means of iron rods, which even shortly after it was put down would not pierce it. It had also been examined by divers, who, when it happened that too much was deposited in one place, preventing the granite blocks from being properly bedded, found great difficulty in picking it away. The best test, however, of the uniform setting of the concrete was to be found in the stability of the walls. It was only natural to expect, if there had been any irregularity in the setting of the *béton*, that the walls would have shown symptoms of settlement: but nothing of that kind had been noticed. With regard to the observations, as to the danger of depositing concrete in exposed situations, where it was apprehended the action of the waves might, to a certain extent, wash out the lime, leaving only the gravel and stones, he remarked that this would not take place unless the concrete was put down in thin layers, and in that state was allowed to be acted upon by the waves. It should not, however, be employed in that manner, but in large masses, and continuously; and though it was possible that some of the lime might be washed out from the surface, yet this would be replaced by the mass of *béton* that followed, so that the homogeneity of the whole mass would not be injured. In illustration, he exhibited a specimen of

the concrete, taken from the most exposed part of the Greenock Pier, which had been laid in a soft state, and was afterwards washed by the waves. In point of setting firm, nothing more could be desired. That concrete had been put down in a wet state, and was exposed to the action of the waves during the whole of the unusually stormy and severe winter of 1862-63, when several ships were driven from their moorings, in the vicinity of the harbour works, and the large steam dredger was wrecked on the new pier. This specimen showed that the danger to be apprehended from the washing out of the lime was not so great as had been supposed.

It had been remarked, that the system of casing adopted at Greenock did not give sufficient bond to the rest of the work. He quite agreed that, in many cases, it might be beneficial to adopt the system of bonding, and in fact it was upon that plan that the pier at Greenock was originally intended to have been built. However, the particular style of casing to be adopted would depend upon local circumstances, and upon the individual opinions of different Engineers. It was also said that, in any case, the facing could only be looked upon as a veneer, without proper connection with the rest of the work. He could not admit that; because it was efficiently held in position by the iron ties. Besides, he considered that if the concrete set thoroughly, as it would not fail to do if properly made, both it and the casing must together form a solid wall, as much as an ashlar facing did with a backing of rubble masonry in ordinary walls. As to the probable decay of the tie-rods, the great durability of iron when so imbedded was well known. But, whether or not, the tie-rods had only to serve a temporary purpose, inasmuch as when the concrete became consolidated they would not be required.

A great deal might no doubt be said for and against any new system of construction; but the best evidence of the plan advocated in the Paper was to be found in the success of the works already completed, and of that success it was open to any one who chose personally to satisfy himself, by paying a visit to Greenock. With regard to the application of the principle to the construction of breakwaters, he considered it had been sufficiently tested to justify the further extension of the plan; and it must be recollected that the Greenock sea pier was essentially a breakwater. In the construction of similar works in more exposed situations, it would only be necessary to make them stronger in proportion, and to take precautions according to the circumstances. There might be danger to the concrete from the action of the waves in a stormy sea; but he proposed to build the work in sections, with cross walls, or casings, at given distances, so that the facing and the béton work would be carried on together, and in that way the concrete would only be exposed to the wash from the surface,

[1862-63. N.S.]

2 G

which he had shown was not very serious. Breakwaters had been constructed of timber frames filled with loose rubble stones, and these had withstood, successfully, the assaults of the waves. A structure of wrought iron with a stone casing, even though filled in with only loose rubble, would be much stronger than this; but when in addition the interior mass would be concreted like solid rock, he submitted that such a structure would combine all the conditions required for attaining the greatest stability and durability in the construction of breakwaters.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously :—

“ That in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 14th of April.”

April 14, 1863.

JOHN ROBINSON M'CLEAN, Vice-President,
in the Chair.

The following Candidates were balloted for and duly elected :—
WILLIAM DENT DENT, M.A., JOSEPH FOGERTY, JOHN LEWIS,
GEORGE WIGHTWICK RENDEL, and THOMAS CHARLES TOWNSEND,
as Members; HENRY WILLIAM FERDINAND BOLCKOW, HENRY
BOLDEN, OWEN BOWEN, CHARLES WILLIAM ROBERT CHAPMAN,
JOHN DAVIS, CHARLES GOTT, CHARLES TOWNSHEND HARGRAVE,
CHARLES LÖWINGER, RICHARD CHRISTOPHER RAPIER, and ALFRED
RUMBALL, as Associates.

No. 1,090.—“Description of the Line and Works of the Scinde
Railway.”¹ By JOHN BRUNTON, M. Inst. C.E., F.G.S.

So far back as the year 1842 Sir Charles Napier, the conqueror of Scinde, acknowledged and publicly urged the vast importance of the valley of the Indus, as the route for military as well as for commercial communication with the Punjaub and the North-West Provinces of India. He never ceased to press upon the Government the necessity of establishing new modes of conveyance, and pointed out Kurrachee, then but a small fishing town, as the port to which the traffic would infallibly tend. Acting on this conviction, and as a first step towards carrying out these enlightened views and improving the port of Kurrachee, Sir Charles Napier designed and commenced the long mole across the tidal marsh, which separates the town of Kurrachee from Keamaree. This mole still bears his name; and at the point to which it had been carried when he left Scinde, and from which he embarked on that occasion, a small obelisk is erected recording these facts.

Nor has Sir Charles Napier been the only eminent man who has pointed out the natural advantages of the valley of the Indus, as the route of communication with the Punjaub and the North-West Provinces of India. Amongst the many who have recorded their opinions on the subject may be mentioned Lord Dalhousie, Sir Henry Pottinger, Sir John Lawrence, Sir Justin Shiel, General Jacob, and Sir Bartle Frere.

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

In the year 1849 the Government recognised the necessity of introducing into India the improvements in communication which were offered by railways; and the two great lines,—the East Indian and the Great Indian Peninsula,—were inaugurated, with a view to open up the districts having the two great ports of India, Calcutta and Bombay, as the outlets for their produce. The success which attended the guarantee system, as affording facilities for raising the capital for Indian railways, was at once evident, and the importance of extending it to other districts was acknowledged.

Attention was immediately drawn to the Indus Valley route, having Kurrachee as its sea terminus; and a concession having been granted to Mr. W. P. Andrew in 1855, a company was formed, called the Scinde Railway Company, but embracing under its management not only the Scinde Railway proper, or the line from Kurrachee to Hyderabad upon the Indus, but the Punjaub line, from Moultan to Lahore and Umritsir, and a flotilla of steam boats on the river, with a view to complete the through communication. (Plate 10.) Three distinct capitals were originally raised, under the following titles:—1, The Scinde Railway; 2, The Indus Steam Flotilla; and 3, The Punjaub Railway. The accounts of these sections are kept perfectly distinct, while economy and harmonious working are secured, by the concentration of the management in the hands of one board of directors. Within the last three months, another section of this great scheme has been intrusted by Government to the Scinde Railway Company. It is called the Delhi Railway, being an extension of the line from Umritsir to Delhi, where it will form a junction with the northern terminus of the East Indian Railway. The lengths of these sections are respectively;—Scinde Railway, from Kurrachee to Kotree, on the Indus, 108 miles; Indus Steam Flotilla, Kotree to Moultan, 570;¹ Punjaub Railway, Moultan to Lahore, 222, Lahore to Umritsir, 32 = 254; Delhi Railway, Umritsir to Delhi, 300. Total, 1,232 miles.

It is to the construction of the first section of the line, between Kurrachee and Kotree, (Plate 12,) that this communication is specially devoted; and it is hoped that the facts thus recorded may be useful, not only to the Engineers whose professional labours may lie in India, but also to those Contractors who may find it their interest to undertake the execution of the great works which the extension of the railway system throughout India will infallibly render necessary. Although this section of the entire system is the shortest, it constitutes, as has been graphically observed, 'the neck of the funnel.' Over it must pass, not only the whole of

¹ This distance being measured upon the river is, on account of the windings, fully 100 miles more than the direct line by land.—J. B.

the existing traffic, but as the other sections are completed, the developed commerce of this vast territory, hitherto locked up, will pour in upon it, taxing its capabilities as a means of communication, and, doubtless, realising the sanguine anticipations of its promoters.

Kurrachee, the western terminus of the railway, is situate in lat. $24^{\circ} 47' 21''$ and long. $66^{\circ} 58' 15''$, and is not only the natural port of Scinde, but also of the Punjaub and of Central Asia. The plan, (Plate 11,) shows its form. Like many other land-locked harbours, it has the disadvantage of a bar at its mouth; but, nevertheless, the depth of water upon the bar at ordinary tides is sufficient to admit ships drawing 17 feet to 18 feet, and at spring tides, ships drawing 21 feet have passed in with safety. When once within Manora Point the depth of water is much greater, as is shown by the soundings upon the plan. The fast-increasing traffic of the port, and the large size generally of the vessels trading there, demanded that some measures should be taken to increase the depth of the water over the bar, thus rendering the entrance to the harbour available at all seasons; and that, by the erection of wharves and other appliances suggested by modern science, greater accommodation should be afforded. With this view her Majesty's Government, in 1856, applied to the late Mr. James Walker, F.R.S. (Past-President Inst. C.E.), for a Report upon the subject; and in 1858 he submitted plans, sections, and estimates for various suggested improvements. These recommendations were accepted by the Government, and immediate steps were taken for carrying them out. The groyne shown at A, (Plate 11,) is now advanced for about one-half its proposed length, and the result already is an increased depth of water on the bar. There is no doubt that when the works in progress are completed, Kurrachee Harbour will take a high rank as a safe and commodious port.

The population of the town of Kurrachee is about 60,000, and is rapidly increasing. The number of vessels entering and clearing outwards is shown in the following Table:—

Year.	Arrivals.		Departures.		Total.	
	No.	Tons.	No.	Tons.	No.	Tons.
1854-55	1,086	56,695	1,103	58,194	2,189	114,889
1858-59	1,589	131,311	1,654	138,176	3,243	269,487
1859-60	1,656	148,096	1,577	142,647	3,233	290,743

The principal articles of export consist of oil seeds, and grain of all sorts, wool, cotton, hides, indigo, munjeet, drugs and dyes, raw silk, fruit, and saltpetre. The import trade comprises cotton

piece goods, woollen goods, malt liquors, railway materials, metals, wines and spirits, tea, coffee, timber, pipe staves and casks, regimental necessaries, spices, fruit, oilman's stores, and wearing apparel.

The following Table shows the increase of the import and export trade :—

Year.	Imports.	Exports.	Total.
	£.	£.	£.
1843-44	121,150	1,010	122,160
1844-45	217,700	9,300	227,000
1845-46	312,900	40,500	353,400
1846-47	293,400	49,300	342,700
1847-48	287,872	154,730	442,602
1848-49	344,715	107,133	451,848
1849-50	419,352	114,378	533,730
1850-51	425,831	196,461	622,292
1851-52	489,220	244,122	733,342
1852-53	535,690	376,337	912,027
1853-54	..	..	900,000 ¹
1854-55	604,000	629,000	1,233,000
1855-56	628,913	604,440	1,233,353 ²
1856-57	685,665	734,522	1,420,187
1857-58	1,081,101	1,078,128	2,159,229
1858-59	1,540,605	1,044,272	2,584,877
1859-60	1,712,751	947,335	2,660,086 ³

Within the last two years, a large number of European and native mercantile firms have established themselves in Kurrachee, and have erected extensive warehouses, in order to meet the rapidly increasing trade of the port. Her Majesty's Government has found it necessary to erect a new and more commodious Custom-house ; and the harbour improvements now in progress include not only the deepening of the water on the bar, but greatly extended wharf and quay accommodation. The Scinde Railway will communicate directly with these wharves and landing places, and a great improvement in the system of loading and discharging cargoes has already been introduced, and is daily making rapid strides.

Hitherto all commercial communication with the upper districts has been carried on by native boats on the Indus, or by cafilahs of camels. No roads worthy of the name exist. Until the opening of the Scinde Railway these river boats were accustomed to stop at Khettie, a river station at one of the mouths of the Indus, (Plate 10,). and there discharge their cargoes into native sea-going craft, which conveyed the greater part to the port of Bombay,

¹ There are no exact returns of the sea trade for 1853-54.

² This return is for eleven months only.

³ The trade of 1862-63 has amounted to £3,500,000 in the nine months, and is estimated at £5,000,000 for the whole year.

only a comparatively small portion reaching Kurrachee. The import trade had to struggle with the same impediments, increased by the slow progress made in 'tracking' the boats up the Indus, against an average current of 3 miles, or $3\frac{1}{2}$ miles per hour, and a portage at Sukkur of $1\frac{1}{2}$ mile. During the prevalence of the south-west monsoon, lasting from May to September inclusive, even this wretched and dilatory system was suspended, paralysing commerce and creating an indescribable amount of expense, inconvenience, and irregularity. The formation of the Scinde Railway, and the improvement of the port of Kurrachee, have met all these obstacles, and will open up a magnificent field for commercial enterprise, introducing civilisation, with all its attendant benefits, to a district inhabited by millions of human beings hitherto shut out from its influences.

On the 29th of April, 1858, the works of the Scinde Railway were commenced by Sir Bartle Frere, K.C.B., then the highly-respected Commissioner of Scinde, who wheeled the first barrow-load of earth into an embankment in the neighbourhood of Kurrachee. The contract for the execution of the whole of the works was originally let to Messrs. James and Edwin Bray; but in June, 1859, the line was taken over by the Company, and the works then remaining to be completed were executed departmentally by the Engineers, Inspectors, and other officers of the Company. Without entering into a statement of the causes of Messrs. Bray's relinquishing the works, which at present form a subject of legal reference, it will suffice to say, that when the Company's Engineers took possession of them, they had to encounter difficulties which were not due entirely to the peculiarities of the country. There was a great dearth of the ordinary railway plant: irregularity in the payment of the native labourers of all classes had driven many away, and had caused an unnatural and serious rise in the rate of wages. To meet this position of affairs, and to secure the economical execution of the works, a fair tariff of wages, at a reduction of fully 25 per cent. upon those which were paid by Messrs. Bray, was published by the Company's Engineers, and daily payments were guaranteed. This had the effect of drawing a considerable number of labourers to the undertaking.

The Province of Scinde contains but a sparse population, which is principally located on the low-lying alluvial land on the banks of the river, where the rich earth yields ample returns with a minimum amount of labour. The Scindee, born and bred on these plains, is naturally indolent and devoid of muscular power; at the same time he is not deficient in talent, easily acquiring a knowledge of account-keeping and writing. The natives of the neighbouring state of Cutch are a much superior race. Cutch sends carpenters, masons, smiths, and skilled handicraftsmen to the whole

of the northern portion of the Bombay Presidency ; and from thence came a large majority of the skilled workmen employed on the Scinde Railway. From the hill tribes of Beloochistan and Afghanistan were obtained a hardy race of labourers ; men of great stature and personal strength, but wholly ignorant of the use of other tools than the powrah, (a large kind of hoe,) and a basket in which to carry the loosened earth. Half-wild and unaccustomed to the restraints of a more civilised state, these men required much tact, and at the same time a strong arm, to keep them in order. To secure and maintain discipline amongst such a body of men, it was found advisable to organise a regular railway police force, consisting of about 80 men. Police stations were erected at intervals along the line. To facilitate the administration of justice the Government appointed a special magistrate, whose duty it was to move up and down the line, and to hear any cases which might be brought before him. To these wise precautions may be attributed the fact, that few outrages of a serious character occurred, the majority of cases being petty thefts and attempts at imposition. This facility for obtaining justice, and the rapidity with which punishment followed crime, were highly appreciated both by the Europeans and the natives.

In districts like Scinde, where the population is scanty, and it becomes necessary to depend upon distant provinces for the supply of labour, it is obviously wise policy to offer every inducement, not only to secure, but to maintain such a supply. A higher rate of wages than ordinary may, in the first instance, draw together large bodies of men, but other arrangements are absolutely essential for establishing contentment and permanence. Hardy as these Beloochees and hill tribes were, and unaccustomed to anything approaching luxury, they appreciated highly such attentions to their feeding, shelter, and health, as policy no less than humanity suggested. When it is borne in mind, that the course of the line of railway lay at a considerable distance from existing towns, or villages, only passing through the small village of Jemedar-ke-Landi, and leaving the important towns of Tatta and Jerruck at distances of 10 miles and 17 miles respectively,—it will be seen, that a difficulty arose in obtaining food for the large masses of men congregated at the various heavy portions of the works. This was met by the Company licensing a number of bunians, or native provision merchants, to establish themselves at various points along the line ; their scales of charges being regulated by a nerrick, or list of prices, settled by the nearest kardhar, under the orders of the railway magistrate. To supply the workmen with wholesome water for drinking was equally imperative. When this precaution was not observed, the men were under the necessity of using such water as was most easily accessible, and as it was

generally of very bad quality, the results were cholera and fever of a bad type. A regular system of water carts and bullocks was first organised, and as the railway progressed, water trains were dispatched from the Mulleer, the Indus, and the Bahrin, to meet the daily requirements of the men. It was remarked, that a supply of wholesome water was always followed by the disappearance of the diseases above-mentioned, and more particularly of fever. To protect the men from another source of fever, mat huts were erected, which sheltered them from the heavy dews, and rendered them more comfortable and contented. To afford medical aid in cases of sickness, or of accident, permanent hospitals were erected at Kurrachee and Kotree, under the charge of the civil surgeons of these stations; and in addition, two temporary hospital buildings were erected at Joong Shaie and Doraji Gore, under the charge of a resident apothecary. These arrangements were very successful in preserving the health of the employes of the Company, both European and native, and in cases of accident, they were doubtless the means of preserving many lives.

The natives work in gangs, under a self-elected muccadam, or ganger, whose orders they cheerfully obey, and to whom each man pays a stipulated small per-centage from each rupee earned by him. It is through the muccadam, or ganger, that all agreements are made for work, and it is he who receives the amount of the earnings for division. There exist also, in Scinde and in the neighbouring States, native landholders who, by inheritance, are chiefs of large districts of country, and are recognised by Government as possessing a sort of feudal right therein. They are heads of clans, and as there is no longer any necessity for summoning their vassals for defence, or for other less lawful objects, they find it their interest to use their power for the purpose of supplying labourers to any large public work, receiving a small remuneration in the shape of head money. In the year 1856, while acting as Commissioner in Scinde, during the temporary absence of Sir B. Frere, General Jacob, recognising the demoralising influences which attended the system of compulsory labour, proclaimed all labour in Scinde to be free. This edict is highly prized, though sometimes taken advantage of and abused, by the labouring classes.

The departmental execution of the works gave the Engineers and other officers engaged, favourable opportunities of becoming acquainted with the capabilities of the various classes of natives, as well as of ascertaining the cost of each description of work. When work of any kind was executed by day labour, it was found that its economical execution entirely depended upon the energy and honesty of the muccadam, or native overseer; but these good qualities were so rare, that it became necessary to resort to the