

piece-work system. It was with some difficulty that this was established as a rule; but by degrees opposition was overcome, and the earthwork, masonry, and ballasting, were let to small gangs, with considerable advantage to the Company, while the labourer himself, excited to more vigorous and diligent exertion, earned higher wages than by the day-work system.

The following are the average prices paid for earth and rock work along the line:—

|                                                                                                                                     |                                                            |
|-------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|
| Alluvial earth excavated from side trenches and placed in embankment, the average distance of conveying it being 22 yards . . . . . | 10 annas per 100 cubic feet, or 4·09 pence per cubic yard. |
| Firmly set gravel, or soft shaly material . . . . .                                                                                 | 12 annas per 100 feet, or 4·9 pence per cubic yard.        |
| Rockwork requiring bars, but no powder for blasting . . . . .                                                                       | 1s. 9d. per cubic yard.                                    |
| Hard rock requiring blasting,—the powder, drills, and other tools being found by the Company . . . . .                              | 2s. 0d. „ „                                                |
| Ballast, consisting of small stones, or gravel, gathered in the neighbouring jungle, selected and placed <i>in situ</i> . . . . .   | 1s. 0d. „ „                                                |
| Ballast of broken stone . . . . .                                                                                                   | 1s. 10d. „ „                                               |

The total quantities of the different classes of work executed upon the line, and the average cost of each kind, inclusive of the cost of the provisional staff of superintendents, but exclusive of that of the permanent Engineering staff, are given in the following Table:—

| Description of Work.                                                                     | Quantity. | Average Cost. |
|------------------------------------------------------------------------------------------|-----------|---------------|
| <b>EARTHWORK.</b>                                                                        |           |               |
| Embankments . . . . . cubic yds.                                                         | 1,831,916 | 0 0 11½       |
| Cuttings (a large portion consisting of rock of different degrees of hardness) . . . . . | 432,705   | 0 1 6½        |
| Diversion of roads and streams . . . . .                                                 | 212,532   | 0 0 8½        |
| Ballasting . . . . .                                                                     | 408,596   | 0 1 6         |
| Pitching slopes . . . . . sup. yds.                                                      | 1,745     | 0 2 0         |
| <b>PERMANENT WAY.</b>                                                                    |           |               |
| Leading and laying . . . . . lineal yds.                                                 | 193,600   | 0 6 0         |
| FENCE WALLING . . . . . „                                                                | 338,700   | 0 3 0         |
| <b>MASONRY.</b>                                                                          |           |               |
| Concrete . . . . . cubic yds.                                                            | 10,756    | 0 4 6         |
| Dry rubble . . . . . „                                                                   | 2,526     | 0 3 0         |
| Common ditto . . . . . „                                                                 | 17,434    | 0 12 0        |
| Coursed ditto, with rubble backing . . . . .                                             | 352       | 0 15 0        |
| Coursed ditto . . . . . „                                                                | 32,550    | 1 0 0         |
| Block in course . . . . . „                                                              | 15,192    | 1 11 6        |
| Ashlar . . . . . cubic feet                                                              | 87,806    | 0 1 7½        |

The geological character of the district traversed by the Scinde

**Railway demands a few remarks.** The aspect of the country generally is barren in the extreme, but in some places there is sufficient soil to repay cultivation. Situated in what is termed the rainless zone, the average quantity of rain is very small. The annual rainfall from 1855 to 1860 is given in the following Table:—

RAIN MEASURED at the OBSERVATORY of the EUROPEAN HOSPITAL, KURRACHEE,  
from the 1st September, 1855. to the 31st August, 1860.

[illegible]

**Kurrachee, 31st August, 1860.**

(Signed) C. RICHTER,  
Observer.

The rain is looked for about the 20th of July. Except during the rainy season, the river beds are dry, but in them water can generally be obtained, by sinking to depths varying from 5 feet to 30 feet. All the water procured from these wells is, however, more or less saline. The following analysis of several samples was made at the Government laboratory, Bombay, and will show to what extent this property prevails:—

**TABLE 1.**  
**The Numbers indicate parts in 10,000 of Water.**

|                        | A                 | B       | C       | D          | E                  | F          |
|------------------------|-------------------|---------|---------|------------|--------------------|------------|
| Specific gravity . .   | 1000·72           | 1000·54 | 1000·44 | 1000·75    | 1001·10            | 1000·69    |
| Carbonate of lime . .  | 1·160             | 1·328   | 1·252   | 1·720      | 1·011              | 1·136      |
| "    magnesia . .      | ·908              | ·757    | ·621    | ·247       | 1·151              | 1·120      |
| Lime . . . . .         | ·241              | ·333    | ·161    | ·611       | ·257               | ·289       |
| Magnesia . . . . .     | ·210              | ·113    | ·187    | ·269       | ·087               | ·135       |
| Chlorine . . . . .     | { 2·281<br>·825 } | 1·598   | 1·731   | 2·281      | { 2·689<br>1·473 } | 2·130      |
| Chloride of sodium . . | 4·445             | 2·485   | 2·185   | Not tried. | Not tried.         | Not tried. |
| Silica & oxide of iron | ·100              | ·310    | ·386    | ·756       | Not tried.         | Not tried. |
| Sulphuric acid . .     | ·334              | ·601    | ·479    | ·851       | ·741               | ·896       |

TABLE 2.  
SOLID CONSTITUENTS IN WATER marked B, in 10,000 parts.

|                                       |       |
|---------------------------------------|-------|
| Chloride of sodium . . . . .          | 2·485 |
| Sulphate of lime . . . . .            | ·809  |
| Chloride of magnesium . . . . .       | ·115  |
| Sulphate of magnesia . . . . .        | ·188  |
| Carbonate of lime . . . . .           | 1·328 |
| „ „ magnesia . . . . .                | ·757  |
| Silica and oxide of iron . . . . .    | ·810  |
| Total . . . . .                       | 5·992 |
| Total solids by evaporation . . . . . | 5·490 |

TABLE 3.

|                              | WATERS AT KURRACHEE, (selected). |                                                              |                                                                                      |                                                       |                                   |
|------------------------------|----------------------------------|--------------------------------------------------------------|--------------------------------------------------------------------------------------|-------------------------------------------------------|-----------------------------------|
|                              | 21                               | 22                                                           | 23                                                                                   | 24                                                    | 25                                |
|                              | Bed of Lyaree River.<br><br>H    | Campwater, Company's well, near Government Gardens.<br><br>H | Well on the Bunder Road, in front of Messrs. Warwick and Waller's premises.<br><br>H | Well on the Bunder Road, near Muches Meanee.<br><br>H | Well in the Rutton Tank.<br><br>H |
| Date of Collection . . .     | June, 1859                       | June, 1859                                                   | June, 1859                                                                           | June, 1859                                            | June, 1859                        |
| Specific gravity at 60° Fah. | 1000·4                           | 1000·9                                                       | 1006·6                                                                               | 1087·8                                                | 1001·4                            |
| Chloride of sodium . . .     | 2·35                             | 8·12                                                         | 58·20                                                                                | 423·75                                                | 9·41                              |
| „ „ magnesium . . .          | ·02                              | —                                                            | —                                                                                    | —                                                     | —                                 |
| „ „ calcium . . .            | ·66                              | —                                                            | —                                                                                    | —                                                     | —                                 |
| Sulphate of soda . . .       | —                                | ·78                                                          | 4·84                                                                                 | 48·73                                                 | 2·02                              |
| „ „ magnesia . . .           | —                                | ·05                                                          | 6·61                                                                                 | 76·85                                                 | ·02                               |
| „ „ lime . . .               | ·53                              | ·69                                                          | ·44                                                                                  | 12·04                                                 | ·45                               |
| Nitrate of magnesia . . .    | —                                | —                                                            | —                                                                                    | —                                                     | —                                 |
| „ „ lime . . .               | —                                | —                                                            | —                                                                                    | —                                                     | —                                 |
| Carbonate of magnesia . .    | ·04                              | ·38                                                          | 1·09                                                                                 | 2·91                                                  | ·95                               |
| „ „ lime . . .               | ·55                              | ·96                                                          | 2·37                                                                                 | 2·37                                                  | 1·26                              |
| Silica . . . . .             | (X)                              | (X)                                                          | (X)                                                                                  | (X)                                                   | (X)                               |
| Organic matter in solution   | —                                | —                                                            | —                                                                                    | —                                                     | —                                 |
| „ „ „ suspended              | —                                | —                                                            | —                                                                                    | —                                                     | —                                 |
| Total solids. . .            | 4·15                             | 10·98                                                        | 73·05                                                                                | 561·65                                                | 14·11                             |
| Gaseous contents . . .       | —                                | —                                                            | —                                                                                    | —                                                     | —                                 |

Samples Nos. 21 to 25 were selected from nineteen specimens taken from all the wells and tanks in use at Kurrachee. The difference in the quality of the water is extreme. Nos. 21, 22, and 25 are fair drinkable waters. In No. 23 salt is present in enor-

mous quantity, the water being a strong brine, twice as salt as sea water. The purest water was obtained from the River Indus at Kotree, and from wells in the bed of the Mullee.

In the neighbourhood of Kurrachee, the principal features of the country are low hills, varying from 150 feet to 200 feet in height, and consisting of a coarse-grained arenaceous rock, of a dirty yellow colour, abounding with fossils. Most of these hills are capped with conglomerate, more or less disintegrated on the surface, the pebbles composing it being water-worn, and the majority derived from the nummulitic limestone of the Halla range of hills, which extend from Cape Monze, in a north-easterly direction, to the west of Mithun-Kote on the Indus. All the hills lying north of the Indus to the foot of the Halla range, of which they are spurs, exhibit the effect of considerable volcanic disturbance, and the drainage of the country passes through the fissures thus formed. One of the most remarkable of these is at Dhurwat, where, during the rains, the water of the Bahrūn occasionally rises 70 feet, rushing through the pass with overwhelming force. The Kheytriāni hills are composed of pale arenaceous limestone, containing but few nummulites. This rock is easily worked, and is an admirable building stone, hardening with exposure. It was from quarries opened in this neighbourhood, that most of the stone was obtained for the masonry of the central district of the line. Near the Rhodh River there are many small hills, of conical shape, composed of calcined clays of various colours, and also large collections of nodular masses of flint. In the aluminous clay beds, veins of foliated gypsum abound. In the plains lying between these hills the soil is alluvial, and in many places it is covered with boulders of nummulitic limestone and conglomerate. The following Table, taken from a letter addressed to Sir R. I. Murchison by Captain N. Vicary, of the Hon. East India Company's service,<sup>1</sup> will serve to give a general idea of the relative position of the formations existing in Scinde:—

- |                                              |                                |
|----------------------------------------------|--------------------------------|
| 1. Conglomerate.                             | 7. Pale arenaceous limestone,  |
| 2. Clays and sandstone.                      | with Hyponyces, Nummu-         |
| 3. Upper bone-bed.                           | lites, and Charoidæ.           |
| 4. Sandstone; fossils rare.                  | 8. Nummulitic limestone of the |
| 5. Lower bone-bed.                           | Halla Range.                   |
| 6. Coarse arenaceo-calcareous rock           | 9. Black slates, thickness un- |
| with <i>Cytherea exoleta</i> and <i>exa-</i> | known.                         |
| <i>rata</i> ; <i>Spatangi</i> ; no Nummu-    |                                |
| lites.                                       |                                |

The fact that indications of considerable volcanic disturbance

<sup>1</sup> Vide "The Quarterly Journal of the Geological Society of London." Vol. iii. p. 335. London, 1847.

are visible among the ranges of hills lying to the north-east of the line of railway has been already noticed. At 3 o'clock in the morning of Tuesday the 9th of April, 1861, a rather smart shock of an earthquake was felt at Kurrachee, and at several places along the line, which occasioned some cracks in the walls of the Author's house in Kurrachee; and those observed shortly after, in some of the masonry of the bridges along the line, may be referred to the same cause. It is, therefore, suggested that, to guard against the consequences of such an event, hoop-iron bondings should be introduced into the walls of future buildings. This would be attended with but small extra cost, and it is submitted that such a precaution on other lines of railway in India may not be unadvisable. The natives of Scinde and Cutch possess legends of the occurrence of violent earthquakes; and though there is no authority for it, the utter prostration of the extensive buildings of Brahminabad, 60 miles east of Hyderabad, may lead to the inference, that an earthquake completed the ruin of that once important city.

The distance between Kurrachee and Kotree traversed by the Scinde Railway is 108 miles 10 chains. Of this distance 32 miles 50 chains are level, and the remaining 75 miles 40 chains are on inclines more or less favourable, 1 in 200 being the ruling gradient, as will be seen by the following classified abstract of the gradients:—

| From                      | To         | Length. |         |
|---------------------------|------------|---------|---------|
|                           |            | Miles.  | Chains. |
|                           | 1 in 200   | 10      | 27      |
| 1 in 200                  | 1 ,, 300   | 22      | 33      |
| 1 ,, 300                  | 1 ,, 400   | 15      | 67      |
| 1 ,, 400                  | 1 ,, 500   | 5       | 5       |
| 1 ,, 500                  | 1 ,, 600   | 3       | 48      |
| 1 ,, 600                  | 1 ,, 700   | 6       | 63      |
| 1 ,, 700                  | 1 ,, 800   | 3       | 10      |
| 1 ,, 800                  | 1 ,, 900   | 3       | 8       |
|                           | 1 ,, 1,056 | 1       | 0       |
|                           | 1 ,, 1,100 | 2       | 31      |
|                           | 1 ,, 1,402 | 0       | 68      |
|                           | 1 ,, 1,760 | 1       | 0       |
| Total length of gradients |            | 75      | 40      |

The total length of straight line being 74 miles 22 chains, the length of the line on curves is, therefore, 33 miles 68 chains, the sharpest curve having a radius of 43 chains for a distance of 76 chains, as will be seen by the following Table:—

| Radius from              | To radius | Length. |         |
|--------------------------|-----------|---------|---------|
| Chains.                  | Chains.   | Miles.  | Chains. |
|                          | 43        | 0       | 76      |
| 57                       | 100       | 9       | 15      |
| 115                      | 200       | 22      | 50      |
| 240                      | 320       | 1       | 7       |
| Total length of curves . |           | 33      | 68      |

Considering the nature of the country traversed by the line, these may be considered favourable features, and place it in a good position for being worked at a moderate cost.

The earthworks generally are executed to accommodate a single line of railway; but all the bridges, culverts, and stone viaducts are constructed to carry a double line. In the cases of the wrought-iron viaducts, the stone piers are adapted to support girders for a double way, while those required for a single line alone are erected. The only portion of double line yet made, is that between the workshops at Ghizree Junction and the terminus at the Bunder Head, a distance of 3 miles 15 chains. In order to accommodate the traffic coming to Kurrachee from the districts called the Eastern Delta of the Indus, during the south-west monsoon, a short branch,  $3\frac{1}{2}$  miles in length, has been constructed, leaving the main line near the workshops, and terminating in an embankment and a timber pier at Ghizree, alongside which native boats discharge their cargoes. The permanent way consists of the ordinary double-headed rail, weighing 65 lbs. per yard, fixed by compressed wooden keys in chairs, each weighing 22 lbs. The joints are fished in the usual way, the fish plates being secured by four bolts, each 1 inch in diameter. The whole is laid on transverse wooden sleepers, at intervals of 3 feet, except at the joints, where the sleepers are only 2 feet apart. The dimensions of the sleepers are:—length, 10 feet; breadth, 10 inches; depth, 5 inches. A large proportion of the sleepers is of red and white pine creosoted, sent from England. To complete the requisite quantity, a contract was entered into with a native merchant at Lahore, for the supply of sleepers of deodar timber, (*Cedrus deodara*,) which grows upon the slopes of the Himalayas, where it attains great size. Several logs sent down to Kotree for the use of the railway measured 5 feet in diameter at the butt, and a calculation of the taper upon the log gave a result of 150 feet as the height of the tree. The trees are felled, and cross-cut into convenient lengths, for rolling to the bottom of the ravines, on the banks of which they grow. The private mark of each proprietor is cut on every log he has felled. These logs remain at the bottom of the ravines until the rains, when they are carried by the torrents into the River

Indus, where they are watched for, selected according to the marks, rafted, and floated to their destination. This rough treatment wastes much of the timber; many of the logs are split, and the ends of all are damaged; while the shortness of the pieces, which vary from 20 feet to 33 feet in length, diminishes their value. Owing to the deficiency of rain in the season of 1859-60, only a small quantity of this timber could be got down. The native merchant thus failed to complete his contract; and a quantity of Australian blue and white gum, and native red eyne sleepers was, therefore, purchased. These were objectionable, on account of their great weight, and the ease with which they were split by the driving of the spikes. The respective cost of each, when delivered in Kurrachee or Kotree, was:—

|                                 | Delivered in<br>Kurrachee. | Delivered in<br>Kotree. |
|---------------------------------|----------------------------|-------------------------|
|                                 | s. d.                      | s. d.                   |
| Creosoted pine . . . . .        | 8 11                       | ..                      |
| Australian blue gum . . . . .   | 8 0                        | ..                      |
| Eyne, a native timber . . . . . | 7 9                        | ..                      |
| Deodar . . . . .                | ..                         | 6 0                     |

The value of the deodar timber is becoming rapidly recognised, and means will, doubtless, be adopted for supplying it in longer lengths, and in greater quantities. When first cut it possesses a very strong scent, which it retains for some years; and to this probably may be attributed its immunity from the ravages of the white ant, which does not attack it until the timber has to a great extent lost this scent. To protect the deodar sleepers from these attacks, and before the Burnettising apparatus was received from England, they were steeped in a solution of sulphate of copper. This proved to be an unfailing specific; but it possesses this serious objection, that iron nails or spikes driven into timber thus prepared are rapidly destroyed by the action of the sulphuric acid. The result of the Author's experience, with reference to the important question of sleepers, is that pine sleepers, whether red or white, imported from England and creosoted, are liable to split and twist to a great extent, probably on account of the extreme dryness of the climate. They also become very brittle, the nature of the timber being destroyed. The creosoting process only penetrates a certain distance from the surface of the sleeper; and so long as the sleeper does not split, the creosote effectually protects it from the attacks of the ant, but immediately a part of the interior becomes exposed, the ant attacks it, and soon destroys the uncreosoted core of the sleeper. Hitherto, the necessity for replacing sleepers has mainly arisen from their giving way by splitting, rather than from any damage by the attacks of the white ant, or from ordinary decay. The

excellent ballast on the Scinde Railway, consisting chiefly of broken stone or clean gravel, assists in preserving the sleepers from the white ant.

The cost of creosoting sleepers in India varies with the description of timber submitted to the operation. In 1854 Mr. Turnbull, Chief Engineer of the East Indian Line, gave the following summary of the details of the cost supplied in a former portion of his Report<sup>1</sup>:—sâl,  $6\frac{1}{2}d.$ ; teak, 1s.; soondry, 1s.  $5\frac{1}{2}d.$ ; and sissoo, 2s.  $1\frac{1}{2}d.$  per sleeper. He further states, in the same Report, that one thousand sleepers of fir wood, prepared by Sir W. Burnett's process with chloride of zinc, were landed and stacked in Calcutta, where they remained for two years. On being examined at the end of this period, they were all found to be sound, and in as perfect a condition as when they were landed. This statement led the Author to recommend the adoption of Sir W. Burnett's process, and a complete apparatus was shipped from England. The vessel was, unfortunately, lost on the passage; and considerable delay occurred in replacing the apparatus, so that the majority of the deodar sleepers were submitted to the sulphate of copper process. The cost of the Burnettising process at Kotree is  $5\frac{1}{2}d.$  per sleeper, which contrasts favourably with the cost of creosoting.

The forests of Scinde consist chiefly of babool, a species of acacia, of which there are two kinds, red and white, so named from the respective colours of the heart wood. The former is by far the more valuable of the two, as it is extremely hard, and resists the attacks of the white ant. This timber is used by the natives for the manufacture of carts and Persian wheels; but as it is very crooked, it is not available for railway sleepers. A few pieces of timber were carefully selected, and accurately gauged to size, with a view of testing their comparative strengths, but the experiment was not carried out. When thoroughly seasoned, the following comparative Table of the weights of each kind was obtained:—

|                                        |                                       |
|----------------------------------------|---------------------------------------|
| Red eyne . . . . .                     | 56 $\frac{1}{2}$ lbs. per cubic foot. |
| Jarrah (Australian mahogany) . . . . . | 52 $\frac{1}{2}$ " " "                |
| Common jungle teak . . . . .           | 34 $\frac{1}{2}$ " " "                |
| Moulmein teak . . . . .                | 33 $\frac{1}{2}$ " " "                |
| Deodar . . . . .                       | 31 $\frac{1}{2}$ " " "                |
| Yellow pine . . . . .                  | 24 $\frac{1}{2}$ " " "                |

Neither eyne nor jarrah timber will float in sea water before it is thoroughly dried. Red eyne is obtained from the forests of Guzerat, and costs in log, delivered in Kurrachee, about 1s. 6d. per cubic foot. It is not, however, very plentiful. As a pile it

<sup>1</sup> Vide "Selections from the Records of the Madras Government. Report of the Railway Department for 1854," page 238.  
[1862-63. N.S.]

drives remarkably well, hardly requiring either ringing or shoeing in ordinary ground. It is reported to be impervious to the attacks of the white ant; but of this the Author has no positive proof. The Moulmein, or Rangoon teak, judging from the quality of the best the Railway Company could procure, is inferior to the southern, or Malabar teak, which, however, is scarce and expensive. The cost of Moulmein teak in log, delivered in Kurrachee, varies from £15 to £18 per load. The jarrah is a fine Australian timber, and is obtainable in logs of large scantling and length. If not well seasoned before being submitted to the dry climate of Scinde, it cracks and rends seriously, but not so if it is allowed to season for twelve months before being shipped. Its cost in Kurrachee is about 1s. 6d. per cubic foot. The deodar timber, the qualities of which have been before adverted to, costs at Kotree in log about 1s. 1d. per cubic foot.

The majority of the fencing used on the Scinde Railway consists of a dry rubble-stone wall, having a coping of stones on edge, set in mortar. Its height is 4 feet above the surface of the ground. Its thickness at the bottom, just above the footings, is 1 foot 10½ inches, and at the top 15 inches. Its average cost was 3s. per lineal yard. Along 15 miles of the line, between Jemedar-ke-Landi and Guggur, five-strand wire fencing was adopted, on account of the distance of suitable stone, and the necessity for its rapid completion. Its cost was 2s. 4½d. per lineal yard. The cost of maintenance of the wire-fencing is high, compared with that of the stone wall.

At Kurrachee, the locomotive erecting and repairing shops are built, at the junction of the Ghizree branch with the main line. These works consist of a sawmill, smiths', fitters', heavy and light tool shops, iron and brass foundries, with engine and carriage-erecting shops, all furnished with the requisite machinery, and with tools driven by engine power. Previous to the establishment of these works, there existed no means, nearer than Bombay, for the execution of the necessary repairs, or the construction of the numerous articles required by a railway; and even Bombay offered but few facilities, and those involving great expense. Hence the necessity for pushing forward these works, which, in the formation of the line, proved to be of great assistance in the manufacture of plant, &c. The organisation of these works, with a view to their ultimate utility, and at the same time, with a due regard to economy, formed an important consideration, and was surrounded with many difficulties. To man these shops entirely with European workmen would involve an enormous cost; it became necessary, therefore, to call in native assistance, as far as practicable. The Cutch carpenters and smiths, as has been before remarked, are intelligent and excellent workmen; but they were wedded to the

use of their own rude tools, in their own fashion, involving great delay in turning out work. Their usual method is to carry on all operations while seated on the ground; and, in the case of the carpenters, to make almost as much use of their toes as of their fingers. It became, therefore, the duty of the English foreman to induce them, first of all, to stand to their work, and then, to teach them the use of European tools. This has been accomplished by degrees, and the result has been most satisfactory. The carriages now framed and erected at these shops, entirely by Cutch carpenters, display workmanship which would be a credit to the best European manufactory. It is found necessary still to employ two European smiths for heavy and important work.

To keep up a supply of European foremen, fitters, engine erecters, and engine drivers, the system of taking apprentices in the workshops has been adopted. The following liberal terms were offered :—

|                                                                |   |   |    |   |    |
|----------------------------------------------------------------|---|---|----|---|----|
| During 4 months' preliminary trial, per mensem 4 rupees or 8s. |   |   |    |   |    |
| First year from date of indentures,                            |   |   | 30 |   | £3 |
| Second                                                         | " | " | 40 | " | 4  |
| Third                                                          | " | " | 50 | " | 5  |
| Fourth                                                         | " | " | 60 | " | 6  |
| Fifth                                                          | " | " | 80 | " | 8  |

In India there are many intelligent lads, sons of European soldiers and of men employed in various departments of the Government service as clerks, &c., who are educated in the regimental and Government schools: these lads and their parents are very glad to avail themselves of the opening thus offered for learning a trade, and obtaining substantial employment. By this arrangement a staff of men, thoroughly acclimatised, is being educated in all branches of railway mechanism, and without doubt great advantages will, in a few years, accrue therefrom.

The electric telegraph, with two lines of wires, is laid along the Scinde Railway. The wires are carried upon posts of deodar timber, fixed in cast-iron sockets. The block system of working the trains is adopted. Needle-speaking instruments are used for conveying the information required between the several stations and passing-places. On the Continent of Europe there exists but little difficulty in obtaining suitable and intelligent clerks for working the telegraph signals; but in India the case is widely different. There, for the sake of economy, the staff of telegraph clerks is formed and recruited from the class of half-castes and more intelligent natives, very often lads of fourteen or fifteen years of age. It is true they have to pass a preliminary examination as to their capabilities in writing and reading English; but the Author's experience of men who have passed this examination is, that they

are often deficient in the important point of understanding the messages they transmit or receive. This becomes a more serious matter when the signalman, a native, is trusting to the verbal instructions he receives from the telegraph clerk, who, in several instances on the Scinde Line, holds the combined offices of telegraph clerk and station master, a system which, for many obvious reasons, is to be deprecated. Greater security would be obtained by the separation of the train-signalling machine from the conversing telegraph, and also by the introduction of permanent train-signals, which would speak to the eye, and could not be liable to misinterpretation. Native clerks are too apt to occupy the speaking-machine, and at the same time to amuse themselves with a conversation, to the exclusion or the delay of important messages.

- In India, train-signalling stations, on which depend the proper and safe working of the trains, are often in isolated situations, and economy only allows the maintenance at each station of one signalling-clerk, who may often be taken ill with fever, or otherwise be rendered unable to perform his duties. The reduction of the train-signalling to as simple a system as possible, and the training of all policemen and inspectors in the use of the instrument for this purpose, would be attended with much benefit.

The line of the Scinde Railway, as will be seen by the map, (Plate 12,) crosses the natural drainage of a great extent of country, thus rendering necessary a large provision for waterway. The rains in Scinde are very partial, and as there are no records of rainfall which throw much light upon the subject, and no existing bridges, a careful examination of old flood marks was the only guide as to the requirements. Fixing the spans of the bridges at the large rivers and nullahs was comparatively easy. It was in crossing wide, flat plains, such as that at Pipri, that the question was surrounded with difficulties. This plain is nearly 5 miles wide. A certain number of culverts was originally built, and in addition, large catch-water drains were cut, with a view of conducting the rain water to the Guggur River, the natural and main drain of the valley. In 1861, when the rain was very heavy for about six hours in this locality, the drains were found insufficient to carry off the water in the time, and the embankment of the railway, which ponded up the water, was soon breached in many places. To remedy this, it was considered a waste of money to erect more culverts; but the plan was adopted of lowering the line to the surface, laying it, in fact, in a ditch 16 feet wide and 2 feet deep, just large enough to receive the ballast, and allowing the water to flow over the line. This plan was severely tested in the unusually heavy rains of 1862, when the water passed over the rails to the depth, in some places, of 9 inches, without either damaging the line, or stopping the traffic. In districts like Scinde, where the

rainfall is so partial, and of such short duration, but at the same time so heavy, it is submitted that this mode of crossing a large, flat plain is the safest and most economical.

The scarcity of pure water fit for use in the locomotive engines, except at a few points, caused considerable trouble on the first opening of the line. The watering stations are nine in number. The salts, which the water obtained at these stations held in solution, differed materially, and the consequence was, that if an engine started from Kotree, and took in water at Jheem Peer, or Joong Shaie, priming occurred to a serious extent; but this was not the case if water was taken at the Bahrūn. As the water at these stations was considered fair drinking water, and as there was nothing in the taste to induce the suspicion that they might not be used indiscriminately for locomotive purposes, it would appear desirable, that a careful analysis of the water obtainable along a line of railway in India should be made at an early stage of the operations. The Author has arranged that the waters used and obtainable upon the Scinde Railway should be analysed, and when combined with a report upon the effects produced in the locomotive engine by mixing them, some useful information will be obtained for guidance in parallel cases. When completed, it shall be submitted to the Institution.

The haulage of materials constitutes an important item in the cost of the construction of railway works everywhere, and especially in India. The following facts will assist in forming calculations on this head. About 5,500 tons of permanent-way materials were required at Loyach, one of the stations on the line, and were conveyed by native boats from Kurrachee to Soondah, a point upon the River Indus where there was a convenient landing place. It was necessary to form a road for carts between Loyach and Soondah, through the jungle, a distance of  $12\frac{1}{2}$  miles, and the following were the details of the cost of the whole proceeding:—

|                                                                                                                                                  |                  |
|--------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| Freight from Kurrachee to Soondah by native craft, including cost of loading and discharging cargo . . . . .                                     | 8s. 6d. per ton. |
| Loading and unloading the native carts . . . . .                                                                                                 | 0s. 6d. „        |
| Haulage $12\frac{1}{2}$ miles, at 1s. per ton per mile . . . . .                                                                                 | 12s. 6d. „       |
| The cost of forming and maintaining the road for twelve months was £323.13s.6d., equal on the above-mentioned quantity of materials to . . . . . | 1s. 2½d. „       |

The following is a list of the different-sized culverts erected on the line, distinguishing the number of culverts, and the number of openings of each size:—

| Number. | Size of Opening. | Number of Openings. |
|---------|------------------|---------------------|
| 46      | 2 feet 6 inches  | 191                 |
| 2       | 3 feet           | 2                   |
| 2       | 6 feet           | 2                   |
| 113     | 8 feet 6 inches  | 329                 |
| 5       | 10 feet          | 9                   |
| 18      | 12 feet          | 53                  |
| 2       | 15 feet          | 2                   |

The line of rails was carried over the openings of 2 feet 6 inches, by placing ordinary sleepers upon stone piers, the rail itself bridging the opening. Though this appears to be an economical mode of obtaining waterway through low embankments, it was found that the vibration of the line was communicated to the piers, which, though very carefully built, thus required frequent repairs, and in some cases cramping. Whenever the height of the embankment would admit of it, and to secure the largest amount of waterway, openings of 8 feet 6 inches were extensively introduced. In such cases the ordinary permanent way was carried upon teak timber beams, 12 inches square in section, supporting a platform of planks 4 inches thick below the sleepers, to carry a thin layer of ballast, protecting the platform from fire, and forming a footway across the openings. The timber in these culverts was carefully paid over with dammer, or pitch, laid on very hot. This process protects the timber from the attacks of white ants, but it is objectionable on account of the inflammable character of the material. The other culverts in the list were built of stone, with pitched invert and aprons.

The bridges along the line are of the following number and general dimensions :—

19 bridges, containing 48 arches, each of 20 feet span.

|   |   |   |    |   |   |    |   |
|---|---|---|----|---|---|----|---|
| 1 | " | " | 3  | " | " | 30 | " |
| 2 | " | " | 10 | " | " | 40 | " |
| 2 | " | " | 4  | " | " | 45 | " |

The large stone viaduct across the Bahrur River is 1,728 feet in length. Its greatest height, measuring from the bed of the river to the rails, is 31 feet 6 inches, and its average height is 25 feet 6 inches. The superficial measurement of the bridged area is 44,064 square feet. It consists of thirty-two arches, each 45 feet span, and having a rise of 10 feet 6 inches. This was the heaviest piece of masonry upon the line, and the time required for its completion was the measure of that for the opening for public traffic. The quantities of the different classes of work in this viaduct, and the average cost of each kind, (full details of which are given in the Appendix, page 475,) are as follows :—

|                                                                  | Quantity.          | Cost.               |
|------------------------------------------------------------------|--------------------|---------------------|
|                                                                  |                    | <i>s.</i> <i>d.</i> |
| Excavation of foundations . . . . .                              | 20,513 cubic yards | 0 9½ per cubic yd.  |
| Concrete . . . . .                                               | 6,814 "            | 4 0½ "              |
| Common rubble . . . . .                                          | 4,455 "            | 11 9½ "             |
| Coursed rubble . . . . .                                         | 7,233 "            | 20 0½ "             |
| Block in course . . . . .                                        | 5,244 "            | 31 6 "              |
| Ashlar . . . . .                                                 | 29,000 cubic feet  | 1 3 per cubic foot. |
| Broken stone for backing and<br>filling in between the spandrils | 2,650 cubic yards  |                     |
| Ballast . . . . .                                                | 3,780 "            |                     |

The total cost of this viaduct was £27,185. 12*s.* 10*d.* The cost per lineal foot of viaduct was £15. 14*s.* 7*d.*, and per square foot of bridged area 12*s.* 4*d.* The viaduct was commenced on the 5th of March, 1859, and a locomotive engine ran over it on the 26th of January, 1861. The work was thus completed in twenty-two months and a half.

There are six viaducts with iron girders. The girders sent out from England were on Warren's principle, of 80 feet clear span. These were erected at the following rivers:—

|                          |           |
|--------------------------|-----------|
| The Mulleer . . . . .    | 21 spans. |
| " Guggur . . . . .       | 3 "       |
| " Dorbagi . . . . .      | 2 "       |
| " Runnpittiani . . . . . | 6 "       |
| " Loyach . . . . .       | 8 "       |
| " Rhodh . . . . .        | 3 "       |
| Total . . . . .          | 43 "      |

With regard to the Mulleer Viaduct, the most extensive of this class, the Author would merely observe, that the foundations and general construction were of an interesting character, on which he abstains from enlarging, as he finds that Mr. J. E. Hartley, (M. Inst. C.E.,) who was the Resident Engineer during its construction, is engaged in writing a special Paper upon it. From the experience acquired by the Author from these examples of Warren's girders, he is compelled to report unfavourably of them, when contrasted with plate girders. There is an amount of vibration, both laterally and vertically, caused by passing trains, which had the effect of breaking, or of loosening the bolts fixing the longitudinal timber stringers to the cross girders. To such an extent did this occur, that it was found necessary to appoint one, two, or three native workmen at each viaduct, according to its length, whose duty it was to inspect and repair these breakages, or loosenings, after the passage of each train. The cost of this was so serious, that it was found advisable to take up the original rails, and although it raised the line and interfered slightly with the gradients, to lay the ordinary permanent way upon transverse sleepers. This has had the effect of diminishing the evil, but not of removing it entirely. The arrangement of the timber platform

over these viaducts the Author considers highly objectionable, inasmuch as, while loading the bridges, it adds nothing to the lateral stiffness, nor does it distribute the load over the whole area, as might have been the case. It is submitted that two layers of planking, each  $3\frac{1}{2}$  inches thick, laid diagonally, and crossed, upon which the ordinary permanent way could have been laid, would have been a better arrangement,—stiffening the bridge laterally, and distributing the load more uniformly. The sliding blocks upon which each girder is laid, for the purpose of meeting the effects of contraction and expansion caused by changes of temperature, were not found to work well. In several cases the large ashlar stones upon which the bed plates were fixed, were drawn out of their places, before the blocks would slide. It is considered that the roller system, as originally specified, would have been a better arrangement. The impossibility of getting at all the surfaces of the ironwork, to scrape and repaint them, is likewise a serious objection; for while there is no great amount of rain annually in Scinde, there are heavy dews for months together, which cause a rapid oxidisation of unprotected wrought iron. The large viaduct across the Chiunee Creek, of ten spans, each of 100 feet, for a double line, has not yet been erected, but the ironwork is already complete, and delivered at Kurrachee. The girders are of plate iron, of elliptic form in elevation.

The majority of the works of the Scinde Railway were executed departmentally, as it is termed, or by the Company's own staff, without the intervention of a large Contractor. This mode of carrying on the works was forced upon the Company by the peculiar exigencies of the case. The merits of the rival systems have frequently been the subject of discussion, but the experience of the Author leads him to the conclusion, that for the execution of large works in India, under Government guarantee, the employment of a substantial Contractor is the best mode. The departmental system allows of an amount of Government interference in every petty detail which cannot exist under the contract system. As long as the works are pushed forward in accordance with the terms of the agreement with the Company, the Contractor is untrammelled, and he can act on his own discretion in the mode of carrying on his operations, without being involved in the interminable correspondence and delays which are inevitable under the departmental system.

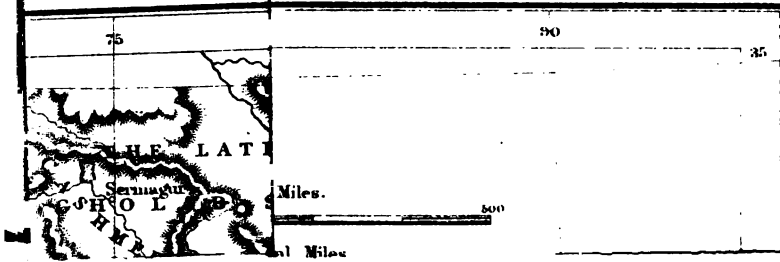
The railway system, which thirty years ago was in its infancy, and struggling into public notice, has now arrived at gigantic proportions, and has not only spread its network over the land of its birth, but is extending, with rapid strides, over the vast continents of the world. During the early years of railway con-

structions, and while the works connected with them lay in civilised countries, the professional Engineer was surrounded by all the appliances of modern science, and had the command of skilled and unskilled labour, which rendered his duties comparatively easy. But the extension of railway communications into wild and uncivilised countries, demands from the Engineers, Agents, and Contractors engaged, the exercise of more than ordinary observation, self-discipline, and energy. This remark applies to all grades of the employés of a foreign Railway Company, from the Chief Engineer and Agent, to the lowest European Inspector. Each European employé almost necessarily occupies an isolated position as regards his fellow-countrymen. He is surrounded by natives, with whose language and habits he is but imperfectly acquainted. Yet upon the obtaining and securing the services and good-will of these natives, the progress and success of the work intrusted to his charge wholly depend. Great tact and temper are, therefore, absolutely necessary. It is flattering to know, that the natives of India place unbounded faith in the truthfulness and justice of a Briton, and when this high position is not weakened, or lost, by the improper acts of the individual, it is a most powerful instrument for good. Kind, considerate, just, and withal firm treatment secures willing service; while an opposite course is followed not by retaliation, perhaps not even by remonstrance, but by the native quietly moving off in search of more humane treatment elsewhere. In carrying out the works of the Scinde Railway there was no lack of examples confirming the above opinion, as to the effect of the European's general treatment of the natives, upon the number and character of those whom he could attract to the works. Again, the Engineer or Inspector situated as above described, at a distance from head-quarters, meets with cases of emergency, when fertility of resource and self-reliance are most invaluable qualities; while at all times, and wherever he may be placed, energy of character and perseverance, combined with temperance, will alone render him a valuable officer. It becomes then the wise policy of all foreign Railway Companies, and of all Contractors for their works, to exercise the greatest strictness, in ascertaining that the agents sent out from this country at immense cost, are not only proficient in the practical details of their profession, but that they are also possessed of gentlemanly feelings and habits, which alone will command the respect of the uncivilised native, attracting him to the work, reducing its cost, and converting the Railway Engineer into a pioneer of civilisation and a missionary of science.

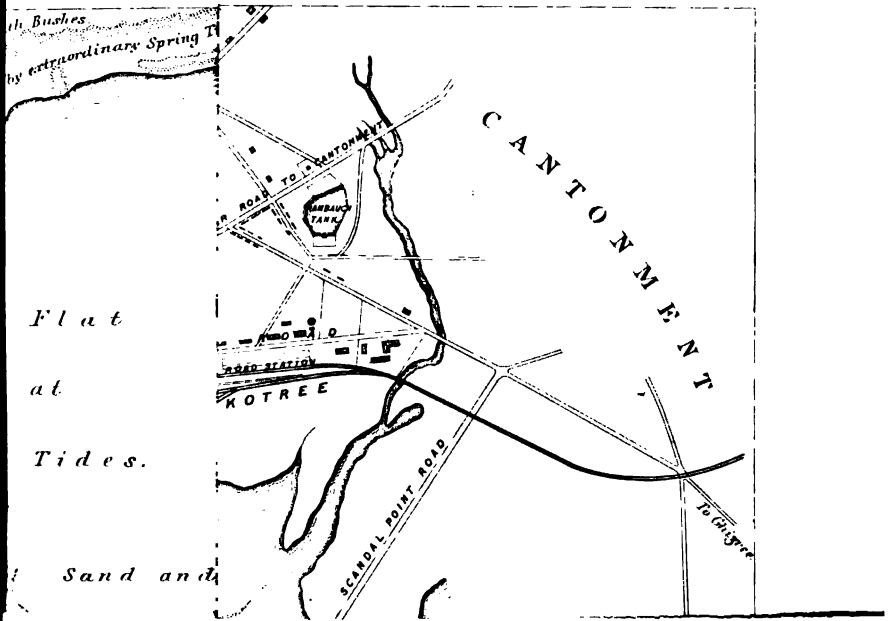
The Author has pleasure in acknowledging, that he is greatly indebted to the following gentlemen, members of the Engineering

staff of the Scinde Railway, for much valuable assistance in collecting and recording the data from which the cost of the various works given in this Paper is calculated :—Mr. W. T. Warren, Mr. Henry Stone, Mr. Thomas Warren, Mr. J. E. Hartley, and Mr. J. Pinder.

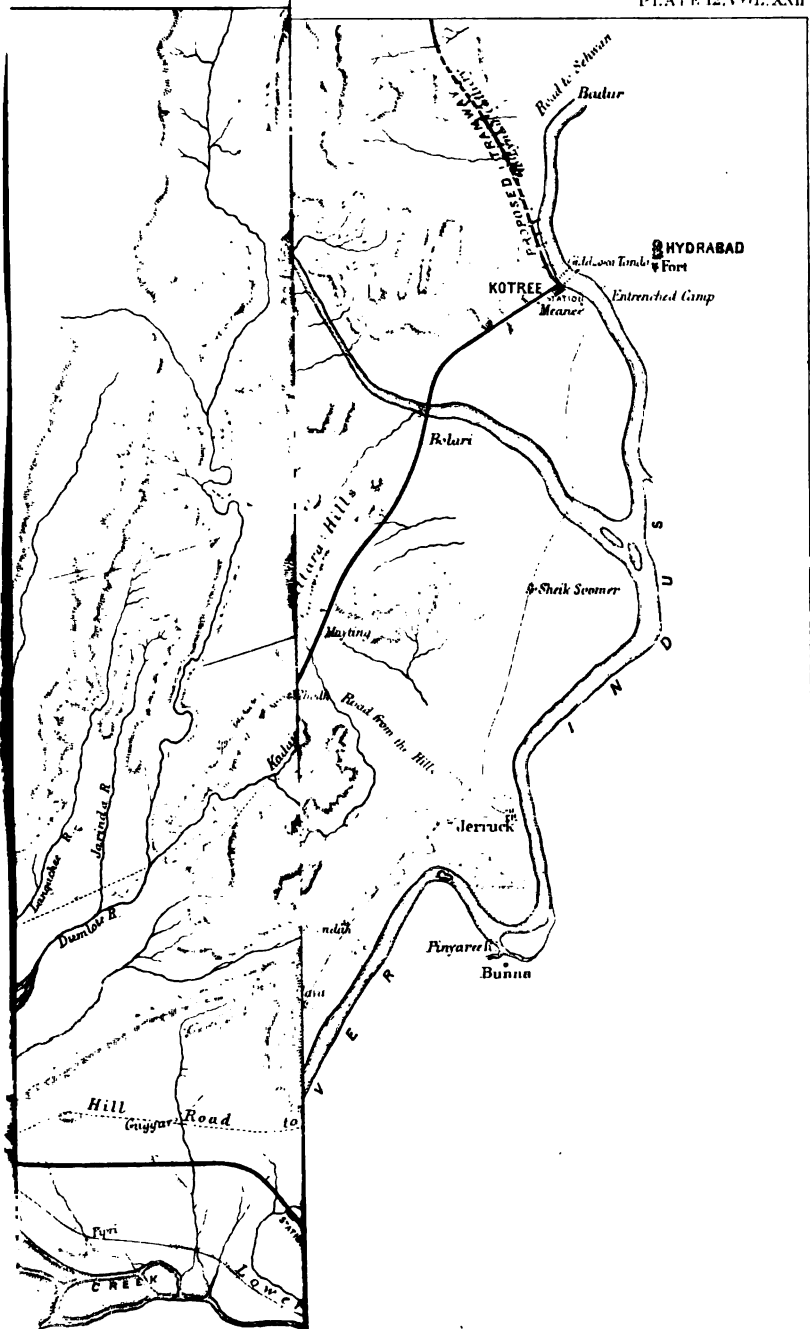
The Paper is illustrated by a plan and section of the line, and by a chart of Kurrachee Harbour, from which Plates 11 and 12 have been compiled, as well as by an elevation, plan, and sections of the Bahrui Viaduct, and details of the mode of forming the masonry piers for the iron girder viaducts.













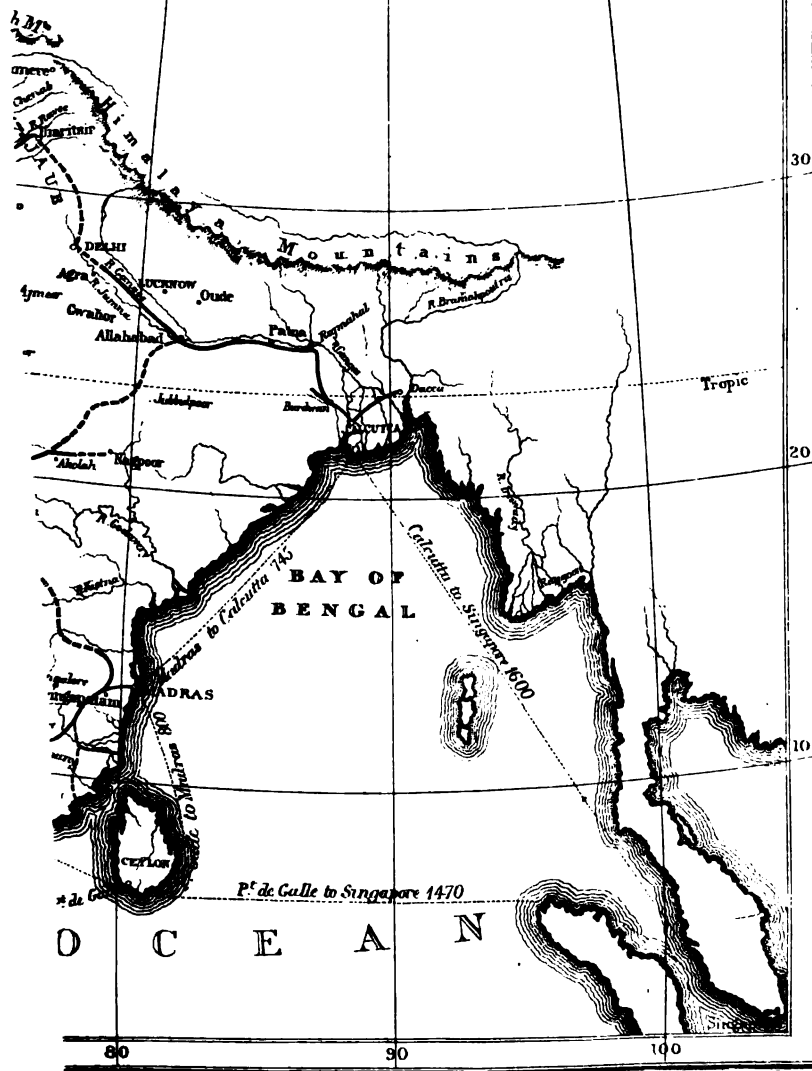
REFERENCE.

Kurrachee to Aden 1435 miles

Bombay to Aden 1640

D° in SW Monsoon 2170

English Miles 69-1 degree of mean latitude





## APPENDIX.

## BAHRUN VIADUCT.

## COST OF EXCAVATING FOUNDATIONS, IN LOOSE SAND, DEPTHS AVERAGING 20 FEET.

Those parts which were let by contract, cost from 12 annas to 1 rupee 4 annas per 100 cubic feet, or per cubic yard 4.36 annas. Those done by day work, (after keeping a strict account for many months,) were found to cost :

|                        | A.   | R. A. |
|------------------------|------|-------|
| One muccadum . . . . . | at 6 | 0 6   |
| Nine coolies . . . . . | at 4 | 2 4   |

Rs. 2 10

For this sum 8½ cubic yards were excavated, thus costing :

|                                                                                       |            |
|---------------------------------------------------------------------------------------|------------|
| Per cubic yard . . . . .                                                              | ANNAS 5.14 |
| About an equal number were excavated by the two modes, therefore add as above . . . . | 4.36       |

9.50

|                                                                         |                |
|-------------------------------------------------------------------------|----------------|
| which, divided by 2, gives as the average cost per cubic yard . . . . . | R. A. P. 0 4 9 |
| Add for tools . . . . .                                                 | 0 0 5          |

|                                                             |       |
|-------------------------------------------------------------|-------|
| Average cost of excavation, }<br>or 9½d. per cubic yard . } | 0 5 2 |
|-------------------------------------------------------------|-------|

## COST OF CONCRETE.

|                                   |       |
|-----------------------------------|-------|
| Lime per maund of 80 lbs. . . . . | 0 3 2 |
|-----------------------------------|-------|

|                                   |        |
|-----------------------------------|--------|
| Sand per 100 cubic feet . . . . . | 0 12 0 |
|-----------------------------------|--------|

Stone per 100 cubic feet :

|                     | R. A. P. |
|---------------------|----------|
| Quarrying . . . . . | 1 0 0    |
| Breaking . . . . .  | 1 0 0    |
| Hauling . . . . .   | 2 12 0   |
|                     | 4 12 0   |

|                                    |       |
|------------------------------------|-------|
| Water per 100 cubic feet . . . . . | 1 4 8 |
|------------------------------------|-------|

*For 100 Cubic Feet of Concrete.*

|                                                  | R. | A. | P. |  | R.    | A. | P. |
|--------------------------------------------------|----|----|----|--|-------|----|----|
| Lime 17 cubic feet, at 0 3 2 per maund . . . . . |    |    |    |  | 0     | 14 | 2  |
| Stone 33 " " 4 12 0 per 100 cubic feet . . . . . |    |    |    |  | 1     | 9  | 4  |
| Sand 50 " " 0 12 0 " " . . . . .                 |    |    |    |  | 0     | 6  | 0  |
| Water . . . . .                                  |    |    |    |  | 1     | 4  | 8  |
| Mixing and depositing in place . . . . .         |    |    |    |  | 2     | 12 | 0  |
|                                                  |    |    |    |  | <hr/> |    |    |
| Total . . . . .                                  |    |    |    |  | 6     | 14 | 2  |
|                                                  |    |    |    |  |       |    |    |
| Or, per cubic yard . . . . .                     |    |    |    |  | 1     | 14 | 0  |
| Add for tools . . . . .                          |    |    |    |  | 0     | 2  | 6  |
|                                                  |    |    |    |  | <hr/> |    |    |
| Total . . . . .                                  |    |    |    |  | 2     | 0  | 6  |
|                                                  |    |    |    |  | <hr/> |    |    |
| Or, 4s. 0½d. per cubic yard.                     |    |    |    |  |       |    |    |

**COST OF ASHLAR MASONRY, PER 100 CUBIC FEET.**

|                                      |          |          |          |                   |
|--------------------------------------|----------|----------|----------|-------------------|
| Quarrying . . . . .                  | 7        | 4        | 0        |                   |
| Earthwork in baring quarry . . . . . | 1        | 0        | 0        |                   |
| Dressing . . . . .                   | 30       | 0        | 0        |                   |
| Water for men . . . . .              | 0        | 8        | 0        |                   |
| Maistry . . . . .                    | 0        | 8        | 0        |                   |
| Smithwork—labour . . . . .           | 1        | 3        | 0        |                   |
| <b>Haulage . . . . .</b>             | <b>3</b> | <b>0</b> | <b>0</b> | <b>40 7 0</b>     |
| Setting . . . . .                    | 12       | 0        | 0        |                   |
| Water for mortar . . . . .           | 0        | 12       | 0        |                   |
| Lime . . . . .                       | 1        | 0        | 0        |                   |
| Sand . . . . .                       | 0        | 4        | 0        |                   |
| Maistry . . . . .                    | 0        | 6        | 0        |                   |
| Tools and contingencies . . . . .    | 4        | 11       | 0        |                   |
| <b>Total . . . . .</b>               |          |          |          | <b>22 1 0</b>     |
| <b>Total . . . . .</b>               |          |          |          | <b>Ra. 62 8 0</b> |
| Or, 1s. 3d. per cubic foot.          |          |          |          |                   |

**BLOCK IN COURSE, (ARCHES,) PER 100 CUBIC FEET.**

|                                      |          |          |          |                    |
|--------------------------------------|----------|----------|----------|--------------------|
| Quarrying . . . . .                  | 6        | 4        | 0        |                    |
| Dressing . . . . .                   | 25       | 0        | 0        |                    |
| Earthwork in baring quarry . . . . . | 2        | 0        | 0        |                    |
| Water for men . . . . .              | 0        | 11       | 0        |                    |
| Smithwork—labour . . . . .           | 0        | 10       | 0        |                    |
| Maistry . . . . .                    | 0        | 10       | 0        |                    |
| <b>Haulage . . . . .</b>             | <b>3</b> | <b>0</b> | <b>0</b> | <b>35 3 0</b>      |
| Setting . . . . .                    | 11       | 8        | 0        |                    |
| Water for mortar . . . . .           | 0        | 14       | 0        |                    |
| Sand . . . . .                       | 0        | 8        | 0        |                    |
| Lime . . . . .                       | 1        | 8        | 0        |                    |
| Maistry . . . . .                    | 1        | 0        | 0        |                    |
| Tools, coal, templates, &c. . . . .  | 4        | 3        | 0        |                    |
| <b>Total . . . . .</b>               |          |          |          | <b>22 9 0</b>      |
| <b>Total . . . . .</b>               |          |          |          | <b>Ra. 57 12 0</b> |
| Or, £1. 11s. 6d. per cubic yard.     |          |          |          |                    |

## COURSED RUBBLE, PER 100 CUBIC FEET.

|                                      | B.          | A. | P. |
|--------------------------------------|-------------|----|----|
| Quarrying . . . . .                  | 6           | 0  | 3  |
| Earthwork in baring quarry . . . . . | 1           | 0  | 0  |
| Dressing . . . . .                   | 12          | 8  | 0  |
| Water for men . . . . .              | 0           | 6  | 0  |
| Maistry . . . . .                    | 0           | 8  | 0  |
| Smithwork—labour . . . . .           | 0           | 8  | 0  |
|                                      | <hr/>       |    |    |
| Haulage . . . . .                    | 2           | 4  | 0  |
| Setting . . . . .                    | 10          | 8  | 0  |
| Water for mortar . . . . .           | 0           | 14 | 0  |
| Lime . . . . .                       | 1           | 8  | 0  |
| Sand . . . . .                       | 0           | 8  | 0  |
| Maistry . . . . .                    | 0           | 4  | 0  |
|                                      | <hr/>       |    |    |
|                                      | 15          | 14 | 0  |
| Total . . . . .                      | <hr/>       |    |    |
|                                      | Rs. 36 12 3 |    |    |

Or, £1. 0s. 0 $\frac{3}{4}$ d. nearly, per cubic yard.

## COMMON RUBBLE, PER 100 CUBIC FEET.

|                                   |             |    |   |
|-----------------------------------|-------------|----|---|
| Quarrying . . . . .               | 3           | 6  | 0 |
| Smithwork—labour . . . . .        | 0           | 8  | 0 |
| Water for men . . . . .           | 0           | 6  | 0 |
|                                   | <hr/>       |    |   |
|                                   | 4           | 4  | 0 |
| Haulage . . . . .                 | 2           | 2  | 0 |
| Setting . . . . .                 | 10          | 0  | 0 |
| Lime . . . . .                    | 1           | 12 | 0 |
| Sand . . . . .                    | 0           | 8  | 0 |
| Maistry . . . . .                 | 0           | 8  | 0 |
| Water for mortar . . . . .        | 0           | 14 | 0 |
| Tools and contingencies . . . . . | 1           | 10 | 6 |
|                                   | <hr/>       |    |   |
|                                   | 17          | 6  | 6 |
| Total . . . . .                   | <hr/>       |    |   |
|                                   | Rs. 21 10 6 |    |   |

Or 11s. 9 $\frac{3}{4}$ d. per cubic yard.

## CENTERING.

Deodar timber in one set of centres 1,910 cubic feet.

Iron in one set of centres 36 cwt.

|                                                |               |   |   |
|------------------------------------------------|---------------|---|---|
| Timber, 1,910 cubic feet, at 1 rupee . . . . . | 1,910         | 0 | 0 |
| Iron, 36 cwt., at 12 rupees . . . . .          | 432           | 0 | 0 |
| Carpenters' work . . . . .                     | 140           | 0 | 0 |
| Smiths' work . . . . .                         | 120           | 0 | 0 |
| Nails, 112 lbs., at 3 annas . . . . .          | 21            | 0 | 0 |
|                                                | <hr/>         |   |   |
| Total for one centre . . . . .                 | Rs. 2,623 0 0 |   |   |

|                                              |                |   |   |
|----------------------------------------------|----------------|---|---|
| Cost of the 12 sets was, therefore . . . . . | 31,476         | 0 | 0 |
| Fixing and removing in 32 arches . . . . .   | 1,920          | 0 | 0 |
|                                              | <hr/>          |   |   |
| Total . . . . .                              | Rs. 33,396 0 0 |   |   |

The timber of these centres was cut to a scantling which made it available for sleepers on the completion of the arching, and it was valued at . . . . .

18,336 0 0

Further, the centres of the Bahrun Viaduct were made use of at the Koonce and Huroola Bridges, so that the apportionment of the total cost of centering is as follows :—

|                                    | R.                | A.       | P.       |
|------------------------------------|-------------------|----------|----------|
| Bahrun Viaduct 32 arches . . . . . | 13,385            | 10       | 8        |
| Huroola Bridge 3 „ . . . . .       | 1,255             | 0        | 0        |
| Koonce Bridge 1 „ . . . . .        | 418               | 5        | 4        |
| <b>Total . . . . .</b>             | <b>Ra. 15,060</b> | <b>0</b> | <b>0</b> |

#### TOTAL COST OF THE BAHRUN VIADUCT.

|                                                                                                                                   |                    |             |             |
|-----------------------------------------------------------------------------------------------------------------------------------|--------------------|-------------|-------------|
| Amount paid to Messrs. Bray for work performed, up to the period of taking over the contract . . . . .                            | 40,412             | 0           | 0           |
| Amount subsequently paid in the departmental execution of the works, exclusive of the higher classes of superintendence . . . . . | 206,944            | 6           | 4           |
| Amounts chargeable under the head of plant, including trollies, crabs, chains, ropes, poles, scaffolding, &c. . . . .             | 24,500             | 0           | 0           |
| <b>Total . . . . .</b>                                                                                                            | <b>Ra. 271,856</b> | <b>6</b>    | <b>4</b>    |
| <b>Or in English money . . . . .</b>                                                                                              | <b>£ 27,185</b>    | <b>12s.</b> | <b>10d.</b> |

#### COST OF MASONRY AT KURRACHEE.

The following is a statement of the prime cost of masonry in the neighbourhood of Kurrachee, exclusive of European superintendence and working plant :—

##### ASHLAR.

|                                                                                                                                                          |               |          |          |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----------|----------|
| Two good men will prepare 8 cubic feet per day for 20 annas $\times 12\frac{1}{2}$ , or for 100 cubic feet . . . . .                                     | 15            | 10       | 0        |
| Two good men will set in general work 20 cubic feet per day for 20 annas, making for 100 cubic feet . . . . .                                            | 6             | 4        | 0        |
| To labour, including coolies', nowgunnies', smiths', and maistrys' pay . . . . .                                                                         | 15            | 4        | 0        |
| <b>Cost of contractor's part . . . . .</b>                                                                                                               | <b>Ra. 37</b> | <b>2</b> | <b>0</b> |
| Add for quarrying stone, exclusive of powder, &c., for 100 cubic feet . . . . .                                                                          | 4             | 0        | 0        |
| Ditto for delivery of stone, if 5 miles lead, and supposing each cart to contain 7 cubic feet, at 12 annas per cart load, or for 100 cubic feet. . . . . | 10            | 11       | 5        |
| Ditto for lime delivered on the works . . . . .                                                                                                          | 2             | 12       | 0        |
| Ditto for sand „ „ „ . . . . .                                                                                                                           | 1             | 4        | 0        |
| Ditto for water „ „ „ . . . . .                                                                                                                          | 0             | 12       | 0        |
| <b>Total for 100 cubic feet . . . . .</b>                                                                                                                | <b>Ra. 56</b> | <b>9</b> | <b>5</b> |
| <b>£1. 10s. 6½d. per yard,</b>                                                                                                                           |               |          |          |
| <b>Or about 1s. 4½d. per cubic foot.</b>                                                                                                                 |               |          |          |

##### BLOCK IN COURSE.

|                                                                                                                           |               |          |          |
|---------------------------------------------------------------------------------------------------------------------------|---------------|----------|----------|
| Two good men will prepare 12 cubic feet per day, at 10 annas per day for each man, making for 100 cubic feet . . . . .    | 10            | 6        | 8        |
| Two good men will set in general work 20 cubic feet per day, at 10 annas each man per day, or for 100 cubic feet. . . . . | 6             | 4        | 0        |
| To labour, including coolies', nowgunnies', smiths', bullocks', and maistrys' pay . . . . .                               | 10            | 8        | 0        |
| <b>Cost of contractor's part . . . . .</b>                                                                                | <b>Ra. 27</b> | <b>2</b> | <b>8</b> |

|                                                                                                                                                        | R. | A. | P. |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|----|----|----|
| Brought forward . . . . .                                                                                                                              | 27 | 2  | 8  |
| Add for stone in quarry, exclusive of powder, &c., per 100 cubic feet . . . . .                                                                        | 4  | 0  | 0  |
| Ditto for delivery of stone, if 5 miles lead, and supposing each cart to contain 7 cubic feet, at 12 annas per cart load, per 100 cubic feet . . . . . | 10 | 11 | 5  |
| Ditto for sand . . . . . per ditto . . . . .                                                                                                           | 1  | 8  | 0  |
| Ditto for water . . . . . per ditto . . . . .                                                                                                          | 0  | 14 | 0  |
| Ditto for lime delivered upon the work . . . . . per ditto . . . . .                                                                                   | 3  | 0  | 0  |

Total for 100 cubic feet . . . . . Rs. 47 4 1

Or £1. 5s. 6½d. per yard.

#### COURSED RUBBLE.

|                                                                                                                                |    |   |   |
|--------------------------------------------------------------------------------------------------------------------------------|----|---|---|
| Two good men will prepare 20 cubic feet per day, at 10 annas per day for each man, making for 100 cubic feet . . . . .         | 6  | 4 | 0 |
| Two good men will set in general work 30 cubic feet per day, at 10 annas each man per day, making for 100 cubic feet . . . . . | 4  | 2 | 8 |
| To labour, including coolies', nowgunnies', smiths', bullocks', and maistris' pay . . . . .                                    | 10 | 8 | 0 |

Cost of contractor's part . . . . . Rs. 20 14 8

|                                                                                                                                                        |    |    |   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|----|----|---|
| Add for stone in quarry, exclusive of powder, &c., per 100 cubic feet . . . . .                                                                        | 3  | 8  | 0 |
| Ditto for delivery of stone, if 5 miles lead, and supposing each cart to contain 7 cubic feet, at 12 annas per cart load, per 100 cubic feet . . . . . | 10 | 11 | 5 |
| Ditto for sand . . . . . per ditto . . . . .                                                                                                           | 1  | 8  | 0 |
| Ditto for water . . . . . per ditto . . . . .                                                                                                          | 0  | 14 | 0 |
| Ditto for lime delivered upon the work . . . . . per ditto . . . . .                                                                                   | 2  | 12 | 0 |

Total for 100 cubic feet . . . . . Rs. 40 4 1

Or £1. 1s. 8½d. per yard.

#### A SUPERIOR CLASS OF RUBBLE.

|                                                                                                                                |   |   |   |
|--------------------------------------------------------------------------------------------------------------------------------|---|---|---|
| Two good men will prepare and set 40 cubic feet per day, at 10 annas per day for each man, making for 100 cubic feet . . . . . | 3 | 2 | 0 |
| To labour, including coolies', nowgunnies', smiths', bullocks', and maistris' pay . . . . .                                    | 8 | 0 | 0 |

Cost of contractor's part . . . . . 11 2 0

|                                                                                                                                      |    |    |   |
|--------------------------------------------------------------------------------------------------------------------------------------|----|----|---|
| Add for stone in quarry, exclusive of powder, &c., per 100 cubic feet . . . . .                                                      | 3  | 8  | 0 |
| Ditto for delivery of stone, if 5 miles lead, and supposing each cart to contain 7 cubic feet . . . . . per 100 cubic feet . . . . . | 10 | 11 | 5 |
| Ditto for sand . . . . . per ditto . . . . .                                                                                         | 1  | 10 | 0 |
| Ditto for water . . . . . per ditto . . . . .                                                                                        | 1  | 0  | 0 |
| Ditto for lime delivered upon the work, per ditto . . . . .                                                                          | 3  | 0  | 0 |

Total for 100 cubic feet . . . . . Rs. 30 15 5

Or 16s. 8d. per yard.

[Mr. W. P. ANDREW,

Mr. W. P. ANDREW,—Chairman of the Scinde Railway Company—observed, that on the map of India, (Plate 10,) this railway appeared to be a very small undertaking; yet in actual length it would be found to compare advantageously with some of the leading railways in England. For instance, it was about the same length, 108 miles, as the Great Western, from London to Bath, and very nearly equal to that of the London and Birmingham Railway, which was 113 miles, while the Scinde Railway was more than twice the length of the London and Brighton line. It was not, however, from its dimensions, but from its relation to other parts of India, that this line derived its great national and commercial importance. The immediate object for its construction was to meet the two great difficulties of the Indus, the creek navigation and the ocean swell of the open sea. All the serious accidents that had been attended with loss had occurred, either in the short navigation of the open sea, or in the creeks of the delta. By the last mail he had received a letter, stating that another company, (not in connection with the Scinde,) which proposed to establish a through navigation between the Punjaub and Kurrachee, had had three of their vessels seriously injured, the back of one being reported to have been broken, in the creek navigation. So alive had the natives been to the advantages gained by the Scinde Railway, and so much did they appreciate the regularity and certainty of railway communication, that the native craft which was formerly in the habit of coming to Khettie in the delta, as the port of transshipment, both for Bombay and Kurrachee, did not now come below Kotree, where the goods were transhipped and conveyed by railway to Kurrachee. In a letter received that day, it was stated that there was a length of two miles of native boats collected at Kotree, the upper terminus—which in itself was sufficient evidence to show the dangers of the sea and creek navigation by steamers and by native country craft, and to demonstrate the necessity for such a work as the Scinde Railway. The Agent of the Company further stated, that not a single native boat had gone below Kotree for the last two months. The immediate object contemplated by the Scinde Railway,—to relieve the commerce of the country from its two great dangers,—had thus been accomplished by substituting a railway of 108 miles, for the creek navigation of 230 miles. Moreover in a political and military point of view, it was of the greatest importance to be able to move troops from Kurrachee to Kotree in a few hours, instead of losing a week in conveying them up the creeks.

Looking at the map of Upper India (Plate 10), towards the

<sup>1</sup> The scales of English miles and of geographical miles attached to this map are inaccurate. The figures should be 0, 25, 50, 100, and 250, instead of 0, 50, 100, 200, and 500.—Ed.

north, a branch line would be observed on the right bank of the River Indus. That was the proposed line from Sukkur, viâ Shikarpoor and Jacobabad, to the Bolan Pass; the surveys had been partially executed, and it was found that the line could be easily and cheaply constructed. Its political importance was great; and a large portion of the traffic of Central Asia came down that Pass on its way to Kurrachee, and was subject to great difficulties and delays. Higher up was Moulton, the lower terminus of the Punjab Railway: that line extended to Lahore and Umritsir, and from thence proceeded the Delhi Railway, which would form a junction with the East Indian Railway at Delhi. The traffic between Moulton and Kotree was now most imperfectly carried on by means of a large fleet of steamers, which he trusted would speedily be superseded by a railway. India would then have one of the longest continuous lines in the world, from Kurrachee to Calcutta, a distance of upwards of 2,200 miles, forming a great steam arch connecting the Arabian Sea with the Bay of Bengal. This would give the greatest protection to the empire of India, by affording the most effectual means of quelling disturbances, either within or without the frontier. It would, moreover, powerfully develop the enormous resources of the interior of the country, bringing to the port of shipment that produce of its plains which was so urgently required in England. The capabilities of India were but little understood. The discrepancies of conflicting authorities might, however, be accounted for when it was considered, that India was a country of vast extent, being as large as the whole of Europe without Russia, that it possessed every variety of soil and climate, and that, from the different elevations of the plateau, its products necessarily varied.

With regard to the cost of the Scinde Railway, he thought that it would slightly exceed the average cost of railways in India, which he believed to be about £15,000 per mile. But there were peculiarities in the case of the Scinde Railway which would, in a great measure, account for this excess. In the first place, there was considerable difficulty in procuring from England freight for the materials, for at the time the concession was granted, Kurrachee was scarcely known; and it became necessary to investigate and to publish the capabilities of the port. In the second place, the Scinde Railway comprised, in proportion to its length, a more than usually large number of such works, as piers, wharves, &c., which did not ordinarily belong to railways. Then there were difficulties when the materials arrived in India; the Company having even to provide their own boats for unloading the vessels, and as there was a deficiency of labour, labourers had to be imported from Cutch and Central Asia, and from the confines of China and Persia. All these obstacles were overcome, however, by the energy and perseverance of the Author of the Paper, and the Engineering staff under him, and Sir Bartle Frere, the then Commissioner in Scinde, and the

present Governor of Bombay, had borne testimony to the admirable manner in which the affairs of the Company were conducted.

There was one important engineering point on which it was desirable to elicit an opinion,—that was the best material for sleepers in India. In Scinde the soil was hard and stony; many of the cuttings were through rock, and the embankments consisted, in great part, of stone. The kind of sleeper which would answer there would probably be ill adapted for the railways in the Punjaub. On the Scinde line, the sleepers had been prepared in a variety of ways, but they had all apparently retained their original size and form, thus presenting, as he understood, a great contrast to the wooden sleepers employed in almost every other part of India. On those lines, the sleepers had, irrespective of the attacks of the white ant and notwithstanding every precaution, become desiccated and had almost entirely disappeared, from the effect of natural decay. From his own acquaintance with India and with the habits of the white ant, in 1846, he had ventured to predict that the apprehension of the ravages of that insect upon railway sleepers was exaggerated. The results had proved as he had predicted, that whatever was liable to sudden concussion, or vibration, would never be much affected by the ant, as it always worked under a covered way, and whenever that covered way was disturbed, it invariably retired. As in the Punjaub there was a great difficulty in procuring wooden sleepers, the Company had, upon the recommendation of Mr. Bidder, (Past-President Inst. C.E.,) sent out several miles of iron sleepers. As they were only being now put down, it was impossible at present to give an opinion as to their adaptability.

He desired also to call attention to another engineering point connected with the Scinde Railway, which was perfectly novel to him. From some cause or other, the waterway appeared to be insufficient to allow the drainage of the country to pass beneath the line, and the Engineer had adopted the expedient of allowing, on a part of the line, the water to flow over, instead of under it. The water appeared to glide over slowly, and the ballast being heavy stone, the line was not injured, nor had the traffic been interrupted by this peculiar mode of treatment.

From the days of Sir Henry Pottinger<sup>1</sup> and Sir Charles Napier<sup>2</sup> to the present time, the attention of Indian statesmen had been directed to the political and strategic, as well as to the commercial importance of Kurrachee. A good port capable of admitting at all hours and seasons ships of large burden, was indispensable to the success of the combined system of rail and river for the valley of the Indus, intended to be carried out by the Scinde and the Punjaub

<sup>1</sup> *Vide* Letter from Sir H. Pottinger to Mr. W. P. Andrew, in "The Scinde Railway, and its Relations to the Euphrates Valley and other Routes to India." London, 1856.

<sup>2</sup> *Vide* "The Indus and its Provinces." By W. P. Andrew. London, 1857.

Railways, in conjunction with the Indus Flotilla. Such was to be found in Kurrachee, the most western port of India, and the only land-locked harbour between Bombay and the Persian Gulf. It was perfectly safe and easy of access for large ships, by day and night, and even during the monsoons. According to Commodore Young of the Indian Navy,<sup>1</sup>—who, as far back as 1854, took the steam frigate 'Queen' twice into Kurrachee in the night time, during the south-west monsoon,—it, though a bar harbour, had sufficient depth of water, even in its existing state, for ships of from 17 feet to 18 feet draught, at high water of ordinary tides. At high spring-tides, the depth was from 20 feet to 21 feet, and at times, even 22½ feet. In this view, Commodore Young was confirmed by Commodore Rennie,<sup>2</sup> of the Indian Navy, who, during the preparations for the late expedition to the Persian Gulf, was constantly in and out of the harbour with troops, and became convinced, that there was frequently more water on the bar than was shown by the port register. As a proof of this, the 'Bussorah Merchant,' a large vessel drawing 20½ feet of water, passed the bar when the register showed 21 feet. To that able and excellent officer, Captain C. D. Campbell, I.N., belonged the credit of having been the first to take, on his own responsibility, a large armed steamer into the harbour of Kurrachee.

From the Ganges to the Oxus, whoever wished to communicate with any place beyond the sea, must pass through Kurrachee, which thus occupied a position scarcely less favourable to commerce than Alexandria. The port was protected from the sea and from bad weather, by Manora Point, a bluff rocky headland projecting south-eastward from the mainland, and leaving a space of about 2 miles between the extreme point and the coast to the east. The harbour was spacious, extending about 5 miles northward from Manora Point, and about the same distance from the town, on the eastern shore, to the extreme western point.

To be the nearest point to Europe of all the British possessions in India was important in many respects, but more especially with reference to the Euphrates Valley route; and every remark relative to the direct communication of Kurrachee with Suez was equally, if not more, applicable to that with Bussorah, as materially reducing the sea voyage from India. When the proposed telegraphic communication should be established with Europe, whether by the Persian Gulf, as advocated by him, or the Red Sea, or, as it ought to be, by both routes, the advantage would be great, of being the medium of disseminating the political and commercial intelligence of Europe to the most distant parts of India, and giving in exchange the most recent events there, and also in Central Asia. Until lately beyond the pale of the electric chain, which

<sup>1</sup> *Vide* "The Indus and its Provinces." By W. P. Andrew. London, 1857.

<sup>2</sup> *Vide Ibid.*

already spanned the eastern empire, Kurrachee was destined, ere long, to become the chief seat of the telegraph in India, and from its geographical position, it must become the European port of India. It was (Plate 13) 205 miles nearer than Bombay to Aden; and for three months in the year, during the prevalence of the south-west monsoon, it was virtually 735 miles nearer.

Nearly ten years ago, Sir Bartle Frere, the present Governor of Bombay, remarked,<sup>1</sup> "it might be premature to dwell on the certainty of this port (Kurrachee) becoming, ere long, the channel of a direct steam communication with Aden. But compare the length of the run hither from Aden with the length of the run to Bombay; and consider that the passage from Bombay to Aden is, for three months in the year, in the teeth of the south-west monsoon; that on the line from this to Aden, the south-west monsoon does not blow with violence, and is, in fact, not more than a steady trade-wind, equally favourable for the run to, or from Aden, the result of a consideration of these circumstances can hardly be other than a conviction, that a direct steam communication will be established at no distant period, and from the large number of passengers between the Punjaub and England, to whom it is of importance to avoid the delays and expenses of going round by Bombay, there can be little doubt but that it would prove a good passenger line."

Mention was made in the Paper of the extensive works carried on by Government for the improvement of the harbour. Mr. Andrew could further state, that the Scinde Railway Company had sent out from England more than one hundred ships, and that no accident had occurred to any of them either in entering, or on leaving the port.

Mr. BRUCE said, it appeared from the statement of the Chairman of the Scinde Railway, that the cost of the line might be estimated at rather more than £15,000 per mile, and the average prices of the different descriptions of work were given in the Paper; but there was another necessary element in the consideration of the case, the price of labour, by which alone it was possible to judge whether the work was cheap, or dear. The price of earth-work was stated to be 11½*d.* per cubic yard, and that of block in course 31*s.* 6*d.* per cubic yard. Now he hoped he should not be considered as stepping beyond proper criticism in saying, that he thought those prices were too high, under almost any ordinary circumstances. The cost of the line was, in his opinion, much too high for a poor country,—for although India was extensive, still the people were poor,—and if railways were to be widely extended in that country, some means must be found of making them at a cheaper rate. He thought it probable, that those railways which

<sup>1</sup> *Vide* "The Scinde Railway, and its Relations to the Euphrates Valley and other Routes to India." By W. P. Andrew. London, 1856.

had been the pioneers, had borne the brunt, and that it would be found possible now to introduce a better system, by which future lines could be laid down at less cost.

The Author had alluded to the difficulties in which he was placed, by the Contractor not being able to carry out his engagements, he being in consequence, compelled, to undertake the management, and to conduct the works himself. The question whether works should be carried out through the medium of Contractors, or not, had often been mooted at the Institution. Although Mr. Bruce himself had set an opposite example, in dispensing with a Contractor in India, he quite agreed with the Author, that the proper system, which should not be deviated from without good reason, was to let the work to a large Contractor, capable of thoroughly executing it, and thus to relieve the Engineer, to a great extent, of the burden of detail. There was nothing like division of labour when properly carried out, and where it was possible to submit work to a fair amount of competition, so as to secure fair prices for the Company.

There were some points of a general character in the Paper, which he thought called for remark. The Author stated, that the price of labour was fixed by the magistrate. Mr. Bruce's experience in such matters was, that the less recourse was had to the magistrate the better, and that the Engineer should fix the prices for everything. The magistrates had too much power, and though they exercised it efficiently in their own work, still it was a mistake to require of them more than to render the protection ordinarily and everywhere expected from magistrates. The Author had followed a system, which was very wise, that of endeavouring to train young people in India for the different trades, but the pay allowed them appeared to be high. From £3 to £8 per month was large pay for a youth learning his business. As to the sleepers, the Author stated that a large proportion of those which had been sent from this country were of creosoted red and white pine, and that they had generally failed. Mr. Bruce had been in the habit of sending out red pine, but as a general rule, he preferred using cast-iron sleepers in India; and he had no doubt it would be found, that those sent out upon Mr. Bidder's recommendation would be efficient and last well. It was, however, quite certain, that if wooden sleepers were sent out, they must be of the best kinds of wood; it was useless to trust to creosote for making good the deficiencies of the timber itself.

With regard to the question of water-way, he thought it would have been a better, a surer, and in the end, a more efficient and economical course, to have provided proper openings for carrying the water under, or through, than to allow it to run over the railway. Although there might be circumstances in this particular case of which he was not fully aware, which might justify the course

adopted by the Author, he thought it was not a desirable system, or one which it would be safe to follow to any extent.

Mr. Bruce cordially agreed with the remark at the end of the Paper, as to the necessity of taking care to send to a foreign country, men who were not only good mechanics, but also of good character. The main element for consideration in the men to be sent out, of whatever grade, should be character, because the natives looked up so much to Europeans, that if they were not men of steadiness and honesty, they obtained very little power, or control in India. That was a point which could not be too much insisted on in carrying out works of this description, in countries far removed from head-quarters.

Mr. G. BERKLEY remarked, that in a Paper submitted to the Institution in 1860, by his Brother, (the late Mr. James Berkley,) it was stated, that the prices paid in Western India for block in course, varied from 16s. to £1. 15s. per yard.<sup>1</sup> It was, therefore, evident that circumstances varied considerably, and that it was extremely difficult to fix upon any average by which to compare prices in two districts, where the conditions might be entirely different. In the same Paper, the price of earthwork was stated to be much lower than in the present case; but it should be remembered, that the lead was only a quarter of a mile, whereas on the Scinde Railway it might have been longer, and thus the prices might be a fair representation of the circumstances under which the Author had been working.

He would refer to the subject of the improvement of the port of Kurrachee, merely with the view of drawing attention to what appeared to be one of the most important objects in these undertakings,—the means adopted for loading and shipping goods at the termini of the various railways. On the Scinde Railway the appreciation of its importance was demonstrated by the early consideration it met with, and by the execution of efficient works at the seaboard terminus. At Bombay there was a first-rate harbour, and although, for many years past, several plans had been suggested, he had not yet heard of any practical step having been taken towards effecting the improvement so much required. Station accommodation at the Bombay Terminus of the Great Indian Peninsula Railway was also a subject the consideration of which had occupied much time.

With regard to creosoted sleepers, he had found them liable to split when they arrived in India, and there was also an objection to them as cargo, on account of their inflammability and their liability to injure other goods. The same objection applied to carrying creosote itself.

He agreed with the remarks, as to the importance of sending

<sup>1</sup> *Vide Minutes of Proceedings Inst. C.E., vol. xix., p. 609.*

out agents and work-people of good character: this was, however, a matter of considerable difficulty. The great desideratum was to find old heads on young shoulders; men prompt and practical, and at the same time, of tact and temper. The Engineers and others who had gone to India had, as a body, very creditably represented their countrymen; but it would be extreme good fortune always to obtain men with these remarkable characteristics combined.

Mr. W. A. BROOKS observed, that Kurrachee was, with the exception of Bombay, the only good harbour on the western coast of Hindostan. With reference to the statement in the Paper, that an improvement had taken place in the depth over the bar at Kurrachee since the Keamaree Pier had been carried out, it appeared from the chart, (Plate 11,) that the greatest available depth was only 15 feet, at low water of spring tides—a depth which did not warrant the statement that any improvement had taken place; because the survey made in 1848-49 by Mr. Fenner, a master in the Indian Navy, and marine surveyor, gave the same depth, (15 feet,) which added to the 9 feet rise of tide, made 24 feet, as shown on the chart. In 1853 it was recorded, that the high water depth was 23 feet. In 1856, the late Mr. Walker reported, that at low water of spring tides the depth was from 9 feet to 12 feet; but in a Paper of Directions for approaching Kurrachee, dated January, 1860, the depth on the bar at high water of spring tides was stated to be, S.W. monsoon, between May and September, from 22 feet to 23½ feet.<sup>1</sup>

It was important to recollect, that at present the harbour of Kurrachee was almost a pure tidal receptacle, and that, therefore, any works which diminished that receptacle for the tide must have the effect of greatly injuring the harbour. Formerly, a large volume of the floods of the Indus passed into the harbour by the Lyaree Channel, but little came down now. He was desirous of directing the attention of the meeting to the contraction of the tidal flow presented by the works projected by the late Mr. Walker, and now in progress; because there was, in his opinion, great danger that a noble harbour might be ruined. It was part of Mr. Walker's design to extend from Manora Point, a pier, on the eastern side of which, a shoal would most certainly be deposited, precisely similar to that now existing on the eastern side of the point. The construction of the pier, as proposed, must be followed by a proportionate extension of sand under the lee side, during the prevailing set of the current along the coast; the bar would be merely shifted a little farther out, and would overlap the Keamaree Pier, just as the bank, in its natural condition, overlapped it at present. This would always render it difficult

<sup>1</sup> Vide "The Engineer's Journal," July 1, 1861. Vol. iv., p. 132. Calcutta, 1861.

for ships to enter the harbour when the wind was from the westward. It must be evident, that vessels trying to weather Keamaree Pier head, would be in constant danger either of falling upon it, or of being driven to leeward of the harbour.

In the 'Calcutta Engineers' Journal' for July and October 1861,<sup>1</sup> there appeared an able Paper on Kurrachee Harbour, by Lieutenant A. D. Taylor of the Hydrographical Department of the Indian Navy, in which he recommended a pier to be made from the shore at Clifton, and, after passing over the Oyster Rocks, to terminate abreast of Manora Point, leaving a capacious entrance between the pier head and the point. Mr. Brooks stated, that he had given much attention to this subject, and that he considered Lieutenant Taylor's plan to be better adapted to improve the mouth of Kurrachee Harbour, and to augment the tidal receptacle, than the present works. Moreover, if the eastern pier were made to extend rather beyond Manora Point, the set of the prevailing current would be against its inner, or harbour face, and would act beneficially in maintaining good water on the bar.

Mr. PARKES said, that he had made the survey of the harbour of Kurrachee, and had assisted the late Mr. Walker in the design, but the work was being carried out entirely under the Public Works Department of the Bombay Government. He would however mention one fact to show the incorrectness of Mr. Brooks's conclusions. At the end of Manora Point the water was about 9 feet deep, in which depth the waves broke. In breaking, they lifted the sand from this shallow bottom, and rolled it forward into the stiller water immediately under the lee of the point. If the pier were carried out, its extremity would stand in a depth of 24 feet, and the waves would not break. There would, therefore, be no tendency to lift the sand, and, consequently, no tendency to form a bar there. He had been informed, that the groyne, which he believed had lately been completed along the Keamaree Spit, on the opposite side to the entrance, had already produced considerable effect upon the bar. The bar was in a transition state at present, and, therefore, all he could now say was, that the sand had been considerably moved. The navigable channel being circuitous would not, in its existing position, be much affected by the increased scour, but the top of the bar had been lowered to a great extent, and when the increased scour caused by the groyne had gone on a little longer, the bar would, no doubt, be reduced to a much greater extent, and a more direct and much deeper navigable channel would be formed. The immediate effect, though as yet incomplete, was very encouraging. Mr. Brooks had alluded to the importance of maintaining the tidal space within the harbour, but he had omitted to mention the fact, that by Mr. Walker's designs, probably about one-fifth would be added to the original

<sup>1</sup> Vide "The Engineer's Journal," vol. iv., pp. 132 and 186. Calcutta, 1861.

area ; the water covering the whole of the space to the eastward of the Napier Mole would be brought through the harbour, instead of escaping, as it now did, through Chinnee Creek. Mr. Parkes thought these few particulars might be interesting in connection with the sea terminus of the Scinde Railway, now under discussion, but he objected to having imported into it any abstract questions of the principles of harbour engineering, as applied to this particular case, to which the subject of the Paper was entirely foreign.

Mr. BROOKS observed, that he had not only offered an opinion, but he had also given the reasons upon which that opinion was based. Mr. Brooks desired to reply to the remarks relative to Kurrachee Harbour, but it was intimated that it was advisable to restrict the discussion to the Scinde Railway, which was the main subject of the paper.

Mr. G. P. BIDDER, Past-President, said, his observations upon the engineering questions would be confined to a few points. With respect to the plan adopted for the passage of the flood water over the Scinde Railway, he quite concurred in the views of the Author, which he believed to be practically and commercially right. It was easy to say, that it would have been more perfect to have constructed archways for the passage of the flood water, but the question was, at what cost could it have been done, and at present, there was no information, there were no facts, upon which to determine the extent of archway required. The only fact before the Meeting was, that the floods to be provided for were exceptional and local ; the Engineer would thus be in the dilemma, either of having to construct an amount of archway altogether unnecessary, or such an amount as would be insufficient, and the effect of the inundation would be occasionally to stop the railway. He believed the smallest estimate of the cost for the provision of such an extent of archway as would be required, was about £70,000 ; and this enormous expense would be incurred merely to obviate the chance of two, or three stoppages of the line, in the course of eight, or ten years. He thought, that on such a railway as the one under discussion, it was better to save the outlay of £70,000, and put up with the occasional stoppage of the line. Perfection might be obtained at too high a cost. As to sleepers, that was still a question to be solved for India. He had recommended cast-iron sleepers, on account of their success in other places. The Company were in a difficulty : the Contractors had failed to supply the wooden sleepers, and the employment of cast-iron sleepers was the only remedy that presented itself. Whether they would prove the best, or whether any other form of sleeper would be better, had still to be ascertained.

Mr. Brooks had raised an important and interesting question. Looking, on the one hand at the vast extent of India, and its prodigious population, and on the other, at the very few effective

ports, and comparing it with Great Britain, with only a fifth of the population, but with ports on every part of the coast, the importance of the question was at once evident; in fact, he believed that no outlay, however large, would be misapplied which would tend towards perfecting the ports of India. Mr. Brooks had correctly stated, that the only two good ports were Bombay and Kurrachee; Madras was no port at all, and Calcutta was as bad as it could be; yet those were, at present, the only outlets for the vast trade of India.

The question to which he wished to direct attention was far more important than that of the engineering, or of the ports. It was as to the mode in which Indian railways were, in future, to be carried out and worked, and he believed that on that question would depend the future extension and success of railways in India. There was one great satisfaction in looking at the map of India, that the lines at present executed and in progress were in the right direction. The lines from Calcutta and Kurrachee, meeting at Delhi, with their eventual connection at Bombay, must be the permanent backbone of the railway system in that country; and if that system were completed, and if nothing more remained to be done, it would be unnecessary for him now to advert to the peculiar conditions which attached to the construction of Indian railways, and the difficulties under which they had been carried out. When the railways in India were projected, three financial systems were open for consideration. First, their being carried out by private enterprise; that broke down at once, because the capitalists of England were disinclined to take them up on their own account. Secondly, the method of subvention, which never was, he believed, seriously entertained. Thirdly, there was the system of guarantee, which had been ultimately adopted. Before further adverting to that system, he would remark, with a view to prevent misconstruction of what he was about to say, that he had no strictures to make upon the mode in which it had been administered, whatever imperfections might attach to the system itself. That it had been carried out with any degree of success was, he believed, greatly owing to the endeavours of all parties to make it work. Every one had gone, more or less, beyond strict routine, otherwise the railway system in India must long ago have collapsed. At present the railways in India were entirely carried out on a system, by which the Government guaranteed a certain rate of interest upon the outlay. The result was that the Government was liable for the interest on all the outlay, so that, in fact, they had to look to the receipts of the railways for the repayment of the liabilities thus incurred. The Government, therefore, felt it necessary to overlook the whole of this outlay, and for that purpose there was established a system of supervision, permeating into the greatest minutiae. The consequence

was, that all individual energy and all independent activity were restrained ; and, as he said before, unless the authorities, particularly the official directors, so far as his experience went, had applied themselves very much to the oiling of the machinery, he thought it must very soon have stopped altogether. He trusted, therefore, that his remarks would be taken as applied to the system, and not to individuals, or to bodies of individuals, for he was bound to say that India was a field which brought out, in every respect, and in a most peculiar manner, the energies of the Anglo-Saxon race.

The whole political system of England, from the beginning of the establishment of her rule in India to the present time, had been, theoretically, the worst possible ; and that glorious empire had been established by the individual energy of those who represented this country in India. This remark applied peculiarly to those who had been connected with the railways of India. The amount of work which the Directors, particularly the Chairmen, had gone through, was prodigious ; the amount of correspondence was marvellous, and that they should have had the patience to drag through it, was, he was bound to say, perfectly astonishing. The question arose, whether it was desirable that the system should be changed, and whether so much yet remained to be done in India as to make it desirable that the reconsideration of the system of making and working railways in India should be seriously entertained. With regard to the extension of railways in India, the backbone of the system was still far from being completed ; the line from Umritsir to Delhi, a length of 300 miles, remained yet to be accomplished. If the Indus had been a deep, quiet canal, the carrying of the railway system along that valley might for some years have been postponed ; but the Indus was perhaps the worst specimen of inland navigation that could be conceived, and, as the Author had stated, the channels of navigation were 570 miles in length, as against 470 miles of direct route. Mr. Bidder had very carefully considered the question of the Indus Flotilla, and he was every day more satisfied, that the necessity of occupying the valley of the Indus with a railway was becoming more urgent. Even in regard, therefore, to that backbone, there were about a thousand miles of railway yet to be constructed. The question then arose as to the best mode in which it could be carried out, and the best system of working it, when completed.

He had already stated that the Government of India was liable for a given rate of interest upon the whole outlay for the railways ; there was, therefore, a distinct interest in the receipts, and the same minute supervision was exercised in the working as in the construction of the lines. Before any comparatively unimportant step could be taken in the Punjaub, sanction had to be obtained from the Lieutenant-Governor of the Province, which he could not

grant without reference to the Governor-General of India; and, in a similar way, the Commissioner of Scinde was powerless without the sanction of the Governor of Bombay. Then again requisitions for manufactured railway material and for workmen, sanctioned by the officials he had referred to, had to be reviewed, commented upon, and indorsed by the Secretary of State for India in Council in London, before the most urgent want could be supplied. As regarded the construction, he was satisfied that the necessary restrictions which the system imposed caused a waste of time to the extent of 25 per cent., and at least an equal waste of money. But in the working the results would, he believed, be far more serious. How was it possible to work a railway efficiently, economically, and energetically, to develop the traffic, and adequately to meet the ever-varying demands of the public for accommodation, when a new foreman could not be appointed, nor his salary be fixed, without the manager undertaking a large amount of correspondence, involving duplicates and references to perhaps two or more jurisdictions, and a necessary delay of months. Take such a case as the London and North-Western Railway, and he asked could such a system be worked at all, if a correspondence begun in England had to be concluded in Calcutta, and passed through the Government Departments, before practical effect could be given to it. These departments, he fully admitted, were most anxious to do what was right and proper,—desirous even to go out of their way to give facilities; but still that channel must be gone through, and the result of such a system, whatever its effects might be upon the original construction, would be felt, in his opinion, much more seriously afterwards in the management and in the traffic arrangements.

To return to what he considered the system ought to be, and on which he spoke with some decision, from the experience he had had of its satisfactory working in another quarter. First, with regard to the construction of the railways, he thought that the Government should receive tenders from companies of capitalists for the completion and equipment of a line of railway, for example, between two given points, for a definite sum of money, and stating the amount of subvention they required from the Government, to be paid in cash, or by an equivalent. The character of the line as regarded materials, workmanship, and accommodation, being defined, the maximum rates of fares, the regulations connected with the public service, such as conveyance of troops, &c., being fixed, the total capital, the amount of subvention, and the approval of the railway by the Government on the completion of the same, being provided and stipulated for, the construction and the working should be left entirely to the management of the Company, who should take, as a first charge upon the net revenue, interest upon their portion of the capital up to an agreed amount, say 5 per

cent., and the surplus revenue afterwards to be divided in agreed proportions between them and the Government. By so doing, all the energy of independent management would be brought to bear, and that management would work with the same responsibility and limitation as in this country. He believed that, upon that system alone, the full advantages of railway communication in India, or in any other country, would be realised.

He would, for the sake of illustration, assume a case, that of a railway up the Indus Valley, 500 miles in length, and that the reasonable cost, including equipment, was £10,000 per mile, or that a capital of £5,000,000 would be required. Of this he would suppose the Government to furnish £5,000 per mile, or two and a half millions of capital, either in cash, or by an equivalent guarantee; and as the Company would have to find the balance, and to satisfy the Government that the bargain had been efficiently carried out, there would be every possible responsibility thrown upon the executive, that all the money would be economically and judiciously applied. Then the working, subject to conditions with the Government similar to those he had indicated, should be conducted entirely by the Company, who should rely upon the receipts of the railway alone for a per-centage upon their capital up to, say, 5 per cent.; and after that, the net receipts should be divided, say two-thirds to the Government and one-third to the Company, as an inducement to the latter still farther to develop the traffic, and to work economically. This arrangement of course implied a proper audit of accounts for the satisfaction of the Government. He believed that it would be to the advantage of Government to apply this system of working to railways already opened for traffic, and to those now under construction; for instance, the lines from Kurrachee to Delhi, a length of from 600 to 700 miles, exclusive of the Indus Valley. For the privilege of working these lines, Government might receive, by tender, a contribution from a Company of say three or three and a half millions sterling, which would be more than adequate for the subvention of the Indus Valley line, which if carried out would complete a system of 1,100 miles, or thereabouts, from Kurrachee to Delhi, with a preferential capital of about five and a half millions sterling, with a preferential interest of 5 per cent., and a further contingent advantage from surplus net receipts. He was certain that the Government would get more profit under that system than under the present one, of taking the whole of the profits to meet the liabilities they had incurred, and they would have that contribution to apply to the extensions which might be made to this great backbone of railways throughout India; because though it was a poor country, mile for mile, yet when it was considered that there was one mile of railway in England for every 3,000 inhabitants, as against one mile of railway in India for every 50,000 inhabitants, it

would at once be seen that, in India, the necessity for branches and extensions would grow in importance every year.

Looking to the rapid rate of increase of the trade of India, exhibited by the growth of the traffic on the Scinde Railway, in the face of the greatest possible hindrances to the transit of goods from the interior, he had the strongest possible conviction, that the application of individual skill and energy would realise a fair return upon all the capital which might be contributed, either by Government or by private capitalists, and concurrently, incalculable advantages would result to the trade of India generally.

He did not think that it was necessary to enlarge his observations on this subject. He had pointed out what occurred to him as the rational system to adopt, a system which, he believed, might be made to work very practically. It was the system on which the Norwegian Trunk Railway was carried out. Parties in England contributed one-half the capital, and the Government the other half. The English contractors took 5 per cent. preference, and the Norwegian Government took 4 per cent., and the surplus was equally divided. That system had been carried out without any difficulty, or contention whatever. He did not mean to say that those exact terms would apply to India; but a system which admitted of independent energy, and obviated the necessity of state interference in construction, and a restriction in all the arrangements by which alone railways could be effectually carried out, would, in his opinion, be found advantageous to that great empire, and economical to the Government.

Mr. J. BRUNTON, in reply, said an objection had been made, that the Paper did not contain a list of the prices of labour. Now it was expressly stated, that he abolished the day-work system almost entirely, and established a system of piece-work, because he was convinced that it was the only means by which he could get the work done at the lowest possible price. Had he given a list of the daily wages paid to the labourers, it would have led to erroneous conclusions, because some were paid 4 annas, and others 5 annas or 6 annas per day, and at those wages they did little, or no work. He did not think the prices of day-labour furnished so good a criterion as the price at which, for instance, a cubic yard of earthwork was excavated and carried a certain distance; it was the same with regard to masonry. With respect to the observations about the magistrates fixing the prices of labour, that was a misapprehension. The magistrates were only called upon to fix the prices at which the provision dealers should sell their flour and other articles for the consumption of the labourers on the works; they did not interfere in any way with the prices of labour. As to the amount of £3 per month paid to the apprentices for the first year, he had a great deal of correspondence in India upon that very subject, before those prices were fixed. He

maintained it was absolutely necessary for the European boy in India, particularly if separated from his parents, or taken away from his guardians, that he should receive a pay that would enable him to keep himself independent of and superior to the natives. The amount of £3 per month would not, in India, be considered a high rate of pay to keep a youth of 15 or 16 years of age in a respectable position; and it was only respectable lads of good character that were admitted as apprentices in the Company's workshops. He was not surprised that £16,000 per mile should have been considered a high rate of cost. It would be so, undoubtedly, for a line of railway running through a very flat country, which was the character of the districts through which most of the lines of railway in India were carried; but a glance at the section of the line between Kurrachee and Kotree would convince any Engineer that it was not an easy one. There was a considerable amount of earthwork upon it; and the earthworks were not of the soft character usually found in alluvial plains. The majority of the excavations were through hard rock, requiring gunpowder; many of the embankments were formed from side cuttings in rock, as no softer material could be obtained, and the embankments were built up with the stone so quarried from the side cuttings. That, coupled with the fact that the line crossed the natural drainage of an extensive hilly district, and required large viaducts and many culverts and bridges, would account for the increased cost per mile. But, as the Chairman of the Company had remarked, the Scinde Railway might be considered as rather exceptional, because, for a short length, it had two expensive termini, and there had been a heavy charge upon the capital of the Company for wharves and other works for the accommodation of the flotilla at Kotree, where from 3,000 feet to 4,000 feet of wharves had been constructed.

Since the reading of the Paper, he had received a communication from General Goodwyn, of the Bengal Engineers, with regard to the Burnettising process of saturating sleepers with chloride of zinc. That gentleman had paid great attention to the subject in India, and had made the following report to the Government:—

“I have the honour to report, for the information of the Board, that I have this morning been engaged in the examination of the timbers, bamboos, and other articles that were subjected by me, in 1846, to immersion in chloride of zinc; the following is the result:—

“II. The hair and woollen articles from the arsenal appear to have been uninfluenced by the solution, and have rotted, whilst some portions of canvas have been attacked by white ants, though slightly. The greater part of the canvas is sound and untouched; the twine and small rope are sound and good; whilst all wooden articles have been entirely preserved—such as the handles of brushes, sieve rims, and fuseses.

“III. The whole of the sāl timbers of various scantlings are quite sound, free from rot, or white ant; whilst one piece that has been buried in a fungus pit five years is as sound as on the day it was put in. The bamboos, a perishable material, are sound and strong in every way.

"IV. These timbers had been indiscriminately piled up in an open shed, where white ants abound, and exposed to alternate heat and moisture, where other timber has been destroyed in less time.

"V. The deal Memel, and even oak timbers, that were received from England in the same year, saturated by Mr. ———'s process, have all been attacked by white ants, some completely eaten. They were stacked in the same way, and in a similar shed.

"VI. The solution that my timbers were soaked in was chloride of zinc; the process patented by Sir William Burnett. It was the refuse liquid from the galvanic batteries in use at the Mint for refining of silver.

"VII. Major Baker and Mr. Turnbull, the senior Engineer of the Railway Department, were with me, (in fact, it was to show them that I scrutinised the whole,) and they were satisfied of the efficacy of the process. I consider this to be so satisfactory, as to be worthy of communication to Government.

"I have, &c.

"(Signed)

H. GOODWYN.

"Fort William,  
"27th September, 1852."

General Goodwyn further stated, in a letter received that day, that since the above report was written he had been confirmed in the opinions he had expressed. This was of great importance; for if the native timber could be preserved by so simple a process as that of immersion in chloride of zinc, more of the woods of India could be used in future for sleepers. Mr. Brunton's experience did not extend over a sufficient time to enable him to form a conclusive judgment upon its preservative qualities; but he had applied it on his own line to sleepers, and to cills and door-frames, and hitherto the timber so prepared had not been attacked by white ants.

With regard to the water-way, and the novel mode he had adopted of lowering the line of railway from the low embankment on to the surface of the country, and laying the rails flush with the surface, he observed that he had done this almost from necessity; for the only alternative was the very expensive one of constructing a continuous series of culverts over the whole distance. Then it was to be remarked, that the rains in Scinde were different from the rains in other parts of India; Scinde, in that respect, must not be judged by the lower parts of Bengal, or Bombay. In Scinde the average fall of rain was about 5 inches, which was very small; but it fell heavily, and in a short period, seldom extending over more than three days, for four, or five hours each day. Though the water passed slowly over the line, the traffic need not be stopped; and, in fact, it was not stopped during the last rainy season, although the water was 9 inches deep over the rails; after the water had passed away, which it did in the course of a few hours, the railway remained in as perfect condition as before. In cases of this kind, only good broken stone ballast should be used.

April 21, 1863.

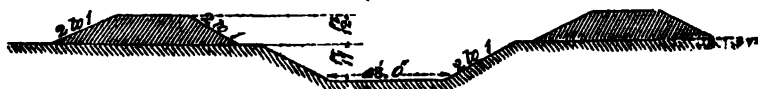
JOHN HAWKSHAW, President,  
in the Chair.

No. 1,092.—“Account of the Cofferdam, the Syphons, and other works, constructed in consequence of the failure of the St. Germain's Sluice of the Middle Level Drainage.” By JOHN HAWKSHAW, F.R.S., President Inst. C.E.

AT one of the meetings of the Institution last year, the Author was requested to give some account of the works proposed to be constructed, consequent upon the failure of the Outfall or St. Germain's Sluice, of the Middle Level Drainage. The disaster having then so recently occurred, the Author, for obvious reasons, refrained from complying with that request; but he stated that at some subsequent time, he would bring the subject before the Institution, in a Paper descriptive of the works. This he proposes now to do.

The original St. Germain's Sluice was situated at the confluence of the Middle Level main outfall drain with the River Ouse, near the upper end of the Eau Brink Cut. This drain was made in 1847, from the designs and under the direction of Messrs. Walker, Burges, and Cooper; but it was not until 1857, that it was deepened to the full extent originally contemplated by them. The success of that work, in improving the drainage of the Middle Level was, as is well known, most satisfactory. The drain, as thus deepened in 1857, has at its lower end a bottom width of 48 feet, the side slopes being 2 to 1. The level of the bottom is 7 feet under low water of spring tides in the River Ouse, at the point where the drain enters that river. The rise of the tide in the Ouse at that point is about 19 feet at spring tides, and the level of the cill of the St. Germain's Sluice is 6 feet below low water of spring tides. The section of the drain near its lower

Fig. 1.



Section of Middle Level Drain near its lower end.

end is shown in Fig. 1. The bed of the drain is there of soft  
[1862-63. N.S.] 2 K

blue clay, and the sides, from the bottom of the drain to the surface of the ground, consist of variable thicknesses of soft blue clay, peat, yellow clay, and surface-soil. Of these materials the side banks above the level of the ground are composed.

On the 4th of May, 1862, the St. Germain's Sluice gave way, thereby admitting the tidal waters from the River Ouse into the drain, which rushed up, and again poured out of the drain with great velocity, and throughout a distance of upwards of 20 miles they ebbed and flowed. This state of things lasted for a few days, during which time much attention was devoted to the banks, and several minor breaches were successfully stopped; but at length the western bank of the Middle Level Drain burst, at a point about 4 miles from the St. Germain's Sluice, inundating upwards of 9 square miles, or about 6,000 acres of land. (Plate 14.)

Immediately on the failure of the sluice the late Mr. Walker, (Past-President Inst. C.E.) was consulted by the Middle Level Drainage Commissioners; but as that gentleman was unable, from advanced age and failing health, to undertake the operations that were urgently needed, he advised the Commissioners to request the Author to act in the matter; and full instructions were given to do whatever was considered necessary to shut out the tidal waters, regardless of expense. In order to expedite the organisation of a staff of men, and to obtain immediate possession of the plant and materials necessary for carrying on the operations, the Author secured the services of Mr. J. T. Leather (Assoc. Inst. C.E.) as contractor. That gentleman was fitted, from his extensive experience, to carry out the Author's plans, which he did with much vigour and judgment. In this he was ably aided by his assistant, Mr. E. P. Smith. Mr. Alexander G. Linn, (Assoc. Inst. C.E.) was, at the Author's request, appointed Resident Engineer, a position he was well qualified, from his previous career and experience, to undertake, and the duties of which he performed in a highly creditable manner.

Previous to the Author's assuming the direction of the works, and directly after the failure of the sluice, an earthwork dam was commenced, which was attempted to be thrown across the drain at a spot about 500 yards from the fallen sluice. This dam was not immediately relinquished, but its construction was pursued by sinking horizontal cradles of fascines weighted with clunch (a hard chalk stone, procured in Suffolk and Cambridgeshire), and by the use of bags filled with clay, the Author not wishing to abandon an experiment, which he did not originate, without having fairly tried it. It is clear, moreover, that if the dam had been carried up even to a moderate height, which was the utmost the Author ever expected, or desired to accomplish, it would have had the effect of shutting out a certain quantity of tidal

water, which would to that extent have relieved the banks of the drain, and have assisted the construction of the permanent cofferdam. On the other hand, by continuing this dam, the introduction of successive layers would pen up an increased quantity of water in the drain; and the more it was raised, the greater would be the scour from the water flowing over it at ebb tide, which scour was considerable when the dam was only raised a few feet. Numerous barges also were required in its construction, any one of which would, if it had broken loose when the tide was running up the drain, have ruined the permanent cofferdam. Great caution was therefore necessary in pursuing its construction; and not long after the permanent cofferdam was commenced, the Author determined to relinquish altogether proceeding with the earthwork and cradle dam, tidal observations having shown that it was unnecessary, when the construction of the permanent cofferdam had advanced to a certain stage. There is no doubt, that the system of raising such a dam by cradles of fascines might be introduced with advantage, in many situations, and under certain circumstances. The Author intrusted the superintendence of sinking the cradles to Mr. Müller, who had considerable experience in raising banks in this manner, and who described the process in a Paper read before the Institution during the last session.<sup>1</sup>

#### COFFERDAM.

Immediately on receiving instructions from the Commissioners to do whatever might be considered necessary to shut out the tidal waters, the Author determined to construct a permanent cofferdam of pile-work across the drain, as the only plan that was likely effectually to answer the desired end. His original intention was to use the road-bridge spanning the drain about 1,000 yards from the fallen sluice, as a staging from which to drive the piles; but the work was scarcely commenced before the bridge, which was a timber structure, was destroyed by a barge breaking loose and running against it. The site finally fixed upon was about 120 yards to the north of the bridge, and that distance nearer the fallen sluice. Figs. 1, 2, 3, and 4, Plate 15, show the dam as constructed.

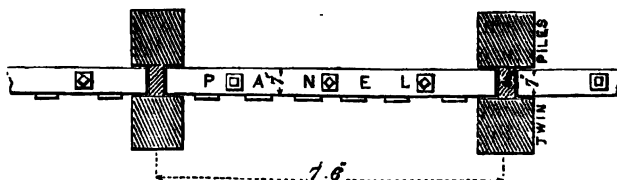
It will be desirable, however, before proceeding to describe the dam, to give some particulars relative to the levels of the water in the River Ouse and in the drain. The level of high water of spring tides in the river is, as before mentioned, about 19 feet above low water, but it was not more than 9 feet in the inundated fen, where, owing to the large area of the inundation, the rise and fall of the tide did not exceed 6 inches. The only in-

<sup>1</sup> *Vide Minutes of Proceedings Inst. C.E.*, vol. xxi., p. 466.

erval of repose, therefore, was when the water in the Ouse was at the level of the water in the fen. Fig. 5, Plate 15, is a diagram explanatory of the tidal action. This interval of repose was of very short duration. A few minutes scarcely elapsed before an inward or outward current (according to the state of the tide in the Ouse) became perceptible, which current rapidly increased in intensity. The velocity of the tide up the drain, and again out of the drain, amounted to about 6 miles per hour at spring tides, and 4 miles per hour at neap tides. The depth of water in the drain below low water spring tides was 7 feet; but the bottom of the drain, in the neighbourhood of the dam, having been scoured away about 2 feet, the depth there, at slack water, was about  $17\frac{1}{2}$  feet. The material composing the drain and the banks being of so soft a nature, and the velocity of the current being so great, it was clear that much caution would have to be exercised, throughout any operations that might have to be undertaken, to guard as much as possible against the effects of the scour.

The cofferdam, which was commenced on the 16th May, may be thus described :—Temporary piles were screwed into the ground in the first instance, and a platform was erected thereon, to form a staging for the pile-driving engines. When this was done, the permanent pile-work was commenced, by driving two rows of sheet-piling, 25 feet apart, transversely down the slope of the drain on each side. This sheet-piling extended from the centres of the banks to within about 20 feet of the bottom of the drain, leaving a space of 20 feet on each slope and of 48 feet (the bottom horizontal width of the drain), together equal to a central space of 88 feet of cofferdam to be completed. This portion of the dam was thus constructed (Fig. 2.) :—Piles of whole

Fig. 2.



Plan showing the Construction of the Central part of the Cofferdam.

timbers were driven on each side, so that when in place they would be in pairs, 7 feet 6 inches apart, from centre to centre. The piles in each pair were placed back to back, a space being left between them of 7 inches, this distance being preserved by a central piece 7 inches by 3 inches. These piles were driven separately, one of the piles, with the distance-piece attached, being first driven, and afterwards the second pile. The grooves thus left

were for the reception of sliding panels, to be used in order to fill up the spaces between these several twin piles. These piles could only be pitched during the few minutes of slack water. Waling pieces of whole timbers were fixed to the inside and the outside, both at the top, and also as near to the low water level as possible. As the piles were driven, proper struts and ties were inserted to stiffen and strengthen the dam, and strongly framed raking struts were fixed, abutting against the dam and against abutments, composed of piles backed with concrete, on the land. The struts, ties, and raking struts will be clearly understood by reference to the drawings of the dam. (Plate 15, Figs. 1, 2, 3, and 4.) The panels are composed of a series of timbers (7 inches thick, and of the length necessary to enable them to slide into the grooves), fastened together by bolts  $1\frac{1}{4}$  inch diameter, and further strengthened and weighted by flat wrought-iron plates on one side, each plate being 6 inches wide by 1 inch thick. In order to put these panels in place, a frame (Plate 15, Figs. 1, 3, and 4) was erected, from which they were suspended, and from which they could be lowered, and raised again if necessary, by pulleys.

The rush of water through the dam, which was considerable before the piles for the panels and the walings were erected, was materially increased when they were in place,—so much so, that there was at times a difference of level of 4 feet, or 5 feet between the water on the two sides of the dam. Already the precaution had been taken of throwing in sacks of clay, with gravel, puddle, and stone (kept in place by footings of clunch) on the upper and lower sides, forming aprons extending the whole width of the drain, and for some distance up the slopes. It now became of the utmost importance carefully to watch these aprons, and also the centre of the dam between the two rows of piles, where, from the necessity which existed of depositing in that space nothing but material impervious to water, there was an increased difficulty in maintaining the bottom from being scoured away. In order to ascertain the state of the aprons and of the centre of the dam, soundings were made, and, for the purpose of throwing in materials, stages were erected. The drain throughout had also to be carefully watched, as the soundings revealed the existence of large holes in the bottom, as well as of considerable scour. In one place the drain had been scoured to a depth of 15 feet from its original bed, maintaining this depth for a length of not less than  $\frac{1}{4}$  mile; and at other places it was discovered that the cast-iron culverts, some of which were of large size, passing originally several feet under the bottom of the drain, had been laid bare. Only a limited quantity of stone was thrown into the centre of the dam, lest it should prevent the clay being afterwards made perfectly water-tight,

and should increase the difficulty of driving the piles that yet remained to be put in place, at the back of the panels on the lower side. Great quantities of puddle, however, were cast into the dam at slack water; but most of this was washed away by the rush of water through it, which acquired a velocity of 8 to 9 miles an hour; and it was only with the utmost difficulty, and by incessantly persevering with this operation, that the level of the bottom of the inside of the dam could be maintained at the same level as the bottom of the drain; all attempts to accumulate material within the dam above that level proving ineffectual. At this period it became very difficult to maintain the aprons on the outside, and with the utmost exertion they could only be raised about a foot above the bottom of the drain at their junction with the dam, and for some length from it, gradually increasing in height from this latter point to the end of the apron, where the footings of clunch were made.

The panels in the first, or lower tier were each 7 feet deep. They were pointed at the lower end, so that they could be driven down some depth into the mud; and when all those of the first set were driven, another set was put in. These latter were of variable depths, inasmuch as the first series could not all be driven to the same level, and the lengths of the second set were so arranged as to raise the panelling uniformly to the level of about low water of spring tides. Whilst the panels were being driven, and after they were down, the operation of throwing in sacks of clay and gravel, both on the inside and the outside of the dam, was persevered in; and although the aprons on the upper and on the lower sides were by this means extended, and raised to the height of the panels, nothing remained in the inside of the dam excepting a few sacks of gravel, which were thrown in close to the panels to prevent any 'blowing' from taking place.

It now became clear, that the only practicable mode of excluding the water was to shut in the remainder of the dam at one operation, and to rely on its strength for resisting the pressure that would come upon it, before it could be finally completed. As before observed, it had been previously well strutted both on the inside and on the outside. It was necessary to do this at still water, when there would be a small differential head for the dam to sustain; and, in order to accomplish the object, the panelling, which was required to be 12 feet deep, was suspended from the scaffolding (Plate 15, Fig. 3) on each side of the dam, so as to be dropped into place at slack water.

The first attempt to close the dam, made on the 10th June, 1862, resulted in failure, from the fracture of three of the twin piles (marked X, Plate 15, Fig. 4) on the lower side of the dam, owing probably to their having been injured in driving, and in giving way

they released some of the bottom panels. These failed after the tide had receded 3 inches, and when there was a head of 8 feet of water. The other panels were readily lifted up and removed; but a delay was occasioned, as the damage had to be made good, which was done by driving sheet-piling (marked Z, Plate 15, Fig. 4) up to the level of the lower waling, thereby filling in the spaces between and adjoining the broken piles. The tendency of this was, of course, still further to contract the waterway; but it was considered the most desirable course to adopt, as, upon a diver being sent down, it was found that the ground had been much disturbed, by the tearing out of the panels between the broken piles. The second attempt was therefore postponed until the succeeding neap tides; but in addition to the work that had to be performed, the interval was taken advantage of to meet and provide against every contingency that might arise. The first attempt was made at still water of flood tide, as the dam would have to sustain a somewhat smaller differential head at high water than at low water, and by the time the tide had ebbed to its lowest point, the dam would have been filled in to a considerable extent. The second attempt (made on the 19th June) proved a complete success. The panels were again slung ready to be dropped at slack water, but this time the operation was attempted at low water of ebb tide as being more convenient, the difference of the head at high water and at low water not being considered of sufficient importance to counterbalance other advantages. The process of lowering the panels lasted about twenty minutes, and immediately this was effected, the inside was filled with clay, and with sacks of gravel, clunch being thrown into the centre. The aprons on the upper and the lower sides were at the same time raised and extended. About 3,000 yards of clay with several hundred sacks of gravel and clunch were prepared for the operation, and 800 men were in readiness to put these materials in place, from several barrow-roads and waggon-roads; and so perfect were the arrangements, that the raising of the dam inside was kept in advance of the rise of the tide, and before high water the operation was completed. The contrast between the rush of water before, and the calm after, the operation, was remarkable. The tide rose quietly, and the dam, as thus far constructed, did not exhibit the slightest indication of failure, or weakness.

After these panels were placed, sheet-piling was driven behind them on the lower side of the dam, thereby filling in all the spaces between the twin piles, and converting the lower side into one continuous row of sheet-piling, and the dam was further completed without any trouble, or anxiety. In addition to the piles before referred to, extra piles were driven at the sides of some of the twin piles, where it was imagined the panels might not have a sufficient

hold. With these exceptions, and one, or two minor alterations, which suggested themselves as the work progressed, the dam was constructed in every respect in the manner, in the order, and to the extent, originally intended by the Author. The cofferdam was commenced on the 16th May, and the tidal waters were shut out on the 19th June, 1862. Appendix A (page 509) contains the quantities of the several kinds of material used in the construction of the cofferdam and in the syphons.

#### SYPHONS.

During the time the cofferdam was being constructed, serious attention was given to the means to be adopted for the future drainage of the Middle Level. After a careful consideration of this question, the Author came to the conclusion that, in addition to such drainage as could be obtained through Salter's Lode Sluice, the old outlet into the Ouse, — the drain leading to which had to be widened, cleared out, and re-opened by the removal of a bank existing across it, — syphon pipes should be laid over the cofferdam, and that nothing should be done as to the erection of a new sluice, until these latter had been fairly tried. The Author had occasion, in 1839, to enlarge the capacity of the reservoir for supplying the Manchester, Bolton, and Bury Canal with water, which was effected by increasing the height of the reservoir embankment. The old outlet, which passed under the embankment, being of insufficient capacity, he adopted a syphon passing over it, for an additional outlet; so that the experiment of discharging water by the action of the syphon was not to him a novel one. It must here be mentioned that, immediately after the cofferdam was closed, feeling it would be impossible to continue to devote as much time to the works as he had hitherto done, the Commissioners, at the Author's request, associated with him Mr. Thomas E. Harrison, (M. Inst. C.E.) who has since continued to act with him.

The syphons are shown in Plate 16. They differ in no respect from the original design and intention of the Author, excepting in the arrangement of the valves. In the first design, a single valve was placed in a box at the top of the syphon, and in the design as executed, a valve was placed at each end, for reasons which will presently appear. The number of syphons at present erected is sixteen. These are laid across the dam at an inclination of 2 to 1 on either side, and horizontally over the top; each end being terminated by a horizontal length containing the upper and the lower valves. The upper surface of these bottom horizontal lengths is laid at a level of 1 foot 6 inches under low water of spring tides, — so that the ends of the syphons are always under water, — and the top of the syphon is 20 feet above the same level.

The total length of each syphon is about 150 feet. The syphons are of cast iron, 3 feet 6 inches internal diameter, put together in lengths (exclusive of the irregular pieces) of 12 feet, and have spigot and socket ends and lead joints. Four bosses, or lugs are cast on the ends of the several lengths, for the purpose of bolting them together with  $1\frac{1}{2}$ -inch bolts. The thickness of the metal in the syphons (excepting at the socket ends, where it is thicker) is  $1\frac{1}{8}$  inch. The syphons rest on the top of the dam and on inclined framework, supported on piles on either side. The piles, which are 14 inches square, are driven so as to be underneath each of the joints of the pipes composing the syphons. These piles are connected together by a horizontal transverse cill, and each syphon rests on whole timbers 1 foot 9 inches apart in the clear, and bolted to the cill. Underneath the extreme ends of the syphons, a row of sheet-piling of whole timbers is driven across the drain, the sheet-piling being properly hollowed out to receive and support the terminal lengths.

The space occupied by the inclined framework between this sheet-piling on each side and the dam, is filled in above the apron that was formed to resist the scour, and up to the underside of the syphons, with clunch, clay, and gravel, thus forming a solid and impervious embankment. The bottom of the dam, at the inlet and outlet of the syphons, is protected by substantial permanent aprons extending across the drain. These aprons are shown in Plate 16, Figs. 1 and 2. The lower parts of the syphons and the aprons were laid by means of dams, consisting of close sheet-piling surmounted by slackers, or sluices. These dams were about 90 feet long, and were thrown across the drain 30 feet from the ends of the syphons. From near their extremities, two parallel rows of sheet-piling, (Plate 16, Figs. 1 and 2,) were driven towards the dam, to within 25 feet of it on the lower side and 35 feet on the upper side. The lower apron extends from the sheet-piling at the termination of the syphons to the sheet-piling of the half-tide dam, and is 30 feet long. It consists, for the first 20 feet of its length nearer the syphons, of piles, 5 feet apart, driven into the ground, and surmounted by cills. The ground, from the top of the cills, is excavated to a depth of 2 feet 6 inches, and the space is filled in with concrete, to the underside of a layer of close planking 4 inches thick, which is spiked to the cills. The remaining 10 feet of this apron, to the sheet-piling of the half-tide dam, is of concrete 2 feet 6 inches deep. The sheet piling of the lower half-tide dam was cut off at the top of the concrete, so as to protect the ends of the aprons from injury and scour. The upper apron is 10 feet long, and consists of piles 5 feet apart, driven into the ground, and surmounted by cills to which close planking,

4 inches thick, is spiked; the toe of this apron being pitched, (Plate 16, Figs. 1 and 2).

Both at the inlet and the outlet of the syphons, a row of sheet piles is driven on each side, inclining towards each other, and contracting the channel to a width of 60 feet. This is for the purpose of keeping the 'wash' off the slopes of the drain.

The upper, or inlet valve (Plate 16, Figs. 4, 5, and 6) consists simply of a flap of teak wood working inwards, and the lower valve (Plate 16, Figs. 7 and 8) is of cast iron, working outwards, and is fitted with a balance-weight. The syphons are put into action by exhausting the air from the inside, by means of an air-pump worked by a steam-engine. This is placed on the western side of the drain, and near to the dam. A horizontal flanged pipe, 10 inches diameter, runs transversely across the dam, over its centre, at a height of 6 feet from the top of the syphons; and vertical pipes, provided with slide cocks, connect each syphon with this horizontal pipe, and with the air-pump. By means of the slide cocks, each syphon can be shut off at pleasure, or be brought into operation when required. Some of the syphons are provided with glass gauges attached to the centre of the sides, and to the vertical pipes at a point above the slide cocks. It can thus be seen when the syphons are full of water. Three brass taps,  $1\frac{1}{4}$  inch diameter, are fitted into the horizontal flanged pipe at the extreme end, for the purpose of admitting air when required, and thus readily stopping, or regulating the working of the syphons. The air-pump has three cylinders, worked together by a three-throw cranked shaft. Each cylinder is 15 inches diameter, and the length of the stroke is 18 inches. The engine is of 10-horse power, and high pressure; the diameter of the cylinder being 12 inches, and the length of the stroke 20 inches. The syphons were cast by Messrs. Cochrane and Co., of Woodside Ironworks, near Dudley; and the steam-engine and air-pump were manufactured by Messrs. Easton, Amos, and Sons, of Southwark.

The reason for adopting two valves in the syphons instead of one, as the Author originally intended, was for the purpose of enabling them to be put into operation, either by exhausting the air, or by filling them with water should there be any necessity for it. The inlet valve, being a loose hanging flap of wood, opens inwards as soon as the outward is the preponderating pressure. The outlet valve turns on a hinge at the top, and is balanced; it is rendered capable of resisting an interior pressure, by means of a bridle which holds it fast, but which can readily be released, when the valve is converted into a flap opening outwards. In filling the syphons with water, the same machinery would be employed as is used for exhausting the air, and the water would be pumped up into a reservoir, where it would be in store, ready to be turned

into the syphons when needed. For the purpose of controlling the operations connected with the raising and lowering of the outlet valves, a chain is attached to each, worked by a small crab, placed on the top of the dam. At present, the only method that has been tried to work the syphons has been to exhaust the air. The inlet and outlet valves are so arranged, that they can readily be drawn out should it be necessary.

On the lower side the syphons, up to the level of high water neap tides, are protected by a rubble deposit of clunch, extending from the centre to 15 inches above the top of the syphons; the surface of the clunch is pitched with Wansford rubble, 9 inches deep, the pitching being continued to the end of the inclined pilework, (Plate 16, Figs 1 and 2). The lower part of the syphons, on the upper side, is covered with puddle to a depth of 15 inches above the syphons, this puddle being similarly pitched with Wansford rubble, also 9 inches deep. The upper part of the syphons on both sides is covered with puddle to a depth of 18 inches, on which grass sods are laid, and on the top of the dam a hut is erected, into which steam heating-pipes, 4 inches inside diameter, communicating with the boiler, are placed. By these means the water in the syphons and pipes can be protected from frost. A grating and an ice breaker are placed across the drain in front of the syphons, at the upper end. In Appendix B (page 509) some examples of the results of the working of the syphons are given.

#### STOPPING THE BREACH, AND CONCLUDING REMARKS.

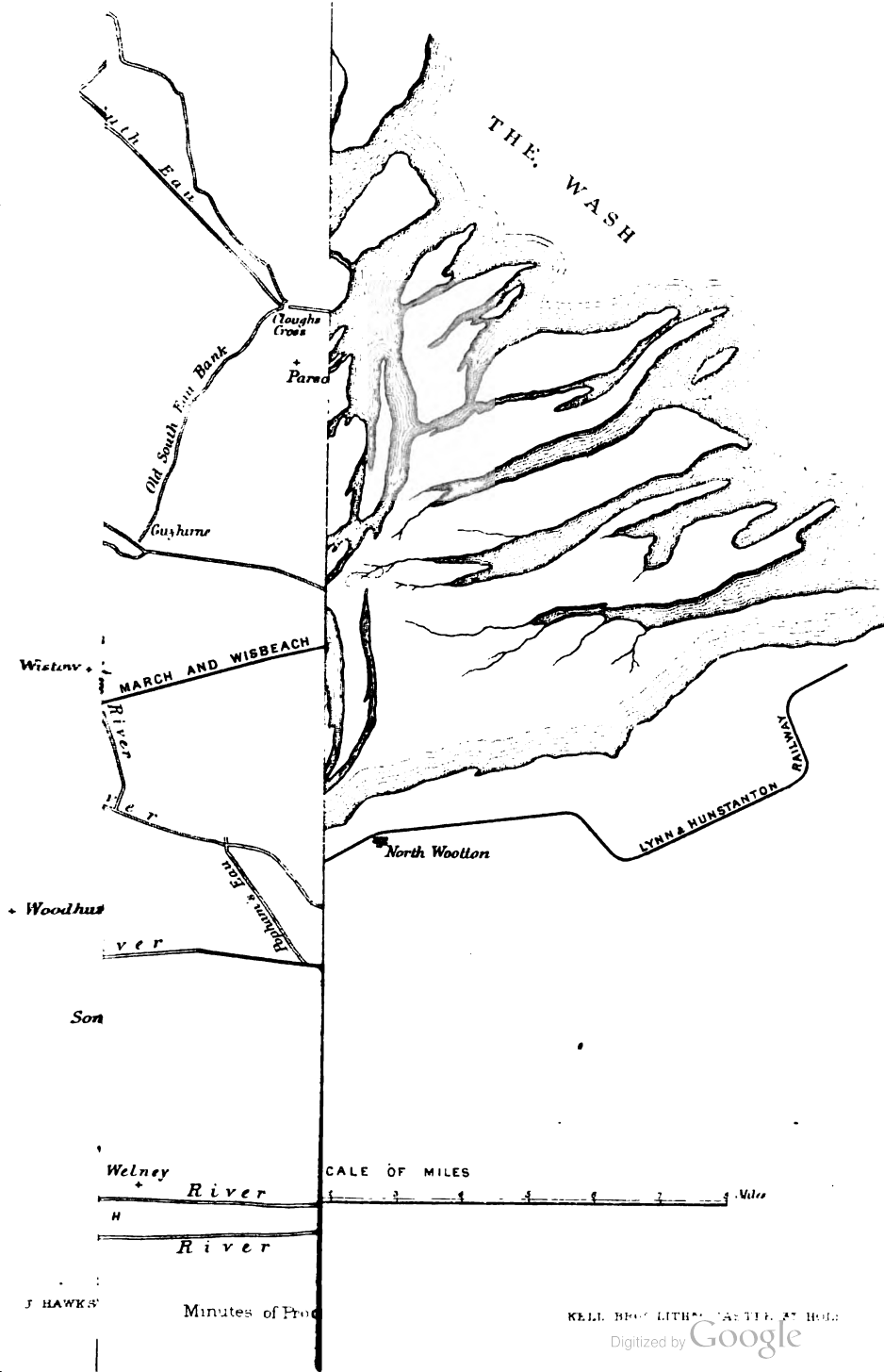
After the breach occurred, it soon became evident, that all attempts to stop it should be abandoned. The area flooded was surrounded by banks, which confined the mischief within limits, as long as those banks held good. Any attempt to stop the breach, until the tidal waters could be excluded, would only have increased the evil, by causing breaches in other places when still greater damage would have resulted, by the flooding of other lands. The large area flooded, operated as a safety valve, preventing the tidal waters from rising to the height in the drain they otherwise would have done, and actually did rise before the bank burst, and to that extent relieving the banks and preventing breaches at other points.

It was not, therefore, until the cofferdam was closed in, and the tidal waters were excluded, that the breach was stopped, and, still water being obtained, this was easily effected. The first operation consisted of tipping stone, so as to form a footing on each side, at the toe of the embankment that had to be raised. This embankment consisted of clay, to the level of the bottom of the drain,

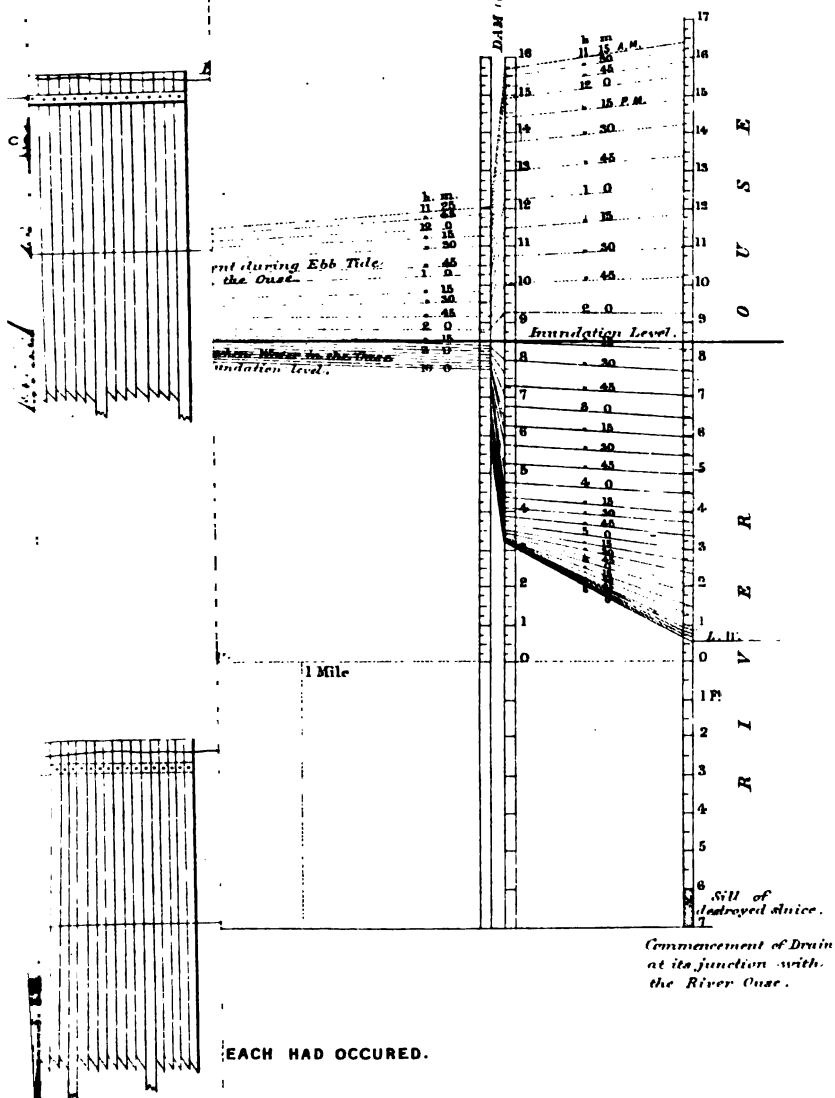
so as to make good the material that had been scoured away. The rest of the bank was of clay mixed with a small quantity of clunch, (about half a dozen barge-loads to every 4 feet of depth,) to stiffen and weight it. The total quantity of material used to restore the bank was about 25,000 cubic yards. The bottom of the drain, where the scour had taken place, was also repaired, and the banks generally were put into good order. After the work connected with securing the breach was completed, the water on the inundated land was let off, through the Marshland Smeeth and Fen Drain, and the adjoining Marshland sewer. Since the dam has been closed, much attention has been devoted to thoroughly securing and making good the banks of the drain between the dam and the River Ouse, which had been much damaged by the scour, and they had, from time to time, to be secured and repaired. They are now put into good order by clay and fascine work, so as to admit the efflux and reflux of the tidal waters without suffering deterioration.

The Author has only, in conclusion, to remark, that he believes syphons will be found to answer all the purposes of a permanent sluice. The results obtained have hitherto been of a most satisfactory character. They possess moreover the advantage of not rendering the safety of a district dependent on single pairs of gates; for it is clear that, from their independent action, any one, or more of the syphons may be damaged, or destroyed, without injuring the operation of the others, or endangering the district. A good deal of consideration was at one time bestowed on the advisability of making a sluice in the dam, in addition to the erection of syphons. It was thought that in this way an outlet could be established for the land water, in the readiest and most rapid manner, in anticipation of a land flood occurring in the interim, and before the syphons could be brought into operation. The desirability, however, of not interfering with the dam after it had been erected, led to the abandonment of the notion.

The Paper is illustrated by a series of drawings and diagrams from which Plates 14, 15, and 16 and Figs. 1 and 2 have been compiled.



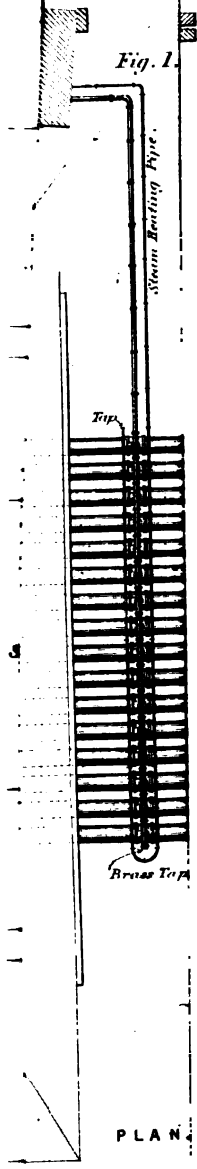






LE LEVEL.

Fig. 1.



PLAN

Fig. 2.

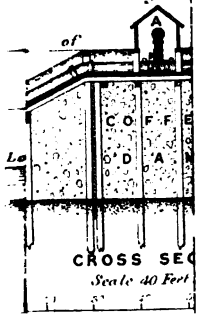


Fig. 6.

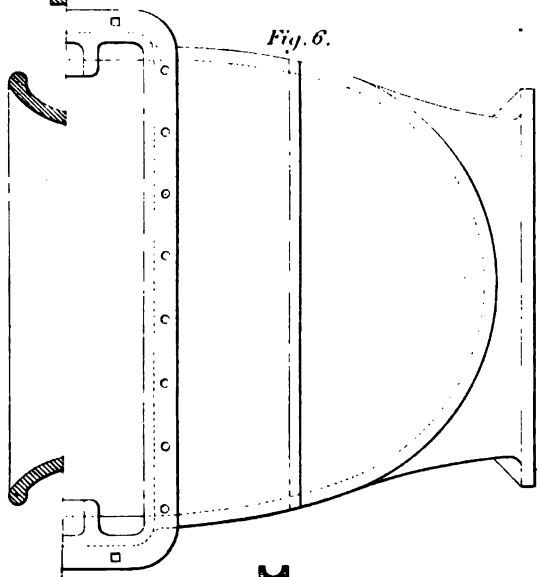
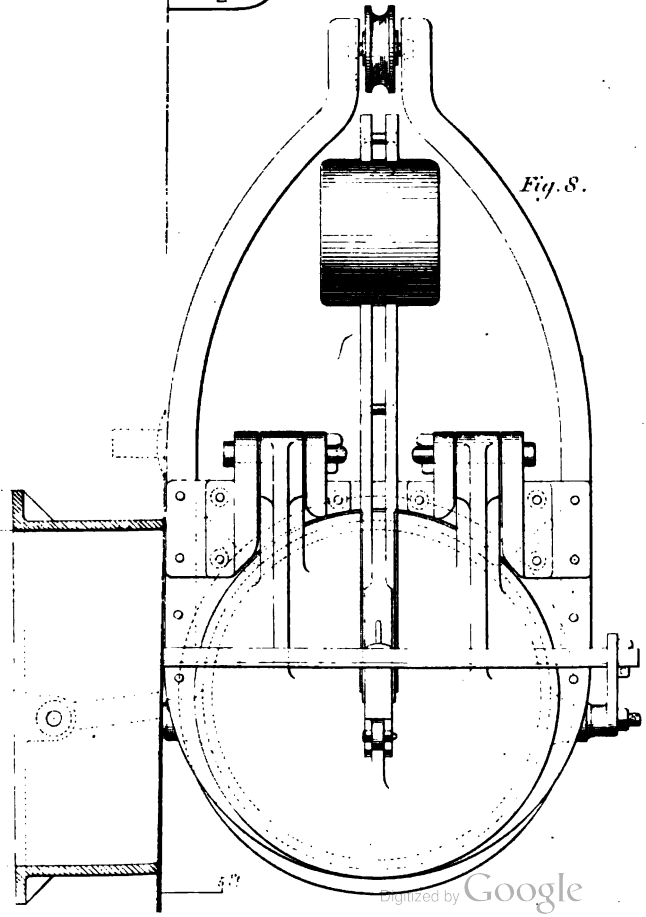


Fig. 8.





## APPENDIX (A).

TOTAL QUANTITIES OF THE SEVERAL KINDS OF MATERIAL  
USED IN THE CONSTRUCTION OF THE COFFERDAM AND THE  
SYPHONS.

## COFFERDAM.

|        |   |   |   |   |   |   |                    |
|--------|---|---|---|---|---|---|--------------------|
| Timber | . | . | . | . | . | . | 90,693 cubic feet. |
| Iron   | . | . | . | . | . | . | 75½ tons.          |
| Cement | . | . | . | . | . | . | 432 casks.         |
| Clunch | . | . | . | . | . | . | 2,444 tons.        |
| Sacks  | . | . | . | . | . | . | 36,524 in number.  |

## SYPHONS.

The total weight of metal-work in one syphon, exclusive of the pipes and the connections, is 36 tons; and the total weight of metal-work in the sixteen syphons, including the communication and air-pipes, and connections, complete in every respect, is 610 tons.

## APPENDIX (B).

## WORKING OF SYPHONS.—6th March, 1868.

| Time. | Gauge above Dam.  | Gauge below Dam.  | Vacuum.            |
|-------|-------------------|-------------------|--------------------|
| 12.50 | 5.9" above datum. | 1.5" above datum. | 11 inches Mercury. |
| 1.0   | 5.6 "             | 1.5 "             | 13 "               |
| 1.5   | 5.3 "             | 1.5 "             |                    |
| 1.10  | 4.10 "            | 1.8 "             |                    |
| 1.15  | 4.8 "             | 1.10 "            |                    |
| 1.20  | 4.6 "             | 1.10 "            |                    |
| 1.25  | 4.6 "             | 1.10 "            |                    |
| 1.30  | 4.5 "             | 1.9 "             | 16 "               |
| 1.45  | 4.3 "             | 1.6 "             |                    |
| 2.0   | 4.2 "             | 1.5 "             | 16 "               |
| 2.15  | 4.0 "             | 1.3 "             |                    |
| 2.30  | 3.8 "             | 1.2 "             | 16 "               |
| 2.45  | 3.2 "             | 1.0 "             |                    |
| 3.0   | 2.10 "            | 0.10 "            | 15 "               |
| 3.15  | 2.6 "             | 0.8 "             |                    |
| 3.30  | 2.4 "             | 0.7 "             | 14 "               |
| 3.45  | 2.1 "             | 0.6 "             |                    |
| 4.0   | 1.10 "            | 0.5 "             | 14 "               |
| 4.15  | 1.10 "            | 0.11 "            |                    |
| 4.30  | 2.0 "             | 1.11 "            | 14 "               |
| 4.35  | 2.2 "             | 2.2 "             |                    |

7th March, 1863.

| Time. | Gauge above Dam.  | Gauge below Dam.  | Vacuum.            |
|-------|-------------------|-------------------|--------------------|
| 12.50 | 1.11 above datum. | 1.10 above datum. | 14 inches Mercury. |
| 1.0   | 1.10 "            | 1.6 "             | 14 "               |
| 1.15  | 1.8 "             | 1.8 "             | "                  |
| 1.30  | 1.5 "             | 1.0 "             | 18 "               |
| 1.45  | 1.4 "             | 0.9 "             | "                  |
| 2.0   | 1.2 "             | 0.7 "             | 18 "               |
| 2.15  | 1.0 "             | 0.6 "             | "                  |
| 2.30  | 0.10 "            | 0.4 "             | 17 "               |
| 2.45  | 0.8 "             | 0.2 "             | "                  |
| 3.0   | 0.6 "             | 0.0 "             | 16 "               |
| 3.15  | 0.4 "             | 0.1 below datum.  | "                  |
| 3.30  | 0.2 "             | 0.3 "             | 17 "               |
| 3.45  | 0.1 "             | 0.4 "             | "                  |
| 4.0   | 0.0 "             | 0.6 "             | 17 "               |
| 4.15  | 0.1 below datum.  | 0.7 "             | "                  |
| 4.30  | 0.1 "             | 0.8 "             | 17 "               |
| 4.45  | 0.2 "             | 0.9 "             | "                  |
| 5.0   | 0.2 "             | 0.2 "             | 15 "               |

8th March, 1863.

|       |      |      |                    |
|-------|------|------|--------------------|
| 12.30 | 4.11 | 4.10 | 12 inches Mercury. |
| 12.45 | 4.8  | 4.4  | "                  |
| 1.0   | 4.6  | 3.10 | 14 "               |
| 1.15  | 4.4  | 3.5  | "                  |
| 1.30  | 4.2  | 3.0  | 15 "               |
| 1.45  | 4.0  | 2.7  | "                  |
| 2.0   | 3.10 | 2.3  | 16 "               |
| 2.15  | 3.6  | 1.10 | "                  |
| 2.30  | 3.4  | 1.6  | 16 "               |
| 2.45  | 3.0  | 1.8  | "                  |
| 3.0   | 2.9  | 1.2  | 16 "               |
| 3.15  | 2.6  | 1.0  | "                  |
| 3.30  | 2.3  | 0.11 | 16 "               |
| 3.45  | 2.1  | 0.8  | "                  |
| 4.0   | 1.10 | 0.7  | 16 "               |
| 4.15  | 1.7  | 0.6  | "                  |
| 4.30  | 1.4  | 0.4  | 16 "               |
| 4.45  | 1.2  | 0.2  | "                  |
| 5.0   | 1.1  | 0.2  | 16 "               |
| 5.15  | 0.11 | 0.6  | "                  |
| 5.30  | 1.3  | 1.3  | 16 "               |

[NOTE.

NOTE.—During the time the syphons were working, the doors at the Outwell Sluice were closed. The following is the capacity per foot in height above datum, of the drain between the syphons and the Outwell Sluice :—

|                                 |   |                      |
|---------------------------------|---|----------------------|
| Between datum and 1 foot above  | . | 3 008,003 cubic feet |
| „ 1 foot and 2 feet above datum | . | 3,165,865 „          |
| „ 2 feet and 3 feet „           | . | 3,411,652 „          |
| „ 3 feet and 4 feet „           | . | 3,681,918 „          |
| „ 4 feet and 5 feet „           | . | 4,005,962 „          |
| „ 5 feet and 6 feet „           | . | 4,253,012 „          |
| „ 6 feet and 7 feet „           | . | 4,567,515 „          |
| „ 7 feet and 8 feet „           | . | 4,886,176 „          |
| „ 8 feet and 9 feet „           | . | 5,047,941 „          |
| „ 9 feet and 10 feet „          | . | 5,273,587 „          |

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It having been represented that it might be inconvenient, while the matters relating to the Middle Level Drainage were under litigation, to discuss the questions raised in the Paper by the President, it was resolved—

That the discussion upon Mr. Hawkshaw's Paper, "On the Cofferdam and Syphons, Middle Level," should be abandoned.

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April 28, 1863.

JOHN HAWKSHAW, President,  
in the Chair.

No. 1,093.—“The Charing Cross Bridge.”<sup>1</sup> By HARRISON  
HAYTER, M. Inst. C.E.

#### GENERAL DESCRIPTION.

THE Charing Cross Bridge is being erected for the purpose of carrying the Charing Cross Railway across the river Thames, under the provisions of an Act which received the Royal Assent on the 8th of August, 1859. It occupies the site of the Hungerford Suspension Bridge for foot-passengers, which was built by the late Mr. I. K. Brunel, and the superstructure of which it was necessary to remove; but as the footway had to be maintained, the new bridge, in addition to carrying the rails of the railway, is provided with a footway on either side.

The Charing Cross Bridge comprises nine spans (Plate 17, Fig. 1)—six of 154 feet and three of 100 feet—the centre opening of the Suspension Bridge having been divided into four spans, each of 154 feet; the opening between the Surrey Pier, or Tower, and the abutment into two spans, each also of 154 feet; and the opening between the Middlesex Pier, or Tower, and the abutment into three spans, each of 100 feet. The superstructure over the three latter spans is fan-shaped (Plate 17, Fig. 2), inasmuch as the ground available for the Charing Cross Station being somewhat restricted in length, it was necessary to begin the widening out on the bridge. It was hence found more convenient, for reasons which will be hereafter explained, to divide the opening between the Middlesex Pier and abutment into three spans of 100 feet, instead of into two spans of 154 feet, as on the Surrey side.

The chains and the ironwork of the Hungerford Suspension Bridge are being removed to Clifton, and are to be erected, under the joint supervision of Mr. Hawkshaw, President, Inst. C.E., and Mr. W. H. Barlow, M. Inst. C.E., on the piers which were originally intended to carry the chains of a suspension bridge, and which have so long existed on the banks of the River Avon.

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

Mr. Brunel having also been the Engineer of the Clifton Suspension Bridge, the piers of which were erected by him, it is considered fortunate, that the Hungerford chains can be rendered available towards the completion of that work, the span of which does not materially differ from the centre span of the Hungerford Suspension Bridge. The Hungerford chains, however, will have to be strengthened, as the Clifton Bridge is being made wide enough for a carriage roadway, as well as for a footpath on either side.

The superstructure of the Charing Cross Bridge is carried by cylinders, sunk into the bed of the river, and by the piers of the Hungerford Suspension Bridge (Plate 17, Fig. 1), the upper portions of which have been removed, while the lower portions have been added to and modified, so as to adapt them for the railway bridge. The abutments of the Hungerford Suspension Bridge are also retained, but have been considerably lengthened and altered. The width of the river at the bridge is 1,350 feet. The greatest depth of water between the two brick piers is 13 feet below low-water spring tides, and the average depth is about 10 feet. The rise of spring tides is  $17\frac{1}{2}$  feet. The level of the rails is 31 feet above Trinity high-water mark, and the clear minimum headway is 25 feet above the same level, that height having to be preserved, to comply with the requirements of the Admiralty and of the Conservators of the River Thames.

The Charing Cross Bridge was designed by Mr. Hawkshaw, President, Inst. C.E., the Engineer to the Railway, and is being carried out under his immediate supervision,—Mr. John H. Stanton, M. Inst. C. E., being the Resident Engineer. Mr. George Wythes is the contractor for the construction of the railway, but he sublet the erection of the Bridge to Messrs. Cochrane and Co., Woodside Ironworks, near Dudley, who, up to the present time, have carried out the work in a satisfactory and creditable manner, the immediate direction of the operations having been intrusted by them to Mr. Joseph Phillips, Assoc. Inst. C.E.

#### CYLINDERS FOR THE OPENINGS 154 FEET SPAN.

The cylinders, excepting those at the fan end, which will be hereafter described, are 14 feet diameter below, and 10 feet diameter above the ground, the junction between the two sizes being effected by an intermediate conical length (Plate 17, Fig. 3). There are four piers (three intervening between the towers of the Hungerford Suspension Bridge and one between the tower and the abutment on the Surrey side) formed of cylinders of the above diameters, and each of the piers consists of two cylinders, 49 feet 4 inches apart, from centre to centre. They are of cast iron, and are shown in detail in Plate 17, Figs. 5, 6, and 7. The circumference of each

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cylinder of 14 feet diameter, is divided into seven equal parts or segments, the segments being generally 9 feet high; that of the cylinders 10 feet diameter, is divided into five equal parts or segments, each segment being also generally 9 feet high; whilst that of the intermediate or conical piece is similarly divided into five equal parts or segments, each 9 feet high. The segments are fastened together inside, by bolts  $1\frac{1}{4}$  inch diameter, passing through flanges cast on the top, bottom, and sides of the segments. A horizontal interior strengthening rib is cast on the middle of each segment. All the joints of the segments, both horizontal and vertical, are planed, and spaces are left in the inside between the flanges for the introduction of iron cement, to render the joints water-tight. The vertical joints of the segments in each of the two lengths of different diameters respectively are over one another. There are thus continuous vertical lines of ribs, securing a strong columnar arrangement. The horizontal joints can also be made to fit better in this way than by breaking the vertical joints. The thickness of the metal in these cylinders is  $1\frac{1}{8}$  inch throughout, excepting in the bottom length where it is  $1\frac{1}{2}$  inch.

#### SINKING THE CYLINDERS.

The staging for sinking the cylinders consists of piles erected round the pier, supporting a stage or platform at the level of 4 feet above high-water mark. When this staging was in its place, an opening of 45 feet was left between two adjoining piers; but in order that the navigation might not be interrupted, only two openings, in the space between the two brick piers, were allowed to be narrowed to that extent at the same time. The staging used in the two Surrey openings, which is generally similar to that employed for the other openings of the same span, is shown in Plate 1, Figs. 8 and 9. The part up to the lower platform was erected for the purpose of sinking the cylinders. This was afterwards carried up, as shown, and the 45 feet opening spanned, for the purpose of erecting the girders, as will be hereafter explained.

The strata through which the cylinders are sunk (Plate 17, Fig. 1) consist of mud and gravel, of varying thicknesses, overlying the London clay. The cylinders were sunk by excavating the material from the inside, by means of divers with helmets, and then by weighting them as the excavation proceeded, until they had passed through all the porous material, and had entered a few feet into the solid London clay. The water was then pumped out, and the cylinder was kept dry for the rest of the operation, very little pumping being required. The sinking was then proceeded with, by excavating the material and by weighting the cylinders. The weight with which it was found necessary to load the cylinders, in

order to overcome the friction of the sides, and to sink them to their final depth, averaged about 150 tons. The London clay at the base of the cylinders was of a hard character, of a dark-blue colour, and it extended to a depth far below the level at which the cylinders were founded.

The cylinders constituting the pier between the Surrey abutment and the brick pier, are sunk to a depth of 52 feet below Trinity high-water mark. Those between the two brick piers are sunk to a depth of 62 feet below the same level, excepting the up-stream cylinder of the middle pier, which had to be sunk 10 feet deeper, on account of some of the material through which it passed being softer than that met with at the sites of the other cylinders.

The Act for the railway provided, that the foundations of the bridge should be laid at such depth, as would admit of the river being deepened, at any subsequent time, to 30 feet below Trinity high-water mark.

#### FILLING-IN THE CYLINDERS, AND WEIGHTING.

After the cylinders had been sunk, and the material had been excavated, they were filled with concrete up to where the conical part commences, and with brickwork from that level to the underside of the granite bearing blocks occupying the top of each cylinder. The concrete was composed of Thames gravel or ballast, that obtained from the excavation from the inside of the cylinders being used, so far as it was suitable and sufficient, the remainder of the gravel being purchased from the Conservators of the River Thames. This was mixed with the best Portland cement, in the proportion of one part of cement to seven parts of gravel. The brickwork is generally composed of the best pavimour bricks, set in Portland cement mortar, in the proportion of one part of cement to two parts and a half of sand.

Before the lengths above high-water were put on, the cylinders, after they had been filled with the concrete and brickwork, were weighted with a load of about 450 tons, excepting the two cylinders in the pier nearest to the Surrey side, which were the first sunk, and which Mr. Hawkshaw required to be weighted each with 700 tons, that being about the greatest load that could come upon any one cylinder, assuming the four lines of rails on the bridge to be loaded with locomotive engines. Upon the removal of the loads, it was found that each of the cylinders which had been weighted with 700 tons had permanently sunk 4 inches, and each of the others that were loaded with 450 tons had permanently sunk, on an average, nearly 3 inches. The larger loads were applied in order to test the strength of the foundations, and the subsequent smaller loads to bring the cylinders to a bearing, so

as to prevent any settlement, after the completion of the bridge, from the weight of the permanent and moving loads. The load was applied by piling the permanent rails of the railway on the cylinders. After it was removed, the top lengths were put on, and were filled in with brickwork, and then the granite bearing blocks, which are from the Cheesewring Quarries, were fixed in place. These blocks are 2 feet 6 inches thick, and are in two equal pieces, which, when together, fill the cylinder, the joint being under and longitudinal with the girders. The granite blocks project 1 inch above the top of the cylinders, in order that the weight may be prevented from coming on the upper edge of the ironwork.

Each pair of cylinders forming a pier is connected together transversely by a wrought-iron box girder, 4 feet deep, strongly attached to the top of each (Plate 18, Fig. 12). This girder also serves the purpose of a cross girder for supporting the roadway. Assuming the four lines of way on the bridge to be loaded with locomotive engines, the pressure on the base of the cylinders would amount to about 8 tons per square foot, and that on the brickwork at the top of the cone, where the cylinder is 10 feet diameter, to about 9 tons per square foot. The former pressure, however, is on the supposition, that no relief is afforded by the friction of the sides against the material through which the cylinders penetrate. If this were taken into account, as it should be, the 8 tons per square foot would be much reduced, and it is clear that this pressure will never be approached.

#### SUPERSTRUCTURE OF THE OPENINGS 154 FEET SPAN.

The superstructure of each of the openings, 154 feet span, consists of two main girders, underneath which are cross girders (Plate 17, Fig. 3). The main girders are, like the cylinders, 49 feet 4 inches apart from centre to centre transversely, leaving a space between them sufficient for four lines of rails, the roadway platform being supported by the cross girders. For the purpose of carrying the footpaths, each of which is 7 feet wide in the clear, the cross girders extend beyond the main girders, forming a series of cantilevers on each side of the bridge.

#### MAIN GIRDERS SPANNING THE 154 FEET OPENINGS.

These girders are of wrought iron. They are not continuous over two or more openings, but are all detached. Each has to support, inclusive of its own weight, a maximum distributed load of about 700 tons. The elevation, sections, and details of these girders are shown in Plate 18, Figs. 1 to 7. The extreme depth of the girders is 14 feet, and the depth between the centres of

gravity of the top and bottom members is 12 feet 9 inches. When the girders are loaded with a maximum strain of 4 tons per square inch in compression, and of 5 tons per square inch in extension (which are the limits allowed for the wrought ironwork throughout the bridge), the sectional area in the top, at the centre of the girder, will be somewhat less than 300 square inches, and that in the bottom, excluding the rivet holes, will be somewhat less than 235 square inches; these being the respective central areas of the girders as constructed.

The sides of the girders between the bearings are divided by vertical bars into fourteen equal parts, each division containing a double set of two diagonals crossing each other. These are placed, as nearly as practicable, at an angle of  $45^{\circ}$  with the top and bottom of the girder; and both the diagonals and the vertical bars are connected to the top and bottom webs by pins of puddled steel. The top and bottom webs of the girders are of boiler-plate, and consist of horizontal tables 4 feet wide at the top and 3 feet wide at the bottom, and of four vertical ribs, the two outer rows being 24 inches deep, and the two inner 21 inches deep. The joints of the plates, in the horizontal tables of the top and bottom webs, are covered by a continuous plate running the whole length of the girder; that in the top being of the same thickness as the plates covered, and that in the bottom one-sixteenth of an inch thicker (Plate 18, Figs. 3, 4, 5, and 6). The joints in the vertical ribs in the top and bottom occur near the pin-holes, and are covered by 1-inch plates, 2 feet 4 inches long, placed on both sides of the ribs, thus forming a good bearing for the pins (Plate 18, Fig. 7). The vertical ribs are united to the horizontal tables by angle-irons, 6 inches by 6 inches, by 1 inch thick in the centre and  $\frac{3}{4}$  of an inch thick at the ends, covered at the joints in the usual manner. The rivets used throughout the top and bottom of the girders are 1 inch diameter, and their pitch is about 4 inches.

The aggregate thickness of the plates in the horizontal table of the top in the centre of the girder being  $3\frac{1}{8}$  inches, and in the bottom  $3\frac{1}{8}$  inches, without the angle-irons, and  $4\frac{1}{8}$  inches and  $4\frac{1}{8}$  inches respectively, with the angle irons, but excluding the angle-iron covers, it would not have been easy to unite the parts composing such a thickness, by rivets passing through holes punched in the metal. However perfectly the holes may be set out in the first instance, the process of punching always stretches the iron; so that, when the plates are put together, the holes do not come accurately over one another. Neither would they have been truly cylindrical throughout, as they are always, when punched, larger on one side than the other; so that where so many thicknesses had to be united, imperfect

riveting would have resulted, unless rimering out to a great extent had been resorted to. Mr. Hawkshaw therefore required the holes to be drilled. This was done by machines designed by Messrs. Cochrane and Co., which were capable of drilling a large number of holes simultaneously. These machines answered their purpose very satisfactorily, and the drilling enabled the riveting to be well and readily done. And while great saving was effected in the cost of putting the work together, it was also found that, where so many holes had to be made, drilling was in itself less costly than punching.

The diagonals which act as ties are of Howard's patent rolled suspension links, each separate tie being composed of two or three links, as required, riveted together. The diagonals acting as struts are each in one solid forging. The struts and the ties have swelled ends for the pins. The struts are united together in pairs, by zigzag bracing of wrought-iron,  $4\frac{1}{2}$  inches wide by  $\frac{3}{4}$  inch thick, riveted to them, and by bolts passing through cast-iron distance-pipes. The ties, also in pairs, are not united together; but in the centre of the girders, where the diagonals act both as struts and ties, the pairs are united together in the two central spaces by the zigzag work. The dimensions of the struts vary from 12 inches by 3 inches at the ends, to 6 inches by  $2\frac{1}{2}$  inches in the middle, and of the ties from 12 inches by  $2\frac{1}{2}$  inches at the ends, to 6 inches by 2 inches in the middle. The turned pins, of puddled steel, were procured from Messrs. John Brown and Co., of Sheffield. They are 7 inches diameter at the ends of the girders, decreasing to 5 inches diameter at the centre, and are 11 feet apart from centre to centre.

At the ends of the girders under consideration, the sides over the supports are boxed, being composed of  $\frac{3}{8}$ -inch plate iron, stiffened by angle and T irons. Where the girders bear upon the brick piers and upon the Surrey abutment, they rest upon roller bed plates, but upon the cylinders, sheet lead only is interposed between the girders and the granite blocks. The force of expansion and contraction will probably cause the cylinders between the brick piers to rock to and fro to a certain but inappreciable extent. The girders were put together in place, on the staging before referred to (Plate 17, Figs. 8 and 9). The top of the girder was put together on the top upper platform, and the bottom of the girder on the top lower platform, the two platforms being kept at the correct distances apart by diagonals, converting the whole into a framework of timber. The supports on the platforms, on which the girders were erected, were accurately adjusted to the proper camber of the girders. The rivet holes in the plates forming the top and bottom of the girders were all drilled at the works of Messrs. Cochrane and Co.

before being sent to London, but the pin-holes were not bored out to the full diameter.

The struts, with the diagonal bracing, were also put together at the works of Messrs. Cochrane and Co., and the pin-holes were bored out to the full size, so that they, and also the ties, were sent up in a complete state. When the top and bottom webs were in place, the struts and the ties were erected, and the pin-holes in the girders were accurately bored out, by means of a boring apparatus worked by a small steam-engine, the gauge of the running wheels of which was so adjusted, that it might work backwards and forwards on the two outer vertical ribs of the lower part of the girder. Great care was taken to insure accuracy in the direction and position of the holes. The pins, after being coated with grease, were forced into the holes, the diameter of the latter being such that the former could only be driven in by exerting a considerable force, a perfect fit being thereby established. The vertical bars dividing the sides into the several spaces are 6 inches wide by 1 inch thick. They have not been taken into account in calculating the strains. They fit on to the ends of the steel pins, and are in pairs, one on either side, and outside the outer vertical ribs of the top and bottom, and are connected together by bolts and distance pipes. The only use they serve is to stiffen the girder to a certain extent.

The ends of the pins are covered with circular castings screwed on, and over the ends, resting on the cylinders, ornamental castings are to be fixed.

The weight of each main girder spanning the 154 feet openings is 190 tons.

One of the main girders was tested, when in place, with a distributed load of 400 tons, and the deflections were accurately taken. The load being very great, and the girder being unconnected transversely, (the cross girders not having been fixed,) great care had to be observed in putting on the weight, which consisted of the rails of the railway. The manner in which it was loaded will be understood from Plate 18, Figs. 15 and 16. The greatest deflection in the centre, when the load was on, was  $1\frac{5}{16}$  inch, and the permanent deflection, after the load was removed, was  $\frac{1}{2}$  inch. (Plate 18, Fig. 14.) If the girders had been rigidly connected transversely by the cross girders, the deflection would doubtless have been less. This has since been proved to be the case. The whole of the bridge, in its completed state, has been tested by a maximum load, and the greatest deflection of the main girders has not been more than  $\frac{1}{4}$  of an inch in the centre.

The plate iron used throughout the bridge was also tested, and the results are given in the Appendix, page 527. These are

interesting, as both the extension and the permanent set were carefully taken by an accurate extensometer.

It has been before stated, that the girders are all detached, and not continuous over two or more openings. Mr. Hawkshaw's original intention was to connect the girders spanning the two end openings on the Surrey side, and also to connect the girders spanning the four central openings. As regards the girders spanning the two openings on the Surrey side, it was found that it was not easy to gain the full advantage from continuity, inasmuch as the girders having to support a considerable load, the thickness of the plates in the top and bottom was too great to render it practicable to reduce them to a minimum at the point of contrary flexure. Moreover, the strain on the diagonals would have been greater at the central support than at the end supports, and the uniformity in size of the struts and ties could not have been maintained, had their correct dimensions consequent upon continuity been adopted. It was also desirable not to increase the strain on the diagonals, as the end struts are already large forgings. The same remarks apply, more or less, to the girders spanning the four central openings, although in this case greater advantage would have been gained by continuity. More difficulty, however, would have been experienced in their erection, inasmuch as the Conservators of the River Thames, only allowed the staging to be erected in the river for two of the central openings at one time. It is clear also, that much more trouble would have been incurred in constructing continuous girders over several openings, than in putting together a series of detached girders. In the former case there would be a multitude of dissimilar parts, whilst in the latter all the girders would be duplicates of one another. Better workmanship is thus insured, and at a less cost per ton. In order to ascertain whether any saving of metal would be effected, by the girders being constructed on the continuous or non-continuous system, drawings of both were prepared, and the weights were accurately calculated. The difference was inconsiderable in the case of the side openings, and was not of sufficient importance over the central openings to counterbalance the advantages to be derived from non-continuity; Mr. Hawkshaw therefore determined to abandon the idea of continuity. The Author does not argue from the foregoing, that continuity in girders may not be sometimes, or even as a general rule, desirable. In this, as in most other similar matters, no rules universally applicable can be laid down. In the case under consideration there are exceptional circumstances, which, after being fully investigated and considered, led to the abandonment of continuity.

## CROSS GIRDERS FOR THE OPENINGS 154 FEET SPAN.

The cross girders for the openings 154 feet span are shown in Plate 18, Figs. 8, 9, 10, and 11. They are of wrought iron, and are suspended from the main girders. The top and the bottom of that portion of the cross girders between the main girders consist of two plates, 18 inches wide by  $\frac{7}{8}$  inch thick. The sides are of lattice-bars united to the top and bottom by two angle irons, 5 inches by 3 inches by  $\frac{7}{16}$  inch thick. These cross girders are 4 feet deep in the middle, and 2 feet  $1\frac{1}{8}$  inch deep where the cantilevers are united to them outside the main girders, the bottom being fish-bellied, and the top having a camber of  $3\frac{1}{2}$  inches in the centre. The lattice-bars are fixed at an angle of about  $45^\circ$  with the top and bottom. The ties are in two bars throughout, and each bar varies from 6 inches by  $\frac{1}{2}$  inch at the ends to 4 inches by  $\frac{1}{2}$  inch in the middle. The struts are in one bar passing between the two ties, and vary from 6 inches by 1 inch at the ends to 4 inches by 1 inch in the middle. The rivets in the cross girders are  $\frac{1}{2}$  inch diameter. The cantilevers decrease from 2 feet  $1\frac{1}{8}$  inch deep at their junction with the cross girders to 1 foot 2 inches deep at the extremities. The top and bottom of the cantilevers are composed of two angle irons,  $3\frac{1}{2}$  inches by 3 inches by  $\frac{1}{2}$  inch thick, and the sides are of lattice-bars also placed at an angle of about  $45^\circ$  with the top and bottom; the ties likewise consist of two bars and the struts of one bar passing between them, each of the former being 2 inches by  $\frac{3}{8}$  inch, and the latter 2 inches by  $\frac{3}{4}$  inch.

It will be seen, therefore, that the cross girders are generally similar in character to the main girders. They are suspended from the under side of the main girders at the points where the pins occur. They are therefore placed 11 feet apart, from centre to centre. The sides of the cross girders, where they are underneath the main girders, are boxed in with plate iron. They are suspended by four angle irons—two on either side,—and outside the outer vertical ribs of the bottom of each main girder, to which, and to the boxed sides of the cross girder, these angle irons are riveted. By this means a strong and good attachment is established. The cross girders are connected together by wrought iron cross-bracing attached to the centre of each (Plate 19, Fig. 1). Each cross girder, including the two cantilevers, weighs 9 tons. They were tested by erecting two cross girders in the contractor's yard, placed transversely 6 feet apart in the clear, the cantilevers being removed. They were then loaded with 140 tons (equivalent to 70 tons on each girder) distributed over the span. The maximum deflection in the centre, when the load was on, was 1 inch; and the permanent deflection, when the load was removed, was  $\frac{1}{4}$  inch. This result would doubtless have been better had the cross girders

been in place and rigidly fixed at the ends to the main girders. The whole of the cross girders have since been tested in place with a maximum load, and the deflection has in no case been more than  $\frac{3}{8}$  inch in the centre.

#### FAN END.

The superstructure of the three openings, 100 feet span each, of the Fan End is supported by the Middlesex brick pier and by the Middlesex abutment of the bridge, and intermediate to these by piers of cast iron cylinders, that next to the brick pier, consisting of a row of seven cylinders, and that next to the abutment of a row of nine cylinders. In these two rows (Plate 17, Fig. 4, and Plate 19, Fig. 1) the outer cylinders are 10 feet diameter below and 8 feet diameter above the ground, and the inner ones are also 10 feet diameter below but only 6 feet diameter above the ground, the junction between the two lengths of different diameters being effected by a conical length. The circumference of the lower lengths of the cylinders, 10 feet diameter, is divided into segments, which are generally similar, and are connected together in the same way, as the upper lengths of the cylinders already described, of the same diameter, in the piers of the openings 154 feet span. The upper lengths of the outer cylinders 8 feet diameter and of the inner cylinders 6 feet diameter, are not divided into segments, but are cast in pieces complete on the circumference, and 5 feet long. These pieces are fastened together, by bolts  $1\frac{1}{4}$  inch diameter, passing through flanges cast on the top and bottom. All the joints throughout these cylinders are made water-tight in the usual manner by iron cement. The cylinders in these two piers have been sunk in place, precisely in the same manner as the cylinders of the openings of 154 feet span, and to depths averaging about 40 feet below Trinity high-water mark. When in place and when all the material had been excavated from the inside, they were filled with Portland cement concrete to the level of about 5 feet above Trinity high-water mark. It was not considered necessary to fill in the remaining portion of these cylinders.

As some irregularities, or deviations from the perpendicular, occurred in sinking some of the cylinders in the row next the Middlesex brick pier, a horizontal casting, extending over all the cylinders of this row, was bolted to them at about the level of the ground, Plate 17, Fig. 4; on this casting the upper parts of the cylinders of this pier are fixed.

On account of the great width of the Fan, which increases from 49 feet 4 inches from centre to centre of the outside girders at its commencement at the Middlesex brick pier (this being the width between the parallel main girders spanning the 154

feet openings) to 168 feet from centre to centre of the outside girders at the abutment, the system pursued in the other openings, of supporting the roadway on cross girders suspended from outside main girders, was clearly inadmissible. It was also undesirable to introduce intermediate main girders, projecting above the roadway. An unbroken platform is at all times more or less a desideratum, but in close proximity to a large station it is almost a necessity. The roadway over the Fan is, therefore, carried by interior plate girders (Plate 19, Fig. 1,) laid at right angles to the piers and the abutment, and by the outside main girders, which are at the angle of inclination of the Fan. These latter (Plate 19, Figs. 2, 3, 4, and 5,) are of the same depth, and although lighter in all the parts, are generally of the same character, and are fixed at the same level, as the girders of the openings 154 feet span. The faces of the bridge have, therefore, a uniform appearance throughout.

The interior plate girders, where they bear on the cylinders, rest on a bed plate, (Plate 17, Fig. 4, and Plate 19, Figs. 1 and 8,) extending over all the cylinders of each row. They are connected together by cross bracing in the centre of each span, and at points intermediate between the centre and the supports; and where they rest on the Middlesex pier and abutment, are built into the brickwork. The bottom of these girders is at a lower level than the bottom of the outside main girders, inasmuch as it was impossible to obtain sufficient depth without resorting to this arrangement. As it is, the depth of these girders is only 5 feet; or one-twentieth of the span. If the spans in the Fan had been 154 feet, the interior plate girders instead of being one-twentieth would have been less than one-thirtieth of the span. Hence the advantage of introducing the smaller spans of 100 feet. The elevations and sections of the interior plate girders are shown in Plate 19, Figs. 6 and 7. They are of the ordinary construction, and weigh about 26 tons each.

The outside main girders do not make exactly the same angle with the centre line produced of the parallel portion of the bridge. The shape of the Fan is therefore not accurately that of an isosceles triangle—the distance between the centre line of the Fan and the centre line produced of the parallel portion of the bridge, being 7 feet 9 inches at the Middlesex abutment. (Plate 19, Fig. 1.) These outside main girders, which are over the centre of the outside cylinders of the piers, are raised above the interior plate girders by cylindrical making-up pieces of the same diameter (8 feet) as the upper lengths of the outside cylinders. (Plate 17, Fig. 4.) These cylindrical pieces are filled with brickwork in cement, resting on the bed-plate, the top being covered with a bed of an inch in thickness of Portland cement, raised half an inch

above the top of the cylinder, and forming the bearing surface of the girders.

The triangular spaces between the outside main girders and the outer interior plate girders are filled in with cross girders, riveted to the sides of the latter, and suspended underneath the former, and are terminated by cantilevers projecting beyond the face girders. (Plate 17, Fig. 4, and Plate 19, Fig. 1.) These cantilevers are similar to those outside the main girders of the 154 feet openings, and like them are placed about 11 feet apart from centre to centre, thus preserving the uniformity.

The girders of the Fan rest directly on their supports, no rollers being interposed, excepting underneath the outside main girders, where they rest on the Middlesex brick pier and abutment; but the bearings for the interior plate girders on the cast-iron bed-plate over the cylinders are planed. The ends of the cylinders on which the bed-plate rests are also planed.

#### ROADWAY AND FOOTPATH PLATFORMS.

The roadway platform over the openings 154 feet span, consists of planking 4 inches thick, spiked to longitudinal timbers, 15 inches by 15 inches, placed underneath the rails, and bolted to the cross girders. The roadway platform over the Fan End, consists of planking 6 inches thick, secured to the interior plate girders, and to longitudinal timbers spanning the cross girders in the triangular spaces. By abandoning the longitudinal timbers in the Fan, over the shallow interior plate girders, which the arrangement permitted, additional depth was obtained for these. The footpath platform on each side consists throughout of planking 6 inches thick, secured to the top of the cantilevers. The roadway platform is to be covered with tar pavement about 2 inches thick, and the footpath platforms with asphalte 1 inch thick. The longitudinals and the whole of the planking are creosoted, and the latter is grooved and tongued with iron, and caulked with tar and oakum. The rails over the bridge are flat-bottomed, and of the ordinary section. On the outside of the footpath an ornamental railing, of cast iron, is being fixed. (Plate 18, Fig. 13.) A railing of a pattern generally similar will be fixed to the main girders on the inside of the footpaths, to prevent the railway being trespassed upon.

#### CONCLUDING REMARKS.

The first cylinder of the Charing Cross Bridge was pitched on the 6th of June, 1860. The bridge is on the eve of completion. Its construction will thus have extended over a period of about three years. Some time was necessarily occupied, in consequence of obstacles tending to retard its completion; the principal ones

being, the retention of the Suspension Bridge during the construction of the works, because of the necessity for keeping open the footway traffic, which has not been interrupted; the time occupied in the removal of the Suspension Bridge; and also the necessity of almost completing several parts of the bridge before others could be commenced, the extent of staging that was permitted to be in the river at one time being limited.

The total weight of metal work in the bridge will be :

|                                         |             |
|-----------------------------------------|-------------|
| Wrought-iron work, including steel pins | 4,950 tons. |
| Cast-iron work                          | 1,950 tons. |

The total cost of the bridge, including the abutments, will be £180,000. The superficial area of the roadway and of the footpaths being 103,000 square feet, the cost per square foot of roadway will be about £1 15s.; and the bridge being 1,375 feet long, the cost per lineal foot will be about £131.

The cylinders of the openings 154 feet span, including the portions in the ground and the portions above the ground, cost, when in place, complete in every respect, and filled with brickwork and concrete, about £22 per lineal foot; the outside cylinders of the piers of the Fan, about £14 per lineal foot; and the inner cylinders of the piers of the Fan, about £12 per lineal foot. The average actual cost of excavating the material from the inside of the cylinders, and depositing it in barges alongside, was about 12s. per cubic yard. This was the case whether divers were employed, or whether the material was excavated when the cylinders were dry, inasmuch as in the latter case the material had to be lifted to a greater height.

It is probable, that the cost of the main girders would have been about the same if the sides, instead of being constructed as they have been, had been composed of a number of lattice bars, or had been of ordinary plate work. In the last case, the workmanship would have cost less, but on the other hand there would have been more metal in the sides than in either of the two former cases.

Almost all the parts of the Charing Cross Bridge are open to view, and can be readily reached to be painted, or repaired when needed.

In conclusion, the Author has only to remark, that his desire has been to describe the Charing Cross Bridge as it exists, and as it will be when entirely completed, and the mode of its construction, without asserting that the design is superior to any other, or, assuming that, if best adapted to the site where it has been erected, therefore it would necessarily be equally suitable for any other similar place. In railway structures the great desideratum is evidently to plan a work that is appropriate, and that can be

erected at a minimum cost. This has been kept in view throughout, and the Author believes that Mr. Hawkshaw has succeeded in designing a bridge that is well adapted to the situation where it is placed, and for the purpose intended, and its comparatively small cost proves that no outlay has been incurred beyond what was needed.

The Paper is illustrated by a series of drawings and diagrams from which Plates 17, 18, and 19, have been compiled.

Fig. 8.

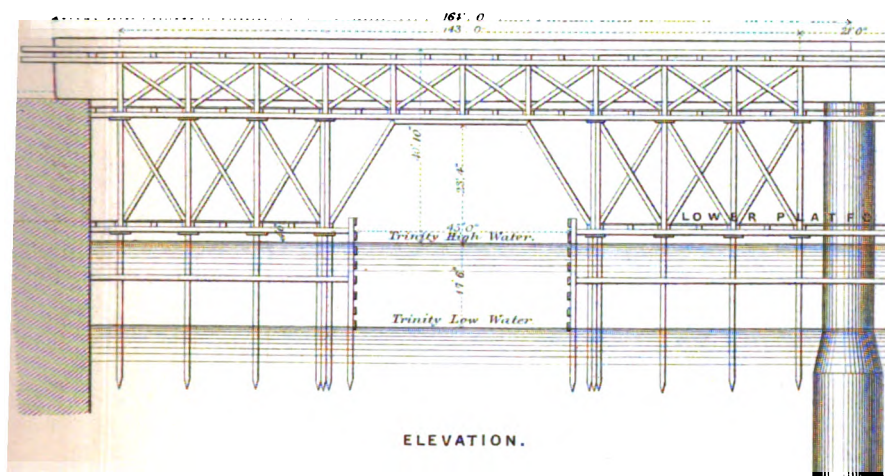
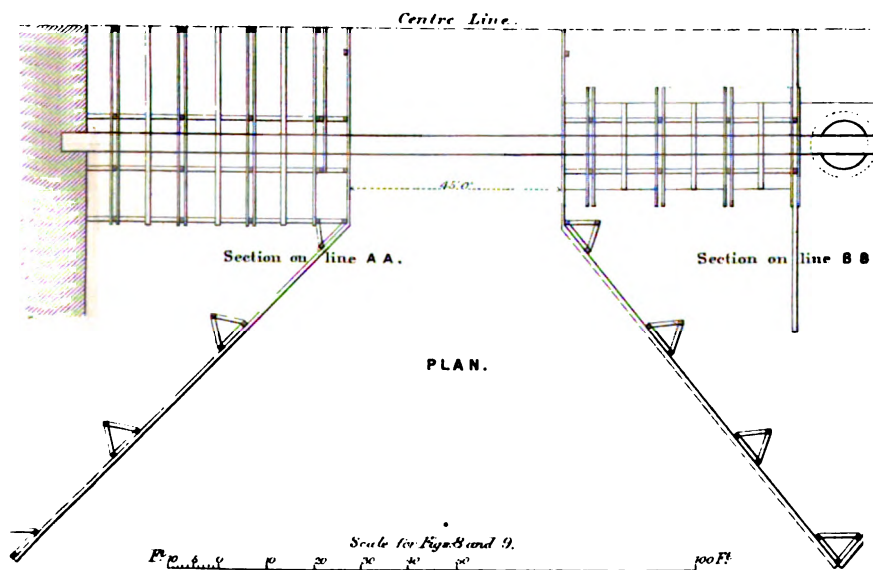


Fig. 9.



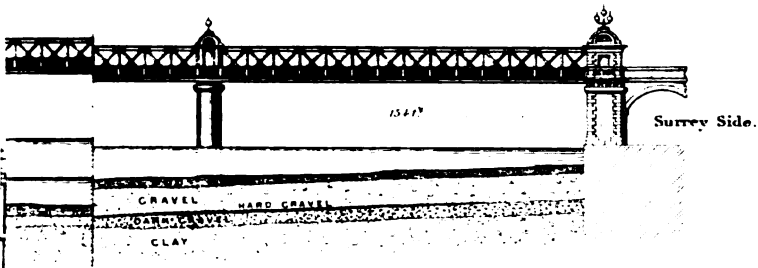
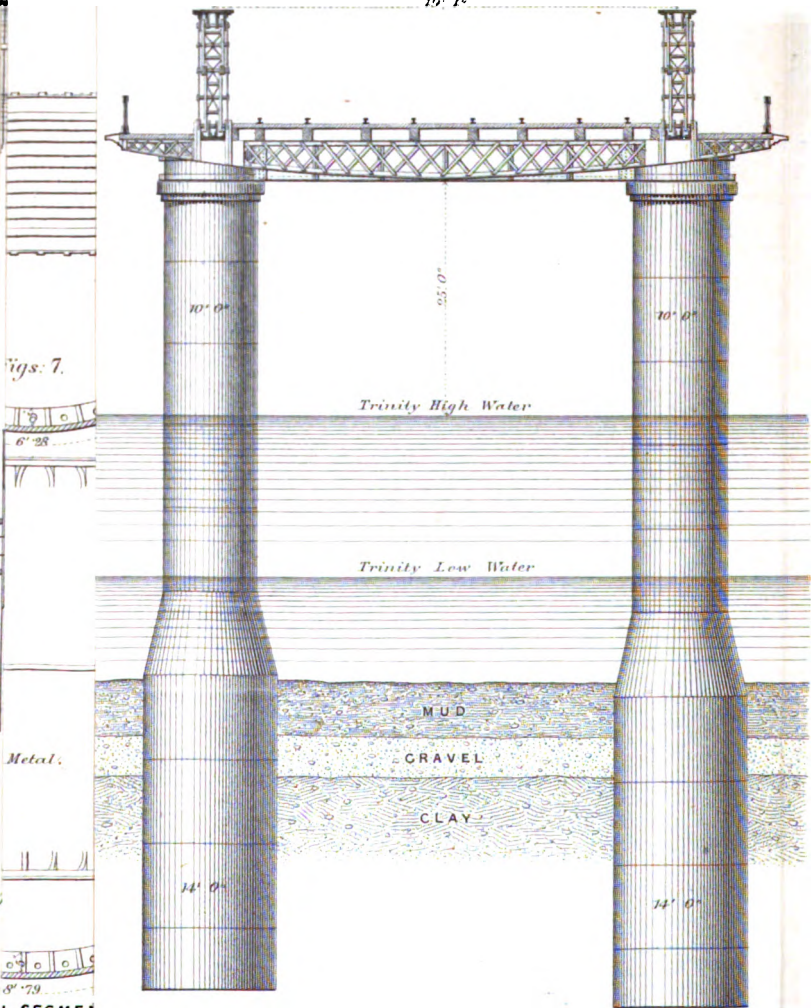
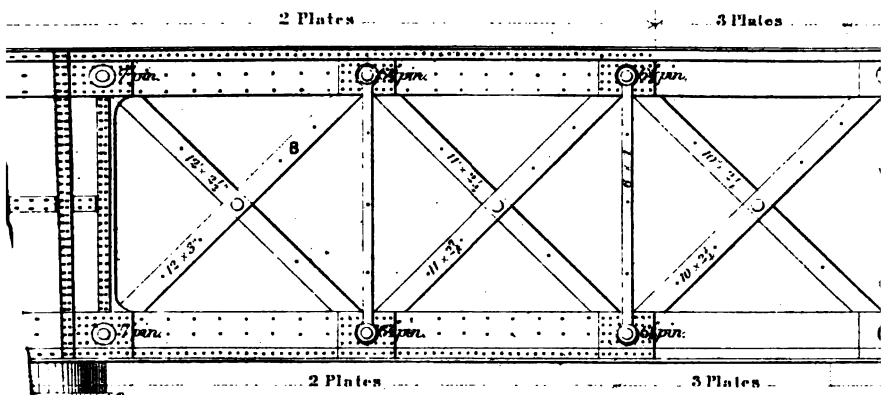


Fig. 3.

19' 1"

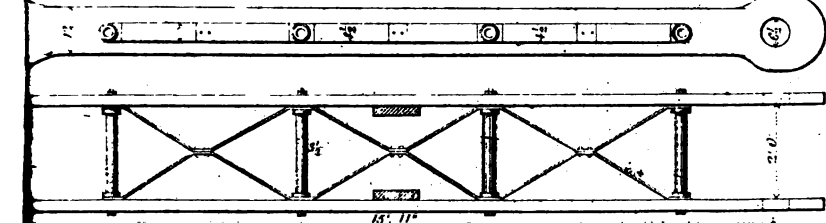


CROSS SECTION OF OPENINGS 154 FEET SPAN.

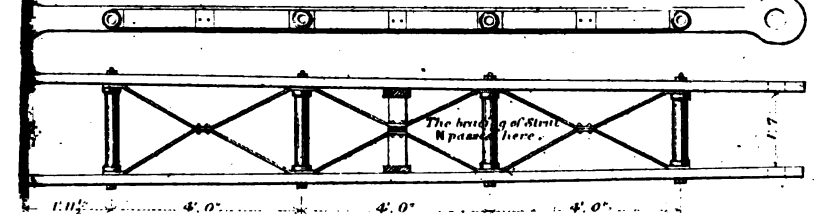


*Figs. 2*

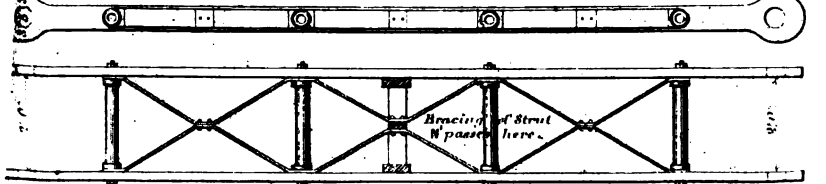
**Strut B.**



**Strut O.**

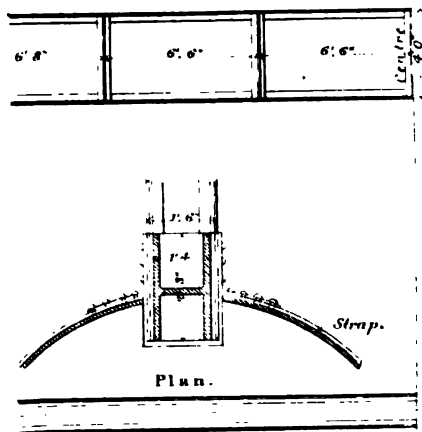


**Strut O'.**



Scale for Elevation: 1/4 Inch = 1 Foot.

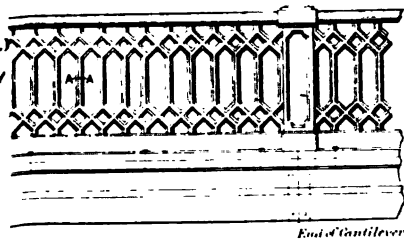


Figs. 12.  
Elevation.

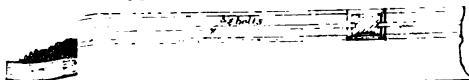
R CONNECTING CYLINDERS.

Scale 1/4 Inch = 1 Foot.

1 2 3 4 5 6 7 8 9 10 Feet

Figs. 13.  
Elevation.

Plan.

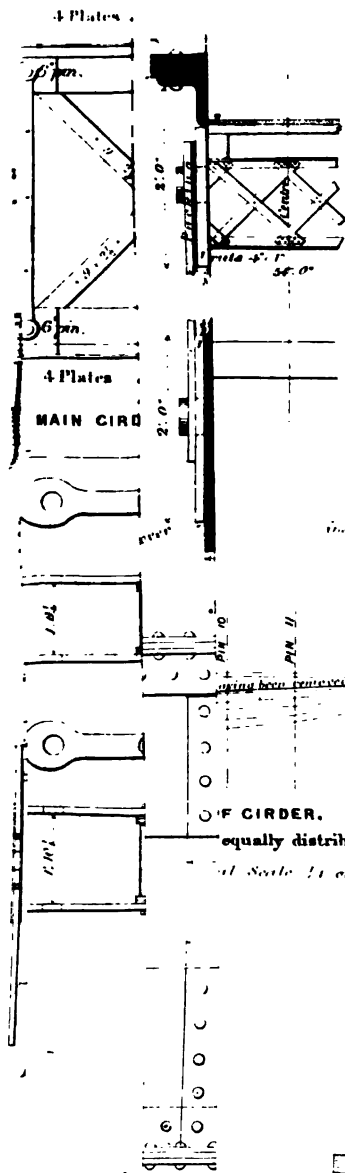


G AND CORNICE.

Scale 1/4 Inch = 1 Foot.

1 2 3 4 5 6 7 8 9 10 Feet

FALL BRIDGE CASTLE STUBBORN.

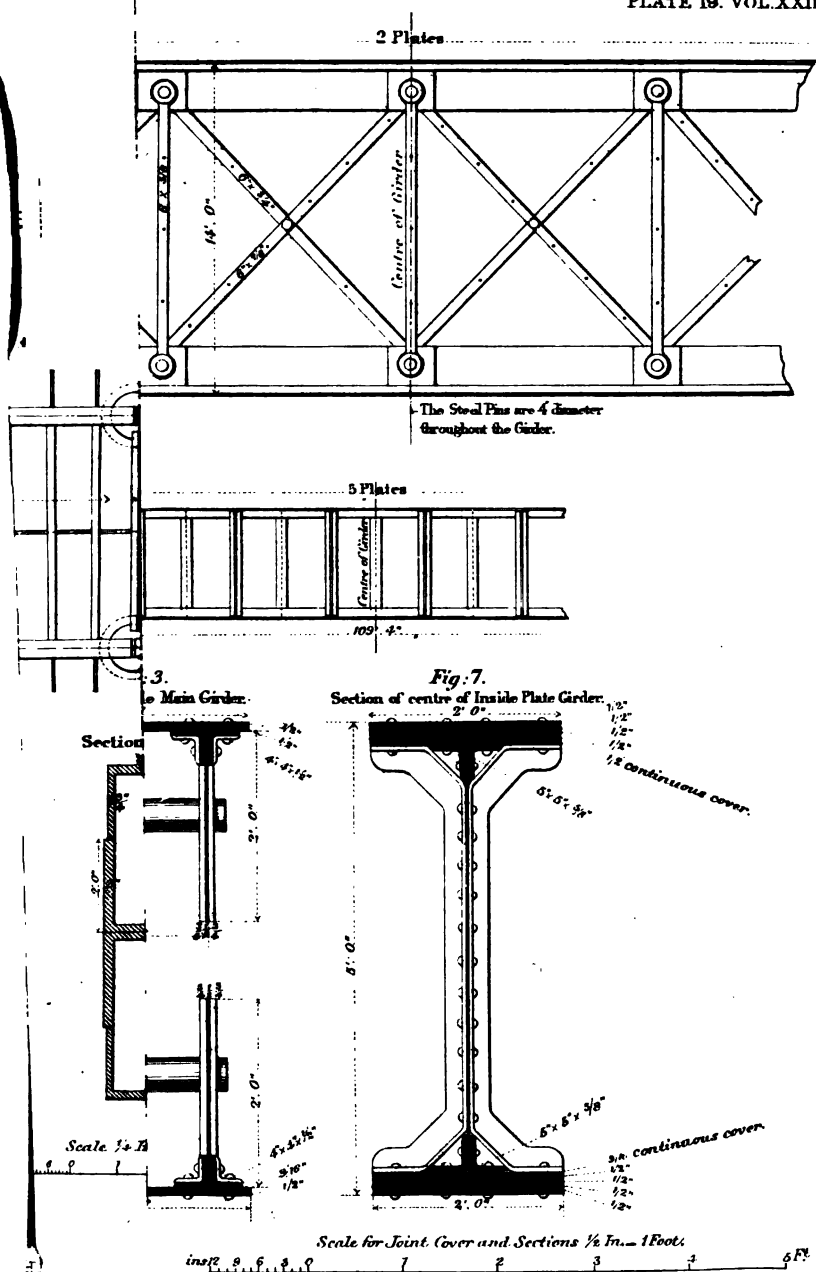


AD.

Scale 1/4 Inch = 1 Foot.

1 2 3 4 5 6 7 8 9 10 Feet

ceiling





## APPENDIX.

Results of Experiments on Plate Iron, of the kind used in the construction of the Charing Cross Bridge.

Brand L  W  
O

NOTE.—The whole of the Extensions were taken with an Extensometer up to a load of 18 tons, when the Extensometer was removed, the remaining Extensions being taken by compass and scale.

The four Plates operated upon were each reduced to a sectional area of 1 square inch as nearly as possible, the following being the exact dimensions:—Plate in Experiment No. 1,  $2\cdot04 \times \cdot51$ ; Plate in Experiment No. 2,  $2\cdot04 \times \cdot51$ ; Plate in Experiment No. 3,  $2\cdot03 \times \cdot51$ ; Plate in Experiment No. 4,  $2\cdot03 \times \cdot51$ .

All the Extensions were taken after the movement had ceased unless otherwise noted. The load was applied by an Hydraulic Press connected with Naylor's Pressure Gauge.

| Load in<br>Tons. | Extension in Inches of One Lineal Foot. |                     |                     |                     | Permanent Set in Inches of One Lineal Foot. |                 |                 |                 |
|------------------|-----------------------------------------|---------------------|---------------------|---------------------|---------------------------------------------|-----------------|-----------------|-----------------|
|                  | Plate<br>No. 1.                         | Plate<br>No. 2.     | Plate<br>No. 3.     | Plate<br>No. 4.     | Plate<br>No. 1.                             | Plate<br>No. 2. | Plate<br>No. 3. | Plate<br>No. 4. |
| $2\frac{1}{2}$   | begins to<br>extend                     | ..                  | ..                  | begins to<br>extend | ..                                          | ..              | ..              | ..              |
| 3                | ..                                      | begins to<br>extend | begins to<br>extend | ..                  | ..                                          | ..              | ..              | ..              |
| 10               | ·010                                    | ·009                | ·008                | ·009                | ·000                                        | ·000            | ·000            | ·000            |
| 12               | ·014                                    | ·010                | ·010                | ·010                | ·000                                        | ·000            | ·000            | ·000            |
| $13\frac{1}{2}$  | ·015                                    | ·012                | ·011                | ·011                | ·000                                        | ·000            | ·000            | ·000            |
| 15               | ·016                                    | ·014                | ·011                | ·012                | ·001                                        | ·001            | ·000            | ·000            |
| 16               | ·025                                    | ·035                | ·013                | ·015                | ·011                                        | ·021            | ·002            | ·001            |
| 17               | ·155                                    | ·150                | ·130                | ·130                | ·140                                        | ·136            | ·116            | ·114            |
| 18               | ·285                                    | ·255                | ·270                | ·260                | ·270                                        | ·237            | ·252            | ·248            |
| 19               | ·360                                    | ·330                | ·310                | ·290                | ·360                                        | ·330            | ·310            | ·298            |
| 20               | ·450                                    | ·500                | ·400                | ·360                | ·450                                        | ·500            | ·400            | ·360            |
| 21               | ·630                                    | ·580                | ·540                | ·490                | ·630                                        | ·580            | ·540            | ·490            |
| 22               | ·750 <sub>x</sub>                       | ·750 <sub>x</sub>   | ·710 <sub>x</sub>   | ·650 <sub>x</sub>   | ..                                          | ..              | ..              | ..              |
| Do.              | ·820 <sub>y</sub>                       | ·820 <sub>y</sub>   | ·800 <sub>y</sub>   | ·710 <sub>y</sub>   | ..                                          | ..              | ..              | ..              |
| $22\frac{1}{2}$  | ..                                      | ..                  | Broke               | ..                  | ..                                          | ..              | ..              | ..              |
| 23               | Broke <sub>z</sub>                      | 1·07                | ..                  | ·900                | ..                                          | ..              | ..              | ..              |
| $23\frac{1}{2}$  | ..                                      | Broke               | ..                  | Broke               | ..                                          | ..              | ..              | ..              |

<sub>x</sub> Are Extensions taken at once.

<sub>y</sub> Are Extensions taken after 2 minutes, when movements had ceased.

<sub>z</sub> Extension taken at once was 1·07, the plate breaking after the load had been on 1 minute.

The following are the dimensions in inches of the Plates measured at the fracture after breaking:—Plate No. 1,  $1\cdot96 \times \cdot48$ ; Plate No. 2,  $1\cdot94 \times \cdot47$ ; Plate No. 3,  $1\cdot98 \times \cdot48$ ; Plate No. 4,  $1\cdot95 \times \cdot47$ .

Mr. G. H. PHIPPS said, he had examined this bridge several times during its progress, and he considered the workmanship was the finest he had ever seen. The finish was more like joiners' work than ordinary boiler-plate construction. Although the merits of nearly every variety of girder had been canvassed in the Institution, he hoped it would not be deemed out of place, or hypercritical, to draw attention to some minutiae of the construction of this bridge. The form of the upper member of the main girder might be compared to an inverted trough, but having, besides the external sides, two other longitudinal plates dividing the trough into three parts. The top of the trough was of considerable substance, but towards the ends of the girder, the external sides were each 2 feet deep and  $\frac{3}{4}$  of an inch thick. The pins by which the diagonals were attached to the top of the girder, at intervals of 11 feet from centre to centre, and along the line of which the pressure was propagated from the ends to the middle, were, he thought, too low down; being, in effect, about 8 inches below the centre of gravity of the section of the trough. Wherever the object was to communicate pressure to any material acting in the nature of a column, it was important to carry that pressure along the line of the centre of gravity of the section; for if this precaution were neglected, flexure must take place. In the Newark Dyke bridge,<sup>1</sup> the upper, or compressed member, was made of cast iron, the strain being carried, as it ought always to be, through the axis of the column. Referring, now, to the Charing Cross Bridge, the sectional area of the iron at the middle of the second bay from the end of the girder was not so great, of course, as at the middle of the girder; but the pressure brought on there by the diagonals was greater in proportion than it was in the middle. If his calculations were correct, it would appear, supposing all the iron in the section to be compressed, square on, to the extent of 3 tons per square inch, that that pressure was increased, by flexure, to about 7 tons per square inch on the outside fibres at the lower edge of the trough. There was no point in the construction to which more attention ought to be paid, than this agreement of the line of strain with the neutral axis of the column; and where the intervals between the points of application of the compressing force were considerable, in the present case as much as 11 feet, in which there was room for the column to bend, the matter was very important. In the Britannia Bridge, where the area of the upper member was very great, the pressure was brought on by rivets every 4 inches, and though these were attached quite at the bottom, the radius of flexure could never be greater than that due

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<sup>1</sup> *Vide* Minutes of Proceedings Inst. C.E., vol. xii., pp. 601-611, for "A Description of the Newark Dyke Bridge, on the Great Northern Railway," by J. Cubitt.

to the whole deflection of the bridge. The case was very different where the pressure was brought on at wide intervals, and the wider these were, so much the more would be the importance of confining it to the axial line of the material. He would like to hear the opinions of other Engineers on this question, inasmuch as if he were correct in his assumption, that the strain might thus be increased from 3 tons up to 7 tons on the square inch, on any of the fibres of the material, it was evidently a consideration that could not be safely neglected.

Mr. HEMANS said, he regarded this bridge as one of the most perfect pieces of ironwork of the kind ever produced. The great duty each individual cylinder had to perform, from their being so wide apart, and the great load they had to sustain, under the severe tests applied, showed that the work had been admirably put together. There was one part of the structure, however, which seemed to admit of criticism;—that was, the mode of suspending the cross girders, by stirrup-irons, which he thought was not usual; nor did he observe, in the Paper, that the sectional area of the rivets attaching the stirrup-irons to the bottom girders was stated. As a matter of taste, the appearance of the structure would have been improved, if the bottom line of the bridge had been continuous, and the ends of the cross-girders had not been shown. Though there might be a difficulty in making a continuous line, in consequence of the projection for the formation of the footway, still means might be devised for uniting the ends of these girders, so as to present a continuous line. That mode of construction had been adopted in the little bridge over the ornamental water in the St. James's Park; but he thought the effect in that case was not good. He could not agree in the views which had been expressed, as to the position of the pins relative to the top and bottom webs, causing so much greater pressure; because the ultimate thrust and strain must come upon the top and bottom webs, and could not be taken as confined entirely to the line of the pins.

Mr. J. M. HEPPEL said, it has been truly stated, that no universal rule could be laid down for the adoption, under all circumstances, of either continuous or non-continuous girders. In India he had used the continuous girder, not only for the sake of economy of materials, but also for convenience of construction; because the effect of that plan was to save the necessity for providing staging, or scaffolding. The girders were constructed in continuous spans of two lengths each, so that each girder had three bearings,—one in the centre and two at the ends. These double-span girders were put together at one end of the bridge, and were then hauled over to their bearings on the piers. The rivers in India being subject to heavy periodical floods, the erection of staging was a difficult matter, and the plan alluded to had been

found to be very advantageous. He imagined, in the present instance, with girders of such magnitude it might be attended with more difficulty. In the cases he referred to, the spans of the girders did not exceed 70 feet, or 80 feet. With regard to the observations of Mr. Phipps, he should have thought the deviation of thrust from the centre of resistance of the upper member, which might be considered in the nature of a column, was calculated to act prejudicially upon it; at the same time it was but fair to presume, that the designer of the bridge had kept that point in view, and would be able to show, that it had been designed throughout on the best principles.

Mr. JOHN COCHRANE said, it was a matter of some difficulty to give a verbal description of the drilling-machine, because, though simple in its action and effective, it was rather complicated in its parts. In consequence of the great number of plates in the top and bottom flanges, Mr. Hawkshaw decided, in order to secure accurate work, that the rivet-holes should be drilled, and not be punched out. For that purpose a machine was designed, which was capable of drilling all the holes through one series of plates, simultaneously, as it would have been too costly to have drilled each hole separately. The result was, that the cost of drilling was less than that of punching; and the cost of three of these machines was covered by the saving of labour which they effected. The main girders had a camber of 4 inches in the middle. This was not obtained in the ordinary way, by variation in the lengths of the diagonals, but by drilling the holes in the plates of the top flange with a pitch of 4 inches, and in the bottom with a pitch of 3·995 inches. Of course great mechanical accuracy was necessary to secure so small a variation, but when the girders were erected, the camber was perfect.

Mr. F. J. BRAMWELL remarked, that they owed a great deal to the President for having decided that the holes should be drilled, and to Messrs. Cochrane for designing the machinery which made it practicable in a commercial point of view. Nothing could be more barbarous than punching the holes. It was a process that destroyed the iron; it was, generally speaking, inaccurate; and it rendered uncertain what portion of the iron carried the strain. It could not be too generally known, that good workmanship was always the cheapest.

Mr. J. SCOTT RUSSELL, V.P., said, that before seeing this bridge, he had been in favour of that more simple process which approached nearer to ship-building and to ordinary girder-building; but the workmanship of this structure appeared to be more of the nature of fitted and finished engine work, and therefore likely to be on the whole more costly, than a simple lattice, or girder bridge. It did not, however, appear, from the actual prices given, which he

hoped had been satisfactory to the contractors, that the cost of the bridge was greater than that of a lattice, or a girder bridge; while the workmanship was, in accuracy and precision, greatly superior to anything usually met with in such structures. The success of the plan for drilling rivet-holes had certainly been complete. The general design and organization of the work had enabled this accuracy to be attained; but unless a bridge was systematically designed, so as to admit of the easy application of this system, it might turn out to be dear and unsatisfactory. He should like to hear the reasons which had caused the principle of continuity in the girders not to be adopted to the full extent. He had so high a sense of the value of continuity, that unless the local difficulties were considerable, and the special advantages of an opposite course were very strong indeed, he should in all cases make such a bridge as this continuous. So far as he understood Mr. Phipps' remarks, he agreed with them in principle, he could not say in measure, because he had not made the necessary calculations. He quite felt that the pins which terminated the parallelogram were a great way from that part of the upper web which did sustain the strain, and that before the strain was conveyed to a sufficient quantity of that section, the pins themselves would undergo a strain nearly double that which the top of the girders would ultimately have to sustain as a mean of the whole. No doubt there was some explanation for that, and he only repeated his impression of the correctness of that statement, in order to elicit from Mr. Hawkshaw a full narration of all the circumstances. Possibly it might be said, that the parallelograms, as constructed, took off so much of the strain, that there remained only a comparatively small strain between point and point.

Mr. E. A. COWPER observed that if, as he imagined was the case, in the last bay there was a thick joint to receive the last pin; and that bay was stiffened, to a considerable extent, with plate, so that instead of the line of thrust being horizontal it might with safety be slightly inclined, there could be no objection to the construction. He should be glad to know how the proof weight of 400 tons, for one bay of 154 feet, had been arrived at. It was an excellent proof weight for a girder supporting two lines of rails, as it amounted to nearly  $1\frac{1}{2}$  ton per lineal foot on each line, and locomotives frequently weighed 1 ton per lineal foot, or even a little more. He thought all bridges ought to have ample strength to carry a crowd of people; and the public had a right to be informed, what proof weight was adopted, by the Government Inspectors, for proving common road bridges, such as those at Westminster and at Lambeth. He had tried the weight of a number of labourers, by weighing each man individually, and then by measuring the exact space they occupied when standing close together, as in a

crowd, when he found their collective weight was fully 140 lbs. per square foot; therefore in designing bridges of large and small spans, he had taken 140 lbs. per square foot as the possible load. He was, however, aware that from 60 lbs. to 80 lbs. was often taken as a test load, but that was far below the weight of a crowd of able-bodied men.

Mr. R. MALLET remarked that, during the building of Buckingham Palace, Mr. Nash ascertained the greatest possible load of human beings that could be brought upon a given space, with reference to the so-called fire-proof floors of the Palace. Within a hoop, he thought of about 20 feet diameter, as many men were caused to stand as could be wedged into it, the last men being lowered down amongst the others. The result gave a load of 120 lbs. per square foot. The particulars of that experiment would be found in the blue-book relative to the floors of that Palace.

Mr. HAYTER stated, that 70 lbs. per square foot was probably the maximum living load that could be crowded on a given space. It was not important to determine this with accuracy, as regarded the Charing Cross Bridge, inasmuch as the side footpaths were the only public thoroughfares across it, and the load on these would be insignificant, when compared with the load that could come on the bridge, if the four lines of railway carried by it were weighted. He might, however, mention, that Messrs. Cochrane and Co. had tried an experiment, selecting for it the tallest and most muscular men in their establishment, and the result proved that the above estimate of 70 lbs. was ample.

In answer to the inquiry as to the amount of strain on the rivets by which the angle-irons carrying the cross girders were attached to the main girders, and also the amount of the strain on the rivets uniting the cross girders to these angle-irons, he would remark that this—which would be a direct shearing strain—would amount to about 3 tons per square inch. This would be the case, assuming a moving load of heavy locomotive engines packed closely together on the four lines of railway, and the footpaths simultaneously crowded with people—an excessive assumption, inasmuch as it was inconceivable that such an occurrence could ever happen by mere accident.

Mr. F. W. SHEILDS said that, with respect to placing the pins in the centre of the section of the top flange, all his experience convinced him, that such a construction, however plausible, was not calculated to obtain the best results from the iron. He believed that the greater part of the section should be at the top of the flange, where the strain was most severe, as in dealing with iron the object was to prevent the commencement of fracture. It was sufficient, therefore, in all such cases, to provide that the pin

which attached the diagonal brace to the flange should have sufficient section of flange underneath it to prevent the pin from tearing away from the flange; and if that were done, the pin might be trusted with safety to distribute the compression along the length of the flange. It appeared that the amount of pressure, 8 tons per square foot, upon the clay bottom in the cylinders, was somewhat unusual. In his own practice, unless the clay was indurated so as to approach the nature of shale, he should hardly think of exceeding 4 or 5 tons per square foot. No doubt the results of the severe tests which had been applied to the Charing Cross Bridge were the best proof of its solidity. With regard to the workmanship of the girders, he could also bear his testimony, that he never saw so accurate and well-finished a piece of work of the kind.

Mr. HAWKSHAW,—President,—said, the weight that could be put upon London clay would depend upon the point where the weight was placed. All geologists knew, that if London clay was penetrated to a sufficient depth, it was capable of carrying a very great weight, much more, in fact, than he had put upon it, although the clay near its surface could not generally be loaded to that extent. With regard to the observations of Mr. Phipps, he agreed that it was desirable the pins should be, as nearly as possible, in the line of the centre of gravity, but practically, in all plate girders, it was difficult to do so. In the case of the Charing Cross Bridge, there must be room for the pins, which were 8 inches in diameter, and for the upper portion of the diagonal bars, which were large forgings. Care was taken to provide sufficient strength in the web, through which the pins passed, to avoid mischief.

With reference to the loading of the cylinders, the first two were tested with 700 tons each, and the others with 400 tons each; the greater load was not continued, as it was a tedious, and rather dangerous, process to build up a solid cube of rails 22 feet square, upon cylinders 10 feet diameter, before any stays were attached to them; and it required careful balancing to make the experiment. In applying the load of 700 tons upon the cylinders, as it was necessary to prevent the weight bearing on the castings, spruce deal planks, 3 inches in thickness, and having together a diameter of rather less than 9 feet, were laid upon the top of the brickwork in the cylinder. The upper surface of these planks was about 2 inches above the edge of the cylinders, and on this surface a thin stratum of cement, nowhere exceeding 1 inch in thickness, was carefully laid, to receive first flat-bottomed iron rails, and then other rails laid crossways, and so on, until the cube of 22 feet was built up. When the rails were taken off, there was not the slightest crack in the cement, and the spruce deals looked as if they had not carried any weight. He was surprised to find so

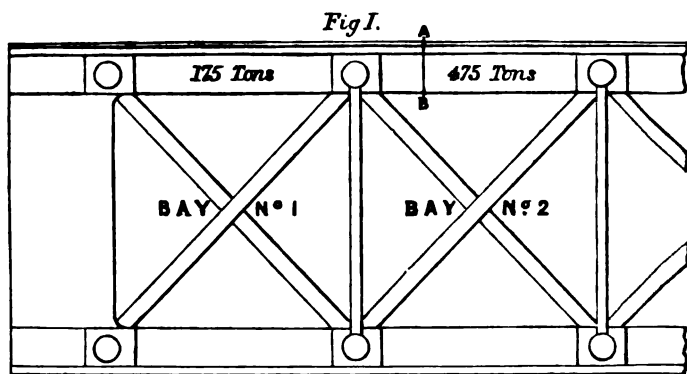
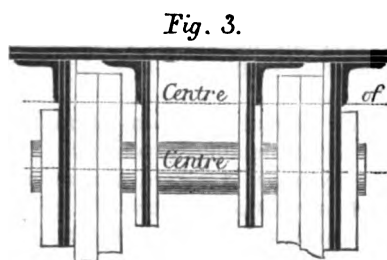
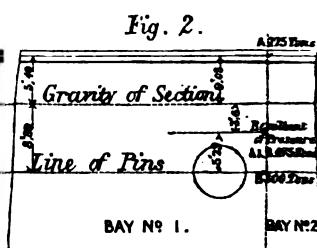
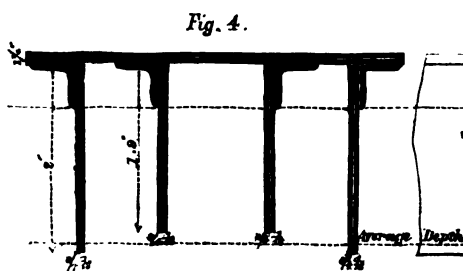
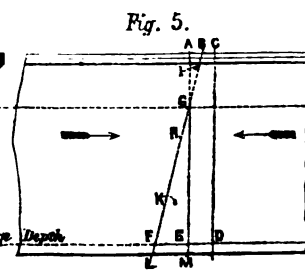
thin a layer of cement, placed on an irregular surface of wood, carrying so great a weight, without a trace of the work it had performed. He gave up the continuity in the construction of the girders with some reluctance. At one time it was thought that the girders might be constructed singly, and be lifted into their places. Then, in order to carry out the system of drilling, instead of punching, the plates, he was desirous of simplifying the plates as much as possible. The whole bridge consisted of a repetition of a few forms; two sizes of plates, with a given number of holes in each, being all that was required for a large portion of the structure. By means of the ingenious machine designed by Messrs. Cochrane, for drilling the plates, much better and stronger work had been obtained. The drilling was executed with very remarkable accuracy. He saw plates of the same description piled one upon another for a height of 6 feet, and the accuracy of the drilling was such, that on putting the finger into the holes, or looking down them, they appeared nearly as smooth as the inside of a gun-barrel.

As to the appearance of the ends of the suspended cross girders being objectionable, when the footway was completed that defect would be removed, as the ends would then be hidden from view. He had been found fault with for assuming so much as 80 lbs. per square foot, as the weight of a crowd of human beings. French engineers, and others, were said to be content with 50 lbs. to 60 lbs. per square foot: but he was satisfied with 80 lbs. per square foot,—not that it had much to do with his calculation, because the test on this bridge would be chiefly locomotives. He was bound to say that the work had been executed by Messrs. Cochrane in a very accurate and creditable manner.

Mr. J. SCOTT RUSSELL, V.P., remarked that in the bow and string bridge erected over the new street at Southwark, for the Charing Cross Railway, the top and bottom members were similar to those of the parallel girder bridge over the Thames at Hungerford; but in the former case the points of support of the diagonals were even farther away from the centre of gravity of the cross section at the top, than in the Charing Cross Bridge; so that the defect pointed out by Mr. Phipps, if it really was a defect, was carried to a greater extent in that structure. However, in the bow and string bridge, the uprights and the diagonals had much less to do; indeed, from the ends being filled up solid, he thought the Engineer intended that the work should be done by the top and the bottom members, the diagonals merely keeping the truss in shape. If that were so, no doubt the construction was right; and in this case, with proper proportions, the work would undoubtedly be duly performed. Now, in

the case of the Charing Cross Bridge, the top and the bottom members each consisted of a three-sided box, one of the three sides of each being composed of a large mass of plates, the uprights and the diagonals being at a considerable distance from the centre of gravity of the cross section of the top and bottom members, and the truss being filled up solid at both ends. Therefore, what had, in his opinion, to be determined, was the share of the work which the uprights and the diagonals took. If these were expected to bear a great part of the burden of the work, then he could agree with Mr. Phipps, that the points were too far removed from the centre of gravity of the top and bottom webs, and therefore from their work, and that a heavy strain would come upon them. If, on the contrary, the top and bottom were so firmly fastened, as in this case, that they might be depended upon to do the major part of the work, then the diagonals and the uprights were mere stays to keep the truss in form, and the evil likely to arise from the displacement, so to speak, of the centres of action, was not great; and Mr. Shields would, under such circumstances, be perfectly right in saying, that the points of attachment should be kept from interrupting the continuity of the top member, and that it would be preferable to cut the flanges at some distance from the centre of gravity of the cross section, than in any way to interfere with their continuity.

Mr. PHIPPS thought the question he had raised was of sufficient importance to justify a closer examination; especially as the opinion seemed to be entertained by some Members, that although his theory might be correct, yet very little effect would be produced upon the bridge from the cause referred to. For the sake of brevity, his remarks would be limited to the upper, or compressed, member of the girder, although it was obvious that similar reasoning would apply equally well to the lower, or extended, member. The effect on the former, however, was well understood to be the more detrimental of the two. The calculations applied to the upper part of the girder, in the second bay from the end, at A B, Fig. 1, page 536. With a distributed load of 700 tons on one girder, including the weight of the girder itself, the pressure on the upper member in the first bay would be 175 tons, and in the second bay 475 tons, leaving 300 tons of pressure to be brought on to the intervening pin by means of the diagonals. It was not easy to determine at what height above the centre of the pin this pressure of 175 tons was transmitted from the first bay to the second; but he had assumed it as being very near to the top part of the compressed member, which he had reason to believe was not far from correct. With these data, the resultant of the pressure at A, of 175 tons, and at B, of 300 tons, was 475 tons at C, Fig. 2, a point situated 3.6 inches below the line of the centre



of gravity of the section. Fig. 5 exhibited the manner in which this force of 475 tons operated to produce detrimental pressure on the outer fibre of the iron at M. The method of ascertaining this had occurred to him two years ago, when studying the strains upon iron arches, in cases where the curve of equilibrium had travelled away from the line of the centre of gravity. It depended upon this axiom, that whenever a prism of any elastic material was compressed by a force on some line not corresponding with its centre of gravity, flexure must take place, and that to such an extent as would remove the centre of resistance from its original situation until it was perpendicular beneath the force applied. Now, the force of compression on the prism, when applied over the centre of gravity of section G, Fig. 5, might be represented by the content of the solid intercepted between two parallel planes A E and C D. If the compressive force be removed from G to H, in the line of the arrows, the flexure which would ensue might be represented by a certain amount of angular motion of the plane A G M, around the centre of gravity G. By a property of the centre of gravity, any angular movement around G would generate solids of equal magnitude, G A B and G E F, on contrary sides of the centre, and these represented equal forces. Now if I, and K, were the centres of gravity of these solids, then, in order that the point H should become the centre of gravity of the solid F B C D, the solid A C D E into G H must be equal to  $(G A B \times G I) + (G E F \times G K)$ . When this condition was fulfilled flexure would cease, and H would be the true centre of resistance directly opposed to the compressive force. If E D be laid down from any scale of equal parts, as equal to the pressure in tons on the square inch, then L M would represent the additional pressure brought on the outside fibre of the iron, on account of the flexure, and A B would represent the diminution of pressure on the uppermost fibre.

Applying this to the Charing Cross Bridge, and calling—

|                                                                     |                         |
|---------------------------------------------------------------------|-------------------------|
| $a$ = the area of the whole section of the girder . . . . .         | = 161·25 square inches. |
| $b$ = the total pressure . . . . .                                  | = 475 tons.             |
| $c$ = the pressure on the square inch . . . . .                     | = 2·94 „                |
| $d$ = the solid A C D E = $a \times c$ . . . . .                    | = 475 „                 |
| $e$ = the solid G A B.                                              |                         |
| $f$ = the solid G E F.                                              |                         |
| G H . . . . .                                                       | = 3·6 inches.           |
| I K . . . . .                                                       | = 16·37 „               |
| G E = the average depth below G . . . . .                           | = 17·75 „               |
| G M = the full depth below G . . . . .                              | = 19·25 „               |
| $t$ = the aggregate thickness of the four vertical plates . . . . . | = 3·25 „                |

$$\text{Then } f = \frac{d \times G \ H}{I \ K} = \frac{475 \times 3 \cdot 6}{16 \cdot 37} = 104 \cdot 4,$$

and in consequence of G E F being a triangle

$$F \ E = \frac{104 \cdot 4}{G \ E \times \frac{1}{2}} = \frac{104 \cdot 4}{17 \cdot 75 \times 1 \cdot 62} = 3 \cdot 63.$$

$$L \ M = F \ E \times 1 \cdot 08 = 3 \cdot 63 \times 1 \cdot 08 = 3 \cdot 92.$$

$$A \ B = \frac{L \ M}{3 \cdot 2} = \frac{3 \cdot 92}{3 \cdot 2} = 1 \cdot 2.$$

Thus, then, the square on pressure = E D = 2 \cdot 94 tons on the inch.

The pressure on the bottom fibre = E D + L M = 2 \cdot 94 + 3 \cdot 92 = 6 \cdot 86 tons on the inch.

The pressure on the upper fibre = A C - A B = 2 \cdot 94 - 1 \cdot 2 = 1 \cdot 74 ton on the inch.

Mr. HAWKSHAW,—President,—thought that Mr. Phipps' observations on the Charing Cross Bridge were sound. It was clear that the diagonal strain on that bridge must be transmitted from one pin to another, along the top and bottom members of the bridge; and the nearer those strains passed along the line of the centre of gravity of those members the better. He did not however agree, that in boiler-plate bridges this desideratum was secured by the closeness of the rivets which connected the sides to the top and bottom. He believed the objection applied with more force to many of those bridges than to the Charing Cross Bridge. The girders of the Charing Cross Bridge were so designed, that the diagonal strain at the ends of the girders, if passed from pin to pin, through the vertical webs only, could produce no injurious effect, for the vertical webs at those points were made very strong; and the diagonal strains at the centre of the bridge were so small, that the vertical webs at that point also were stronger than necessary for the mere transmission of the vertical strains. Mr. Scott Russell had, in discussing this point, compared the Charing Cross Bridge with another bridge which was being erected over the new street in Southwark. But that bridge was constructed on totally different principles. It was in fact an arch, and Mr. Phipps' observations could not apply to it. It followed the same laws as any other arch, the weight being merely suspended from, instead of being placed upon, it. The bottom web was substituted for fixed abutments, and it also served to stiffen the roadway and to distribute the load. In that bridge the diagonal braces might be taken away, and still the bridge would stand. They were, however, of use

in assisting to distribute the load, and to provide, to some extent, against flexure in the arch. For with loads unequally distributed, all iron arches were subject to flexure. This accounted for the small strain per ton which, it had been observed, was usually placed upon iron arches. If those arches could always be uniformly loaded, the whole would be put in compression; but light malleable and cast-iron arches, with heavy rolling loads, were subject to compression in some parts, and to extension in other parts; and thus it happened that a considerable portion of the cast-iron arches usually erected were not always available in resisting compression, and hence frequently not more than  $1\frac{1}{2}$  ton to the square inch, having regard to their whole sectional area, was placed upon them. In some cast-iron bridges subjected to the rolling load of a railway, probably not one-half the section of the rib would be brought into compression.

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May 5, 1863.

JOHN HAWKSHAW, President,  
in the Chair.

The following Candidates were balloted for, and duly elected :—  
JOHN BLOUNT and Captain VIRIATO DE MEDEIROS, as Members ;  
EDWARD APPLETON, Captain FRANCIS JOHN BOLTON, and ROBERT  
TREFUSIS MALLET, as Associates.

No. 1,091.—“ American Iron Bridges.” By ZERAH COLBURN.

In the United States, the first cost of the truss, or ‘superstructure,’ of a timber bridge of any given span is generally less than one half that of an iron bridge of the same strength. This fact will account for timber bridges having been so largely adopted in America. Iron was occasionally employed there as long ago as 1835, but it is only within the last ten or twelve years, that it has been used to any considerable extent. At the present time, it is generally admitted by American Engineers, that the original cheapness of timber structures does not compensate for their rapid decay, their frequent destruction by fire, and the constant repairs and watching which they demand.

Among the earliest iron bridges erected in that country were a few cast iron tubular arches, including one of 80 feet span. The design of these was due to Major Delafield, of the United States Engineers, who adopted them at about the time when somewhat similar arches were employed in France, by the late M. Polonceau, in the construction of the Pont du Carrousel, over the Seine. Major Delafield’s arched ribs were elliptical in section, the transverse vertical axis being about four times the length of the conjugate axis. In 1858, an aqueduct bridge was erected at Washington by Captain Meigs, of the United States Engineers, who used for this work two arched ribs formed of water-pipes, through which the water flows, the pipes being circular in section, as that form encloses the greatest quantity of water with the least amount of iron. (Plate 20, Fig. 1.) The span of this bridge is 200 feet, the rise being 20 feet ; and the width of the bridge over all is 28 feet. The pipes are 4 feet in diameter inside, and  $1\frac{1}{2}$  inch thick. They are lined with staves of resinous pine, 3 inches thick, to prevent the freezing of the water. The pipes are not cast to the curve of

the arch, but are in straight lengths of about 12 feet, with flanged joints, faced in planes parallel to the corresponding radii of the arch. At the skewbacks, the ends of the pipes are faced to large conical bases admitting the water, and resting upon the masonry. There is no allowance for expansion, or contraction. The roadway is of timber, supported on spandrels formed of rolled wrought iron beams 9 inches deep, and weighing 90 lbs. per yard. The bridge was tested with the arched ribs filled with water, and with a load of 125 lbs. per square foot upon the roadway. The weight of each arched rib, when filled with water, is about 160 tons; that of the spandrels of each rib and of one-half of the roadway is about 30 tons; while the test load was equal to about 160 tons on each half of the roadway, making the whole weight about 350 tons on each rib. The thrust of one-half of this weight upon each abutment would be about 470 tons, and as there are  $238\frac{1}{2}$  square inches of sectional area of iron in the pipes, this would correspond to a strain of about 2 tons per square inch. This strain, while it includes that due to the weight of the water in the pipes, is exclusive of that due to its pressure. The pipes were proved to a pressure of 300 lbs. per square inch.

Major Delafield's and Captain Meigs' bridges are, so far as the Author is aware, the only iron arches yet completed in the United States; unless the application, in 1849, of a light cast iron arch to each side of a timber truss, of 133 feet span, on the Pennsylvania Central Railroad, may be regarded as another instance. A roadway bridge, with two cast iron arched spans of 185 feet each, to cross the Schuylkill River at Philadelphia, had been designed by Mr. Strickland Kneass, C.E., and was about being let to contract when the Author was last in America. The rise of these arches was to be 20 feet, and the whole width of the roadway and of the footways 42 feet. Each arch was to be formed of seven ribs segmental to a circle of 224 feet radius, and of a uniform depth of 3 feet 6 inches; the top and bottom flanges were to be 8 inches wide and 3 inches thick, the web  $2\frac{1}{2}$  inches thick, and the whole sectional area of each rib 138 square inches. The thrust at the skewback of each rib, including that caused by the weight of the spandrels, cast iron floor-plates, 6 inches of gravel, a granite paving, and a load of 70 lbs. per square foot of the roadway, will be 217 tons, equal to 1.63 ton per square inch of the section of the rib. In addition to diagonal bracing of cruciform section, the ribs are to be tied together at fourteen points in their length, by round wrought iron rods, enclosed in cast iron distance pieces. The spandrels are to be upright posts, 4 feet apart from centre to centre, cruciform in section, and having each  $28\frac{1}{2}$  square inches of cross sectional area. Some ornament is contemplated upon the bridge, but the violation of symmetry, involved in the adoption of an even

number of arches, would alone prevent its consideration as a work of art.

But few simple, or compound cast iron girders are in use as bridges in America; and the instances already given include, it is believed, nearly all the cast iron bridges in that country, with the exception of a few cast iron pivot bridges, and perhaps one, or two ornamental bridges in the Central Park at New York. Long accustomed to trussed timber bridges, American Engineers, in adopting iron, naturally employed it in trusses also; and, with the exception of the tubular and plate girder bridges erected under the direction of English Engineers in Canada, there are but a small number of plate iron bridges in America. The first was constructed in 1846, and was erected in place of an old timber bridge in 1847, by Mr. James Millholland, then the Engineer to the Baltimore and Susquehanna (now the Northern Central) Railroad. This was 50 feet span, and the girders were each formed of two sides of plates  $\frac{1}{4}$  inch thick and 6 feet in depth, a balk of timber 12 inches square being bolted, as a compression member, between the sides at the top, which was further stiffened by two wrought-iron bars, 5 inches deep and  $\frac{3}{4}$  inch thick; while four bars, each 5 inches by  $\frac{3}{4}$  inch, were riveted along the bottom of each girder. The sides of each girder were stiffened by stay-bolts  $\frac{3}{8}$  inch diameter, enclosed in cast iron distance pieces, and 12 inches apart from centre to centre. The centre of each girder was placed exactly under the rails, which were spiked to the timber forming the compression member of the girder. The breaking strength of the pair of girders would be equal to about 250 tons of distributed load, the weight of the bridge being 14 tons. When completed, this bridge was coupled at each end to a railway waggon; a temporary timber truss, resting through transomes upon the waggons, being erected over the bridge, which was then raised clear of the ground, and slung by chains to the truss. (Plate 20, Fig. 2.) A locomotive was next attached, and the bridge was thus taken 19 miles down the line, from Baltimore to a stream known as Carroll's Run. The plate girder bridge was run exactly over the place it was intended to occupy, the wheels of the waggons were blocked, and some large screws were set up, to lower the bridge from the trussing by which it was supported. The existing timber bridge was then cut away into the stream below, and the girder bridge was lowered into place with the permanent way ready for traffic. The temporary trussing was next taken apart and piled upon the waggons, the engine crossing the bridge to pick up one of them, and then returning home; the whole interruption to the traffic not exceeding two hours. Mr. Millholland afterwards erected a bridge of similar construction for ordinary street traffic in the city of Baltimore. This

latter bridge had four girders, 85 feet long, only 4 feet deep at the centre, and 3 feet deep at the ends. Mr. Herman Haupt, C.E., subsequently erected several boiler-plate bridges, of somewhat different construction, upon the Pennsylvania Central Railroad.

Before describing the various forms of iron truss bridges adopted by American Engineers, it is proper to give some information as to the strength of American iron. Exact data upon this point cannot easily be obtained; for, unfortunately, the practice of imposing a test of breaking strength, upon the iron supplied by contractors for large structures, has not been adopted in the United States. The Government there have, however, for many years caused careful experiments to be made upon the iron employed for, and upon samples cut from, guns cast for the coast and naval defences. The iron employed generally has a tensile strength of from 5 tons to  $6\frac{1}{2}$  tons per square inch in the crude state, or pig-iron. On melting this iron, however, it is kept for some time in fusion, and the first castings generally have a tensile strength of about 9 tons per square inch. For guns, the iron is now always re-melted, sometimes for the third or fourth time; and at each melting it is retained for from one to three hours in a state of fusion before being poured. This is done in an air-furnace, or, in other words, a furnace in which the fuel is burnt on a separate grate, and only the natural draught is employed. By this treatment the iron is decarbonised to a considerable extent, and its toughness is greatly increased. Iron of the second melting often has a tensile strength of 13 tons, and that of the third melting of  $15\frac{1}{2}$  tons. These may be given as about the mean of a number of experiments made by Major Wade of the United States Ordnance Board, and published, in 1856, in a quarto volume entitled "Reports of Experiments on the Strength and other properties of Metals for Cannon. With a description of the Machines for testing Metals, and of the Classification of Cannon in Service." The strongest cast iron tested by Major Wade had the great tensile strength of  $20\frac{1}{2}$  tons; samples cut from one hundred gun-heads had a mean tensile strength of 14.9 tons; a large number of proof bars in another case had a mean strength of 16.23 tons; and in the case of a 10-inch gun, cast hollow, upon Lieutenant Rodman's process, the mean tensile strength of thirty-eight samples was 16.875 tons, the strongest sample having a strength of 19.83 tons, and the weakest 15.275 tons. In another case, the mean strength of fourteen pigs of iron in the crude state was 5.66 tons, while that of twenty-seven guns cast from these pigs and others from the same furnace was 15.75 tons, the guns having been cast only after the metal had been three times melted, and kept in fusion from one to three hours at each melting. There appears to be but little iron in any American cast guns of a less

tensile strength than 11 tons per square inch; and in 1851, the Author himself saw portions cut from 11-inch guns, weighing 6 tons 15 cwt., tested up to 16.14 tons. Major Wade also tested the transverse strength of a large number of gun irons. The trials were made upon bars 2 feet long and 2 inches square, supported on knife edges 20 inches apart. The results may, however, be reduced to the standard to which English Engineers are most accustomed, that of a bar 2 inches deep and 1 inch wide, resting on supports 3 feet apart. Thus reduced, the transverse breaking strength of a large number of samples of re-melted iron, made from pigs cast at five different furnaces, varied from  $27\frac{3}{4}$  cwt. to 48.1 cwt., the general strength of the samples being 34 cwt. Major Wade also gives the crushing strength of the irons upon which he experimented, the minimum being  $37\frac{3}{4}$  tons, and the maximum  $77\frac{3}{4}$  tons. It should be observed that, by re-melting and protracted fusion, the specific gravity of the iron is raised from 6.9 in some cases to 7.4, or from a weight of  $430\frac{1}{2}$  lbs. up to  $461\frac{3}{4}$  lbs. per cubic foot. A Committee of the Franklin Institute made a series of experiments twenty-five years ago, from which it appeared, that the mean tensile strength of a large number of specimens of cast iron poured at the first melting was  $9\frac{1}{2}$  tons; and the iron employed by the Philadelphian Engineers now bears from 7.14 tons to 10.2 tons. Mr. Albert Fink, C.E., in testing the iron employed, in 1858, in the construction of a large bridge, on the line of the Louisville and Nashville Railroad, adopted bars of the sizes upon which Mr. Fairbairn had experimented, viz., 5 feet long and 1 inch square, placed on supports 4 feet 6 inches apart. Mr. Fink adopted, as his minimum transverse breaking weight, a load of 550 lbs. in the centre. From a published statement which he afterwards made of the results, it appeared that the mean breaking weight was 610 lbs., and the highest 728 lbs. Reduced to bars 2 inches deep and 1 inch wide, placed on supports 3 feet apart, the minimum breaking weight was  $29\frac{1}{2}$  cwt., the mean 32.68 cwt., and the highest 39 cwt. This iron was a mixture of two-fifths cold blast, two-fifths hot blast, and one-fifth scrap. Without the scrap, Mr. Fink says his bars would bear but 500 lbs., equal to 26.8 cwt., when reduced to the standard already referred to.

Of wrought iron, the experiments made by the United States Board of Ordnance gave a tensile strength ranging, with different specimens, from 17 tons to 33.3 tons per square inch. Experiments made twenty-five years ago, by a Committee of the Franklin Institute, gave a mean strength of about 26 tons for plate iron. At the present time 27 tons is generally expected of American boiler plate. Mr. Roebling, in his last Report to the Directors of the International Bridge Company, for whom he designed and

constructed the Niagara Suspension Bridge, details some experiments upon cold blast charcoal iron, the ultimate strength of which he gave as from  $31\frac{1}{4}$  tons to 35.71 tons per square inch. Bars of this iron, after lying in a winter's night at a temperature hardly above zero of Fahrenheit, were suddenly put under a strain of  $20\frac{1}{2}$  tons per square inch, with which there was no visible stretching. They were then struck violently with a heavy iron bolt, and only broke after a considerable number of blows. Professor Walter R. Johnson, by whom most of the Franklin Institute experiments were conducted, has tested iron bars, from the Lake Superior district, to the extraordinary tensile strength of 39.99 tons. In the year 1859, Mr. Albert Fink tested three bars of iron which had been in use for between seven and nine years, under full loads as tension bars in some of his bridges on the Baltimore and Ohio Railroad. One bar, 14 feet 6 inches long and 2 inches by  $\frac{3}{4}$  inch, bore 30.61 tons per square inch; another bar, 12 feet 8 inches long, and 1.46 inch by 0.6 inch, bore 30.28 tons per square inch; and a third bar, 13 feet long and 1.62 inch in diameter, broke at a weld with  $24\frac{1}{2}$  tons per square inch. All these bars, it is to be remembered, had for an average of eight years been subjected to repeated strains of about  $5\frac{1}{2}$  tons per square inch, in addition to the effects of severe frosts, vibrations, &c. Mr. Roebling, a few years ago, removed 30 tons of hammered charcoal bars from the old Monongahela Bridge at Pittsburgh, and notwithstanding that they had been in severe service for thirty years, he reported that every bar would bear a strain of nearly 27 tons per square inch, or, in round numbers, 60,000 lbs. This strength was ascertained also in the case of the plates of locomotive boilers, after thirteen years' work, on the Baltimore and Ohio Railroad. From what has been stated it will be seen, that American Engineers may work up to rather higher strains than are commonly allowed in this country. The qualities of the best American iron—known here to some extent through the Acadian iron, which, although made in Nova Scotia, is of the same quality as the best class of cold blast charcoal iron made in many parts of the States—are due to the purity of the ore and of the fuel employed in the manufacture. The hot blast anthracite iron, largely made in the Eastern States, is also strong and of good working quality.

On the first adoption of iron for railway bridges, American Engineers permitted high working strains. One bridge of 66 feet span, which broke down in the summer of 1850, on the New York and Erie Railroad, had but 12 square inches of cast iron in the top chord, and but 4 square inches of wrought iron, weakened by bolt holes, in the bottom chord, of each truss for a single line. The ordinary working strain was found to be about 13.4 tons per square

inch of the wrought iron. The best present practice in America is, however, to work the iron to as low, if not a lower strain than is allowed even in England; or, in bridges of less than 150 feet span, to a tension of 8,000 lbs., or 3·57 tons per square inch of wrought iron, and a compression of 10,000 lbs. or 4·46 tons per square inch of cast iron. Even these moderate strains occur only under a load of 3,000 lbs., or 1·34 ton per lineal foot of a single line bridge. This load is estimated to be made up as follows:—A span of 150 feet is assumed to be covered by two first-class locomotives with a snow plough attached, the latter weighing about 15 tons, and with two and a half eight-wheel loaded goods waggons, the whole weighing 108 tons, or 1,600 lbs. per running foot. To this is added an estimate of the weight of saturated snow, equal to 6 inches in depth of water, or 30 lbs. per square foot over the whole floor of the bridge. The pressure of a high wind against the bridge and the train upon it is furthermore estimated at 30 lbs. per square foot, and resolved into a vertical strain of nearly 600 lbs. per lineal foot; and a further allowance of 200 lbs. per lineal foot is then made, upon the supposition that the breaks upon the tenders and goods waggons are all applied while the train is in motion, thus throwing a strain upon the chords of the bridge.

Of the iron trussed bridges about to be described, all have, in common, certain peculiarities distinguishing them from the trussed structures adopted in this country. In almost every case the compression members of American iron trussed bridges are of cast iron cylindrical or octagonal pipes. These simply abut, end to end, against each other; and although means are employed to prevent lateral motion of the ends, flanges and bolts are never introduced for that purpose. Another, and one of the most important peculiarities is the depth of truss employed, a depth which is seldom adopted by English Engineers, except in a few instances, as at Chepstow and at Londonderry. American Engineers consider a depth of one-eighth, for spans of 200 feet, as only moderately deep; for shorter spans depths of one-seventh and one-sixth are common; and in the case of one bridge of 120 feet clear span, the depth from the centre of the top to the centre of the bottom chords is 23 feet, a proportion of nearly one-fifth the span. It should, however, be observed that, in some of the American trusses, the arrangement of the tension members is such that, if the depth of truss were not considerable, the diagonals would be inclined at hardly more than  $8^{\circ}$  or  $10^{\circ}$  from a horizontal line, in which case a very large quantity of material would be employed in proportion to the supporting power obtained. No American iron, or timber bridge is ballasted. With the exception of a plank footpath, the floor is, indeed, very often left

quite open, or more correctly speaking, the bridge has no floor. In the case of bridges having the rails at, or above, the level of the top chords, known in the States as 'deck bridges,' parapets of any kind are seldom employed. The trusses are often placed at so short a distance apart, in the case of deck bridges, that the carriages actually overhang the sides, and a passenger on looking out of a window, is unable to discover any support beneath the train. In no bridges of two or more spans erected in the States are the trusses made continuous over a pier, each span being always treated as a bridge by itself.

One of the earliest iron trusses adopted in the States was a trellis known as Rider's bridge. Cast iron T or angle irons were employed in compression, and wrought iron bars in tension. These bridges were so slightly proportioned, that they occasionally broke down, and the Author is not aware that the plan is now adopted in new structures.

The Whipple Bridge was introduced by Mr. Syrene Whipple, C.E., in 1848, and has since been improved in detail by Mr. J. W. Murphy, C.E. Drawings are exhibited of one of these bridges of 125 feet span, with the railway supported on the lower chords (Plate 20, Fig. 3), and of another of 86 feet span, with the railway on the top. (Plate 20, Fig. 4.) These spans are measured from centre to centre of the bearings on the abutments, the clear spans between the masonry being 120 feet and 80 feet respectively. Referring to the 125 feet span, for a double line, there are three parallel trusses, the outer trusses being each 14 feet from the middle truss, measuring from centre to centre. Although the middle truss may possibly have to bear an occasional load equal to that on both the other trusses, its strength is only about one-half greater than that of either of the outer trusses. The depth of the trusses, from the centre of the top to the centre of the bottom chords, is 23 feet, or 0.184 of the span. The top chord is formed of cylindrical cast iron pipes, all of which are 8 inches in external diameter. At the centre of the middle truss these are  $1\frac{1}{4}$  inch thick, giving  $26\frac{1}{2}$  square inches of section; at the centre of the outer trusses they are 1 inch thick, giving 22 square inches of section; and at the ends of both trusses, they are  $\frac{3}{4}$  inch thick, giving 17 square inches of section. The leaning end columns are 8 inches in external diameter at the ends, 9 inches at the centre, and  $\frac{3}{4}$  inch thick, and are stiffened to some extent by mouldings. The bottom chord of each truss is formed by a chain of square bars, 10 feet 5 inches long between the centres of the eyes. At the centre of the middle truss there are four of these bars,  $2\frac{7}{8}$  inches square, giving 33 square inches, and at the ends two bars  $2\frac{1}{8}$  inches square, giving 9 square inches. The outer trusses have four bars,  $2\frac{1}{2}$  inches square at the centre of each bottom

chord, equal to 25 square inches, and two bars  $1\frac{1}{2}$  inch square at the ends, equal to 7 square inches. The upright cast iron posts are all 6 inches in external diameter, and  $\frac{3}{8}$  inch thick, each post being made in two lengths, faced at the ends, and abutting on each other, with a truss of four round rods  $1\frac{1}{4}$  inch in diameter, to prevent lateral failure. The diagonals are in pairs of square rods, those at the ends of the middle truss being  $2\frac{1}{2}$  inches square, and at the centre  $1\frac{1}{2}$  inch square. In each outer truss there are two diagonal tension bars at the ends, each  $1\frac{1}{2}$  inch square, the two at the centre being  $1\frac{1}{2}$  inch square. The diagonals are formed also as eye-bars, and grasp pins  $2\frac{1}{2}$  inches diameter in the top chord, and others  $3\frac{1}{2}$  inches diameter where the links, or bars of the bottom chord are connected. The upright posts bear also upon these latter pins; and in the top chord the pins, passing transversely through the joint where the cylindrical pipes abut upon each other, also serve the purpose of preventing lateral failure, no other means being employed to keep the separate pipes of the top chord in line. The diagonal tension bars only cross each other in two panels on each side of the centre of the truss. The bars which are carried past the centre are 'counter rods;' they are of light section, and have slots and keys at their lower ends, for adjusting their length to any required camber of the truss. They assist also, to a certain extent, in the transmission of the strains due to unequally distributed loads. The top and bottom chords are respectively braced horizontally with transverse and diagonal bars. The railway bars are supported upon longitudinal timbers, which rest at every 10 feet 5 inches, upon a pair of transverse wrought iron rolled beams, each 9 inches deep, and weighing 90 lbs. per yard. The ends of these beams rest upon cast iron blocks forming the bases of the upright posts. The height or headway, from the top of the rails to the under side of the top bracing, is 19 feet 6 inches. The ends of the truss are not supported on rollers, the bottoms of the leaning end columns resting directly on the masonry. The weight of the three trusses, with the horizontal top and bottom bracing, but exclusive of the floor beams and longitudinal timbers for supporting the rails, is  $73\frac{1}{2}$  tons, or nearly 6 cwt. per foot of single line. Of this weight, 43 tons are cast, and  $30\frac{1}{2}$  tons wrought iron. Of the whole weight of the three trusses, about 32 tons, or 43 per cent., are in the upright posts and their truss rods, and in the leaning end columns and the vertical and diagonal tension rods. The rolled floor beams for the double line weigh 9 tons, the longitudinal timbers about 14 tons, and the rails and fastenings 6 tons, making a total weight for the double line of  $102\frac{1}{2}$  tons, equal to a little more than 8 cwt. per foot of single line. With an additional distributed load of 3,000 lbs. per running foot on each line, the tensile strain at the middle tension rods of the

middle truss would be 4.27 tons per square inch, and in the outer trusses 3.12 tons per square inch. The compressive strains in the top chords would be respectively 5.32 tons per square inch in the middle truss, and 3.55 tons in the outer trusses. These strengths, calculated for the maximum load on both lines, are not carried out in every part of the bridge; but with a train on a single line, no part is strained in tension beyond 8,000 lbs. per square inch, nor in compression beyond 10,000 lbs., and the ordinary working strain does not exceed  $2\frac{1}{2}$  tons per square inch in tension, nor 3 tons per square inch in compression.

In the construction of the bridges just described, the tension rods are rolled in entire lengths, without weld, and from iron of the kind employed for railway carriage axles of good quality. The bars are rolled square, because that form comes out of the rolls best, when bars of unusual length are required. The eyes of all the tension rods are formed by bending the full size of the bar around a pin, the end overlapping the bar for 12 inches, and being closed by a long scarf weld. At the eyes, therefore, there is twice the section of iron that is allowed throughout the rest of the bar. The eyes are truly bored out, the pins are turned, and all the flat bearing surfaces are faced in a lathe. Bridges of this construction, up to spans of 165 feet, possess as much stability as timber trussed bridges; and the deflection of one of these bridges, of 165 feet span, on the Lehigh Valley Railroad, under a goods train of full weight was only three-quarters of an inch.

The cost of American bridges, of all kinds, is always estimated at so much per lineal foot. For a single line railway bridge, of 165 feet span, of the construction already described, the cast iron would weigh about 6 cwt. per lineal foot, and the wrought iron, including floor beams, as much more, making 12 cwt. per foot. The cost of pig iron is usually £4 10s. per ton, and castings in considerable quantities £10 per ton. Wrought iron of the extra quality employed costs £23 per ton in the bar, being usually quoted at 2½d. per pound. At these high prices of materials, bridges containing equal weights of cast and wrought iron are sold at about £25 10s. per ton in the builder's yard, although this sometimes covers the whole cost of the work erected in place. These prices, it is to be understood, are those which prevailed before the suspension of specie payments.

In 1861, an iron bridge was erected on the line of the Pennsylvania Central Railroad, across the Schuylkill river at Philadelphia. It had two clear spans of 192 feet each, and one pivot span, or turning bridge, 192 feet long. The construction was much like that already described as a Whipple's. The truss, however, was only 19 feet deep, giving a proportion of depth to span of rather less than one-tenth. The upright posts, or struts, were

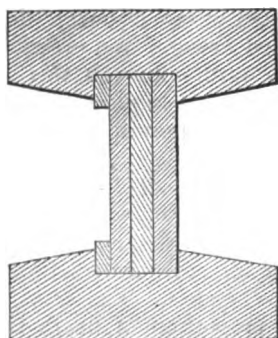
formed of wrought iron, so rolled that two bars, when put together, formed an octagonal tube. The top and bottom chords of the turning bridge were formed of wrought iron rolled beams, so that either might resist extension or compression, according as to whether the span was turned on, or off, the line of the bridge. The three spans for a single line contained an average of 5 cwt. of wrought iron, and  $7\frac{1}{2}$  cwt. of cast iron per lineal foot. The bridge was constructed and erected by the Pennsylvania Railroad Company, and its nett cost, exclusive of masonry, was as follows:—

|                                       | £.            | s.        |
|---------------------------------------|---------------|-----------|
| 145 tons wrought iron at £22 15s. 6d. | 3,303         | 0         |
| 214 „ cast iron „ £6 11 3 .           | 1,404         | 0         |
| Workmen in shops . . . . .            | 1,442         | 0         |
| Timber . . . . .                      | 127           | 0         |
| False work and raising . . . . .      | 842           | 0         |
| Pivot of turning bridge . . . . .     | 592           | 0         |
| Painting . . . . .                    | 270           | 0         |
| Engineering . . . . .                 | 131           | 0         |
| Incidental expenses . . . . .         | 33            | 10        |
| <b>Total . . . . .</b>                | <b>£8,144</b> | <b>10</b> |

The average cost was thus £22 13s. 6d. per ton, and about £14 4s. per lineal foot. The price of the cast iron is the mean of the prices of all the cast iron purchased, whether in the pig, or in castings from the founder's.

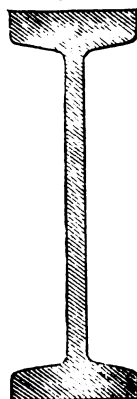
While referring to the wrought iron rolled beams employed for the top and bottom chords of the pivot span of the Pennsylvania

Fig. 1.



Beam Pile.

Fig. 2.

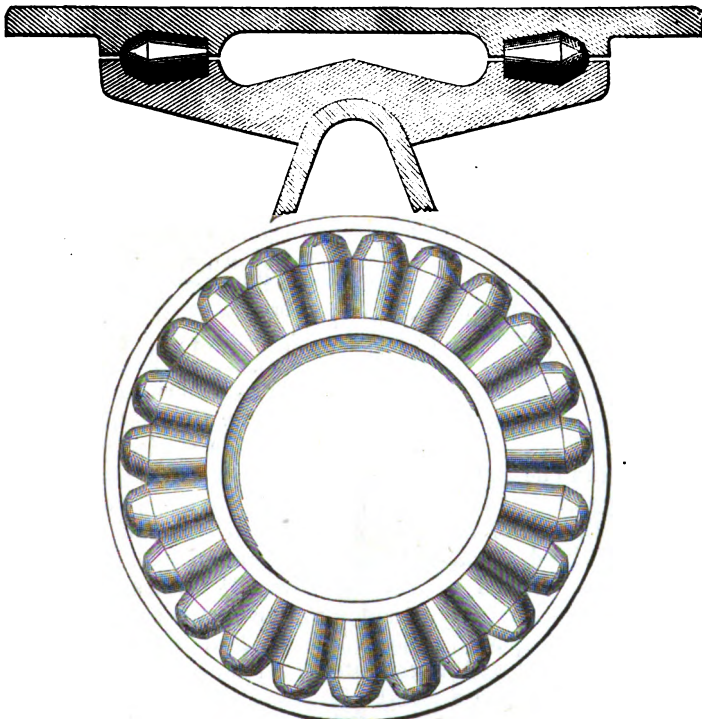


Finished Beam.

Railroad bridge, it should be mentioned that they are rolled in a peculiar manner, and that it has been proposed to employ beams of the same kind, but of greater depth, for bridging considerable spans. Figs. 1 and 2 show sections of the beam pile and of the finished beam. The parts of the beam pile intended to be rolled out into the top and bottom flanges are first rolled into slabs by themselves, with a deep groove on one side. That portion of the pile intended to form the web is then fitted between these slabs, and the pile, thus approximating to the form of the finished beam, is then easily rolled out between rolls of moderate diameter, with comparatively little power, and without crushing, or other injury to the edges of the flanges.

The pivot, upon which the turning span of the bridge just described is made to revolve, is of a kind now extensively employed in the States for railway turntables, Fig. 3. It consists of a fixed

Fig. 3.



Turntable, and Pivot for Turning Bridges.

and of a movable cast iron disc, both being circularly grooved out to receive a number of steel rollers, each turned to the frustra of a

double cone. A circular railway, upwards of 30 feet in diameter, is laid around the pivot, for a turntable 48 feet diameter, and wheels are fitted beneath the bridge, to bear upon this railway only when the bridge does not balance truly on the conical rollers. With a weight of 14 tons balanced upon one of these bearings,—this weight consisting of an iron turntable 54 feet in diameter,—the whole was revolved by a weight of  $3\frac{1}{2}$  lbs. hung over a pulley, and connected by a cord to the periphery of the turntable. In the case of railway turntables fitted with these bearings, the heaviest engines are turned by pressing against them by hand, no gearing being now employed. Pivots of the same kind have been applied to two turning bridges of cast iron, each 230 feet long, and covering two openings of 100 feet each. One of these bridges is at Galena, the other at Chicago, both in the state of Illinois.

The form of truss introduced by Mr. Wendel Bollman, C.E., may next be noticed. This has been extensively adopted upon the Baltimore and Ohio Railroad, where it was first introduced eleven years ago. In this bridge the load upon each panel is transferred directly to the ends of the truss through a pair of straight suspension bars, doing duty only in that panel. With the exception of one pair of suspension bars, supporting the centre of the bridge, the bars in each pair are of unequal length, and their lower ends are attached to the upper extremity of a compensating link in order to allow for contraction and expansion. The bridge cannot alter its form under unequal loading. A bridge upon this plan at Harper's Ferry, on the line of [the Baltimore and Ohio Railroad, has four parallel trusses, for a double line, and a clear span of 124 feet. (Plate 20, Fig. 5.) The span is divided into eight panels, and the depth of the truss is 17 feet 6 inches, or 0.137 of the span. The top chords are each formed of a single line of octagonal cast-iron pipes, 12 inches in diameter, and having 36 square inches of cross sectional area. The vertical posts are of cast iron, and one-eighth of the whole weight of the truss and its load is supported at the foot of each post. The weight at the foot of the middle post of the truss is transferred, one-half to each end of the top chord, through a line of suspension bars 67 feet long. Each line is formed of parallel bars,  $2\frac{1}{8}$  inches by 1 inch, connected together by eyes and pins, the sectional area in each line being  $4\frac{1}{4}$  square inches. The load at the foot of each end post is transmitted, in the ratio of seven-eighths to the nearest and one-eighth to the farthest pier, by similar lines of bars, the longer of which is 112 feet 7 inches, and the shorter 25 feet 3 inches. The shorter line is formed of bars, in pairs,  $1\frac{1}{2}$  inch by  $\frac{7}{8}$  inch, and has  $2\frac{5}{8}$  square inches of sectional area. The longer line is formed of bars, in pairs,  $1\frac{3}{8}$  inch by 1 inch, and has

$3\frac{1}{2}$  square inches of sectional area. The strains upon the various parts of the truss, caused by the weight of the bridge and of a load of  $1\frac{1}{2}$  ton per lineal foot, are 2.8 tons per square inch in compression in the top chord, and vary from 4.46 tons per square inch in tension in the longer suspension bars to 7.14 tons in the shorter bars. There are seven different lengths of suspending bars, and the maximum calculated strains in these vary from 10,000 lbs. per square inch of the longest bars, 11,000 lbs. in the next size, and so on, successively, through 12,000 lbs., 13,000 lbs., 14,000 lbs., and 15,000 lbs., up to 16,000 lbs. per square inch in the shortest bars. The weight of this bridge, including timber work, has been given by Mr. Bollman as  $21\frac{1}{2}$  tons of iron and  $13\frac{1}{2}$  tons of timber for each span for a single line; but the Author finds, by calculation, that the iron-work must weigh considerably more than this, and he is disposed to take it as 6 cwt. per foot of single line. Mr. Bollman states, that the bridge was tested with a moving weight of 122 tons of locomotives on one span of single line, or nearly 1 ton per foot run, and that the deflection at a speed of 8 miles per hour was  $1\frac{1}{8}$  inch at the centre, equal to  $\frac{1}{110}$ th of the span. The Author believes that no bridges upon this plan have been erected of a greater span than 160 feet. One of five spans, of 160 feet each, crosses the Muskingum River, at Zanesville, on the line of the Central Ohio Railroad.

The iron bridge designed by Mr. Albert Fink, C.E., has been more extensively adopted than any other on the railways of the United States. (Plate 20, Figs. 6 and 7.) In this bridge a pair of diagonal tension bars connects the foot of the principal strut, or 'king post,' in each truss, with the ends of the top chord. This pair of diagonal bars supports one half of the whole weight of the truss and its load. Each half span is subdivided by a strut, and two diagonal tension bars extend, one to the nearest end of the top chord, and the other to the top of the centre post. Each quarter span is again subdivided into eighths, and these again, for spans greater than 100 feet, into sixteenths. In a truss of this kind, having sixteen panels, the weight at the bottom of the strut nearest to either of the piers is distributed as follows:— Calling the weight one, one half is transferred directly through a tension rod to the nearest end of the top chord, and thus upon the pier. The other half is carried up to the top of the second strut from the pier, and is received at the bottom of that strut by a pair of tension rods, which subdivide this half between them, one fourth being taken directly to the nearest pier, while the other fourth is transferred to the top of the strut at the quarter span. This fourth is again subdivided at the foot of this strut, one eighth being transmitted through a tension rod to the nearest pier, while the other eighth passes to the top of the middle strut

of the whole span, and is received at the foot of this strut by the main tension rods, which thus transmit, each one sixteenth of the original load, to each pier. Thus the weight at the foot of the first strut from the end of the truss is distributed as follows:—One-half, one-fourth, one-eighth, and one-sixteenth, or, in all, fifteen-sixteenths of that weight reach the top of the nearest pier, through four converging sets of tension rods, while the remaining sixteenth reaches the opposite pier, after having been first brought to the foot of the centre strut, through the intervention of three separate systems of tension bars. With the exception of the load at the foot of the centre strut, which load is transmitted directly to the piers, the loads at the bottoms of the vertical struts are more or less subdivided, in the manner just described, before reaching the ends of the truss. It may be mentioned, that a few years after Mr. Fink had executed bridges upon this system, it was introduced to the notice of English Engineers by Mr. Pittar. Under the direction of Mr. B. H. Latrobe, C.E., then Engineer of the Baltimore and Ohio Railroad, Mr. Fink erected, in 1852, an iron bridge of three spans, of 205 feet each, on that line, where it crosses the Monongahela River (Plate 20, Fig. 7). The trusses for a single line are 16 feet apart from centre to centre, and the main tension chords are attached to the foot of the centre strut, 22 feet 8 inches below the centre of the top chord, thus giving a depth of truss equal to 0.11 of the span. The top chords and the centre struts are of cast-iron pipes, octagonal in their external form, 12 inches diameter between their parallel surfaces, and 10 inches in internal diameter, thus giving 41 square inches of section. The main tension rods in each truss are each formed of six bars,  $4\frac{1}{2}$  inches by  $1\frac{1}{4}$  inch, giving a section of  $33\frac{3}{4}$  square inches. The vertical struts, with the exception of the centre strut, are cast-iron octagonal pipes, 8 inches in external and 7 inches internal diameter. This bridge, and others by the same Engineer, are not proportioned to sustain heavy loads with so little strain as the Murphy-Whipple Bridge, already described; but, for a span of 205 feet, Mr. Fink's bridge, including the permanent way, weighs only  $\frac{1}{2}$  ton per foot of single line, and with an additional load of 1 ton per foot run, the tensile strain upon the wrought iron would not exceed 5.15 tons per square inch, and the compression on the cast iron 4.25 tons. The trusses rest, at the ends of the top chords, upon iron towers, swing links being employed instead of rollers, to allow for expansion and contraction. In the case of the bridge over the Monongahela River, the railway is carried at a little above the level of the bottom of the truss. The tension rods are attached at their lower ends to transverse timbers, upon which longitudinal

timbers are laid to carry the rails. To prevent the timbers from swaying under the impulse of passing trains, cast iron longitudinal distance pieces are interposed between the feet of the vertical struts. The line of distance pieces thus formed has the appearance of a bottom chord, or tension member, but must not be mistaken for one. The same arrangement for supporting the roadway is also adopted in an iron bridge of two spans, of 205 feet each, over the Barren River, on the line of the Louisville and Nashville Railroad. But in the Green River Bridge, on the same line, the rails are carried above the level of the top chord, and only the vertical struts and the diagonal tension rods appear below. Instead of suspension links, rockers are placed under the ends of these trusses to allow for the effects of temperature. The Green River Bridge is the largest work of the kind yet executed by Mr. Fink, having three spans of 205 feet each, and two of 180 feet, the rails being 115 feet above low water. The construction, dimensions, and strength of the 205 feet spans of this and of the Barren River Bridge are identical, or very nearly so, with those of the Monongahela River Bridge, already described.

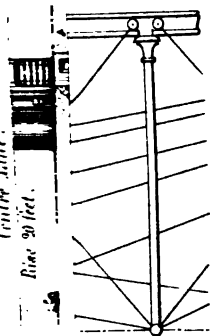
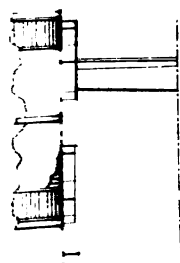
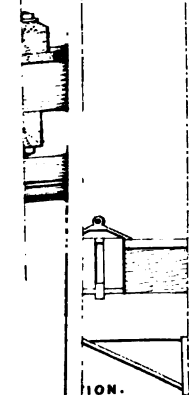
The Bollman and Fink trusses for a single line, and in spans of from 160 feet to 200 feet, cost £14 per lineal foot, or nearly £28 per ton, while timber bridges of the same span cost but from £5 to £7 per lineal foot. Even at this comparatively great cost, iron bridges are now meeting with an amount of favour in America, which appears certain to insure their ultimate substitution, for most of the timber bridges on the railways of that country. A gradual preference, too, is being shown for the plate girder; and already, on one or two of the New England railways, plate girders of nearly 100 feet span have been erected. These have drilled rivet holes, the edges of the plates are planed, and the working strain on the iron is only 4 tons per square inch. The trussed bridges which have been described have much more stability than might be supposed; but the great annual range of temperature, from 20° below zero to a reflected heat of 130° in the summer sun, or a total range of 150°, is not favourable to the use of cast iron in structures of such importance as railway bridges. The trusses described cost less at the outset than plate girders of the same strength, but if wrought iron were employed throughout in the trusses, they would then become more costly. The Canadian Engineers now import best Staffordshire plates, at a cost of £13 per ton, including freight and a duty of ten per cent. levied by the province, and these are made into girders at the Great Western Railway Company's workshops, at Hamilton, at a cost of £7 10s. per ton, making the whole expense of the girders £20 10s., which sum includes no profit. Girders of considerable weight have been made at this price at Hamilton.

It should be mentioned that most of the iron bridges erected on the Great Western Railway of Canada have been made by Messrs. Fairbairn & Co., of Manchester.

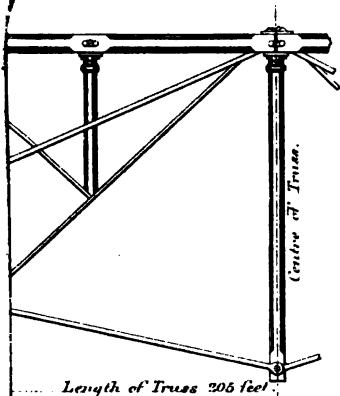
In conclusion, the Author would acknowledge the assistance he has received from Messrs. J. W. Murphy, Wendel Bollman, and Albert Fink, Civil Engineers practising in the United States, each of whom supplied the original drawings from which those now exhibited, in illustration of their respective bridges, have been copied. He is also indebted for important information to Captain Meigs, United States Engineers, and to Mr. Strickland Kneass, Engineer to the City of Philadelphia.

The Paper is accompanied by a series of diagrams, from which Plate 20 and Figs. 1, 2 and 3 have been compiled.

Centre Line.  
Line 9 feet.

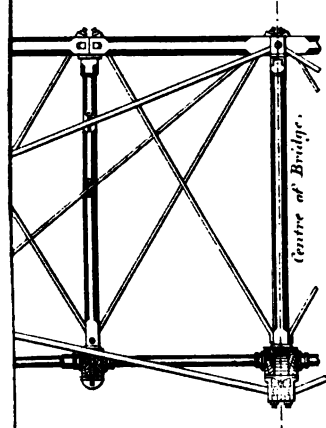


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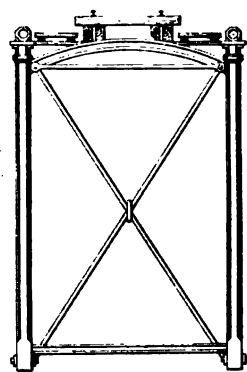
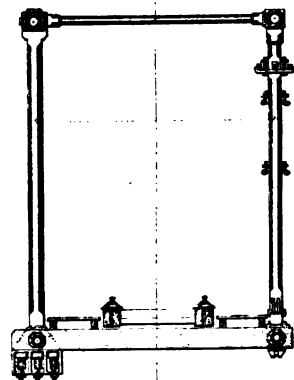
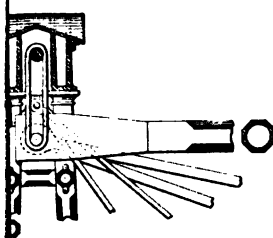


Length of Truss 205 feet

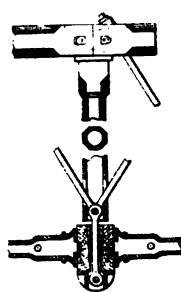
Centre of Truss.



Centre of Bridge.



WAY.



TELL BRIDGE WITHIN CASTLE ST. HOLBORN



Mr. ZERAH COLBURN said, he had refrained from entering more into detail, to avoid making the Paper tedious, but he should be happy to reply to any questions. No doubt, in looking at the diagrams, it would be considered that American engineers had practised great economy in designing these bridges. The fact was, that if bridges could not be constructed of iron at a moderate cost, the Railway Companies in the States would not adopt them, but would continue to use timber bridges, which could be built at from £5 to £7 per lineal foot. It was on the score of cost, alone, he believed that American engineers had adopted cast iron for all parts in compression; so many square inches of section could be put into the tubular form for one-third the cost in cast iron that would be incurred with wrought-iron plates. In the case of the Green River Bridge, the top chords and the vertical posts were of cast-iron pipes. Care was requisite in casting the pipes. Mr. Fink tested the iron for all the pipes, and holes were drilled in the side that lay uppermost in the sand, to ascertain that the cores had not floated, and thus that the metal was of uniform thickness. The fact of cast iron being used in the top chords was a sufficient explanation, why bridges were not made continuous over two, or more, spans in America. In nearly all these bridges almost the whole of the iron was made to do work in carrying the load. They no doubt differed from what English engineers were accustomed to, and he feared the diagrams would present an extraordinary appearance to English eyes; but they were faithful representations.

Mr. Colburn then called attention to the drawing of a bridge with truss rods to every upright post. The span was 125 feet, and the depth was 23 feet from the centre of the top chord to the centre of the bottom chord; yet all the iron posts, the truss rods, the diagonal tension rods, and the leaning end columns were not together equal to a quarter of an inch in thickness of iron, if spread out as a plate, over the whole side, and half of that thickness was cast iron; still no portion of the iron was subjected to a greater working strain than 4 tons to the square inch. Under ordinary circumstances a working strain of 3 tons to the square inch was the utmost that existed. He contrasted with that design some plate girder bridges, erected three years ago, on the Boston and Worcester Railway. They were 87 feet span and 7 feet 6 inches deep. The plates were 6 feet 3 inches wide and 7 feet 6 inches high. At every vertical joint there was a pair of butt straps, 8 inches wide, double riveted on each side of the web, and over these a pair of angle irons, 3 inches by 6 inches. Midway between the vertical joints, there were two angle irons, 6 inches by 3 inches, the longer sides being turned over at right angles, to form a knee by which they were riveted to the top and bottom chords. Mr. Philbrick, the engineer, adopted that form of stiffening the

webs of girder bridges, because, as he said, he had found that in England and in France, the T irons used for stiffening had begun to split in some cases. He had only called attention to the butt straps and angle irons used by Mr. Philbrick, because these, spread out as plates over the side of the web, were alone equal to one-quarter of an inch in thickness, while in the Murphy-Whipple Bridge the whole of the members forming the web amounted to less than a quarter of an inch.

He might add, that none of the bridges shown in the drawings had broken down, and he had never heard that they had exhibited any signs of weakness. They were considered in America, and he believed them to be, very strong, and good bridges. If they had any peculiar merit, it might be in the fact that they were not overloaded with ballast. The trusses were deeper, and, therefore, there was not so much iron put into the sides as might be expected to keep the strains down.

In Bollman's Bridge the test load was  $1\frac{1}{2}$  ton per lineal foot, for a single line. In America the assumed load was arrived at, by supposing that there was on the bridge a train of loaded goods' waggons, with two engines and a snow plough weighing about 15 tons; and, in addition, when the bridge had a floor, that this was covered with snow, equal to a weight of 30 lbs. per square foot of floor; and that a side wind, equal to 30 lbs. per square foot was blowing. It was further assumed that, as every wheel had a break, all the breaks were put on at once, which would throw the strain upon the top chords of the bridge. That was the assumed load of the bridge of 200 feet span, and it was adopted by Mr. Murphy, Mr. Whipple, and Mr. Bollman.

In answer to inquiries from several members, Mr. Colburn said that the highest breaking strain of the cast iron alluded to in the Paper was  $20\frac{1}{2}$  tons per square inch; but it was certainly never subjected to that strain in a bridge. It was boiled cast iron, that was melted and kept in fusion for several hours, and partially decarbonized. Previous to the present war in America, every cast gun was made of iron melted two, three, or four times.

Mr. F. J. BRAMWELL regretted to hear that the arrangements for the reading of other communications were such, that it was desirable to limit the present discussion; as he feared there would be great difficulty in investigating the principles of construction of the Trusses described in the Paper, unless some considerable time were devoted to that purpose.

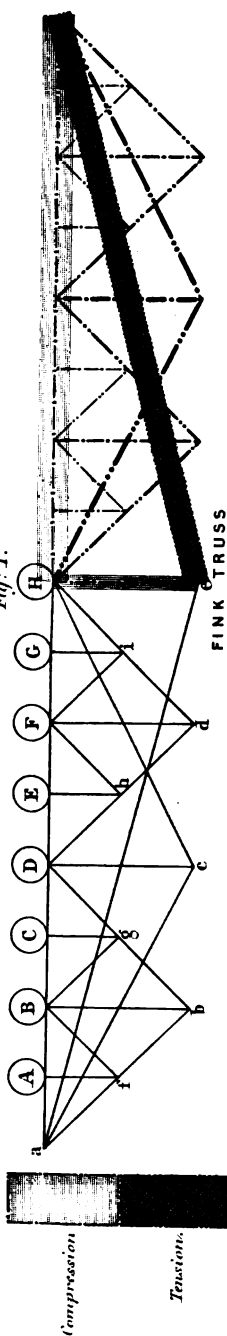
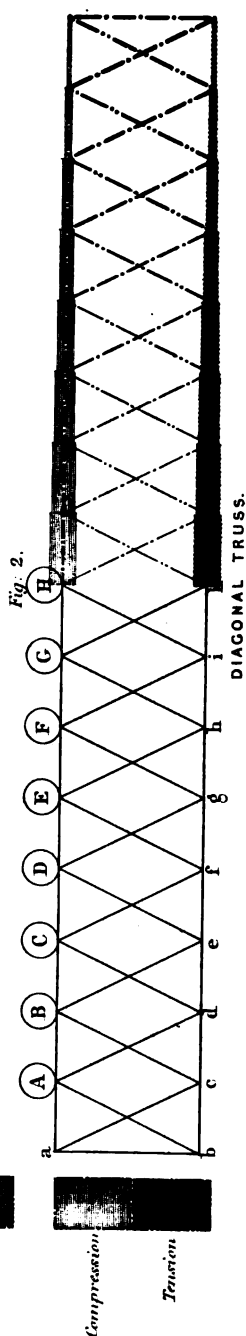
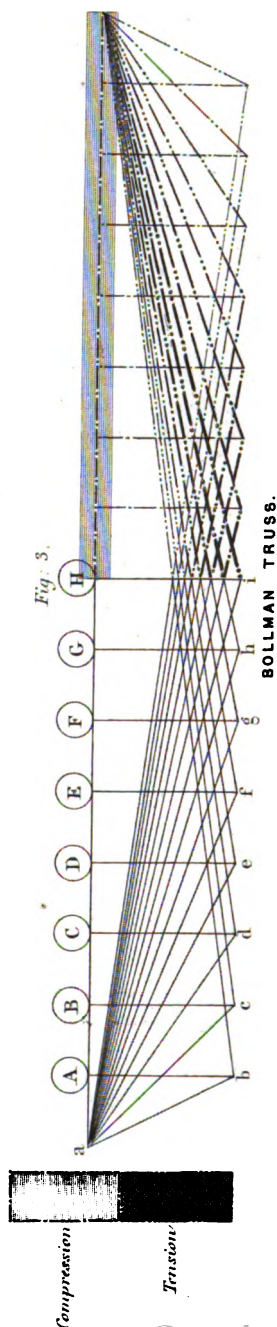
Before entering into the question of the Trusses, however, he wished to give a few facts bearing on the strength of cast iron. They were corroborative, to a great extent, of the statement on this subject made by the Author. That statement

seemed to excite surprise, but Mr. Bramwell was quite prepared for such a statement, having had occasion, some time back, to investigate the strength of a particular quality of cast iron, which gave results nearly agreeing with those mentioned in the Paper. He exhibited two samples of Acadian cold blast iron, the produce of Nova Scotia, which had been broken, in his presence, by the proving machine at Woolwich Arsenal. Being No. 1 iron, a mixture of scrap was required before strength could be obtained. But as the experiments were made to test the quality of this individual iron, it would have rendered those experiments nugatory, had scrap from any other source been mixed with the iron. The only way of proceeding, that occurred to him, was to melt some of the iron into pigs, to make scrap for the second melting, reserving trial bars of the first melting. The order of the experiments was as follows:—The iron was put into an air furnace, and as soon as it was fused, eight sample bars were cast. These bore an average tensile strain of  $7\frac{1}{2}$  tons per square inch of section. The iron was kept in fusion, and two hours after, eight other bars were cast. These did not break until a strain of 8 tons 6 cwt. was attained, being nearly 1 ton more per square inch than the strain which broke the first lot of bars. After a further interval of one hour and three-quarters, eight other bars were cast, which broke with a strain of  $10\frac{8}{10}$  tons; so that by keeping the metal in fusion for three hours and three-quarters, the tensile strength was increased from 7 tons 10 cwt. to  $10\frac{8}{10}$  tons, or about 50 per cent. The iron was then poured out, and pigs were cast from it. On the next occasion, the furnace was charged with half of the fresh No. 1 iron, and half of the pig iron from the prolonged fusion. The result was, that the bars cast immediately upon melting required for their fracture a tensile strain of 11 tons; while those cast after two hours' continued fusion only bore 9 tons 4 cwt. As this result did not agree with those obtained from the bars cast before and from those cast after this particular lot, Mr. Bramwell had no doubt, there was some error in the marking to identify these bars. The bars that were cast after two hours' further fusion gave an average tensile strength of  $18\frac{1}{2}$  tons. The strongest, of which he exhibited a sample, did not break until the tensile strain per square inch rose as high as 19 tons 12 cwt. As an evidence of the unusual strength of this iron, he might state that the whole of the weights belonging to the proving machine were not quite sufficient to enable this strain to be applied, so that extra weights had to be obtained. This sample of cast iron was undoubtedly the strongest that had ever come under his notice. The specific gravity of the metal increased from 7·09 for the No. 1

pig, to 7.29 for the sample which bore the strain of 19 tons 12 cwt.

The Author, in alluding to the method of melting iron in America, stated that its toughness was increased. Mr. Bramwell hardly knew in what sense the term toughness was used. If it meant merely tenacity, or capability of bearing tensile strain, no doubt that was increased; but if it meant tensile strain, coupled with movement through a considerable space before rupture took place, so that the 'work done' to produce fracture would be large, then he questioned whether the melting spoken of did, after a certain point, add to such toughness; although no doubt it added to the power to bear a great load, if very gradually and quietly applied. He regretted that there were no means of ascertaining, by the machine at Woolwich, the facts involved in this question of toughness. The samples were however tested for their power to resist compression. This was found to be, practically, about three times and a half greater than that to support tensile strain; a lower ratio no doubt than was ordinarily obtained. It would perhaps be considered surprising, that the iron he had spoken of was rejected as being bad, because it contained silicon. It must be borne in mind, that this silicon could not be detected in the behaviour of the iron, but required the careful analysis of the chemist to discover it. Nevertheless, the silicon being there, the iron was as much condemned as if the silicon had exercised its supposed baneful influence, so as to render the iron bad under mechanical test. This seemed to him to be yielding too much to chemical authority, which, after all, must base its opinion, as to the injurious, or non-injurious, character of any foreign substance in a metal, upon the results derived from mechanical test.

With regard to the principles involved in the construction of the Trusses of American Iron Bridges, he referred to three diagrams (Plate 21) he had caused to be prepared, showing, respectively, the Fink truss (Fig. 1), an ordinary diagonal truss which was so well known in this country (Fig. 2), and the Bollman, or Harper's Ferry Bridge, truss (Fig. 3). In these diagrams, one-half of each figure was drawn merely in lines, running along the centres of the various members of the truss; while in the other half of each figure the members were indicated either by dotted lines simply, or by dotted lines and shading on each side, so as to show, by the width of the shading or of the dotted lines, the relative amounts of iron required in each member; and by the different kinds of dotted lines and the different kinds of shading, to distinguish between the parts in compression and those in tension; discarding, for the sake of simplicity, all consideration of rivet holes, joints, and such





matters, and assuming the whole of the iron to be brought to an uniform thickness, and to be equally valuable for compression and for extension. Thus if the shading along one member of the truss were twice as wide as along another, then it indicated that there must be double the sectional area of metal in the first of these two members, that there was required to be in the second of such members. In this way the diagrams would at once instruct the eye, as to the consumption of metal in each part of each truss, while the difference of the shading would show, which part was in compression and which in tension. Further, at the end of each figure a parallelogram had been drawn, which indicated the relative amount of each kind of metal required in the three different trusses. Assuming that there would be no special circumstances of convenience, or inconvenience, attending the manufacture of any particular truss, there could be no question, that was the best truss which consumed the least metal in its construction. And if the decision, as to the merits of the Fink truss (Fig. 1), and of the Bollman truss (Fig. 3), were to be arrived at by the consideration of this test, Mr. Bramwell believed he was correct in saying, that they were both of them inferior to the ordinary diagonal truss (Fig. 2), and in the following ratio :—

|                         |     |                 |
|-------------------------|-----|-----------------|
| Diagonal truss required | 262 | parts of metal. |
| Fink                    | 396 | „               |
| Bollman                 | 370 | „               |

The distribution of the metal would be as follows :—

|                  |                   |     |     |
|------------------|-------------------|-----|-----|
| DIAGONAL TRUSS : | Compression . . . | 136 |     |
|                  | Tension . . .     | 126 |     |
|                  |                   | —   | 262 |
| FINK TRUSS :     | Compression . . . | 200 |     |
|                  | Tension . . .     | 196 |     |
|                  |                   | —   | 396 |
| BOLLMAN TRUSS :  | Compression . . . | 185 |     |
|                  | Tension . . .     | 185 |     |
|                  |                   | —   | 370 |

These results were arrived at by a calculation which he believed to have been based on correct principles, and to have been accurately worked out. He would, however, endeavour to explain the causes of the extra consumption of iron in the Fink and the Bollman trusses.

First, as to the Fink truss :—The diagram was made on the assumption, that the depth of this truss, and of course of  
[1862-63. N.S.] 20

the other two trusses also, was one-eighth of the span, and that the truss was loaded with fifteen units of load, one over each of the vertical struts. The struts on the left-hand side were lettered from A to H, the latter letter being over the central strut. The effect of these units of load would be, that unit A would, by its vertical A *f*, be carried one-half by the tie rod *f a*, and one-half by *f B*; and that the unit B would be carried on its vertical B *b*, which would also have to carry the half of unit A, brought on by the tie-rod *f B*, and also one-half of the unit C, brought on, in a similar manner, by the tie-rod *g B*. In this way the vertical B *b* would get a load of two units, one-half of which, or one unit, would have to be upheld through the tie-rod *b a*, but as the upper part, *f a*, of this tie was already strained by the weight due to one-half of the unit A, and as the angle of the tie was  $45^\circ$ , the tie *b a* would bring a compression of exactly a unit and one half on the top member of the girder. It was clear that a downward load of one unit and a half must also be brought, by the tie *b g D*, on to the point D, and that a similar load of a unit and a half must be brought on to the same point by the tie *d h D*, making together a load of three units. This added to the unit D itself, would cause a load of four units to have to be carried by the vertical D *c*. Of these four units two would be carried by the tie *c a*, and the other two by the tie *c H*. The tie *c a* would bring the compression on to the top member of the girder due to these two units. If the tie *c a* had been at the same angle as the tie *b f a*, this compression would only have been two units; but as the tie *c a* was at an angle only half as favourable as the tie *b f a*, the compression brought on to the top member of the truss by the tie *c a* would be double that of the vertical load carried by it, or a compression of four. The last source from which compression would come upon the top member of the truss would be from the strain of the tie *e a*. This tie, it would be seen, had to bear one-half the duty of upholding the central strut H *e*. This strut H *e* would have to support, first, two units of load brought on it by the tie *c H*; secondly, one unit of load brought on by the tie *d i H*, owing to that tie upholding one-half of the load of two on F *d*, and, thirdly, one-half of a unit of load brought on by the upper part *i H* of the same tie *d i H*, which upper part would have to support the half of the unit of load on G *i*. These three sources of strain would amount together to three and a half units. There would of course be an equal load brought on by the corresponding ties to the right hand of the strut H *e*, which strut would thus be loaded with seven units, to which must be added the unit on H itself, making eight as the total load on the strut H *e*. Of this eight, one-half, or four, would be upheld by the tie *e a*, and by this tie would exert a compressive force on the top member of

the girder. It would be seen, that the angle at which this tie  $ea$  lay was twice as unfavourable as that of the tie last considered, and four times as unfavourable as that of the tie  $ba$ , the angle of which was  $45^\circ$ . Owing to this unfavourable angle of the tie  $ea$ , the load supported by it would exert a compression of four times its own amount, or sixteen. The sum of the compressions, therefore, on the top member of the girder would be,

|             |      |               |      |          |                            |                   |                 |
|-------------|------|---------------|------|----------|----------------------------|-------------------|-----------------|
| For the tie | $fa$ | $\frac{1}{2}$ | unit | $\times$ | by the effect of the angle | $1 = \frac{1}{2}$ |                 |
| "           | "    | $ba$          | 1    | "        | "                          | "                 | $1 = 1$         |
| "           | "    | $ca$          | 2    | "        | "                          | "                 | $2 = 4$         |
| "           | "    | $ea$          | 4    | "        | "                          | "                 | $4 = 16$        |
|             |      |               |      |          |                            |                   | <hr/>           |
|             |      |               |      |          |                            |                   | $21\frac{1}{2}$ |

It would be seen, that this compression extended from end to end of the top member of the truss, so that the top member would require to have as great a sectional area at the extremities as in the middle. Assuming that one part of iron was required to resist one unit of load, then the sectional area would be  $21\frac{1}{2}$ , and the length of the truss being taken as 8, the amount of iron consumed in the compression bar would be equal to  $21\frac{1}{2} \times 8$ , or 172 parts of iron.

Before considering the amount of iron in the other members of the Fink truss, Mr. Bramwell would compare the compression bar, or top member, of this truss, with that of an ordinary diagonal truss (Fig. 2). In the latter case it was well understood, that as fifteen units of load, distributed as shown, were equal to a central load of eight, and as the girder was eight times as long as it was deep, the compression in the centre would of course be sixteen units of load. This then would represent the maximum sectional area, which would exist only at the very middle of the compression member, as it would become less and less towards the ends of the girder; the diminution being in such a ratio, if the number of points of attachment of the ties and struts were infinite, as would give a parabolic curve, the area of which would of course be two-thirds of the parallelogram containing it. Therefore  $16 \times \frac{2}{3} = 10\frac{2}{3}$  would represent the average depth of the compression member, which multiplied by the length 8, would give  $85\frac{1}{3}$  as the amount of iron in that member, or rather less than one-half of the iron in the similar member of the Fink truss. In the diagonal truss, with the number of ties and struts as drawn, this theoretic amount was diminished only to the extent of  $1\frac{1}{3}$ ; that was to say, the whole amount of iron was 84, arrived at thus:—

2 0 2

| Between the points <i>a A</i> the compression would be $3\frac{1}{2}$ units, which, multiplied by the effect of the angle |     |   |                  |   | Pressure.        |
|---------------------------------------------------------------------------------------------------------------------------|-----|---|------------------|---|------------------|
|                                                                                                                           |     |   |                  |   | =                |
| "                                                                                                                         | A B | " | 10 $\frac{1}{2}$ | " | 1 $\frac{1}{2}$  |
| "                                                                                                                         | B C | " | 16 $\frac{1}{2}$ | " | 5 $\frac{1}{2}$  |
| "                                                                                                                         | C D | " | 21 $\frac{1}{2}$ | " | 8 $\frac{1}{2}$  |
| "                                                                                                                         | D E | " | 25 $\frac{1}{2}$ | " | 10 $\frac{1}{2}$ |
| "                                                                                                                         | E F | " | 28 $\frac{1}{2}$ | " | 12 $\frac{1}{2}$ |
| "                                                                                                                         | F G | " | 30 $\frac{1}{2}$ | " | 14 $\frac{1}{2}$ |
| "                                                                                                                         | G H | " | 31 $\frac{1}{2}$ | " | 15 $\frac{1}{2}$ |
| Giving for the sum of the compressions . . . . .                                                                          |     |   |                  |   | 84               |

This divided by the number of spaces 8, made  $10\frac{1}{2}$  as the average depth.

It was, he thought, not improbable that a cursory view of the drawing of the Fink truss might lead to the idea, that it was one that must be economical; inasmuch as it appeared to have a compression member only, and to be without any corresponding formal tension member, the diagonal ties being made to serve the purpose of a regular tension member. But even if this were so, and if the ties were made at no greater consumption of metal than the ties and struts of a diagonal girder, which he would prove was not the case, even then the Fink truss would have no advantage; inasmuch as its one compression member contained slightly more iron than the compression member and tension member together of the diagonal truss. He had stated that the compression member of this latter girder contained 84 parts. The tension member contained rather more, thus,—

| Between the points <i>b c</i> the tension would be 4 units, which, multiplied by the effect of the angle |           |   |    |   | Tension.         |
|----------------------------------------------------------------------------------------------------------|-----------|---|----|---|------------------|
|                                                                                                          |           |   |    |   | =                |
| "                                                                                                        | <i>cd</i> | " | 11 | " | 2                |
| "                                                                                                        | <i>de</i> | " | 17 | " | 5 $\frac{1}{2}$  |
| "                                                                                                        | <i>ef</i> | " | 22 | " | 8 $\frac{1}{2}$  |
| "                                                                                                        | <i>fg</i> | " | 26 | " | 11               |
| "                                                                                                        | <i>gh</i> | " | 29 | " | 13               |
| "                                                                                                        | <i>hi</i> | " | 31 | " | 14 $\frac{1}{2}$ |
| "                                                                                                        | <i>ik</i> | " | 32 | " | 15 $\frac{1}{2}$ |
| Giving for the sum of the tensions . . . . .                                                             |           |   |    |   | 86               |

This, divided by their number 8, made  $10\frac{3}{4}$  as the average depth. The amount of metal 86 in that member, added to that in the compression member, gave 170 parts for the metal in those two members, as compared with 172 parts in the compression member alone of the Fink truss.

He would now revert to the consideration of the Fink truss:—

It would be remembered that the main tie bar *e a* had to transmit four units of load; but these became multiplied in their power of strain on the tie, by the number of times the length of that tie exceeded the depth of the girder. This depth being 1, and the

half length of the girder being 4, the length of the tie would of course be equal to  $\sqrt{1^2+4^2} = \sqrt{17}$ . The strain, therefore, would be the load  $\times \sqrt{17}$ . But as the length of the tie was also  $\sqrt{17}$ , it followed that the amount of metal must be  $\sqrt{17} \times \sqrt{17} \times$  the load of 4; in other words, the amount of metal increased as the square of the length of any sloping tie. In this case the amount was 2 ties each  $17 \times 4 =$

Parts of  
Metal.  
136

Similarly, it could be shown, that the ties *ca*, *cH*, and their counterparts on the other side of the truss, would require

$\sqrt{5} \times \sqrt{5} \times 2$  load  $\times 4$  of them = 40

That *ba*, *bD*, *dD*, *dH*, and their counterparts on the other side of the truss, would require  $\sqrt{2} \times \sqrt{2} \times 1$  load  $\times 8$  of them = 16

and that the upper parts of these ties, *fa*, *gD*, *hD*, *iH*, and their counterparts on the other side of the truss, with the corresponding short ties, *fB*, *gB*, *hF*, *iF*, and their counterparts on the other side of the truss, would require  $\sqrt{\frac{1}{2}} \times \sqrt{\frac{1}{2}} \times \frac{1}{2}$  load  $\times 16$  of them = 4

Making the total of iron in tension, as already stated, 196

Further, the compression member, it had been proved, would contain

Parts of  
Metal.  
172

The strut *He* would contain  $1 \times 8$  units = 8

The strut *Dc*, and the corresponding one on the other side of the truss, would contain  $1 \times 4$  units  $\times 2$  of them = 8

The struts *Bb*, *FD*, and their corresponding ones on the other side of the truss, would contain  $1 \times 2$  units  $\times 4$  of them = 8

The struts *Af*, *Cg*, *EH*, *Gi*, and their corresponding ones on the other side of the truss, would contain  $\frac{1}{2}$  long  $\times 1$  unit  $\times 8$  of them = 4

Making the total of iron in compression, as already stated, 200

In order to complete the comparison between the Fink truss and the diagonal truss, it would be necessary to ascertain the amount of metal in the struts and ties of this latter truss. The lengths of the various struts and ties would be uniformly  $\sqrt{1\frac{1}{4}}$ , the multiple of strain would therefore be  $\sqrt{1\frac{1}{4}}$ , and the amount of iron in each of them  $1\frac{1}{4} \times$  the units of load :—

On the strut  $A b$  there would be 4 units.

|   |       |   |                |   |
|---|-------|---|----------------|---|
| " | $B c$ | " | $3\frac{1}{2}$ | " |
| " | $C d$ | " | 3              | " |
| " | $D e$ | " | $2\frac{1}{2}$ | " |
| " | $E f$ | " | 2              | " |
| " | $F g$ | " | $1\frac{1}{2}$ | " |
| " | $G h$ | " | 1              | " |
| " | $H i$ | " | $\frac{1}{2}$  | " |

Making a total of . . . . . 18 "

This sum, multiplied by the  $1\frac{1}{4}$ , would give . . . . . 22 $\frac{1}{2}$   
 To which must be added the end upright  $a b$  . . . . . = 3 $\frac{1}{2}$

Making . . . . . 26

Or, for the two sides of the truss . . . . . 52

Adding the amount of metal in the compression member  
 before given . . . . . 84

The total of iron in compression would then be, as already  
 stated . . . . . 136

Next, as regarded the parts in tension :—

On the tie  $a c$  there would be  $3\frac{1}{2}$  units

|   |       |   |                |   |
|---|-------|---|----------------|---|
| " | $A d$ | " | 3              | " |
| " | $B e$ | " | $2\frac{1}{2}$ | " |
| " | $C f$ | " | 2              | " |
| " | $D g$ | " | $1\frac{1}{2}$ | " |
| " | $E h$ | " | 1              | " |
| " | $F i$ | " | $\frac{1}{2}$  | " |
| " | $G k$ | " | 0              | " |

Making a total of . . . . . 14 "

This, multiplied by  $1\frac{1}{4}$ , would give . . . . . 17 $\frac{1}{2}$

Making for the two sides of the truss . . . . . 35

Adding the amount of metal in the tension member before  
 given . . . . . 86

The total of metal in tension was thus found to be . . . . . 121

But to this should be added the ties  $G k$ , which, although not called into action, when an uniform load was on the girder, would have to bear a strain if the load were a passing one. They might then be required to support a single unit of load. Under similar circumstances two ties on each side might require to be strengthened, so as to bear a further half unit each; then 4 ties 1 unit  $\times$  the  $1\frac{1}{4}$  . . . . . = 5

Giving as the total of iron in tension, as already stated, 126

He would not occupy any further time, by entering into the details of the calculation of the quantity of metal in the Bollman Truss ; but would simply refer to the figures already given, by which it would be seen, that while it was more economical than the Fink Truss, in the proportion of 37 to 39·6, it was less economical than the ordinary diagonal truss, in the proportion of 37 to 26·2.

The cause of the waste of metal in the Fink and in the Bollman trusses appeared to him, on a little consideration, to be sufficiently obvious. The strains which related to the centre part only of a truss, and which might be got rid of in a comparatively short distance near that centre, were, in the Fink and in the Bollman trusses, carried to the very ends of the compression member, so that the whole length of that member sustained a pressure that need only be borne near the centre. Further to carry out this bad arrangement, the tie-rods were of necessity placed at most unfavourable angles, by which not only was an unnecessary amount of metal consumed, but the already useless strain on the compression member was aggravated.

It was unnecessary to investigate the construction of the Murphy-Whipple truss, as the drawing showed that truss to be free from the radical error, of carrying the whole of the compression to the very ends of the top member. It was, however, clear, that the use of struts in a vertical position was not so economic, as the use of struts in a diagonal position, inasmuch as the struts when placed vertically did not assist in the progression (if such a term might be allowed) from end to end of the truss. The ties, also, were not disposed at the most economic angle ; but with those exceptions, he had little doubt the Murphy-Whipple truss would, on investigation, prove to be one of good construction, and equal to such as were in ordinary use in England.

He regretted having to pronounce so unfavourable an opinion on these trusses ; but he was glad to be enabled to do so, without the fear of his criticism being displeasing to the Author, who, it was understood, had merely submitted these particular trusses, as matters of interest in the history of railway works in America, without expressing approval of their construction, and for the very purpose of having their merits, or demerits fully discussed.

Mr. FLEEMING JENKIN said, there was an apparent discrepancy in the general practice of Engineers in the use of cast iron under compression. From the Paper it would appear, that the cast-iron compression bars of all the girder bridges were strained up to a maximum of from  $4\frac{1}{4}$  to  $4\frac{1}{2}$  tons to the square inch, whereas in the two cast-iron arches mentioned by the Author, the strain per square inch was limited to 2 tons and 1·6 ton respectively. Nevertheless, in both cases the strains were due to loads of a similar nature ; and at first sight there was no reason why the cast iron

should not be capable of bearing an equal strain in both classes of bridge. The practice in England agreed with that in America. The strain allowed on cast-iron arches was from  $1\frac{1}{2}$  ton to 2 tons as a maximum; whereas in columns and other constructions, strains of 4 tons were admitted without hesitation. He thought it was a point of some interest to examine, how it happened that under similar conditions the same material should be so differently treated. He believed the fact to be, that the calculated strains upon cast-iron arches were exceedingly fallacious; no experiments had been made upon the strains in metal arches, whether of cast iron or of wrought iron, whereas excellent experiments had been made upon girders and columns. The strains upon every part of a girder bridge were well known, and the metal could be accurately apportioned to the work it had to perform; whereas he was not aware of any experiment having been made on arches. The calculations which had been based upon the theory devised for stone bridges were, in his opinion, altogether fallacious, and he thought the subject deserved much more attention than it had hitherto received. The common formula, by which a cast-iron arch was calculated, supposed the existence of an uniform load. This formula gave the compression on the crown of the arch, as equal to the compression which would result at the centre of the top bar of a girder, of a depth equal to the rise of the arch, and loaded in the same manner. This calculation would be correct, provided the arch were formed of two rigid beams, such as the rafters of a house, hinged at the centre, and loaded uniformly, with reference to a horizontal line; but an arch was not hinged, nor perfectly flexible at the centre, nor were the two sides perfectly rigid; therefore the formula could only apply approximately. Still as the arch was really comparatively flexible at the crown and rigid at the spandrels, he believed the formula would, on experiment, be found sufficiently exact. On the other hand, he had never met with any satisfactory calculations of the strain thrown upon a metal arch bridge by a passing load. Professor Rankine mentioned, that a stiffening girder, similar to that required in a suspension bridge, would be required for a cast-iron arch; but, so far as he knew, no person had given the actual strains produced by a passing load, and it was in fact difficult to calculate them. The rigidity of the cast-iron arch played the part which the load over the spandrels took in a common stone arch, bringing the line of pressure from the crown down to the springings. That rigidity, or resistance to bending, was a difficult thing to calculate, especially with such forms as were now common, in which the rigidity was partly due to the main rib, partly to a top girder, partly to the intermediate filling of the spandrels, and partly to a sort of compound beam built of these three parts, which were usually very imper-

fectly connected. The large unknown strain, produced by the flexure due to a passing load, was, he believed, the practical reason why Engineers increased the section of the cast-iron ribs of arches, to such an extent as to reduce the maximum strain, when calculated from the uniform load alone, as low as  $1\frac{1}{2}$  ton or 2 tons; whereas they were able to allow 4 tons on the girder or column, because it was known from experiment, that the actual maximum strain upon these forms would not exceed the calculated strain. With the present form of arch it was almost impossible to calculate the strains. He had endeavoured to design a form of arch which, being a simple piece of framework, or trussing, would permit the calculation of the strains on every member, due to every arrangement of the load. Each member was strained in the direction of its length only. That form was shown in the model of an arch he had placed upon the table. He would not now enter upon a mathematical investigation of the subject, as he hoped soon to have an opportunity of practically testing the merits of that form, and he would then bring the results before the Institution. He thought he should be able to show, that a cast-iron arch could be made, in which the material was subjected to the full strain of 4 tons per square inch, and that such bridges could be built at less cost than the common plate, or parallel girder bridge.

Mr. E. A. COWPER could not allow the observations, with reference to the strains upon cast-iron arches to pass unchallenged. The Washington aqueduct might, perhaps, be taken as a good example of a column placed in the form of an arch. He argued that columns were often compressed with a greater pressure per square inch than arched ribs, if the whole section was taken as the area. A vertical column, without side strain or pressure, was in a very favourable condition for bearing weight; and indeed it was astonishing what columns would sustain. It had been stated, that if the column were in the form of an arch, there was great difficulty in calculating the compression per square inch. To this he dissented, believing that the strains upon a cast-iron arch could be readily estimated. It was necessary to ascertain, first, where the line of strain would come, under the various circumstances, of a passing load, &c., and having found how near the edge, or flange of the rib the strain would pass in the worst case, it was easy to calculate the section that it was necessary to give to the rib, so that the iron might be put to a fair strain per square inch. It was an expeditious, and if carefully performed, an accurate method, of finding the true line of strain of the Distorted Catenary Curve, to hang up a flexible chain to represent the weight and form of the rib, and then to load it, first with the various weights of the bridge itself, if the spandrels had any heavy filling-in, and then with the passing load in various positions. The true curves,

under the various circumstances, would thus at once be obtained, and could be traced on a drawing-board, placed behind the chain. This plan he had practised for many years, no doubt in common with others, and had used it in settling the sections of the ribs of the Barnea, Richmond, and other bridges. Of course, in a bridge in which the strength was intended to be given entirely by compression, it was no more admissible to make the rib so shallow, as to allow the line of strain of any one of the distorted catenaries to pass outside, than it would be, to make a column for bearing compression so crooked, that the vertical line of pressure came outside the column. He need hardly say, that the true line of compression in a bridge would never follow the fancy curves that were often given to arches, such as semicircles and ellipses, but would always be in a catenary curve, more or less distorted, according to the various loads upon it and their position. He had, many years since, designed a suspension bridge, on precisely the same principle as that of an arch inverted, including all the lines of strain, or tension, within the chain, and providing sufficient depth in the section of the chain to take the tension where it came. The chain was, in fact, a wrought-iron plate, with top and bottom flanges, like an ordinary deep wrought-iron girder. Such a bridge would be perfectly stable, as it could not move out of shape, nor deflect from the elasticity of the material so much as an ordinary girder. When, however, it was intended that an arched rib should not depend entirely on compression, but should also rely on the tension of its material, from being made of wrought iron well bolted, or riveted together, or of cast iron, in pieces provided with substantial flanges, and proportionate bolts and nuts, then it might be looked upon, to some extent, as having the stiffness of a girder, and might be made so narrow, that some parts of the distorted catenaries would pass outside it, in which case it was easy to calculate how much compression there would be on one side and how much tension on the other side, as it was a simple case of leverage between the line of strain and the inside and outside flanges of the rib. He had stated that, under certain circumstances, an arched rib might to some extent be looked upon as a girder, and he had spoken thus guardedly, because an arched rib, thoroughly stiffened by bracing, or spandrels extending over the crown of the arch, and having a considerable depth, would so resist the action of rising and falling with the expansion and contraction due to variations of temperature, as to cause fracture in some part or other. For an arched rib pre-supposed fixed abutments to take the thrust, so that when the metal expanded by heat, the arch must rise, or break by crushing. This was not a fanciful objection, as it occurred in every-day practice. For instance, Southwark Bridge was erected in cool

weather, so that in the full heat of the sun, the centre arch rose in the middle  $1\frac{3}{4}$  inch, and the various castings forming the spandrils, being deep and well fitted together, without any allowance for expansion, began to break consecutively. The cause of fracture was owing to the stone abutments being fitted tightly against the ends of the spandrils. It had been found necessary to jump holes in the stone, immediately behind the ends of the spandrils, so as to relieve them, and to allow the rib to rise as it expanded. The effects of expansion and contraction in Southwark Bridge were well shown by the hand-railing drawing out of the stone piers in winter, and being thrust into them in summer, the play over the abutments amounting to  $\frac{3}{4}$  of an inch. The stone paving was also always out of order over the piers, and in some cases the heavy stones had flushed at their top edges. He thought many more experiments ought to be made, on the end pressure that columns of various sections would bear. The few experiments of that kind which he had tried agreed very well with those made by Mr. Eaton Hodgkinson; but proper experiments with columns on a large scale were expensive, chiefly on account of the heavy pressures required to crush them. There was also danger in measuring the deflections when the crushing weight was nearly approached, as a hollow column, for instance, would be separated into many pieces, with great violence, when it was crushed or broken. He had found the want of reliable experiments of this class, when designing large shear legs of 120 feet in height, to lift 40 tons, and had been obliged to rely on his judgment alone as to strength: the result, however, had been satisfactory.

Mr. PHIPPS said, the Paper was for the most part limited to several varieties of trussed girders. On these he would not at present offer any observations, but would confine his remarks to one, or two iron arched constructions, also referred to in the Paper, as he had paid particular attention to the subject of cast-iron arches. Mr. Jenkin had truly remarked, that whenever these arched constructions were loaded irregularly, it became difficult to calculate the strain to which the material then became subject. For instance, iron arches, particularly on railways, might be loaded upon one-half of the span only. In such a case the curve of equilibrium would often shift so much from the middle of the arched rib, as almost to touch the extrados and the intrados of the arch on opposite sides of the centre. Having obtained, however, the position of the curve of equilibrium, it then became a question, how to estimate the effect of the pressure in its detrimental action on the outer fibres of the rib. This was a point upon which, he agreed, that no practical, or reliable, information was to be obtained from books, and, in consequence, he had invented a method which he had found both simple and accurate in

its application. To illustrate the degree to which the shifting of the line of pressure might affect the strain upon an iron arch, when placed under compression, he stated that in a prismatic bar of iron, in shape like a 3-inch plank, the pressure on the outer fibres on one side would be doubled, and on the other side be reduced to nothing, by the removal of the line of pressure only the one-sixth part of the whole width away from the centre of gravity. Now in this, as in every other case, whenever a piece of metal, or other elastic material, was compressed by a force on any other line than that of its centre of gravity, the action upon the outer fibres might be obtained, by conceiving the material, first of all to be compressed squarely throughout, as if the strain were applied over the line of centre of gravity, and then, finding the strain due to the angular motion, by the same process that would be used for obtaining the strain on that portion of a cantilever contiguous to where it was attached to a wall; using the total compressive force applied as the weight, and the distance of that pressure from the line of centre of gravity as the leverage. Then the strain on the outer fibre thus obtained, added to the former square-on pressure, would give the whole detrimental action upon the outer fibre of the material. Thus, as he had previously explained in reference to the Charing Cross Bridge,<sup>1</sup> when a pressure of 475 tons was applied, square on, to a piece of iron of 161.25 square inches sectional area, all the fibres would be strained uniformly up to 2.94 tons on the square inch; but by removing the line of pressure 3.6 inches away from the centre of gravity, the pressure on the outer fibres would be increased up to 6.86 tons on the square inch. Mr. Phipps added that, in cases where the arched rib proper was well connected with the roadway bearer above, by an efficient system of diagonal bracing, the centre of gravity of the whole section of the arched rib and roadway bearer together must be taken, as that around which the previously-named angular motion must be computed.

Mr. F. W. SHEILDS could not agree, that the object of the bracing in a girder bridge was merely to keep the top and bottom members asunder, and to enable them to do their work. In his opinion the chief object of bracing in all parallel girders, was to carry the vertical weight of the bridge, with the extraneous load upon it, to the points of support at the piers; and that duty was just as important as, and quite distinct from, the work to be performed by the top and bottom flanges. The bracing ought to be specially designed for that duty, and in that view he thought the American bridges brought under their notice, even those of the simplest form, showed a want of scientific knowledge

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<sup>1</sup> *Vide ante*, p. 535.

in their construction. Thus, if a girder bridge be supposed to consist of twelve bays, and the driving-wheels of a locomotive loaded with 12 tons rested over the third bay, that load would be transmitted to each pier, by the bracing, in the inverse proportion of the distance of the loaded point from the piers, being nine tons to the nearer, and three tons to the further pier. One of the diagrams exhibited was just in such a case, and he observed that at the third bay, there was no diagonal tie from the lower flange which could carry the load to the further pier. Consequently the girder would have to depend merely upon the rigidity of the top flange, considered as an independent beam of perhaps a few inches deep, for the transmission of that part of the load which reached the further pier, and which should be sustained by the whole girder of several feet deep. Diagonals of great inclination were not advisable, independent of all increase of strain arising from their inclination, as they were free to deflect on a curve struck from one of their ends as a centre and the other end as a radius, and that curve would coincide in practice, for a considerable distance, with a vertical line, so that there was little or no resistance to deflection. There were some bridges in the Regent's Park upon that principle, which fully bore out his foregone conclusions, for he found that by jumping upon those bridges, the whole could be set in motion by his own weight alone.

Mr. ZERAH COLBURN remarked, with reference to the comparison which had been made between the various trusses, that it was well understood in the States, as applying to the Fink and Bollman Bridges. The Murphy-Whipple Bridge (Plate 20, Figs. 3 and 4) was believed to be the best class known in the States; and if there was not much difference between that and many bridges in this country, it was no doubt owing to the fact, that when the principles were fixed, there could not be much room for difference between one good bridge and another.

Mr. HAWKSHAW, President, expressed his regret that, owing to the late period of the Session, and the necessity for reading two other Papers before its close, the discussion upon a subject of so much general interest as American Iron Bridges should have been necessarily restricted. The Institution was under great obligations to Mr. Colburn for the able and elaborate manner in which the communication had been made; and he hoped that the Author would, on other occasions, contribute to, and take part in, the proceedings.

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May 12, 1863.

JOHN HAWKSHAW, President,  
in the Chair.

No. 1,094.—“On the Communication between London and Dublin.” By WILLIAM WATSON, M.A., T.C.D., Assoc. Inst. C.E.

HOLYHEAD, the nearest point of land in Great Britain to the metropolis of Ireland, was naturally thought of at an early date as a convenient port of departure and arrival for the mails; but though its proximity was undoubtedly the principal reason for its selection, yet it possessed also the advantage of being exactly opposite to Dublin, without any great difficulties in the navigation of the channel, and with easy access into the bay, at a time when shore lighthouses were scarcely known on that part of the coast.

This line of mail communication has been used for a century and a half. It is recognised in the Act of Parliament, passed in 1729, to confirm the patent previously granted to the Trench family, for erecting a lighthouse on the Skerries Rock,<sup>1</sup> near Holyhead, which authorised the payment of £50 a year by the Postmaster-General, in consideration of the benefit of the lighthouse to the packets sailing between Holyhead and Dublin. The communication between London and Dublin was then very irregular, and the time occupied on the journey was very protracted. Traveling through North Wales was attended with difficulty and fatigue, and the passage of the channel was altogether contingent

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<sup>1</sup> The history of this lighthouse is remarkable. It is stated in the preamble of the Act 3 Geo. II., “that the lighthouse which had been established by Mr. Trench under authority of the Charter from Queen Anne, he was no longer able to support from the duties then collected, and, that it must inevitably fall into decay unless the said duties were extended, and some further powers and encouragements given.” Accordingly, increased powers and encouragements were afforded by the Act of Parliament to so great an extent as eventually to produce to Mr. Trench’s representatives a clear revenue of £16,000 a-year. The Trinity House having been authorised by Act of Parliament in 1845 to purchase up the light, paid for it no less a sum than £445,000. The means were entirely provided out of the dues collected from commercial shipping.

This, however, was not the only case of an “improvident” grant made by the Crown or Parliament, adding to the burdens of shipowners; there were other private lighthouses, the interests in which were likewise purchased by the Trinity House, at a further cost of upwards of eleven hundred thousand pounds; all of which money was supplied from the dues which had been levied on shipping.

on the state of the weather. Swift, in a letter to Pope, mentions the "quick change" which he "made in seven days from London to the deanery, through many nations and languages unknown to the civilized world." The poet Gay at another time speaks of "the plague which his friend suffered in the little smoky room at Holyhead," where he appears to have been kept weather-bound for ten days, and after "at last setting out he had been driven back by the storm, put to sea again, and was finally landed at Carlingford," sixty miles away from his destination. Fifty years afterwards, Edgeworth, passing through Dublin to cross the Channel, to visit his wife who was ill in England, says in his journal "just as I was going to embark in the packet, the wind became directly adverse, and I sat hour after hour with my eyes fixed on the weather-cock. Day after day the wind continued in the same point; no vessel could sail, and for more than a week I was thus kept in suspense." But even after fairly getting under weigh, the passage of the Channel, little more than 60 miles across, was often extremely tedious. In the journal and correspondence of Lord Auckland, recently published, Woodfall says, in a letter from Dublin to Mr. Eden, "Lord Mornington and his brother came over with me in the packet, and we had a great deal of political chit-chat one of the days (for we were near three on board)."

The public appear to have submitted with wonderful patience to the fatigues, delays, and inconveniences attending the journey between London and Dublin; and although, long before the close of the last century, measures of improvement were proposed, one of which was the construction of a bridge over the Menai Straits, no effectual means were adopted, until after the legislative union had taken place between Great Britain and Ireland, in the year 1801. Thenceforward, the necessary attendance of peers and of the representatives of the Irish constituencies in the Imperial Parliament could not fail to lead to the adoption of such improvements in travelling, and in the communication between the two capitals, as the advance of engineering skill of that day showed to be practicable. Public Commissions were constantly engaged in inquiries, and Committees of the House of Commons presented no less than twenty-four reports on the subject within ten years.<sup>1</sup> In these are described the various impediments which then existed in the way of public communication between the two countries and plans and proposals for improvements, principally in reference to the land part of the journey. Hills were to be reduced, more

<sup>1</sup> The first of these Reports, made in 1810, is exclusively on the improvement of Holyhead Harbour, and recommends the expenditure of £87,862 on the construction of a pier for the use of the small sailing packets then employed in the mail service.

direct and perfect lines of road to be made, and the inconvenient and at times dangerous, ferries near Conway and Bangor, in North Wales, to be bridged over, with the object of providing a continuous and easy road for the entire distance of 267 miles between London and Holyhead. A measure of such great national importance could not fail ultimately to obtain the cordial approval of Parliament. The late Sir Henry Parnell, one of the members for the Queen's County, took the most prominent part in urging forward the adoption of those improvements, and his persevering energy was ultimately rewarded with complete success. Large grants of public money were voted, and all other necessary means provided, to complete the arrangements for making this the most perfect road in the kingdom; even the short length of road between Howth and Dublin, on the Irish side of the Channel, was not overlooked. Nearly a million of money appears to have been expended on these works. The genius of Telford, aided by the talent of Macadam, having mastered every difficulty, in 1826 the astonished and admiring traveller was enabled to pass with regularity, safety, and comparative comfort over the entire distance from London to Holyhead in thirty-four hours.

Improvements for the sea part of the journey had also engaged some degree of attention; but, while sailing vessels were in use, it was not thought that much could be gained in the passage of the Channel. In 1814, passages appear to have extended to three days in duration, and it is recorded, in the Parliamentary returns of that year, that for the space of nine days but one packet could sail, owing to adverse wind. In 1819, the average time occupied on the passage from Holyhead was about twenty hours, and about fifteen hours from Dublin. The vessels then employed were small cutters. Two years afterwards Sir Robert Seppings submitted designs for a superior class of vessel, 65 feet in length, 19½ feet beam, and of 102 tons burthen. The inferiority of the vessels previously employed in the service may thence be imagined.

The packet harbour at Howth was constructed, at a cost of £300,000, with the special object of facilitating the intercourse with England. Improvements, at considerable cost, were also provided from time to time, for the Mail Packet service at Holyhead, at the public expense. Indeed, nothing appears to have been overlooked, which could render more perfect the connexion of the several parts of the chain of communication.

The application of steam power for propelling vessels at sea, which was commenced in these islands by Henry Bell, in 1811, extended but slowly for some years; and no attempt was made to introduce the improvement for Channel navigation until 1819, when the 'Talbot,' of 156 tons, built by Wood, of Port Glasgow, with two engines of 30 H. P. each, by Napier, was placed on the

Holyhead station for the summer and autumn ; and in the following year the 'Ivanhoe,' built by Scott, of about the same size, with engines, also by Napier, of 70 H. P. Their unexpected success overcame the professional prejudices of the experienced commanders of the sailing mail packets, who had recently recorded their opinion "that no vessel could perform the winter service with safety, but sailing cutters." Soon afterwards the 'Royal Sovereign' and the 'Meteor' were built specially for the Post Office service. The sailing cutters then disappeared for ever. The 'Royal Sovereign' was of 205 tons burthen, with two engines of 60 H. P. each. The 'Meteor' was 15 tons less in size, and had 20 H. P. less than her consort. The vessels were built by Evans, and the engines were made by Messrs. Boulton and Watt, who had also the honour of making the first engine placed in any vessel—namely that for Fulton, in 1804, and used by him in his first boat on the Hudson River. The performance of the 'Royal Sovereign' and the 'Meteor' fully established the advantage of steam. The average length of their passages in the first year between Holyhead and Howth was seven hours and thirty-three minutes, the shortest passage was five hours and forty-eight minutes, and the longest is stated to have been upwards of twenty-three hours.

The mail communication between London and Dublin had been thus long maintained exclusively by way of Holyhead ; but the rapidly growing importance of Liverpool,—the sea-port of the manufacturing districts of Lancashire, Yorkshire, and Staffordshire,—justly claimed a direct postal service with Ireland, which was accordingly established in 1826, though the sea passage is more than double that from Holyhead. Packets of a larger size were built, and provided with more powerful engines. The Parliamentary returns, for a period of three years, give the shortest passage as having been made in eleven hours five minutes, while the longest exceeded thirty-five hours. Private enterprise, as early as 1819, had placed steam vessels on this station, for the conveyance of passengers during the summer months. In 1823, however, Mr. Charles Wye Williams, of Dublin, a venerable Associate of the Institution of Civil Engineers, originated a company for the maintenance of a regular steam communication throughout the entire year. His plan embraced not only the conveyance of passengers but of merchandize, an extension of the advantages of the regularity of steam transport till then unattempted. His plan was so eminently and immediately successful, that it was speedily adopted on other lines of the coast, and ultimately over the entire globe.

Though not, apparently, necessarily connected with the subject of the communication between England and Ireland, it is right to draw attention to the substitution of iron for timber in the con-

struction of steam vessels, as having afforded great facilities for building models of the finest form, combined with lightness and strength, and the name of the first builder of an iron steam vessel should not be forgotten. Mr. Aaron Manby, the father of the Honorary Secretary of the Institution, built the first sea-going vessel of that material so early as the year 1820; in which year the first sea voyage was performed, when a cargo was conveyed direct from London to Paris without transshipment, the late Admiral Sir Charles Napier acting as captain, and Mr. Charles Manby as engineer. Many good authorities then questioned the innovation: now, scarcely any but iron steam vessels of every class, are used for commercial purposes. This material has also of late been extensively adopted for vessels of war. In fact it may be doubted, whether vessels of the form of those which now perform the Holyhead Mail Service could have been built of adequate strength of timber.

But if private enterprise was successful by sea, it was soon to be almost eclipsed by still greater success on land. The same spirit in England originated, and soon saw accomplished, that wondrous improvement of modern times, the railway. The line from London to Liverpool was completed in 1838; thenceforward that line became, for some years, the most expeditious route to Dublin, and the mails and passengers nearly deserted the Holyhead route. Liverpool did not, however, long retain this superiority. The proposal to continue the line of railway from Chester to Holyhead met with general acceptance; English enterprise again triumphed over every difficulty. The genius of Stephenson rivalled that of Telford; the Conway River and the Menai Straits were spanned a second time, and in 1849, a continuous line of railway was completed between London and Holyhead, by private capital, three-and-twenty years after the continuous line of road had been constructed by direction of the State and principally by grants of public money. The conveyance of the Irish mails was then retransferred from Liverpool to Holyhead, and the large and powerful packets of the Government, and of the Company which had carried the night mails under contract for the previous ten years on the Liverpool line, were appropriated to other duties.

It is not easy, from the Parliamentary returns, to arrive at the exact cost of maintaining the service between Great Britain and Ireland prior to its concentration at Holyhead, on the completion of the railway to that place. In addition to the principal postal services with Dublin, two other lines of mail communication had for many years been carried on by Government vessels; one in the north, between Portpatrick and Donaghadee, and the other in the south, between Milford and Waterford. The expense of supporting all these communications is stated at £75,000 a year,

without taking into account the original cost of the vessels, built in the royal dockyards, the interest on the capital, the annual depreciation, or the insurance. The outfit of the steam vessels provided for the Irish service appears to have cost upwards of £600,000, between the years 1820 and 1848.

During the period while these recent changes had been in progress, the Asylum Harbour of Kingstown was completed, and having ample depth of water at all times of the tide, which the harbour of Howth had not, the packet service was transferred to it. Ultimately a line of railway, 6 miles in length, connected it with Dublin.

The new Refuge Harbour at Holyhead was next decided on, with the avowed intention of providing the most perfect arrangements for the Irish Mail Service.

The only link then remaining to complete the communication with Ireland was such a superior class of vessels as the mechanical skill of the day could construct. The Government declined the offers of the former mail contractors to supply the vessels, having decided on building four of about 700 tons burthen each, fitted with engines of 350 nominal H. P. Great attention was bestowed on these vessels, and no expense was spared, with the desire of securing a result far in advance of any which had been previously arrived at. The result was universally admitted to have been a success. The 'Banshee,' built of timber, with double planking, but without frames, was a beautiful model, and of light draught of water. Her oscillating engines indicated 1,555 H. P., and her rate of speed at the measured mile on the trial trip was rather over  $18\frac{1}{2}$  statute miles per hour, nearly 4 miles more than had been previously attained by any other vessel. The speed of the 'Llewellyn' was very nearly as good (*vide* Appendix, p. 595), but the other two vessels, having heavier engines, were not equal to the same high rate of performance.

About the same time the Chester and Holyhead Railway Company, under what were considered the exceptional circumstances of the case, succeeded in passing a Bill through Parliament, authorising the novelty of owning and navigating steam-packets for a period of twelve years. Four vessels were accordingly provided by that Company for the conveyance of passengers. Two of these were fully equal in speed to the 'Banshee,' another was considerably less, but the fourth was admittedly a failure.

The Lords of the Admiralty, acting in accordance with the recommendation of a Committee of the House of Commons, decided, after a trial for a short time of the New Service at a heavy cost, to have it performed by contract, as had been the case for some years previously on the Liverpool line, and the tender of the former contractors was ultimately accepted. The service was to

be performed at the average speed of 12 knots, or nearly 14 statute miles per hour. Four hours and forty minutes were allowed on the average for the passage of the Channel, from outside the lighthouse at Kingstown Pier to the light at Holyhead. This service lasted from May, 1850, until October, 1860, and the passages were generally performed within the stipulated time.

Having thus traced the several changes in the means of communication between London and Dublin up to the commencement of the service now in operation, it may be interesting to state the time usually occupied in the journey at various periods, in order to show the gradual improvements in acceleration, which have resulted from the continued attention of Parliament to the subject.

Before the opening of the new turnpike-road by way of Shrewsbury to Holyhead, and of the establishment of steam mail packets, the communication with London was attended with so much uncertainty, that it would be difficult to give any accurate estimate of the time necessary for the journey. Travellers in those days thought themselves fortunate, if they accomplished the distance within four days. But after the opening of that road, and the establishment of steam vessels, the average time occupied in the transmission of the mails was reduced to about forty-three hours: letters posted in London on Monday being considered as due in Dublin on the following Wednesday evening. The adoption of Liverpool as the principal packet station, and subsequently, the opening of the railway from thence to London, shortened the time for the transit of letters to twenty hours, so that letters reached either capital in the evening of the day following that on which they were posted. Within a few months after the complete restoration of the mail service to Holyhead, the time allowed for the transit of the mails was reduced to sixteen hours from Dublin to London, and about fourteen hours in the opposite direction, the reason for the difference being, that the service from Ireland was timed with sufficient margin for the contingencies of the Channel passage, to insure the arrival of the mails so as to allow of their being forwarded by the trains appointed for the ordinary English services; while for the down mails, the packets waited the arrival of the train at Holyhead from London, and invariably proceeded to sea as soon as the mails and passengers were embarked, so that generally, there was an advantage in time in the journey to Dublin. Great however, as was the improvement thus finally effected, it was impossible to afford the public the advantage of the entire day for completing their correspondence in one capital, coupled with a morning delivery in the other, so long as the transit occupied from fourteen to sixteen hours, to which must be added the time required for sorting the letters, after their arrival at the

respective post-offices. The night service was therefore necessarily divided into two parts. First, an early despatch from the one end of the line, accompanied with an early morning delivery at the other; and the second, a late, or night despatch from the one capital, coupled with a late, or afternoon delivery in the other.

The Directors of the Company into whose hands the mail service between Holyhead and Kingstown had been intrusted, soon turned their attention to the subject, with the object of proposing further improvements, to be effected by the substitution of special express trains for the Irish service, in place of the ordinary trains, which were timed more in reference to the requirements of the English mails; and, secondly, by the employment of larger and more powerful steam-packets. Considerable doubts were at first expressed, as to the practicability of running trains with safety, the starting of which was to depend on the arrival of the packets at Holyhead. But the public loudly demanded more commodious vessels. Meetings were held in London, which were attended by the most influential persons interested in the question, who warmly approved of a plan then submitted for consideration, of a vessel of great size and power, which the projectors anticipated might attain the extraordinary speed of 25 statute miles an hour. Meetings of the commercial interest were also held in Dublin, to urge forward the adoption of any feasible measure of improvement, in the postal and passenger arrangements, for communication between Great Britain and Ireland. A plan was soon after submitted to Government, proposing a new service between London and Kingstown, the entire distance to be performed under ordinary circumstances in eleven hours. Express trains were to be appropriated exclusively for the Irish service, completing the land journey in six hours and forty-five minutes. For the Channel part of the service, steam vessels were proposed, 300 feet in length, with sufficient engine power to attain the speed on trial, of 20 statute miles an hour, so that the passage of the Channel could be made under favourable circumstances, in three hours and a half. The ship-builders and engineers who were consulted unhesitatingly stated that such a result was practicable.

A Committee of the House of Commons was appointed in the following year to inquire into the subject; and their report strongly recommended that the improved class of vessels should be provided, and that the speed on the railway should be accelerated, so that the mails, instead of requiring the average of fifteen hours between London and Kingstown, might be conveyed in eleven hours, as had been proposed. The Committee further recommended to the favourable consideration of the Government, the plan and estimates of the class of vessel contemplated, as able to attain a

speed of 25 statute miles an hour, but to be employed only in day-light; their advocates having expressed the opinion, that they could not be safely used at night. This objection, in addition to the great cost of the vessels, estimated at £180,000 each, no doubt caused that plan to be rejected.

The London and North-Western Railway Company, and the City of Dublin Steam Packet Company, having agreed to united action, passed a Bill through Parliament, in 1855, to sanction and facilitate their arrangements.

The Government then made a communication to the Companies, as to the requirements of the Post Office, for two services, one by day and the other by night, to be completed in half an hour less time than that which had been already proposed, and this to be guaranteed under heavy pecuniary penalties for every minute of excess, arising from causes even beyond control. The Companies agreed to undertake this service, but altogether declined to submit to penalties for loss of time arising from fogs, or other causes wholly beyond their control. The subject having been allowed to lie dormant for another year, the Members of Parliament for Ireland collectively urged on the Prime Minister so forcibly the expediency and necessity for providing for the improved means of communication at the public expense, as had been formerly done when the new Holyhead Road and Telford Bridges were constructed, that the matter was at last taken up seriously and the Government agreed to carry into effect the plan recommended in 1853, and which eventually received the cordial approval of the Lords of the Treasury.<sup>1</sup>

<sup>1</sup> Extract from Treasury Minute, dated October 19, 1855.

"My Lords have before them a private Act, passed in the last Session of Parliament, intituled, 'An Act for improving the Postal and Passenger Communication between England and Ireland, and for authorising Arrangements between certain Companies in England and Ireland in relation thereto, and for other Purposes.'

"By this Act the London and North-Western Railway Company, the Chester and Holyhead Railway Company, and the City of Dublin Steam Packet Company, are empowered to provide and use such steam boats for the conveyance of mails and passengers between Holyhead and Kingstown or Howth as they shall think fit; and it is also provided by the 18th section of the said Act as follows:

"It shall be lawful for the aforesaid Companies from time to time to make and enter into and carry into effect any agreements and arrangements with Her Majesty's Postmaster-General, or with the Lords of the Admiralty, in reference to the conveyance in their steam boats of Her Majesty's mails or post letter-bags between Holyhead and Kingstown or Howth: Provided always, that, until an agreement or arrangement for the purposes hereinbefore in this clause mentioned shall have been so made and entered into, none of the powers by this Act granted shall be exercised by the said Companies, and that, unless such an agreement or arrangement shall have been made and entered into on or before the first day of May, one thousand eight hundred and sixty, it shall not be lawful for the said Companies, in pursuance of this Act, to exercise any of the powers granted thereby, and such powers shall thereafter cease and have no effect.'

"My Lords fully recognise the main motive which the Legislature had in

The main provisions of the new postal contract were, first, that the entire distance between London and Kingstown was to be performed in eleven hours (eleven hours and a half being allowed to Dublin), assigning four hours for the sea passage, subject to fines

passing this Act, and in extending, in the respects therein contained, the powers and functions of the three existing Companies referred to. That motive was undoubtedly the hope that, by the combination so created, a more efficient steam boat service would be established between Holyhead and Dublin, thus connecting England and Ireland by the shortest possible passage, and in the shortest possible time, with a view to their postal and passenger communication. But so far did the Legislature recognise in any such arrangement the paramount importance of the postal service, that the clause already quoted was introduced into the Bill, by which the powers granted under it should only take effect in the event of the united Companies being able to make an arrangement with the Postmaster-General or the Admiralty for the conveyance of the mails.

"While, however, my Lords regard this as being the main object of the Act, and the one which the Government is officially called upon to take into its consideration, they by no means desire to leave out of view, in connexion therewith, the enormous social and political advantages which may be expected to be derived from such an improved communication between the two countries as the progress of art and science entitle the public to look for. Nor can my Lords leave out of view the great advantage and convenience which such an improved service would confer upon Irish Members of Parliament whose public duties necessarily lead to their frequent passage between the two countries, and who are entitled to expect every fair facility for that purpose.

"My Lords desire to know if it would be practicable—

"1. For a mail leaving London at a convenient hour in the morning to arrive in Dublin in time for the departure of the evening mails, and also for a delivery in Dublin the same night.

"2. For a mail leaving London in the evening at the usual time of departure to arrive in Dublin in time for the day mails from Dublin, and for a convenient morning delivery in Dublin.

"3. For a mail to leave Dublin in the morning at a convenient hour after the arrival of the night mails from the provinces in time to reach London for the departure of the evening mails, and for a late delivery that night.

"4. For a mail to leave Dublin in the evening, after business hours, and to arrive in London in time for an early delivery, and for the day mails out of London.

"If such arrangements shall prove to be practicable, then my Lords would be prepared to incur a considerable increased expenditure in order to secure them.

"In that case, in the majority of instances, the Irish postal service both ways would be advanced by periods varying from six to twelve hours, and in many cases, practically for business purposes, twenty-four hours, would be saved in replicas, besides which the most perfect passenger accommodation would be secured. A mail would leave from each end at convenient hours, morning and evening, and, occupying only eleven hours, would arrive also at convenient times, and such as would enable passengers to pursue their journey forward without stoppage. For example, letters and passengers leaving London in the morning would arrive in time for the night trains out of Dublin, and by midnight of the same day, or shortly after, would reach all the chief cities in the provinces; and letters and passengers leaving London in the evening, would reach Dublin in time for the departure of the morning trains out of Dublin, and would arrive at all the chief cities in the provinces a little after noon on the following day; so also, letters and passengers leaving Dublin in the morning would arrive in London in time for the Continental and other mail trains the same night, and those leaving Dublin in the evening would arrive in London in time for the departures of the mail day trains. For some great and decisive advantages, such as these, to be enjoyed by the public, would my Lords feel that they were justified in incurring a material increase on the present expenditure of public money."

for loss of time, unless arising from weather, or other causes beyond control ; secondly, that four steam packets should be provided, each 300 feet in length, and 1700 tons burthen builder's measurement, with engines of 600 nominal H. P. ; thirdly, that express trains should be appropriated exclusively to the Irish traffic ; and fourthly, a morning and evening departure from each capital. The Improved Service was arranged to be commenced in January, 1861, two years being allowed by the contract for building the vessels.

To accomplish what had been proposed, and fully to realise the expectations of the public, was naturally a subject of no small anxiety to those on whom the responsibility devolved of providing vessels so much in advance of any which had yet been built. It was not a mere question of speed at the measured mile in Long Reach, or in Stokes Bay ; that had been shown to be practicable, by the great success of the Royal Yacht, which attained the unprecedented rate of speed, at the trial trip, of  $19\frac{1}{2}$  statute miles per hour (*vide* Appendix, p. 595) ; the difficulty was, to maintain such a rate of speed in severe weather, and under the disadvantageous circumstances which must so often occur in the passage of the Channel four times every day in the year, as to insure comparative regularity in the due performance of a mail service, with but very small margin for contingencies at sea. With the object therefore of insuring this result, it was ultimately decided to increase the size of the vessels to 2,000 tons, and that of the engines in like proportion. Designs were received from the most eminent builders in England. Those submitted by Messrs. Laird, of Birkenhead, and Mr. Samuda (M. Inst. C.E.), of London, were adopted. Messrs. Ravenhill, Salkeld, and Co., supplied two pairs of engines, and Messrs. James Watt and Co. the other two pairs. The dimensions and general arrangements of the four vessels are so nearly alike, that the following description of one, the 'Connaught,' will be sufficient for all. This was built by Messrs. Laird, as well as the 'Ulster' and the 'Munster ;' the fourth, the 'Leinster,' was built by Mr. Samuda.

The ships are built of iron. The length between the perpendiculars is 334 feet ; the beam is 35 feet, and depth 21 feet. The keel is formed of a centre keel plate, 3 feet deep and  $\frac{3}{4}$  inch thick, with two bars, 9 inches deep by  $\frac{5}{8}$  inch thick, on each side at the bottom ; these five plates, with the two garboard strakes,  $\frac{7}{8}$  inch thick each, are secured together with iron bolts riveted and countersunk. On the top of the centre keel plate, two angle iron bars are riveted, 5 inches by 4 inches by  $\frac{1}{2}$  inch, and to these angle irons, and to the angle irons on the top of the floorings throughout the entire length of the vessel, as far as the fine ends will allow, is riveted a strong plate, 4 feet wide amidships, and 2 feet 6 inches wide at the ends. There are

also two very strong box keelsons, secured on the floorings at each side of the keel, and another in each bilge. The general framing of the ship and the outside plating are done in the usual way, care being taken to have everything well put together. The engine beams, paddle and spring beams, and all other beams for the main and lower decks, are of iron. Timber has been used only for the decks and cabin fittings. There are nine principal iron water-tight bulkheads, which not only provide for the safety of the ship in case of accident, but add greatly to her strength in a sea-way. The bulwarks are of iron plates, in continuation of the sides of the vessel to the rail, and without any break for gangways, such not being required for landing, either at Holyhead, or at Kingstown. To give additional strength in the centre, where the weight of the engines, wheels, and boilers, has to be carried, the insides of the paddle-boxes are also formed of iron plates, continued from the sides and bulwarks of the vessel, with a strong bow girder, formed of an iron plate 15 inches broad and  $\frac{3}{4}$  inch thick, so as to provide ample means of resistance to the severe shocks which these long vessels must encounter in rough seas, when driven at such a high rate of speed. The gunwale is formed of angle iron bars, 4 inches by 4 inches, riveted to the sheer strake and to a plate which is riveted on the top of the beams. At a distance of about 15 inches from this, an inner angle bar is riveted, against which the wooden waterway is fitted, so as to leave the outer part, between this and the gunwale, to form a drain to take the water off the deck, and to discharge it through the scuppers. This arrangement, which was introduced by Mr. Laird, has been found very convenient, in freeing the decks quickly from water. These iron gunwale plates are 5 feet wide by  $\frac{3}{4}$  inch thick amidships, tapering gradually to about 2 feet 6 inches by  $\frac{1}{2}$  inch at the ends, with a system of diagonal tie plating from side to side, securely bolted or riveted to the deck beams. Between the paddle-boxes, an upper deck, about 50 feet in length, has been placed. It is laid on iron beams well secured, and being provided also with diagonal tie plates, it further adds to the strength amidships; though the primary object was for the more rapid embarkation and landing of passengers and luggage at times of low water, both at Holyhead and at Kingstown. It also forms an agreeable promenade for the passengers in moderate weather. The wheel and the binnacle are placed on this upper deck, so as to allow of the commander and the officers being near to the men engaged in steering. All difficulty is thus avoided in passing the word, a distance of nearly 200 feet, as would have been necessary, in the ordinary way. The entire of the main deck, from the foremost funnel to the bows, is covered over by a hurricane deck formed with angle iron beams, 5 inches by  $2\frac{1}{2}$  inches, extending from the

rail at each side, and boarded over with planks  $1\frac{1}{2}$  inch thick, leaving when at sea but one small opening round the foremast. This construction has been found of great advantage in throwing off the seas, which previously to the vessels being thus protected, occasionally in heavy weather caused damage to the skylights and upper works. The weight of so large a piece of work, about 140 feet in length, is considerable, and increases the immersion of the vessel forward; but this has been amply compensated for, by the security afforded when pressing at a high rate of speed in tempestuous weather. There has not been the slightest damage to any of the vessels, during the last two years, since they were completely provided with this excellent protection. The plan was copied from a small vessel, the 'Menai,' fitted out in Liverpool for the River Plate in 1854.

The engines for all the vessels are on the oscillating principle. In the two pairs made by Messrs. Ravenhill, Salkeld, and Co., for the 'Leinster' and the 'Connaught,' the cylinders are 98 inches diameter, with a length of stroke of 6 feet 6 inches; the air-pumps are 54 inches diameter, with a stroke of 2 feet 6 inches. The eight boilers are multitubular, four being at each end of the engine-room space, arranged in pairs, with one funnel to each pair. There are five fire grates in each boiler, 3 feet 1 inch wide, with bars 5 feet 6 inches long. The boilers being placed lengthways in the vessel, the firing space, which is 11 feet wide, is in the centre. The entire extent of the grate surface in the eight boilers is 677 square feet; and the heating surface measures 19,700 square feet. The bunkers are small, being made to contain only one day's coal, as the vessels can be supplied either at Holyhead, or at Kingstown, during the interval between their arrival and departure. The space occupied in the length of the vessel by the engines and boilers is 108 feet, and this has been subdivided, by iron watertight bulkheads, into three compartments, an arrangement suggested by Mr. Laird, and which has been found most beneficial in giving strength in a part of the vessel which might otherwise have been weak, and unequal to the severe strain of the powerful machinery working in the heavy sea-way of the Irish Channel. The wheels, which are constructed on the feathering principle, with fourteen floats each, are 31 feet in diameter at the outside of the floats, or 27 feet to the centre of axis; and each float is 12 feet long by 4 feet 4 inches broad. On the trial trips, the engines worked at the rate of  $25\frac{1}{2}$  revolutions per minute, under a steam pressure of 25 lbs. per square inch. The mean of the runs of the 'Leinster,' at the measured mile in Stokes Bay, was at the rate of  $20\frac{1}{2}$  statute miles an hour, a greater speed, by upwards of one mile an hour, than had been previously attained by any other vessel. The 'Connaught,' when subsequently tried at the measured mile in

Stokes Bay, attained a higher result, the mean of her runs showing the speed of  $20\frac{3}{4}$  statute miles per hour. (*Vide* Appendix, p. 595.)

The 'Ulster' and the 'Munster' were built by Messrs. Laird, on exactly the same lines as the 'Connaught.' The engines of these vessels were constructed by Messrs. James Watt and Co., of Soho, the same establishment from whence the engines proceeded for the first steam vessels built for the Post Office for the performance of the Holyhead Mail Service. Boulton and Watt would have been somewhat surprised, if it could have been foretold, that their successors would have been called on to construct engines tenfold the size of what they had made, to be placed in vessels tenfold the tonnage of the 'Royal Sovereign' or the 'Meteor,' and for the same line of postal communication. The general arrangement of the engines in the 'Ulster' and the 'Munster' is nearly the same as of those in the 'Leinster' and the 'Connaught.' The cylinders are, with a length of stroke of 96 inches in diameter, 7 feet. The wheels are 33 feet in diameter over all. The boilers have each six fire-places, 2 feet 6 inches wide, and the bars are 5 feet 6 inches long, giving in the aggregate as large an extent of grate surface as in the others. The area of the heating surface is 18,033 square feet. One funnel is used for the four boilers of each compartment, and as the coals are carried on the top of the boilers, the entire space occupied in the ship by these engines and boilers is but 102 feet. These engines were erected on board the vessels in the Liverpool Docks. There is not any measured mile at that port for testing speed; but from a return supplied by Messrs. Watt and Co., of observations made on several trips, the rate attained appears to have been  $17\frac{1}{2}$  knots, or 20.3 statute miles per hour, and the average performances of the 'Ulster' and the 'Munster,' contrasted with the average performances of the other vessels, fully proves, that this in no degree overrates their speed, when going under the usual conditions of a trial trip.

The internal arrangements of the vessels were planned with the object of providing for the comfort and accommodation of the public, in the way best calculated to mitigate, and as far as possible to prevent, the sufferings so usually inseparable from the passage of the rough Irish Channel. For although the talented builders endeavoured to design a form which should be easy in a sea way, both they, and those for whom they were building, were well aware, that it was utopian to expect, as many appear to have expected, with ships of even their large dimensions, a uniform horizontal position in tempestuous weather. Enlarged size has no doubt, in many cases, lessened the motion at sea; but the chief advantage in this instance is that, it has afforded the means of providing reasonable accommodation for many passengers,—a want

which had been so much felt with the previous smaller class of packets. The saloons and cabins in the new vessels are large, lofty, and well ventilated. The principal one is upwards of 60 feet in length, by 17 feet in breadth, and 9 feet 6 inches in height. On each side of this saloon there are state-rooms, with several berths, or sofas. The ladies' saloons and cabins, which are entered from a large deck house by a separate staircase, are provided with upwards of forty sofas and berths, independent of the accommodation in the deck saloon and in the adjoining state-rooms also on the main deck. First-class passengers have excellent sleeping cabins in other parts of the ship, and there are also two commodious deck cabins, one of which is appropriated as a smoking-room. The cabins for the second-class passengers are placed forward. Throughout the whole of the communications which took place between the builders, the engineers, and the Directors of the Company, the most perfect concord prevailed; all parties appearing to be actuated by the desire to produce vessels and machinery in every way calculated to fulfil the high expectations which so much public discussion had raised.

A better opportunity could not have been desired for attaining a good result, than the Holyhead and Kingstown mail line. There was sufficient depth of water at all times of the tide, with no natural obstruction to the navigation of the Channel, and the short distance needing no great weight of coal, and no cargo being carried, the vessels would at all times have very nearly the same uniform immersion. Besides, the vast importance of the communication justified an expenditure for the mail service, which could not be undertaken as a commercial speculation, to be remunerated solely by the conveyance of the traffic. All these advantages united, afforded an unprecedented opportunity, which those engaged in the work fully appreciated, and they endeavoured to make the most of it. It is due to them to state, that after the contracts had been entered into, every suggestion made during the progress of the work, with the desire of providing further improvements as to strength, or accommodation, was at once adopted though attended with increased cost. The result proved that the unbounded confidence which was placed in the contractors, by the Directors of the Company, was well deserved.

The cost of the four ships to be provided, in accordance with the contract, was £75,000 each. The actual cost has, however, greatly exceeded the amount agreed to be expended by the Company, in consequence of the size of the vessels having been enlarged to upwards of 2,000 tons, and the engines in about the same proportion; a change which has obtained increased accommodation for the public, and probably a superior performance of the vessels at sea.

One of the principal peculiarities, which render these vessels of so unique a class, is the post-office fitted for sorting letters during the passage. The space occupied for this purpose extends across the entire breadth of the vessel, and for the length of 30 feet, between the first and second class cabins. It is divided into two rooms, one for letters, and the other for newspapers. In these rooms the sacks are opened, the contents taken out and arranged, by eight, or ten sorters, under the direction of a head superintendent. The letters are stamped with the post-office packet brand, the postage label cancelled, and all the operations completed, so that the letters are ready for delivery, or to be forwarded to their destination, on the arrival of the vessel at Kingstown. About two hours are thus saved in the transmission of the mails, in consequence of their being made up on board, instead of after their arrival at the General Post Office in Dublin. Besides the gain in time thus secured for postal purposes, the main object to be attained was regularity; while for passengers, accommodation was perhaps even more to be valued than extreme speed. To fulfil all these conditions, it was necessary to have very large vessels; such only obviously allowing the requisite extent of accommodation, and experience had shown that the larger the vessel, when provided with adequate power, the less was the difference in the length of the passage at sea caused by severe weather.

The contract with the Postmaster-General had appointed January, 1861, for the commencement of the Improved Service. But the vessels being in readiness some months sooner, it was commenced, by mutual agreement, in October, 1860, and has since been continued without interruption. When two of the vessels, the 'Leinster' and the 'Ulster,' were completed, and ready for duty, it was thought advisable to make a trial with them, by way of practice, in the performance of the old contract. Each performed the distance between the lighthouse on Kingstown Pier to the lighthouse at Holyhead, upwards of  $65\frac{1}{2}$  statute miles, in nearly the same time on the average, namely, the 'Leinster' in three hours and thirty-one minutes, and the 'Ulster' in three hours and thirty-two minutes, being respectively thirteen and twelve minutes less than the shortest monthly average of the 'Banshee' in 1848-49, and twenty and nineteen minutes less than the 'Llewellyn,' when the distance between the lights was one mile less than in 1860—the Holyhead breakwater not having been then in existence.<sup>1</sup> The gain in speed realised by the new vessels was therefore at the rate of from 1.2 to 1.7 mile per hour.

Before however giving an account of the actual performance of

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<sup>1</sup> The courses are laid down on the plan of Holyhead Harbour attached to this communication.

the contract for the Improved Service, which is one combining the land journey with the passage of the Channel, inclusive also of the time occupied in the transfer of the passengers, mails, and luggage, between the packets and trains at the Holyhead jetty, it will be right to state the means agreed to be provided by Government for the berthing and accommodation of the large vessels at Kingstown and at Holyhead. This subject had from the first engaged the anxious attention of the promoters of the Improved Service, for they were well aware, that any attempt to convey the mails with regularity between London and Dublin in eleven hours and a half as proposed, would be wholly unsuccessful, unless landing piers were provided at both sides of the Channel, easy of access in all weathers, and such as would allow of the berthing of the vessels, and the transfer of all on board, with the utmost economy of time. A stone jetty, perfectly adapted to meet all these requirements, had been commenced in Kingstown Harbour by the Board of Works, in accordance with the plans of the late Mr. Barry Gibbons, in 1852, provision having been made for the continuation of the line of rails, so as to connect it with the Dublin Station. The late Mr. Rendel having stated his objections to this pier, both as connected with the safety of the vessels and the convenience of the public, the work was ordered by Government to be suspended, and it was not again resumed, until after a full inquiry by a commission of naval officers appointed for the purpose by the Admiralty. Their report was so decisive in favour of the pier as originally designed, that the work was immediately resumed, and it was completed and ready for use in good time. After a daily experience of nearly three years, it is due to the memory of Mr. Gibbons to testify, that this packet pier has fulfilled to the utmost the most sanguine expectations of all who were qualified to give an opinion on the subject. The packets usually arrive at the west side, where the passengers land under shelter, and taking their places in the railway carriages, are conveyed to Dublin in fifteen minutes. The packets are afterwards backed round the semi-circular end of the jetty to the east side, where they remain in readiness for the outgoing mails. They lie in still water at all times.

The new harbour at Holyhead, which was sanctioned by Parliament with the twofold purpose of providing for the mail packet service and for refuge, had made considerable progress before any definite plan was arranged for the primary of these objects. Mr. Rendel, a short time before his last illness, had been in communication with the steam and railway companies, to ascertain their views as to the arrangements which would best suit the Irish service; but requiring that the position should be in a depth of water sufficient for the accommodation of the Trans-

atlantic vessels, it being at that time anticipated that Holyhead would be fixed as their port of call. The death of Mr. Rendel soon afterwards left the decision in the hands of his successor, Mr. Hawkshaw, (President Inst. C.E.,) who renewed the inquiry with a similar limit as to choice of position. The result of his investigation was a plan for very extensive piers, with quays upwards of 3,000 feet in length, which met with the approval of all the parties whom he consulted, and he omitted none who were interested in the subject. These plans, the estimated cost of which was £425,000, were sanctioned by Government and by Parliament in 1858. Provision having thus been agreed to be made for the safe, easy, and expeditious berthing of the large vessels, near the entrance of the new harbour, and for convenient communication with the railway and trains, the united companies entered into the joint contract with the Postmaster-General for the performance of the entire journey between London and Kingstown pier in eleven hours, guaranteed under penalties for excess of time, unless arising from causes beyond control. These penalties were not, however, to be put into operation, as proposed on the part of Government, until the piers which had been agreed to be provided were completed. The vessels being ready, it was arranged by Government, that the service should be commenced and carried on, as well as the circumstances would admit, without penalties, so long as the vessels and trains were confined to the use of the timber-jetty, constructed at the end of the old packet quay for temporary use, pending the completion of the permanent works. It will thus be seen, that there is yet to be provided one link for the chain of the improved communication between London and Dublin; a most important link which had been very carefully considered, and specially stipulated for, as essential to the full accomplishment of the plan which had been proposed for adoption.

It remains now to give some information as to the manner in which the new service has been performed since it was commenced in 1860. From what has been already stated, with regard to the speed of each of the vessels on their trial trips, when, as is usually the case on such occasions, the utmost power of the engines is exerted during the short time required for the run of a few miles, it may be readily seen, that for actual daily duty, the difference between the four vessels is inappreciable, a matter of paramount importance to a mail service. The extreme difference in the rate of speed on trial appears to have been about half a mile an hour, which would add but six, or seven minutes to the passage between Holyhead and Kingstown, taking the present course at 57 knots, or a little over 65½ statute miles; the extension of the great breakwater having added more than a knot to the distance

given in the Admiralty Returns, as having been performed by the 'Banshee,' the 'Llewellyn,' and other packets in 1849-50. A speed of  $17\frac{1}{2}$  knots, or 20 statute miles per hour, on the trial trip, allows a safe margin for making the passage commonly in four hours, the time proposed by Government; but this large margin has not in practice been found too much. Again, it may be observed, that there is a considerable difference in running a few times by the measured mile, when all is tasked for a short time to the utmost; and making a single complete passage of the Channel, even under favourable circumstances. Thus, while the 'Connaught' attained a speed of  $20\frac{3}{4}$  statute miles an hour on her trial trip, her shortest passage of the Channel occupied three hours and fourteen minutes, being at the rate of about 20 miles an hour. The shortest passage of the 'Leinster' was made in three hours and twenty minutes; that of the 'Ulster' in three hours and eighteen minutes, and of the 'Munster' in three hours and twenty-six minutes. But the average performance of the vessels for the two years and five months during which they have been on service is still closer. Inclusive of all passages made in fogs, gales, &c.,

|                                                   |     | h. | m.     |
|---------------------------------------------------|-----|----|--------|
| The 'Connaught' made 1,064 in the average time of |     | 3  | 51·5   |
| The 'Leinster' . . . . .                          | 919 | "  | 3 52·5 |
| The 'Ulster' . . . . .                            | 925 | "  | 3 55   |
| and the 'Munster' . . . . .                       | 920 | "  | 3 58·1 |

So close a performance by the four vessels, not identical and not all from the same builders and engineers, could scarcely have been anticipated. The longest passage made in the severest gales has not exceeded five hours and forty minutes, and one vessel only has been that length of time on but two occasions. The previous packets were retarded by the weather to a far greater degree. The 'Banshee' has taken nearly eight hours to cross the Channel; the 'Llewellyn,' the 'Caradoc,' and the 'St. Columba' still more. Nearly four thousand passages have been already made without collision, except on one occasion, which happily was not attended with very serious consequences. Experienced naval officers anticipated frequent and serious disasters, but the rate of speed, 16 miles an hour, though high for night-work, does not appear to have been too high for safety. The sense of greater responsibility, and the larger number of men engaged in the navigation and management of the vessels, must naturally induce additional precaution, as well as afford the means of guarding against danger. The facility with which these large vessels are handled and brought alongside the jetties is remarkable. The practised skill of the officers, and the quickness with which the engines are managed, frequently succeed in getting the vessels along-

side, in making them fast, establishing the means of communication with the shore, and in landing the mails in three, or four minutes.

The consumption of coal in the first few months was considerably in excess of the quantity originally estimated. Steam of from 25lbs. to 28lbs. pressure was then used, which not only required much extra coal, but severely taxed the durability of the boilers. Arrangements were therefore made to reduce the consumption to the amount stated in the estimates submitted to Government, on which the contract was founded. The result has been satisfactory, while the additional time occupied on the passages is but a few minutes, and they are still made on the average within the time allocated to the sea service by the proposal of Government. The necessity of laying up the vessels more frequently for repairs has been also diminished, which is a matter of much importance, as they are of so unique a class, that in the event of more than two being laid up at the same time, it would be impossible to obtain an efficient substitute, and therefore, the postal service might be exposed to some danger of interruption, if such circumstances were to continue for any length of time. The engines in the 'Ulster' and the 'Munster' were provided with superheaters, but experience has not shown any advantage resulting from their use, either as reducing the consumption of coal, or tending to a superior performance. These vessels have made in the aggregate 1,845 passages, in the average time of 3 h. 56 m., and have consumed 30 tons 7 cwt. on the average of each, inclusive of the quantity required for raising steam, which is very considerable. The 'Leinster' and the 'Connaught,' without superheaters, have made 1,983 passages, in the average time of 3 h. 52 m., and have consumed (inclusive of raising steam) on the average, 30 tons 1 cwt. of coal.

No break-down has taken place with any of the engines. On two occasions some derangement occurred with the wheels. Very constant attention is given during each 'rest' after the usual term of duty, to the machinery and the boilers, so as to prevent the necessity of extensive repairs.

The principal trouble has arisen from the difficulty which appears to be experienced, in obtaining sufficiently sound forgings for the large intermediate air-pump crank shafts. As a precautionary measure, two duplicate shafts fitted with cranks had been included in the original order, one suitable for either pair of engines from each firm, so that no time might be lost in replacing one, if at any time it was found to be defective, or appeared to be doubtful. This was no needless precaution, as within the first year it was found necessary to condemn two shafts, and to use the duplicates, and the vessels were ready within the week for service instead of being laid up for months. Two new spare shafts were

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immediately again ordered, and these have since been required; and another of steel, made by Mr. Krupp (of Essen), is also now in use. Thus, within the space of two years and a half, five of these costly pieces of work have been already condemned. It is justice to the makers of the engines to state, that they have met the case in the most satisfactory manner. No failure has hitherto occurred with any of the shafts supplied by the Mersey Steel and Iron Company, and they have done their full share of duty. Very great exertion was made by that establishment on one occasion to prepare a forging within the short space of three weeks, to replace one under peculiar circumstances, which rendered the utmost expedition important.

With regard to the ships, it is very satisfactory to be able to state, that no repairs have so far been needed. They are now in as perfect a condition, after the performance of their severe duty, as when they commenced in 1860. The frequency of docking, for the purpose of cleaning and coating, has afforded constant opportunity of examination, but painting only has been found necessary.

To maintain speed, it is obviously indispensable to keep the bottoms of the vessels clean; but as no docking accommodation has as yet been provided at Holyhead, and it being objectionable to remove the vessels from the station to the graving-docks of other ports, if possible to avoid doing so, the experiment of employing divers, while the vessels lay alongside the jetty, was tried last summer, and with some success. The growth of marine vegetation, and the adhesion of marine animals, which take place rapidly in the summer months, were prevented to a considerable extent.

The Author, connected as he has been with the sea part of this service, has thus endeavoured to give the information which constant and anxious watching over it from the commencement has enabled him to do. He postponed submitting to the notice of the Institution any communication on the subject, until a sufficiently-prolonged experience might justify the expectation of a continuance of the same performance. It would be wrong, however, to close this Paper, without referring to the admirable performance by the London and North-Western Railway Company, of the land portion of the journey from London to Holyhead; the punctuality of the arrival of the trains on the jetty there, the speed maintained, and the excellence of the carriages supplied, are the subject of universal approval. Further improvements at present unthought of may no doubt be yet brought into operation; but whatever changes may take place, there would appear no reason for anticipating that the communication by way of Holyhead will ever cease to be the best for postal purposes, and to be preferred by the travelling public, so long as the entire distance between London and Dublin can be accomplished within eleven hours and a half.

[APPENDIX.

## APPENDIX.

## PARTICULARS OF THAL TRIPS.

| —                              | Banahoe.         | Llewellyn.      | Victoria and Albert. | Leinster.         | Connaught.         |
|--------------------------------|------------------|-----------------|----------------------|-------------------|--------------------|
| When tried . . . . .           | 10th Jan., 1848. | 15th May, 1848. | 23rd July, 1855.     | 26th July, 1860.  | 27th Sept., 1860.  |
| Where tried . . . . .          | Long Reach.      | Nore and Mouse. | Stokes Bay.          | Stokes Bay.       | Stokes Bay.        |
| Draft of Water {               | 8 ft. 8 in.      | 8 ft. 6 in.     | 13 ft. 10 in.        | 12 ft. 2½ in.     | 12 ft. 9 in.       |
|                                | 9 ft. 0 in.      | 9 ft. 2 in.     | 14 ft. 0 in.         | 13 ft. 2½ in.     | 13 ft. 2 in.       |
| Area of Midship Section . . .  | 192 feet         | 185 feet.       | 401 feet.            | 336 feet.         | 341 feet.          |
| No. of Revolutions . . . . .   | 30·5             | 28·5            | 25·4                 | 26·25 mean.       | 25·5               |
| Pressure on Safety-valve . . . | 19 lbs.          | 20 lbs.         | 23 lbs.              | 25 lbs. by gauge. | 26½ lbs. by gauge. |
| Vacuum in Condensers . . . .   | ..               | ..              | 25 inches.           | 25 inches.        | 25½ inches.        |
| Nominal Horse-power . . . .    | 350              | 350             | 600                  | 720               | 720                |
| Indicated Horse-power . . . .  | 1,555            | 1,890           | 2,980                | 4751              | 4735               |
| Speed of Vessel—Knots . . . .  | 16·1             | 15·912          | 16·827               | 17·747¹           | 18·079¹            |
| „ Statute Miles . . . . .      | 18·553           | 18·317          | 19·877               | 20·429            | 20·811             |

¹ The mean of four runs.

Mr. J. SCOTT RUSSELL,

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Mr. J. SCOTT RUSSELL, V.P., said, the regularity in the performances of these vessels in all weathers, their close approximation with each other, and the high speed that, considering all the circumstances, had been uniformly maintained, must be regarded as most satisfactory; for with so high a rate a serious mistake in any of the vessels must have led to a marked loss of speed. A vessel built on suitable lines, and 320 feet long, ought to attain a speed of between 20 and 21 miles an hour, and these vessels had, it appeared, done all that could be expected in bad weather, as well as maintaining the speed due to their length. This result he considered peculiarly gratifying, inasmuch as he was many years ago examined before a Committee of the House of Commons, as to whether a velocity of 20 miles an hour, then thought to be impossible, could be obtained, or maintained, between Holyhead and Dublin, by vessels of any conceivable dimensions; and he could only succeed in convincing the House that such a result could be obtained, by repeating the same evidence before several Committees. At last, however, it was accomplished: and ship-builders began to consider, that, with adequate power, 20 miles an hour was what a properly designed vessel ought to do.

Although the particulars given were interesting and valuable, there were several points on which further information was desirable, to make the Paper complete; as, for instance, in each case, the area of the midship section immersed, the displacement of the ship, the extent of immersed skin, and the proportion of power given out by the engines, when a given amount of performance was attained by the vessel. These were a few technical points, which Engineers would like to have, in order to see what difficulties had been overcome, and how they had been surmounted.

Mr. SAMUDA stated that, on the trial trip of the 'Leinster' in Stokes Bay, the area of the midship section was 336 feet, the displacement was 1,900 tons, the average draught was 12 feet 9 inches, the steam power was 4,751 indicated H. P., and the speed was  $17\frac{3}{4}$  knots, or  $20\frac{1}{2}$  miles per hour. Taking these particulars, the co-efficient did not appear high: but the vessel went through the water with very little disturbance, in fact, it scarcely raised a wave, so that as far as could be judged by ordinary observation a considerably higher performance might have been expected. Whether the great speed had anything to do with the comparatively low co-efficient, or whether it arose from the dip of the wheel, he could not say. The extreme diameter of the paddle-wheels was 31 feet, the diameter at the centre of the axis was 26 feet 10 inches, the stroke of the engines was 6 feet 6 inches, the diameter of the cylinders was 98 inches, and the number of revolutions was 26.4 per minute. The engines worked very

smoothly and well. The slip of the paddle-wheel during the trial of the 'Leinster' was actually 19·41 per cent.

Mr. BRERETON thought it desirable to have some explanation, with regard to abandoning the use of the superheating apparatus so soon after its application, and the grounds on which it was given up. There were strong advocates for superheating, and, as far as experience went, the moderate use of it appeared hitherto to have been satisfactory.

Mr. E. A. COWPER considered, that in a Paper of this kind, full details should be given. He would be glad to know whether the cylinders and cylinder covers were fitted with steam jackets; at what degree of expansion the steam was cut off; what was the surface of the superheaters, to what temperature the steam was superheated, and how long the superheaters lasted; and what was the diameter and width of the wheels, and the size and dip of the floats.

Mr. WATSON said, it had not been his purpose to enter into the engineering details of these vessels, but merely to give the results of his experience of their working. The course he pursued, with regard to the plan of vessels for the Improved Service, was this. He made inquiries as to the speed of the fastest ship then known,—the Royal Yacht,—and as soon as it was determined that this service should be established, the Admiralty afforded him every facility for ascertaining the capabilities of that vessel. The result satisfied him and his colleagues that what was desired could be achieved, by building vessels with finer lines, with less immersion, and with less midship section, than the Royal Yacht; and then by putting more power into them, a slightly higher speed might be obtained. The result had been as anticipated. The speed of the Royal Yacht was a trifle under 17 knots, and the fastest of these boats was over 18 knots, an hour. The Appendix to the Paper (page 595) would be found to contain some of the particulars asked for, in reference to two of the vessels engaged in the Improved Service, the 'Leinster' and the 'Connaught,' as well as of some others.

With regard to abandoning the use of the superheating apparatus, the Company had placed themselves unreservedly in the hands of the Engineers. Mr. Ravenhill did not recommend superheaters, but Mr. Blake (of Messrs. James Watt and Co.) was in favour of the system, and on the Company acquiescing in his advice, the apparatus was supplied. The superheating apparatus mentioned in the Paper consisted of a casing round the lower part of each funnel, about 12 feet deep, in which were placed divisions of iron plates, which acted also as stays inside. It was found, however, after some time, that these divisions were wholly destroyed by oxidation, and some anxiety was felt lest this might cause an accident; as portions of the decayed parts of the divi-

sions, having fallen to the bottom of the superheaters, got into the slide-valves, and materially damaged them. The great inconvenience and expense of renewing the slide-valves induced the discarding of these superheaters; and as it further appeared that economy of fuel and greater speed were rather in favour of those vessels in which they were not employed, the reasons were all on the side of abandoning the system. Besides, there was to be considered not only the question of the expense of the repairs of the slide-valves, &c., but the laying up of the vessels during the time of these repairs, as laying up one vessel out of four, with a service of four passages daily, was a serious matter. If from such causes the Company should be reduced to two vessels—as had been the case—and an accident occurred to one of those two, the mail service between England and Ireland would be jeopardized. It was most important, therefore, not to have anything connected with these ships which involved increased liability of interruption of the service.

Mr. PHIPPS thought no subject was more interesting than that of the skin resistance of vessels, as being one of the elements of calculation which limited their length; and he should have been glad if the Paper had contained details of that kind. On previous occasions<sup>1</sup> he had drawn attention to the singular difference in the co-efficient of the friction occasioned by water flowing through pipes, or water courses, as compared with the skin resistance of vessels. On a vessel going 12·2 miles per hour, or 17·9 feet per second, the skin resistance was shown to be about 1 lb. on every square foot, whilst in a pipe the resistance was about 2 lbs. at the same velocity. It would be useful to inquire, what was the cause of that difference. In the present case, at 20 miles an hour he calculated the friction on every square foot of the ship's immersed surface was about  $2\frac{3}{4}$  lbs.; it was evident, therefore, that this was an important element in determining the best proportion between the length and the breadth of a vessel. From data in the Paper it appeared that the slip of the paddle-wheels was about one-seventh only of the speed of the vessel. This he conceived to be unprecedentedly small. It would be interesting to know whether practically the slip differed much in the feathering and the common paddle-wheels, and whether the floats of the feathering paddles were liable frequently to get out of order.

Mr. E. HUMPHRYS observed, in reference to the statement that vessels 320 feet in length might be expected to have a speed of from 20 to 21 miles an hour, that if the results obtained by these boats were compared with the Royal Yacht, it would be found that

<sup>1</sup> *Vide Minutes of Proceedings Inst. C.E., vol. xiv., p. 302; and vol. xvi., pp. 337 and 360.*

their extra length had been a considerable drawback ; although he fully admitted that their performances were remarkable. The proportion between the length and breadth of the Holyhead boats was  $9\frac{1}{2}$  to 1, whereas the length of the Queen's Yacht was only  $7\frac{1}{2}$  times its breadth, the absolute length of the latter being 306 feet, and the beam  $40\frac{1}{2}$  feet. In the absence of indicated H. P., he thought it fair to take the area of the fire-bars as representing the power exerted by the engines ; as he did not believe there would be much difference in the power obtained from a given amount of fire-bar by any of the respectable makers of marine-engines. If the cube of the speed of the Holyhead boats ( $20\frac{3}{4}$  miles an hour) was multiplied by the midship section, and then the product was divided by 677 feet, the area of the fire-bars in the 'Leinster,' the co-efficient of 4,480 would be obtained. In the same way, taking the speed of the Queen's Yacht at 19.35 miles an hour, the midship section as 393 feet, and the area of the fire-bars as 540 feet, the co-efficient for the 'Victoria and Albert' would be 5,272. Where then, he asked, was the advantage of the longer ship ? These were interesting facts to be discussed amongst Engineers ; and although the commercial value of the transaction should form one part of the inquiry, yet Engineers had to ascertain what results were obtained by increasing the power, by adding to the length of a vessel, and by giving her finer lines. Now turning to the midship section of the two vessels ; in the 'Leinster,' the midship section on the trial trip was 336 feet, and the power exerted is now stated to have been equal to 4,751 horses. If the power was divided by the midship section, the result per square foot of section would be 14.1 horses. In the Queen's Yacht the power indicated on the trial trip was as nearly as possible equal to 2,980 horses ; that power divided by 393 feet, the midship section on the trial trip, gave only 7.59 horses per foot of section. Where, again, was the value of the long ship ? He believed that, when the length exceeded seven, or seven and a half times the beam, it was a positive disadvantage ; and he disputed altogether the assertion of Mr. Scott Russell, that length only should be considered, in determining the proportions of a fast steamer.

With regard to superheaters, he had fitted a great many vessels with them, and had found that when they were made of iron their duration was about two years and a half ; in the Holyhead boats they did not appear to have lasted so long. Mr. Humphrys now made them of copper a quarter of an inch thick, and steamboat companies found it advantageous to have them of copper.

The slip of the feathering wheels was about 20 per cent., taking the centre axis of the float-boards. He believed the slip of the common wheels would be found to be about 30 per cent. upon the outer circumference of the boards.

Mr. A. I. ROBERTSON said, taking the midship section of the 'Connaught' at 336 square feet, the indicated H. P., at a speed of  $20\frac{1}{2}$  miles an hour, at 4,730, and allowing two thirds of the indicated horse power as effective, he found that the resistance per square foot of midship section at 10 knots an hour, which was a usual standard of comparison between vessels, was 51 lbs. He expressed a hope that Mr. Scott Russell would furnish the Institution with the results obtained from the 'Great Eastern,' which he believed contrasted favourably with this.

Mr. HAWKESLEY said, as this subject had engaged his attention for many years, he would venture to say a few words. During the session of 1856-57, an interesting discussion occurred "On High Speed Steam Navigation."<sup>1</sup> On that occasion he investigated the several properties of vessels of this description, and then submitted a rule, with some examples,<sup>2</sup> for ascertaining the resistance to a vessel, when moving through water at any given speed. He found by applying that rule to the vessels under consideration, that the result would be a speed of rather under 20 statute miles per hour, which agreed very closely with the speed he understood these vessels had actually attained. Since that period he had taken advantage of opportunities of practically testing those investigations in various ways, and he found they might be relied upon with certainty, within 5 per cent.

With regard to the question of the skin resistance, he disagreed with the opinion, that it was greater on the inside of a tube than on the outside; in point of fact the skin resistance was the same in both cases, and taking the speed at 10 miles an hour, or 15 feet per second, it amounted to about 25 ounces per square foot of surface. That might be taken as a practical fact, and the result was this: that in vessels of this description going at high speeds,—the vessels being of considerable length and attaining high velocity,—the midship resistance might be disregarded, and the skin resistance alone be considered. The minimum resistance took place when the length of a vessel was about seven times its breadth. If that was exceeded, the result was less satisfactory. The midship resistance, which had hitherto been generally regarded as important—and correctly so in the case of slow-moving vessels—became of no importance, and almost vanished out of the equation, when applied to a vessel of sharp lines and moving at a high velocity, and in fact the only thing to be considered practically was the amount of skin resistance. The problem was thus reduced to a simple solution: and taking that mode of calculation, of which examples were given in the discussion he had alluded to, it was possible, with regard to

<sup>1</sup> *Vide Minutes of Proceedings, Inst. C.E., vol. xvi., pp. 327-370.*

<sup>2</sup> *Ibid., p. 355.*

any of these fast-going sharp vessels,—knowing the power of the engines, and the dimensions of the vessels,—to calculate certainly within 5 per cent. the actual speed they would attain.

Mr. SCOTT RUSSELL, V.P., thought it only wanted an explanation of words to clear up any apparent discrepancies. He made some experiments twenty years ago, which first acquainted him with the true state of the facts, in regard to skin resistance and midship section. He was able to do what had not been often done in steam navigation, to tow one large steam ship by another large steam ship, with a rope, and a dynamometer; and to ascertain, before he applied the steam, how much positive, direct tractive force was necessary to draw that vessel through the water at given speeds. He then found that on a fine smooth copper bottom, with a favourable form for the speed intended, 1 lb. per foot, at 11 knots an hour, gave the measure of the resistance of the skin. The coefficient of resistance on the midship section, not being of the fine forms since used, was one-sixth part of what was called head resistance. This would lead to a conclusion similar to Mr. Hawksley's formula. The resistance of the skin was most important. As Mr. Humphrys said, it was fatal to extreme length in proportion to breadth. He did not think, however, that a little short boat, with fine lines, say with a beam of only  $\frac{1}{30}$ th of the length, could ever be made to go fast. He believed that an absolute length of ship was necessary to a given speed. Mr. Russell doubted whether a speed of 20 miles an hour could ever be obtained in a vessel of less length than about 300 feet, however much the midship section might be diminished, and whatever the character of the marine engine by which she was propelled. With a vessel 300 feet in length, a wide boat could be made to go faster than a narrow one. That was a direct consequence of what Mr. Hawksley had said, and was carrying out Mr. Humphrys' own conviction. The reason was,—and it was much stronger in an iron ship than in a wooden ship,—that the skin resistance of an ordinary iron ship might be as much as 2 lbs. per foot at 12 miles an hour. That accounted for the enormous quantity of power that was expended in making these long fine boats go 20 miles an hour, and he believed, that by adopting what he called the wave form of vessel, which disturbed the water to the least amount possible, the resistance of the midship section would be reduced to a surprisingly small quantity. He had found it come under one-twelfth part of the direct head resistance, and therefore he almost believed that in a proper ship the resistance due to the midship section might be got rid of altogether. For the last twenty years he had expressed the belief that the wave form would accomplish that; and he thought it was now arrived at, as all the calculations, from the data given, as to the resistance due to the skin of these

vessels, showed that nearly the whole of the power was required in dragging them away from the water which hung to them.

He mentioned a curious phenomenon which he could not explain, nor had any one else, that he was aware of, yet been able to explain it. On looking along a vessel when she was going fast, a ribbon of water would be seen sticking to her, which was in a totally different condition to all the rest of the water around. In the next place it would be observed that that ribbon never changed its breadth with an alteration of the speed; that on a boat 100 feet long that ribbon became 3 inches wide, on a boat 200 feet long it was 6 inches wide, and on a boat 300 feet long it was 9 inches wide. That ribbon was in the act of being torn into shreds, and the innermost layer stuck to the boat and went with it at the rate of 20 miles an hour; then the next layer only went 19 miles an hour, and so on to the outer layer, which was still. What must be the effect of that ribbon sticking to the ship he left them to judge; but it had been considered enough to exhaust all the power of the engines. He had driven small vessels through the water with enormous power, at such a pace that they had communicated the whole of their impulse to this skin of water, and in such a manner that the water in contact with the entrance of the bow had risen up in one continuous sheet. This was a phenomenon he confessed he did not understand. It was a new state of things, and he was not prepared to say at what velocity it would be found to take place, nor what was the critical velocity at which the vessel no longer dragged its ribbon of water with it, but forced it into the air.

As to H.P. per foot of midship section for the purposes of comparison, when it was known that at 22 knots, or 26 miles per hour, the resistance on the skin would be 8 lbs. per foot, it was clear that the skin of the vessel demanded more consideration than the midship section. He hoped Mr. Humphrys would give the Institution the benefit of his data, because what arose out of this question would be important. The only fault Mr. Russell would find with the propagation of the power through the paddle wheels was, that he would have given a longer stroke, to a given diameter of paddle wheel, and that might have gained a little speed: but that was a difference of opinion to which he did not attribute much value.

Mr. WATSON remarked with regard to the length of these vessels, that the question of passenger accommodation had mainly to be considered. The space occupied by the engines and boilers was so large, that without great length there would have been insufficient passenger accommodation, and the vessels could have done little more than carry the engines. He quite agreed with what had been said about skin resistance. Some years ago he

had a conversation with Mr. C. Atherton (M. Inst. C.E.) on the subject, when the City of Dublin Steam Packet Company contemplated lengthening one of their vessels, with the expectation of gaining considerably in speed, as well as in carrying capacity. Mr. Atherton was not sanguine of obtaining any great increase of speed by decreasing the immersion, from the intended extra length of the ship. The result was, that an increase of speed was obtained, but not to the extent anticipated by the Company, from the decreased immersion, and thus Mr. Atherton's views were proved to be correct.

He had been much interested in the subject of the skin resistance, feeling sure that it had a greater effect upon the speed than was generally supposed. The captains were constantly complaining, that the vessels were losing speed from fouling; therefore the ships were repeatedly docked, and when examined, it was astonishing how little there was apparently calculated materially to affect the speed, which practically corroborated what had been said with regard to skin resistance.

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May 19, 1863.

JOHN HAWKSHAW, President,  
in the Chair.

THE following Candidates were balloted for and duly elected :—  
WILLIAM NEILL and GEORGE SMITH, Junior, as Members;  
FRANCIS FOWKE, Captain, R.E., ALGERNON JOY, ARTHUR WILLIAM  
STIFFE, JOSEPH HENRY TUCK, and WILBERFORCE WILSON, as  
Associates.

No. 1,095.—“On the Manufacture of Duplicate Machines and  
Engines.” By JOHN FERNIE, Assoc. Inst. C. E.

THE block-making machinery, designed by the elder Brunel for Portsmouth Dockyard, was nearly the first introduction of that system of special machines, each adapted to perform a particular operation, which may be said to have culminated so successfully in the Small Arms Factory at Enfield. Shortly before Brunel's day the factory system had been established, in which one machine shook out the impurities of the material, another spread, a third twisted, and a fourth spun; but there was no similar arrangement as applied to such refractory materials as wood and iron. In the year 1851 a great impetus was given to the extension of this system in Great Britain. It then became more generally known, that the Americans had established factories for the making of locks and fire-arms, and had, by means of the Blanchard lathe, and of a system of copying from patterns, greatly advanced in the manufacture of duplicates.

In Mr. Beamish's “Life of Sir M. I. Brunel,”<sup>1</sup> it is stated, that a saving was effected by the introduction of the block machinery of about £20,000 per annum; that four men, with the machinery, could make as many block shells as fifty men could produce without it, and that, in making the sheaves, six men could do the work of sixty; so that ten machine-men could do the work of one hundred and ten workmen. Another important result was that the blocks were duplicates of one another, and the parts were interchangeable.

In the year 1855 the old establishment at Enfield was broken up, and a new one was formed for the purpose of making rifles of the 1853 pattern, on the system established in America. The accounts for the year 1859-60 show, that the number of rifled

<sup>1</sup> Vide “Memoir of the Life of Sir Marc Isambard Brunel.” By R. Beamish, F.R.S. 8vo. Lond., 1862. Page 97.

muskets which had then been delivered into store was 87,405, on which there had been expended a total sum of £178,588 10s. 7d., being at the rate of about £2 1s. 8½d. per arm; while the contractor's price for the same, at £3 3s. 8d. per arm, would have been £272,509 5s.; thus, a saving had been effected of £93,920 14s. A proper allowance for depreciation on tools and buildings was made, and no money value is claimed by the Enfield authorities on account of the arms being duplicates of one another. It is only necessary to see a rifle put together at Enfield thoroughly to appreciate the mechanical advantages of the duplicate system. Thus, the separate pieces which form the lock are picked up indifferently from heaps of such pieces, every one fitting into its place most perfectly; and a rifle, the parts of which have never been together before, is formed in a few seconds from a lot of fittings promiscuously thrown together, as any lock will fit any stock, any stock will fit any barrel, and each part, however minute, will fit any rifle. If any part be broken, or requires replacing, there is a new one which will exactly fit it, so that wherever troops are armed with the Enfield rifle, there is not any fear of a mischance through a bayonet not fitting, and the armourer's duty is confined to the exchange of a few duplicate cocks or springs; and, as it is only a system of exchange, a skilled armourer may be dispensed with. Whether serving in Canada, India, or China, the various parts of that delicate instrument can be sent from home, with the certainty that they will fit the places for which they are intended, and thus there is a great saving of time and money, and the soldier is inspired with confidence in his rifle by the knowledge that it can be quickly made as good as new. It is no part of the Author's intention to describe the machines employed at Enfield. The parts of the rifle being small, special machines are adopted. These examples are only intended to show, that the system of duplicates both cheapens and improves the manufacture of all articles to which it can be applied.

Until lately, little or nothing had been done in the application of this system to the manufacturing of machines, or engines on a large scale. It is true the principle had been acknowledged, and various writers had urged the desirableness of its introduction into the railway system; but with such large component parts special machines were out of the question, and the only other possible mode was working to a correct standard. In the year 1840, Mr. Whitworth (M. Inst. C.E.), of Manchester, read a Paper at the meeting of the British Association in Glasgow "On Plane Metallic Surfaces, or True Planes;"<sup>1</sup> in 1851, at the Great Exhi-

<sup>1</sup> *Vide* "Miscellaneous Papers on Mechanical Subjects." By J. Whitworth, F.R.S. 8vo. Lond. 1858. Page 3.

bition in Hyde Park, he exhibited a machine for obtaining accurate minute measurements by touch ; and at meetings of the Institution of Mechanical Engineers at Glasgow, in 1856, and at Manchester, in 1857, he advocated the adoption of a system of measurement for mechanical engineering work, in which the inch was to be the basis, sub-divided into a thousand parts for the finer dimensions. In these Papers<sup>1</sup> Mr. Whitworth demonstrated, most satisfactorily, the importance of fine measurements, and by models he showed that the thousandth part of an inch was not only an appreciable quantity, but that in a great many cases that difference was what constituted a bad fit.

The Author had long been satisfied, that the mode of taking dimensions in the workshop was far behind the times. A long and carefully graduated rule was considered the standard, and was used for setting out some of the work ; but its application in the workshop was out of the question. The workman's rule was the real standard ; and a bare  $\frac{1}{16}$ th, or a full  $\frac{1}{32}$ nd, of an inch embraced a very wide field indeed, extending to the shrinking on of a tire, or to the boring out of a wheel. With the sanction of Mr. Kirtley, the locomotive superintendent of the Midland Railway, the Author established a system which has, during the last five years, proved most beneficial, not only in reducing the cost of the work, but in greatly improving it, and at the same time perfecting the only plan by which all the parts of engines become duplicates of one another. At first a small machine, made by Mr. Cocker, of Liverpool, from Mr. Whitworth's gauges, was used ; but it was soon found, that a larger and better machine was required. The system of end measurement with a gravity piece, as invented by Mr. Whitworth, was then adopted, and the machine first made took in 12 inches ; but this also was found to be insufficient, and it was lengthened out to receive 100 inches. This machine consists of a strong bed plate (Plate 22, Figs. 1 to 7), having a V groove planed throughout its whole length. At one end there is a headstock, through which a square spindle, which fits the groove, is propelled by a hand wheel, which forms the nut of a screw having ten threads to the inch. This nut is in two parts, and can be tightened up by screws, so as to prevent any lateral play ; and a collar and washer, also adjustable, prevent any play in the headstock. The other end of the bed has also a headstock and a screw movement, so as to adjust the length of the pieces in the groove, and to bring the readings of the index to 0. The difference between this machine and Mr. Whitworth's is in the way the subdivisions of the inch are obtained. In the Whitworth machine a screw, with exactly ten threads to the inch, is first made ; whereas in this machine, as

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<sup>1</sup> *Ibid.*, pages 39 and 57.

a screw could not be found with exactly ten threads, it was necessary to run a thread on the face of the hand wheel, and to subdivide this for the length required for an inch.

The manner of obtaining duplicates with such a machine is very simple. First, a piece of metal exactly one inch in length is cut, and from it a second piece is made in the machine, by means of the gravity piece; then pieces, 3, 4, 5, 6, of 2, &c., up to 100 inches are cut. These sizes are now kept as duplicates. The finer dimensions are read from the divisions on the wheel, and from these, gauges for the use of the workshop are now made. All dimensions are thus duplicate multiples, or divisions of an inch, and a bare one-sixteenth of an inch becomes not an unknown quantity, variable with the rule or the eye of the workman, but so many thousandths of an inch, which are stamped on the gauges, and are soon understood. One of the first applications of the system in the workshop was to establish the necessary degree of tension required to insure the perfect fit of a wheel on its axle. Two workmen were directed to make a pair of male and female 6-inch gauges for this purpose; the one allowed  $\cdot 012$  of an inch, the other  $\cdot 003$  of an inch, taking the larger dimension first, and gradually reducing the difference. The experiments gave the following results:

EXPERIMENTS ON DIFFERENCES IN DIAMETER IN BORING AND TURNING WHEELS AND AXLES.

| No. of Experiment. | Length of Boss. | Diameter of Boss. | Diameter of Axle. | Difference in Diameter. | Permanent Stretch of Boss. | Remarks.                                                                              |
|--------------------|-----------------|-------------------|-------------------|-------------------------|----------------------------|---------------------------------------------------------------------------------------|
| 1                  | Inches.<br>7.0  | Inches.<br>5.988  | Inches.<br>6.000  | Inch.<br>0.012          | Inch.<br>0.006             | Very tight. After pressing off, wheel and axle cut and slightly taper.                |
| 2                  | 7.0             | 5.992             | 6.000             | 0.008                   | 0.004                      |                                                                                       |
| 3                  | 7.0             | 5.995             | 6.000             | 0.005                   | 0.002                      |                                                                                       |
| 4                  | 7.0             | 5.995             | 6.000             | 0.005                   | 0.003                      | Very smoothly bored and turned.                                                       |
| 5                  | 7.0             | 5.997             | 6.000             | 0.003                   | 0.000                      | Ditto; rather too easy a fit.                                                         |
| 6                  | 7.0             | 6.495             | 6.500             | 0.005                   | 0.001                      | <p> Axle slightly taper; diameter at 1.5 inch from outer end . . . 6.498 inches. </p> |
| 7                  | 7.0             | 6.493             | 6.500             | 0.007                   | 0.003                      | Tight. Ditto " " 6.498 inches.                                                        |
| 8                  | 7.0             | 6.491             | 6.500             | 0.009                   | 0.005                      | Very tight. Ditto " " 6.497 inches.                                                   |

From this Table it will be seen, that with a difference of  $\cdot 005$  of an inch in the dimensions, there is a very small, permanent set in the wheel boss, but with a difference of  $\cdot 003$  of an inch the set is hardly perceptible. It was found, however, that with ordinary lathe work,  $\cdot 003$  was rather too fine a dimension, as lathes are seldom exactly true in their spindles, some boring slightly taper, and some an oval hole. The size  $\cdot 005$  was finally adopted, and for

some years past all the wheels and axles have been adjusted to those dimensions.

In shrinking on outside cranks it was found, by a series of experiments similar to the above, that a difference of  $\cdot 015$  of an inch was amply sufficient to retain them in their places, the old allowance being  $\cdot 030$  of an inch; while crosshead spindles, of  $2\frac{1}{2}$  inches diameter, pushed into their places by hydraulic pressure, require a difference of  $\cdot 004$  of an inch; and levers with 3-inch holes require a difference of only  $\cdot 001$  of an inch, when they have to be driven into their places with a lead hammer. All these dimensions were previously empirical; but with this system of working they become known quantities.

The gauges used are exceedingly simple. Each consists of a piece of steel about 1 inch wide, parallel in the width, two-eighths of an inch thick in the middle, and tapered towards the ends, which are rounded. Each gauge is made nearly to the required length. The ends are then hardened, and the bar is brought to the correct standard by a whetstone. This gauge should just pass through the eye of a wheel. The gauge for the shaft is of the horse-shoe shape, and is made of steel, with the ends hardened. For wheel work, the lathe men have copies of these gauges, and the foreman of the press-shop has also copies, and it is his business to try if the wheels and the axles are turned to the gauges, and if they are not correct, to reject them. It will be seen from this, how accuracy is not only easy of attainment, but how it is checked. There is no difficulty in this way of working; it has been in use for years, and a misfit is unknown. The valve motions of locomotive engines having to sustain a great deal of wear, from the speed and pressure on the backs of the valves, the pins and joints require to be carefully fitted and case-hardened, after which they are ground to fit their places. While exposed to the carbonizing process, the pins expand and the joint-holes contract. With the measuring-machine, this expansion and contraction is easily found, and an allowance being made for it in the boring and turning, only the smallest amount of "lapping" out is required, and a great deal of grinding is saved.

Plate 22, Figs. 9, show how the lengths of the eccentric rods are preserved uniform. A is a hollow casting, supported on legs, and being about the same height as a workman's bench. This casting is planed on three sides, and two castings, D D, which are facsimiles of the eccentrics, are bolted on at one end. At the other end two jaw-pieces E E are bolted on, corresponding to the position which the links bear to the eccentrics. The workman first scrapes the eccentric straps to D, and the joint is then brought down over the jaws E E, and the pin F must pass through the joint and the jaw-piece. The rod is now perfect as regards length, nor can there be any twist in the joint or pin, and the strap and rod are now

ready for hanging on the engine from the hands of the fitter. Plate 22, Figs. 10, show how the key groove is cut in the outside cranks. A strong casting A, has its top and bottom surfaces and the top of the lugs B planed; a wrought-iron plate C is then fastened to the lugs B, and the tool being taken to the lathe, the holes D and E are bored in it. The key bed and hollowed-out part in C are carefully set out, and after being cut, the plate is case-hardened, and a large pin F is turned to fit the holes. The crank H is pushed through between the surfaces A and C, until the crank-pin fits the hollow part in C. The pin F is then pushed into its place, and the set screws being brought down on the crank, the work is ready for slotting. The eccentric key grooves are cut in a precisely similar way; no setting out is required, and there is no chance of any mistake from the carelessness of the workmen. The cranks and eccentrics must be exact, or they will not fit these tools, and thus a certainty is attained in the depth and the position of the key groove. The corresponding templates for cutting the grooves in the axles are shown in Plate 22, Fig. 8.

Considerable improvements have been effected in plate-moulding during the last few years, and no system of machine-making would be perfect, without their application in the foundry. The plan adopted at the Midland Railway works at Derby is not new, but it is believed to be its first application to such large and complicated castings as locomotive cylinders.<sup>1</sup> Plate 22, Figs. 11 to 17, show how the cylinders are moulded. Fig. 11 shows one-half of one of the patterns ready for moulding. A is a hollow-plate casting, the surface of which is planed for the half pattern to lie upon; eight small strips on the edge of this plate are also planed, to fit a large template, which has four holes in it corresponding to the pins D D. The moulding boxes have corresponding strips on all their edges, and after their joints are planed, these strips are planed to fit the same template; all the pin holes for the plates and the moulding boxes being drilled with a pin drill from the template. Centre lines are also run on the boxes and the plates from centre lines on the template, and the half patterns are then attached to the plates by pins, the centre lines on the patterns corresponding to the centre lines on the plates. Fig. 12 shows how the steam chest is moulded. A is a planed surface plate as before, and a pattern, representing the surface of the steam chest, is inserted in it at M, as shown in plan, Fig. 13, and two elevations, Figs. 12 and 14. The moulding box is dropped on the pins D D, and the sand is rammed up as usual, after which the box is ready for the drying stove. Figs. 15, 16, and 17, are longitudinal and transverse sections of the moulding boxes, fixed together ready for casting.

<sup>1</sup> Moulding boxes for axle brasses were exhibited at the Meeting.  
[1862-63. N.S.]

The core barrel G has strong castings at each end I I I I, which are bored for the spindle K H K, and are turned on the outer edge to fit the moulding boxes. The middle part of the core barrel is a wrought-iron plate, pierced with holes, on the outside of which is shown the hay-band and the core. The four different box parts are shown at C 1, C 2, C 3, and C 4. Box C 1 is moulded from a plate as shown in Fig. 12. Boxes C 2 and C 3 are moulded from half patterns as in Fig. 11. These two boxes C 2 and C 3 have their ends carefully bored out from the centre lines to fit the turned parts of the core barrel, so that the weight of the core is not sustained by the sand, but rests on the metal of the box part. C 4 is moulded on a plate similar to Fig. 12, and requires no especial description. The steam and exhaust cores are moulded in cast-iron core boxes, carefully fitted on the inside, and the cores are placed in the stove in their own boxes, and by that means are free from twist, and are accurate in length and shape. As will be seen from the sections, a minimum quantity of sand is used, and the projecting pieces cast on the boxes do away with all lifters. By this mode of moulding, the castings come cleaner from the sand, the patterns are not knocked to pieces by rapping, the cylinders are perfectly true in the bore and passages, and at the same time the manufacture is brought within the grasp of any man who can throw in the sand and ram it. Fig. 16 shows partly an end elevation, and partly a section, of the boxes fitted together; the holes O O O being for pouring in the metal and for the rising head.

It would be tedious to describe the different templates and gauges used in completing the various parts of a locomotive engine made on this system. It will be sufficient to say, that each separate part is as carefully fitted as those already described, and that all the dimensions are obtained from duplicate templates, representing inches and parts of an inch, to three places of decimals.

Plate 23, Figs. 1 and 2, show the first step in fitting together the various pieces, so as to insure uniformity in erection as well as in construction. A is a large surface plate, strengthened by deep ribs and bars, the surface and edges being planed. Two brackets B B are bolted to this plate, and have all their faces and edges planed. The cylinders, after being fitted together, are placed on the two brackets, the parts on which they rest being also planed. The two brackets C C have recesses planed in them to receive the slide bars, and it is the duty of one set of men to fit the slide bars D D, the spectacle plates, the cross head and slide blocks, the piston and rod, the valve spindles, guides, and pumps. When all these have been fitted together, the next operation is to lift them on to the cradle C C, Plate 23, Figs. 4 and 5, which show the mode of erecting engines from a true plane, all the upright

lines being squared up from the beams A A, B B, the horizontal lines being obtained by a surface gauge working on the same true surfaces. The cradle C C is firmly fixed on the two cast-iron girders A A, about 30 feet long. Their upper surfaces, which are slightly above the floor of the workshop, are carefully planed, as well as the edges and the grooves which correspond to the edges of the rails. The planed lower edges of the cylinders, already described, rest on the planed surfaces of the cradle at the proper angle, and are brought to the centre lines on the cradle F F, by the set screws at E E. At the ends they are adjusted to lines which pass through the cylinders to the uprights S S, the longitudinal position being obtained by a straight edge laid on the face of the cylinders, corresponding with the planed surface on the front of the cradle, on which are drawn the centre lines. The inside frames L L are then attached to the cylinder; the holes of both being drilled to a template, only require rose-bitting, the end of the frame being supported by the upright at N. The outside frames J J are then attached, by means of the bracket plates and the buffer beams. As the pieces R R R correspond to the position and dimensions of the axle-boxes, all that is required is to describe on the horn blocks lines squared up from these pieces. These are then removed, and being planed to the lines, the boxes are fitted into their places; after which the wheels, motions, and rods, being hung on, the engine is run over another pit to have its boiler put on, an operation which does not require a special description.

It will be seen, from this description, how parts, however large, may, by this system of accurate measurement, become duplicates of one another, and can at any time be replaced; and that the parts become interchangeable, so that any part may be sent to a distant station, with the certainty of fitting when it arrives there. The advantages claimed are, first, economy in manufacture; secondly, greater perfection in workmanship; and thirdly, an accurate system of duplicates, whereby the parts become interchangeable. The Author especially recommends this system to the Engineers of Indian and Colonial Railways, and he sees no reason why the different parts of the engines and rolling stock sent to those places should not be as perfect duplicates, as the different parts of the Enfield rifle.

The communication is illustrated by a series of diagrams, from which Plates 22 and 23 have been compiled.

MR. FERNIE stated that the whole system was founded on the application of Mr. Whitworth's true plane. He explained the mode of working with the different machines and tools, of which several specimens were exhibited, including the gauges, which could be regulated to the 1000th part of an inch, the moulding boxes, and the callipers used for taking the diameter of wheels.

MR. BRAMWELL said, that while there could be no question as to the great advantage to be derived from the use of such delicate and accurate means of measurement as those alluded to in the Paper, nevertheless there were many factories which did not possess, and perhaps for a long time to come would not possess, such expensive measuring implements. This being so, he thought it might even now be of service to allude to a plan that he had used for insuring the accurate boring of tires, which, looking at the small range there was between a loose tire on the one hand and a burst tire on the other, was a matter that demanded the greatest care. The plan was this; to make a gauge so much shorter than the correct bore of the tire, that when the gauge was put inside the tire and one end of it was kept stationary, the other end could be vibrated some convenient measurement, say  $\frac{1}{30}$  part of the diameter of the bore. If, for example, the tire were to be bored out to 50 inches diameter, then the gauge would be made so much less than 50 inches in length that its moving end could be vibrated exactly 1 inch. Then assuming that such a gauge were applied to a tire in which it could only vibrate  $\frac{2}{10}$  of an inch, it would indicate that that tire was bored  $\frac{1}{100}$  part of this difference too small, or, in other words, it would detect an inaccuracy in bore of  $\frac{1}{1000}$  of an inch; and as a workman could, with the greatest readiness and certainty, read a measurement much finer than  $\frac{1}{10}$  of an inch, say four or five times as minute, it followed that he would, by this contrivance, be enabled to detect errors in bore as small as even  $\frac{1}{4000}$  or  $\frac{1}{5000}$  of an inch. There was also this convenience in the use of such a mode of measurement, that the gauge could be got within the tire before the full bore had been attained, and in this way the finishing cuts could be watched and regulated with the greatest nicety. Looking at this, by no means inconsiderable, advantage in working, and at the great delicacy of measurement obtained by such simple and inexpensive implements, Mr. Bramwell believed that this plan, of making the gauge so much smaller than the true bore of the tire as to admit of a definite vibration within that bore, was far better than the ordinary mode of having the gauge the full and exact length of the intended internal diameter.

MR. BEYER remarked that great credit was due to the Author for the trouble he had taken in getting up the illustrations for his Paper; but the substance of the communication was rather more

Fig: 11.

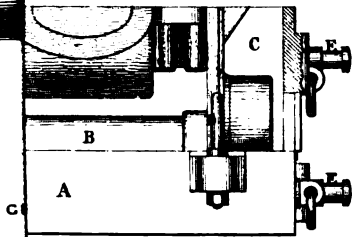


Fig: 15.

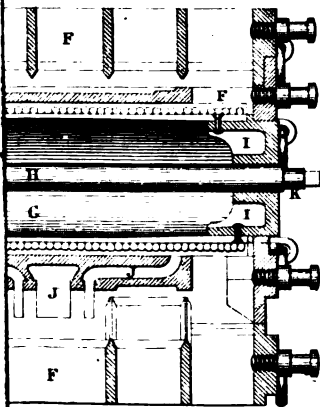


Fig: 12.

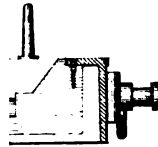


Fig: 14.

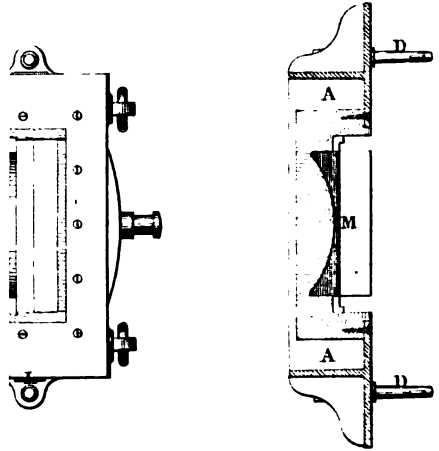
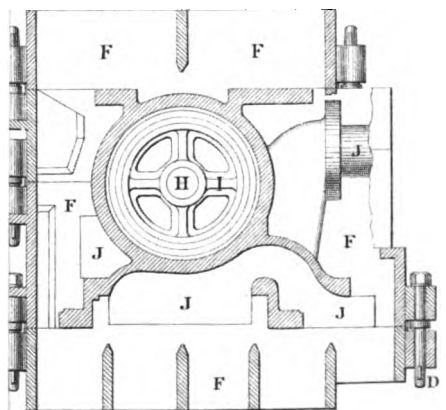


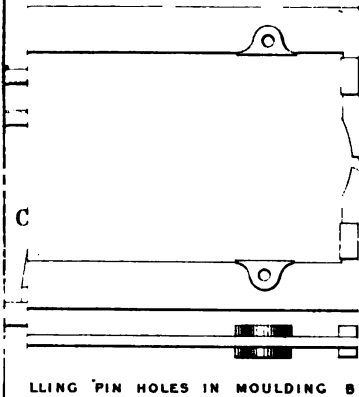
Fig: 17.



IMPRC



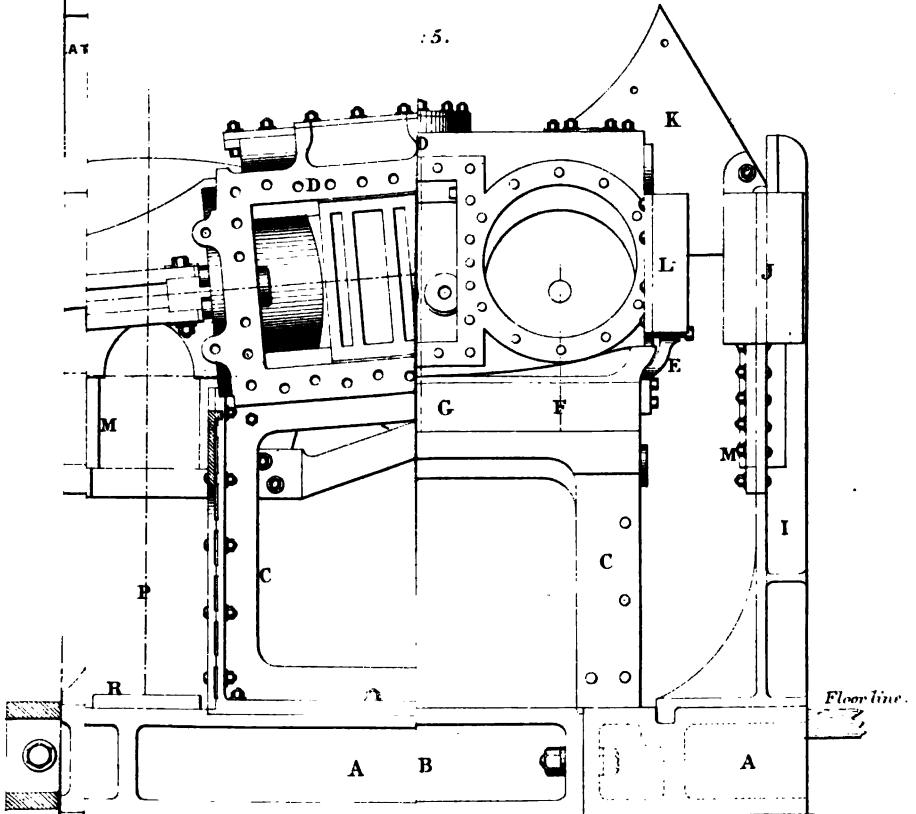
Fig. 3.



LLING PIN HOLES IN MOULDING B

AT

5.





suitable for a school of Engineering than for the Institution. The subject was an old one. Mr. Richard Roberts had supplied duplicate machinery thirty years ago, and for more than twenty years Mr. Beyer had been engaged in making duplicate locomotive engines, and had made such for the greater number of the railways in this country, including the Midland Railway.

Mr. VIGNOLES stated, that Mr. Beyer had manufactured upwards of fifty locomotive engines for the Tudela and Bilbao Railway, which were exact duplicates of each other, and of which all the parts perfectly fitted on their arrival in Spain. He was glad to have this opportunity of expressing his fullest confidence of the way in which the duplicate system had been carried out, and he too was surprised, that it was not more generally known and adopted.

Mr. FERNIE conceded that all honour was due to Mr. Beyer, for the excellent manner in which his work was executed. He quite understood that mode of working, but something more was required, and it should be stated, in justice to the large firms who devoted themselves to railway work, that all of them had for years been aiming at a system of duplicates. The plan now laid before the meeting was, however, different from the others, inasmuch as it was a system of working from known gauges. It was not the custom of railway companies to order all their engines from one maker. Twenty might be purchased from one firm, thirty from another, and so on, and on some lines there were as many as twenty different types of engines. Now, by the system of Mr. Whitworth, all the engines from those various manufacturers would be perfectly alike, whereas, by what might be termed the individual system, only the different lots would be duplicates of one another. There was no doubt that, at the present time, there was a want of uniformity in the dimensions of engines, as supplied by different makers, and what was wanted was, a standard by which all makers should work alike. The parliamentary yard of 36 inches must be the standard, and from the inch, as he had already shown, it was an easy matter to obtain any dimension. He had said that the engines were, as a rule, unlike in their dimensions; but a slight correction was required in this statement, for all the screws were of the same pitch and thread, and every nut would fit every bolt of its own diameter. It was hardly possible to calculate the immense saving to the country through the adoption of Mr. Whitworth's taps and dies; and yet when they were first introduced, they were not generally approved, and one firm in Manchester hesitated for many years, until at last they were compelled to adopt them. No one, he thought, would now raise an argument against them, for their many advantages had been realized; and so with regard to this new system, he expected there would be some opposition to it. This was an age of

precision, and from a careful working for five years on this system, he was satisfied of its practicability, and thought that hereafter it would be carried out with still greater minuteness. He felt certain the time was not far distant, when there would be no more guess-work as to the finer divisions of the inch. It was only necessary to show mechanical men the importance of accuracy of dimensions, and the ease by which that accuracy could be attained, and their own good sense, and desire to excel, would soon prompt them to adopt the new system. This was quite as much a question for the manufacturer as for a railway company. If England was to continue to be the manufactory of the world, let the makers take up this system, and with excellence of material and scientific precision of construction, so attain to the perfection of production.

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In pursuance of the notice on the card of the meetings, it was proposed, and resolved unanimously:—"That in order to avoid holding a Meeting on the evening of Whit-Tuesday, the meeting be adjourned until the evening of the 2nd of June."

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June 2, 1863.

The Session was concluded by a *Conversazione*, at which the President received the Members of the Institution, and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited a large and interesting collection of mechanical models.

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## APPENDIX TO VOL. XXII.

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MEMOIRS.

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**HIS ROYAL HIGHNESS ALBERT FRANCIS AUGUSTUS CHARLES EMMANUEL, DUKE OF SAXE COBOURG AND GOTHA, PRINCE CONSORT, K.G., K.T., K.P., G.C.B., K.S.I., G.C.M.G., &c., &c.,** was born August 26, 1819. He joined the Institution of Civil Engineers as an Honorary Member on the 7th of March, 1843. **H.R.H.** died December 14, 1861.

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**MR. PETER BARLOW** was born in Norwich, in October, 1776, and was sent at an early age to a foundation school, where he acquired a good English education. He was then placed in a mercantile establishment in Norwich, and while in that position and still at an early age, he, together with some young friends of a similar turn of mind, formed a juvenile scientific society, where they discussed questions in mathematics and the physical sciences, for which young Barlow had a natural predilection, and eventually by his industry and perseverance he acquired considerable scientific knowledge.

The political excitement of the times broke up this little society, and the members of it became dispersed, some entering the Army and others the Navy, whilst Mr. Barlow, turning his attention to tuition, for which he had partially qualified himself by careful study, although without enjoying the advantage of good masters, obtained the mastership of a school. He soon became a regular correspondent of 'The Ladies' Diary,' then under the management of Dr. Hutton, Professor of Mathematics at Woolwich, under whose advice Mr. Barlow was induced, in 1801, to become a candidate for the post of additional Mathematical Master at the Royal Military Academy, a position which was only obtained after a severe competitive examination. There he became acquainted with Mr. Bonnycastle, to whose judicious advice and assistance he always acknowledged himself to have been much indebted. Under the same advice he, in 1808, commenced writing for the 'Encyclopædia' conducted by Dr. Rees, and from the letter H to the end, he contributed the majority of the mathematical articles of that

work. In 1811 he published his first work on the 'Theory of Numbers,' and in 1814 appeared his 'Mathematical Dictionary,' and immediately afterwards his 'Mathematical Tables,' a work which has since been reproduced by the Society for the Diffusion of Useful Knowledge. In 1817 he published the first edition of an 'Essay on the strength of Timber and other Materials,' founded on experiments made in the Dockyard and the Arsenal at Woolwich, by permission of the Admiralty and of the Board of Ordnance. While thus engaged he became acquainted with the late Thomas Telford, and assisted him in experiments and calculations for his then proposed structure of the Menai Suspension Bridge, and also conducted for him a series of experiments on the tides in the Thames, in reference to the then projected erection of the new London Bridge. In the report upon the latter subject, the effects which the removal of the old London Bridge have since manifested upon the bridges of Westminster and Blackfriars were fully considered. About this time he also contributed many articles to the 'Encyclopædia Metropolitana.' In 1819 his attention was directed to the variation of the compass needle and the local attraction of ships, and he was induced to undertake a series of experiments, with a view to discover the laws of the reciprocal action subsisting between magnets and simple iron bodies, and to devise some means of correcting the errors of compasses on shipboard. The Government liberally allowed him the facilities which the Dockyard and Arsenal at Woolwich presented for prosecuting these experiments, and the laws of terrestrial magnetism which he, after much labour, discovered were subsequently confirmed by Captain Basil Hall, Captain Mudge, and other officers. These laws and their proposed application for correcting the local attractions of ships formed the subject of his 'Essay on Magnetic Attractions,' published in 1820. In a second edition of this work, in 1823, it was shown that all the laws which had, up to that time, rested on experimental deductions were consistent with a certain hypothesis of magnetic action, which theory was subsequently elaborated and confirmed in a more general investigation of the subject by M. Poisson, in a memoir read to the Institute of France in 1824. All doubt on the subject being now removed, Mr. Barlow received numerous gratifying marks of approbation. He was elected on the Council of the Royal Society, and received the Copley medal. He also received the reward for useful discoveries, provided by Parliament, in connexion with the then existing Board of Longitude. He further received a handsome personal present from the Emperor of Russia, and was elected a member of the Imperial Academy of Brussels, a corresponding member of the Institute of France, and received many other similar distinctions.

On the 31st of January, 1825, he presented to the Institution of

Civil Engineers a communication 'On the Force exerted by Hydraulic Pressure in a Bramah Press; the resisting power of the cylinder, and rules for computing the thickness of metal for presses of various powers and dimensions.'<sup>1</sup>

Mr. Barlow next turned his attention to electro-magnetism, and was the author of a work on that subject. While engaged in the experiments he conceived the idea of making electric signals by deflecting a magnetic needle with a current of electricity, generated by a galvanic battery, and passed along a conducting wire. With this object he caused an experiment to be made upon a mile of copper wire, arranged upon posts in his garden, at Rushgrove Cottage, Woolwich. The battery employed consisted of about twenty pairs of plates 15 inches square. No insulation was given to the wires, and no coil was employed to multiply the action upon the needle. In this experiment, which contained the germ of an invention destined afterwards to become of such important public utility, although a certain amount of deflection was obtained, yet from imperfect insulation increased length of wire was found to produce great loss of power, and as other subjects of great interest occupied his mind at this time, he discontinued his experiments upon the electric telegraph.

Although engaged at this time in contributing articles to several scientific works, he applied himself to the improvement of achromatic object-glasses, on which subject he communicated a paper to the Royal Society.<sup>2</sup> Pursuing this subject, he was led to try the effect of substituting a fluid contained between two sheets of plate, or crown glass, instead of using the concave flint glass lens, generally employed, and he constructed two telescopes on this principle. Subsequently the Council of the Royal Society engaged Mr. Dolland to construct a fluid lens telescope under his superintendence, the result of which was satisfactorily reported upon by Sir J. Herschel, Professor Airy, and Admiral Smyth.

Between the years 1833 and 1835 he was engaged in the prosecution of an extensive series of mechanical and other experiments, and in the production of a volume containing a description of 'The Manufactures and Machinery of Great Britain.'

The railway system was at this time in its infancy, and before Engineers had established practical data, Mr. Barlow was much occupied in experiments, and in testing the strength and best form of section of railway bars, the effect of gradients and curves, and in determining other questions.

In 1836 he was appointed one of the Royal Commissioners for determining the best system of railways for Ireland, the report on this subject being presented to Parliament in 1838.

<sup>1</sup> *Vide* Trans. Inst. C. E., vol i. p. 133.

<sup>2</sup> *Vide* Phil. Trans., 1827, p. 231.

In 1839 he was appointed on a similar commission for determining the best route to Scotland and Wales, and the most convenient port for steam communication with Ireland.

On the 5th of March, 1839, a Paper of his was read at the Institution of Civil Engineers, intituled 'An Investigation into the Power of Locomotive Engines, and the effect produced by that power at different Velocities.'<sup>1</sup>

In 1842 he was similarly employed upon an inquiry into the general merits of the atmospheric system, and in 1845 he was appointed one of the Gauge Commissioners, in which he was associated with Sir Frederick Smith and Professor Airy.

In 1847, being then seventy-one years of age, he retired from his duties at the Royal Military Academy, and in consideration of his eminent public services, the Government awarded him his full pay on his retirement.

From this time, although he ceased to engage in active professional duties, he continued to take a lively interest in all the leading scientific questions of the day.

So late as the year 1857, although he was eighty-one years of age, he wrote a postscript to a Paper communicated to the Royal Society by his son, Mr. W. H. Barlow, M. Inst. C. E., on the 'Resistance of Flexure,' which postscript contained a mathematical investigation of considerable difficulty.

Mr. Barlow was elected a Fellow of the Royal Society in May, 1823, and he was a member of most of the other scientific societies of this and other countries. He joined the Institution of Civil Engineers as an Honorary Member in 1820, and always took much interest in the proceedings. Of a kindly and cheerful disposition, he retained his full powers of mind until his death, which took place on the 1st of March, 1862, deeply regretted by his numerous friends, and especially by those Officers, his former pupils, who, whilst under his guidance at the Royal Military Academy, had ever found him as valued a friend as a conscientious and talented tutor.

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MR. JAMES JOHN BERKLEY was born at Holloway, on the 21st of October, 1819, and completed his education at King's College, London, under Dr. Major. He was articled to Mr. Wicksteed (M. Inst. C. E.), then Engineer of the East London Water Works, in the year 1836; but very soon left him, and entered the office of Mr. G. P. Bidder (M. Inst. C. E.), and in 1839 he may be said to have commenced his real pupilage under Mr. Robert Stephenson (M. Inst. C. E.), by whom he was very actively

<sup>1</sup> *Vide Minutes of Proceedings, Inst. C. E., vol. i. (1839) p. 46, and Trans. Inst. C. E., vol. iii. p. 183.*

employed, travelling with his chief, writing reports for him upon his numerous works, arbitrations, and other engagements.

Among these may be mentioned the Bute Docks at Cardiff; the examination of a system of railways projected to connect London, Brussels, and the various towns of the north of France, with Paris, which was reported on by the late Robert Stephenson in 1842; the Hesse Cassel and the Leopold Railways; the construction of the Northampton and Peterborough, the Trent Valley, the Churnet Valley, and the North Staffordshire Railways, on which latter Mr. J. J. Berkley held the position of Resident Engineer.

At the latter end of the year 1849, an Engineer of ability, experience, and judgment being required to go to Bombay to lay out an extensive system of railways in that presidency, Mr. J. J. Berkley was so strongly recommended for the important work by the late Mr. Robert Stephenson, Mr. Brunel, Sir W. Cubitt, Sir John Rennie, Mr. Bidder, and other eminent Engineers who knew and appreciated his talents, that he was unhesitatingly appointed to the position of Chief Resident Engineer of the Great Indian Peninsula Railway, and he left England for India in January, 1850.

The Company's undertaking was at that time confined to the construction of 33 miles of "experimental line" from Bombay to Callian, and having early decided the most important points connected with the course of that line, through the town of Bombay, and the mode of crossing the creek which divided the island of Bombay from the mainland, Mr. Berkley turned his attention to the extensions which he perceived would inevitably be called for, and to the means of surmounting the great barrier of the Western Ghâts, which any extension into the interior immediately involved. The original projectors of the Great Indian Peninsula Railway proposed to make one ascent of the Ghâts, bifurcating at the top to the north-east and the south-east; but an examination of the line of Ghâts led Mr. Berkley to report unfavourably of that scheme, on account of the almost impracticable nature of the works, and to recommend the adoption of lines branching off from Callian to the south-east and north-east, ascending the Ghâts at the Bhore Ghât and the Thul Ghât on the line of a large existing traffic.

In 1852 the surveys for both the lines were commenced. Four years were spent in the surveys of the Bhore Ghât, and during that period Mr. Berkley laboriously worked out the details of the plans and designs.

On the 16th of April, 1853, the first 20 miles of the line, from Bombay to Tanna, were opened for public traffic, thus initiating the Indian railway system. This is alluded to in a very interesting letter from Sir Bartle Frere, who, doing full justice to the intelligence, skill, and energy of Mr. Berkley, alludes to

the previous unexecuted scheme of Mr. George Clark, in 1844, which, he says, preceded the plans of Mr. Chapman, and of Sir Macdonald Stephenson, to whom, however, he gives credit for their energy and perseverance, and in pressing forward their plans to fruition.

Considerable delay occurred in obtaining official sanction to the Thul Ghât portion of the scheme, owing to the Government of India having entertained a project for turning the Ghâts, by a line from Surat along the course of the Taptée River. This resulted in further surveys and elaborate reports on the Ghât ascent, by which the superiority of the line, as proposed by Mr. Berkley, was fully established.

In 1856 the North Eastern Line, viâ the Thul Ghât, was sanctioned by the Government of India, thus completing the Great Indian Peninsula system of lines, as projected by Mr. Berkley, comprising a total length of 1,237 miles, forming a grand trunk communication, by the North Eastern line, between Bombay, Calcutta, and the North-West, and by the South Eastern line, between Bombay and Madras; including also an important line to Nagpore, passing through some of the most extensive cotton districts of Western India.

The control which the Government exercises, under the guarantee system, has unquestionably been a source of special difficulty to the Engineers of the respective companies, and it was mainly due to Mr. Berkley's firmness and tact that a minute and harassing supervision was avoided, and that efficient co-operation established between the company and the Government authorities, which has generally subsisted on the Great Indian Peninsula Railway, to the manifest advantage of both parties.

Mr. Berkley was a firm and zealous advocate of the contract system, under which the whole of his works were constructed. The system on a large scale was new in India and was regarded at first, by the Government, with some suspicion; it has now, however, been adopted almost entirely in the public works, with the best effect in the rapidity and extent of their operations.

The details of the great works, comprising the inclines of the Ghâts, are so well known, from the description given by Mr. Berkley in his address to the Mechanics' Institution at Bombay, and from other publications, that it is only necessary here to allude to the satisfactory solution of the question of practicability, by the successful working of them with enormous traffic, although these inclines exceed in difficulty and importance those of the Sömmerring, and the Giovi. In connection with this undertaking mention should be made of the courage of the widow of Mr. Solomon Tredwell, the Contractor, who, after his too early decease, determined, for the honour of her husband's name, to continue the

works, and with the efficient aid of Mr. Clowser and Mr. Adamson, did complete them most satisfactorily.

The labour entailed upon Mr. Berkley by the works he had undertaken, affected his health, and he visited England in the year 1856. Advantage was taken of the opportunity, by a number of the principal Civil Engineers, to invite him to dine with them ; when Mr. Robert Stephenson, who occupied the chair, spoke thus of his former pupil :—

“Gentlemen,—I have very sincere pleasure in presiding at this entertainment, which is offered to my friend Mr. James Berkley. I feel that on the present occasion it is not necessary to enlarge upon the professional acquirements, or talents, or the social virtues of my friend, for he has already prominently brought himself to your notice by his professional abilities under exceedingly trying and adverse circumstances, and by the esteem in which he is held by all who know him. Very early in his life, and when I was tolerably advanced in my career, he was introduced to my notice as a young and professionally inexperienced man, but a very short acquaintance and association with him, convinced me that he was possessed of a good heart and a good head, and in a short time he became not only confidentially associated with me in professional life, but my intimate friend in my domestic circle. I freely imparted to him my own views and opinions, and employed him in the construction of several of the principal lines intrusted to me. When the opportunity for his going to India presented itself, I felt that he had embarked in an exceedingly difficult task. Having myself been thrown in early life upon my own resources, in a foreign country, where engineering operations were of a very difficult character, I well knew the variety and nature of the obstacles he would have to encounter, and you will readily comprehend how operations, even such as are easy in this country, would become extremely arduous when undertaken abroad. The Directors of the Railway Company were influenced by my recommendation, strengthened as it was by the highest testimonials, and my friend went to India, where he has amply justified the opinion I had formed of his capabilities, and has successfully overcome numerous difficulties and impediments of no ordinary character. A favourite expression of my father's, in his early career, was—‘I can engineer matter very well, but my great difficulty is in engineering men.’ Mr. Berkley has, I am happy to say, succeeded not only in engineering matter in a foreign country, with few available resources for railway operations, but he has also been eminently successful in that more difficult task of engineering men. No small tribute to his talents and temper.

“It is scarcely necessary for me to do more than allude briefly to the works executed by our guest, during his comparatively short stay in India. He has already executed 90 miles of railway which are on the point of being opened, as far as the Ghâts, the great physical feature of the West of India. The question of the ascent of the Ghâts, is one of considerable difficulty, and demanding much knowledge, skill, and consideration. Excellent designs of them have, however, been prepared by Mr. Berkley, and the explanations he has afforded me are so minute and interesting, that I assure you I should feel proud of being the author of the plans he has proposed. Throughout these operations he has encountered all the formidable obstacles which the Ghâts present, and has overcome them with remarkable success. And this redounds all the more to his credit, when we consider, that the Ghâts present greater engineering difficulties than either the passage of the Sömmerring to Trieste, or the Giovi Incline between Turin and Genoa ; and that the ascent of those mountains was

long considered barely practicable. Although these mountain inclines are serious undertakings, it is compulsory for the good of the country to make and to maintain them, and, in spite of all difficulties, Mr. Berkley has, after six years of laborious research, succeeded in designing a series of lines, which I have no doubt will be amongst the most successful in the world. I trust, however, that greater wisdom will be displayed by the Indian Government than by our home legislature in that respect. That they will be watched over with something more like parental care, for here they have been deserted like prodigal sons. India demands accommodation for an enormous traffic and population, and if the railways are permitted to be extended with discretion and wisdom, there cannot be a question that they will be both beneficial to those who have invested capital in the enterprise, and of incalculable advantage to that important country. My friend at my side has also the honour, whether accidental or not, of being the engineer who constructed and opened the first railway in India. This is no small credit to him, and in all that he has done I feel proud of him, and that he has reflected honour upon my recommendation."

Notwithstanding the extent and the laborious nature of his professional duties, Mr. Berkley took an active part in many of the useful and scientific institutions of Bombay. In the Mechanics' Institution especially he took a lively interest, and by his personal exertions and active measures, as President, he greatly increased its sphere of public utility, and gave an interest to its proceedings which had before been wanting.

The Council of the Mechanics' Institution has accorded a "Berkley Gold Medal" as an annual prize for competition among its members in commemoration of his valuable services, and the first gold medal was sent to his widow with a resolution expressing sympathy and condolence.

Constant demands were made upon his services, but he was obliged to decline everything except the nomination to such position as indirectly bore upon the chief events of his life. In 1855 he became a magistrate. In 1857 he was appointed one of the commissioners of the Municipal Board, and in 1858 he was elected a member of the Senate of the Bombay University.

Mr. Berkley's energy of mind far exceeded his physical strength, which was suffering severely from the effects of the Indian climate, so that in April, 1861, the state of his health compelled him to return to England. At that time he had the satisfaction of seeing his plans and designs of the Bhoré Ghât, his most cherished work, fully developed, and the works being carried on with extraordinary activity under a very efficient management. He eagerly desired to return to India to witness the accomplishment of the great work he had designed and almost carried out to completion, but it was otherwise ordered; and after a lingering illness he closed his short but useful career, at Sydenham, on the 25th August, 1862.

From early boyhood, James John Berkley showed signs of great

activity of mind and love of knowledge. He was a great reader, and was ever ready with his pen as a contributor to general literature, or as a clear and able writer on professional subjects. In after years, when his position in India called forth the particular talent, he proved himself both as President of the Bombay Mechanics' Institution, at the meetings, and on public occasions, a fluent and indeed an eloquent speaker.

By his devoted attention to the important duties of his office as Chief Engineer, in Bombay, of the Great Indian Peninsula Railway, by his high sense of honour, by his gentlemanly bearing and liberal sentiments, as well as by the kindness and consideration which he ever displayed towards all those who were connected with him in business, he deservedly obtained the esteem and affectionate regard of all who knew him.

The high estimation in which he was held is proved by the following extracts, which have been selected from numerous voluntary testimonials.

The Directors of the Great Indian Peninsula Railway in reporting his death to the shareholders stated :—

"The Directors have the melancholy duty of announcing to the Proprietors the death, on the 25th August last, of Mr. James J. Berkley, M. Inst. C. E., the Company's Chief Resident Engineer in India. Mr. Berkley from the commencement of operations in January, 1850, down to the beginning of last year, when his failing health compelled his return to England, conducted the whole of the engineering operations with remarkable devotion, energy, and engineering skill, to the entire satisfaction of the Directors. In order to record more permanently their sense of the valuable services which Mr. Berkley rendered to the Company, the Board have directed a tablet to be erected to his memory in some favourably conspicuous position at the Bhoré Ghât Incline."

Sir James Outram, whose large experience of Englishmen in India, rendered him no mean judge of his fellow-countrymen, and who has established a world-wide character for truthfulness and talent, wrote to him on his leaving Bombay in 1857 :—

"MY DEAR BERKLEY,

*Parrell, 9th July, 1857.*

"I am loth to leave Bombay without seeing and bidding you goodbye, for which purpose I called at your old house in Mazagon, which I found shut up, and there was no one at the premises to tell me where you are. I am informed, however, that you are travelling in Candeish, I hope out of harm's way in these troublesome times.

"When your line meets our line (from Calcutta) I trust we may have personal communication, if not before ; but in the meantime I hope you will not scruple to command me, wherever I may be, for there is no one for whom I have a greater esteem, or to whom this Presidency is more indebted, than yourself.

"Believe me to be, my dear Berkley,

"Very sincerely yours,

(Signed) "J. OUTRAM."

In addition to the above, the Engineers on the staff of the

Great Indian Peninsula Railway, and a few other gentlemen in Bombay, united soon after the death of Mr. Berkley to prove their high appreciation of his talent, as well as their great esteem and affection for their late friend and companion, by a substantial testimonial.

In a few days a sum of nearly £3,000 was raised, and it was determined to erect a monument over the grave of their late friend, at a considerable cost, and to expend the remainder of the fund, amounting to about £2,000, in the establishment of a fellowship, to be called the "Berkley" fellowship, at the Bombay University. They well knew that the high value he attributed to education and the proper development of the powers of the mind, and the great interest he always evinced in this excellent university, would, were he living, render this, in his eyes, one of the most valuable testimonials of their regard which could be offered to him.

Mr. Berkley was elected a member of the Institution of Civil Engineers in the year 1855, and his Paper on "Indian Railways," in 1860, obtained for him a Telford Medal and a Council Premium of Books.

He was one of the men who, if his mission had not been to become one of the engineering pioneers in the East, would have risen to a very eminent position in the profession, for which he possessed the highest qualifications.

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MR. JAMES COOPER was born at Highgate, in the year 1817. Soon after leaving school he entered the factory of Messrs. Cooper, of Old Street, where he only remained a short time, but where he acquired useful practical knowledge, which was of service to him in his future career.

After studying for some time under Mr. Hale, land surveyor at Colchester, he entered the office of Messrs. Walker and Burges, as a pupil, in the year 1835, and he rendered himself so useful that he subsequently continued with them as an Assistant, and finally was admitted into partnership with the firm in 1851.

Under the direction of, and in connection with, Messrs. Walker and Burges, he enjoyed rare opportunities of observing, and of being actively engaged in, many of the great engineering works of the period, such as the Caledonian Canal, the Middle Level Drainage, the Admiralty Works at Dover, Jersey, Alderney, Plymouth, &c., the Birmingham Canal, and the Lighthouses for the Corporation of the Trinity House, with many other important undertakings.

Whilst he was in charge of the works at the Edystone Lighthouse, in 1839, when it was decided to carry out Smeaton's inten-

tion of filling up the cavern in the rock, he nearly lost his life from one of those sudden risings of the waves to which the sea there is subject. The mason standing beside him was swept away, and was drowned, but Mr. Cooper continued his labours until the hazardous work was completed.

His decease was very unexpected, as there were not any symptoms which induced any anticipation of such an event. On Sunday, after church, he took a walk of only a few miles, and returned apparently without fatigue. After dinner his sisters quitted the dining-room, leaving Mr. Cooper and his father in conversation. On the servant going to the room to summon them to tea, both father and son appeared to be asleep; the former awoke, but the latter had in his slumber peacefully passed away. His death occurred on the 2nd of March, 1862.

The opportunities he enjoyed professionally were unusually good, and had his life been spared he might have taken a high position.

Mr. James Cooper was elected an Associate of the Institution of Civil Engineers in 1836, was transferred to the class of Graduates in 1838, and to that of Member in 1847. He was a very constant attendant at the Meetings, and frequently took part in the discussions.

**MR. HENRY HINDE EDWARDS** was born at Plymouth in November, 1800. His father, who was a practical Engineer and steam-engine builder, perceiving that there would be a good opening on the Continent, sent his son, in 1814, to complete his education in France, and he some time afterwards followed and settled in Paris, where he eventually became the partner of Monsieur Casimir Perier at Chaillot, and took his son into the works, of which, in 1829, Henry Hinde Edwards became the managing partner, as successor of his father, in the firm of Perier, Edwards, Chaper, and Co. The establishment, following closely after that of Messrs. Manby, Wilson, and Co. at Charenton, founded in 1820, became important in the history of mechanical engineering in France, and from thence there were produced large numbers of the double cylinder, high and low pressure engines, on Wolf's system, which are now so generally used on the Continent. Mr. Edwards also gave valuable aid in numerous establishments for mining, pumping water, grinding corn, &c., and displayed considerable mechanical ingenuity and skill. Among other works, he built, under the direction of Monsieur Polonceau, the cast-iron bridge across the Seine, called the Pont du Carrousel.

During the period of the political crisis, when all industrial undertakings were brought to a standstill, Mr. Edwards returned to England, whence he was eventually summoned to take charge  
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of the Locomotive and Rolling Stock Department of the Eastern (Strasbourg) Railway, duties which he performed with undoubted skill and rare conscientiousness.

He joined the Institution of Civil Engineers, as a Member, in the month of December, 1855, but his residence abroad precluded his paying frequent visits during the Sessions. He was also a Member of the Société des Ingénieurs Civils de Paris, amongst whose members he, at his decease on the 13th February, 1861, at the age of sixty-one years, left many friends who sincerely regard his memory as that of a modest and honest man who had done good service in his particular sphere.

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**MR. JOHN EDWARD ERRINGTON**, the eldest son of Mr. John Errington, a cadet of an old Northumberland family, was born at Hull, on the 29th December, 1806. He early evinced signs of great intelligence, and was remarked at school for his high spirit, for the prominent position he took in all his classes, and as being a general favourite with his masters.

Having shown in his youth great predilection for engineering and for the constructive arts, he was placed at an early age under an engineer officer, then conducting extensive public works in Ireland. After remaining some time on these works, he became the assistant of the late Mr. Padley in the various surveys which that gentleman conducted in the early stages of railways in this country. This employment brought him into connection with the late Mr. Rastrick (M. Inst. C.E.), by whom he was engaged to assist in various surveys, and his first active employment in railway projection was at the time of the preparation of the plans for the Birmingham end of the Grand Junction Railway, and it was at this period that Mr. Errington first met Mr. Joseph Locke, with whom he eventually became associated for the rest of his life. When the Grand Junction Railway came under the sole direction of Mr. Locke, he gave Mr. Errington an appointment as Resident Engineer, and intrusted to him the superintendence of the construction of a portion of the line, where he had an opportunity of making himself thoroughly acquainted with the practical methods adopted by Mr. Locke in carrying out the various contracts. After the completion of that railway, Mr. Errington took charge of the line from Glasgow, by Paisley, to Greenock, and the works were carried out under his superintendence: the harbour works at the latter port were also laid out by him, and the construction was carried on under his immediate supervision.

To an active and thoughtful mind like his it was not surprising that, during his residence in Scotland, various projects should have

suggested themselves to him for connecting the political and commercial capitals of Scotland—Edinburgh and Glasgow—with England. At that time Mr. Vignoles had constructed the North Union Railway, a line extending from Newton, on the Liverpool and Manchester Railway, and virtually forming an extension of the Grand Junction line, to Preston, and various other projects were started to connect Preston with Lancaster. These lines would place Preston in direct communication with London, and the subject of extension northwards to Scotland had already occupied the attention of a Government Commission and of several of the most eminent Engineers of that day. The two principal projects, however, that interested the public in that special district were the rival schemes of Mr. George Stephenson for a coast line crossing Morecambe Bay and the direct scheme for uniting Lancaster and Carlisle by as straight a line as the nature of the country would permit. The plans for this latter project were deposited in 1842, under the name of the Caledonian Railway Company, with Mr. Locke as Engineer in chief. This project was, however, withdrawn; but it was brought forward again in a subsequent session, as the Lancaster and Carlisle Railway, and Mr. Errington's name was then associated with that of Mr. Locke as the joint Engineers. The immediate superintendence of the works remained in Mr. Errington's hands, and whilst Mr. Locke attended to various details of his largely-increasing practice in London, Mr. Errington devoted himself to the carrying out of the numerous bridges, viaducts, and other works which abound on that line.

Mr. Errington, although generally giving his assistance to Mr. Locke in the laying out of the several lines that came under Mr. Locke's charge, devoted himself principally to the works in the north of England and Scotland. He carried out the Caledonian Railway, upon which he evinced great judgment, by his mode of constructing the line across and forming junctions with the various tramways then in use for carrying on the traffic between the several collieries, without stopping the train. He constructed the Clydesdale Junction Railway, the Scottish Central, the Scottish Midland Junction, the Aberdeen Railway (now the Scottish North Eastern), and he either brought forward or was consulted about the entire system of railways from Lancaster to Inverness. After the commencement of the larger works in Scotland, Mr. Errington removed to London and devoted his attention to the various additions and branches made to the railways constructed under his and Mr. Locke's superintendence. About that period the London and South Western Railway Company were projecting anew their extension of the narrow-gauge system into Devonshire; and, owing to some difference between himself and the Board of Directors, Mr. Locke having ceased to be Engineer to that Company after the

revival of their projects to the westward, the Directors naturally sought the advice and assistance of some well-known Engineer, whose antecedents might justify some knowledge of the locality. At this juncture they selected Mr. Errington, and under his direction various lines were deposited to meet the necessity which had arisen. After several deposits of plans and subsequent withdrawals, the Company finally sought powers to construct a line from Yeovil to Exeter. The plans for this project were deposited in November, 1855, and the Act received the royal assent in 1856. The works on the line were immediately commenced, and after great difficulties, owing to the heavy tunnels at Crewkerne and Honiton, the line was opened to the public in 1860. Several branches of this line were also constructed under his direction, and shortly after the completion of this work, Mr. Errington, whose health had been for some time precarious, suddenly became worse, and he expired at his residence in Pall Mall East, after a short illness, on the 4th of July, 1862, at the comparatively early age of fifty-five years, and he was interred at Kensal Green, in close proximity to his early friend and associate, Mr. Locke, who had not long preceded him to his final rest.

During the whole of Mr. Errington's career, both in Scotland and subsequently, when Engineer to the South Western Railway, he was actively engaged in various parliamentary contests, and the conscientious manner in which he gave his evidence, coupled with a marvellous power, which he had possessed from his childhood, of simplifying and bringing vividly before his hearers anything that he thought necessary they should know, gave his opinion great weight with the Committees before whom he was examined, and the Boards which he attended.

Mr. Errington, like his partner, Mr. Locke, had early learnt the lesson of endeavouring to make railways commercially successful, and his principle was therefore to study economy to the greatest possible extent; at the same time his taste in matters of art led him to combine elegance with strength and economy of design. His bridges on the Lancaster and Carlisle and the Caledonian Railways, those across the river Thames at Richmond, Kew, and Kingston, and lastly, the works of art on the Exeter line of the South Western Railway, show with what success his efforts were crowned.

In private life, Mr. Errington's kindness of heart, his great tact, and his affectionate disposition, tended to endear him to his associates and to his pupils. Possessed of sound talents and modesty, and a retentive memory, his society was sought by a large circle of friends, who deeply regretted his loss, and the respect of all his associates in his professional life was secured by his honourable character and fair dealing.

Mr. Errington joined the Institution of Civil Engineers, as an Associate, in the year 1831, and was transferred to the class of Members, on the 22nd of January, 1839. He became a Member of Council for the Session 1850, and was elected one of the Vice-Presidents for the Session 1861-62. He attended the meetings very regularly, took part in the discussions, was ever ready to advise and assist in every way for the benefit of the Society, and at his decease bequeathed the sum of One Thousand Pounds to the Institution.

He was a Member of whom the profession and the Institution might be justly proud, and his example should be carefully studied by the younger Members.

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MR. JOSEPH LANE MANBY, the third son of the late Mr. Aaron Manby (M. Inst. C.E.), was born at Horseley, Staffordshire, December 22nd, 1814. At an early age he was sent to Paris for education at the school of Monsieur Massin, and in due time he was placed in the gas works of Manby, Wilson, and Co., where he studied gas engineering. He then returned to England, and was for a time engaged in the mercantile and banking establishment of Messrs. Jeremiah Harman and Co., Adam's Court, Broad Street, where he acquired the aptitude for commercial affairs which was subsequently so useful to him.

At the dissolution of the firm under whom he was engaged, he sought the advice of his father's old friend, Mr. George Lowe (M. Inst. C.E.), by whom he was induced to undertake the management in France of the concerns of the Continental Gas Company, which he continued to direct for some years. He then became connected with similar affairs in Spain, where he resided for some time, but he eventually settled in Paris, where, associated with the late Monsieur Savalète, he undertook contracts for the construction of the Seville and Cordova Railway, for some building speculations in Paris, and other works.

After the decease of his partner he came to London, in prosecution of some building speculations in Paris and elsewhere, and having some contract work in view at Cadiz, he, in 1862, visited that city. He there engaged to make a survey in Africa, where he received a sun-stroke, from the effects of which he rapidly sunk, and died shortly after his return to Cadiz, on the 18th of August, 1862, at the early age of forty-eight years.

Mr. J. L. Manby, although not strictly educated as an Engineer, had a very good knowledge of his special branch of the profession, and his natural talent and acuteness carried him through all difficulties. He was an excellent companion, a very well read and

well-informed man, and possessed abilities which, under favourable circumstances, would have carried him probably to fame and fortune. He was deeply regretted by his relatives and friends.

He joined the Institution as an Associate in June, 1844, and was transferred to Membership in May, 1854.

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MR. JAMES WALKER, LL.D., F.R.S., L. & E., &c., was born at Falkirk, N.B., in the year 1781. His education commenced at the school of that place, and was finished at the University of Glasgow. He had talent and was industrious; so that his studies were completed with distinction in a comparatively short time; and in the year 1800, when he was nineteen years of age, he was articled to his uncle, Mr. Ralph Walker, at that time an Engineer in considerable practice in London. Under him he was employed at the East and the West India Docks, and became conversant with the best class of constructions, eventually succeeding his uncle in the greater portion of his works.

Mr. Walker was intrusted, in 1803, with the formation of the Commercial Road, an important work, which was excellently carried out, and where he eventually tried the system of providing stone tramways for facilitating the traction of the heavy loads passing along that important route, from the docks to the metropolis.

He was appointed Engineer to the Commercial Docks in 1806, and the extensions and improvements effected up to the time of his death were designed by, and executed under, the superintendence of Mr. Walker and his partner, Mr. Burges.

At the decease of Mr. Telford, in 1834, many of his important works fell into the hands of Mr. Walker, and he was at that period, and for many years after, constantly consulted by almost all the branches of the Government, and by many public boards and corporations; especially that of the City of London, for which latter body he made numerous Reports upon the City sewers, and the navigation of the River Thames, projecting the plan of embankment, now known as 'Walker's lines;' upon which the present constructions are in a great degree based. He also had under his charge the bridges at Blackfriars and Westminster, executing extensive works for their maintenance, until their demolition was decided upon.

Any attempt to mention all the works upon which Mr. Walker had been engaged at some period of his long professional career, would involve the enumeration of nearly all the principal undertakings of the kingdom; but among them must be mentioned the construction of Vauxhall Bridge over the Thames, and of the Victoria Bridge over the Clyde, at Glasgow; the improvements of the River Clyde,

which, from the death of Mr. Telford up to a recent date, were under his direction; the great repairs of the Caledonian and Crinan Canals; the Coffey Dam and River Wall of the New Houses of Parliament; the extensive works of the Birmingham Canal, including the Tame Valley Canal, the Betley Canal, and the Netherton Tunnel; the extensions of the Bute Docks at Cardiff; the Pier and Harbour of Granton; the improvements of the Harbour of Belfast, and the Harbour Works at Dover; the designs and execution of the Harbours of Refuge at Alderney, St. Catherine's, Jersey, Dover, and Harwich, on the former of which he was penning a Report in his own hand on the day before his decease; the Tyne Piers; the completion of Plymouth Breakwater, and the foundation for the Fort about to be constructed there for the War Department. But, perhaps, the most lasting monuments of his skill may be found in the various Lighthouse Works of the Corporation of the Trinity House. As a difficult and successful engineering work, the Bishop Rock Lighthouse, off the Scilly Islands, may be placed in the foremost rank with those of Smeaton, at the Edystone; of the elder Stevenson, at Bell Rock; and of that built on the Skerryvore, by Alan Stevenson, his son.

For many years the extensive drainage operations in the Fens, particularly in the Middle Level, occupied his attention; and the great cut, nearly 30 miles in length, by which, with its numerous branches, upwards of ninety thousand acres of valuable land are rendered susceptible of cultivation, is a work deserving the attention not only of the Engineer, but of the landowners in similar districts.

At an early period in the history of railways, Mr. Walker was appointed, in conjunction with the late Mr. Rastrick, to report on the system of traction to be employed on the Liverpool and Manchester Railway. Their recommendation was that a continuation of locomotive with stationary power should be used; but their Report was replied to so effectively by Robert Stephenson and Joseph Locke, that the celebrated Rainhill trials were instituted, and the locomotive system was fully established.

Mr. Walker never entered largely into railway engineering, preferring the other branches of the profession; but he did construct the Leeds and Selby, and the Hull and Selby Railways, both now forming valuable portions of the North Eastern system of lines.

The printed Reports proceeding from Mr. Walker's pen are very numerous, and they are valuable as giving the history of many important works. He was a strict disciplinarian, was very regular in his business habits, and indefatigable in his attention to the works under his charge. He was fortunate in attracting to him a number of men who have since risen to eminence in the

profession; and he was very ably seconded by his partner, Mr. Burgess, and subsequently by the late Mr. James Cooper.

Mr. Walker was connected with many of the principal scientific bodies of the kingdom. He was a fellow of the Royal Societies of London and of Edinburgh, LL.D. of Glasgow University. (an honour conferred only upon distinguished students of that body), a member of the Senate of the University of London, and an honorary member of several foreign societies.

He joined the Institution of Civil Engineers, as a Member, in the year 1823, was elected a Member of the Council and Vice-President in 1826, succeeding the first President, Mr. Telford, in 1834, and occupying the chair for nearly eleven years, during which time, by his attention to the interests of the Society, he contributed largely towards placing it in its present position. In the year 1845 it was considered desirable to introduce certain modifications in the constitution of the Society, one of the chief points being the limitation of the period of holding the post of President, in order to afford opportunity for the leading members of the profession to attain consecutively that honourable position. This and other proposals necessitated the revision of the Code of Bye-laws of the Institution, and, after several special meetings, the proposed modifications were carried, and Mr. Walker resigned the Presidential Chair, in which he was succeeded by Sir John Rennie, who occupied it for three years. Subsequent to that period no President has held the position longer than for two consecutive sessions.

Under the presidency of Mr. Walker the Institution made important strides; the number of the Members increased; the Society was enabled to remove to the present premises at No. 25, Great George Street, Westminster; the Annual Conversazioni were instituted, setting an example to all the other Societies of the metropolis; and the special feature of the Institution—the free expression of opinion, at the discussions upon the Papers—was largely encouraged. Mr. Walker had a peculiar talent for guiding the Meetings, and for eliciting the information possessed by the Members and the Visitors; and he was solicitous to have invitations issued to all those who were capable of contributing to the interest of the discussions, which he generally summed up very cleverly. His extensive acquaintance among scientific men and noblemen who felt an interest in the progress of Engineering science enabled him to induce many distinguished visitors to attend the Meetings, and, in some instances, to join the Society.

During the period of his filling the Presidential Chair, he liberally assisted the then comparatively young Society, as by his great wealth he could afford to do. The necessary alterations, however, in the constitution of the Society not meeting his views, he ceased to feel as great an interest as formerly; still, in his capacity

of a Past-President, he was a not unfrequent attendant at the Meetings.

In spite of somewhat declining health, Mr. Walker continued to exercise his profession up to the period of his decease, and to the very last he retained his vigorous and shrewd intellect. He was eminently a man of business, and he had, at least, as much skill "in the engineering of men as of matter."

It has been correctly stated, that "his works were remarkable for their solidity and permanency, and not less for their utility, as having a material share in aiding the commercial progress of this country in the present century, during sixty years of which he had been in the active exercise of his noble profession."

He died on the 8th of October, 1862, and was interred, by his own desire, in his family vault, at St. John's episcopal burial-ground, at Edinburgh.

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**MR. WILLIAM WEALLENS** was the descendant of a German family, who emigrated many years ago and settled in the North of England, in connection with some proposed steel works. Subsequently his immediate parents devoted themselves to agricultural pursuits, and his father, John Weallens, held a farm, called the East Houses, at North Dissington. His mother was the daughter of the Rev. John Furness, of Ponteland, where William Weallens was born, on the 8th of March, 1823. He received his education under Dr. Cowan, of the Grange, Bishopwearmouth, and having exhibited a talent for mechanical pursuits, he was apprenticed to Messrs. Robert Stephenson and Co., on the 3rd of September, 1838, and became the pupil of his stepfather, who took much pains with his professional education. His mother, who was early left a widow, with two sons and a daughter, married Mr. Hutchinson, who subsequently, as a reward for his faithful and efficient services, was admitted to a partnership in the celebrated firm of Messrs. Robert Stephenson and Co., of whose works he was the acting manager.

On the decease of Mr. Hutchinson, in 1853, the direction of the mechanical department of the works was intrusted to Mr. Weallens, and eventually, in January 1855, he was presented with a partnership in the firm, to whose concerns he devoted himself for some years with great energy. He was a very good mechanic, had clear judgment, and was fertile in resources. His temper was peculiarly amiable, and he endeared himself to the workmen and those with whom he came in contact by the gentleness of his disposition. These qualities were especially appreciated by the late Mr. Robert Stephenson, with whom he was a great favourite, and they were also recognized by his fellow-townsmen, who elected him a member of the Town Council. He took an active part in the Volunteer movement, commanded

a company composed of men belonging to the works, and his example contributed essentially to the present state of efficiency of the corps. He joined the Institution of Civil Engineers, as a Member, in the year 1857, and was a Member of the Council of the Institution of Mechanical Engineers, of Birmingham.

His decease occurred almost suddenly, and in an unexpected manner. It had been the custom for him to make an annual visit to the Continent, generally with his friend Mr. Charles Manby. When the usual period for the journey approached, although they had both been somewhat indisposed, they did not see any reason for postponing their departure, but they travelled more leisurely than usual as far as Turin, where Mr. Weallens' state caused his companion so much uneasiness that he called in medical advice; but he was assured that the journey further south could be undertaken with safety, and probably even with benefit to the invalid. On arriving at Genoa, on consulting a physician of eminence, it was, however, thought desirable to return home, and Mr. Weallens was taken to Marseilles by sea, and thence, in a bed-carriage on the railway, to Paris, which was reached with comparatively little fatigue at seven o'clock on the evening of Saturday, the 1st of November, 1862. The best medical advice was immediately sought, but a sudden change occurred, and in spite of the most skilful treatment, the patient sunk rapidly, and expired at two o'clock on the morning of Sunday the 2nd of November, 1862. So tranquil was his end that the actual moment of his decease was only perceived from the inability to swallow the liquid which was administered to him in spoonful at very short intervals, by Mr. Manby, who from the commencement of the serious attack had not left him, day or night.

His remains were brought to England, and were interred in the family vault at Ponteland, near Newcastle-on-Tyne, on Saturday, the 8th of November, 1862, when a well-deserved tribute of respect was paid to his memory by the attendance of his partners, a large number of his fellow-townsmen, the workmen from the factory, and a large body of Volunteers under arms, all anxious to pay the last tribute of respect to the memory of a man who had been so deservedly beloved and esteemed, and who, at the early age of 40 years, had been removed so suddenly from amidst a large circle of friends. A mural tablet was subsequently erected to his memory in the church at Ponteland, by a few of his attached friends.

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LIEUTENANT-COLONEL JOHN FRASER LODDINGTON BADDELEY, Royal Artillery, Chevalier of the Legion of Honour, and of the Order of Medjidie, &c., was the sixth child of the late Major John Baddeley, Superintendent-General of the Barracks

in Ireland, formerly of the 7th Hussars and 22nd Light Dragoons. At fifteen years of age young Baddeley joined the Military Academy, Woolwich, and at seventeen he obtained his commission in the Royal Artillery. His earliest services were in Ireland and in the West Indies, and on his return he was appointed to the Horse Artillery. On his promotion he was made Adjutant to the Tenth Battalion, but this appointment he resigned, and volunteered for the Crimea, where he was appointed Acting-Adjutant to Colonel Lake, R.A., and was attached to the Light Division under Sir George Brown. He was present at the actions at Boulganak, the Alma, Balaclava, and Inkerman, where he was dangerously wounded: He received the Crimean Medal with four clasps, the Legion of Honour, the Order of the Medjidie, and the Turkish Medal, and was appointed shortly afterwards second officer of the Royal Powder Works, Waltham Abbey, where he remained five years. He was subsequently made Assistant-Superintendent at the Royal Small Arms Factory, Enfield Lock, where he died, after one week's illness, aged thirty-six, leaving a widow and six children to deplore his early and untimely death.

The service thus lost an excellent officer, and the department to which he was attached, a most able and valuable assistant. The great mechanical abilities and untiring devotion to his duties which he exhibited during the period of his service at the Royal Gunpowder Factory at Waltham Abbey, as well as at the Royal Small Arms Factory, justly entitle his loss to be regarded in the light of a public one. The funeral of this much-lamented officer took place at Enfield on the 1st of March, 1862, and was conducted with more than the usual military honours due to his rank, being attended by a considerable body of troops, both regulars and volunteers. A spontaneous and most gratifying exhibition of feeling was shown by the workmen of the factories at Enfield and Waltham Abbey, who in a body of upwards of twelve hundred men accompanied the remains of the deceased officer to their last resting-place. The universal feeling of regret at the loss they have sustained, as well as the deep estimation in which he was held, have been shown by the publication of most creditable compositions in verse by workmen of the factory, and also by a subscription raised amongst themselves for the purpose of erecting a marble tablet in the church of the factory to the memory of their departed and acknowledged friend.

Lieutenant-Colonel Baddeley possessed all the qualifications for eventually attaining a very distinguished position. He had clear intuitive perception, good judgment, indefatigable industry, and had studied hard to extend his scientific and mechanical knowledge. To him may be ascribed the merit of the introduction to the service of the foreign mode of purifying saltpetre; and he published

a tract, "On the Manufacture of Gunpowder, as carried on at the Government Factory, Waltham Abbey (1857.)"<sup>1</sup>

On becoming attached to the Royal Small Arms Factory, at Enfield, he immediately took a marked position; and if his life had been spared, he would have taken a very active and useful part in the War Office Manufacturing Department.

He was a general favourite in the branch of the service to which he belonged, and his decease was deeply and deservedly regretted by a large circle of friends.

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CAPTAIN CARLTON THOMAS COLLINGWOOD joined the Institution of Civil Engineers as an Associate, in the year 1857; and died in India on the 7th of March, 1860.

It is regretted that repeated applications have failed to obtain any materials for a memoir.

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COLONEL SAMUEL COLT was born on the 19th of July, 1814, at Hartford, Connecticut, U.S., America. He was of Scotch descent, his father, Christian Colt, being the son of an early settler in Connecticut.

Sam Colt had not the advantage of careful education, and at a very early age he ran away to sea, and made several voyages to India. He had latent mechanical talent and great energy, and it is stated that he was constantly devising some supposed improvements in the tackle, &c., on board, for which the commander did not award him the credit which he imagined was his due; and he turned his attention to a repeating fire-arm which should be also a breech-loader, and thus afford to the solitary pioneers of the Western States the immunity from danger which only could be obtained by rapid firing, in case of attack by the Indians. Whilst at sea he is supposed to have produced the first wooden model of the revolver pistol which bears his name; and it has been asserted that, on his return to America, he fell in with another untaught inventor, like himself, whose attention had also been directed to the same subject, and that he received from this accidental acquaintance the first notions of the necessity of adopting mechanical and automatic machinery for the production of these weapons. For some years he had to struggle with great difficulties, and during that period he turned his attention to other subjects; but always keeping in view the production by machinery of the several parts of the repeating fire-arm, and for this he invented and adapted various machines. He received his first patent in 1835, and established a factory in Paterson, New Jersey, but

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<sup>1</sup> Library Inst. C.E. Tract 8vo. vol. cxx.

met with indifferent success. He subsequently disposed of his right to manufacture revolving fire-arms, and, as it was generally understood at the time, expended the proceeds in a vain attempt to clear his brother, John C. Colt, of a charge of homicide. Sam Colt afterwards invented a submarine torpedo, which was intended for the destruction of vessels. He gave two exhibitions of the power of his new invention in the bay off Castle Garden, by blowing up first a schooner, and afterwards a large brig. He then established a line of telegraph between New York and Sandy Hook and Montauk, which was intended to announce the arrival of vessels, and to facilitate the despatch of important foreign news; but this enterprise failed, and he became very much reduced in circumstances. Colonel Colt is also reputed to have been the inventor of the first submarine telegraph cable, as shown and tested from Fire Island to New York, and from the Merchant's Exchange to the mouth of the harbour, in 1843. A few years later he again obtained possession of his patent for the revolving pistol, and with the assistance of a few capitalists who joined him, a company was formed and a manufactory was established at Hartford, which has proved very successful, not only in the making of pistols, but in the manufacture of a revolving rifle, which was also the invention of Sam Colt. The factory was supposed, before the war, to be worth nearly \$5,000,000, and since then has, most probably, considerably augmented in value. The proceeds have been so great, that Colonel Colt realised a large landed estate, and he was no doubt one of the wealthiest men in New England.

At the period of the International Exhibition in 1851, Colonel Colt first visited London, but so little was generally known of the use of repeating fire-arms, that "Colt's Revolvers" scarcely attracted any attention, and it was only towards the time of the closing of the Exhibition that General Gibbs MacNeill (U.S. army), who had experience of the value of these arms in the Texan and other expeditions, directed to them the attention of some Members of the Institution of Civil Engineers, by one of whom a Paper was written, from the information given by Colonel Colt, describing the automatic machinery used in the production of these weapons. The Paper<sup>1</sup> was read, and the subject was discussed at two meetings of the Institution in the month of November 1851. This induced the attention of the Government to the mode of manufacture, and Colonel Colt was permitted to establish a small-arms factory in a building belonging to the Government at Thames Bank, Pimlico. This was not successful as a commercial speculation, but it had the result of inducing the attention of the intelligent gunmakers of the metropolis and the provinces to the

<sup>1</sup> *Vide Minutes of Proceedings, Inst. C.E. vol. xi. p. 80.*

subject, and eventually at the Government Small Arms Factory at Enfield, the same kind of automatic machinery was adopted, with the present evident beneficial result for Her Majesty's service. This is another instance, among many, of the too general neglect of useful inventions from abroad, and their eventual forced introduction. In this case Colonel Colt lost a large sum of money, and the Engineer who introduced him and the repeating arm to the Institution, the Government, and the public, and wrote the article in question, is not publicly known in connection with the subject. After the closing of the manufacture at Thames Bank, Colonel Colt returned to America, and on the breaking out of the war, he used great exertions to extend the production of arms, supplying also considerable funds for raising a corps of men for the service of the Northern army. He is stated to have greatly extended the Hartford works, and to have realized a very large fortune.

His decease occurred, from disease of the brain, on the 9th of January, 1862, in the forty-eighth year of his age. He was a man of determined will, of great natural powers, and only lacked the advantages of early education and training to have become a man of mark in his generation.

He joined the Institution as an Associate in the year 1852, and received a Telford Medal for the Paper already referred to.

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MR. ROBERT COWEN was born at Biglands, near Wigton, Cumberland, in 1787. He received the rudiments of his education at the village school, and from youth onwards he was a diligent self-instructor. At the early age of fifteen he was associated with his father in the management of the cotton-mill carried on in Carlisle by the firm of Cowen, Heysham, and Co. In a short time he was found capable of taking upon himself the entire direction of the machinery department, and few young men, at their entrance into life, ever more closely attended to the duties of their allotted position than Mr. Cowen did. Although the long hours and rigid rules of a cotton-spinning establishment leave the persons engaged in it but little leisure, Mr. Cowen contrived, by systematic application, to extend his knowledge of scientific subjects. Mechanics were especially his delight, and his proficiency was shown by improvements in the spinning and carding machinery, which essentially contributed to the success which attended the house. In process of time the style of the firm was altered to Jacob Cowen and Sons, and Mr. Robert Cowen became a partner in the concern with which he continued to be connected for so many years. Without neglecting the business, he found time for pursuing his studies, and there were few men who better understood the principles and practice of mechanics. His know-

ledge, in fact, extended to most of the sciences and the useful arts: and, amidst his active engagements, he was still able to cultivate the arts of drawing, painting, sculpture, and engraving: but this stringent taxing of the mental powers produced their natural effects upon the body, and up to his fortieth year Mr. Cowen was an ailing man, and very reluctantly mixed with society.

He was, however, hospitable in an eminent degree, but he was not a demonstrative man, and he was never heard to boast of what he had done or intended to do. He shrank from display, save in the matter of the fine arts, and his love for and patronage of them was demonstrated by the possession of an unusually large collection of paintings and sculpture, a well-selected library of sterling books, and a great number of valuable engravings and drawings. Few private residences contained more or better selected attractions.

At a somewhat early period of his career, in 1824, Mr. Cowen had conferred on him by the Society of Arts the Gold Vulcan Medal<sup>1</sup> "for his improved method of carrying off the Dust produced in grinding Cotton Cards," which, up to that date, the workmen of Sheffield and elsewhere were compelled to inhale at the terrible cost of lung-disease and premature death. In 1827, he received a second gold medal from the same Society<sup>2</sup> for his Draining Syphon; a practical and useful invention for the extraction of liquids from large vessels, and water from pools, lakes, &c., below the ordinary level, or for raising water from lower to higher levels.

In due time Mr. Cowen, having to some extent retired from the active management of the mills, determined to gratify the natural bent of his inclinations, and to adopt the profession of a Civil Engineer, for which he was technically qualified by his mechanical knowledge and practice, and theoretically by his intimate acquaintance with the applied sciences. He took a very active and useful part in the improvement of the City of Carlisle, promoted the establishment of water and gas works, of which latter he became the Chairman, and by his influence enabled the Company to avoid expensive litigation. He held the office of Government Inspector of Steam Boat Machinery for a part of the Solway. He was in the Commission of the Peace for the County of Northumberland and the City of Carlisle, of which also he, for some time, was an alderman and town-councillor; and there was scarcely a charitable institution in the town that had not the benefit of his pecuniary support.

To several young men who have since risen to honourable positions he afforded timely and effectual aid, and among them must be especially mentioned the late Mr. Joseph Miller, F.R.S., M. Inst.

<sup>1</sup> *Vide* "Transactions of the Society of Arts," vol. xliv. p. 132.

<sup>2</sup> *Ibid.*, vol. xlv. p. 113.

C.E., &c., to whom the advice and assistance he rendered in early life was most valuable, and it was always gratefully acknowledged. In later years, when Mr. Miller had attained his deservedly high reputation as an Engineer, he delighted to recall the advantages he received from the precepts and example of Mr. Cowen, and they remained fast friends through life.

Mr. Cowen joined the Institution of Civil Engineers as an Associate in the year 1844, and always took much interest in its welfare.

"He died on Sunday afternoon, 27th April, 1862, at his house in Devonshire Street, Carlisle, in the 75th year of his age, after a long course of sickness and suffering; but, in the closing stages of his decline, although his bodily strength failed, and his form became greatly attenuated, his mental powers and memory were mercifully preserved to him in perfection, and enabled him to direct all that a man must wish to have done who is conscious that he is on the point of yielding up his breath to Him who gave it. His complaint was hereditary gout of great severity, involving a complication of ill and acute pains. He, however, bore his affliction with fortitude and resignation. He had no desire to live; he looked beyond this world. He said, in reply to the inquiries of a friend, that 'he had made his peace.' The troubles and cares of life at an end, he sleeps soundly. Those who well knew him and appreciated his worth will never cease to cherish and honour his memory."

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MR. JOHN WITHERS, of Whalley Abbey, joined the Institution of Civil Engineers as an Associate in the year 1857. He died on the 25th October, 1862, at the age of 43 years.

All attempts to obtain materials for a Memoir have been unsuccessful.

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MR. JOHN BRANNIS BIRCH, F.G.S., was born in London in the year 1813. He studied architecture and surveying under his father, and subsequently embraced the profession of a Civil Engineer. At an early period of his career he entered into partnership with his brother, Eugenius Birch (M. Inst. C.E.), a connection which continued up to the period of the death of J. B. Birch. He was actively engaged in works of varied character up to 1845, when he took a prominent part, as Engineer, in the parliamentary survey and sections of several important lines of railway. He was then engaged in laying out the section of the East Indian Railway from Calcutta to Delhi, and with his brother designed the whole of the bridges and viaducts, and upon the material thus furnished the guarantee of the line was obtained. He was subsequently employed in the construction of several works of interest

and public utility, among which may be mentioned the Margate Pier, which was erected in 1853 from the designs and under the supervision of his brother and himself. It is remarkable as being a very early example of the complete adaptation of iron as the material in the formation of sea structures of that kind.

He was elected a Graduate of the Institution of Civil Engineers in 1842, and in that capacity he remained to the time of his death. He became a Fellow of the Geological Society in 1847, and a considerable portion of his leisure time was devoted to geological researches, in which he took an interest second only to that with which he regarded the works of the profession he had so happily chosen for himself, and which he for so many years earnestly and zealously pursued.

He died in London on the 17th of June, 1862, deeply regretted by all his connections and friends.

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# I N D E X

TO THE

## MINUTES OF PROCEEDINGS,

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