TRANSACTIONS
OF THE
INSTITUTION
OF
CIVIL ENGINEERS

VOL. III. PART 5.

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TRANSACTIONS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS.

VOLUME III.—PART V.

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CONTENTS OF PART V.—VOL. III.

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ADVERTISEMENT.

XIII.—*An Account of the Mode of Construction adopted in Building a New Stone Bridge over the River Lea, at Stratford-le-Bow.*

By JOHN BALDRY REDMAN, Grad. Inst. C.E.

Read June 18th, 1839.

The Old Bridge.

Previous to entering on a description of the present bridge, and of the works connected therewith, it may be well to give a short history of the ancient structure, which was one of the most interesting of the kind in this country; for, supposing any portion of it to have formed part of the original edifice, it must have possessed claims to antiquity to which few others could pretend, a bridge having been known to exist at this spot during the last seven centuries.

Mr. Burges' History of the Bridge.

The following account is abstracted from a very able communication made by Mr. Alfred Burges to the Antiquarian Society in May, 1836, and published in the Archæologia, vol. xxvii.:—

After adverting to the celebrity of the bridge, the author thus proceeds,—"It is situated in the immediate neighbourhood of London, crossing the river Lea on the high road to Essex, at a distance not exceeding three miles from the metropolis.

"It was erected in the early part of the eleventh century, under the auspices of the pious Matilda, queen-consort of Henry I., to form a more direct and safe communication between the metropolis and the county of Essex than the then existing passage across the river by the dangerous ferry at the Old Ford."

Speaking of the general appearance of the bridge, Mr. Burges says,—"It possessed the character of building that marked the first attempts at bridge-building in this country: such as large piers formed for the support of small and low arched openings, and high battlements for the protection of a roadway of the narrowest possible dimensions."

The line of communication anterior to its erection is then described, and

Great Roman Road into Essex.

some references to the writers on Roman antiquities in this country are made, to justify the author's conclusion, that the Great Roman Road into Essex, crossed the river Lea by means of a ferry at Old Ford, in which direction it continued for many centuries after the Romans had left the island, until the erection of a bridge at Bow.

Early mention of the Road.

"This road is noticed as early as the seventh century, when the body of St. Erkenwald was stopped at Ilford and Stratford by the flood, as it was being conveyed from the abbey of Barking, where he died, for interment in London: this event occurred about A.D. 685, nearly 300 years after the Romans had left Britain."

Building of the First Bridge.

"Morant, in his history of Essex, has particularly noticed these roads, and the circumstances leading to the erection of the bridge, in the following passage:—'The ancient road from this county to London was by Old Ford, that is, through the ford then without a bridge; but that passage being difficult and dangerous, and many persons losing their lives, or being thoroughly wetted, which happened to be the case of Maud, queen consort of Henry I., she turned the road from Old Ford, to the place where it now is, between Stratford, Bow, and West Ham, and caused also the bridges and causeway to be built and made at her own charge.'"

The Bridge mentioned by Stow.

The accurate historian, Stow, also records this event in an interesting passage, which is in substance nearly the same as that already quoted: he further notices the grant of certain manors to the Abbess of Barking for the repairs of the bridge: these lands were afterwards purchased by Gilbert de Mountfichet, he agreeing to keep the bridge and road in repair; "till at length," says Stow, "hee laid the charge upon one Godfrey Prat, allowing him certain loaves of bread daily, that hee should repair the bridge and way; who being helpen by the ayde of travailers, did not only performe the charge, but was also a gainer to himselfe, which thing the abbot perceiving, hee withholdes from him parte of the bread promised: whereupon Godfrey demanded a toll of the way-faring men, and to them that denied he stopped the way, till at length, wearied with toyle, hee neglecteth his charge, whereof came the decay and ruine of the stone bridge and way."

Litigation relative to the Repairs of the Bridge, &c.

The memoir, after referring to other authors, gives some extracts from the records preserved in the Chapter-House at Westminster, furnishing detailed accounts of the proceedings in the Court of King's Bench, in the sixth and eighth years of Edward II., wherein it appears that the Abbot of Stratford, the master of London Bridge, and the master of St. Thomas of Acre, were charged with the repairs, in consequence of their holding the lands originally granted by Matilda to the Abbess of Barking for the support and maintenance of the bridges and causeway.

In Easter Term, 9th Edward II., Godfrey, Abbot of Stratford, acknowledged his liability to keep them in repair as holding these lands, after many years of litigation in consequence of his having compelled persons to pay toll. "From this period," says the author, "to the dissolution of the monastery in the year 1539 (30 Henry VIII.), we do not find any attempt was made to throw off the responsibility: the bridges were, no doubt, during that period properly taken care of, and for some time after they fell into the hands of the Crown required but little repair, as we do not find any complaint being made until the year 1643, when they were again dilapidated."

At this period the holders of the lands originally granted for the repairs of the bridge denied their liability, upon the plea, that, the lands having gone to the Crown at the dissolution of the monastery, they were not therefore liable: a verdict was, however, given for the king. In 1663 the question was again agitated; but the landowners being advised by counsel, withdrew their opposition to the payment. In 1690 attempts were again made to throw off the burthen; but the decision was still in favour of the Crown, the Court being of opinion that all the lands of the former monastery were liable to the charge.

"From that period to the present day the landowners, profiting by the experience of the past, and not forgetting the wholesome advice of the honest lawyers of 1663, have continued the charge of the bridge and causeway at Stratford, for the free and uninterrupted use of the public, as was originally intended by the royal founder."

The great Essex Road.

The great Essex Road, traversing a rich agricultural district, and connecting some of the most influential towns and seaports of the south-eastern district of the kingdom with the metropolis, becomes necessarily a very important land communication; and to render it as perfect as possible several costly improvements have taken place from time to time: perhaps the most important of these alterations has been the reconstruction of Bow Bridge.

Derivation of the Name of the Bridge.

Authors have assigned to the word "Bow" various derivations. Stow says, "The bridge was arched like a bowe, a rare piece of worke, for before that the like had never been seen in England." And again, he says, "Stratford Bridge being the first builded with arches of stone was therefore called Stratford-le-Bow." And Grose observes, that it might have derived its name from the word *beau*, an epithet very likely to have been given to it in those days.

The words "atte Boghe," or "atte Bowe," appear to have been added to the name of the village on the Middlesex side of the river, which is now known by the name of Stratford-le-Bow.

This venerable and time worn structure had, during the lapse of centuries, undergone many alterations; the piers and abutments were probably the only remaining portions of the original edifice; the pointed arches could have formed no part of the bridge of Queen Maud, as circular arches alone were used in those days; the pointed, or Tudor arches, were probably built subsequent to the 15th century.

Alteration in 1741.

The bridge was widened in 1741, by which the original elevation above the pointed arches was, in a great measure, obliterated: as that of the eastern arch remained more entire than the others, a separate elevation of it is given (Plate XIII.)

The piers occupied a large proportion of the waterway, and were placed at an angle to the stream, causing interruption to the current; but, unlike most of the old bridges in England, the piers were not surrounded by starlings: the shallowness of the water may account for this.

Description of Piers and Arches.

Very little attention appears to have been paid to uniformity, the piers being of different lengths and widths, and the arches springing from different levels. The side arches had a strong rib projecting below the soffit at the centre, as was at that period the general practice.

The elevation presented a very patched appearance from the numerous additions; and if any portion of the original structure remained, it was, as before stated, within the casing of the piers and abutments. The bridge was built of Portland and Kentish stone, with some Caen stone for the arches.

Character of the Masonry.

Mr. Burges concludes his account by saying,—"The filling in of the arches, between the face courses and the centre rib, is little better than rubble masonry, the stones of which are both rough and irregular in size, the joints wide, and in several places tiles are employed to wedge the whole together.

"The masonry of the centre arch is of a different character to that already described: the outside face courses are also in two thicknesses, composed of

Kentish ragstone with a few of Caen stone, which no doubt had been saved from a former arch; while the filling in between is entirely built of Kentish stone in regular courses, very neatly put together, and, as already stated, without any rib or other projection."

"The external face of the bridge above the arches is formed of common rubble masonry. The masonry of the additional arching, &c., made to the bridge in 1741, consists principally of Purbeck and Portland stone, built in regular courses, in a firm, substantial manner."

On referring to the drawing of the old bridge (Plate XIII.), it will be seen that the centre arch sprung from a higher level and was less pointed than the side ones, in order most probably to increase the waterway for the barges frequenting the navigation. From the projections in the sides of the piers, whence apparently the former arch sprung at a lower level, it would appear that the centre arch had been originally similar to the side ones: the elevation had likewise evidently been much altered in widening the bridge in 1741, by the addition of angular projections to the piers, and by extending the face of the bridge, on arches springing from these projections, at a higher level than the original ones. The extreme width of the bridge, before this alteration, was 18 feet 3 inches, including the side walls: by the above addition the clear width of the bridge was increased to 20 feet 5 inches at the west, and 22 feet 2 inches at the east end. The span of the side arches was 20 feet 3 inches, and that of the middle arch 22 feet 10 inches, making 63 feet 4 inches waterway; but the Middlesex arch was considered of little use for navigation, and its capabilities of drainage were much reduced by the lateral projection of the wharfs.

Dimensions of Old Bridge.

The soffits of the side arches in the centre were only 3 feet 9 inches above the level of high water at spring-tides, the middle arch being 2 feet higher; and an extraordinary flood has been known to close the side arches. From the above causes, and from the contraction of the waterway by the great thickness of the piers, and their direction not being in a line with the course of the river, the bridge was considered an obstruction to the free navigation, and also dangerous as a highway, on account of its narrowness and the want of footpaths: the wooden platform which had been erected on the north side affording only a partial accommodation to pedestrians.

The bridge being thus considered insufficient, Mr. Walker was requested, by the trustees of the Middlesex and Essex turnpike roads, to estimate the expense of widening the bridge, and also to prepare plans and estimates for a new bridge of one arch. A report was accordingly made in January, 1828, which, after giving a short history of the old bridge, showed that, owing to the causes stated above, it occasioned a greater inconvenience to the navigation than even to the road-trust. Various estimates and plans accompanied this Report, that for a stone-bridge of one arch being the one selected. An Act of Parliament, for taking down the old bridge and erecting the new one, was obtained in 1834; and drawings of the bridge having been prepared by Messrs. Walker and Burges, the tender of Messrs. Curtis of 11,000*l.* founded on the same was accepted, and the preliminary operations were commenced in April, 1835.

New Bridge directed to be Built.

Demolition of the Old Bridge.

The temporary bridges being finished (as described page 349) and opened to the public in July, 1835, the removal of the old bridge was proceeded with, the best of the stones being preserved for the rubble masonry of the new bridge.

Old Roadway visible on Arch-stones.

The arches, during the removal, were supported by proper centering; when the covering was removed and the old roadway laid bare, the track of horses and cattle was clearly defined by a hollow worn into the arch stones, and on each side of it were deep wheel-cuts, on an average 6 to 8 inches deep and 9 inches wide, and distant from each other from centre to centre about 4 feet 6 inches, being worn in places to within 3 or 4 inches of the soffit: the Section (Plate XIII.) illustrates this more clearly. This most probably was the state of the bridge at one of those early periods already mentioned, when, owing to the disputes relative to the maintenance of the structure, it had become dilapidated. The piers were removed down to the bed of the river, and those portions of the abutments which interfered with the new work were taken down.

The New Bridge.

Dimensions of New Bridge.

The new bridge is constructed of Aberdeen granite: it consists of a single elliptical arch of 64 feet span on the square line and 66 feet on the skew, with a versed sine of 13 feet $9\frac{1}{2}$ inches; the high water of ordinary spring tides rises to within 6 feet 9 inches of the crown of the arch, the low water level of the same tides being 7 feet lower. The foundations of the bridge are all laid upon the gravel, the clay substratum being 20 feet below the level of low water.

The width of the bridge between the parapets is 40 feet, consisting of a roadway 30 feet in width, and two paved footpaths of 5 feet each. The abutments on the square line are 42 feet $7\frac{3}{4}$ inches wide, and on the skew 43 feet $10\frac{1}{2}$ inches; their greatest thickness is 15 feet, with wing walls and counter-forts each measuring 5 feet in thickness; the wing walls are 25 feet in length, and the counter-forts 15 feet, formed as shown (Plates XIV. and XV.) The total length of the bridge to the ends of the wing walls is 146 feet, the lengths of the retaining walls varying to suit the adjacent property.

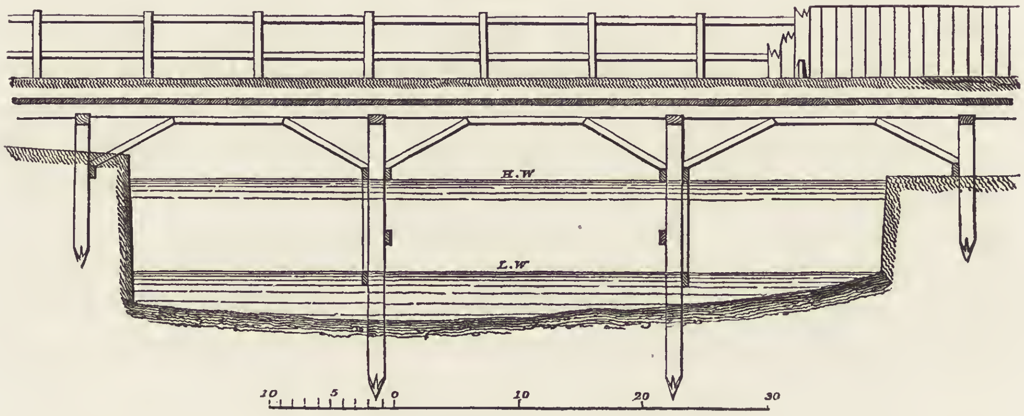
Description of Arch. The arch is composed of 65 voussoirs, varying from 4 feet to 2 feet 6 inches in depth, the latter being the dimensions of the key stone. The ashlar facing runs in horizontal courses, header and stretcher alternately, the former being from 2 feet to 3 feet long, and from 1 foot 3 inches to 1 foot 9 inches on the face; and the latter averaging 3 feet to 4 feet in length, by 1 foot 3 inches in depth: the heights of the courses vary from 22 inches to 12 inches, the upper courses increasing in height towards the centre, so as to range with the cornice.

Temporary Bridges. Before the old bridge was removed, it was necessary to construct temporary bridges, the situations of which are shown in the plan of the abutments and cofferdams (Plate XIV.) The temporary road bridge was supported on piles of whole timbers, with cap-sills 12 inches by 6 inches morticed on to them, and bearers 12 inches square above them to which the planking was spiked. The piles were driven 7 feet deep into the bed of the river; those within the lines of wharfing were from 7 feet to 9 feet below the level of the wharfs. The ends of the cap-sills projected beyond the line of the bridge and carried the posts of the railing, which were let through the planking and tenoned into them, being also secured by a wrought-iron strap round the post: wood spurs were likewise fixed to the outsides of each post, the planking projecting to receive the other end.

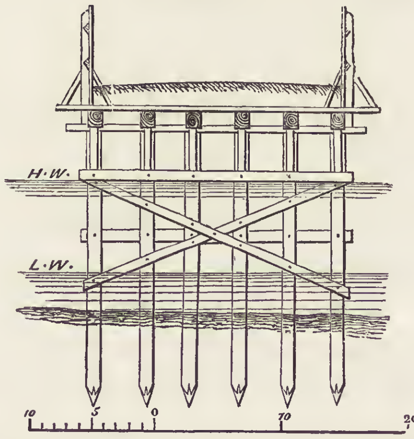
The piles were secured by braces and wales bolted to them. The fences on each side were 6 feet high above the roadway, consisting of planking 1 inch thick nailed to two rails in height, and a plank at the bottom for supporting the material of the roadway. Two recesses were formed in the fences on both sides of the bridge for the protection of foot passengers. The timber foot-bridge formerly added to the old bridge was removed to the north of the site of the new bridge, and being supported on suitable piles and bearers, formed a temporary bridge for pedestrians.

TEMPORARY BRIDGE.

Elevation.



Transverse Section.



Fender-Piles.

Before commencing any of the works connected with the new bridge which might by any means obstruct the navigation of the river, fender-piles of whole timbers, shod with iron, were driven 10 feet apart in front of each abutment, leaving a waterway of 26 feet.

Cofferdams.

The cofferdams for the erection of the new bridge were constructed in front of each abutment, formed to a regular curve, with a chord of 88 feet, and versed sine of 14 feet, abutting on each side against the adjacent wharfing, and projecting about 15 feet beyond the face of the abutments. The dams were formed of main piles 22 feet 6 inches long and 14 inches square, shod with iron and driven 9 feet below the bed of the river, at distances averaging 4 feet 3 inches from centre to centre.

The piles being driven, the waling-pieces were bolted to the outside; each wale consisted of two pieces of plank 13 inches wide by 3½ inches thick, making a waling 7 inches in thickness. A single row of whole timber sheet piles, each 22 feet 6 inches long with iron shoes, was then driven outside to a depth of 9 feet into the bed of the river. The sheet piles were each bolted to the walings, their tops levelled, and the whole well caulked, to render them perfectly water tight. A trench was excavated at the foot of the cofferdam on the outside, and filled with clay, and at the junction with the wharfs on the banks of the river the clay was protected from the current by planks laid on their edges, and supported by short piles; any leakage in the cofferdam was also more fully guarded against by driving piles inside the dams across the angles, with planking laid horizontally against them, and the whole of the intervening space filled in solidly with clay: this piling and planking was further secured by being bolted to the dam.

As the excavation for the abutments proceeded, the cofferdams were further strengthened by part of the excavated material being thrown against the foot of the sheet piling on the inner side; struts, about 45 feet in length and 12 inches square, were placed with one end resting on the ground at the back of the abutments, and the other placed upon cleats against the main piles.

Each dam was furnished with a trunk to which a water-tight valve was fitted for letting off the water; a well was also formed in front of the abutments for the collection of the water, which flowed freely from the land-springs on the Essex side, so that a double-headed pump, worked by twelve men, was kept fully at work draining the cofferdam: on the Middlesex side there was less water.

Foundations.

The dams being closed, the excavation was carried to a depth of 12 inches below the lowest course of footings; the area of the foundations was enclosed by iron-shod sheet piling of elm timber, 10 feet long and 6 inches thick, sawn on the front, planed straight on the edges, and driven vertically into the ground. Great care was taken to drive these piles perfectly straight and close, so as to form, when the tops were levelled, a solid and compact foundation. A wale of sawn timber, 12 inches by 6 inches, was secured outside and bolted to each pile: the whole was secured to the foundations at distances of 6 feet apart by wrought-iron ties, 1½ inch diameter, with jagged ends, let into the upper face of the first course of footings: they were run with lead at one end, and screwed up outside against cast-iron washers let into the waling.

Laying the First Stone. The first stone (containing a plate bearing an inscription, with the names of the Committee of Trustees, &c., and some coins of the realm) was laid on the 12th December, 1835.

Concrete. The concrete was composed of one measure of fresh burnt ground lime, to eight measures of river gravel and sand, mixed dry; water was then added, and the whole mixed together, and in this state thrown in from a height of about 10 feet.

Footings. A bed of this concrete, 12 inches thick, was placed on the site of the foundations, and upon this the lower course of footings was laid: this and the two next courses of footings were formed of Roche Portland stone. The beds and joints were worked square and levelled, and the face and upper surface of the offsets picked fair; the whole was laid in puzzolana mortar, carefully mixed in the proportion of one measure and a half of sand, one of puzzolana, and one of lime; the lime was slaked and mixed with the sand, passed through screens, and afterwards worked to a proper consistency by a horse-mill; a grouting composed of the same materials was poured into the vertical joints. The arch-stones were also completely embedded in the same material.

Puzzolana.

Mortar. The mortar for the interior stone-work, the sides of the abutments, and the upper work, was composed of three measures of sand to one of lime.

Rubble backing. As the courses of the abutments advanced, the backing was brought regularly up to the same level, the best stones from the old bridge being taken for this purpose; the rubble stones composed the mass, and the largest and squarest pieces laid alternately header and stretcher formed the face. The rubble throughout was laid carefully by hand, rammed down, and flushed up solid in mortar. When the stone from the old bridge failed, Kentish ragstone and brickwork were introduced. The best of the excavated material was rammed in front of the wing walls; and at the back, the whole was filled in solid with concrete to the slopes of the excavation.

Centering. After four courses of granite were completed, the arch-stones set at the springings, and the backing advanced to the same level, the first truss of the centering was set up at each side, upon the supporting piles; the work was then advanced to the sixth course upon the first trusses, when the dams were removed: four more courses were then added on the Essex side and two on the Middlesex side, after which the centering was completed: it consisted of eight ribs framed, as shown in Plate XV., bound at the joints by wrought iron straps and keys, and supported on piles 15 feet long, driven 7 feet into the bed of the river. The timber used was Dantzig fir, with the exception of the king-posts and striking wedges, which were of English oak.

The scantlings of the various parts were as follows, viz.:—

Piles	12 inches	×	12 inches
Sills	12 ,,	×	6 ,,
Principal framing .	12 ,,	×	12 ,,
Struts	10 ,,	×	10 ,,
Braces	10 ,,	×	5 ,,
Kings	12 ,,	×	14 ,,

After the centering was framed, the timbers being properly bolted together, and the tressels and cap-sills strongly braced, each rib was accurately shaped to a curve 6 inches below the soffit of the arch, by blocking pieces fixed to the ribs, of the same width, and carefully adjusted to the requisite curve; the covering of fir planking 6 inches thick for carrying the arch stones was then laid and spiked to the ribs. The centering being completed, the work proceeded; the crown of the centering being loaded with the upper arch-stones, to prevent it from yielding to the pressure caused by the laying and setting of the lower arch-stones.

Ashlar Masonry.

The north side of the Middlesex abutment next the washway, from the footings upwards as well as the wing-walls, are faced completely with granite ashlar. The courses of ashlar were flushed up solid in mortar, the stones laid header and stretcher alternately; none of the joints exceeded an eighth of an inch in thickness, the front ones being pointed with cement: care was taken that, when set, the stones should lie on their natural beds, nor was any packing whatever allowed. The ashlar was faced with a draught round the outside, and the space within fine-picked, no stone breaking-joint on the face less than 12 inches.

The Arch.

To form the curve of the arch, and the templates for the arch-stones, the chord and versed sine were laid out on a floor, and the ordinates to the lower and upper angles of the arch-stones calculated and set off; moulds or templates were formed from this diagram, and the stones were worked from them; the moulds for the centering were likewise formed from this curve.

The arch-stones are set parallel to the abutments, consequently the construction is the same as though the arch had been square, the skew or angle of the arch being worked out on the face.

The arch-stones, after being carefully set, were driven close together, and the key stones in closing the arch fitted extremely tight and solidly. The last key stone, containing, in a recess cut in its bed, a bronze medal of Her Majesty Queen Victoria, was laid on the 31st of January, 1838, by John Henry Pelly, Esq.,* the chairman of the Trustees, to whose indefatigable zeal the public are principally indebted for this useful work.

Striking of the Centering.

The arch being keyed and time having been allowed for its settling, the wedges of the centering were eased on the 13th March, 1838, and the next day the centering was completely struck; the level of the arch was tried on the 15th of the same month, both at the north and south side, and it was found to have subsided half an inch from the first easing of the centering; during the erection the structure had settled one inch; in setting out the work 2 inches had been allowed for subsidence, the rise of the arch being made 13 feet 11 inches, for 13 feet 9 inches, the intended rise leaving still half an inch for any future settlement, of which, however, there is not at present any appearance.

Cornice, Parapets, &c.

The arch being completed, and the masonry of the abutments and wing-walls brought up to the proper level, the cornice course was set, the stones averaging 4 feet in length, attached together on the upper bed by joggles of Yorkshire stone 4 inches square by 3 inches long, let flush in. (Plate XV.)

The inclination of the cornice on each side from the centre of the bridge to the finishing pedestals is 12 inches, which is the same as that of the footpaths.

The cornice courses being set, the parapets, which, including the plinth, are in single stones, were next constructed: their height is 5 feet 3 inches, by 12 inches thick, with a projection of 2 inches outside the base, 18 inches in height, forming an outer plinth; the inner face being flush from the foot pavement upwards, thereby increasing the width of the foot ways.

The parapet stones average from 3 to 4 feet in length: they are secured at the joints and at bottom, to the cornice, by joggles 6 inches long, 4 inches square in the middle, and tapering at the ends: each stone was set up in its place by means of an iron clamp of a horse-shoe shape, which, embracing the upper part of the stone and being secured to it by a screw, enabled it to be lifted to its position by a block tackle. The face of the stone was protected from injury by a piece of lead placed beneath the point of the screw.

* Now Sir John Henry Pelly, Bart.

By this means the stones were accurately bedded before any mortar was used; any inequality in the bed or otherwise was rectified, and they were then set in puzzolana mortar: a channel having been cut in the joints of the stones from the top to the bottom, leading to the joggle holes, liquid grouting was poured in until it filled up all the interstices. The pedestals at the ends of the wing-walls were set and joggled in like manner to the parapet.

Concrete Foundation for the Roadway.

The crown of the arch and tops of the abutments were covered with concrete 1 foot 6 inches thick, composed of the same materials as that used for the foundations; on this bed were laid the foot-pavements of Aberdeen granite, in stones of 4 feet 4 inches long, and 6 inches thick, averaging 2 feet to 3 feet in breadth, bounded by curb stones 8 inches wide, outside of which three rows of pitching-stones were placed.

The Roadway.

The roadway was formed of screened gravel, to the depth of 6 inches over the crown of the arch, bedding immediately upon the concrete substratum, and to a like depth over the abutments. It ranges with the cornice in its longitudinal direction, and falls 3 inches from the centre to the curb stone on each side.

The Approaches.

The approaches were formed of a bed of gravel, over which a 6-inch dressing of screened gravel was laid, the whole being graduated to an inclination of one in thirty. On the Middlesex side, north and south, and on the Essex side to the south, brick retaining walls capped with granite were built, and the footpaths of the approaches were protected by granite curbs. The bridge, being completed, was opened to the public on the 14th February, 1839.

The engineers intended this bridge to have been entirely constructed of Aberdeen granite, but the difficulty experienced in procuring a sufficient supply, without delaying the work, rendered it advisable to permit the contractors to construct the north parapet of Penryn granite, and to substitute Herm and Penryn stone for three of the arch-stones; it is nevertheless perhaps the most complete specimen of masonry, in Aberdeen granite, in the neighbourhood of London.

JOHN B. REDMAN.

Limehouse, May, 1839.

XIV.—*Observations on the Effects produced by Wind on the Suspension Bridge over the Menai Strait, more especially as relates to the Injuries sustained by the Roadways during the Storm of January,* 1839; *together with brief Notices of various Suggestions for Repairing the Structure.*

By W. A. PROVIS, M. Inst. C.E.

Read February 16, 1841.

Many erroneous and contradictory reports having been circulated as to the injurious effects of winds on the Menai Bridge, I have thought it right to record such of the principal facts relating to the matter as have come within my knowledge; and believing that they will not be uninteresting, I am induced to submit them to the consideration of the Institution of Civil Engineers.

Movement of the Chains.

In the months of December, 1825, and January, 1826, when the bridge was nearly completed, several severe gales occurred in succession, and considerable motion was observed both in the main chains and the platform of the carriage ways and footpath. At that time the four lines of chains were not transversely connected together, nor were the roadways finished; but as it appeared that the chains were not always acted upon by the wind simultaneously, nor with equal intensity, it was believed that by attaching them to each other, so as to retain them in parallel planes, and thus check the tendency to motion of any one of the lines by the *vis inertiæ* of those which were not similarly influenced, the total amount of movement would be diminished or neutralized.

First Injury by Wind.

Though the parapet railing and some unimportant parts had not been then completed, the bridge was opened to the public on the 30th January, 1826. On the 6th February following there was a heavy gale, which blew some of the yet unfixed parapet into the strait, and caused so much motion in the chains and roadways, as to break several of the vertical suspending rods, and many of the iron bearers or joists which supported the platform of the roadways.

Construction of Bearers.

The bearers or joists were each composed of four horizontal bars, two of them 12 feet long, and the other two 16 feet long each.

The bridge being 28 feet wide, a bar of 12 feet long, with one of 16 feet, made up the total width; and these two being connected with the other two similar bars, having that of 12 feet long placed alongside that previously laid of 16 feet, and the second 16 feet bar alongside the first of 12 feet, the two longer bars thereby overlapped each other 4 feet (or the width of the footpath) in the middle of the bridge. The eyes at the lower ends of the four vertical suspending rods, which ranged in the transverse direction of the bridge at the respective distances of 12, 4 and 12 feet from each other, were passed between the two pairs of horizontal bars and bolted through them. Beneath each of the 12 feet lengths a tie-rod with a king-post was introduced, to prevent the bars from bending between their points of suspension. All these were screwed together so as to become in effect one nearly inflexible joist suspended at four different points of its length.

Undulation.

The motion which had been anticipated was that of simple undulation flowing in waves at right angles to the length of the bridge; and had this been the only motion, the bearers, it is apprehended, would not have been injured by the gale. They would have been equally raised or depressed throughout their lengths as the wave rolled forward, and been subjected to no strain which they were not fully competent to resist.

The movement of this undulatory wave, however, was oblique with the lines of the bearers and their suspending rods as well as with the general direction of the bridge. In other words, when the summit of the wave was at a given point on the windward side of the bridge, it was not opposite this point on the leeward side, but, in relation to the flow of the wave, considerably behind it; the motion appearing to be generated on the windward side, and by the time it had crossed to the leeward it had also moved forward along that on which it had commenced.

Consequences of Undulation.

The tendency of this undulation was to bend every bearer into a form produced by the oblique intersection of a vertical plane with the surface of the moving wave, and this form necessarily varied with every change in the position of the wave.

To this cause must be attributed the failure of those bearers which were broken by the gale. They had been constructed for the purpose of resisting the species of strain to which it was expected they would be exposed, but they were deficient in strength where that strain was greatest. They were uniformly fractured at the eyes of the 16 feet bars where they were suspended from the rods on each side of the footpath, and at those parts of the bridge which were about midway between its centre and the supporting pyramids.

Amount of Motion.

The motion was observed to be greatest about half way between the pyramids and the centre of the bridge. The wave increased in its progress from the pyramid till it attained its maximum altitude near the first quarter, and at the same instant the extreme depression was near the third quarter. The wave then gradually diminished to the centre of the bridge and afterwards increased to the third quarter, when it attained its greatest height at the same time that the first quarter was most depressed. The platform and the main chains were equally subjected to this undulatory motion: the latter also oscillated slightly.

The Platform.

The bearers or joists supported the double tier of planks which constituted the principal part of the platform. Both tiers were placed longitudinally, as giving most strength for supporting passing loads. They were considered to be sufficiently connected transversely by the iron joists upon which they rested.

Cause of the failure of Suspending rods.

The planks forming the roadways were bolted to the bearers, and notched to fit closely around the lower ends of the vertical suspending rods, which were thereby held almost immovably in the platform.

During the undulations to which the bridge was exposed, the surface of the roadway continually changed its position relatively to the lines of the suspending rods; the latter preserving their tendency to hang vertically as when in a state of rest, whilst the platform changed its relative angle with every variation of the moving wave. This bent the suspending rods backwards and forwards at the parts where they were held fast at the surface of the roadways, and there, in many instances, wrenched them asunder.

The failure of these suspending rods and bearers was evidently to be attributed to the character as much as to the amount of motion which had existed during the gale. It was also obvious that, owing to the peculiar nature of this motion not having been anticipated, some of the means which had been adopted to give rigidity to the platform had not possessed sufficient strength, whilst others had acted prejudicially.

Such were the principal injuries caused by the gale; and as the bridge had been opened a week for public intercourse, it was necessary to apply immediate remedies.

Repairs.

There were a few spare suspending rods on the spot, which were immediately used to replace those which had been broken or damaged. The planks of the platform were cut away for about an inch round all the suspending rods, so as to give them room to play where they had previously been held firmly.

Beneath each place of fracture of the roadway bearers an iron stirrup was passed, having a broad sole at the bottom to support the broken ends of the horizontal bars, and a pair of eyes at the upper extremities by which it was suspended from the vertical rod.

Stiffening Planks.

Between each two bearers an oak plank, about 15 feet long, was introduced and bolted to the underside of the platform, thereby tying it together in its transverse direction, and giving it a degree of stiffness combined with elasticity which it had not previously possessed.

Main-chains connected.

The four lines of main chains were also at the same time connected by placing cast iron tubes horizontally and transversely between them, and tying the whole together by wrought iron bolts passed through the tubes and the joint plates of the chains.

When the repairs were completed, the beneficial results of the recent additions were evident. Storms occasionally broke a suspending rod or a roadway bar, but these circumstances rarely occurred, and the injuries were repaired without difficulty or delay.

Storm of 1836.

On the 23rd January, 1836, (ten years after the bridge was first opened to the public,) an unusually severe gale of wind from the W. S. W. caused the chains and platform to undulate violently, and broke some of the roadway bearers with six of the suspending rods. There can be no doubt that ten years' continued friction, combined with the ordinary shrinking of the timber, had considerably affected the original rigidity of the platform, so that during the gale last referred to there was a greater degree of irregular undulation than had previously been observed. It is not easy to define correctly the amount of rise and fall of the roadways, but Henry Fisher, the bridge keeper, who assisted as a carpenter in the original construction, had lived ever since at the Anglesea end of the bridge, and watched every storm by which it had been assailed, stated that there was little less than 16 feet between the extreme of rise and the lowest point of depression.

Oscillation of the Chains.

There was also considerable oscillation of the main chains between the pyramids and the centre of the bridge—not to an extent that could have produced a great proportion of the observed rise and fall of the roadways, though there is no doubt that it was one of the aiding causes.

Platform not fixed at the ends.

The extremities of the suspended part of the platform were not attached to the two pyramids, but rested upon the masonry, the wheel guides and part of the planking being constructed so as to slide under the arches of the carriage ways, in order to prevent the platform being easily blown out of its place. The gale of January 23, however, broke the wheel guides and planks at the Anglesea pyramid, and forced that end of the platform sideways about 15 inches from its true position. By cutting away the ends of the planks which were jammed against the masonry of the pyramid, and then applying some powerful hauling tackle, the platform was restored to its proper situation.

Provis and Rhodes' Survey.

In consequence of the injurious effects of this gale, and likewise of various statements which had been circulated respecting the bridge, the Commissioners of Her Majesty's Woods directed me, in conjunction with Mr. Rhodes (who had originally superintended the fixing of the iron and timber work of the bridge), to examine the whole structure very carefully, and to report to the Board our observations on its state, as well as on any repairs or additional works which might appear necessary for increasing its strength or security.

Report upon the Bridge.

The result of our examination was satisfactory: the whole of the masonry, the main chains, their fastenings to the rock, the rollers and other iron work on the supporting pyramids, and all the principal parts of the bridge, were as perfect as when first constructed. Wherever a suspending rod had been broken it had been replaced by a new one, and the stirrups which had been applied to carry the damaged bearers of the platform had answered the intended purpose.

We were well aware that the suspended portion of the bridge possessed an amount of flexibility, as well as a susceptibility of motion which it was very desirable should be reduced: we therefore stated it to be our concurrent opinion, "that a greater degree of rigidity should be given to the roadways, so that they should not bend so easily under vertical pressure."

The bridge, however, remained in the state which has been described, from the period when our examination was made, until the memorable hurricane of the 6th and 7th January, 1839.

Storm of January, 1839.

The storm, according to the account of those who observed it at the bridge, commenced on the evening of the 6th with a strong but unsteady wind veering a few points on both sides of S. W. The gale increased during the night so much, that between 2 and 4 o'clock of the following morning it became a hurricane, and all approach to the suspended part of the bridge was impracticable. The fury of the storm having somewhat abated after 4 o'clock (A.M.), the bridge keeper made an attempt to examine the chains and roadways. It was with difficulty he could make his way to the platform, and it was only by watching the lulls of the wind and holding fast by the iron-work that he was enabled to reach the suspended part of the bridge. The general darkness was too great and the tempest too violent to allow him to make any close or accurate observation, but he ascertained during occasional gleams of moonlight that the roadways were broken through, and that it was necessary to take immediate measures for preventing any attempt to cross the bridge.

He returned and closed the approach at the Anglesea end; then procuring a boat, he reached the opposite side of the Strait just before the arrival of the down mail from London. The guard and bags were conveyed across the Strait in the boat, and information of what had happened was forwarded to Mr. John Provis at Holyhead, under whose care the bridge had been placed after it was first opened to the public.

Effects of the Storm.

When daylight arrived the general injury was evident. Both carriage-ways had been partially destroyed and were rendered impassable; the footpath between the carriage-ways however was but slightly injured, and the bridge could still be traversed on this central line.

The weather continued too tempestuous to admit of men working on the bridge, and the day was spent in making preparations for a temporary repair of the carriage-ways as soon as the wind should subside.

Details of the Injuries.

The plan and elevation given in Plate XVI. explain the nature of the injuries sustained by the bridge: they exhibit, as well as the small scale of the drawings will permit, the several fractures of the roadways and the general appearance of the suspended part immediately after the storm. The elevation is represented as it would appear to a person looking to the north east or towards Beaumaris.

The condition of the two carriage-ways was as follows:—

1st. *The North East Carriage-way.*

a. to *b.*, length 80 feet.—Very slightly injured.

b. to *c.*, „ 55 feet.—One-half of the outer suspending rods broken.

c. to *d.*, „ 15 feet.—The suspending rods on both sides torn asunder, the roadway broken through at the line *d*, and the end of the platform at *e* hanging down about 6 feet.

d. to *f.*, length 175 feet.—The whole of the suspending rods on the inner side broken, and with the exception of 6 rods near the N.W. end and 7 rods near the S.E. end, all those on the outer side were also broken, the timber platform hanging down suspended by the rods at its two corners.

f. to *g.*, „ 85 feet.—All the suspending rods on the outer side broken, on the inner side all broken except 4 near the N.W. end, the north corner of the platform hanging perpendicularly down.

g. to *h.*, „ 55 feet.—All the suspending rods on the inner side broken, and the outer side suspended only by 4 rods.

h. to *i.*, „ 85 feet.—Not injured.

2ndly. *The South West Carriage-way.*

k. to *l.*, length 123 feet.—Not damaged.

l. to *m.*, „ 40 feet.—All the outer suspending rods broken, the platform broken across at *m*, and the corner *n* hanging down about 6 feet.

m. to *o.*, „ 267 feet.—Scarcely injured.

o. to *p.*, „ 30 feet.—All the outer suspending rods broken, and the timber platform at that edge sunk about 6 inches in the middle of its length.

p. to *q.*, „ 80 feet.—Not injured.

Number of Rods broken.

From the foregoing statement it appears that out of a total number of 444 suspending rods rather more than one third had been torn asunder, that the timber work of the S.W. carriage-way had been broken through transversely at one place, and that of the N.E. carriage-way in two places; and that of the latter there was one connected piece of 175 feet in length and 12 feet in width hanging down, and swinging in the air.

Iron Joists broken.

In those parts where the suspending rods had been torn asunder and the platform broken down, the iron joists or bearers had also failed; and much of the parapet railing had been blown into the Strait.

The Ties, &c., destroyed.

The ties and tubes before described, by which the main chains were kept in parallel planes, were destroyed.

Main-chains.

The main chains had sustained the shock admirably; three only of the common bars and one of the adjusting bars having been damaged. These were between the two supporting pyramids, and taking into calculation the total number of bars betwixt those masses of masonry, the proportion they bore to the whole was less than one in a thousand. The injured bars were cracked at the eyes.

Screw bolts.

Two or three of the screw bolts which connected the bars of the main chains into links had their heads struck off;—a fact which may give some idea of the tremendous violence of the storm: for it was quite clear that though the chains were suspended in parallel lines (those on either side of each carriage-way being 12 feet apart) they had, after the breaking of the transverse ties and tubes, been thrown so violently against each other as to cause deep indentations in the iron and to break off the heads of the bolts, the shanks of which were 3 inches in diameter.

Movement of the Platform.

It was also evident from distinct marks on the masonry of the Anglesea pyramid, that after the fracture of the wheel guides, &c., which passed under the roadway arches, the platform had oscillated considerably in its transverse direction, the marks extending at least 3 feet on the leeward side of the platform.

Carriage-way restored.

The S.W. carriage-way having been least injured it was determined on the morning of the 8th to employ all the workmen on that side, so as to render it passable with the least possible delay. The suspending rods which had been broken, were replaced by new ones as far as the spare stock at the bridge would permit, and when these were exhausted chains and ropes were substituted. That portion of the timber platform which had been broken down was lifted again into its place by means of pulley blocks, suspended from the main chains and attached to the most depressed corner of the platform. The broken platform was thus raised to its original position, where it was temporarily fastened by means which have been already described.

Pending these operations I had been apprised of the injuries which the bridge had sustained, and had been directed by the Commissioners of Her Majesty's Woods and Forests to examine the bridge very carefully, and report to the Board my observations upon the injuries sustained, and to suggest the best method of repairing them.

Passage restored.

On arriving at the bridge on the 11th January I found that, through the exertions of Mr. John Provis and Henry Fisher (the resident engineer and the bridge keeper), the S.W. carriage-way had been so far restored, by the means already described, as to allow the mail to pass over the bridge as usual. From that time the public had the uninterrupted use of one carriage-way until the 21st January, when the temporary repair of the N.E. side of the platform having also been completed, the whole of the bridge was again opened for general use.

It has thus been shown that though the damage done to the suspending rods and platform was considerable, foot passengers were not prevented from crossing the bridge at any time, and carriages and horses for only five days.

Proposed Repairs.

In the Report which I submitted to the Commissioners of Woods and Forests it was proposed to effect the following alterations in the construction of the roadways, which were suggested by the experience of thirteen years' observation.

First.—That the new bearers or joists of the platform should be composed of three several lengths, with joints at each point of suspension so as to permit of an action in the transverse direction of the bridge without incurring the risk of the joists being broken, as had occurred with the original inflexible bearers.

Secondly.—To counteract the flexibility so imparted by introducing a complete course of transverse planking between the two courses of longitudinal planks, thus giving a greater degree of transverse rigidity than before with a material possessing more elasticity than iron, and consequently not so liable to fracture.

Thirdly.—To introduce a joint in the suspending rods at the upper surface of the platform, at right angles to that which connected the lower ends of the rods with the joists, so as to prevent their being broken.

Fourthly.—To render the whole platform more rigid in its longitudinal direction by placing two lines of beams along the upper and lower surfaces, bolted through each other and the three tiers of planks.

Fifthly.—To renew the transverse ties and hollow distance pieces which connected together the four lines of main chains.

Restoration ordered.

As other modes of restoration had been suggested, and were subsequently proposed both to the Lords of the Treasury and the Commissioners of Her Majesty's Woods and Forests, some time was necessarily occupied in giving to the subject that mature consideration to which the various schemes were entitled. I was ultimately directed to carry into execution the renewal of the roadways and other parts of the bridge in conformity with my Report and plans.

The works have since been satisfactorily completed, and as a detailed account of the difference in the construction of the old and new platform, with reasons for the several deviations from the original plan, are presented to the Institution by Mr. T. J. Maude, the resident engineer charged with the superintendence of the late restorations, his communication* may be referred to for further particulars respecting this part of the subject.

Other Plans for the Repairs.

There now only remains to describe briefly some of the other plans which were submitted at that period for restoring and securing the roadways.

Mr. Comins' Plan.

Mr. N. P. Comins proposed—"to connect the middle of the bridge by means of chains with the pier on either side midway between the water and the bridge, and to fix chains parallel with these till they approached the apices of the angles formed by the bridge and the piers. The chains should be connected laterally and with perpendicular bars as are the chains above the bridge, to which they should in every respect be similar."

The objections to this gentleman's plan were that his chains, &c., would interfere most injuriously with the free navigation of the Strait, which it is as important to maintain as to preserve a safe passage over the bridge; and that such interference would be a departure from the pledge given to the public when the Bill for sanctioning the construction of the bridge was before Parliament, as well as a breach of the provisions of the Act which was subsequently passed.

Henry Fisher's Plan.

Another mode of tying down the bridge was suggested by Henry Fisher. His plan was to fix thirteen oak beams transversely beneath the platform at unequal distances, diminishing from the pyramids towards the centre of the bridge. Then from the masonry of either pyramid and on a level with the roadway he proposed to carry a pair of iron rods diagonally to a point of the main chains perpendicularly over the first oak beam, to return a pair of rods from the same point of the main chains down to the second oak beam; then carry others up to the chains over the third and down again to the fourth beams, and so on over the whole front of the bridge. He then proposed to cross these rods by others commencing at the top of the pyramid and passing

* See page 371.

down to the first beam, again up to the chains and down to the third beam, and so on throughout the length of the platform. By proceeding thus at each of the four lines of main chains he obtained four series of reticulated ties or braces between them and the platform, connected at both ends of the suspended part of the bridge with the solid masonry of the pyramids. There could be no doubt that this plan would have reduced the motion of the main chains and platform, but it appeared to me that it would not entirely prevent it, and would involve, in the diminished movement, a complexity of action which it was very desirable to avoid. Besides the diagonal braces would have spoiled the general symmetry of the bridge, and have caused such an amount of friction against the vertical suspending rods as might ultimately have cut them through.

Tying the Platform from below.

In reference to tying down the platform from below, it was observed by Mr. John Scott Russell that the points at which the ties should be attached to the platform should be determined by those laws which govern the vibrations of an elastic cord in a state of tension. Those laws might apply if the whole suspended part of the bridge acted simply as one string; but it is composed of many, of different materials, sizes, and degrees of tension, bound together in a variety of ways. It therefore seems doubtful (though the subject is well worthy of investigation) whether the principle admits of correct application under the complicated combinations of a suspension bridge.

Colonel Pasley's opinion.

In the communication which was made to the Institution by Colonel Pasley,* as well as in that which he laid before the Commissioners of Her Majesty's Woods, it has been assumed—"that all the injuries that have ever occurred to the roadways of suspension bridges must have been caused by the violent action of the wind from below." In this opinion I do not fully concur, and I shall state some of the reasons which induce me to think that the conclusion is erroneous.

The action of Wind.

Supposing a current of wind were to rush down from a high ridge of ground to the surface of a river or valley, it would rebound from the place on which it first impinged, but with a force less than that of the original descending current. If a suspension bridge were placed across the valley beyond the spot where the current first struck its surface, but still within the influence of the rebound, the platform of the bridge would be acted upon most powerfully from below. But if the bridge were situated in the direct line of the

* Trans. Inst. C. E., vol. iii. part 3, p. 219.

descending current, the platform would be acted upon with the greatest force from above. In the first case, therefore, the tendency would be to lift the platform, and in the second to depress it.

Again, supposing that there existed no natural impediments to the direct course of a current of wind, it would probably move forward nearly parallel with the surface of the water. If a suspension bridge obstructed this current, the wind so impeded would escape, partly over and partly under the bridge, but would possess no greater tendency to lift the platform than would result from the excess of the force arising from the compression of the air between the platform and the water's surface over that of the air above the platform; and if the areas of the impeding fronts of two bridges were similar, the difference in the amount of pressure would be greatest where the space between the platform and the surface of the water was least; or, in other words, the lifting tendency would be greatest when the platform was nearest to the water.

Conway Bridge not affected by Storms.

Experience has shown that suspension bridges which hang low are not acted upon by winds so violently as those of greater altitude, even where the bridges are constructed upon precisely similar principles. Conway Bridge is 327 feet between the centres of the supporting towers, and 15 feet above the level of high water: its chains, side railing, joists, floors, &c. were all constructed either from the same patterns or on the same principles as those of the Menai Bridge. Now Conway Bridge is not perceptibly moved by the wind, whilst that over the Menai is violently agitated, and it may therefore be inferred that if the disturbing force were uniformly most powerful from below, the former bridge would, in proportion to its size, be subjected to greater undulation than the latter: the reverse, however, is the fact.

Conway and Hammersmith Bridges compared.

Conway and Hammersmith Bridges are of nearly equal spans and heights above the water; but the construction of their platforms and the connections with the main chains are different. Conway Bridge is without trussed longitudinal frames, and the means of resisting undulation are the same as those of the Menai Bridge. The main chains of Hammersmith Bridge are in contact with the platform, and the latter has four lines of trussed longitudinal frames fixed vertically on its surface. Now though so differently constructed, neither Conway nor Hammersmith Bridges are affected by winds, and therefore, instead of attributing the stability of Hammersmith Bridge (as is done by Colonel Pasley) entirely to its trussed framings, the steadiness of this, as well as of Conway Bridge, must be considered to be consequent upon their low and sheltered situations as well as to the diminished scale of these structures compared with that of the bridge over the Menai Strait.

Roof at Chatham destroyed.

The case which Colonel Pasley has alluded to of the roof being blown off one of the sheds in Chatham dockyard may very probably have been owing to the rebound of the wind from the surface of the ground, or it may have been caused by the wind having freer access on one side of the shed than it had means of escape on the other; but it by no means establishes as a fact that suspension bridges are always acted upon most violently from below.

Oscillation of the Main-chains, &c.

It has been previously observed that, in addition to the vertical undulation, both the platform and chains of the Menai Bridge were subject at times to considerable oscillation. In the hurricane of 1839 the main chains, which are suspended 12 feet apart, were, after the destruction of the transverse tubes and ties, thrown violently against each other. In 1836, the Anglesea end of the platform was blown 15 inches out of its proper position; and in 1839 the same end of the platform oscillated at least 3 feet from the vertical plane of suspension. All these facts lead to the conclusion that winds act strongly and prejudicially upon the fronts of suspension bridges as well as upon the horizontal surfaces of their platforms; and further, that the effect of winds is modified and varied by the shape of the country and the local circumstances connected with each individual bridge.

Colonel Pasley's proposed alterations to the Menai Bridge.

The remedies which Colonel Pasley proposed to apply at the Menai Bridge were:—

First.—" That a course of planking should be laid transversely over the existing roadway, which consisted of two courses of planking, both laid longitudinally."

Secondly.—" That two longitudinal lines of strong trussed railing, on the same principle as those of the Hammersmith Bridge, should be substituted in lieu of the former light network."

And thirdly.—" That two more lines of trusses, exactly similar to the former, and parallel to them, should be introduced in the intervals between the footpath in the centre and the carriage-ways on the sides of the bridge."

Though dissenting from Colonel Pasley's opinion as to the universal cause of injury to suspension bridges, I agree with him as regards the propriety of giving increased longitudinal rigidity to their platforms when they undulate to any considerable extent. It has been already stated that I advised this to be done at the Menai Bridge in the spring of 1836, and again after the hurricane of 1839, before I had an opportunity of knowing Colonel Pasley's sentiments on the subject. There were these differences, however, in the details of our respective propositions:—The Colonel recommended the addition of a third course of planks laid transversely *upon* the two longitudinal courses, and also of four lines of trussed longitudinal framings;—my plan was to place the additional course of planks *between* the two longitudinal courses, and to give the requisite rigidity by two lines of longitudinal beams bolted together, instead of by trussed framings. My reasons for preferring beams to frames were, the facility with which the former could be increased in number if the degree of stiffness first obtained was not sufficient, and the difficulty which I believed would be experienced in keeping trussed frames at all times firm and in their true vertical positions.

W. A. PROVIS.

24, Abingdon Street, June, 1840.

XV.—*Account of the Alterations made in the Structure of the Menai Bridge, during the Repairs in consequence of the Damage it received from the Gale of January* 7, 1839.

By THOMAS JAMES MAUDE, Grad. Inst. C. E.

Read January 12, 1841.

The roadway of the Menai Bridge having sustained considerable injury during the hurricane of the 7th of January, 1839, it was considered necessary, after a minute examination of the structure, to replace the damaged platform by a new one. Instructions were accordingly given to Mr. Provis, C. E., by the Commissioners of Her Majesty's Woods and Works, directing him to carry into effect the re-construction of the platform, in conformity with the plans and estimates which he had submitted to the Board, and the author was subsequently appointed to superintend the execution of the works.

Instructions for Repairing the Platform.

Whilst the restoration of the platform was in progress, some modifications in its construction were adopted, which were suggested by the observation of the defects of the original roadway, and which the effects of the recent storm had rendered still more obvious. The nature and extent of these alterations are shown by the sections of the platform in its original state and after the restoration (Plate XVII.), and may be thus briefly described:—

Alteration of the original system of Platform.

First.—The roadway bearers were considerably strengthened, and an additional joint was introduced at the points of their suspension from the two middle chains, thus enabling the motion of the carriage ways and of the footpath to be independent of each other.

The reasons for this alteration are shown by Mr. Provis in his account of the Menai Bridge. After noticing the effects of a heavy gale, which occurred in February, 1826, soon after the bridge was opened, and describing the details of the construction of the roadway bearing-bars, Mr. Provis proceeds thus:—"Each long bar was thereby fixed at three points to the vertical suspending rods, and it was considered that this mode of fastening would tend very considerably to prevent any twisting of the roadway. It had that effect, but as it has been before observed that

Cause of Fracture of Roadway Bearing-Bars.

motion was principally communicated to the roadway by the vibration of the windward chain, that end of the roadway bar which was suspended from it was lifted up, and the other two points of attachment remaining nearly stationary, the bar became a lever with its fulcrum at the middle point of attachment, and the resistance to be overcome being greater than the strength of the bar, it consequently broke at its weakest point or fulcrum. Nearly fifty of the long bars were thus broken principally about half way between the pyramids and the middle of the bridge, those parts having been subjected to the greatest motion."

Mode of Repairing the Roadway Bars.

"To secure the fractured bars an iron stirrup was attached to the lower end of each of the vertical suspending rods, in the same manner as the roadway bars had been fastened, and a hole being drilled through each end of the stirrup and the corresponding ends of the fractured bars, they were bolted together and made perfectly secure."

New Form of Roadway Bars.

In order to prevent the recurrence of such accidents it was considered advisable, in re-constructing the platform, to adopt the new form of roadway bars shown in Plate XVII., by which arrangement each bar, being suspended at two points only, has perfect liberty to play, should the bridge be subjected to violent motion in any future storm. As a further security the depth of the bars was augmented by half an inch; and the strength round the eyes by which they were attached to the suspension rods was considerably increased, it having been found that the old bars were invariably broken across the eye.

Additional Joints in the Suspension Rods.

The additional joint introduced into each of the suspension rods near the floor of the bridge is the next modification to be noticed. It was found that the violent motion of the bridge caused by the storm of January, 1839, fractured many of the suspension rods at the surface of the platform, the planking through which they passed, acting as a fulcrum, against which they were broken in such numbers that a great portion of the platform was entirely torn from its fastenings on one side, and hung down flapping in the gale, only supported by one line of suspension rods. The joint now introduced immediately above the surface of the platform, will in future allow free play to the suspension rods at this point, and thus prevent their fracture. The undue motion of the bridge, as well lateral as longitudinal, is now guarded against by the joints being placed so as to work in an inverse direction to the play of the roadway bar on the one hand,

and to that of the rod immediately above the roadway on the other. Additional strength is given to the short suspension rod thus introduced, it being made $1\frac{1}{4}$ inch square, whilst the other rods are only an inch.

Repairs to the Platform.

The increased thickness given to the platform itself by the addition of a course of three-inch planking laid in a transverse direction is next to be considered. The planks are laid close together across the entire breadth of the bridge, being placed between the two longitudinal courses, which are of the same thickness as before. The transverse course of planking serves to bind the platform together in the direction of its breadth in the most perfect manner, accomplishing this object far more effectually than was done by the insulated oak planks, which were introduced between the roadway bars beneath the platform after the fracture of the latter in 1826. It also assists materially in imparting longitudinal rigidity to the platform, the three courses being firmly bolted together throughout the whole length of the bridge, at intervals of every $2\frac{1}{2}$ feet in each breadth of plank in the upper longitudinal course. It may be observed that the two courses of planking in the original roadway were only spiked together, which mode of fastening afforded much less firmness and solidity than the present compact bolting. The lower tier of planking is bolted to the roadway bars in the same manner as was formerly done. The oak-planks underneath the platform are now removed.

Method of fastening the Planking and strengthening it.

As a means of giving additional stiffness to the platform, and of checking undulation in a longitudinal direction, beams are bolted to the under side of each carriage road, as is represented in the section of the new platform. Each beam consists of two pieces of Memel fir 13 inches in depth by $4\frac{1}{4}$ in thickness, one on each side of the king-posts of the trussed roadway bearers; between these pieces an inch plank is introduced, which fills the intervals between the king-posts; and the top of the beams being notched up 1 inch on to the roadway bars, the remaining space to the lower side of the platform is filled up by a 3-inch plank, indicated in the section by dotted lines. The two lowest pieces are bolted together by $\frac{5}{8}$ inch bolts at intervals of $2\frac{1}{2}$ feet, and the whole is then secured to the platform by $\frac{3}{4}$ inch bolts, also at intervals of $2\frac{1}{2}$ feet, passing through the three courses of planking and the beams, and screwed up on the lower side of the latter. The two pieces forming the lower portion of these beams are so arranged that the joints on one side nearly coincide with the centres of the pieces on the other. The pieces are about 40 feet in length;

and the joints are further strengthened by a 3-inch plank about 6 feet in length, bolted on the side of the beam, and equally overlapping the joints: these pieces, to avoid confusion, are omitted in the section.

Alteration of the Wheel-Guides.

In order to gain a still greater degree of stiffness, the wheel-guides are increased in size; their height is 16 inches, and their breadth at the base 14 inches. These wheel-guides are composed of three distinct portions; of the two lower parts the one next the carriage-track is of African oak, which on account of its superior hardness is well calculated to resist the wear and tear arising from carriages, &c.: the outer lower portion, as also the cap or upper piece, is of Memel fir. The two lower pieces are bolted together with $\frac{5}{8}$ inch bolts at intervals of $2\frac{1}{2}$ feet: the caps are fastened to these, and the whole are fixed to the roadway by $\frac{3}{4}$ inch bolts, passing through to the bottom of the platform at the same distance from each other.

The lengths of the various beams, planks, and other timbers introduced throughout the whole structure, are so disposed that they break joint as regularly as possible. By means of the stiffening beams beneath the platform and of the wheel-guides above it, a total depth of 3 feet 4 inches from the top of the wheel-guides to the under-side of the beams is gained as a resisting power to the undulatory motion of the platform. In the original construction the depth, from the under-side of the floor to the top of the wheel-guides, was only about 1 foot 3 inches; and the action of the latter in resisting motion was very imperfect, in consequence of the short lengths of the beams which merely abutted at the joints.

Having thus endeavoured to describe the alterations which have been made in the construction of the platform, it remains to be observed that the preservation of that simplicity of construction, which is so striking a feature in the original design of the bridge, was one of the principal objects always kept in view in effecting the alterations. In none of the improvements now introduced has that simplicity been interfered with. So that now, as formerly, should any accident occur to any part of the bridge, that part can be repaired or replaced without disturbing the other parts of the structure, and at the least possible expense of time or labour.

Original Plan of Bridge adhered to.

Weight of Timber and Iron-work.

The weight of the additional timber and iron-work recently introduced into the bridge is about 130 tons, still leaving the weight of the suspended part of the bridge far below that which the chains are estimated to be capable of bearing.

The whole of the timber has been Kyanised, and each course of planking coated with Archangel tar. Felt, however, has not been used, as was originally done between the tiers of planks, that material not appearing to have answered the intended purpose.

There have been no gales of sufficient violence to test the stability of the bridge since its restoration. During the progress of the work, however, about the end of January (1840), some high winds occurred: by that time the two lower courses of planking were completed, and a part of the third was laid down, the stiffening beams underneath were also in their places, but not yet bolted up to the platform; the wheel-guides were not yet on the bridge; but even in this imperfect state of the work, the effects of the wind were so slight, that it was evident the most beneficial results would follow the completion of the improvements.

It is satisfactory to state that the repairs have been effected without any inconvenience to the public, one or other of the roadways having been kept open during the whole time; nor did any accidents occur during the progress of the work, which was completed within the estimate furnished by Mr. Provis previous to its commencement.

THOMAS JAMES MAUDE.

Abingdon Street, Westminster, June, 1840.

XVI.—*Description of a Cofferdam adapted to a hard Bottom, used in Excavating Rock from the Navigable Channel of the River Ribble; designed for the Ribble Navigation.*

By DAVID STEVENSON, C. E., EDINBURGH.

Read February 23, 1841.

Usual construction of Cofferdams.

COFFERDAMS, constructed of timber piles driven into the ground by the piling engine being extensively employed in the hydraulic works of all countries, are familiar to every one. It occasionally happens, however, that the construction of cofferdams by driving piles in the manner alluded to is found to be impracticable, owing to the hardness of the soil in the bottom of the sea, river, or lake, as the case may be, in which they are to be erected, and in such situations some modification of the ordinary apparatus is rendered necessary. The cofferdam described in the following pages was designed with the view of overcoming some formidable difficulties, which presented themselves in executing the works at present in progress for the improvement of the navigation of the Ribble, and was erected in a part of that river where the bottom consists of sandstone rock, and to which a cofferdam of the ordinary construction was consequently quite inapplicable.

Improvements of the Navigation of the river Ribble.

Before explaining the construction of this cofferdam, however, it may not be out of place to give a brief sketch of the projected improvements of the Ribble navigation, in effecting one department of which, the apparatus about to be described has been successfully employed.

Description of the Ribble.

The river Ribble, in the county of Lancashire, is the natural outlet for the trade of the large manufacturing town of Preston, which stands on its north bank, at the distance of about 15 miles from the Irish Sea. But the geological formation of the bed in which the river flows, consisting alternately of solid sandstone rock, compact gravel, and loose sand, renders the present state of its navigation very imperfect; *flats* or *keels* of small draft of water being the only craft which can safely and regularly approach the quays of Preston.

State of its Navigation.

Impressed with the great importance of improving the navigation of the Ribble, and facilitating the communication with the sea, the inhabitants of Preston resolved to take some vigorous measures in order to bring about the attainment of this object. A Company had been formed so long ago as 1806, which, under the Act of Parliament then granted, had at various times made some improvement in the navigation; but the resources of this Company having fallen greatly short of the object which its shareholders had in view, the Corporation of Preston in 1835, consulted Messrs. Robert Stevenson and Sons of Edinburgh, as to the practicability of improving the navigation; and the opinion expressed, after completing the survey and examination of the river, being favourable, a subscription was immediately commenced for carrying the plans proposed by them into effect, and for obtaining an Act of Parliament for the formation of a Joint Stock Company, to be called the "Ribble Navigation Company." Satisfactory arrangements having been entered into with the shareholders of the former Company, the Bill as amended received the Royal Assent in May 1838; and preparations for effecting the improvements in the navigation having been commenced without loss of time, the operations forwarded by the zealous exertions of Mr. Haydock the chairman, and the directors of the Company, are now proceeding expeditiously and satisfactorily.

Ribble Navigation Company formed.

Description of the Works.

The works at present in progress of execution are the excavation of rock from the bed of the Ribble, the removal of gravel and sand by steam-dredging, and the formation of low rubble walls, for the purpose of directing the low water channel of the river at a part of its course where the configuration of the banks renders this operation necessary, in order to obtain a permanently straight navigable track for shipping. It is, however, only on one of these departments, namely the rock excavation, that I am induced to offer a few remarks; as I believe, from the extent of rock which has been removed and from the simple means by which the excavation has been effected, that this work may be considered somewhat novel in its nature, and that a brief account of it may prove interesting, and perhaps instructive, to those who may happen either now or hereafter to be engaged in similar undertakings.

Extent of Red Sandstone Rock.

About half a mile below the quays of Preston, a solid bed of red sandstone, upwards of 300 yards in length, stretches quite across the bed of the Ribble. The position of this band of rock, which extends inland under both banks beyond the limits of the river, is shown in the Plan and Section Plate XIX., Figs. 1 and 2. Its surface is on a high level compared with the general bed of the river both above and below it, and where it is washed by the stream it is quite bare, and free from any deposit of sand or mud, and the higher parts are occasionally left dry during the long droughts of summer. The influence which this band of rock exerts in distorting the tides and currents of the river can be viewed in no other light than that which would be produced by a great artificial weir thrown across the stream. The free flow of the river and tides being checked on approaching it, the power of the tidal and fresh water scours is thereby neutralized, and rendered almost unavailable in keeping open the upper and lower stretches of the navigation. In proof of this it may be stated, that the tide at Lytham, which is situated near the mouth of the river, and is 12 miles distant from Preston, was ascertained by Captain Belcher, R.N., while engaged in making the Admiralty survey of the lower part of the Ribble, to have risen on one occasion, in July, 1836, no less than 25 feet 7½ inches. The ordinary rise of spring-tides, however, at that place is about 19 feet, and that of neap-tides 14 feet; whilst at the quays of Preston, the ordinary rise of spring-tides did not exceed 6 feet, and neap-tides of 14 feet rise by the Liverpool Tide Tables did not show at Preston at all previous to the commencement of the operations. Such was the scarcity of water and the imperfect state of the navigation in the upper part of the Ribble; and the removal of the rock which encumbered its bed was naturally viewed as the most urgent and important work for effecting an improvement.

Impediment to the Navigation.

Height of Tides.

The old Navigation Company already alluded to had, by the erection of low tide-dams, succeeded in excavating a channel about 70 feet in breadth and from 3 to 4 feet in depth in this band of rock. But that operation was too limited to meet the views of the new Company; the directors of which resolved to carry the works of excavation to a great extent, both as regards depth and breadth, and after due deliberation, determined to excavate a channel 100 feet in breadth, as shown by the cross section, Fig. 3, Plate XVIII., and affording a navigable depth of 20 feet at high water of spring-tides through the whole extent of the rock, which, as formerly mentioned, is upwards of 300 yards in length.

Improvements previously effected.

It had been suggested that a new cut might be formed and the course of the river *permanently* diverted so as to avoid the rock entirely; but from the formation of the banks, as ascertained by minute examination, as well as from the nature of the adjoining property, it was concluded that under all circumstances no advantage could be obtained by the proposed diversion, and it was accordingly resolved, in commencing the operations under the

Diversion of the Channel proposed.

new Act, to keep to the old course of the river as the track for the improved channel, and to limit the breadth of the excavation in the first instance to 100 feet, so as to leave ample space for the free flow of the river and an uninterrupted navigation during the progress of the work; the excavation of the remaining part of the rock being a work which may be undertaken at any future period, should the trade of the port render it necessary to provide a broader channel.

The best means of executing this work, involving an excavation in solid rock at some places not less than 13 feet 6 inches in depth, in the bed of a rapid river liable to sudden and extensive land floods, engaged a good deal of attentive consideration, and after weighing the merits of various expedients, such as the use of the diving bell and the formation of a new cut so as to obtain a *temporary* diversion of the stream, whilst the work was going on, it was at length resolved to make use of a series of cofferdams as the most efficient and economical method of effecting the excavation.

Difficulty of fixing Cofferdams.

The chief obstacle which presented itself in designing a cofferdam for this situation, was the difficulty of obtaining on a rocky bottom (covered with water varying from 2 feet to 10 feet in depth at low water and from 8 feet to 16 feet at high water) fixtures of a nature sufficiently secure, to enable the cofferdam to resist the rapid currents which occur during floods and high tides; whilst the inequalities of the bed of the river occasioned another difficulty in attempting to form a water tight joint between the bottom of the cofferdam and the irregular surface of the rock. As the water way of the river also, so long as the dam remained in its bed, would necessarily suffer a very considerable reduction in its breadth, it was considered highly important, as well for the trade of Preston as for the safety of the work, to construct a cofferdam which would occupy as little space, and present as little interruption as possible to the free flow of the currents and the passage of vessels. The construction which I designed for executing this work has now been in use for upwards of twelve months, and has been found fully to answer all of these conditions, the fixtures in the rock having proved quite sufficient, and the dams being exceedingly tight, while the space occupied by the walls or sides is very small considering the water-pressure to which they are occasionally exposed.

Description of Cofferdam.

The Elevation, Plan, and Section, Figures 4, 5, and 6, represent the cofferdam exactly as it was executed, a few improvements in the details of its construction having been from time to time introduced by Mr. Bond, the contractor for the work. It will be seen that the cofferdam consists of a double row of iron rods 2½ inches in diameter, placed 3 feet apart, the spaces between the rods which form each row being 3 feet also. On the inner side of each row of rods, linings of three inch Memel planking are placed; and the space between these linings of planking which form the two sides of the cofferdam is carefully filled with well wrought clay puddle. The sides of the dam are kept together by bars of iron connected to two horizontal wale pieces of Memel timber, measuring 10 inches by 6 inches, placed on the outside of the iron rods. These iron bars pass horizontally through the heart of the puddle at proper intervals, and serve to counteract the tendency which the puddle exerts to force the iron rods and planking outwards, and thus to derange the whole structure. A row of strong stays, placed 18 feet apart from centre to centre, as shown in the Plate, is also applied in the inside of the dam. To avoid interrupting the navigation, as well as for greater safety, the dams were stayed entirely from the inside. These stays, as shown in the drawing, have joints at the upper extremities, and being simply slipped over the tops of the iron rods, and kept in their places by *cotters*, their lower ends, which rest on the bottom, can be moved either horizontally or vertically, and thus be easily adapted to the level of the rock. The shorter stays applied in the first instance can be removed as the work proceeds by simply driving out the *cotters* at the tops of the iron rods, and their places supplied by longer stays resting on the bottom of the excavation, as shown in dotted lines in Figure 6. A sluice, at the level of low water, which can be opened so as to admit the water and prevent the dangerous consequences of a sudden rising of the river while the interior of the dam is empty, two cast iron pumps of 12 inches bore, with their gearing, and a steam engine of 10 horses-power for pumping the dams dry, complete the whole apparatus.

Means of strengthening the Dams.

Mode of fixing the Iron rods.

In constructing the dams according to this design, the most tedious parts of the operation were those of fixing the iron rods into the bed of the river, and securing the lower tier of planking which rested on the irregular surface of the rock. The manner in which these operations were effected I shall endeavour briefly to explain.

In order to fix the iron rods, a jumper point was first worked on the end of each of them. They were then successively *jumped* into the bed of the river to depths varying from 12 inches to 18 inches, according to the soundness or hardness of the rock, by labourers who worked from punts moored in the line of the dam, three or four men being employed at each rod. Gauges were used for enabling the workmen to *enter* the rods properly, so that they might retain a nearly perpendicular position when fixed, and also for the purpose of preserving the proper line of the dam and placing the rods at equal distances apart. No other fixture than that produced by simply jumping the rods into the rock was applied, but this was necessarily a tedious process, from the difficulty of working in a rapid run of water, and from the repeated interruptions which occurred, occasioned by the rise of the tides and by land floods. When a sufficient length of rods had been fixed in the manner described, the lower tiers of planking, which were to be placed below the level of the water, were secured to the iron rods by clasps of iron, as shown in the drawings, and slipped down into their places one above another. The under edge of the lowest tier of planking, the fitting of which often occasioned much trouble, was cut, previously to being put down, as nearly as possible to suit the inequalities of the rock, which were ascertained approximately by measuring from the surface of the water down the iron rods to the bed of the river. The plank being then lowered into its place, a small iron rod, with a hooked end which could go under the plank, was used for finding what parts of it did not touch the rock, and this having been ascertained, the plank was raised and again cut. This operation was repeated two or three times until a near approach to the contour of the rock was obtained. The lower edge of the plank was then cut with the adze in a bevelled or wedge-shaped form, and the plank, being finally lowered into its place in the bottom, was beaten down by blows from a heavy mallet upon an upright piece of wood resting on the upper edge of the plank, and extending above the surface of the water, and the sharp bevelled edge yielding to the blows, sank into the smaller irregularities of the rock, and thus ultimately, as experience proved, formed, in connexion with the puddle behind it, a perfectly water-tight joint. The planks above low water had no fixture to the iron rods, and were kept in their places simply by the pressure of the puddle in the inside of the dam.

Mode of fitting the Planking immediately in contact with Rock.

Method of removing Cofferdams.

In removing the dams from the bed of the river at the completion of the excavation, the clay and planking were first taken up, and the rods being then moved to and fro could generally be raised after a little trouble, by men who worked from punts, as in putting them down. When the rods resisted this force, however, which not unfrequently happened, they were made fast at low water to cross bars resting on two punts, which, being gradually raised by the flowing tide, threw a great strain on the rods, and they were then easily sprung from their fixtures in the rock by a few blows from a heavy hammer. Some of the iron rods were unavoidably a good deal bent in being raised; but most of them, when taken up, were found to be ready, without repair, for being used in forming the next stretch of dam.

Cases in which this kind of Dam was used.

It may be proper to remark that this dam was used only in those parts of the river where the rock was kept bare by the scour of the river and tide, or was covered to the depth of 8 or 9 feet with gravel. In the latter case the gravel was dredged out and the rods fixed in the bottom as already described. But wherever the deposit on the rock exceeded the depth of 8 or 9 feet, as at the upper and lower extremities of the excavation, recourse was had to a timber dam, constructed in the ordinary manner with gauge and sheeting piles of timber driven into the bottom by the piling-engine. The execution of these parts of the cofferdam, however, being in no way remarkable, I shall only in conclusion state briefly the extent of work executed by the means which I have described, my information on this point being extracted chiefly from the monthly reports and measurements of Mr. Brebner, the former, and Mr. Park, the present resident engineer for the navigation works.

Extent of Excavation performed.

The whole extent of the excavation, as already noticed, is upwards of 300 lineal yards; and it was determined to execute it with three lengths of cofferdam, as shown in Figure 1, (Plate XVIII.,) which is a plan of part of the river. The first stretch of dam, which was 350 feet in length and 120 feet in breadth, and enclosed an area of 4,666 square yards, was completed and pumped dry in October, 1839. A large force of men was employed in the excavation, and by working with a night and a day gang, the Contractor succeeded, when the weather was favourable, in raising no less than 185 cubic yards of rock during 24 hours. The whole quantity excavated from this stretch was 10,714 cubic yards; but, from the unfortunate state of the weather during the winter, the excavation was not completed till February, 1840. The second dam, which was constructed of the same materials that had been used in the first, was placed so as to enclose the lower end of the first stretch within its limits, in order that the rock on which the first dam stood might be removed. This stretch, which was the largest, measured 384 feet in length and 130 feet in breadth, and enclosed 5,546 square yards, being an area of one acre and twenty-three poles. It was pumped dry in

Quantity of Rock raised in 24 hours.

April, 1840, and the excavation, which amounted to 12,449 cubic yards, was completed in the month of June of the same year. The third stretch of dam, which is about 300 feet in length, 130 feet in breadth, and encloses an area of 4,333 square yards, was pumped dry on the 1st of November, 1840, and the excavation is rapidly proceeding. The whole quantity of rock removed when the work is completed will amount, it is expected, to about 31,000 cubic yards.

The soft nature of the rock rendered it unnecessary to have recourse to blasting in forming the excavation, as it was found to yield easily to the quarriers' tools. The greater part of the stone excavated being loaded on punts was floated down the river, and used in forming the walls for the direction of the lower channel, already alluded to in speaking of the navigation works generally.

It was hardly to be expected that a series of cofferdams, exposed for so great a length of time in the bed of a rapid river, would escape the casualties attending such works, and some accidents accordingly occurred on the Ribble, which, however, were happily attended with no more serious consequences than the delays which they occasioned. It was satisfactory to find that the fixtures effected by merely jumping the iron rods into the rock in the manner described, the sufficiency of which I considered as somewhat problematical, proved, without a single exception, to be perfectly secure. The best proof indeed which can be adduced of the strength and efficiency of the whole structure is the fact of the river's having risen, on one or two occasions, some feet above the top of the dams without injuring them in the smallest degree. I had an opportunity of seeing the river in this state in the month of March, 1840, when on a visit to the works. At that time no part of the dams was visible, the tops of the iron rods being quite submerged, while the velocity of the current which was rushing over them could not be less than five miles per hour. Notwithstanding this great trial, I had the gratification of hearing from Mr. Park a few days afterwards, that the water having subsided, and the pumps having been set on, the dam was again perfectly dry and the men busily at work.

DAVID STEVENSON.*

Edinburgh, 1st December, 1840.

* Since the preceding paper was written, the last stretch of excavation has been completed, and the whole of the cofferdam has been removed from the river. The total quantity of rock excavated was 30,793 cubic yards, and the time occupied in the execution of the work, including all interruptions occasioned by floods and other causes, was about 18 months.—D. S.

Edinburgh, 3rd June, 1841.

XVII.—"*Memoir on the Practicability of Shortening the Duration of Voyages, by the Adaptation of Auxiliary Steam Power to Sailing Vessels.*"

By SAMUEL SEAWARD, F.R.S., M. Inst. C.E.

Read February 9, 1841.

Application of Steam Power to Navigation.

A QUARTER of a century has barely elapsed since the application of steam power to the purposes of maritime and river navigation was regarded more in the light of an ingenious problem than as a practicable undertaking; the perseverance and skill of scientific and enterprising men have, however, triumphed over the difficulties which beset them, and the result is that steam power has not only been rendered subservient to coast and river navigation, but by its means the shores of the Mediterranean and of the Atlantic are approached and those seas traversed with celerity and certainty, in defiance of winds and tides: it may now, therefore, be presumed that steam navigation is permanently established, though at present not so extensively as the exigencies of maritime transport require.

Limit of duration of Steam Voyages.

Notwithstanding the numerous improvements which have been made in the form and dimensions of the hulls of steam-vessels, and the perfection to which the machinery has been brought, still the weight of the latter, together with the space required for the fuel, has rendered it hitherto impracticable to extend the duration of a steam voyage beyond the period of twenty days, without the necessity of taking in a fresh supply of coals. It must therefore be concluded that until some great reduction can be made in the weight of the engines and in the amount of fuel required to keep them in motion, the use of steam as the sole moving power must be limited to voyages of three weeks' duration, a period of time wholly inadequate for the performance of an Indian or South American voyage.

Cause of limited application of Steam in Sea Voyages.

A practical examination of the cause of the limited application of this noble invention shows that every attempt to adapt engines to vessels of a large size, so as to obtain increased space with a degree of speed proportionate to that of smaller boats, is frustrated by the invariable result, that the weight of the enlarged engines is greater in the proportion of about 25 per cent. than that of the smaller engines; and that whilst the machinery of a boat which has an engine of only 30 horses-power, weighs, including the boiler, water, &c., only 30 tons, or 1 ton per horse-power, the engines of a ship having 300 horses-power will weigh 375 tons or $1\frac{1}{4}$ ton per horse-power. The immediate consequence of this disproportionate increase of weight is a greater immersed section of the vessel, and a necessary increase of the resistance offered to her motion, so that the force required to propel her through the water must always increase with the power employed, and not even cubing the steam power would produce double the velocity. The experience of persons acquainted with steam navigation has determined, that if a vessel be propelled by the application of steam power at the rate of 8 miles an hour through the water, no multiplication of that power could double her speed: it is further a matter of great doubt whether, supposing a vessel be propelled at the rate of 8 miles an hour by an engine of 200 horses-power, an additional speed of $1\frac{1}{2}$ mile per hour could be given to her by the application of 400 horses-power.

Weight and bulk of fuel a further cause of limit.

Independently also of this question, though intimately connected with it, is the consideration of the additional weight and bulk of the fuel required for the increased consumption of the enlarged engines, and which is found to be in the same ratio with the increased power; so that if 150 tons would suffice for 10 days' consumption of a boat with engines of 200 horses-power, 300 tons would be required for the same length of time in a boat with 400 horses-power; and the conclusion to which these statements inevitably lead is, that if a vessel of 200 horses-power can be propelled at the rate of 8 miles an hour by an expenditure of 15 tons of coals per diem, the same vessel with 400 horses-power, and a consumption of 30 tons per diem, would only obtain a speed of $9\frac{1}{2}$ miles per hour, an increase in velocity quite disproportioned to the means by which it is effected.

A third, and, in a commercial point of view, a most material circumstance affecting the utility and economy of steam-vessels of great power, is the space necessarily occupied by the engines and the supply of coals, which are found to require three-fourths of the whole area below deck, leaving only one quarter for the stowage of cargo; and that, owing to the great weight of the former, must principally consist of measurement goods. Thus the "President," and the "British Queen," although of 2000 tons register, have never been able to carry more than 500 tons of measurement goods as freight.

From a due consideration of these three features of the question, with respect to the expediency of employing large steam-vessels, (and it is believed that few practical men will dispute the facts by which they are developed,) it is evident that the attempt to perform voyages of lengthened duration by the power of steam alone must, in the present state of engineering science, be attended with an expense wholly disproportioned to the profits, when the cost of the hull and engines, the consumption of fuel, the wages of the engineers, stokers, &c., are compared with the amount of freight.

The question next to be examined, therefore, is the extent to which steam power may be profitably employed in shortening the duration of commercial voyages; for, with respect to passengers and mails, it is conceived they do not enter into the category of considerations proposed by the author of this essay.

Diminution of Power of Engines recommended in some cases.

A strong and at the same time an apparently well-grounded opinion is entertained by the author, that in many cases steam-vessels are actually overburthened by the size and weight of their machinery, and that the speed of several steamers now afloat might be materially improved, as well as a considerable saving effected in their wear and tear and the cost attendant on them, by reducing the power and weight of their engines. A recent case, which is familiar to the profession, affords an apt and strong proof of the truth of this opinion; and it may be cited with advantage as illustrative of a point in steam navigation, which has hitherto not received quite so much attention as it merits.

Advantages of diminished Power, illustrated by the "Liverpool."

The "Liverpool," constructed at the port after which she was named, in the year 1837, for Sir John Tobin, was considered to be a perfect model of an Atlantic steamer, her beam being only 29 feet to a length of 220 feet, whilst her sharp bows and clean run aft were calculated, it was anticipated, greatly to increase her speed. The measurement of the "Liverpool," according to the old rule, would have given her a register of 1000 tons, but this burthen was virtually diminished to 900 tons by the sharpness of her bows and stern, which lessened her stowage to the extent of 100 tons. Into this vessel, so constructed, engines of 450 horses-power were placed, thus giving her exactly one horse-power to each two tons burthen, which was the greatest proportion of power to tonnage that had up to that period been adapted to a steam-ship. The weight of the engines, together with that of the boilers when filled with water, brought the hull of the vessel down to within two feet of the estimated water-line with her coals and cargo on board; but when 500 tons of fuel (a short supply for 18 days' consumption) were added to the weight already on board, she sank so deep that her paddle-wheels became immersed 4 feet below their proper dip, and the action of the engines was very much impeded, occasioning great waste of power.

The "Liverpool" subsequently made two or three voyages across the Atlantic in a very indifferent style; she was then taken off the line, having proved altogether unfit for the purpose for which she was built.

It may fairly be estimated, that had engines of 300 horses-power been placed in this vessel, instead of those of 450 horses-power, her speed would have been materially increased, as the full force of the engines could have been exerted, and the diminution of one-third in the quantity of fuel required, as also one-third of the weight of the engines, would have eased her of a burthen of upwards of 300 tons, and have kept the vessel in fair trim for sea-going purposes.

The correctness of this supposition may be inferred from the result of the alterations which were made subsequently at a great cost, in the form of the hull of the "Liverpool." Upon being taken off the line of Atlantic steamers, she was docked at Liverpool, the whole of her sides were removed down to the bilges; futtocks and new sides were worked up to the same height as her former bulwarks, with an additional width on each side of 3 feet, thus changing a vessel of 29 feet beam into one of 35 feet, and giving her thereby an additional burthen of 400 tons, increasing the register from 900 tons up to 1300 tons.

The improvement which resulted from these judicious alterations, not only in her speed, but also in her sea-going qualities, was very obvious during her passage to Alexandria, and her performances have since been satisfactory and regular, the proportion between the tonnage of the ship and her steam power being now as one to three and a quarter, instead of, as before, one to two.

Ratio of Steam Power to Dimensions of Vessel.

The author is enabled, from his own observation, to mention another interesting case illustrative of the opinion which he entertains with respect to the ratio which steam power and the dimensions of vessels ought to bear, one to the other.

The "Gem," Gravesend steamer, was fitted in 1836, by Messrs. Seaward and Co., with a pair of engines of 50 horses-power; the vessel was 145 feet long with 19 feet beam: when she was tried, her speed fell short of the expectations that had been previously entertained, and it was seen that the cause arose from the weight of the engines, which overloaded her and brought her too low down in the water: the utmost speed ever attained by the "Gem" with these engines was 12½ statute miles per hour. After the season was over these engines were taken out of the "Gem" and placed in the "Ruby:" the latter vessel was 5 feet longer and 9 inches broader than the former, and consequently possessed a greater degree of buoyancy. Upon the first trial the speed of the "Ruby" was found to be 1 mile an hour greater than that of the "Gem," her velocity being 13½ miles an hour. A pair of engines of 45 horses-power was then placed in the "Gem:" the immediate result of this was, to lessen her draught 5 inches, and to increase her speed from 12½ to 13 miles an hour.*

It is conceived that these two cases exemplify, in a striking manner, the opinion before stated; but at the same time it must not be assumed that, in quoting them, the author condemns the employment of a high degree of power on board steam-vessels. The object which he proposes to effect in making these observations, is to demonstrate what he conceives to be an undeniable fact, namely, that, under the present circumstances of steam power, vessels are frequently overburthened by their engines and fuel; but at the same time, if increased weight and space were not the inseparable concomitants of increased power, it is admitted that there would be no possibility of assigning any real limits to the employment of this means of propelling ships. It may also be observed that those engineers have succeeded best who have studied how to combine diminished weight with equal strength in the construction of their machinery, by the judicious choice and application of materials.

Classes of vessels in which Steam is used as the sole moving power.

Taking therefore a general view of these facts, it may be stated that the vessels in which steam is employed as the sole moving power must be ranged under three distinct classes:—

First: Those of the largest class, such as the "President," the "British Queen," &c., which from their size and capacity can carry a supply of fuel enabling them to undertake a voyage of the duration of twenty days, which forms at present the boundary of steam voyages.

* Since the above was written, the Ruby has had her bow lengthened, and a boiler placed in her weighing, with the water, 22 tons, instead of the former one, which weighed 44 tons: this has diminished the draught of water 4 inches, and has increased her speed ¾ of a mile per hour; her ordinary velocity through still water being now 14¼ miles per hour.

Secondly: Those which are able to carry a supply of fuel sufficient for twelve days' consumption; and lastly, those which cannot carry more than eight days' fuel. Of the first class there are only five: of the second class there are about thirty: of the number of the third class no exact estimate can be formed, but it must be observed that the majority of steam-boats fall into a rank much below this mark, not being able, generally speaking, to carry more fuel than is sufficient for three or four days' consumption.

Present state of Steam Navigation inadequate to the purposes of Commerce.

The present state, therefore, of steam navigation is evidently altogether inadequate to meet the large and daily increasing demands of commerce, and in this respect as far as maritime navigation (as contradistinguished from river and coast navigation) is concerned, steam must be considered to be in its infancy; for the communication by this means with our own, or with foreign distant colonies,—India *viâ* the Cape of Good Hope, the West Indies, the Pacific Ocean, Australia, the Brazils, and other highly important productive commercial countries,—is at present impracticable to any extent, as the facts hereafter stated will more distinctly show.

Steam as a sole moving power unfit for long Sea Voyages.

It is moreover to be apprehended that the difficulties which have hitherto been found to impede the direct communication, by means of steam power only, with these distant parts of the globe will be found to be insurmountable, and that therefore with respect to economy of time as well as of space, fuel, outlay, &c., some intermediate plan must be resorted to, before any profitable result can be looked for from the employment of this power.

Junction of Steam Power with Sailing recommended.

This intermediate plan is to employ the wind, with the common agency of sails, as the principal moving force, and to use steam power only in those cases, where the failure of the wind or its being contrary, would cause delay on the voyage; and thus by the combination of these two moving forces, to ensure dispatch, safety, and economy, and open a wide field for British skill and enterprize.

This plan was first suggested by the author in a pamphlet published in the year 1829.*

Although, during the interval which has since elapsed, the views therein exposed have been fully established, little has hitherto been done towards carrying them into that full and complete operation which the success attendant

* "Observations on the Advantages and Possibility of successfully employing Steam Power in navigating Ships between this Country and the East Indies."—London, 1829.

upon their partial application has, it is conceived, entitled the author to expect.

The "Maria," first example of combining Steam power with Sailing.

The earliest attempt to adapt steam power to a sailing-vessel was made in the year 1839, when the ship "Maria," of 460 tons burthen, was fitted with engines of 20 horses-power as auxiliary steam machinery, by Mr. John Melville; and in the years 1839 and 1840 two other vessels have had auxiliary steam-engines adapted to them, so that the experiment may now be said to be undergoing a fair course of trials.

The suggestions contained in the pamphlet above referred to (a copy of which, accompanied by a chart of the route to India and China, has been presented by the author to the Institution) were, that vessels of from 1500 to 1800 tons burthen should be constructed to sail 10 or 11 knots an hour before the wind, to be rigged and equipped in the same manner as ordinary Indiamen; engines of small power were to be placed in these vessels, to be brought into action only during calms, or to assist the sails under light airs; by this means it was calculated that the duration of the voyage to India would be decreased to seventy-five days, allowing seven days for stoppage at the Cape of Good Hope to take in water, coals, and provisions; whereby a saving of thirty-five days in the passage to India would be effected, one hundred and ten days being the average duration of the voyage.

Class of vessels best suited for combining Steam power with Sailing.

Before entering upon the details of this scheme, either as regards its past success in the partial and limited application which it has hitherto received, or as to its future adaptation, it may be desirable to describe the class of sailing-vessels, to which auxiliary steam may be regarded as an applicable power, and where its employment may be expected to be attended with success; and here it must be observed that commercial, and not scientific success, is the only result looked to: for nothing can be considered successful, in a commercial point of view, to which a fair profit upon the capital employed does not attach.

Auxiliary steam, then, may be considered to be applicable to all well-built vessels ranging from 400 tons upwards, wherein the engines can be placed so as not to encroach upon the stowage. On or between the decks of vessels of this tonnage sufficient space exists to contain power equal to the effort of propelling a ship at the rate of 5 knots an hour in a calm, the power necessary to attain this degree of speed being in the proportion of about one horse to twenty-five tons; the only stowage-room required would be for the coals necessary for the consumption of the engines, the quantity of course depending on the nature and duration of the voyage.

Number and class of Vessels to which the Author's plan is peculiarly suited.

The number and classes of sailing-vessels in our commercial navy to which auxiliary steam might be at once advantageously applied, may be thus roughly estimated :—

East India Traders about	250	sail averaging	800	tons each
Australian and New Zealand Packets	60	„	600	„
West India Traders	300	„	500	„
Other Merchant Vessels	1000	„	400	„

To all these it is conceived that auxiliary steam power may be applied with a certainty of its success in shortening the duration of voyages, and consequently of proportionately reducing the expense.

Usual speed of Sailing-vessels.

The generality of merchant vessels, particularly those which trade round the Cape of Good Hope and Cape Horn, sail before the wind, upon an average, at the rate of from 11 to 12 nautical miles an hour; in a gale this speed is increased to 13 or 14 miles, being from 2 to 3 miles an hour faster than any ordinary steamer could be propelled under similar circumstances. This result is occasioned by two causes, first by the impediment to the steam-vessel's progress through the water arising from the trailing of large wheels; and secondly because the masts and spars of such ships are so light, that the same spread of canvass and the same wind which would propel an ordinary sailing-vessel at the rate of 13 or 14 miles an hour would destroy the masts and sails of a steamer. It has, moreover, been found, by experience, to be extremely hazardous to use the full power of steam, when the speed of the vessel under canvass amounts to 9 miles an hour; so that under the most favourable combination of circumstances the utmost average speed that can be obtained by a steamer is 12 miles an hour, whilst with a wind on her quarter or abeam, her crank build reduces her way to 6 or 7 miles an hour; a sailing-vessel with the same wind, and holding on the same course, making 11 or 12 miles: even when a sailing-vessel is close-hauled or steering within five points of the wind's eye, she will make from 6 to 7 knots, if there be any wind amounting to a breeze, so that a sailing-vessel can always steer twenty-two out of the thirty-two points of the compass, with a way varying (according to the degree to which she is close-hauled, and to the amount of wind) from 5 to 12 or 13 knots an hour.

Average speed of Steam-vessels.

Advantages of the Author's plan in the Trade Winds.

It should also be borne in mind that in the Atlantic, Pacific, and Indian Oceans, there always prevail what are termed trade winds, which blow with varying force, in one constant direction within certain parallels of latitude, all the year round, and it is by the knowledge and skilful use of these winds that our Indiamen are enabled to perform their voyages so quickly as they do. The detention experienced on an average by these vessels in consequence of calms and contrary winds, amounts to about twenty-five days, which deducted from one hundred and ten days, the average duration of the passage, leaves the period of eighty-five days for the performance of the distance which the vessel has to traverse before she reaches her destination, giving an average speed of from 7 to 8 knots an hour, the actual speed, however, varying from 3 to 12 or 13 knots, according to the force and direction of the wind.

Causes of the lengthened Voyages of Vessels using Steam only.

Hence it is that the duration of the voyages of steam-vessels of great power which have been sent out to India has in every instance been lengthened to the extent of one-fifth beyond the average period occupied by sailing-vessels in making the same passage. The reasons for this are obvious, for, in the first place, the full power steamers, as now built, are bad sailers, their spars and rigging being very inefficient; consequently they rely almost wholly for their progress upon the power of steam, which, as has been shown, is not equal under certain, and not uncommon circumstances, to the power of the wind. Steam-vessels constructed like those which have hitherto gone round the Cape, can only run fourteen or fifteen days before they are compelled to put into port for fuel, a necessity which the length of the voyage to India obliges them to submit to four or five times, whereby many days are lost, during which the sailing-vessel is steadily pursuing her course: the time thus expended may be fairly balanced against that during which the sailing-vessel is becalmed or retarded by adverse winds, and the duration of the voyages to India (viz. from 130 to 150 days) of the steamers "Enterprise," "Atalanta," "Berenice," and others can therefore be amply accounted for.

Results of the employment of Steam as an Auxiliary Power, exemplified by the "Vernon."

Having thus weighed the advantages and drawbacks attendant upon both systems of navigation as at present practised, and having compared the powers of steam with those of sailing-vessels, it may be considered expedient to state the results that have been obtained by the employment of auxiliary power which has been adapted to the "Vernon" East Indiaman.

This vessel, measuring 1000 tons, was built by Mr. Green, of Blackwall, in the year 1837, and during one or two passages to India, proved herself to possess first-rate sailing qualities. Her hull is constructed much upon the model of a frigate; her masts are large and taunt, her yards square, with capacity for spreading a great breadth of canvass, and she sails with ease twelve to thirteen knots in a fresh gale. The "Vernon" therefore presented peculiar qualifications for the application of the auxiliary steam power, and as Mr. Green was fully impressed with the necessity of endeavouring to shorten the duration of sailing voyages round the Cape to India, in order to enable his vessels to compete with the Red Sea steamers, he readily adopted the suggestion which was made to him for applying auxiliary steam to this ship, and gave an unlimited authority to Messrs. Seaward, to equip the "Vernon" with the engines and machinery which they might deem necessary to effect the purpose required. Considering it to be a matter of great importance that the smallest possible steam power should be employed, Messrs. Seaward constructed a condensing engine of 30 horses-power, which with its boiler, &c., was placed midship between decks, occupying the space between the main and fore hatchways, the whole apparatus being comprised within the dimensions of 24 feet in length and 10 feet in breadth; no part of the engine going into the hold, which was filled with cargo in the ordinary manner. The total weight of the machinery was 25 tons; the cylinder was placed horizontally, and in order to economise space the shaft was fixed behind the cylinder bottom, and the two side rods from the piston cross head became the connecting rods to the shafts. The paddle wheels and shafts rested upon bearings placed in the bulwarks, from which the paddle wheels projected 5 feet on either side: there were no paddle boxes or beams, the whole apparatus being left open, and the wheels were so constructed that they could each be separated into two pieces and taken on board, leaving the ends of the shafts projecting about 18 inches from the ship's sides. The diameter of the wheels was 14 feet, the floats being constructed to reef to the extent of 18 inches, according as the dip of the wheel was altered by the varying draught of the vessel whether fully or partially laden. An apparatus was also attached to the engine by which the paddle wheels could be disengaged from the main shaft in the space of one minute, whenever that operation was necessary; a very important feature it must be observed in the adaptation of auxiliary steam to sailing-vessels, as it is essential that the engine should be stopped whenever the breeze which it is intended to assist freshens,

Description of the "Vernon's" Engine and Machinery.

during the action of the steam, so much as to propel the vessel by its own force, at the rate of six or seven miles an hour. The engine being stopped and the wheels disconnected by the apparatus referred to, the way of the vessel is not impeded by their trailing in the water as fixtures, for they turn freely round, and thus offer little or no resistance to the ship's progress. During the voyage of the "Vernon," the wheels were frequently disengaged while the vessel was going about or tacking, the contrivance, which fully answered the purpose, being the very simple one of attaching a moveable head to the paddle-shaft crank, which being turned a quarter of a circle liberates the crank-pin, and enables the wheel to revolve freely in whichever direction the motion of the water impels it.

The boiler, cylinder, and steam-pipes were enveloped throughout with felt clothing doubled, and covered with deal staves 2 inches thick, hooped with iron and painted. This non-conducting medium was found to be so effectual, that the thermometer only rose 3 degrees on being hung on the covering of the boiler while the engine was at work, the minimum heat underneath the covering being probably at 220°. The advantages derived from this plan were, that not only was greater safety insured to the ship, as well as a considerable saving effected in the expenditure of fuel, but also the personal comfort of the passengers in the tropical latitudes was greatly increased by the slight extent to which the employment of steam affected the temperature of the vessel. This system which was first applied to the boilers, &c., of Her Majesty's ship "Gorgon," is now very generally adopted throughout the Navy.

First voyage of the "Vernon."

In June, 1839, the "Vernon" having on board 900 tons of cargo, and 60 tons of coals, with a draught of 17 feet in the river, (16½ feet at sea,) steamed down to the anchorage at Gravesend from the East India Docks, in three hours. During the last three quarters of an hour, she made way against the tide unassisted by her sails, at the rate of five knots an hour, equal to five and three-quarters statute miles. A speed like this attained by the employment of a steam power of one horse to thirty two tons, astonished all on board, and whilst it exceeded the expectations that had been entertained of the engine's performances, it afforded a convincing proof of the small amount of power requisite to obtain a low speed. The engine made twenty four strokes per minute, appearing to work easily and well, and giving no indications of the mishaps which afterwards befel the machinery. On the third day from her leaving the Docks she sailed from Gravesend and made the voyage to Portsmouth, partly under canvass and partly by the aid of steam, at a speed, varying according to circumstances, from five to seven knots an hour. In the Channel off Brighton, the piston rod broke; this was replaced by a spare one, and the vessel finally started from Portsmouth during a calm, the steam being used for the space of eighteen hours, when, being off Dartmouth, the second piston rod snapped at the same part where the first had failed, affording however no means of accounting for the accident or of preventing its recurrence, the rod itself being quite sound and without a flaw at the fracture, and the other parts of the machinery standing remarkably well. Under these circumstances the "Vernon" proceeded on her voyage, making use of her sails only, until she reached the Line, where calms generally prevail. The engineer then fitted his third and last piston rod, and the engine was again brought into action, the hopes of all on board being now directed towards this means of avoiding the delays of from six to eight days that are usually experienced by vessels in the calm latitudes. These hopes were however speedily disappointed by the fracture of the third piston rod at the same place in which the two former ones had given way, namely inside the cross head, against the shoulder. The vessel being thus thrown entirely on her sailing resources, the wheels were unshipped and the Cape was made in eighteen days from the time of the last accident.

Accidents to the Engine.

Upon examining the machinery at the Cape, it was discovered that an original defect existed in one of the paddle shafts, the main bearing of which being split into two equal portions, threw the whole strain of the engine at each stroke upon one arm of the cross head, and thus the piston rods were snapped in succession close off at that part.

The necessary repairs being done to the shaft by the engineer, with the assistance of a Dutch boor, the "Vernon" again proceeded on her voyage to Calcutta. After she had passed Madagascar, light winds alternating with calms, prevailed during the remainder of her course through the Indian Ocean and up the Bay of Bengal, and the engine being now brought into requisition, performed its work in a manner that proved most essentially serviceable to the ship. During eight days and nights the engine was kept in constant work, the vessel averaging $4\frac{1}{4}$ knots an hour (5 statute miles) when steady, and 4 miles when rolling under the swell of the sea. She steamedup the Hooghley against the current, passing the ships at anchor, and finally anchored off Chandpal Ghaut, in the month of November, 1839, having made the passage in ninety-five days.

Completion of the "Vernon's" voyage and speed obtained.

The news of the arrival of the "Vernon," and of the peculiar qualifications afforded by her fittings for making a quick passage, soon spread throughout the presidency, and applications for cabins and for freight became so numerous that the agents augmented the prices of the former one-fifth, and the freight of cargo 1*l.* per ton, at which rate the whole accommodation of the vessel was speedily taken up. It must be remarked that the East Indian public fully appreciate the high value of steam, being aware of the tedium and *ennui* to which they are exposed by the calms often experienced in the voyage to and from India; nor does the most frightful gale of wind convey to the seaman half the horrors which he attaches to the idea of being becalmed on the Line for a week or a fortnight beneath a vertical sun.

Return Voyage of the "Vernon."

The "Vernon" raised her anchor on the 28th February, 1840, and steamed down the river on her passage homewards amidst the acclamations of thousands of spectators whose curiosity had been excited by her performances. The "Windsor," another ship belonging to the same owner, and of about the same tonnage, had sailed exactly three weeks previously. In the Bay of Bengal the "Vernon" encountered a constant calm, and the engine was in consequence unremittingly worked during the space of fifteen days. On the 17th April she made the Cape and steamed into Table Bay, coming to an anchor off the town during the night to the astonishment of the natives, no vessel having up to that moment ever ventured, owing to the dangerous nature of the ground, either to enter or to quit the anchorage after sunset. Vessels in consequence of this circumstance frequently lie becalmed under the table land during three or four days, while, by the aid of her steam, the "Vernon" accomplished this in six hours. Having stayed a week at the Cape the vessel started again on the 23rd of April, under steam, which she used occasionally during the ten subsequent days. On the 6th May, St. Helena was left astern, and finally Spithead was made on the 4th June, the passage from the Cape having been thus made in the unprecedentedly short period of forty-two days between the raising and the casting of the anchor; a passage which for quickness exceeds all the performances of the largest steamers that have gone round the Cape, the shortest of those passages having been fifty-two, and the longest sixty-two days.

Duration of Voyage and speed obtained.

The "Vernon" steamed up the Channel, passing the "Windsor" lying in the Downs waiting for a tug, thus gaining upon that vessel twenty-one days. She arrived at Blackwall under steam on the 10th June, the "Windsor" reaching the same place on the 12th, whereby a further gain of two days was added to the former. The whole distance between Spithead and Calcutta was accomplished, by the alternate agency of steam and wind, in the short period of ninety-five days, and deducting seven days for stoppage at the Cape, the duration of the passage is reduced to eighty-eight days, being one of the shortest passages on record.

Great praise must be awarded to Captain Denny, her commander, whose valuable assistance on all occasions to the engineer, and whose enthusiasm and courage, which never once abated, greatly promoted the success of this experiment; although the early difficulties of the outward voyage were of a nature to dishearten him, and to lessen his confidence in the powers of steam.

The "Earl of Hardwicke" fitted with an Auxiliary Engine, and starts for India.

The success which attended the voyage above described induced the owner of the "Vernon," to equip the "Earl of Hardwicke," a sister vessel, with an engine of the same power. The experience acquired during the experimental voyage however led the. engineers to introduce some modifications into the machinery of both the engines.

The "Earl of Hardwicke" started on her outward voyage on the 20th August, and made the Sand-heads on the 8th December. The passage was certainly a long one, but the autumnal season of 1840 was characterised by very tedious passages. The steam was used during three hundred and sixty-four hours at various intervals of the voyage out, and the number of miles gained thereby in the calm latitudes, and where without it the vessel might have been delayed for days together, amounted to nine hundred and forty-six. Captain Hemming, in a communication addressed to Messrs. Seaward, accompanying an extract from his log, wherein the exact work done by the auxiliary steam is noted, states that the performances of the engine were satisfactory.

Result of Voyage.

"In a calm with perfectly smooth water," says Captain Hemming, "it will move the ship $4\frac{1}{2}$ knots an hour. As the ship gathers way from a breeze the engine's propelling power increases in proportion. When the ship will sail 5 knots with canvass the engine will increase her rate to 7 knots, and when sailing close-hauled the engine makes the ship hold a much better wind. We have had no accident with it. The consumption of coals is at the rate of $3\frac{1}{4}$ tons in 24 hours. I did not reef the paddles any more as the ship lightened daily, and they are not too deep for a sea-going steamer; but I have never been able to get more than 22 revolutions, even when the ship has been going through the water 8 knots by canvass, at which rate the piston could have little resistance to overcome. I very strongly approve of and recommend the simple and expeditious way of disconnecting the paddles, which we had recourse to so constantly during the passage."

Second Voyage of the "Vernon."

The "Vernon" steamed down the river and through the channel to Portsmouth, in the month following after the departure of the "Hardwicke," leaving England finally on the 19th September, 1840, and arriving at the Sand-heads on Christmas-day, thereby gaining 13 days upon her predecessor.

The log of the "Vernon" had not yet arrived when these observations were penned, but a letter from her commander, Captain Denny, dated Calcutta, January 16, 1841, has been received, wherein he speaks in the most favourable terms of the effects of the auxiliary steam on board his ship, as having enabled him to gain six weeks upon several vessels which had sailed from England early in August. So favourably impressed was Captain Denny at the period when he wrote with the power of auxiliary steam, that he recommends it to be used to a larger extent than that to which it is carried in the "Vernon." "The advantage," he says, "of having double the steam power would be, first, that it would take but little more room, or no more if occupying the two decks, and only about half as much more coals; no more engineers, and it would take you more quickly through the calm spaces, and render ships more independent of steam-hire in going up rivers. The circumstance of getting more rapidly through calms would reduce the expenditure of coals to our present quantity. My passengers wish it much, and all speak well of the 'Vernon.'" The consumption of fuel on board these two vessels was 90 tons each during the outward trip.

Result of Voyage, and Comparison with the "India" Steam ship.

The "India" steam ship of 800 tons burthen, with engines of 300 horses-power, started from Portsmouth on the 7th of September, and had not yet arrived when Captain Denny's letter above referred to was despatched from Calcutta. It is since known, however, that this vessel reached the Sand-heads in one hundred and thirty-two days. All that remains now to be done in the way of further illustration of the views laid down in the preceding pages is to offer a concise statement of the comparative expenses of a vessel navigated in the manner described by auxiliary steam, and of a vessel which like the "India" depends wholly upon her engines for her progress; or if not wholly, is at least constructed in such a manner that her engines and their appurtenances and stock of fuel form by far the most important item of her contents and expenditure.

Comparison of Expenses of Steam as Sole and as Auxiliary Moving power.

The expenses attendant upon the employment of auxiliary steam in the "Vernon" were as follows:—

	£.	s.	d.
Interest of capital sunk in the purchase of engines, 1800*l.* at 5 per cent., 4 months	30	0	0
Wear and tear of ditto at 10 per cent., 4 months	60	0	0
Ninety tons of fuel at 1*l.*	90	0	0
Loss of stowage-room, 30 horses-engine at 1 ton per horse. 30 tons at 3*l.* per ton	90	0	0
Loss of stowage room on 90 tons of coals at 3*l.*	270	0	0
Wages of 1 engineer at 10*l.* per month, 4 months	40	0	0
Wages of 1 stoker at 5*l.* per month, 4 months	20	0	0
Total	£600	0	0

The presumed expenses attendant upon the "India" for the same period, calculated at the same rate of expenditure as the above, would be as follows:—

	£.	s.	d.
Interest upon the cost of the engines, 15,000*l.* at 5 per cent., for 4 months	250	0	0
Wear and tear, 10 per cent., 4 months	500	0	0
Coals, say 55 days at 25 tons a-day, upon the supposition that she steamed half the time occupied in her passage: 1375 tons at 1*l.*	1,375	0	0
Loss of stowage of engines, 300 horses, at 1 ton per horse: 300 tons at 3*l.*	900	0	0
Loss of stowage in fuel: 300 tons at 3*l.*	900	0	0
Wages of 4 engineers, averaging 9*l.* per month	144	0	0
Wages of 14 stokers and coal-trimmers at 4*l.*	224	0	0
	£4,293	0	0
Deduct cost of auxiliary steam in "Vernon"	600	0	0
	£3,693	0	0

Showing an excess of that amount of expenditure above the cost of employing a small steam power in a vessel, which was thereby enabled to gain at least 35 days over the more costly apparatus of the "India."

These remarks and the comparison above instituted are by no means intended to disparage the "India" or the engines on board of her. The appositeness of the unintentional rivalry of the two ships at the moment when a new and interesting experiment was in a course of trial, has alone induced the writer to give the results as above stated, merely with the view of strengthening his own arguments in support of the system of navigation which he is endeavouring to introduce. It is satisfactory to state that other vessels engaged in the Indian trade have been equipped with auxiliary steam machinery, the advantages of which are beginning to be generally understood.

In conclusion it may be observed that in a preliminary essay, such as the present, it was not deemed necessary, in order to meet the views of practical men, to enter into any recondite calculations for the purpose of justifying the opinions or elaborating the ideas intimated above; the writer preferred having recourse to a plain statement of facts supported by such examples as the abundance of steam-vessels of all sizes and powers now afloat so amply afforded, a careful examination of which will enable any person to draw a right conclusion for himself.

Theoretical speculations upon such a subject, however suited to the philosopher's study, are of little value to the practical engineer or shipbuilder. To quote the language of the late revered president:—"What we want for this society is the development of that knowledge which is founded upon practical experience;" and judging of the final success of the experiment by the results at present obtained, it will probably be admitted that the expectation is not too sanguine which looks forward to the general and speedy adoption of auxiliary steam throughout the whole commercial navy, when, and when only the advantages of steam navigation will have received their full and true development.

SAMUEL SEAWARD.

Canal Iron Works, Limehouse, January, 1841.

APPENDIX I.

SINCE the foregoing Memoir was written, the Engines of the Vernon and the Hardwicke have been removed from their respective ships, and thus the more general application of auxiliary steam power to sailing vessels has for the present been suspended; a circumstance greatly to be regretted, as preventing the more complete development of a plan, judged to be of the highest importance to navigation.

Several circumstances conspired to cause the removal of these engines: the Hardwicke did not make a very short voyage, either out or home, and although the captain of her admits that by the use of auxiliary steam the duration of the voyages was considerably abridged, yet being himself part owner of the ship, and finding on his arrival at Calcutta, that freight was at a high rate, he calculated that could he have availed himself of the space occupied by the engine and coals, his pecuniary advantage would have been greater than that gained by the saving of time, through the use of steam power; he therefore availed himself of an opportunity which offered at Calcutta, to sell his engine for the sum it had cost, and it is now on its way back to India.

The Vernon, on the contrary, made two very short voyages, both out and home, and the interesting letters of her commander, Captain Denny, (than whom no one could be more capable of judging the advantages of this new application of steam power,) show how perfectly he was satisfied with it. This very success, however, has led him to become an advocate for an increase of power, from 30 to 50 horses, under the impression that there would be a proportionate gain in point of time, without any material increase in the consumption of fuel. It was, however, determined that the Vernon should proceed on her third voyage, without any change of engine. About the time she was preparing to start, a contract was entered into by Mr. Green, (her owner,) for the immediate conveyance of 1000 soldiers to India, and the whole available space in the three ships he had at home being required for that purpose, it became necessary to take the engine and machinery out of the Vernon which was one of them, and she sailed from Gravesend in August last, with 300 soldiers on board.

It rarely happens that an invention or a novel application of a system presents pecuniary advantage on its first essay, but notwithstanding the circumstance of the engines being taken out of these ships, before the benefits which it is confidently believed must result from the adoption of auxiliary steam power could be fully demonstrated, still much has been effected. The success of the Vernon on both her voyages must be nearly conclusive as regards the advantages of the plan, of which her owner is so fully impressed, that far from abandoning it, he is preparing to adopt it, still more extensively, in the ships he is at the present moment constructing for the East India trade. The prejudices of seamen are almost proverbial, so that some opposition was to be expected from them, not only from the novelty of the system, but that it added somewhat to their labour, as they were occasionally called upon to hoist up coals from the hold, as well as to aid the stokers; occupations which they were both unused to, and averse from: neither had they any interest in diminishing the duration of the voyage, as the amount of their wages was curtailed by the number of days gained. The officers, too, were somewhat opposed to the plan, from their ignorance of the nature of the machinery, and that it occupied some of the space which might have been devoted to increasing the comfort of their cabins; the commander and the passengers, on the contrary, fully appreciated all the advantages of the system, as is evident by the letter addressed to Captain Denny by the passengers, and which letter appeared in the public prints of the day.

It is certain that further essays will be made, and if they shall be aided by the commander of the ship, whose personal interests ought not to be injured by the plan, the ship owner will soon see the advantages of it, and gladly avail himself of a plan by which a long sea voyage may be considerably diminished, and the comfort of the passengers promoted, with increased safety to the cargo. It is, therefore, confidently hoped that the application of auxiliary steam to sailing vessels will speedily be more perfectly developed to the advantage of marine enterprise.

Canal Iron Works, Limehouse, November 10, 1841. SAMUEL SEAWARD.

APPENDIX II.

Auxiliary Steam to Vessels of War.

The previous description of auxiliary steam refers only to merchant vessels. But it must be obvious to all naval and scientific men, that it is equally applicable to vessels of war; in fact, this has always been one of the favourite objects of the writer of the preceding essay, as he feels confident that the time is not far distant when no British line-of-battle ship will be considered completely equipped without this useful auxiliary; from their size, and from the fact of their carrying no cargo in the hold, more ample space for placing the machinery and stowage of the fuel is to be found on board these ships than on board merchant vessels, added to which, from the superiority of their forms for sailing, a less proportionate power will produce the velocity required.

There can be little doubt that in all the operations of a naval engagement, the possession of a locomotive power, by which a line-of-battle ship could move four or five knots per hour in a calm, would give her an immense advantage over her opponents; and, it should be borne in mind that most of our great naval engagements have been fought in a calm, or with such a light breeze that the firing of the guns caused such a stillness in the air as to leave the ships nearly helpless; it is then that they foul one another and get into confusion, and, as the smoke of the firing occasionally subsides, it is not unusual to find that they have been firing into ships belonging to their own flag instead of those of the enemy; it is at such times that the full value of auxiliary steam would be duly appreciated; ships having steam power would then take up a position by which all or most of the fire of the enemy would be lost or unnecessarily expended, whilst they would continue to rake the enemy till the decks would be completely stripped of every living soul; the heaviest three-decker could not withstand the well-directed fire of a 74-gun ship, supposing the latter to be able to choose her own position.

The noble class of ships now introduced into our Navy by that talented constructor Sir William Symonds, affords a most favourable opportunity of trying auxiliary power: their beautiful lines, their seagoing qualities, and great speed under canvass afford the best assurance that a very small power would be sufficient to propel them at the rate required; ample room can also be found on board these ships to place the necessary power, without interfering with a single gun or any of the usual stowage for ammunition.

Feeling impressed with the advantage which auxiliary steam would give to our frigates and line-of-battle ships a letter was addressed by the Messrs. Seaward to Sir William Symonds, the Surveyor of the Navy, upon the subject in the month of October, 1839, and by him it was strongly recommended to the notice of the Lords of the Admiralty; the subject was by them most favourably received: but as their Lordships at that time had already commenced building the formidable fleet of war steamers now nearly completed, and as there was no immediate apprehension of a war, the project remains in abeyance.

In that letter it was proposed to equip the "Vanguard," 80-gun ship, with an engine of 60 horses-power, the engine to be so arranged that it could also work the pumps in the event of a considerable leak, as well as be used for heaving up the anchor.

The drawings sent with the letter showed the "Vanguard" in section, with the space on the lower deck occupied by the engine, the paddle-wheels, boiler, &c.; and the area required was exactly the size of the sail-room, and in the same position, so that the most vulnerable portions of the engine and boiler were under the water-line.

SAMUEL SEAWARD.

Canal Iron Works, Limehouse, June 30, 1841.

APPENDIX III.

Log of the "Earl of Hardwicke" Indiaman.

Voyage of the Ship "Earl of Hardwicke" from London to Calcutta, with Auxiliary Steam.

1840.	Latitude.	Longitude.	Whole Distance Sailed.	Hours Steaming.	Distance Steamed.	Winds.	Remarks, &c.
	North. ° ′	West. ° ′					
August 23	48 55	5 31	Reckoned from noon to noon.	Reckoned from noon to noon.	Reckoned from noon to noon.	N.W. Calm.	On Thursday, 20th August, sailed from St. Helen's Roads, with a light westerly wind; beat down Channel, and on Sunday morning, the 23rd, took our departure from the Lizard, at noon, latitude and longitude as per margin; the wind declining to a calm, attempted to steam but found the engine would not work; employed overhauling it, re-stuffed the air-pump bucket, and at 10.30 began steaming; made 14 revolutions per minute, and propelled the ship three knots per hour.
,, 24	48 01	6 13	61	13½	47	S.E.	Light airs from S.E. continued; steaming increased to 16 revolutions.
,, 25	46 27	7 00	100	24	60	N.W. S.E. to	A.M. Light breezes at noon; found from the most accurate estimate the engine to have propelled the ship 60 miles in 24 hours. The following appears at present an accurate estimate of its power:—In a calm with smooth water, it will move the ship 4 knots; as the ship gathers way from a breeze the engine's propelling power decreases in proportion: when the ship will sail 5 knots with canvass, the engine will increase her rate to 7 knots, and when sailing close hauled, the engine makes the ship hold a much better wind. Noon. Light breezes from northward, the ship sailing 6 knots; let off the steam, and disconnected the paddles. Sunset, inclining to calm. At 8, the ship sailing only 1 knot, began steaming, and went 4 and 5 knots, making 16 to 18 revolutions. Light airs, 16 revolutions. Noon, an increasing breeze: in disconnecting the engine, strained the starboard radius and side rods after the larboard were disconnected from the ship, having too much way; if the ship is going fast, it is necessary to heave-to to disconnect, which is done in a few minutes.
,, 26	45 11	8 27	99	16	52	E.	P.M. Steady breezes, and cloudy; lightning to the southward: barometer steady 30, 18. It is remarkable that we should have had 53 hours' calms, and steamed 159 miles across the Bay of Biscay.
,, 27	42 50	11 43	200	..	..	E. to N.N.E.	Steady breezes and cloudy. Engineer repairing the radius and side rods; cleaned the engine throughout.
,, 28	40 56	13 17	133	..	..	N.E.	Steady breezes and cloudy: under all sail. Sunset, a decreasing breeze.
,, 29	39 38	14 12	91	4½	18	N.E. Calm.	Light breezes and cloudy, with light showers; showed colours to a line-of-battle ship with a rear-admiral of the red flag, supposed the "Donegal." Noon, light airs, nearly calm; sailing 1 knot. At 12.30 commenced steaming, 4½ to 5 knots. At 5 a breeze from N.E. disconnected. N.B. Blew off generally every two hours, or whenever the "Saline Detector," a very useful instrument, indicated it was necessary.
,, 30	37 59	15 10	111	..	..	N.E.	Moderate and fine under all sail.
,, 31	35 38	16 30	150	..	..	N.E.	Unsteady breezes and fine weather.
Sept. 1	33 01	17 16	163	..	..	N.E.	A.M. Steady breezes and fine weather. Noon, saw Madeira S. ¼ W. 4 leagues the West Point. Passed it and caught the N.E. trade.
	Carried	forward .	1108	58	177		

VOYAGE of the Ship "EARL OF HARDWICKE"—*continued.*

1840.	Latitude.	Longitude.	Whole Distance Sailed.	Hours Steaming.	Distance Steamed.	Winds.	Remarks, &c.
	Brought fo	rward. .	1108	58	177		
	North. ° ′	West. ° ′					
Sept. 7	18 52	21 26	883	3	7½	N.E. Calm.	The N.E. trade, which commenced with a fine fresh breeze, soon became light and unsteady; continued running with it under all sail until the morning of the 7th instant, when it appeared decreasing towards a calm. At 9 A.M. commenced steaming; made 17 revolutions. Noon calm; position in the margin; the engine propelling the ship 4½ knots in a perfect calm.
,, 8	16 41	21 38	132	24	72	E.N.E.	A.M. Light easterly airs and calms, making 17 to 20 revolutions.
,, 9	14 57	21 33	104	24	70	N.E. Calm.	A.M. Light airs and calms, a swell checking the engine's power. Sunset, a breeze from N.W. Increasing, disconnected, and left off steam.
,, 10	12 44	21 44	134	10	30	North. East. S.S.E.	A.M. Moderate breezes and fine clear weather. Noon, ditto, a southerly swell; 8 P.M., inclining to calm: commenced steaming, 19 revolutions, light N.W. airs assisting.
,, 11	10 51	22 09	115	10	35	N.E. East. Calm. S.S.E.	A.M. Light airs and calms, with a southerly swell; engine making 16 to 19 revolutions. At 6.20 a breeze from east; disconnected and eased the fires. Noon, light breezes from the southward, and cloudy. At 8 began steaming. At 9 a heavy squall from S.E. short sail, hove-to, and disconnected; carried away the fore-sheet, which got foul of the paddles. Under double reefs; fresh breezes.
,, 12	10 22	21 58	32	3½	8½	S. by W. W.S. Calm. N.W.	A.M. Fresh breezes and cloudy, with rain and squalls. At 6, moderate, all sail set. At 9.30 light breezes; began steaming. Noon, calm, a confused southerly swell checking the engine's power, making only 13 revolutions, and propelling the ship 2½ knots per hour against the swell. P.M. Sharp squalls, 6.30, hove to and disconnected.
,, 13	9 03	20 55	101	10	25	N.W. W S.W.	Light airs and squally; a heavy southerly swell. At 10.30 began steaming. Noon, squally with rain, the ship running 8½ knots; the engine making 21 revolutions. Sunset more steady; settled looking weather, and moderate breezes, but a heavy southerly swell.
,, 14	7 37	19 12	137	24	50	S.W.	Light steady breezes from S.W., ship close hauled, engine assisting and making 16 to 18 revolutions. Noon moderate and fine; observed two of the lee paddles broken at the outer arm. P.M., moderate breezes, varying in strength, and cloudy; the engine making from 18 to 22 revolutions, and jerking with an uneven motion, on account of the two broken paddles and the swell.
,, 15	5 36	17 30	161	15½	30	S.W.W.	A.M. Squally, with rain, the ship running 8 knots. At 3.30 hove-to, disconnected, and let off the steam. Noon, squally, with showers; unshipped half the paddles. Steady breezes, all sail set.
	South.						
,, 29	18 56	17 14	2082	..	..	..	From 15th to the 22nd September, encountered S.S.W. and southerly winds. Crossed the Line on the latter day in long. 12° W., when the southerly winds had gradually hauled round to the S.E. trade, which proved a moderate one, and set the ship to only 18° 44′ W. long. On 29th September, at noon, at the place noted in the margin, towards evening, the wind, which was from N.E., had gradually decreased, inclining to calm. At 11.30 began steaming, and steered S. by E.
	Carried fo	rward. .	4989	182	505		

VOYAGE of the Ship "EARL OF HARDWICKE"—*continued.*

1840.	Latitude.	Longitude.	Whole Distance Sailed.	Hours Steaming.	Distance Steamed.	Winds.	Remarks, &c.
	Brought forward. .		4989	182	505		
	South. ° ′	East. ° ′					
Sept. 30	20 21	16 18	100	12½ 1	31 2	Calm. N.W.	A.M., light airs ; a heavy swell on the beam. At 2 a perfect calm, engine making 17 revolutions, and propelling the ship 3½ knots, the ship rolling deep. Noon, a breeze, increasing from northward and clear. 1 P.M. disconnected, and going 6 knots.
October 10	30 31	5 07	1008	..	..	Easterly. Variable. S. by E.	Unsteady, variable; contrary winds prevailed until the 10th October, during no period of which steam could be used. Noon, at the place noted in the margin P.M., light airs, declining to a calm. At 6, began steaming, a heavy swell on the starboard beam, making the ship roll deep, the paddles alternately immersed and out of the water, making 15 revolutions, and propelling the ship 2¾ knots. At 8, a light air from the southward, furled all sails, and continued to steam 2¾ knots, with 15 revolutions.
,, 11	31 32	4 43	65	18	49	Variable. Calm. East.	A.M., calm and fine weather ; a swell on the beam as before ; steaming 2¾ knots. Noon, calms and variable airs ; all sail. At 6 P.M. calm ; furled all sails. 9.30, a breeze from the east, disconnected and made sail.
,, 12	33 02	3 30	109	11	30	East. North. Calm.	A.M., light breezes from the eastward decreasing. At 4, began steaming. At 6.30, a light breeze, disconnected. P.M., decreasing breezes. At 11.20, began steaming ; a swell on the beam as before.
,, 13	34 35	2 39	103	6	17	N. to N.W.	A.M. Light airs and cloudy, 17 revolutions. At 6.30, a light breeze from north increasing, disconnected. Noon, a steady breeze, and cloudy, with rain. Having now reached those high southern latitudes where calms are unusual, unshipped the whole of the paddles and the funnel.
Nov. 10	27 59	87 23	4799	..	..	N.E. to N.W.	From the 13th October, employed running to the eastward, but found winds more unfavourable than generally prevail in the parallels of 38 and 40 degrees south latitude ; after which steered to the northward to reach the S.E. trade, on the 10th of November, position in the margin, where calms are occasionally encountered, having in the interval repacked the cylinders, cleaned the boilers throughout, and overhauled the engine ; shipped the funnel and upper paddles to be in readiness. P.M., the breeze decreasing and inclining to calm. At 6.30, commenced steaming, a light air from N.W. Engine making 14 revolutions, and propelling the ship 2½ knots, and 2¾, furled all sails, and steered N.N.E. A westerly swell making the ship roll.
,, 11	27 10	87 45	53	17	40	N.E. N.W. S.E.	A.M., light airs continuing from the northward ; 14 and 15 revolutions, 2½ knots. At 6, a breeze from N.E. made all sail, and steered N.N.W., and kept the engine going, increased to 4½ knots. P.M. Light airs and calms, a westerly swell continuing. At 10, air increasing, breeze from S.E. disconnected and left off the steam, having caught the S.E. trade.
,, 12	25 33	87 48	98	10	25	Easterly.	A.M. Unsteady breezes from east and cloudy. At daylight unshipped half the paddles. Noon, steady breezes and fine weather.
	North.						
,, 23	2 02	93 46	1793	..	..	N.E. S.E. Calm.	From the 12th to the 23rd instant, not having calms, the engine was not required at noon, the ship's position in the margin. P.M. Light breezes decreasing ; employed getting the engine ready, the ship having lightened considerably, drawing about 15½ bodily ; let out the reefs of the paddles. Mid. calm, commenced steaming.
	Carried forward. .		13,116	257	699		

VOYAGE of the Ship "EARL OF HARDWICKE"—*continued.*

1840.	Latitude.	Longitude.	Whole Distance Sailed.	Hours Steaming.	Distance Steamed.	Winds.	Remarks, &c.
	Brought fo South. ° ′	rward. . East. ° ′	13,116	257	699		
Nov. 24	3 35	93 19	93	12	36	N.E. Calm. S.W.	Light airs from N.E.N. and cloudy weather. Steered N.W. by N., constant sheet lightning; engine making 14 to 17 revolutions, and propelling the ship 3 and 3½ knots. P.M., light variable airs altered the course occasionally, to benefit by the light airs in steering to the northward, and kept the engine going. At 8, west breezes and cloudy.
,, 25	5 13	93 01	100	17	37	Westerly. Calm. Westerly. East.	A.M. Squally with rain, the feed-pipe having broke had been parcelled, but being leaky, did not supply the boiler sufficiently. No steam generated, disconnected to repair it, and refilled the boiler with the force-pump, the hot well became too hot to condense; took off the apron, and employed cooling it with cold water. At 7, commenced steaming. At 10, a light breeze ahead, furled sails; the engine making 14 and 15 revolutions, and propelling the ship only 1¾. At 11, the feed-pipe again leaky; stopped the engine to repair. Noon calm, the pipe being repaired at 12.30 began steaming. At 1, a light air from westward, made all sail, 16 revolutions. Midnight, light variable airs with rain.
,, 26	7 14	93 08	122	18	38	East. E.N.E.	A.M. Light breezes from the eastward increasing. At 6 hove to, disconnected and unshipped half the paddles. Mem.—As the engine had propelled the ship more slowly than before, supposed the paddles to be too deep; reefed them as before; engineer repairing the feed-pipe. Noon, light breezes from the eastward; saw the Great Nicobar, east 10 leagues. P.M., moderate breezes from eastward, and passing showers.
December 4	16 35	91 13	722	..	..	N.E. by N. N.E.	From the 26th November to the 4th December, encountered the usual N.E. monsoon wind, which had set in steadily. At noon, latitude and longitude as per margin. P.M., steady light breeze from N.E. decrease. Sunset, light breeze declining. At 11, ship going only 1 knot, began steaming, and increased her rate to 3, 4, and 5 knots; a light air assisting.
,, 5	18 10	By Lunar 90 04	102	13	40	N.E.	A.M. Light airs from N.E., engine making 16 revolutions. At 8, light breezes, stopped the engine, and found the ship sail 2½ knots. Gave her the steam, and found it increased her rate to 5½ knots. Noon, light breezes and fine clear weather, making 16 to 21 revolutions; a light breeze assisting.
,, 6	19 36	89 24	97	24	54	N.E. by E. to N. by E.	A.M. Light breezes and fine clear weather; wind varying from N.E. by E. to N. by E., employed working to the northward, assisted by the engine. Noon, light breezes from N.N.E. disconnected. P.M., the wind decreasing, recommenced steaming.
,, 7	20 33	88 36	74	23	42	N.E. by N. N. by E. N. by W.	A.M., light breezes from N.E. by N., all sail set, steaming with full power, and making 20 revolutions. At 8, the wind more northerly, disconnected, having very few coals remaining. P.M., light airs from N.N.E., employed turning to windward.
,, 8	21 04	88 14	40	..	..	N.N.E.	A.M., moderate breezes from N.N.E. At 2, saw the pilot vessel. At 8, Mr. Cooper, master pilot, came on board, and took charge of the ship. At 9.30, came to near the Hoogly Light to stop tide.
		Total. .	14,466	364	946		

APPENDIX IV.

The accompanying Table of the Velocity of Steam Ships with Engines of various Powers is the result of numerous experiments with steam vessels ranging from the burthen of one thousand tons, down to that of sixty tons, under different circumstances of draught of water; but invariably in calm smooth water without either current or tide.

This Table fully corroborates the facts contained in the memoir, and the deductions drawn from them, while it is evidence of the small power requisite to propel a vessel of considerable magnitude at a moderate speed: it also shows that to gain a velocity which shall exceed ten miles per hour, it becomes necessary to augment the power of the engine in an immense degree.

The Table terminates in all cases with the velocity of 13 knots, equal to 15 statute miles per hour: this speed has not hitherto been exceeded, while in order to arrive at it, the whole tonnage of the vessel is occupied by the engine, leaving no room for cargo, and only space for the fuel necessary for about two days' consumption.

This immense speed has been attained by two or three vessels only, and it has been arrived at by adapting the vessel for speed alone—making every other quality of the ship subservient to this one object. The vessels running on the Thames are known to be the fastest in the kingdom: the most celebrated among them are the "Ruby," "Railway," "Blackwall," "Brunswick," and "Eclipse," the whole of which were built and had their engines constructed and fitted in London.

S. S.

TABLE OF THE VELOCITIES OF STEAM SHIPS.

The top line of Figures represents the number of Horses' Power ranging from 30 Horses to 300 Horses.

This side Line represents the Tonnage of the Steam Ship ranging from 100 tons to 1,200 tons.

Tons	300	290	280	270	260	250	240	231	222	213	204	195	186	178	167	158	150	144	137	131	125	118	112	106	100	95	90	85	80	76	72	68	64	60	57	54	51	48	45	42	39	36	34	32	31	30
1200	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5	5 3/5	5 2/5	5 1/5	5	4 4/5	4 3/5	4 2/5	4 1/5	4
1150	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5	5 3/5	5 2/5	5 1/5	5	4 4/5	4 3/5	4 2/5	4 1/5
1100	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5	5 3/5	5 2/5	5 1/5	5	4 4/5	4 3/5	4 2/5
1050	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5	5 3/5	5 2/5	5 1/5	5	4 4/5	4 3/5
1000	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5	5 3/5	5 2/5	5 1/5	5	4 4/5
955	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5	5 3/5	5 2/5	5 1/5	5
910	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5	5 3/5	5 2/5	5 1/5
865	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5	5 3/5	5 2/5
820	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5	5 3/5
780	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6	5 4/5
740	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6	6
700	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6	6 1/6
660	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6	6 2/6
625	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6	6 3/6
590	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6	6 4/6
555	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7	6 5/6
520	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7	7
490	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7	7 1/7
460	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7	7 2/7
430	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7	7 3/7
410	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7	7 4/7
375	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7	7 5/7
350	13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8	7 6/7
325		13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8	8
300			13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8	8 1/8
280				13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8	8 2/8
260					13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8	8 3/8
240						13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8	8 4/8
220							13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8	8 5/8
205								13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8	8 6/8
190									13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9	8 7/8
175										13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9	9
160											13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9	9 1/9
150												13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9	9 2/9
140													13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9	9 3/9
130														13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9	9 4/9
120															13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9	9 5/9
115																13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9	9 6/9
110																	13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9	9 7/9
109																		13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10	9 8/9
107																			13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9	10
105																				13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9	10 1/9
103																					13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9	10 2/9
102																						13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9	10 3/9
101																							13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9	10 4/9
100																								13	12 8/9	12 7/9	12 6/9	12 5/9	12 4/9	12 3/9	12 2/9	12 1/9	12	11 8/9	11 7/9	11 6/9	11 5/9	11 4/9	11 3/9	11 2/9	11 1/9	11	10 8/9	10 7/9	10 6/9	10 5/9

The weight of Engines per Horse Power under 200 Horses may be estimated at 1 ton per Horse, and above that at 23 cwt. per Horse.

The intermediate spaces represent the number of Nautical Knots a Ship of known Tonnage, with a given Power, will travel through still water, per hour.

The Table is constructed upon the Principle, that each Vessel will carry, at a proper draught, a weight equal to her measurement tonnage, and that such a Vessel will admit of a proper modern form being given to her, suitable for a good Sea Steamer.

The Tonnage is calculated by the Old Rule, "13th of George III. cap. 74." "Thus from the length subtract 3/5th of the breadth, then multiply this length by the breadth, and that product by half the breadth, that sum being divided by 94, the quotient is deemed the true tonnage."

In the above Table, each Ship is presumed to be loaded equal to her Tonnage, either by the Engines, Cargo, or Coal, and this Table terminates at 13 Knots, at which speed the weight of the Engines only becomes the full Load.

Note.—The Nautical Knot or Mile is in the proportion of 6 to 7 of the Statute Mile, that is, 6 Nautical Miles are equal to 7 Statute Miles.

SAMUEL SEAWARD, 1841.

Back of
Foldout
Not Imaged

XVIII.—*On the Percussive or Instantaneous Action of Steam and other Aëriform Fluids.*

By JOSIAH PARKES, M. Inst. C. E.

Read May 25, 1841.

In my last communication, "On the Action of Steam in Cornish Single Pumping Engines," it was shown, by the analysis of three examples, that the simple elastic force exerted throughout the stroke—as ascertained by the ratio of the volumes of water, and steam consumed—was insufficient to overcome the opposed resistance. The appearance of this deficiency of power, on the preceding well known, and usual manner of estimating it, led me to an examination of the particular circumstances under which the steam is employed in those engines; and I came to the conclusion that though steam, in a state of quiescence, or of equilibrium with surrounding matter, possesses only a certain pressure at given densities, it will produce, under the conditions of its application, in such engines, a peculiar and specific action—independent of that due to its simple elastic force—which action being imparted to the piston, the effect will necessarily be exhibited in the final result. This action I then denominated the steam's percussive or instantaneous force, as contradistinguished from the exertion of its simple elastic continuous force (see ante p. 268); under the impression that the term percussion would convey to practical men a definite idea of the instantaneous force to which the piston would be subjected, on the sudden opening of the communication between the boiler and the cylinder.

For proofs of such a force having operated, I then relied upon, and cited various phenomena attendant on the working of the engines; considering that the substantiation of the views advanced should rather depend on facts disclosed by such phenomena, than be derived from any extraneous data, or phenomena, however close the analogies might be. If reasoning alone could have been deemed sufficient to establish the soundness of these views, I might have relied upon the general law of physics, that all matter, in motion, whether solid, liquid, or aëriform, has a specific momentum; deducing, thence, that a body at rest, like the piston of an engine which opposes the motion of the aëriform fluid steam, must be struck by a force, identical, in nature, with that denominated percussion, when communicated by liquids or solids; also, that the effect of impact by one body on another, must vary only in degree, not in character; and, then, it might have been conceded to me to attribute to this action a share in the effects obtained by a Cornish engine.

But this mode of disposing of the subject would not have been satisfactory either to other engineers or to myself. Neither the fact, nor the amount of the deficiency of the steam's simple elastic force, compared with the resistance, were previously established. The extent of the steam's expansive action—its elasticity at the termination of the stroke, relatively to the load of water, and to the absolute resistance—as well as other important practical questions—required explanation. All these questions were involved in the general one of the steam's action in a Cornish engine. In default of positive experimental determinations, I ventured to assume that the apparent deficiency of the steam's simple elastic force might be compensated by the force of percussion; thus, the former amount was used, as the measure of the latter, in the analysis. I considered that I was not departing from the strict rules of philosophical reasoning, by applying this single deduction; being unable to discover any other source, whence the deficiency of power could be supplied; and being of opinion that the steam's percussive or instantaneous action was equivalent to the effect then assigned to it. It must be remembered that the elastic force of the steam, as determined by the method of volumes—that the continuous action due to that elastic force, during the steam's contact with the piston—that the force of the resistance opposed throughout the stroke—are ascertained with sufficient precision; and that, in the absence of all other explanations of the means by which a portion of such resistance may be overcome, any cause which has a real existence may be considered to be a true cause. That such a cause does exist—whatever may be the amount to be referred to it—will, I think, appear from the facts which it is my present object to lay before the Institution, in further corroboration of the opinions previously advanced. These facts are derived from a number of experiments, which show, in the most direct manner, the existence and great effect of percussive or instantaneous action in steam; and furnish an approximation towards an estimate of its amount at given elasticities. I shall also adduce some phenomena of the same nature from other aëriform fluids. [Note A.]

Experiments with the Indicator.

The results to which I shall first allude were obtained while engaged, professionally, in testing with the indicator the power of different engines. The diagram drawn by this instrument will, under certain conditions of structure, and use, afford tolerably correct transcripts of the steam's method of action, and of its force upon the piston of an engine. Forty-one diagrams were taken from four engines by different indicators; they supply examples of the steam's percussive or instantaneous action, through a range of absolute pressures varying between 6·5 lbs. and 34·7 lbs. per square inch.

These diagrams manifest that, in every instance, the indicator piston was driven upwards, higher than the steam's simple elastic force could have raised it. In many instances, a pressure is marked, greater than that which existed in the boiler: though, in every case, the action of the governor on the throttle valve caused the steam's elasticity in the cylinder to be considerably less than that in the boiler. When the steam valve, or the indicator cock is very suddenly opened, at high pressures, the motion of the indicator piston is so instantaneous, and its ascent so rapid, as scarcely to be followed by the eye; but, the pencil transcribes the effect on the diagram, and if the finger be held within the range of the extremity of the piston rod, above the true height to which the steam's simple pressure would raise it, it is powerfully struck. This phenomenon has occurred in all these instances during the regular working of the engines; that is, on each fresh admission of steam; and it takes place to a diminished extent, the more gradually the steam is admitted. [Note B.]

Experiment on the Mercurial Column.

I had an opportunity, whilst conducting some experiments on the newly invented Disc engine, of ascertaining on a cistern gauge, the height to which mercury would be raised in a glass tube, by suddenly letting the full pressure of the steam in the boiler upon the surface of the mercury in the cistern. The pipe and cock connecting the boiler with the gauge were one inch in diameter. The cock was first gradually opened, and the mercury rose slowly in the tube, exhibiting the steam's pressure in the boiler to be 40 lbs. above the atmosphere; equal to 54·71 lbs. absolute elasticity. The cock was then shut, and the mercury subsided into the cistern from condensation. The cock was again opened as rapidly as possible, and the mercurial column instantly indicated 59 lbs. above the atmosphere, or 73·71 lbs. absolute force. The effect was produced instantaneously, and it required close attention by the observers to determine the precise height to which the mercury ascended in the tube. Other experiments were made in a similar manner at pressures diminishing from 40 to 21 lbs. above the atmosphere, and, in every case, the steam's sudden impact elevated the mercury to a height so nearly corresponding with the ratio of the foregoing, that I have deemed it only necessary to cite one result in the following table. [Note C.]

Experiment with steam of 26 atmospheres' elasticity.

Shortly after my last Paper was read, Mr. A. M. Perkins informed me that he thought he could afford me an example of the effect of the steam's percussive or instantaneous action, at elasticities much higher than those in common use. I found at his manufactory a steam generator to supply a steam gun, capable of resisting a pressure of many atmospheres. It was connected with an indicator constructed similarly to the common steam engine instruments, as regards its cylinder and piston, but denoting the pressures by an index moving round a divided dial plate, like the spring balance. A two way cock formed a communication between the instrument and the steam in the boiler, or the atmosphere, so that the steam's pressure could be applied to the piston, and removed at will. Mr. Perkins justly concluded that if I was correct in ascribing a superior effect to the sudden and full opening of the admission valve, in a Cornish engine, the index of his dial would be carried beyond the degree indicative of the steam's simple elasticity, on suddenly opening the cock of the generator.

Such was the effect; but the velocity given to the index was so great as to render its motion quite invisible. The eye could only distinguish that the index, which previously stood at zero, now marked 26 atmospheres, which was the pressure in the generator; but, we ascertained that it had been driven round the dial as far as 36 atmospheres. This was determined, on repeated trials, by applying the finger, or a strip of lead, to the dial plate, and moving it till the extreme stroke of the index was only just perceptible. [Note D.]

Table 1.

The results of all the foregoing experiments are classified in the following Table, commencing at the lowest elasticities, being those obtained from steam below atmospheric pressure.

The pressures marked in column 3 are those of the simple elastic force of the steam which existed in the cylinders, at the commencement of the down stroke, as shown in figs. 1 and 2. [Note B.] Column 4 registers the highest pressures denoted by the indicators, or mercurial gauge, on the instant of the steam's admission. The term *momentum* adopted in the heading of column 4 may be objected to on some grounds; but after much consideration, it appears the best in common use to include all the action besides that due to simple pressure.

TABLE I.

Number of Experiments.	Mean pressure in the Boilers.	Pressure due to the Steam's Simple Elasticity	Pressure due to Momentum.	Difference of Elasticity and Momentum.	Particulars of the Engines, and Remarks.
No.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	
1	16·	6·50	9·00	2·50	Condensing engine, Great Western Company's Works, Bristol. Working idle. Diameter of cylinder 17 in. Length of stroke . . 30 „ 40 strokes per minute. Diagram taken by Mr. Humphrys.
2		9·71	13·41	3·70	Condensing engine at Mr. Jas. Hancock's, Broadwall, London, working with a very light load. Diameter of cylinder 13¾ in. Length of stroke . 28 „ 42 strokes per minute.
3		10·71	12·11	1·40	
4		11·00	13·51	2·51	
5		11·11	12·51	1·40	
6		11·71	13·21	1·50	
7	16·	11·71	16·71	5·00	
8		15·71	18·71	3·00	Ditto, working with a heavier load.
9		16·21	18·91	2·70	
10		16·41	20·71	4·30	
11		16·71	19·21	2·50	
12		16·96	19·71	2·75	
13		17·21	20·21	3·00	
14		17·21	22·46	5·25	
15		17·71	20·71	3·00	
16		17·71	21·21	3·50	
17	20·	17·96	21·21	3·25	
18		21·21	23·71	2·50	Two condensing engines at Mr. Thos. Cubitt's, Thames Bank, London. Diameter of cylinder 12 in. Length of stroke . 36 „ 42 strokes per minute.
19		22·21	25·00	2·79	
20		23·71	29·21	5·50	
21		25·21	29·51	4·30	
22		25·21	30·21	5·00	
23		26·21	30·21	4·00	
24		27·21	30·00	2·79	
25		28·90	32·41	3·51	
26		29·21	34·31	5·10	
27		29·30	32·21	2·91	
28		29·30	33·71	4·41	
29	34·71	29·71	35·71	6·00	

TABLE I—*continued.*

Number of Experiments.	Mean pressure in the Boilers.	Pressure due to the Steam's Simple Elasticity	Pressure due to Momentum.	Difference of Elasticity and Momentum.	Particulars of the Engines, and Remarks.
No.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	
30		28·71	37·71	9·00	Double cylinder expansive engine by Mr. Edward Humphrys, at Parrott's flour-mill, Broad-street, Lambeth.
31		31·71	41·71	10·00	
32		32·21	40·21	8·00	Diagrams from small cylinder.
33		32·21	40·71	8·50	Diameter of cylinder 8 in. Length of stroke . 32 „
34		32·71	37·71	5·00	42 strokes per minute.
35		32·71	44·71	12·00	
36		33·71	37·71	4·00	
37		33·71	43·71	10·00	
38		33·91	45·71	11·80	
39		34·21	47·71	13·50	
40		34·46	44·96	10·50	
41	37·71	34·71	44·21	9·50	
42	54·71	..	73·71	19·00	Experiment on a mercurial gauge at the Disc engine Company's Works, Birmingham.
43	382·46	..	529·56	147·10	Experiment on Mr. Perkins's generator and index, London.
1	2	3	4	5	

Although, as might be expected, the indicator diagrams—taken as they were from differect engines, and the valves of which were opened with greater or less rapidity—do not furnish a scale exhibiting an uniform increase of percussive or instantaneous action, for increasing pressures, yet the fact is demonstrated that this action took place in every instance; and that its intensity increases with the steam's elasticity.

Approximate ratio between the elastic and percussive force of Steam.

From these experiments an approximation may be made to the amount of the action due to the steam's momentum.

Assuming Mr. Perkins's dial plate to have been truly graduated, it results that, for each pound of the steam's simple pressure, (experiment 43,) an instantaneous action was exerted on the piston equal to 1·384 lbs. per sq. in. The ratio on the mercurial column, (experiment 42,) is as 1 to 1·347. Experiment 39, which exhibits the maximum effect obtained at the highest ranges of pressure taken by the indicator, gives a ratio of 1 to 1·394. Experiment 7 shows a ratio of 1 to 1·427. It is important to notice that whilst taking this diagram, and that in experiment 2, which gave a ratio of 1 to 1·381, the excentric rod was disengaged, and the valve *handed*, which occasioned a fuller and more instantaneous entrance of the steam into the cylinder, than could be effected by the excentric's motion in the other experiments on the same engine.

It must be observed that none of these experiments were made with the expectation of arriving at an exact determination of the abstract amount of percussive or instantaneous action. An apparatus for experimentally solving this problem would require to be constructed expressly for the purpose, for the reasons hereinafter assigned (page 422). In consequence, therefore, of the inadequacy of the instruments, I can only employ the maxima of the effects denoted, as the nearest approximation to the truth; for, the highest result marked at any one elasticity, may be at all times obtained, from steam of similar elasticity, by using proper means.

Table 2. The following table exhibits the greatest results in a scale descending from the highest to the lowest elasticities experimented upon :—

TABLE II.

Number of Experiments Table I.	Pressure due to the Steam's Simple Elasticity	Pressure due to Momentum.	Difference of Elasticity and Momentum.	Ratio of Elasticity and Momentum.
No.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	Ratio.
43	382·46	529·56	147·10	1 to 1·384
42	54·71	73·71	19·00	1 to 1·347
39	34·21	47·71	13·50	1 to 1·394
7	11·71	16·71	5·00	1 to 1·427
2	9·71	13·41	3·70	1 to 1·381
1	6·50	9·00	2·50	1 to 1·384
Means	83·21	115·01	31·80	1 to 1·386

The results of these experiments are in perfect accordance with the general principle that the increase of force, arising from the steam's momentum, is in the direct ratio of its elasticity.

That the increment of the percussive or instantaneous action should be in simple proportion to the increment of the elastic force of steam, appears to be consistent with its nature, as a perfectly elastic, and, dynamically considered, perfectly imponderable body ; for, the weight of steam operating in an engine cannot form any appreciable quantity of its mechanical effort or effect. The motion of steam is simply due to its elasticity; or, more properly speaking, to the repulsive forces which exist between the particles: the velocity of that motion, and, consequently, the momentum of the steam—since it may be considered imponderable—will also depend, simply, on the elasticity. When these repulsive forces are in equilibrio with each other, or are counterbalanced by the reaction of any containing surface, the steam is at rest; but, so soon as that equilibrium is disturbed, as by opening a passage, or removing part of the containing surface, motion ensues; unless steam, of the same elasticity, be on the other side; in which case, there will be no motion, since the elasticities will then counterpoise each other. The velocity of the steam will depend on the difference of the elasticities; and, that this difference may produce its full effect —or that the steam may have the greatest velocity—the opposing surface must be withdrawn, or the communication made, instantaneously. As this, however, is not, strictly speaking, practicable, the more quickly the communication can be effected, the greater will be the velocity and momentum of the steam issuing from the boiler into the cylinder, and the greater the percussive or instantaneous action on the piston. [Note E.]

Difference between a single-acting and crank engine, on the instant of the steam's admission.

I will now proceed to apply the information furnished by these instrumental tests to illustrate, still further, the theory of the steam's action in Cornish single pumping engines.

It is apparent that, in all the experiments above cited, a greater or less amount of percussive or instantaneous action was transmitted to the piston of an engine. It is also seen that in two experiments, distinct from an engine, the sudden admission of steam upon the surface of mercury in the basin of a gauge, and upon a piston connected with an index, produced an effect upon the column of mercury, and upon the index, more than a third greater than the actual elastic force of the steam. The fact of the steam's percussive action is irrespective of the engine; but its dynamic use depends on the circumstances of an engine at the time of its application. All the indicator diagrams, referred to, show that the valves of the engines were so set, as to let the steam upon the pistons, when the engines were absolutely at rest; or, more correctly, when the piston was on the point of reaching the extent of its stroke. Such, or very nearly similar, is the condition of all reciprocating, double-acting, rotative engines. At this instant of time, the connecting rod and crank are in the same line—in beam engines, vertical—so that no amount of force, then impressed on the piston, can act with any useful effect. On admitting steam to engines so circumstanced, no other result is produced than a sudden pressure, which is perfectly useless. The simple elastic force of the steam in the cylinder acts efficiently, as soon as the altered position of the crank, through the agency of the fly-wheel, permits the piston to move: but, no motion, no useful effect, is produced by the steam's percussive or instantaneous action; as the condition of the engine, at the time of its being exerted, prohibits motion. The piston is not free to move at the instant of the admission of the steam, and its initial percussive or instantaneous action is expended ineffectively on the parts of the machine.

The condition of single acting engines is entirely different. The beam and scales of a balance truly represent it. There is nothing to oppose the descent of the piston on the instant of applying any kind of force to it, which exceeds the amount of the inertia of the mass, and other resistances. Thus, the piston is prepared—it is in the best condition—to receive, and yield to the exertion of any preponderating effort upon its surface; there is no crank prohibiting motion, at that instant, as in rotative engines; whatever, therefore, is the amount of the steam's force, and, of whatever nature that force may be, the whole must tell upon the piston, and be accounted for in the effect. By applying the ratio just given, of the excess of force arising from the steam's momentum over that of its simple elasticity, to the examples of the Cornish engine examined in my last paper, it will be found that the effect then attributed to it, is less than the *maximum* which can be obtained from the pressures employed by the Cornish engineers. [Note F.]

Phenomenon illustrative of percussive action in Cornish engines.

If further proof were wanting of the great excess of the steam's initial force over its simple elasticity, as well as of the nature of that force, I think it will be found in the following phenomenon communicated to me by Mr. William West, the designer of the Fowey Consols engine. He stated to me that additional load had been laid upon that engine, since the period of the trial which gave the facts used in my former investigation; and that he was fearful the cylinder cover would give way, as he observed it to "breathe upwards," very sensibly, at each admission of steam. I requested him to measure very carefully the amount of this springing of the cover, and to supply me with the particulars of its weight, and strength of material.

The cylinder is 80 inches diameter. The cover weighs 4 tons. Its bottom is flat, $2\frac{1}{2}$ inches thick, strengthened on the upper side with 16 ribs, radiating between the centre and circumference, and averaging $2\frac{3}{4}$ inches deep, by $1\frac{1}{2}$ inch thick.

Notwithstanding the massiveness and strength of this construction, it was ascertained that the cover is sprung upwards at the centre $\frac{5}{32}$ of an inch by steam of 49·71 lbs., and $\frac{8}{32}$, or $\frac{1}{4}$ of an inch, by steam of 61·71 lbs. per square inch, absolute pressure in the boiler. This effect is instantaneous on the steam's admission.

To complete this experiment, Mr. West also tried, at my instance, to what amount the cover would be sprung by maintaining steam, in a state of quiescence, between it and the piston, at the full pressure of the steam in the boiler. He found, as I anticipated, that no change of shape whatever was produced in the cover by steam under these circumstances. He brought down the piston to the bottom of the cylinder, and let the engine hang, for some time, on the spring beams; the steam valve being kept open to establish a perfect equilibrium between the steam in the boilers, and cylinder. Its elasticity was 54·71 lbs. per square inch. Mr. West observes: "These experiments have been made as accurately as possible; there have been many covers, of the same dimensions, broken in Cornwall by the steam's blow." [Note G.]

Additional phenomenon illustrative of percussive action in Cornish engines.

I will now consider another phenomenon, also supplied by the engine, and which seems to me to be equally demonstrative of the great effect of the percussive or instantaneous action.

In the section of my last paper (p. 280) explaining the action of the elastic cushion of steam which brings the engine to rest, I restricted myself to the observation that some gain might arise from it, as it is a quantity of steam recovered at the end of each stroke—a quantity, in fact, replaced at each reciprocation—and which by its ultimate expansion below its original pressure, produces useful effect. I did not enter, at that time, into a consideration of the influence which the greater or less volume of this cushion might have upon the economy of the engine.

The nature of the work done by a single acting engine, having no crank, or other mechanical means of regulating the length of a stroke, requires that the equilibrium valve shall be closed in time to imprison, between the piston and cover, steam of a pressure sufficiently great to bring the engine to rest, and prevent the piston from striking the cover. The time of closing that valve thus partly regulates the length of the working stroke, and positively determines the volume of the cushion. But it appeared to me that the less this volume, the greater should be the effect of the percussive or instantaneous action of the steam; and consequently, the greater the economy produced—or, what is the same thing, that the greater the space into which the initial steam has to expand, on entering the cylinder, the percussive force, or instantaneous action on the piston would be diminished in a corresponding degree. The inference, therefore, which I felt disposed to draw was, that the more the volume of the cushion could be contracted, the greater would be the force of the steam's impact on the piston.

Several Cornish engineers have since confirmed the soundness of this view: they assure me that, when making special trials of their engines, they always exceed, and sometimes very considerably, the amount of duty done in the regular course of work; for, when attending to the engines personally, they allow the piston to ascend till it nearly touches the cover; but they dare not trust the regular attendants to work in this manner.

It must be observed that, in effecting this increase of performance, no change has been made in the amount of resistance to be overcome; nor in the engine, with the exception that, on the termination of the return stroke, the piston rests nearer the cover. No change has been made in the elastic force of the steam in the boiler, nor in the lift, nor duration of the opening of the steam valve: the density of the steam in the cushion is also unaltered; its volume only is diminished. The consequence of this apparently simple circumstance is, that the working stroke is accomplished with a less consumption of steam. The cause of the increased effect seems to me to receive its explanation from the increased intensity of the steam's impact on the piston; and, hence, the superior economy of a small cushion. [Note H.]

Oscillation of Mercury in gauges.

A complete explanation of certain phenomena, commonly noticed by attendants on steam engines, appears to me to be afforded by the foregoing observations and experiments. I refer to the excessive oscillation of the mercurial column in steam, and vacuum gauges. It is a frequent remark that when an engine is in action, the mercury rises higher, and falls lower, than is due to the exertion of the steam's, or the atmosphere's simple elasticity.

On a steam valve being suddenly shut, a certain amount of reaction takes place upon every portion of the internal surface of the boiler, and upon every object exposed to its influence. Consequently, the mercurial column yields to its force, and is elevated to a height exceeding the true measure of the steam's simple elastic force. Several instances of the complete evacuation of mercury from these gauges have been communicated to me, when the column was superior to the simple pressure of the steam, or of the atmosphere. I will cite two, as sufficient for the illustration, though I could enumerate many other similar phenomena; but, as they all find their explanation in the principles before stated, it would be mere iteration to quote them.

Instance 1.—A safety valve being very suddenly closed, whilst the steam was blowing off, and the pressure of which did not exceed 3 lbs. above the atmosphere in the boiler, the whole of the mercury was expelled from a syphon gauge, though it contained sufficient to indicate truly 6 lbs pressure.

Instance 2.—The mercury of a syphon vacuum gauge was blown into the condenser of an engine, on suddenly opening a cock of communication, though it contained mercury enough for a perpendicular column of 33 inches. The vacuum in the condenser did not exceed 28 inches.

These incidents are not uncommon, and engine-men not unfrequently incur blame from their masters, by losing the mercury of their gauges; the masters asserting that the safety valves must have been overloaded to produce the effect. A case has been reported to me in which a valve was weighed, to decide a dispute of this kind, and the engineer was found to be correct in his assertion that the mercurial column exceeded the pressure on the safety valve, though the gauge was frequently evacuated of its contents. [Note I.]

Phenomena of the impact of one elastic fluid on another.

The illustrations hitherto adduced have been derived from, or considered with reference to, the cases of an elastic fluid being brought to act, suddenly, on a solid, or a liquid, but, in several of these cases, the percussive or instantaneous action is rendered available by transmission, or through the intervention of a mass of elastic fluid. This is the case in the Cornish engine, and, in further illustration of the subject, it may be important to consider some cases of the impact of one elastic fluid on another. With this view I shall select some experiments made by Mr. William Greener, gun-maker, of Newcastle-upon-Tyne. His object was to determine the distance to which a ball would be projected from a barrel, open at both ends; or, what is the same thing, to ascertain the repulsive power of the atmosphere against the explosive force of gunpowder. For this purpose, he prepared two barrels of 6 feet, and 8 feet, in length, their bore being No. 15 of the trade, or somewhat more than $\frac{5}{8}$ths of an inch diameter. From the various, and curious results obtained by Mr. Greener, I will select the following from the 8 feet barrel, as most suitable for my purpose.

A cartridge, containing three drams of powder, was pushed down to a touch-hole pierced at 32 inches from one end, so that a column of air remained behind the cartridge of 64 inches in length, acting as a breech. A ball, which fitted the bore well, but not over tight, was pushed down upon the cartridge. The barrel was then placed at a slight elevation, and fired. The ball was projected considerably above 200 yards. Mr. Greener observes, "This effect was not quite equal to that commonly obtained from a breeched barrel, as I used a smaller charge of powder; but it nearly equalled the resisting strength of the barrel, as was proved by another experiment."

In this last he employed four drams of powder, and placed three balls above the cartridge. On firing, the barrel burst, immediately behind the touch-hole or point of inflammation, on the column of air side. On this phenomenon Mr. Greener remarks, "It shows the repulsion of the particles of air driven back upon themselves to be equal to the strength of the barrel; and, no doubt, if the barrel had been strong enough, and the charge of powder increased, the velocity of the bullet would have been as great, when propelled by the reaction of the explosive force against this column of air, as if the barrel had been closed with a solid breech."—"It must be observed," he adds, "that it is only at a high velocity this wonderful arrangement of nature to curb our longing for extremes is shown. The mean velocity of the ball must at least equal that at which sound travels, for a perfect exhibition of the propulsive power of gunpowder acting against an air breech."

These experiments and remarks of Mr. Greener's are replete with instruction: they show that an aëriform elastic fluid, in a state of repose, closely resembles a liquid. When slowly acted upon, the mobility of our atmosphere is such as to yield easily in all directions, and to offer but little sensible resistance to the movement of objects through it; but, when only partially confined, and acted upon violently, and suddenly, the difficulty of displacing it is great. They show, also, that upon the velocity of the stroke depends the effect produced by the impact of aëriform fluids; and that a close analogy exists between the law of percussive action in aëriform fluids and solids, though the former must be considered as imponderable, and perfectly elastic.

Mr. Greener informed me that the thickness of the barrel, where the explosive force acted, was $\frac{5}{32}$ds of an inch; and he estimates the instantaneous pressure exerted as equal, in this case, to about 1,200 lbs. per square inch. In all these experiments but little smoke, and very few sparks, issued from the open breech; showing, together with the effect upon the projectile, that, for an instant, the air must have been most powerfully compressed: for, to use Mr. Greener's pertinent and expressive language, "the repulsion of the particles of air, driven back upon themselves," opposed a resistance nearly equal to that of a solid breech.

Scarcely a sound succeeds the firing of powder in these open-ended barrels; there is little or no vacuum to be filled up, as the air follows the gunpowder gas as fast as it escapes; and "it is thus proved," Mr. Greener observes, "that the report of a gun is altogether the work of air."—[Note K.]

Difficulty of Measuring the Percussive or Instantaneous Force of Aëriform Fluids.

Table 2 contains certain results, selected from the experiments with the indicator and mercurial column, affording the nearest *approximate* measures obtained of the pressure due to the steam's momentum at different elasticities. But Mr. Greener's extreme experiment with another elastic fluid, gunpowder gas, warns us both of the difficulty of contriving and of placing an instrument so as to indicate truly the force of percussion, or of the instantaneous action derived from aëriform fluids; and it induces doubts of the sufficiency of the instruments for that purpose employed in the preceding investigation.

In the experiment at Mr. Perkins's, atmospheric air formed the medium by which the force of the steam's instantaneous action was transmitted to the piston of the indicator, and exhibited by the index. It seems, however, certain that if a similar instrument had been applied to the extremity of Mr. Greener's gun-barrel, it would not have truly marked the force which operated on the other end of the column of air next the cartridge, at the instant of the explosion of the gunpowder. The phenomena of the projection of the ball, and of the bursting of the barrel, disclose the remarkable fact that the cushion of air, against which the force acted, was not displaced; or not to such an extent as to drive it out of the barrel. It is, therefore, evident that, at some certain distance from the point of explosion, in a barrel of greater length (and possibly in the one in question), no compression of the air would take place; and that an indicator placed at that spot would be unmoved by the explosion. Mr. Greener ascertained for me that the flame of the explosion, in the eight feet barrel, had only extended six inches from the touch-hole into the column of air. It may then be concluded that the atoms of air which lay nearest to and first received the stroke of the generated gas, became so condensed as to offer a resistance like a solid or liquid body, and that a very small portion of the initial momentary pressure was transmitted to the air at the extremity of the barrel. The exertion of a small amount of force, slowly applied, would expel all the air; but if the velocity of the impinging force be greater than that at which an aërial wave can be propagated along the barrel, then the air will present a base against which reaction can take place: and hence it is that the air served as a breech for the projection of the bullet.

Of the velocity of steam we know little, at any elasticity, but, it must be immensely great when expanding from a pressure of 26 atmospheres to that of 1 atmosphere; and it is possible that the column of air (about three feet in length) enclosed between the cock of the generator and the piston of the indicator, in the experiment at Mr. Perkins's, may not have transmitted the whole force of the steam's instantaneous action to the piston: it is possible that, in this case, as in Mr. Greener's gun, a portion of the force may have reacted against the confined air, and not have reached the piston. The same remarks apply to the mercurial gauge, from which the air in the pipe and above the mercury could not be expelled; and it is probable that if the glass tube had been of larger dimensions, particularly at the end immersed in the mercury, and if the steam pipe had been shorter, and larger at its junction with the cistern, the effect would have been increased.

I am the more earnest in drawing attention to the inadequacy of the instruments for determining the abstract amount of the action in question, as the experiments on the cylinder-cover convey to my mind an impression that the force which sprung it (and which has broken so many very massive covers) must have considerably exceeded in amount the pressure which would appear to have acted, as deduced from the ratio of the results in Table 2. A pressure of 54·7 lbs. per square inch, the steam being at rest, produced no change in the parallelism of the cover; yet, the momentum arising from steam of 5 lbs. less elasticity, viz., of 49·7 lbs. per square inch, sprung the cover $\frac{5}{32}$ds of an inch at the centre. By applying the ratio of 1·386 to 1, to 49·7 lbs., a force is obtained of 68·7 lbs. per square inch as the amount of the pressure due to the steam's momentum. I am disposed to doubt the adequacy of this force to spring the cover to the extent measured. Seeing that a quiescent force of 54·7 lbs. per square inch did not change the figure, it seems to me very questionable whether a force greater only by 14·0 lbs. per square inch would suffice; and whether the additional force of 16·6 lbs. per square inch would have sprung the cover to the further extent of $\frac{3}{32}$ds of an inch. However this may be, doubt cannot extend to the fact or degree of the springing; nor, I think, to the soundness of the conclusion that an amount of force, equal to that which acted upon the cylinder cover, must also have operated upon the piston of the engine, and have produced a corresponding dynamic effect.

The steam engine indicator, as commonly applied and as used in the foregoing experiments, is open to many objections as an instrument for detecting the value of forces acting with great suddenness, and velocity. The influx of the steam is usually much throttled by the contracted dimensions of the cock, and a column of air exists above, and in some cases below, the piston, which must impair its accuracy for this purpose. No reliance could be placed on its indications of such a force as that which sprung the cover of the Fowey Consols engine, unless it were so constructed and applied as to have the bottom of its piston coincident with the interior face of the cover on the instant of the steam's admission. Other precautions will also be suggested by these remarks as regards the construction and use both of this instrument, and of the mercurial gauge, in conducting experiments for measuring the percussive force of aëriform fluids.—[Note L.]

Phenomena of Steam-boiler Explosions.

In conclusion, I would suggest whether some of the hitherto unexplained phenomena, attending the explosion of steam-boilers, may not be explained by the foregoing experiments on the effect of instantaneous action.

The greater part of these phenomena are more or less characterized by suddenness; few exhibit signs of the operation of a gradually increasing or of a continued force. We have examples out of number of boilers, weighing many tons, embedded in masonry, and fastened down by various attachments, being projected to a vast height or distance without the slightest warning. I am unable to comprehend that the simple elastic force of steam can be made to separate a boiler into two parts, projecting the one into the atmosphere and leaving the other quiescent. I have still greater difficulty in understanding how the character of a projectile can be given to such a body as a boiler, without its having received, originally, a sudden impulse, using that term as implying momentary action, in contradistinction to continuous pressure. It is conceivable that a gradual increase in the elasticity of confined steam might dislocate some plates of a boiler, and even open several seams, at one and the same time; but in most of these cases the substance of plates is divided—in many cleanly and truly, as if done by a hammer and chisel, or shears. Such is not the effect of an uniformly increasing tensile strain: under these circumstances, extension of the metal would precede rupture. The development of some extraordinary and sudden power can alone, in my opinion, account for such effects.

As regards the projection of the whole body of a boiler from its seat, the operation of an immense force, combined with instantaneousness of action, seems necessary for the production of the effect.

Instances have occurred in which an internal fire-tube has been projected in one direction, and the cylindric shell in the opposite one. These and many other remarkable facts respecting the rupture of boilers, on the instant of starting and stopping engines, as also on the instant of suddenly closing and opening safety valves, may, it appears to me, be readily explained by some of the views here advanced.

The causes of these explosions are numerous, often insidious; and it is a subject involving so many considerations relative to the material and structure of boilers, their management, the action of the fire, and the action of sudden disturbances both within and without the vessel, that I can at present only allude to them as intimately connected with the subject of this communication.

JOSIAH PARKES.

12, Great College Street, Westminster,
April, 1841.

NOTES AND ILLUSTRATIONS.

(A.)

" In framing a theory which shall render a rational account of any natural phenomenon, we have *first* to consider the agents on which it depends, or the causes to which we regard it as ultimately referrible. These agents are not to be arbitrarily assumed; they must be such as we have good inductive grounds to believe do exist in nature, and do perform a part in phenomena analogous to those we would render an account of; or such, whose presence in the actual case can be demonstrated by unequivocal signs. They must be *veræ causæ*, in short, which we can not only show to exist, and to act, but the laws of whose action we can derive independently, by direct induction, from experiments purposely instituted; or, at least, make such suppositions respecting them as shall not be contrary to our experience, and which will remain to be verified by the coincidence of the conclusions we shall deduce from them, with facts. For example, in the theory of gravitation we suppose an agent, viz., force, or mechanical power, to act on *any* material body which is placed in the presence of *any* other, and to urge the two mutually towards each other. This is a *vera causa;* for heavy bodies (that is, all bodies, but some more, some less) tend to, or endeavour to reach, the earth, and require the exertion of force to counteract this endeavour, or to keep them up. Now, that which opposes and neutralizes force *is* force. And again, a plumb-line, which, when allowed to hang freely, always hangs perpendicularly, is found to hang observably aside from the perpendicular when in the neighbourhood of a considerable mountain. Moreover, since it is a fact that the moon does circulate about the earth, it must be drawn towards the earth by a force; for if there were no force acting upon it, it would go on in a straight line without turning aside to circulate in an orbit, and would, therefore, soon go away and be lost in space. This force, then, which we call the *force* of gravity, is a *real cause*."—*Discourse on the Study of Natural Philosophy*, p. 197. *Sir J. F. W. Herschel.*

(B.)

The two following indicator diagrams will sufficiently illustrate the steam's initial action :—

Fig 1 is a copy of No. 39, table 1, taken from the smaller of the two cylinders of Mr. Humphrys's engine. A simultaneous observation was made on the pressure existing in the boiler, on the instant of taking the diagram, by means of a thermometer graduated for temperatures and pressures.

Fig. 2 is a copy of No. 7, when the valve was *handed*, (referred to, page 415,) the steam in the boiler being, at the instant, exactly of atmospheric pressure. To ensure accuracy as to the elasticity in this boiler, the steam was blown off till it issued only at the boiling point.

Fig. 1.

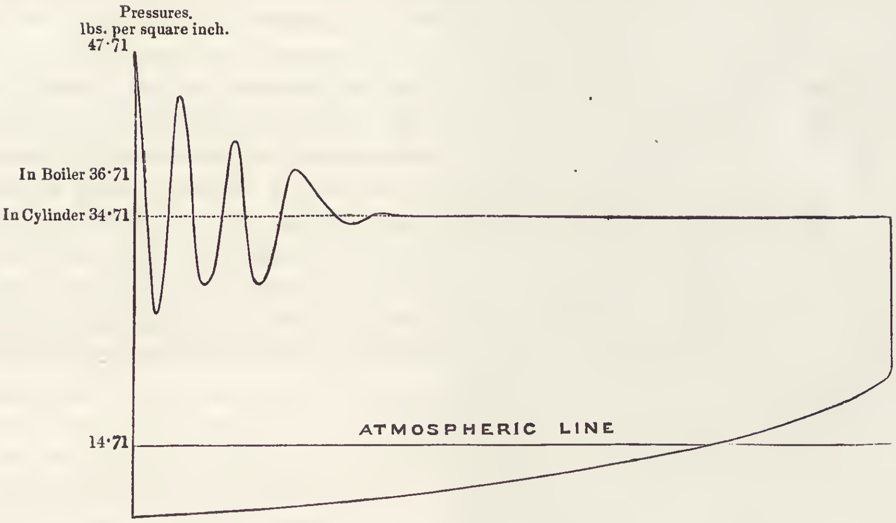
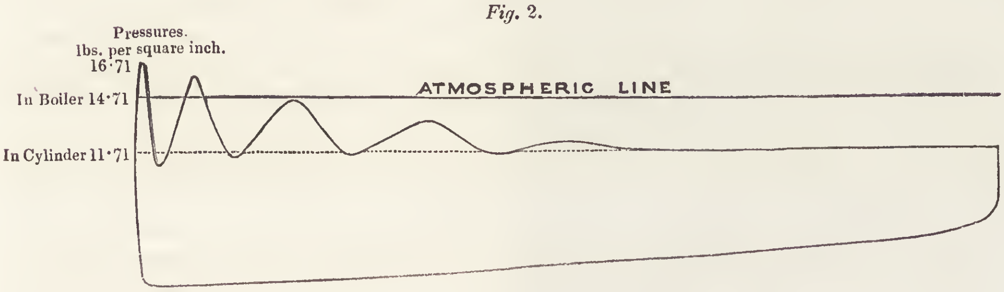


Fig. 2.

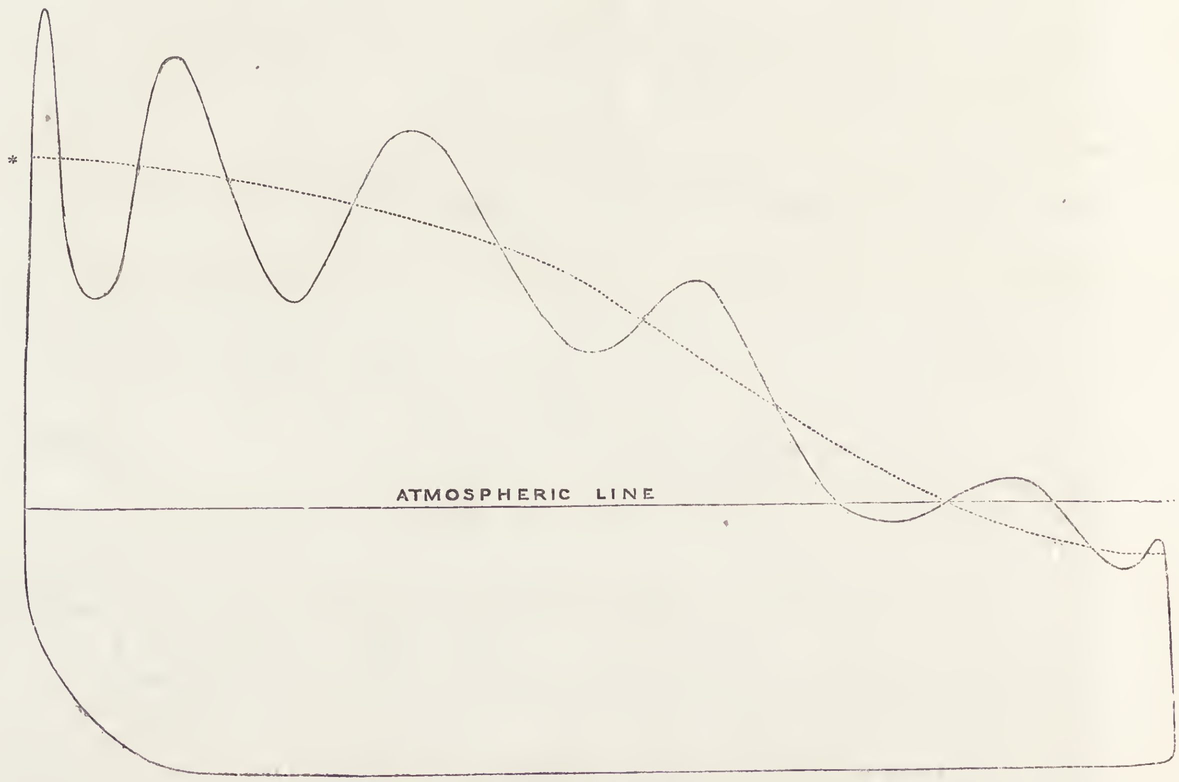


The scale of both the indicators used, which were different in each case, the one belonging to Mr. Humphrys, the other to myself, were verified in their places, by comparing the pressures indicated with those of the thermometric steam gauge.

The steam valve in Mr. Humphrys's engine is very quickly opened by a tumbler on the crank shaft; as quickly, perhaps, as could be effected by hand. I have made numerous experiments on the instantaneous action of steam at atmospheric pressure with the indicator on the cylinder of the engine from which Fig. 2 was taken, by setting the throttle valve open, and *handing* the steam valve as sharply as possible, the crank being kept at rest on the bottom centre. An exhaustion was made before laying on the steam, which was effected when the indicator piston stood at 10 lbs. below the atmospheric line. On admitting the steam, the indicator marked the force of impact as varying between 19 and 20·5 lbs. per square inch. To prove that the steam possessed this momentum, and that the piston of the instrument did not ascend by virtue, solely, or principally, of any acquired momentum of its own, higher than was due to the steam's action upon it, a small clamp was fixed on the piston rod, which rested on the cover, and kept the piston suspended to a height corresponding with the pressure in the boiler. The result was much the same; the piston was, in every case, lifted, and it instantly descended on the clamp.

The vibrations of the indicator piston, which arise from the spring exerting, after percussion, a greater force than the counteracting elasticity of the steam existing in the cylinder, may be controlled, or altogether prevented by throttling the steam's passage through the cock, or by giving some additional friction to the piston; but, by so doing, the instrument is impaired, and its indications rendered less worthy of confidence. It is remarkable that the well known fact of the instrument having traced lines, above the ascertained elastic force of the steam, should not have earlier induced some examination into the cause of their production. I am in possession of numerous diagrams exhibiting the vibrations of the indicator piston to have continued throughout the entire stroke of the engine. No faithful computation of the power exerted on the engine piston can be made from such diagrams. A diagram, of which the following wood-cut is a fac simile, was given me by the Secretary of the Institution, which will illustrate this opinion. Mr. Atherton was totally unacquainted with my investigations on this subject, when he wrote the remarks appended to the figure.

Fig. 3.



* Imaginary line of the steam's elasticity in the cylinder.

"Diagram showing the rapidity and force of the stroke of high pressure steam exemplified by its driving the piston of an indicator far above the point corresponding to the pressure of the steam even in the boiler, and the consequent oscillation with which the piston of the indicator moved."

(Signed) CHARLES ATHERTON.

(C.)

It may be useful to state the dimensions of this gauge. The area of the cistern was 6 square inches; that of the perpendicular glass tube 0·03, and of the orifice of the steam pipe 0·4 square inches. The distance between the surface of the mercury in the cistern, when at the fullest, and the cover, was about $\frac{3}{4}$ of an inch, and the capacity 4·5 cubic inches. Thus, the areas of the tube and cistern were to each other as 1 to 200; and the mercury was depressed about 0·6 inch, when the difference between the two levels of the column showed a pressure of about 59 lbs. per square inch. The motion of the mass in the cistern, therefore, only took place through 0·6 inch, whilst that in the tube was through 119 inches nearly.

Let it be supposed that the end of the tube immersed in mercury was furnished with a valve opening upwards. It is clear that the column of 119 inches would be sustained in the tube when the valve closed, which would occur on the instant after the mercury attained its extreme elevation; and this column would represent and measure the effective work performed by that single stroke of the steam, independent of all friction. Yet, the simple pressure of the steam was balanced by, and could only support, 80 inches of mercury.

Regarding the gauge, so arranged, as an engine of the simplest form, and comparing the results obtained, under the circumstances, by admitting the steam gradually, or suddenly, upon the surface of the mercury, the economy of the latter process will appear in the value of the difference between the weight of water as steam, filling the cavity of the cistern, at 40 lbs., and at 59 lbs. pressure per square inch above the atmosphere. For, it would have required a given volumn of steam of 59 lbs. pressure, if gradually admitted, to have displaced the mass of mercury in the cistern, and have elevated it 119 inches; whereas, the expenditure of the same volume of steam of 40 lbs. pressure, admitted suddenly, actually effected that performance.

I am at a loss to conceive that there can exist any distinction in the action or effect of steam, whether operating on a mass of mercury or on a piston. We may not, from circumstances into which it is unnecessary to enter, realize in the steam engine the whole of the force, however applied, but a like method of applying the steam must, as it seems to me, produce like results in both cases.

(D.)

A phenomenon which occurred during some experiments on the steam gun at Mr. Perkins's seems to me to be strictly analogous to the phenomena exhibited by the indicators, and the mercurial gauge.

I observed that, occasionally, a bullet stuck in the barrel; that it was not discharged, though the communication with the generator remained fully open. On shutting, and then re-opening the steam valve, the ball passed; in one case, three discharges of steam were necessary for its projection. Now, in that short interval of time, not a second, between the operator observing the non-expulsion of the bullet, and his closing and opening the valve, I cannot imagine any increase in the steam's elasticity to have taken place in the generator, sufficient to overcome the existing resistance. The ball fitted the barrel, as a piston in an engine cylinder; steam of 26 atmospheres' pressure was unable to move it; not a particle of steam issued from the muzzle; yet, by merely shutting off, and sharply re-admitting the steam, the ball was expelled. This occurrence took place several times. Whether these balls were not, originally, truly spherical; or had been flattened by the steam's first impact upon them; or had some roughness on their surface; or, whatever may have been the immediate cause of their sticking in the barrel, certain it is that steam of an elasticity identically the same with that which had proved insufficient, did, on its *sudden* re-admission, expel the balls with violence.

For a perfect comprehension of these facts by persons who are not familiar with the apparatus, it may be well to explain that the ball is dropped into the barrel through a perpendicular tube at the breech, and rests in a chamber close to the steam valve, which may be called the breech. The bore of the barrel is parallel throughout, and $\frac{5}{16}$ths of an inch diameter. The diameter of the valve is $\frac{5}{8}$ths of an inch; its area, therefore, is four times that of the barrel, so that there is no throttling, or *wire drawing* of the steam on its admission.

A ball being introduced into the barrel, the valve is rapidly opened by a handle. In the cases under examination, the first action of the steam is to drive the ball some space along the barrel. It there remains unmoved, and hermetically fits the tube. The steam, at this instant, is in a state of rest, still acting against the ball, but exerting only the simple elastic force of the steam in the generator; it possesses no momentum. The operator, perceiving that the ball has not been expelled, shuts off the steam, and again suddenly admits it. The expulsion of the ball is now effected, having been struck by a force superior to the steam's simple pressure, viz. by its momentum. The first blow sufficed to drive the ball a certain space; but, when the momentum, communicated to it by the steam's percussive or instantaneous action, was expended, the force remaining in action fell below the resistance, and the motion of the ball ceased; a second blow was requisite for its complete expulsion. Such appears to me to be the explanation of this phenomenon.

(E.)

No apparatus for opening steam valves with rapidity, and, therefore, for letting loose the steam upon the piston of an engine with the full velocity due to the difference of the elasticities existing in the boiler, and in the cylinder, has yet been applied so effective as the cataract. And, perhaps, no description of valve, hitherto constructed, opposes so little resistance as the Cornish double-beat skeleton valve; nor one which discharges so much steam for an equal amount of lift.

The opening of this valve, by the falling of a weight, is as nearly instantaneous as the discharge of fire-arms by the action of a hair trigger.

To the introduction of this valve and its enlarged dimensions, combined with the use of the cataract, much of the increased performance of modern, over older, Cornish engines, is attributable. An authentic history of the invention of this valve, and of its original construction, with the changes it has undergone in form and dimensions, relatively to the pressure of steam in the boiler, and to the area of the cylinder, would not only be highly interesting, but illustrative of one principal cause of the progressive advance in the economy of the pumping engine.

(F.)

Though having only referred to *single* acting, the observations apply equally to other engines of the same kind which are *double* acting, but not rotative. Blast engines are frequently so constructed, and also some pumping engines.

It is not absolutely necessary for the good working of a crank engine that the steam should be admitted previously to, or on the instant of the piston coming to rest, at each end of the stroke, though such be the practice. The steam might be let on after the crank has passed the centre, but, for obvious reasons, its instantaneous or percussive action would not, even then, be so efficiently exerted upon the piston, as under the more favourable circumstances of the single-acting engine.

(G.)

The "breathing," or springing upwards, of cylinder covers on the steam's admission is familiar to engineers. It is, I believe, the present practice in Cornwall not to strengthen them with ribs, but to give a greater thickness of material, by which a sufficient elasticity is secured, and fracture avoided.

This experiment on the effect produced on the cylinder cover by steam of nearly similar elasticity, when in motion, and when at rest, is, in the language of Bacon, a "*glaring instance*" of the "*crucial*" kind; it is a definitive experiment of the most satisfactory description. We obtain from it no *measure* of the difference between the forces under investigation: but it leaves no doubt on the mind as to the one being superior to the other; nor, as to the *character* of the greater action. Sir John Herschel, in illustrating Bacon's philosophy, says, "One of what he calls '*glaring instances*' has just been mentioned. In these the nature, or cause inquired into, (which in this case is the cause of the assumption of a peculiar external form, or the internal structure of a chrystal,) stands naked and alone, and in this eminent manner, or in the highest degree of its power. No doubt such instances as these are highly instructive; but the difficulty in physics is to find such, not to perceive their force when found." And again, "the surest and best characteristic of a well-founded and extensive induction is, when verifications of it spring up, as it were, spontaneously, into notice, from quarters where they might be least expected. Evidence of this kind is irresistible, and compels assent with a weight which scarcely any other possesses."—*Discourse on the Study of Natural Philosophy*, pp. 170, 184.

(H.)

In consequence of the greater intensity of the steam's impact, when the piston starts from nearer the cover, the engine requires regulation, and the throttle valve is more closed, since a less pressure of steam is requisite to complete the stroke. (See also ante, p. 272.)

A small increase in the length of stroke might be occasioned by starting the piston from nearer the cover, but the volume of steam in the cylinder when its influx is stopped would be unaltered, as the period of closing the steam valve remains unchanged. The fact of several millions more duty being performed under these than under the ordinary circumstances, assures us that the steam, which fills the cylinder at the termination of the stroke, is of less elasticity than when the piston is started at a greater distance from the cover, since the higher performance, or resulting economy, consists only in having used less water as steam to effect the stroke. Steam, therefore, of less density filled the space of the cylinder when its influx was stopped; yet, the same resistance has been overcome, as by an equal volume of steam, of higher elasticity, under the ordinary circumstances.

(I.)

The second instance occurred at Mr. Stuteley's saw mills, Bankside. On visiting the place, I found the statement, as originally made to me by Mr. Edward Humphrys, to be confirmed by the engineer, who had provided against the loss of the mercury, in future, by interposing a second, and longer syphon-pipe, between the gauge and condenser, to retain the mercury if again blown over.

By referring to Note C, and the experiment to which it relates, it will be apparent that, had not the cistern contained mercury enough to balance a force of 59 lbs. per square inch, the whole of it would have been evacuated, by steam of an elasticity of 40 lbs. suddenly admitted.

I lately had an opportunity of measuring the amount of oscillation produced on a mercurial syphon gauge attached to a Cornish engine. The gauge was fixed on the steam pipe in the engine-house, between the throttle valve and boilers. The steam in the boilers was at 40 lbs. above atmospheric pressure. On each admission of steam, and during its flow into the cylinder, the gauge exhibited the pressure in the pipe to be 37 lbs.; on the instant of closing the steam valve, the mercury rose to 44 lbs., settling again to 40 lbs. before the succeeding stroke.

Mr. Lowe stated, (see "Minutes of Proceedings," 1841, p. 150) in the conversation which followed the reading of this paper at the Institution, that, on opening the stop-cock connecting a main gas pipe with his water-pressure gauge, the water experienced an instantaneous action, equal to a column of six inches; though the simple pressure of the gas in the pipe only balanced four inches. This, and the depression observed in his gauges when the gas is in motion along the pipes, are instances showing the identity which obtains in the action of different aëriform fluids.

(K.)

These, and other, experiments, equally remarkable for their novelty and ingenuity, are contained in a work recently published by Mr. Greener, entitled the "*Science of Gunnery*," which records a mass of information interesting to the philosopher and engineer, as well as to the gunner and sportsman. The quotations above given are from Mr. Greener's correspondence with me, previous to the publication of his work, and not exactly in the words of his text, pages 37, 38, 39, by which it appears that his researches on the subject have been considerably extended.

The action of gunpowder gas, on the instant of its generation, seems to possess characteristics very analogous to that of steam suddenly put in motion. The following experiment is related by Mr. Robins, who first discovered the permanently elastic nature of gunpowder gas:—

"When gunpowder is fired in an exhausted receiver, the mercurial gauge instantly descends upon the explosion, and as suddenly ascends again. After a few vibrations, none of which, except the first, are of any great extent, it fixes at a point which indicates the density of the enclosed gas."—*New Principles of Gunnery*. The phenomena of the action of steam upon mercurial columns, and upon the indicator, are exactly described by these words.

It has, long since, been demonstrated that the report of a gun is produced by the rush of air into the barrel to replenish the vacuum. The residual gas left in a barrel, after the explosion, is estimated at about 1-8th of the pressure of the atmosphere, the velocity and momentum of which, on re-entering, must, therefore, be very considerable. These, and many other similar phenomena, which offer themselves to the recollection, furnish the fact of an audible blow being given by the impact of an elastic fluid on a solid, and also by the concussion of opposing elastic fluids.

Several instances have been brought to my notice of an audible blow, or shock, similar to that of the hydraulic ram, taking place when a cock is very rapidly shut in a pipe through which steam is flowing into the atmosphere. I witnessed one instance of this nature at Mr. Thomas Cubitt's works, Thames Bank. It occurs on quickly shutting a cock in a wrought iron pipe of considerable length, and about an inch bore, conveying steam through the building. Whether the noise and shock were occasioned by the sudden stoppage of the current of steam on one side, or by the sudden entrance of atmospheric air on the other, caused by the vacuum, partial or perfect, which might result, certain it is that the closing of the cock was instantly succeeded by an audible sound (as if produced by a blow) and by a tremor of the pipe, which resulted from the momentum of one or other of these elastic fluids.

(L.)

Whilst making the experiments at Mr. Perkins's, I happened to grasp the pipe close below the indicator, in order to steady my body, and bring my eye as near the dial-plate as I could, to observe the motion of the index, on suddenly letting on the steam of 26 atmospheres. It immediately afterwards occurred to me that my hand would have been burnt if the steam had mixed with the air, and reached the spot where my hand was placed; but this was not the case, as the pipe, though hot from conduction, could be grasped (at the commencement of the experiments) notwithstanding that the steam pipe, on the other side of the cock, had the temperature due to that of the steam. The pipe full of air was, as above stated, about a yard in length; and this phenomenon clearly shows that the force of the steam's instantaneous action, or of such portion of it as reached the indicator piston, was transmitted by the air in mass, as if a diaphragm, or piston, had separated the columns of steam and air. There was no time for the diffusion of the gases and mixture of their particles. The space and substance of the cock-plug alone divided the two columns; and the steam, on the sudden and full removal of this obstacle, must have effected its impact on the air, much after the manner of a solid or liquid body moving at the same velocity. It seems to be a settled physical fact, that a pulse of air cannot be made to move at a greater velocity than that of sound, or at a rate exceeding about 1,300 feet per second. It is distinctly seen from the experiments detailed.

that the velocity and momentum of steam increase with its elasticity, but the phenomena exhibited by the impact of one elastic fluid on another, coupled with our ignorance of the velocity of steam, and with the fact of its force being transmitted to the meters, in every case, by an elastic fluid, show that the construction of an instrument, as well as its position, for truly measuring the amount of persussive action, require much consideration.

J. P.

Erratum.—I take this occasion of correcting an error of computation in the last paragraph of page 153 of this volume. It is there stated that the ineffective portion of the steam consumed by the engine in question was only about $\frac{1}{40}$th, or $2\frac{1}{2}$ per cent. of the total quantity. The loss, however, amounted to about 20 per cent.; the ratio of the volumes of steam and water consumed for the observed pressure being 911, instead of 771, as in the text. This error in no degree affects the quantities set down in Table VI. respecting the performance and consumption of the engine; it has reference only to the observations contained in the paragraph.

J. P.

XIX.—*On the Circumstances under which Explosions frequently occur in Steam Boilers, and the Causes to which such Explosions may be assigned.*

By CHARLES SCHAFHAEUTL, M.D., Assoc. Inst. C. E.

Read March 30, 1840.

Of the explosions which occur in steam boilers, it may with reason be assumed, that a very large proportion must be assigned to some other cause than the simple pressure of the steam due to the accumulation of a surplus quantity in the boiler, or the overloading of the safety valve, since many cases of explosions have occurred in which it has been ascertained beyond all doubt that the safety valve was in perfect order, and also cases in which it had acted immediately before the explosion, or was even in action at the instant of that occurrence.

Undoubted and indisputable facts of this nature, and the considerations hereafter referred to, show that these calamitous occurrences must be referred to other causes than the gradual increase of pressure in the steam, or defects in the ordinary safety valve.

Bursting due to simple pressure.

The pressure which hollow vessels will sustain without bursting, so long as that pressure is added gradually and by small accessions, would scarcely be suspected or credited without trial. In an extensive series of experiments, I found that the substance of metallic boilers was almost uniformly reduced in thickness by the action of a continuously increasing pressure within. Boilers under these circumstances exhibited no signs of rending; and in several cases the boiler sustained an internal pressure double that which it might reasonably have been expected to bear.

In an experiment of Cagniard de la Tour, a glass tube one-fourth part filled with water was hermetically closed, and inserted in a bath of metallic zinc, which was carefully heated until its temperature was sufficient to convert the water entirely into steam. The temperature of this bath, as ascertained by Daniell's pyrometer (a proper correction being made for the expansion according to the coefficient of Dulong and Petit) was 755° F. According to the formula of the same eminent philosophers, the pressure of the steam at that temperature would have been 4382 lbs. per square inch, but with a relative volume of 10·24; therefore only 0·39 of the water would have been converted into steam; but as, according to Cagniard de la Tour, the whole of the water was converted into steam, a temperature of at least 945° F. would have been necessary to reduce the relative volume of steam to 4, and a corresponding pressure of 13,000 lbs. per square inch, or more than 866 atmospheres pressure would have existed in the tube.

In repeating the experiments of Cagniard de la Tour, I subjected glass tubes of from 1 to 2 inches in length, containing steam of an elastic force of not less than 400 atmospheres to an external pressure in the bath of zinc, of from 1 to 40 lbs., without breaking them; and the tubes under this internal pressure would bear considerable pressure with an iron rod so long as the pressure was gently applied; but if one end of the rod were pressed against the glass tube, and the rod made to vibrate longitudinally by rubbing it with a leather glove covered with resin, the tube was invariably shattered to pieces.

In this case we have a distinct illustration of the effect of something besides the simple excess of pressure of steam in a boiler, in causing a disruption of its parts, or an explosion. In a great variety of experiments which I made, with the view of elucidating these points, I found that any vibratory motion, or any motion communicated to the boiler at intervals in an irregular manner, were extremely likely to produce a disruption of the parts, or an explosion. These considerations, together with the circumstance that in very many cases of explosions we may fairly presume the safety valve to have been of no use, may lead us to consider whether in all cases of explosions there may not have been in action a force momentary in its nature, tearing asunder the plates of the boiler at the instant of its generation, and before there was time for its transmission to the safety valve.

Suggested causes.

The existence of a force of this nature, sudden in its origin, and instantaneous in its duration, has suggested itself to many minds, and some persons have been inclined to ascribe it to the presence of hydrogen generated by the decomposition of water; but besides the great difficulty of generating a large quantity of hydrogen in steam-boilers, it could never cause an explosion without the presence of oxygen or atmospheric air, and even this explosive compound would not take fire when mixed with $\frac{7}{10}$ths of its own volume of steam, as I have proved conclusively by the following experiment:—

Experiment.

I introduced into the shorter end of a glass tube bent in the form of a syphon a mixture of one volume of hydrogen and two volumes of atmospheric air. The gases were then confined in the tube by means of mercury, and subjected to a pressure of an atmosphere and a half. A small quantity of water, the weight of which was accurately calculated according to the required volume of the gas in the experiment, was allowed to be absorbed by a texture of asbestos, and then by means of a wire the asbestos was conducted through the mercury into the mixture of gases contained in the tube. The tube was then placed in an iron cylinder filled with mercury, and kept at a temperature of about 236° F.; the closed end of the glass tube was then carefully heated by means of a blow-pipe to a red heat, for the purpose of causing an explosion. The following were the results of the experiments:—One volume of the explosive mixture with $\frac{1}{10}$th of its volume of steam exploded and broke the tube. The same result took place with $\frac{2}{10}$ths of its volume of steam, and with almost the same violence; with $\frac{3}{10}$ths of its volume of steam, but with less violence; with $\frac{4}{10}$ths of its volume of steam, but with still less violence; with $\frac{5}{10}$ths, or one half of its volume, a very feeble explosion took place just as the heated glass tube began to be extended by the pressure of the gas. With $\frac{6}{10}$ths of its volume of steam only one explosion took place, though the experiment was tried six times; and with $\frac{7}{10}$ths, and all greater proportions of steam to gas, up to two volumes, no explosion could be procured.

Conclusions from preceding.

From these experiments we may conclude that, even if an explosive mixture were formed in a boiler, no explosion could ever take place unless its volume were at least double that of the steam, which under any circumstances is highly improbable, and unless the boilers were almost dry, next to impossible.

Mr. Parkes's views.

The very ingenious paper by Mr. Josiah Parkes on the action of steam in Cornish engines induced me to turn my attention to the effect of the sudden development of an action in steam-boilers, and to investigate analytically the laws of the concussion of liquid and gaseous bodies; the details of these investigations I shall hope soon to be able to lay before the Institution. On the present occasion I have to offer some practical observations on the effect of sudden changes of pressure within a boiler, due to the sudden generation of steam as distinguished from the uniform and regular increase of pressure due to accessions of steam gradually generated and accumulating by degrees.

There is at present only one mode in use for converting water into steam, viz. by successively adding a small proportion of caloric to a relatively immense body of liquid; but all the heat imparted in successive intervals of time to a given quantity of water might be imparted in one unit of time. For example, if a drop of water be put on a blacksmith's anvil, and a bar of iron be heated to a white heat, or until it becomes covered with a layer of liquid slag, and the bar be laid in this state on the drop of water and struck with a heavy hammer, the liquid slag on the surface of the iron will communicate its caloric at once to the water, the slag becoming solid at the same instant that the water is converted into vapour, with a loud report similar to that of a gun. This is an extreme case; but a nearly similar occurrence may take place in a steam-boiler where a quantity of water is suddenly thrown in contact with the overheated bottom plate of the boiler, either from a sudden motion of the vessel, or from a portion of incrustation giving way, and opening at one instant a passage for the water to the red hot plate.

In a high pressure boiler, the sudden separation of a deposit causes first a diminution of the quantity of evaporation, and immediately afterwards a sudden bursting up of steam, which very often endangers the boiler. This separation of deposit may be occasioned or promoted by a sudden opening of the safety valve, or by a rapid increase of heat causing a sudden ebullition in the water.

Consequences of sudden increase of pressure.

In all cases where a sudden explosive development of steam takes place in the boiler, the first and principal part of its action is directed against the place of its development; that is, against the bottom, or even the sides of the boiler, then spreading itself through the water, and finally through the steam to the top of the boiler.

Let us consider this last circumstance more closely. The boiler is supposed to be filled with two fluids, water and steam, superposed in equal or unequal heights or depths: if we now assume that a small body is made to explode on the surface of the water, the moving particles of the generated gas will communicate their motion of course at the same time to the molecules of water as well as steam nearest to them; but as both fluids are elastic and compressible, though in very different degrees, the imparted motion will not be transmitted instantaneously through the whole mass: the molecules of the water and steam nearest to the exploding body will be compressed only for a small depth, which compression will communicate itself successively to the next and succeeding molecules of the fluids, till the motion like the undulation of a wave finally arrives at and is communicated to the sides of the boiler. But the velocity with which this takes place depends on the power the fluids in question have for conducting undulatory motions, that is, on their compressibility. According to Laplace's formula, we obtain for the conducting power of steam at a pressure of four atmospheres and 294·1° F., 1041·34 feet per second, and for water 6036·88 feet. The ratio of the different conducting powers, or of the velocities of the waves in the respective media, is as 1 to 5·7, that is, the wave created by the explosion or the sudden pressure is transmitted through the water 5·7 times faster than through the steam, and consequently the action will be exerted on the bottom and sides of the boiler in $\frac{1}{5\cdot 7}$ of the time that it is exerted on the equidistant parts in contact with the steam. Now as the safety valve can only receive the action transmitted through the steam, the part of the containing surface at which it is situate will not in general be the first part of the surface to receive the action so transmitted.

From this it follows that the first effect, spreading from the centre of the boiler or the surface of the water, will in general reach the sides and bottom of the boiler sooner than the safety valve; and if we consider it to originate at successive depths of the water, the denominator of the fraction expressing the ratio of transmission will decrease as the numerator increases. When the explosion takes place near the bottom, the time in which the wave or sudden pressure reaches the safety valve is now the sum instead of the difference of the two velocities.

It may be objected that, notwithstanding the relative difference between the two velocities, the quantity of both velocities is so great that their sum or their difference may be considered infinitely small in respect to the space it has to pass through; but in comparison with the momentary action of the explosion, the high numbers of the velocities lose nothing of their value as a constant quantity, and there is sufficient time to admit of the rupture of the material, which would have yielded by its own elasticity had the ratio been less sudden in its origin.*

A good illustration of this law is the well known fact that a ball shot from a rifle will pass through a pane of glass without splintering it: but a very striking illustration of the case at present before us is the passing of a cannon

* The well known physical law, that in the communication of motion, and in the generation and destruction of momentum, time must be consumed, and that the nature of the effects produced will depend on the time which is consumed, or on the period of duration of a given action, is a law or ascertained fact which has been but little regarded in comparison with its great importance.

ball through a board, leaving only a very small opening in comparison with the diameter of the striking sphere. The ball breaks only the part of primary contact; then the compression of the wood begins from the centre of contact to the equator of the ball, and then the elastic force of the wood closes the opening again, preventing in its return the further spreading of the force.

The following experiments give a further proof of these circumstances:—If we ignite a grain of gunpowder on the scale of a very sensible balance, accurately counterpoised by a grain weight, a slight motion will be first communicated to the scale of the balance in the opposite direction in which it is thrown by the counterbalancing weight. If, on the contrary, we explode a grain of chloride of nitrogen on the same scale of the balance, a hole is broken at the instant of the explosion through the scale where the chloride lay, and the balance follows undisturbed the action of the counterpoise.

As a small yielding or elongation of the boiler plates in a direction parallel to their sides would prevent all explosions of this kind, I endeavoured to ascertain by experiments as near as possible, and on a sufficiently large scale, the quantity of elongation which would take place before giving way to a breaking force suddenly applied.

An iron wire four feet in length was selected for the experiment: it was to be fixed vertically, and the breaking force applied to its lower end. In order to accomplish this object, I enclosed four inches of its upper end between two steel brackets fitted to the diameter of the wire, and secured the whole as firmly as possible between the jaws of a large vice which was fixed horizontally on a solid vertical stone pillar so that only three inches distance was left betwixt the wire and the pillar. The lower end of the wire was now likewise secured in a similar way in the jaws of another vice, after it had been pushed through the slit of a strong cast iron lever of the second order four feet long from the centre of the fulcrum to the centre of the application of the force. The lever rested in this way on the jaws of the lower vice at a distance of three feet from its fulcrum, and one foot from the centre of the power, to which latter a scale was applied, and the whole apparatus counterbalanced so as not to disturb the result. Weights, each ten pounds, were now gradually and successively applied: with 18 cwt. the wire began to stretch; 22 cwt. stretched it ·298 of its entire length, which was three feet clear; and 23·2 cwt. tore the wire asunder.

Other wires of the same sort of iron were now fixed in the same way, only the scales were removed and a parallelopipedon of cast iron was placed on a strong foundation under the short end of the lever near the jaws of the lower vice, so that when the end of the lever was loaded with 10 cwt. the distance of the lower end of the lever from the cast iron parallelopiped was just the $\frac{1}{16}$th of an inch, as the distance which I allowed it to stretch.

Over the centre of the free end of the lever, where the scales had been applied, was suspended a weight of 81·76 lbs. with a rounded end, at a distance of 7·58 feet, and then suddenly and carefully liberated from its point of suspension. It is evident that by touching in its fall the shorter end of the lever it created a pressure of nearly 22 cwt. on the suspended wire, a weight which, slowly applied, stretched the iron wire, as before mentioned, ·289 of its entire length; but by the cast iron pillar below not more than $\frac{1}{16}$th of an inch was allowed for stretching. Nevertheless, the wire which supported a dead weight of 22 cwt. very well, broke invariably when the same weight was suddenly applied in twelve different experiments. The same effect took place five times in twelve, when the weight was falling only through a space of six feet. The cross fracture of the rod was even, and its whole length was found to be not at all altered, a proof that it had not stretched before it broke.

I do not consider it out of place here to mention some rather unexpected results which I obtained by experiments made on iron rods and railway bars. Two rods of the same size, one of English, close grained, and the other of long fibrous tough iron, were strained with the same weights, applied gradually. Their strength was found to be just in an inverse ratio by changing the mode of application of the load; the fibrous iron, which was found to be strongest under the gradual application of the load, was found to break by the sudden application of the same load. The same circumstance occurred in testing the transverse strength of iron bars: the toughest but open fibrous iron, which was capable of being doubled by a gradual application of the force, broke invariably short when the same load was suddenly applied; on the contrary, a rail of granulated iron, which would bear bending only in a slight degree before it cracked, resisted the same load suddenly applied perfectly well—facts which appear worthy of consideration in selecting or preparing iron for boiler plates, which ought to be chosen with the closest possible grain, as there the sudden action of the rending force is most to be feared.

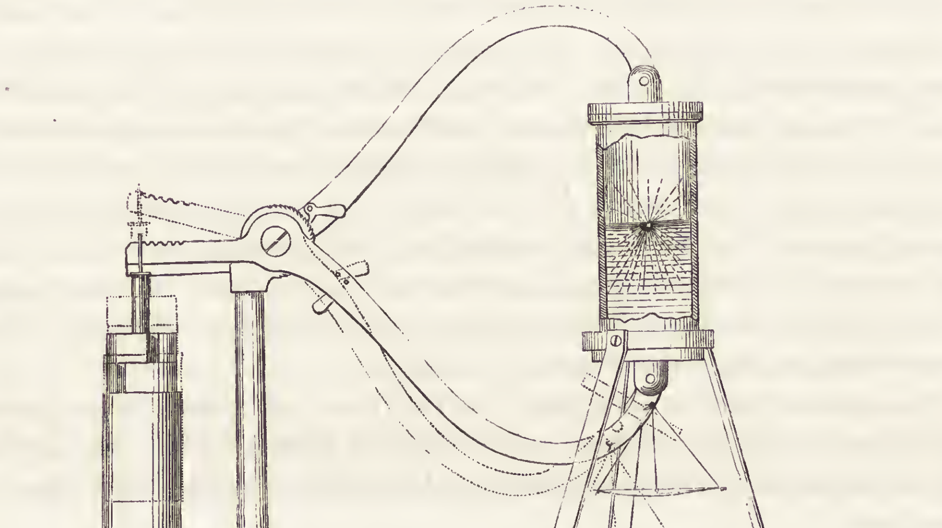
To return to our subject again:—As the views and ideas advanced in the former part of this paper were only derived by merely viewing the circumstances theoretically, I at once proceeded to confirm or refute those ideas by experiment.

Practical confirmation of preceding views.

I placed a hollow cylinder 2½ inches long and about 1 inch internal diameter vertically on three legs three inches long; to the upper and lower end moveable flat lids or plates were fitted air tight, and fixed with their moveable centres to two arms or levers of the first kind, bent in the form of an S, which reached back to a pillar as their fulcrum, which carried a vertical disk whose half circumference was toothed like a ratched wheel. To the centre of this disk and on either side were attached the two arms or S levers, carrying the plates or lids on one end; and near to the ratchet wheel a click, in order to retain both arms at every distance to which they might be thrown off in the direction of the axis of the cylinder. The lower plate or lid, carrying a scale attached underneath to its centre, was now placed so as to close the lower end of the cylinder, into which water was poured to the height of 0·86 of its entire length, and then the opposite end of the lever loaded till one ounce weight in the scale would open the lid slightly and permit the water to escape.

The upper lid, with its lever, was now nicely counterpoised, and the ounce weight from the scale below removed and placed on the upper lid, in order that both lids might be pressed with equal force against the openings. The cylinder, filled to 0·86 of its height with water, resembles in this state a sort of boiler, the top and bottom of which are moveable, yielding to a force exerting the pressure of an ounce: the steam of course was represented by common air.

The following diagram will convey a correct idea of the apparatus above described:—



The next object was to cause an explosion at the surface or at any depth of the water contained in the cylinder, and I readily obtained this object by means of a globule of potassium.

The affinity of potassium for oxygen is the greatest of all known substances. Potassium, therefore, on coming in contact with water, decomposes the latter with great rapidity, developing hydrogen, a process which may be considered in our experiment analogous to the generation of steam from boiling water. But potassium has another property extremely favourable for our purpose. The potassium, after its combustion, is entirely converted into potassa; this potassa remaining in a fused state as a globule, which combines in one instant, developing at once a still higher temperature, with 16 per cent. of water, causing and concluding the combustion with a perfect explosion.

The potassium floats, during its combustion, at the surface of the water. In order to cause its action under water, it must be wrapped loosely in white blotting or filtering paper, and the folds tied with a small piece of lead wire, which sinks it to the bottom, the blotting paper at the same time preventing its too rapid contact with the water.

If we now take a large globule of potassium and throw it into the small cylinder on the surface of the water and immediately shut the lid, the combustion of the potassium and consequently the development of hydrogen, commences immediately; and when the quantity of potassium was large, the upper lid is slightly lifted to let the air and gas escape; but as soon as the combustion is completed and the explosion takes place, the upper lid closes, and the water is forced out through the lower one entirely as the preceding theory predicts.

If we now sink another globule wrapped in blotting paper to the bottom of the water, an explosion ensues as soon as the water penetrates the blotting paper, and water and burning potassium are at once thrown out at the lower end without moving the upper lid at all.

But even a less violent explosive mixture, which developes its power more successively, as gunpowder in an unconfined state, acts in the same way.

I prepared wax paper by placing thin paper on a sheet of metal, heated to the melting point of wax, and rubbing the surface of such paper with a lump of bees' wax until it was entirely saturated with it. From this paper cartridges were formed about half an inch in diameter and about the same length, closed on the one end by folding the paper slightly over it, the joints easily adhering together by being exposed only to a slight degree of heat. Nine grains of gunpowder were now wrapped in a small bag of writing paper, of a diameter just to fill the cartridge, the folds of which on one end were only slightly twisted together with the fingers, and the bag pressed into the cartridge with its twisted end downwards. A small piece of potassium like a lentil, placed betwixt a small piece of blotting paper, the edges of which were loosely folded, was then placed in the centre of the surface of the gunpowder bag and covered with a wadding of two single disks of filtering paper, a little larger in diameter than the cartridge, and finally the closely filled cartridge covered with another larger disk of blotting paper, the edge of which was bent and folded down the sides of the cartridge and held there firmly by a ring of thin lead wire of $3\frac{1}{2}$ inches long and of 8 grains weight.

The cartridge charged in this manner, weighing 45 grains, when quickly thrown into the water, explodes in about 5 seconds.

The effect of the explosion, when the mouth of the cartridge is kept downwards, is invariably to throw the lower lid from the opening about $1\frac{1}{4}$ inches, leaving the upper one untouched, although the combustion goes on rather slowly, and a great portion of the gunpowder is forced out without being burnt.

If the bottom of the cartridge is formed of blotting paper only, by bending a disk of blotting paper over a wooden cylinder of the same diameter as the cartridge, and holding the folds forming the sides of it simply by surrounding them with a slip of warm wax paper, this capsule is able to float at the surface of the water. If then a disk of double filtering paper is put on the bottom, (the potassium wrapped slightly in a double piece of blotting paper with folded edges as before, and a capsule of writing paper containing the gunpowder placed immediately upon it,) the gunpowder will be ignited from below whilst the capsule is floating at the surface of the water.

By this means we see remarkably well the progress of the combustion going on with the gunpowder. The gunpowder, without confinement, ignited from below, throws the uppermost grains in the air, where they become ignited, and the whole product of the combustion is deposited on the lid in a beautiful ramified web-like layer. The sides of the cylinder show only traces of this web near the lid. But even in this instance, where the whole combustion goes on entirely in the air chamber and nearest to the lid, the lower lid is at the same instant thrown open and to the same distance as the upper one.

If now, instead of placing the capsule with the gunpowder open upon the potassium, we close this capsule up so as to confine the gunpowder and prevent as much as possible its being thrown into the air before it is thoroughly ignited, the lower lid is generally thrown open twice the distance of the upper one; and in short, the relative distance to which both lids are thrown seems to be somewhat as the distance of the exploding gunpowder from each of them.

The fulminates of gold, silver, and quicksilver, act with still more decisive effect, but the final result of all these experiments is that, under certain circumstances, the exclusive, and in all cases the most powerful, action of the exploding preparation takes place on the lower lid or on the bottom of the cylinder.

Practical conclusions from preceding experiments.

The results of the preceding experiments must, I conceive, be considered in every respect in perfect accordance with the conclusions derived from the theoretical views and calculations already advanced, and I may be permitted to assume that the action due to any sudden increase of pressure will be transmitted through the water and through the steam according to rates at which a wave is transmitted through them respectively. If, then, the sudden increase of pressure arise from the sudden generation of steam near the sides or bottom of a boiler, as on the exposure of a red hot portion of the plates to the water, or from any other cause which may produce such sudden increase of pressure, the bottom or sides of the boiler will receive the action consequent thereon before the safety valve, and thus a boiler may explode before the action which causes that explosion has had time to be transmitted to the safety valve. It follows, also, from the preceding views, that a boiler must receive a succession of these transmitted actions or shocks, and though the first may not have been sufficient to burst the boiler, any shock occurring subsequently in order of time at another part of the boiler may produce that effect. Also, the bursting may, as it were, be commenced by the first and completed by the subsequent shocks, which will be successively experienced at other parts of the boiler. I conceive that these successive shocks may in general be reduced to two, the one, the action which is exerted at the bottom of the boiler, or that part of the sides immediately contiguous to the point at which the sudden action is at first produced; the other, the action which takes place subsequently and almost immediately after on the upper parts of the boiler in contact with the steam, or at the top of the steam chamber.

In addition to the causes of sudden actions already mentioned, are others of constant occurrence and of too much importance to be omitted altogether in this communication.

The sudden opening and shutting of the safety valve will cause a sudden action at every part of the boiler, which, under certain conditions, may be highly dangerous. Any increase in the intensity of the fires at particular parts of the boiler may be attended with similar consequences; and, in fact, any of the various causes which occasion sudden starts of the steam in a boiler, and which frequently arise from the saturation of the water with certain earthly salts, as sulphate of lime, silicia, and alumina.

The causes last mentioned cannot be conceived likely to lead to the disastrous consequence of an explosion so long as the boiler is unimpaired by use. But the rapidity and amount of the change which takes place in the plates of a boiler, subject to the continuous action of the fire, is of too much importance, as the following cases will show, to be passed over entirely without remark on the present occasion.

On inspecting the edges of the fracture of a boiler which had exploded with considerable force, I found that a part of the plate which had been red hot had undergone a remarkable change. A slip of the upper part of the boiler, 1 inch in breadth, was bent to nearly a right angle, by applying a weight of 3 cwt., whilst a slip, exactly of the same size, cut out of the part which had been red hot, broke by an application of 2 cwt.

The fractured end of this slip was cut off and polished with a fine file; and on being carefully examined, exhibited, to a considerable depth, a combination with sulphur.

On a careful inspection of various fragments of other steam boilers which had burst, I found the fractured edges always changed in a similar manner; and I found that the edges of a piece of iron, which was shown to me as a fragment of the boiler which burst on board the Hull steamer, were so brittle that a slight stroke of the hammer was sufficient to break them off; and, when put into a retort and diluted in chlorydic acid, a great quantity of sulphuretted hydrogen was perceptible, the exact quantity of which I was enabled to ascertain by collecting it in a solution of nitrate of lead.

By this experiment it appears to me clearly demonstrated, that the iron plates of a boiler which, by the pressure of steam contained in them, are always kept in a certain degree of extension by the flame acting upon them (especially by the flame of pit-coal, which always contains a quantity of sulphureous acid,) are in time considerably weakened, as the texture of the iron by this means becomes loosened; and the more pyrites the coal contains the worse it will be, particularly when the boiler, by the sinking of the water level, is often allowed to get into a highly heated or an incandescent state, and afterwards, by the rising of the level, cooled again.

The expansive force of the steam always tends to separate the fibres of the iron, which, in addition, is kept in a state of expansion by the caloric which it imbibes by being allowed to get into an over heated or incandescent state. Afterwards the irresistible contraction of the doubly-expanded metal, caused by its coming in contact with the water, must act upon it in a very powerful and detrimental manner. The slightest irregularity in the generation of steam, which occasions its developement by sudden starts, must naturally tend to burst such a weakened boiler, whether the sides be at the time cool or in a state of incandescence.

Conclusion.

The considerations and experiments contained in this communication open a somewhat new field of practical research; and, as it would appear that the actions on the bottom of the boiler, or on those parts in contact with the water, are the first in order of time, the importance and practicability of obviating these effects is naturally suggested. It has occurred to me, whether some additional security might not be obtained by a valve properly weighted and placed at the bottom or lower parts of a boiler. There are, however, various considerations of importance in the placing and construction of such a valve, and I content myself on the present occasion with suggesting the utility and practicability of such a contrivance as a means of affording some security from the consequences of sudden action arising from the causes which have been mentioned.

CHARLES SCHAFHAEUTL.

London, March, 1840.

XX.—*Remarks on the Duty of the Steam Engines employed in the Mines of Cornwall at different periods.*

By JOHN S. ENYS, ESQ., Assoc. Inst. C.E.*

Read January 14, 1840.

The advantage of an intimate union of theoretical and practical knowledge in the application of steam power will be readily admitted, and the certainty, that in case of difference of opinion the latter ought to be relied on, should lead us to a cautious investigation of the conditions which may influence the results: it will be the object of my remarks, which embrace only a portion of this subject, to further this union by an attempt to trace the progress of improvement in Cornwall, and to point out some of the principal causes by which it appears to have been effected; the inquiry may perhaps be found deserving of attention, since extravagant and undefined ideas have been prevalent in Cornwall of an almost unlimited increase of duty, while elsewhere the reported duty has been sometimes treated as incredible and inconsistent with the laws of Nature.

I would observe in the first place that no change has taken place in the use of the term duty, or in the principles of its calculation, since its introduction by Watt, yet it may have been materially influenced by causes unconnected with the engine, viz., by the reduction of pitwork friction, and the greater average depth of the shafts from which the water is drawn; the advantage due to the former cause is however in some degree counterbalanced by the improvement

* The author, in compliance with the regulations of the Institution of Civil Engineers, soon after his admission as an Associate forwarded Remarks on Cornish Engines to that Society, an abstract of which was read in January, 1840, and published in the Minutes of that Session. At this period it should be remembered that a duty of 70 millions had been discredited, and the usual proofs had been treated as inconclusive by many persons.

During the last two years, several publications and numerous discussions have rendered this subject more familiar to the public, and the author's opinions on several points have undergone some modification, so that when he was requested, in October, 1841, to revise the paper for publication, it seemed most advisable that notes in explanation should be added.

of the actual, in proportion to the calculated, delivery of water, arising from the better workmanship of the pitwork, and the greater attention paid to the state of its repair by the managers of the mines under whose care it is placed to the exclusion of the engineers, to whom the construction and care of the steam engines are entrusted.

In calculations necessary for the comparison of the power and work performed by steam, it will be convenient to estimate the force and space of action of the steam on the piston in terms similar to those which have been so long employed for duty, viz., of lbs. raised one foot high per bushel of coal, but care must be taken in reference to the older duty, to raise it to the present standard of the imperial bushel of 94 lbs. of Welsh coal; an addition of 5 per cent. to the duty of the Winchester bushel, is an approximation, I believe, in favour of the old engines.

In 1827 Mr. Davies Gilbert, in the Philosophical Transactions, and Mr. Tredgold, in his work on Steam Engines, published in the same year, brought forward independent investigations respecting the power to be derived from steam, and both parties adopted the unit of one cubic foot of water; the former, in reference to the Cornish idea of work performed, estimated the weight of water that would rise 34 feet into a perfect vacuum, assumed to have been formed by the condensation of steam of atmospheric pressure, produced from one cubic foot of water. Tredgold, on the contrary, on the engineer's view of power, calculated the power that could be exerted on a piston by the volume of steam of atmospheric strength formed from one cubic foot of water, obtained by multiplying together the pressure per square foot, and the space through which it could act. The results will be similar if the same volumes of steam are assumed—yet the method of Tredgold seems preferable, since it can be extended to the steam power that may be derived from steam of any pressure, as shown in the Report of the Cornwall Polytechnic Society for the year 1835.

Annexed is a corrected table of pressures translated from the French tables of Clement Desormes, in which the French estimate of the atmosphere is taken at 29·92 inches of mercury.

Obstacles to the correct application of Theory.

The obstacle to the general application of the correct method of expansion pressure calculations, appears to have been the attempt to use the pressure in the boiler instead of the pressure in the cylinder at the closing of the steam valve, as the basis of calculations of the gross power supplied at each stroke by the boilers, and of the gross power exerted on the piston, which differs from the former wherever expansion is used.

In engines not worked expansively, the boiler's supply is a measure of the steam power—but in expansive engines an addition must be made of the power derived from the steam after the communication between the cylinder and boiler has been closed.

A practice has been also adopted among engineers of deducting the resistances arising from the imperfect vacuum from the boiler pressure, and calling the remainder the gross power on the piston, and of occasionally calculating the expansion pressures at different parts of the stroke from this erroneous basis: this seems to have arisen from a reference to indicator diagrams of double acting engines, in which the difference of the pressure on the two sides of the piston is shown.

The errors due to the belief that the consumption of fuel was proportional to the temperature, which at one time led to the expectation of an enormous advantage from the use of high steam, may be considered as entirely exploded, and the necessity of the introduction of the wasted atmosphere in comparative estimates, where steam of different pressure is used, is also acknowledged. The atmosphere wasted in high pressure engines obviously bears a different ratio to the pressure as higher steam is employed, and the loss theoretically becomes less; in practice we can prevent escape of heat by perfect clothing of the boilers and engines.

I shall now endeavour to show that the Cornish engines are worked under such conditions that a large proportion of the advantage of the expansive action of the steam is rendered available on the piston; but previous to any remarks on this point, I am bound to advert to the corrections which are required in the application to Cornish engines of Boyle's and Marriotte's law, that the pressures of elastic fluids are inversely as the volumes, when the temperature is constant.

Correction of the deficiency of Water in high Steam.

In the first place, the temperature is not constant, but decreases in an unknown ratio, as there is a deficiency of water in a given quantity of high steam to produce another quantity of lower steam of a density exactly proportional to the volumes of expansion—yet for practical purposes the pressures may be assumed proportional to the water at the end of each volume of expansion, unless the temperature is raised by the effect of the correction due to the steam jacket usually employed, containing steam of 270° Fahrenheit,

Correction for Steam Jacket.

while the steam in the cylinder would vary during five times expansion of two and a half atmosphere steam from 260° Fahrenheit to 180° Fahrenheit.*

This jacket steam has also a tendency to produce an increase of pressure by the evaporation of water due to priming, or the admission of water mixed with steam.

Assuming that steam of $2\frac{1}{2}$ atmospheres pressure is nominally expanded to $\frac{1}{2}$ an atmosphere at the end of the stroke, we should have about 593 grains of water at the end of the stroke according to the tables annexed to this paper; but this quantity would afford only 119 grains to each cubic foot of expanded steam—now steam of $\frac{1}{2}$ atmosphere pressure requires 135 grains for its formation; the deficiency of 16 grains is $\frac{1}{8}$th, but as it is probable the deficiency of pressure will be found to be in a similar ratio to the deficiency of water in the expanded steam, capable of affording the full density due to its nominal expansion, the average loss of pressure during 5 times expansion would be about $\frac{1}{20}$th.

It has been stated to me, on authority on which I place confidence, that extended trials of the steam jacket at Wheal Alfred by Woolf, afforded grounds for the belief that the advantage of the steam jacket amounted to 10 per cent., and Mr. Wicksteed has expressed on a recorded trial a similar opinion. Under these circumstances I conceive I am justified in balancing these corrections, and in using the common theory in expansion calculations, believing that the limits of error will not exert too much influence in the comparison with reported duty.

In mining engines, the boiler at each stroke supplies a quantity of steam to fill the space through which the piston has been moved, until the steam valve is closed, and also a smaller portion to raise the clearance steam compressed by the preceding stroke to an equality with that employed to move the piston.†

* The heat expended in the jacket is exclusive of that employed in producing the evaporation. The water condensed in the steam jacket is always in Cornwall returned to the boilers, but at least $\frac{1}{7}$ths of the heat expended during its conversion into steam has been absorbed; the larger portion of this heat is probably communicated through the cylinder to the steam during expansion when its temperature is so much reduced, and tends to keep up its pressure—but to what extent the most accurate experiments alone can determine.

The jacket steam is considered of value in keeping the top and bottom of the cylinder at an equal temperature, but there seems no direct proof in favour of this opinion.

† The words compressed steam refer to the appearances shown by indicator diagrams toward the end of the out-door stroke. When the equilibrium valve is freely opened, the unbalanced weight of rods produces out-door velocity, which is checked and brought to rest by the increase of the steam pressure above the piston, acting through a given space by resistance to compression. In case an engine, or rather the pitwork, is out of balance, or the water in fork, and the pumps are not full, either the equilibrium valve connot be opened freely, or it must be closed sooner.

This clearance steam exerts no power, while the communication between the cylinder and valve is open, but acts during expansion. The complex action is too important to be neglected in expansion calculations, and its effect increases with the amount of expansion. The method I have usually adopted is to measure the portion of the strokes during which the steam valve is open, as the unit of expansion, and to add to the full pressure steam the advantage due to the Hyp Log of the amount of the expansion on the common theory, together with the value of the clearance steam, or to obtain the centre pressure of each volume of expansion, and increase it by the value of the clearance steam.* Perhaps the more correct method would be to calculate the full pressure as before, and then add the clearance steam, before the amount of expansion was calculated; but in this method the expansion shown by the indicator, and the actual expansion in the cylinder do not coincide. When the pressures are all calculated by the centre pressure of each volume of expansion as in the second method, the values of each portion of the steam may be clearly shown at any point of the stroke, and a means is thus obtained of comparing theory with the diagrams formed by the piston of an indicator. For this purpose, it is obviously a point of extreme importance that the pressure in the cylinder, while the communication with the boiler is open, should be ascertained with as much accuracy as the case admits of.

Methods of ascertaining the Steam Pressure in the Cylinder.

Woolf employed a mercury gauge, but the results have not been recorded in a satisfactory manner, and the diagrams made by him, with an indicator that I have recently used, have been lost or mislaid.

In 1835 Mr. Smith visited Cornwall to inquire, on behalf of Mr. Fairbairn of Manchester, respecting the reported duty of the mining engines, and I am indebted to his kindness for a copy of the diagrams then taken, which coincide with the diagrams subsequently taken by the same instrument in January 1838, at Davey's and Hocking's engines by Mr. Loam, the engineer of the Consolidated and United Mines, to whom it was subsequently presented.

I propose to advert only to these diagrams,† in which the coincidence of the

* See Tables at the end of the Paper.

† It has not been considered necessary to insert the diagrams of these engines. The steam was cut off in Davey's engine, at $\frac{1}{6}$th of the stroke, and in Hocking's engine at $\frac{1}{7}$th of the stroke; results which I have since seen confirmed.

The straight line of pressure while the steam valve was open was well defined.

calculated expansion pressures, and the actual pressures as shown by an indicator are more apparent.

The duty of these engines averaged about 70 millions, the column of water on Davey's shaft is 286 fathoms, and above 200 fathoms at the United Mines, at Hocking's engines, and the load on the piston were respectively 13·12 lbs., and 12·7 lbs. per square inch.

The steam valves were rapidly closed, so that the commencement of the expansive action seemed better defined than on the diagrams taken by Mr. Henwood in 1831, in which a convex curve occurs; in those cases I apprehend either the steam valves were more slowly closed, or the clearance spaces were larger, or the full pressure steam was partially wire-drawn during its admission.*

* I do not exactly remember the view I entertained at the period respecting the wire-drawing the steam during its admission from the boiler into the cylinder, the expression refers to the indicator's diagrams taken by Mr. Henwood in 1831 at Huel Towan, the steam valves of which engine was, I understand, $\frac{1}{100}$th of the cylinder area. A double beat valve of 8 inch diameter on an 80 inch engine I conceive is unable to supply the steam with sufficient rapidity after the piston has attained velocity; the result is a partial expansion before the communication between the boiler and cylinder is closed, and a convex curve of pressures is shown by the indicator.

In the engines at Consols, and at the United Mines, 12 and 13 inch steam valves are used, and the area is about $\frac{1}{45}$th of the cylinder; and several indicators showed that while the steam valve remained open, steam of the same pressure was admitted into the cylinder, and consequently the expansion curve assumed a concave form, and the actual coincided more closely with the nominal expansion, and with a calculated curve of expansion including the clearance.

However, the duty of several engines with 8 inch valves has exceeded that performed by Davey's, at Consols, and Hocking's engine at the United Mines.

It is possible there may be an advantage in this method from a pressure gained from high steam in the boiler, without any expenditure of water; but whether this plan is preferable to the introduction of equal quantity of water at an equal pressure of steam while the steam valve is open is an undetermined point which involves questions of strength of boilers and cylinders in a manner such as not to admit of an easy solution.

Recently at an engine (Taylor's United Mines) in which a 14 inch steam valve is used for an 85 inch cylinder, several indicators have shown that the steam of the same pressure, while the valve is open, viz., about 25 lbs. above atmosphere, is admitted, and expanded about 12 times; this engine has performed a duty of 100 millions for three months in succession.

The variation of the pressure at the top and bottom of the stroke, in consequence of the proportional greater effect of the clearance steam during expansion, seems to be about as 8 to 1.

Woolf once attempted to work a 90 inch cylinder with a 4 inch valve; under these circumstances the velocity of the steam through the aperture would approach the limit of its velocity. A duty of 44 millions was the result, but it was subsequently increased to 67 by means of an 8 inch valve. The use of small valves may be traced to Woolf's practice.

Mr. Henwood's most valuable series of indicator diagrams have been published in the Transactions of the Institution, vol. ii., page 49, and are the earliest on record.

It may perhaps be questioned whether the spring of an indicator can follow with sufficient rapidity the decreasing steam pressure during expansion; whether it has not a tendency to exhibit a pressure higher than is exerted by the steam on the surface of the piston, occasioned by the small passage of communication through a wooden plug fitted into a small grease cock, &c.; still I conceive it may be relied on sufficiently for the steam when the valve is open, at least for those engines in which the full pressure steam exhibits a straight line, from which calculations may be made of the gross power capable of the performance of a duty equal to that reported in 1838.*

With a view of showing the progress of improvement, and its connection with the results that may be deduced from theory, it is proposed to select the duty or work performed in the years 1778, 1798, and 1838, as representing

* During the spring I had an indicator constructed with a small piston, under the impression that it might give more accurate results from steam admitted only through the small aperture, a wooden plug was inserted into a small grease cock. I had reason to believe it was properly adjusted for low temperatures, as on a trial at Halen Beagle, on an engine loaded only to 5·76 lbs. to the square inch of it, together with the Consol's indicator (made by Woolf), both indicators showed that a decreasing steam pressure crossed the atmospheric line while the steam valve was open. On opening the grease cock at the same moment as the steam valve, a very small puff of steam was visible, and the engine audibly took air before the steam valve closed, some proof of the accuracy of the indicator under these circumstances; but when the smaller indicator was placed on Taylor's engines, where the temperature of the steam was much higher, the first stroke when cold gave a much higher result on the scale than when heated; but the scale when heated coincided with the Manchester indicator, which belonged to Mr. Loam, one of the engineers of the mine. A similar result again occurred after correction by the maker.

I mention this circumstance, as I wish to retract, in some degree, the strong expressions I had used as to the dependence that may be placed on indicators without extreme attention to accuracy of adjustment, as well as to the channel of communication with the cylinder.

I may, perhaps, be permitted to advert to another necessary precaution in their use: several diagrams were recently taken, with this and Woolf's indicator, at Tresavean, with a string from the radius rod, which in this case made rather a greater angle than usual with one of the grease cocks, and also with a parallel motion introduced between the radius rod and indicator, which was fixed by a temporary frame of boards. The average result of the diagrams from the string was an expansion of $5\frac{1}{2}$, and with the parallel motion of $5\frac{1}{4}$ times, the difference was about $\frac{1}{16}$th of a foot in the cylinder, or 1·2 of the point at which the steam valve was closed.

The engine is similar to that at the United Mines, except that the stroke is 12 instead of 11 feet: it had scarcely been at work 3 weeks. The expansion will be soon much increased.

the performances in Cornwall of Newcomen's atmospheric engine, Watt's low pressure engine, and Watt's engine working high steam expansively.

The duty is a calculated quantity which has at all times been affected by numerous causes, exclusive of the changes that have taken place in the boilers and pitwork, which will be adverted to at the end of this paper.

The annexed list was published in the Appendix to the Ordnance Geological Survey of Cornwall, in reference to water raised from the mines :—

" At all periods, the friction in the pumps on a given load has varied in different shafts from several causes, among which may be enumerated the original quality of the workmanship of the pitwork, the state of order in which it is kept, the length and number of the lifts, the diameter of the pumps, the underlie of the shaft, and the use of flat rods to work a second column of water in another shaft.

"The delivery of the actual water raised, as compared with that calculated has always varied from the impracticability of at all times supplying the exact quantity of water, when pumps of different diameter are employed at different lifts, especially when part of the water is taken from the upper levels, which are liable to be affected by rain in winter, or where the pumps are worked in shafts of unequal depth, independently of leakages of all kinds; all these circumstances have been neglected for the sake of a convenient method of comparing the work performed by steam engines with different velocities, and loads within certain limits, a course rendered necessary by the nature of the agreement between Messrs. Boulton and Watt and the Mining Adventurers, and, since 1812, by the spirited competition that had been established among the mining engineers by monthly reports of the duty of the Cornish engines."

It appears to me almost impracticable to attempt, in contracted shafts, to prove the duty in the manner often demanded of weighing the water delivered by each separate lift, without which precaution the real duty could not be exactly ascertained, the adit delivery is unsuited even for an approximation, as it includes the water drained from the upper portions of the lode; the objections above enumerated are less felt in new pitwork, such as is attached to the engines adverted to in these remarks.

Water Delivery.

The earliest attempt to ascertain the water delivered was made by Mr. Henwood, at Huel Towan, who estimated the deficiency at 7 or 8 per cent; subsequently Mr. Wicksteed weighed and measured the water from three lifts of pumps, at Holmbush, and found the deficiency 10 per cent. In September, 1839, the water of four strokes of Eldon's engine was separated and measured out of a cistern, the plunger was 14 inches in diameter, the stroke 7½ feet, and the lift 34 fathoms ; the calculated contents of the pump was 49 gallons, the delivery 47, a deficiency of 4 per cent.

The position of this pump near a road, over which I constantly passed, enabled me to watch the performances, and in course of 30 visits or more, I never but once detected an air bubble, and even then the amount was scarcely appreciable—less than a cubic inch.

Summary of Improvement.

It will perhaps be found a convenient form to exhibit a short summary of the principal changes that have taken place during 60 years, in connection with the amount of duty performed at the periods selected :—

Newcomen's engine, 1778.	Dome boilers under the cylinder.	
	Separate pump rods for each lift.	
	Bucket pumps.	
	Full load for atmospheric pressure, probably 7 or 8 lbs. per square inch.	
	Column of water seldom exceeding 90 fathoms.	Duty.
	Trial at Poldice of two engines in one shaft	7,126,822 Winchester. 7,483,163 Imperial.
	Average of other engines under	5,000,000 Winchester.
	Evaporation of water . .	6 or 7 cubic feet.
1798. Watt's low pressure engine.	Waggon boilers.	
	Cylinder placed on a separate foundation.	
	A connected main rod, with pump rods attached to each lift.	
	Bucket pumps.	
	Loads generally too heavy for much expansion with low pressure steam.	
	Duty of 4 best engines	27,473,500 Winchester. 28,847,170 Imperial.
	Average of 23 ditto .	16,925,000 Winchester. 17,770,000 Imperial.
	Column of water seldom exceeding 160 fathoms.	
	Evaporation of water from 9 to 10 cubic feet.	

1838. Watt's engine, using high steam expansively.	Trevithick's boilers. Main rods as before. Plunger pumps, except at the bottom of the shafts. Loads from 5 to 18 lbs. per square inch. Expansive action from 2 to 6 times the volume used at full pressure. Column of water in one instance 286 fathoms. Evaporation of water from 10 to 14 cubic feet.

Before adverting to the theoretical estimates due to the assumed water evaporation of the different periods, I would observe that the Cornish system of mining accounts, in which no reference is made to the capital expended, has afforded the mining engineers more liberty in the adoption of whatever proportions appeared advantageous in the boiler surface in the flues, or in the size of the cylinder for expansion, and in an increase of strength of the pitwork, required for the first impact of high steam, on commencing motion at each stroke with a pressure that so much exceeds the total resistance, while the resistance exceeds the power in a greater ratio at the end of the stroke.

On the commencement of the present system of encouragement of an improvement of duty, the weakness of the waggon boiler was soon found by Messrs. Jeffree and Gribble, at Dolcoath, to be the limit of expansion and to an increase of duty, much beyond that which had been performed by Watt; but on the adoption of Woolf's cast-iron tubular boilers and a modification of Trevithick's locomotive boilers the strength of the pitwork became the limit to expansion,* and recently in some cases the low rate of duty has been traced to weak pitwork.

* The increasing depth of the shafts, and the greater strain occasioned by high steam at the commencement of motion at each stroke, required a greater strength of main rods, and consequently timber of larger dimensions, and a greater weight of iron connecting straps, on a given water load; these increased weights enabled expansion to be again extended, as the means of equalizing the variable action of the steam became more efficient. This mode of meeting the difficulty arising from the variable pressure of steam worked expansively is due rather to the circumstances under which the mines were worked than to design on the part of the engineers. Mr. Davies Gilbert, I believe, was the first person who fully understood the principle on which the success of expansion depended, and foretold the failure of a scheme suggested by a gentleman of Penzance, who attempted to introduce a scheme of the same nature as the patented contrivances of Watt, for the purpose of equalizing the action of steam during expansion. The inconvenience and expense of breakages during the progress of expansion was experienced in all the deeper mines, and in none more so than in the United Mines, which,

As it is my object only to deduce a probable duty from the conditions under which the steam is assumed to have been worked in the cylinder by means of a co-efficient, it seems unnecessary to enter upon the question of total resistances of mining engines* (as the subject would require more information

which, about 1814, were about 170 or 180 fathoms in depth, and the levels were below those at Consols, which are situated to the north, and the mine consequently was over pressed with water.

I have recently received an account of the expense of these breakages from a gentleman through whose hands the payments passed, and whose opinion was strongly in favour of strong main rods for mining to meet the strain occasioned by deepening shafts and increased expansion. The difference of the strain on the main rods with 12 times expansion in Watt's engines, or in Woolf's, or rather Hornblow's double cylinder engine, and also in the double cylinder engine recently erected by Sims at Carn Brea, ought to become a subject of consideration to the miner. It may, however, be observed that the only friction due to the additional weight, of rods and balance, is that occasioned by the additional friction thrown on the gudgeons of the balance beams; the cost of the repairs of which would be scarcely appreciable, while the practice of not charging the interest on capital expended in mining machinery in Cornwall renders a commercial comparison impracticable with the amount of annual coal savings.

* The evasion of this question in 1839 arose from the author's inability to assign sufficient reasons for his belief that the friction and other resistances of good mining engines, even in the deep shaft, did not exceed ½ the calculated water-load, or rather that the addition of ½ to the calculated water-load, would represent the total resistances. This idea had been derived from the calculations attached to the diagram forwarded to him by Mr. Fairbairn, and without doubt it has influenced the co-efficient of that he employed for engine and pitwork resistances.

This rule, however, gave a friction much too high for Eldon's Engine United Mines, a 30 inch cylinder employed in raising injection water in a one plunger lift of 34 fathoms, conditions equivalent to those under which the Cornish Engine at Old Ford is worked. Lately the author, on the suggestion of Mr. Parkes, attached a mining gauge to the following engines :—

1841	——	Cylinder in Inches.	Load in lbs. per Square Inch.	One-half added for resistances.	Barometer.	Atmosphere in lbs., 49 lbs. per Inch of Mercury.	Steam above or below.	Total Steam per Square Inch.	Addition for Atmosphere on Piston Rod.	Total pressure in-doors.
16 April .	North Roskear	70	9·54	14·31	29·4	14·4	=0	14·4	·12	14·52
4 May .	Halen Beagle.	70	5·7	8·55	29·56	14·48	−5·5	8·93	·12	9·05
13 Oct. .	Tresavean .	85	11·91	17·91	29·5	14·45	+3	17·45	·11	17·56

The steam valve was opened by a hand lever, and the velocity in-doors was extremely slow at North Roskear and Halen Beagle, and the mercury was quite steady; but it amounted to about ½ the usual velocity at Tresavean, and 3 lbs. is taken as the mean between the variations of 1 and 4, as the latter was the pressure for the longer time. The pressure seemed less in the subsequent strokes, when the engine came in-doors slower.

The water load per square inch on the piston in Cornwall is usually calculated from the diameter of the cylinder.

than I possess, and repeated visits to pitwork under ground), and the duty has been taken $\frac{6}{10}$ths, leaving $\frac{4}{10}$ths for friction and other resistances of the calculated power.

It is essential to obtain as near as may be the evaporation of water in cubic feet per bushel of coal, and it is to be regretted that scarcely any attention has been paid to this part of the subject by the engineers of the mines of Cornwall.

The careful experiments of Smeaton cannot be taken as the evaporation due to Cornish practice in 1778, nor can the careless waste of the collieries become our guide. I conceive it probable that it did not exceed 6 cubic feet per bushel in dome boilers.

In this year a trial of two atmospheric engines working in one shaft was made at Poldice (Phil. Trans. 1830), under the superintendence of Messrs. Boulton and Watt, and several gentlemen connected with the mines of the county, when the consumption of coal amounted to 14,080 Winchester bushels in 61 days, and hence each bushel, without allowance for stoppages, worked the engine 6·2385 minutes. The four lifts of pumps were 17 inches in diameter, and raised the water from a depth of 58 fathoms, and made $5\frac{1}{2}$ strokes of 6 feet in length per minute.

$$17^2 \times \overset{\text{lbs.}}{2{\cdot}0454} \times \overset{\text{fms.}}{58} = 34{,}285 \text{ load on the shaft.}$$

$$\overset{\text{ft.}}{6} \times \overset{\text{stro.}}{5\tfrac{1}{2}} \times \overset{\text{min.}}{6{\cdot}2385} = 207{\cdot}87 \text{ feet per minute.}$$

$$\overset{\text{lbs.}}{34{,}285} \times \overset{\text{ft.}}{207{\cdot}87} = 7{,}126{,}832 \text{ lbs. raised one foot high.}$$

This amount was subsequently deducted from the duty of Watt's engine, who was entitled by the conditions demanded for the use of his patent to receive $\frac{1}{3}$rd of the value of the remainder, which represented the coal saving effected by his engines. It may be considered a singular circumstance that the neglect and want of attention and skill produced as great a waste of coal in mining engines, after 1800, as the payments made to Watt; and it may be fairly asserted that Watt's counter to ascertain the duty saved nearly the whole amount of the 170,000*l.* paid to Messrs. Boulton and Watt for coal savings. A portion of this sum arose from the increased duty occasioned by boiler and pitwork improvements, unconnected with the patent.

In 1793 the duty averaged on Watt's authority equalled $19\frac{1}{3}$ millions.

In August, 1811, the duty of several engines equalled $13\frac{1}{2}$ millions, being a difference of 6 millions.

Boulton and Watt's share on 19½ millions would be—

$$\frac{19{\cdot}5-7}{3}=\frac{12{\cdot}5}{3}=4{\cdot}166 \text{ duty to be paid as Watt's share,}$$

$$\text{and } \frac{4{\cdot}166}{19{\cdot}5}={\cdot}213 \text{ of the value of the coal consumed.}$$

The evaporation of Watt's boilers is stated on authority to have been from 8 to 12 cubic feet of water per bushel; but from complaints of the carelessness of enginemen, the frequent stoppages of the pitwork at that period, and waste of steam, and perhaps the practice of allowing the enginemen to take home cinders, would induce me not to rate the evaporation at more than 9 cubic feet per Winchester bushel, expended in the cylinder in mining engines.

The present evaporation of Trevithick's boilers is supposed to be from 10 to 14 cubic feet per imperial bushel (94 lbs.), and even more occasionally, an amount due probably to slow combustion and a large extent of flue surface.* In March, 1826, a trial of 4½ days' duration at Woolf's engine, a single-acting 90-inch cylinder at Consols, gave an average result of 11·4 cubic feet per Winchester bushel in boilers with a less flue surface than is at present employed. The water supply was measured by a cistern, the temperature of which was 90° F., and the temperature of the boiler 263·5 F.

Days.	Hours.	Cubic Feet.	
1	14	12	
2	24	11·34	
3	24	11·64	= 11·4.
4	24	11·11	
5	24	10·93	

This engine first reached 67 millions in the report, and 64 millions on a trial, and exceeded the double cylinder engines in duty, but was soon surpassed by the performance of the Huel Towan, constructed by Grose.

* In 1839 I was an advocate of slow combustion and an extended boiler surface. The Cornish evidence in its favour is founded in a great measure on duty, and it has been mixed up with expansion from high steam, and with the additional steam room given, as more flue surface has been added.

Rapid combustion can scarcely be tried in a satisfactory manner with Trevithick's cylindrical mining boiler, unless a steam reservoir is added equivalent to the steam room of the reduced number of boilers.

The water in many mines is extremely bad, and is supposed to be more injurious to the iron when the fires are forced. This revision of opinion has been occasioned by Mr. Wicksteed's experiments, who has thrown some doubt on this subject in relation even to mines.

The calculated performance of this engine at 5 times expansion—the reported amount—would be—

Temp. 263° F. . .		3,880,000	lbs. one foot from one cubic foot of water.
	$\frac{1}{9}$th —	430,000	for clearance steam.
		3,450,000	
	1,609	5,551,050	
	$\frac{1}{9}$th +	616,783	for clearance steam.
		9,617,833 × 11·4=108,643,296 × 6=65,859,777.	

A table has been annexed on similar principles of the duty assumed to be due to the different conditions under which the engines were worked in 1778, 1798, and 1838. It is not intended to exhibit any remarkable coincidence where numerous interferences occur, and it is liable to the charge of having been purposely made to coincide, still it affords some grounds for the assertion that the Cornish mining engines ought to perform the reported duties wherever the weight of the main rod is sufficient to absorb the pressure at the commencement, and restore it at the end of the stroke.

In conclusion I propose to advert to some of the changes that have taken place in pitwork during the last 60 years.

Smeaton, in his report on the Chacewater engine, directed a single main rod to be used for the upper lift, and that a cross-head should be attached with rods on each side to work the two lower lifts. The circumstance of a single main rod at the surface was mentioned to me by Mr. M. Moyle, who was an agent in the counting-house of this mine at the period of or soon after its erection. The extension of this plan seems due to Watt or Murdock in lieu of the separate lifts to each pump, with their apparatus of chains at the arc at the end of the beam.

As the economy of coal and greater certainty in the performance of Watt's engine enabled the mines to be worked deeper, the weight of the rod, being in excess, took the engine out of doors too fast without a balance; and either Watt or Murdock (the latter was the party immediately engaged in the suggestion) proposed to substitute a plunger pole for a balance at Huel Maid. In 1796 a plunger pole was employed at Ale and Cakes, a mine which now forms the eastern part of the United Mines.

Under these circumstances no effect of much importance on the duty was produced, but its subsequent introduction as a system of pitwork in lieu of bucket pumps at the bottom of the shaft has eventually caused the slow out-door stroke. The facility with which the packing can be kept in order, and the trouble of examining and packing common pumps, contributed to its introduction.

Duty of Stamping Engines.

I may perhaps be permitted to refer to an objection which was long urged against the truth of the reported duty of the pumping engines, I mean the low duty of the stamping engines previous to December, 1835, when 43 millions was reported as the performance of a 32-inch single-acting cylinder engine 10 feet stroke, erected by Mr. James Sims at the Charlestown Mines, near St. Austle. In this engine the crank was applied direct to the cam-shaft. The amount of the duty of this engine, and of two similar engines at Huel Kitty and Carn-Brea constructed by Sims, has been increased to above 60 millions. A double engine of similar form at Huel Vor by Richards has equalled this performance.

The expansion of these engines varies from $2\frac{1}{2}$ to 3 times, the steam being cut off at $\frac{6}{10}$ or $\frac{1}{3}$ of the stroke; hence the theoretical duty for 12 cubic feet of water evaporated per bushel scarcely reaches 60 millions for 3 times expansion, a coincidence sufficiently close with the reported duty.

It should not be forgotten that the Cornish duty includes the advantage due to a supposed superiority of Welch coal, and to slow combustion in extended flue surface; still a reference to the first principles of steam power may tend to discourage extravagant expectations, and at the same time afford a reasonable hope that a great improvement in duty may be effected in other districts wherever the conditions may be suitable and high steam would not be considered objectionable.

JOHN S. ENYS.

PER SQUARE INCH.			Temperature Fahrenheit.	Grains of Water in One Cubic Foot.	Pressure in lbs. per Square Foot	Volume from one of Water.	Efficiency or Gross Power.
Steam in Atmosphere.	Steam in Inches of Mercury.	Steam in lbs weight.					
·125	3·74	1·83	124·6	37·	264·6	11801·	3,112,544
·25	7·48	3·67	150·8	70·3	529·2	6198·38	3,280,182
·5	14·96	7·35	179·6	135·	1058·4	3229·36	3,427,954
·75	22·44	11·02	197 6	191·8	1587·6	2217·2	3,520,466
1·	29·92	14·7	212·	256·2	2116·8	1700·	3,598,560
1·25	37·5	18·37	223·88	315·	2646·	1384·36	3,664,016
1·5	44·48	22·05	234·32	372·	3175·2	1171·59	3,720,332
1·75	52·36	25·72	241·78	428·8	3704·4	1061.66	3,766,145
2·	59.84	29·4	250·79	485·	4233·6	899·91	3,809,848
2·25	67·32	33·07	257·4	539·6	4762·8	808·	3,848,424
2·5	74·8	36·75	263·93	593·	5292·	733·45	3,881,417
2·75	82·28	40·42	269·89	645·4	5811·2	672·36	3,907,618
3·	89·76	44·1	275·	702·8	6350·4	620·74	3,941,947
3·25	97·18	47·77	278·8	755·6	6879·6	576·83	3,971,359
3·5	104·72	51·44	284·59	808·7	7408·8	539·1	3,994,084
3·76	112·2	54·94	288·86	861·4	7938·	506·15	4,017,818
4·	119·68	58·8	292·91	920·2	8467·2	477·05	4,039,277
4·25	127·1	62·47	295·95	966·	8996·4	450·96	4,046,926
4·5	134·61	66·15	300·47	1017·8	9525·6	428·36	4,080,386
4·75	142·12	69·82	304·07	1071·3	10054·8	406·76	4,098,890
5·	149·6	73·5	307·91	1122·3	10584·	389·38	4,111,118
5·25	157·08	77·17	311·	1144·1	11123·2	372·32	4,141,399
5·5	164·08	80·85	314·06	1221·7	11652·4	356·86	4,157,282
5·75	172·72	84·52	316·94	1271·	12181·6	342·76	4,175,365
6·	179·62	88·2	320·	1322·5	12700·8	329·65	4,186,518
6·25	187·1	91·87	322·77	1373·	13200·	317·58	4,217,462
6·5	194·58	95·55	325·86	1422·	13739·2	306·62	4,218,937
6·75	201·74	98·22	328·71	1473·	14288·4	296·35	4,233,367
7·	209·44	102·9	331·56	1502·	14817·6	286·7	4,243,206
7·25	216 92	106·57	334·19	1570·	15346 8	277·77	4,261,806
7·5	224·4	110·25	336·93	1617·	15876·	269·52	4,278,899
7·75	231·36	113·92	339·38	1666·	16405·2	261·66	4,292,689
8·	239·36	117·6	341·83	1714·	16934·4	254·27	4,305,909
8·25	246·86	121·27	344·22	1762·	17463·6	247·31	4,318,923
8·5	254·42	124·95	346·6	1811·	17992·8	240·76	4,331,946
8·75	261·48	128·65	348·99	1858·	18522·	234 57	4,350,465
9·	269·2	132·3	351·32	1905·	19051·2	228·72	4,357,390
9·25	276·76	135·97	353·62	1953·	19643·4	223·17	4,385,817
9·5	284·16	139·65	355·8	2001·	20109·6	217·89	4,381,680
9·75	291·32	143·22	357·71	2048·	20638·8	212·82	4,392,547
10·	299·2	147·	359·6	2096·	21168·	207·98	4,402,520

These Tables were calculated from those of Clement Desormes, about three years ago.

The efficiency column is original, in its present form, except for steam of 1 atmosphere strength. See Tredgold, on Steam Engines.

Extract from the Second Paper, by Davies Gilbert, Esq., relating to Cornish engines in the Phil. Trans. 1830.—Winchester bushel of Coal.

—	Diameter of Cylinder in Inches.	Duty, 1798.	Observations.
1 .	20	10,015,000	
2 .	21	16,385,000	
3 .	45	29,668,000	It was believed at the time that some inaccuracy must have occurred in the communications respecting these two Engines.
4 .	36	28,212,000	
Double 5 .	42	18,193,000	On the same Mine, the length of strokes in all but one 6 feet, in that 8 feet. Average duty of the whole 15,985,000.
6 .	63	15,190,000	
Double 7 .	45	15,180,000	
8 .	45	15,571,000	
9 .	45	15,090,000	
10 .	45	14,384,000	
Double 11 .	42	18,740,000	
12 .	42	15,532,000	
13 .	36	18,465,000	
14 .	..	12,226,000	The diameter of the cylinder not returned.
15 .	30	14,050,000	
16 .	20	12,366,000	
Double 17 .	14¾	6,097,000	
18 .	30	13,931,000	
19 .	28	19,739,000	
20 .	36	24,514,000	
21 .	21	13,215,000	
22 .	20	15,034,000	
23 .	48	27,500,000	Supposed to be the best Engine.

It is to be regretted, that the load in the shaft, and other particulars from which the duty was calculated in 1798, by Mr. Davies Gilbert, have been mislaid, so that I have been unable to give the statements in the same form as the present duty report, neither have they been preserved by Mr. Alfred Jenkins, who was jointly engaged in making the requisite calculations from data supplied by the different mines.

The duty on Watt's authority was higher in 1793: at this period few new engines were erected, and the shafts had been deepened and a deterioration of the engines had occurred by age or bad water, circumstances tending to reduce duty.

North Downs, near Redruth.—Newcomen's Engine, with low Steam.

Water in Cubic Feet.	3,600,000 1,800,000 (½) 1,800,000	3,600,000 1,200,000 (⅓) 2,400,000	lbs. one foot high from the water. Waste by condensation. On the piston.—efficiency.
6	10,800,000 6,480,000	14,400,000 8,640,000	Efficiency. Duty.
7½	13,500,000 8,100,000	18,000,000 10,800,000	Efficiency. Duty.
12	21,600,000 12,960,000	28,800,000 17,280,000	Efficiency. Duty.
14	25,200,000 15,120,000	33,600,000 20,160,000	Efficiency. Duty.

WATT'S ENGINE, with low Steam.

—	Full Pressure.	Cut off at Four-fifths.	At Two-thirds.	At One-half.
	3,630,000	3,630,000 733,260 (·202) 4,363,260	3,630,000 1,470,150 (·405) 5,100,150	3,630,000 2,515,590 (·693) 6,145,590
8	29,040,000 17,424,000	34,906,080 20,943,648	40,721,200 24,432,720	49,164,720 29,494,832
10	36,300,000 21,780,000	43,632,600 26,179,560	50,901,500 30,540,900	61,455,900 36,873,540
12	43,560,000 26,116,000	52,359,120 31,415,472	61,081,800 36,658,080	73,747,590 44,248,248
14	50,400,000 30,240,000	61,085,640 36,651,384	71,262,100 42,757,260	86,636,260 51,981,756

WATT'S ENGINE, with high Steam.

	Two and a Half Atmospheres.			Three Atmospheres.	
Expansion.	4.	5.	6.	8.	12.
	3,880,000 388,000 ($\frac{1}{10}$) 3,492,000 4,839,912 (1·386) 483,991 8,816,903	3,880,000 430,000 ($\frac{1}{9}$) 3,450,000 5,551,050 (1·609) 616,783 ($\frac{1}{9}$) 9,617,833	3,880,000 485,000 ($\frac{1}{8}$) 3,395,000 6,078,050 (1·791) 759,756 ($\frac{1}{8}$) 10,232,806	3,940,000 788,000 ($\frac{1}{5}$) 3,152,000 6,453,008 (2·079) 1,291,601 ($\frac{1}{5}$) 10,896,609	3,940,000 985,000 ($\frac{1}{4}$) 2,955,000 6,340,220 (2·484) 1,585,055 ($\frac{1}{4}$) 10,880,275
10	88,169,030 52,801,418	96,178,330 55,704,598	102,232,060 61,396,836	108,966,090 65,379,654	108,802,750 65.281,650
12	106,602,836 63,961,701	118,213,996 70,928,397	122,791,672 73,675,003	130,759,300 78,455,480	130,563,300 78,337,980
14	123,436,642 74,061,985	134,649,662 80,789,797	143,325,928 85,995,556	152,552,315 91,531,389	152,323,850 91,397,310

This Table will account for a great variation of duty in mining engines; on visiting several years ago many engines whose reported duty was low, the principal cause was obviously the small extent of expansion used; the reasons assigned were chiefly weak boilers and weak pitwork: in some cases bad pitwork produced a great amount of extra friction and aided in the reduction of the duty, so that the co-efficient would be erroneous, in other cases.

I believe the co-efficient, 4, will be found to be too high for friction and resistances where the pitwork has been well put up and is nearly new, or during experiments where unlimited quantities of grease are used both in the engine and under ground.

INDEX

TO

VOLUMES I., II., AND III.,

OF THE

TRANSACTIONS OF THE INSTITUTION OF CIVIL ENGINEERS.

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1841.

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Humfrey, John Hambly, Rouen.
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Jones, John Edward, Cannon Row, Westminster.
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Kendall, Henry Edward, Brunswick Square.
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Knight, Samuel John, Waterside Iron Works, Maidstone.
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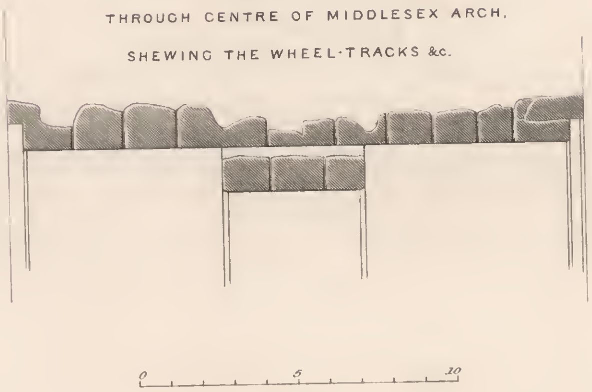
OLD BOW BR

SECTION

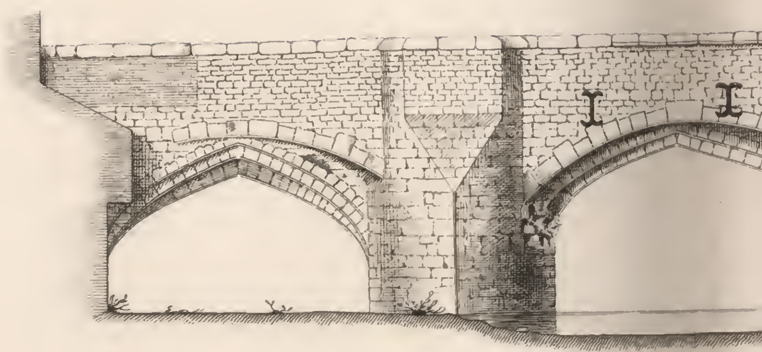
THROUGH CENTRE OF MIDDLESEX ARCH.

SHEWING THE WHEEL-TRACKS &c.

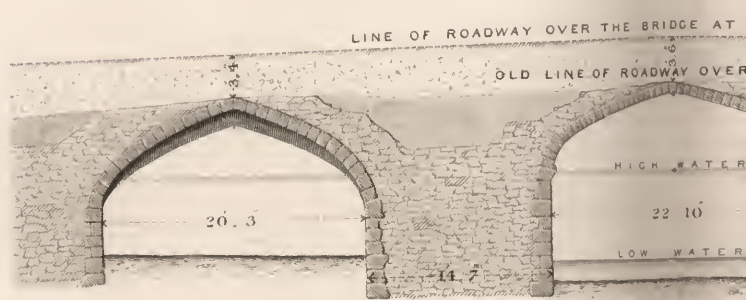


SCALE OF FEET.

ELEVATION.



LONGITUDINAL SE



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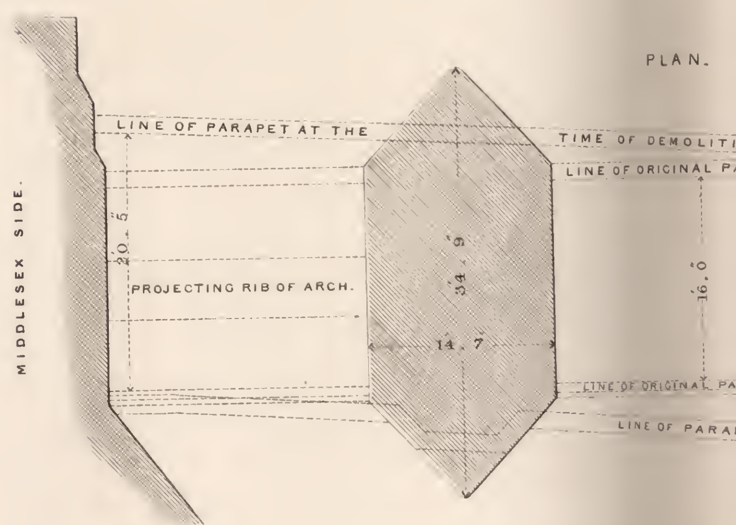

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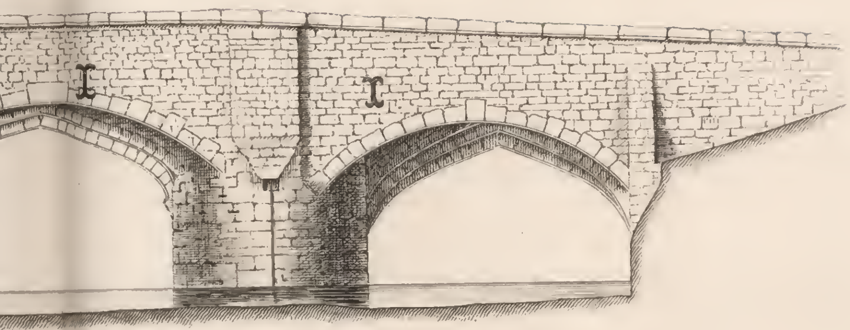
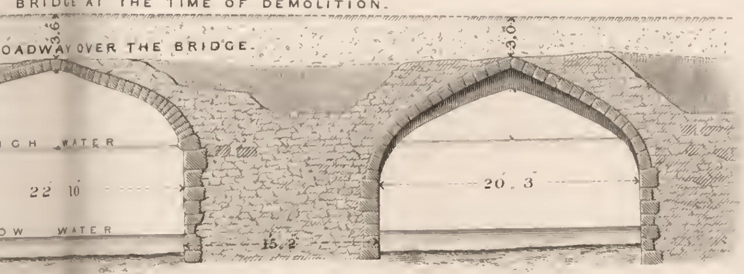
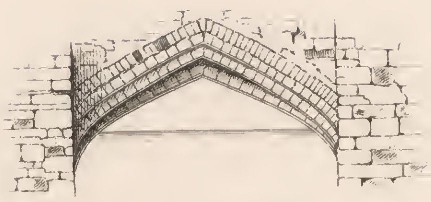
OW BRIDGE.

EVATION.



UDINAL SECTION.



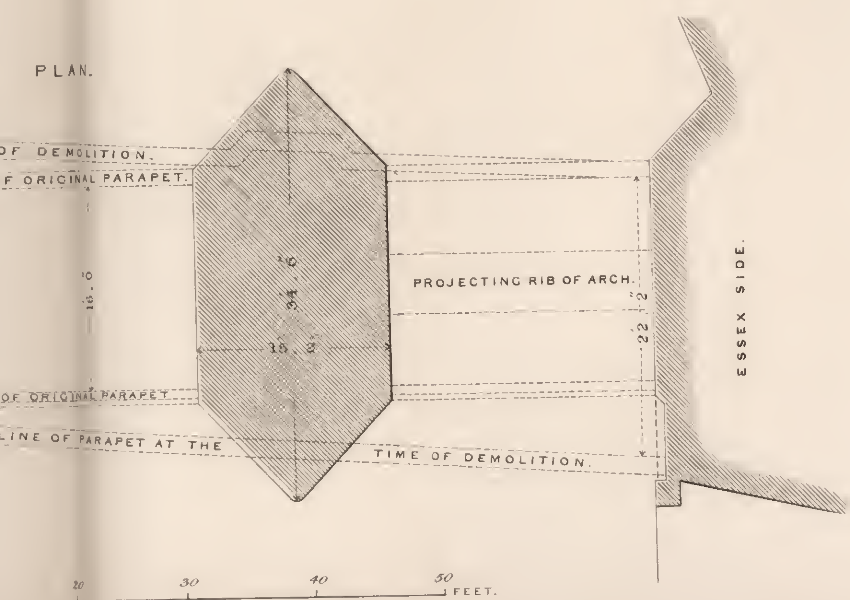


NORTH ELEVATION OF ESSEX ARCH.

SECTION THROUGH ESSEX ARCH.

SHEWING THE PROJECTING RIB.

PLAN.



S. Bellin, sculp.

BOW BRID

CROSS SECTION OF WING WALL.

PLAN OF ABUTMENTS, COF

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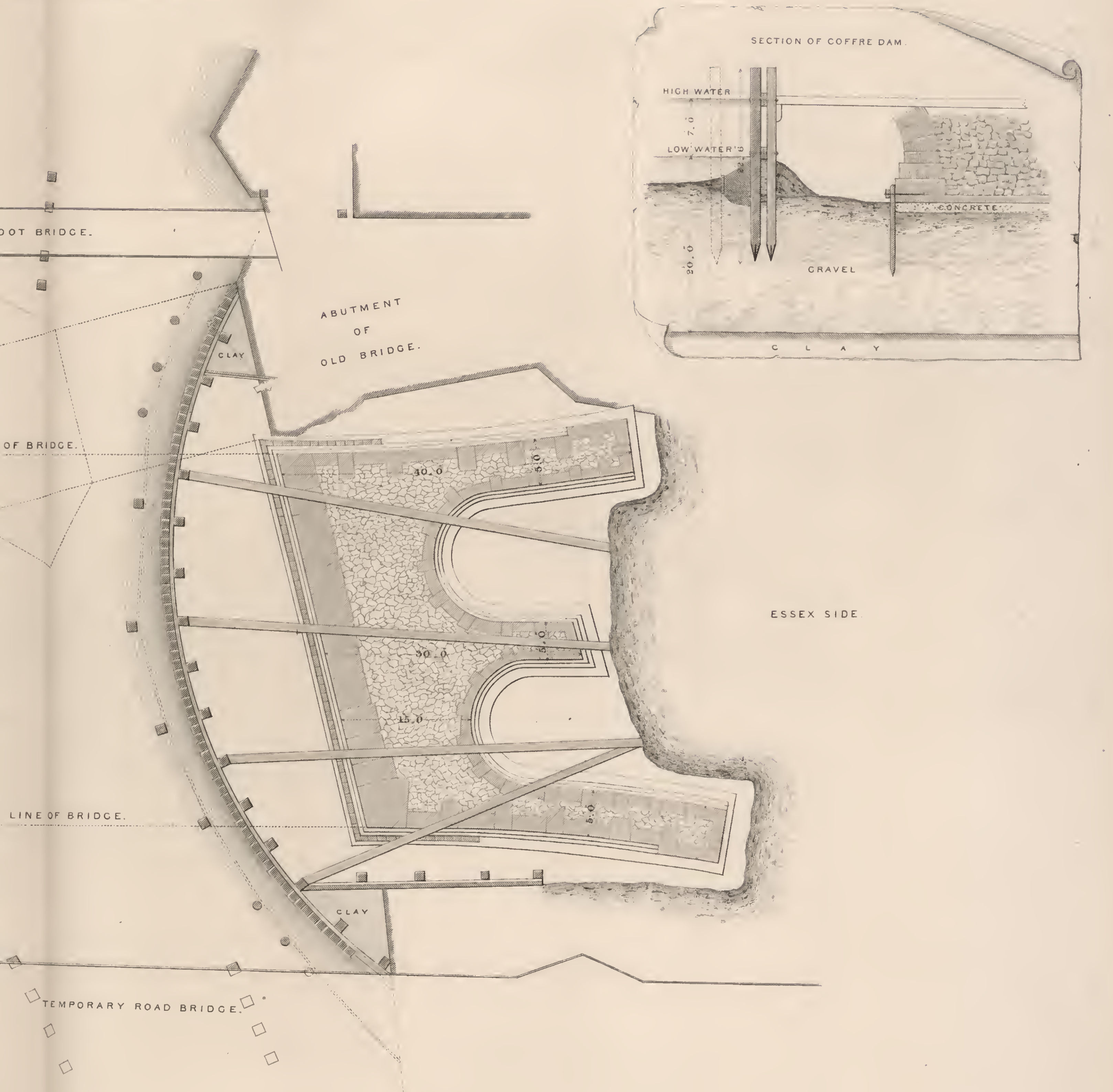
BRIDGE.

MENTS, COFFREDAMS, &c.



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S. Beckon sculp.

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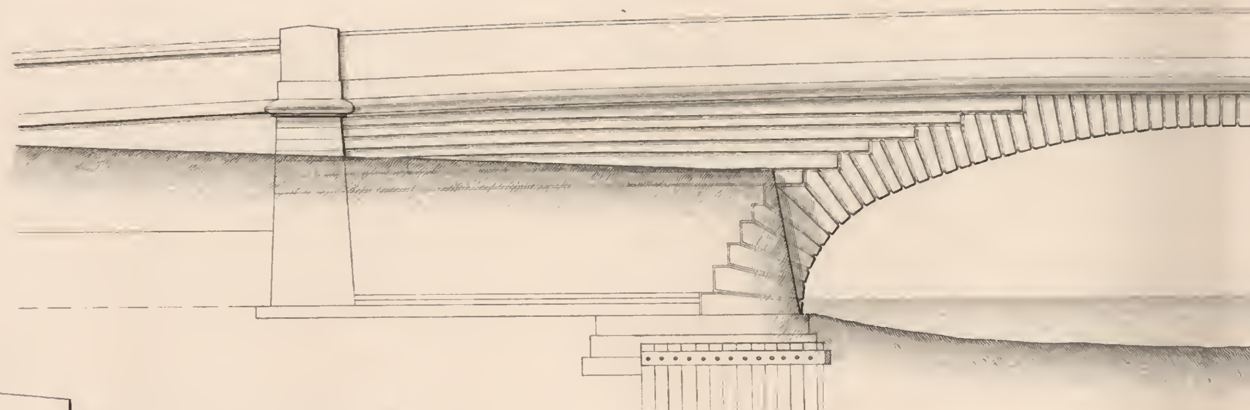

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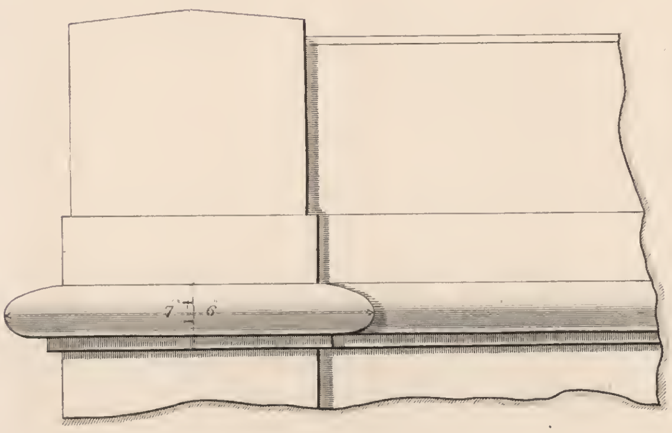
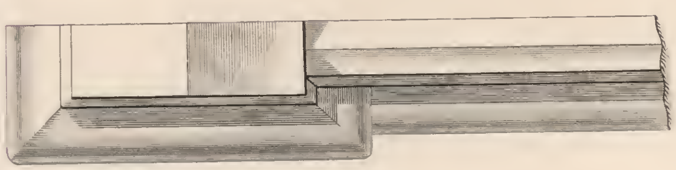
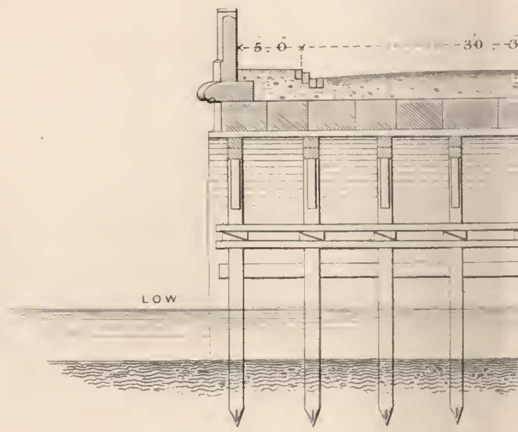
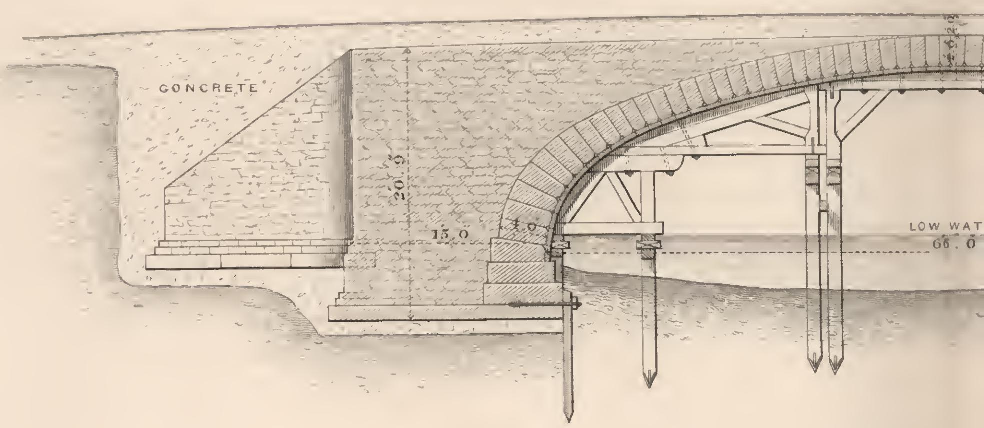


ELEVATION AND PLAN OF PEDESTAL, PARAPET, &c.





CROSS SECTION OF BRID



LONGITUDINAL SECTION OF

GENERAL DIMENSIONS OF BRIDGE.

	FT	IN.
Span of Arch on Square Line	64 .	0
D° on Oblique Line	66 .	0
Rise of Arch above low Water	13 .	9½
Total Width of Bridge on Square line	42 .	7¾
D° Obliquely	43 .	10½
Total Length of Ditto	146 .	0

SCALE OF 10 5 0 10 20

SCALE OF THE 12 6 0

FE

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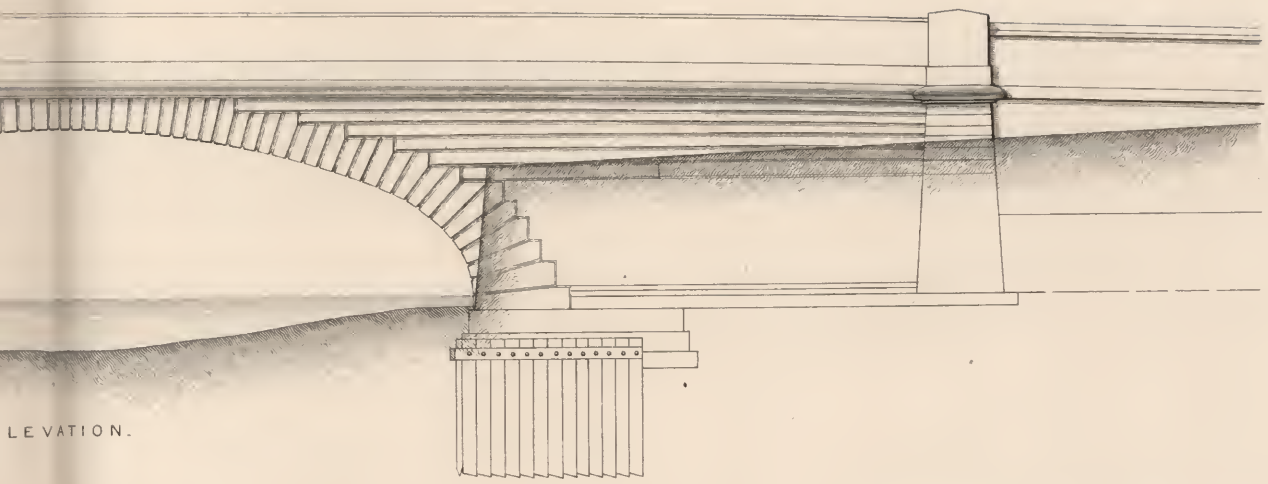
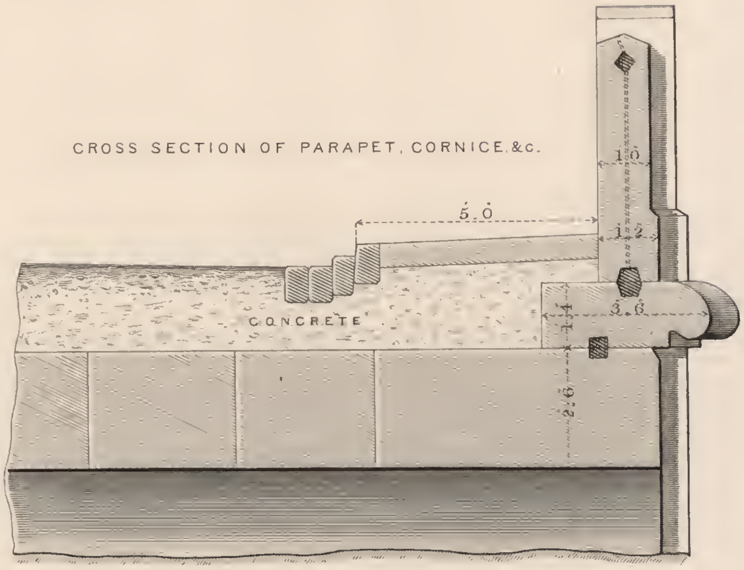
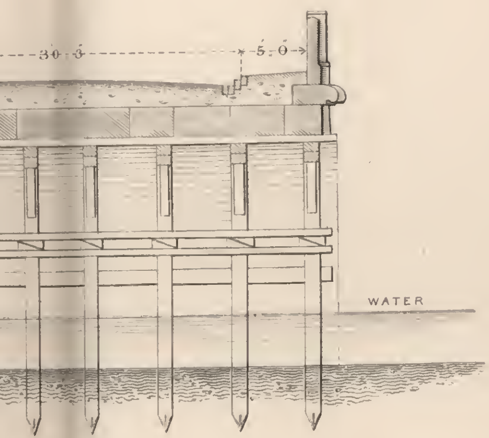
BRIDGE.



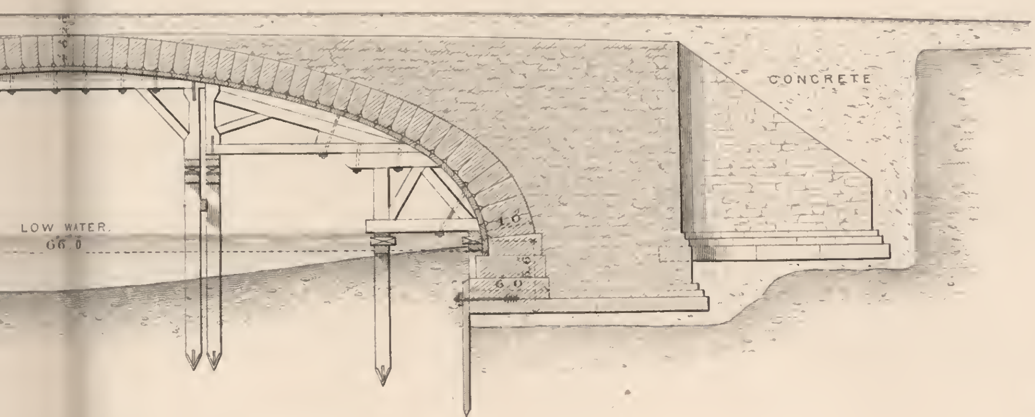
LEVATION.

CROSS SECTION OF PARAPET, CORNICE, &c.





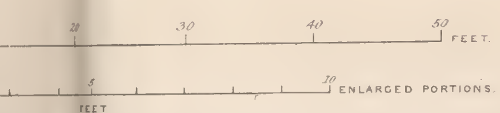
OF BRIDGE WITH CENTERING.



TION OF BRIDGE AND CENTERING.

SCANTLINGS OF CENTERING.

	IN		IN
Piles	12	×	12
Sills	12	×	6
Principal Framing	12	×	12
Struts	10	×	10
Braces	10	×	5
King Posts	14	×	12



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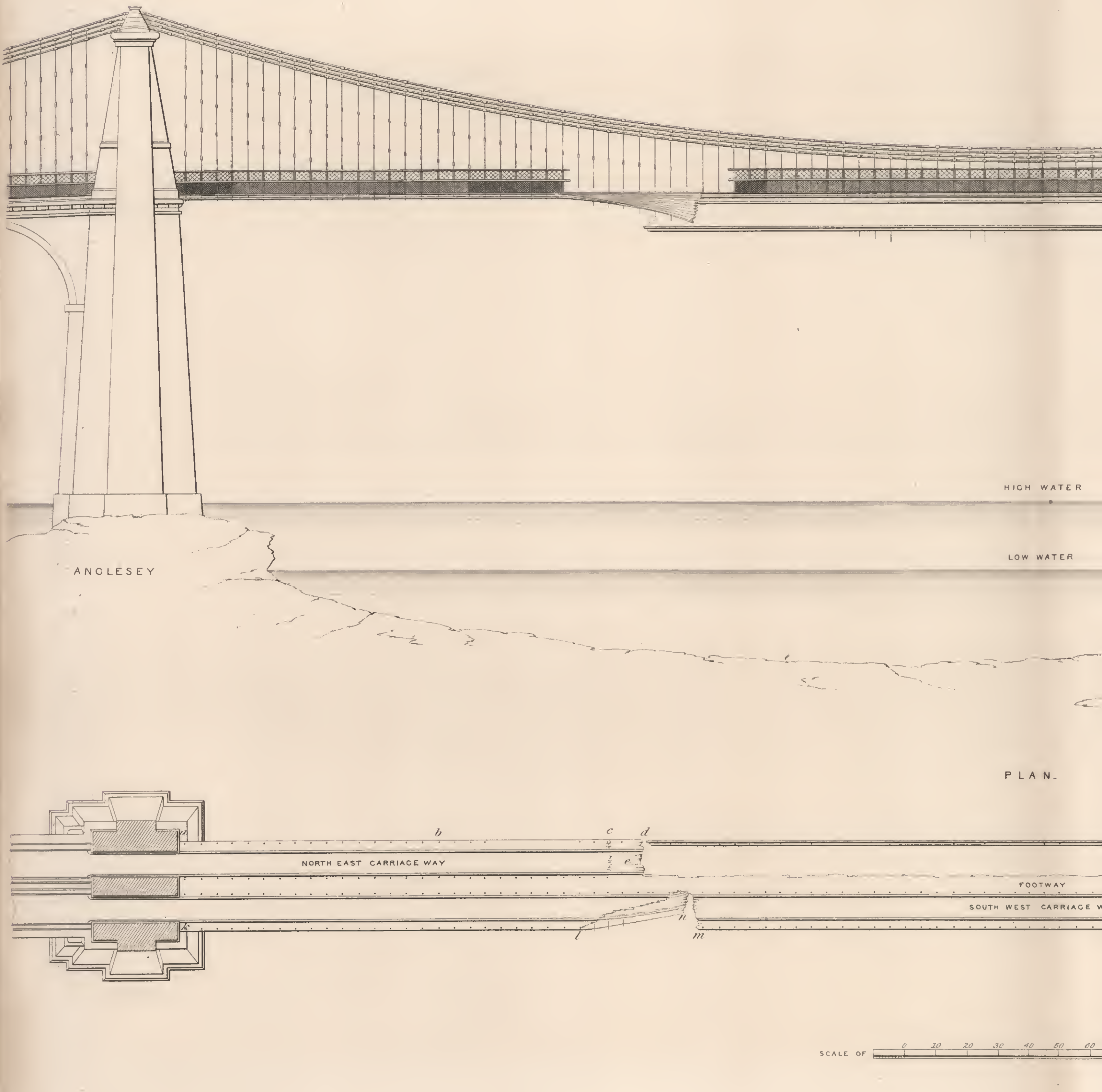
S. Bellin sculpt.

THE MENAI BR

AS IT APPEARED AFTER THE STORM O



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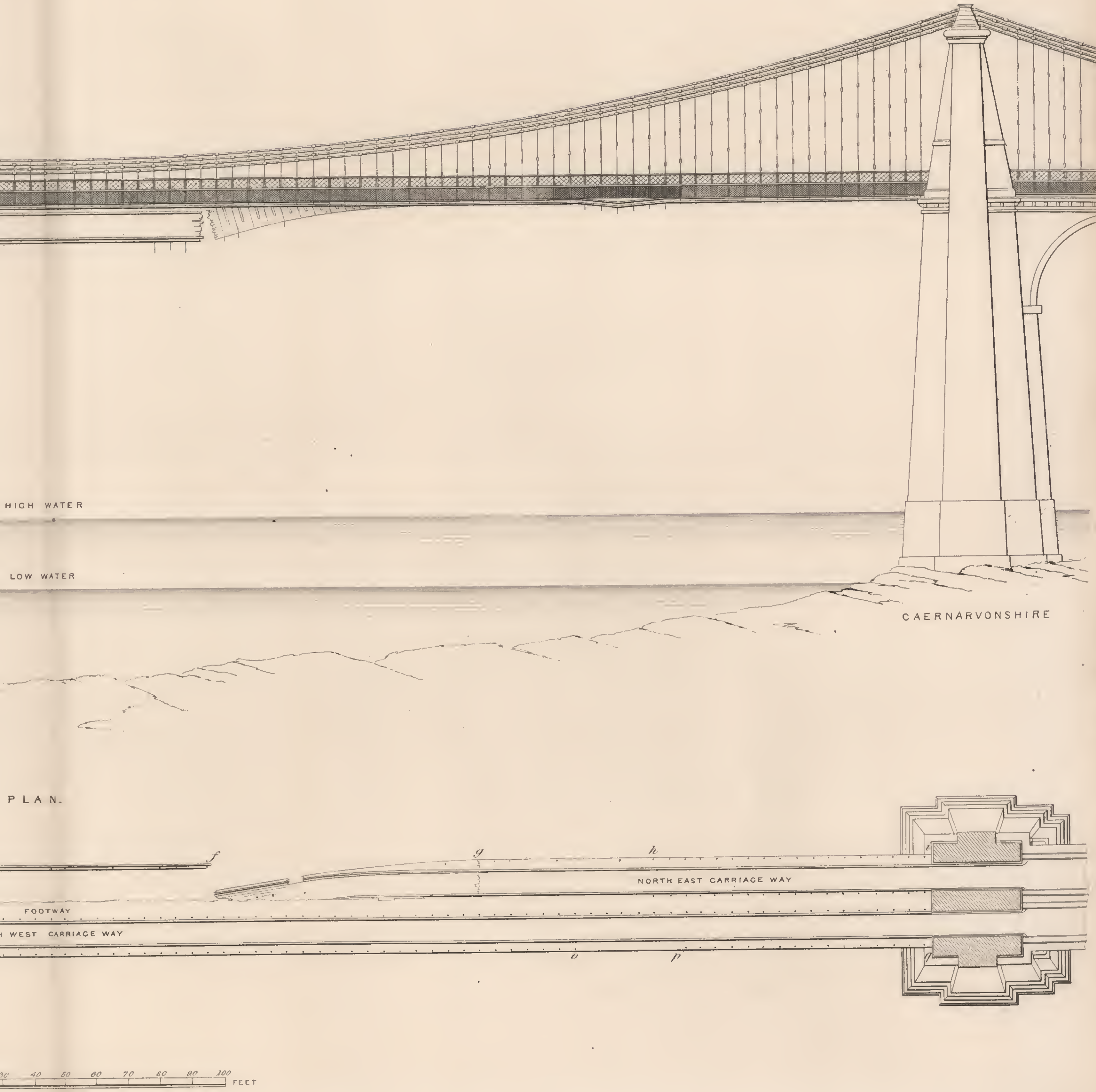
NAI BRIDGE,

R THE STORM OF JANUARY 6.7.1839.



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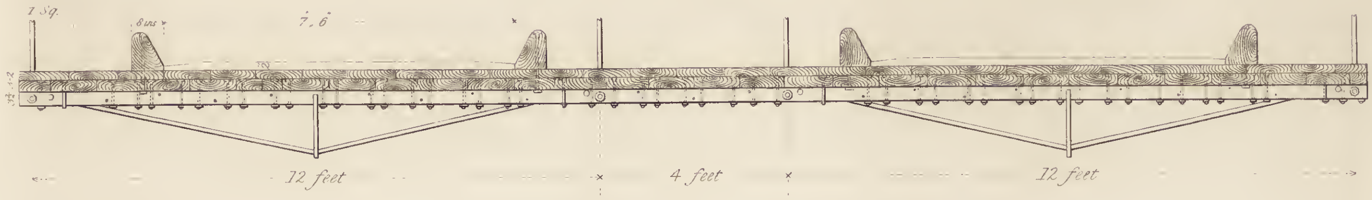
THE MENAI BRIDGE.

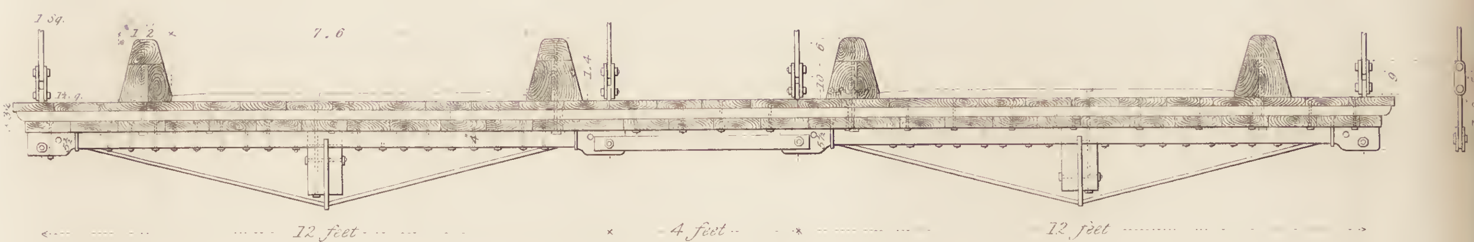
SECTIONS THROUGH THE PLATFORM SHEWING ELEVATION OF THE ROADWAY BEARERS.

AS ORIGINALLY CONSTRUCTED.



PLAN OF ROADWAY BEARERS.

AFTER THE ALTERATIONS.



PLAN OF ROADWAY BEARERS.

SCALE OF 1 2 3 4 5 6 7 8 9 10 FEET.

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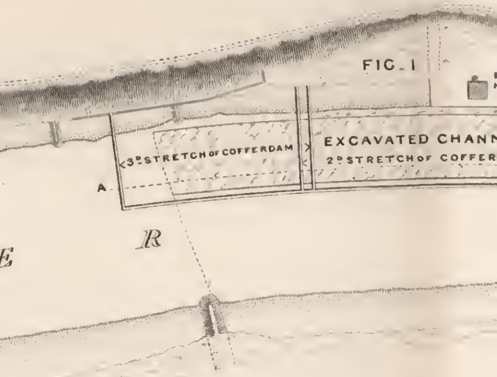
RIBBLE NAVIG

COFFER-DAM USED FOR EXCAVATING RO

DAVID STEVENS

SCALE TO PLAN & LENGTH OF LONGIT.L SECTION

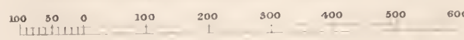
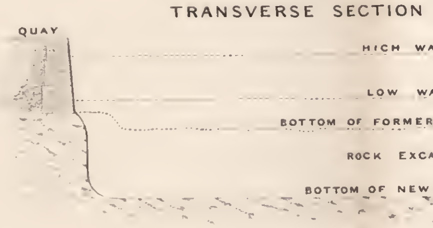


FIG. 2

LONGITUDINAL SECTION OF THE BED OF THE RIVER

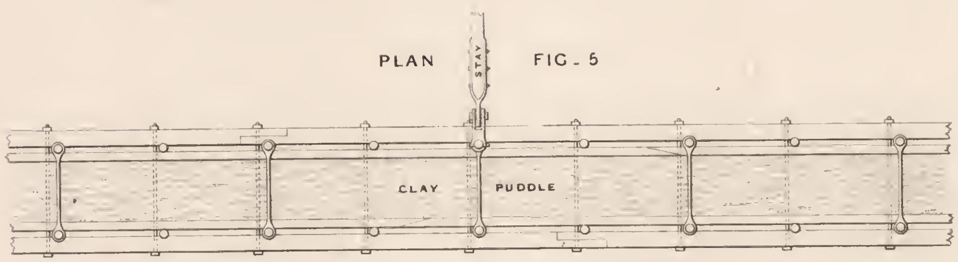
FIG. 3

TRANSVERSE SECTION

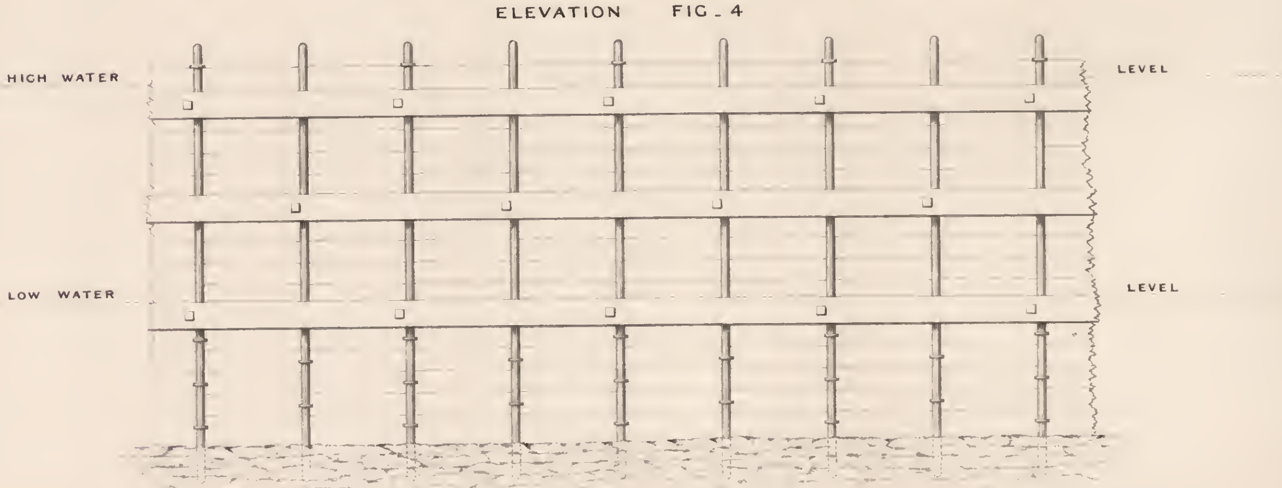


SCALE OF

PLAN FIG. 5



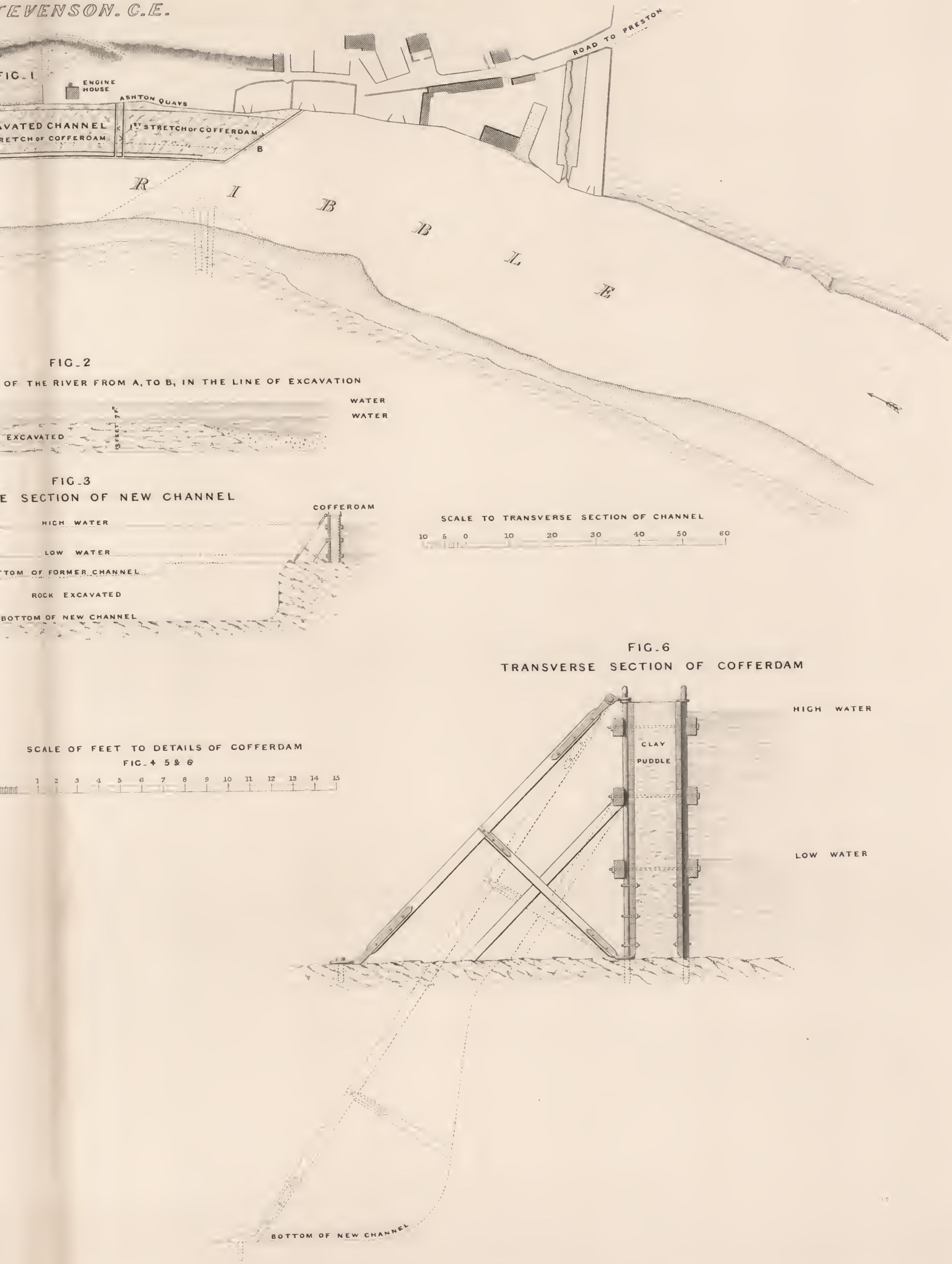
ELEVATION FIG. 4



NAVIGATION.

AVATING ROCK IN THE RIVER RIBBLE.

TEVENSON. C.E.

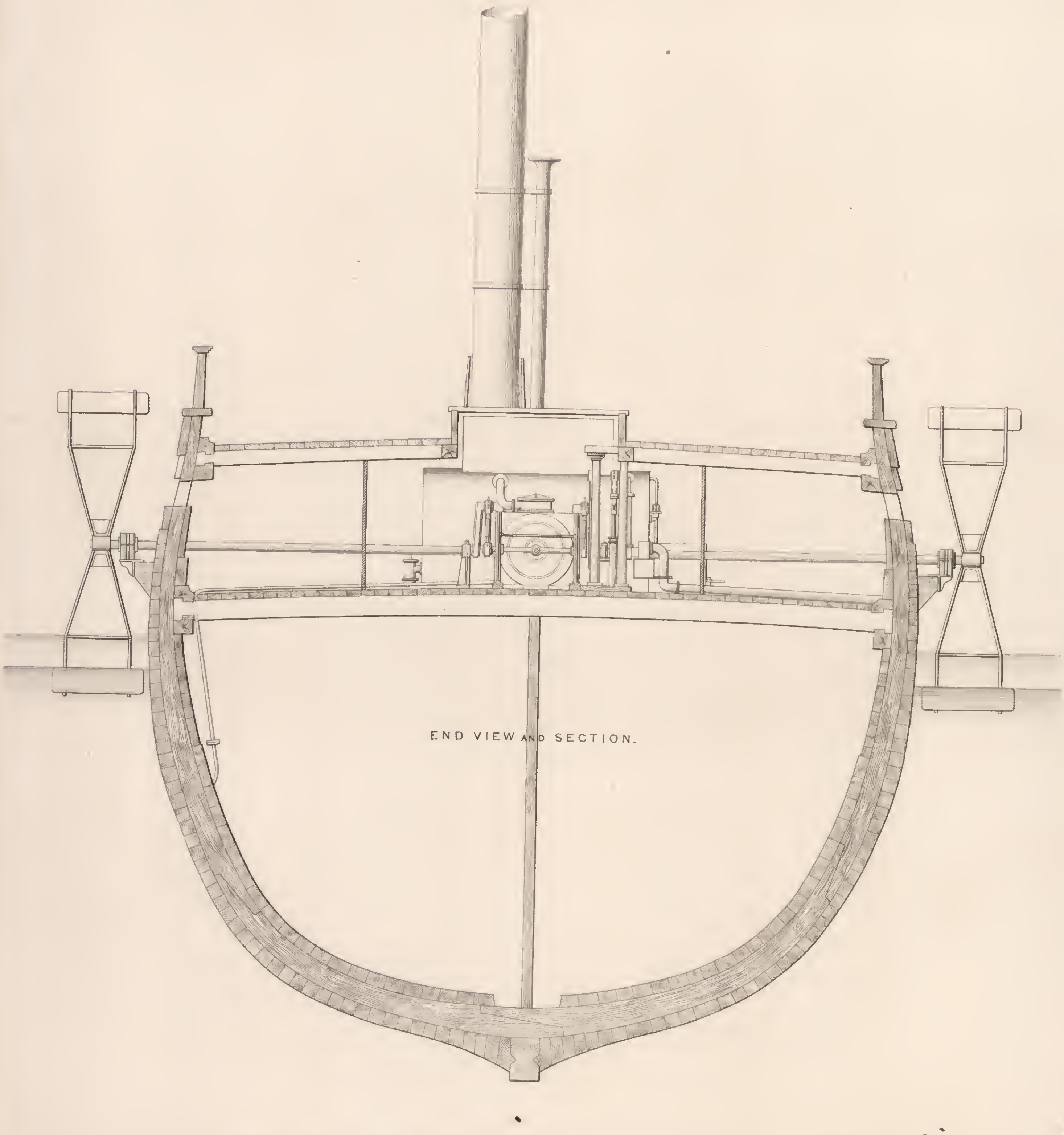


G. Gladwin sculp.t

VERNON, EAST

ONE THOUSAND TONS, WITH AN AUXILIARY STEA

J. & S. SEAWARD



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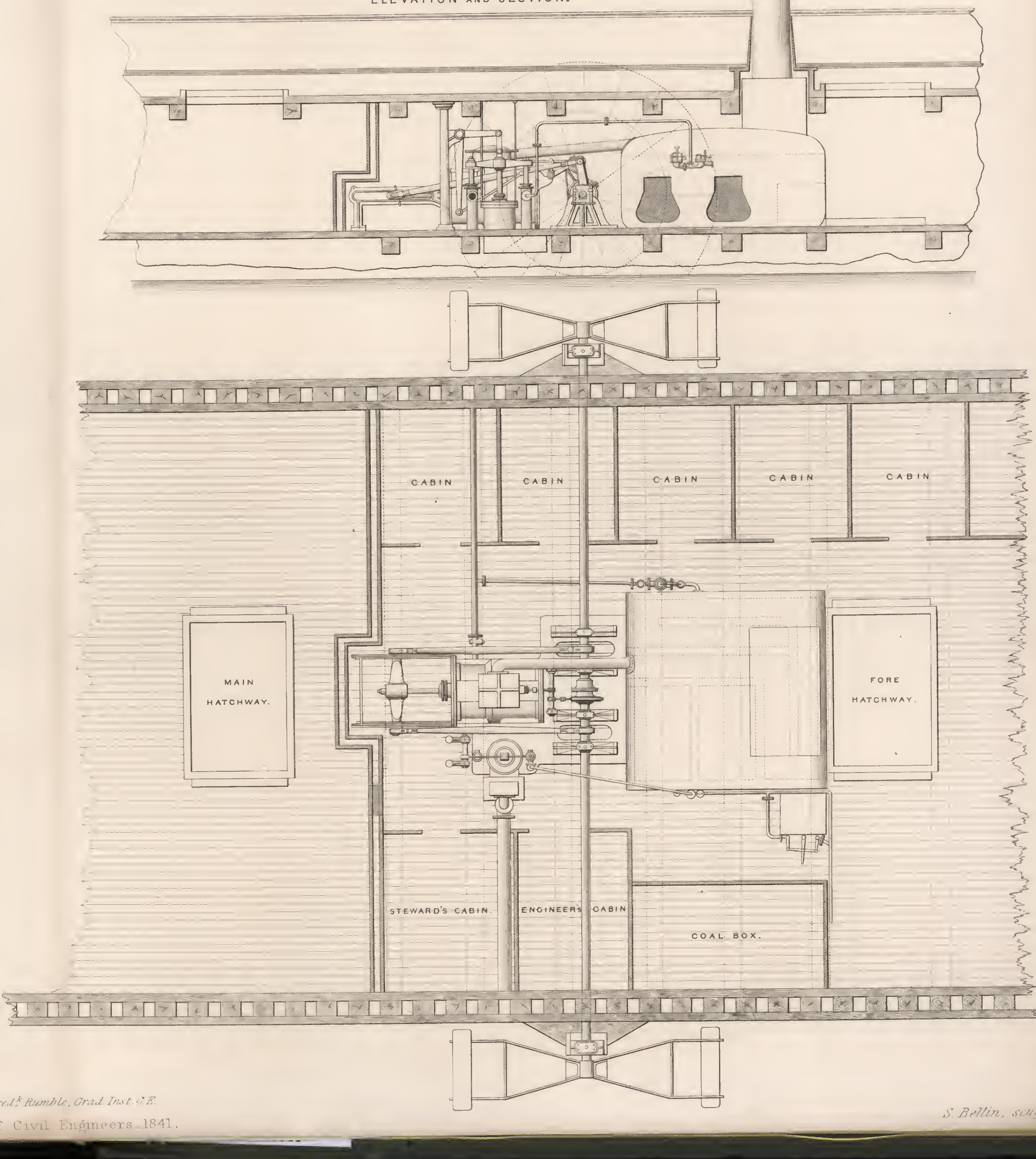
EAST INDIA MAN.

LIARY STEAM ENGINE OF THIRTY HORSES POWER.

EAWARD & CAPEL.



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