General

Geo. Hayward.

GENERAL DESCRIPTION

OF THE

BRITANNIA AND CONWAY

TUBULAR BRIDGES

ON THE

CHESTER & HOLYHEAD RAILWAY.

PUBLISHED, WITH THE PERMISSION OF ROBERT STEPHENSON,
CIVIL ENGINEER,

BY

A RESIDENT ASSISTANT.

LONDON:
CHAPMAN AND HALL, 186, STRAND.

PRICE ONE SHILLING.

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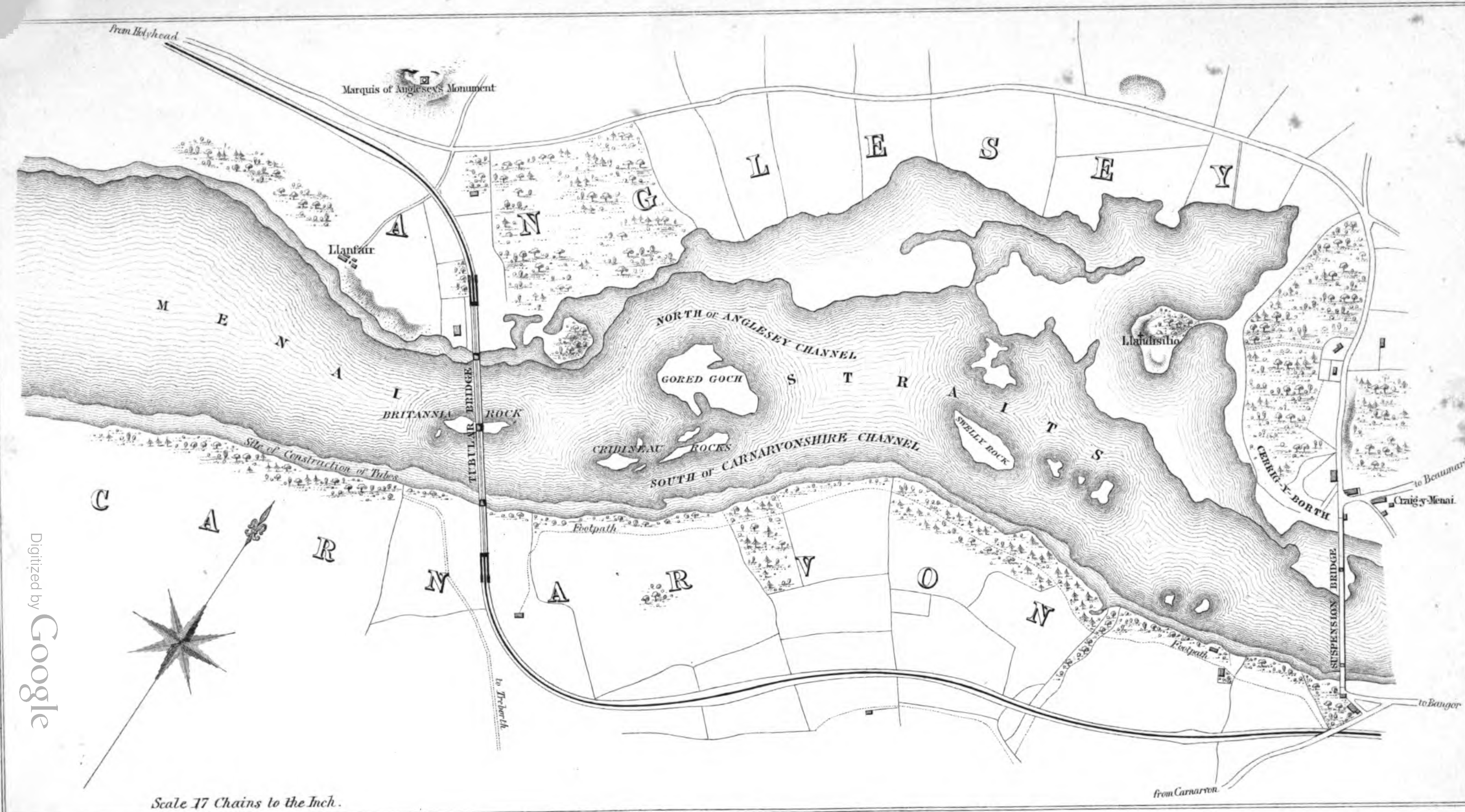
THE following pages are intended for the use of those only who wish to gain a general knowledge of the appearance, method of construction, weight, size, &c. of the Tubular Bridges; and more especially for the information of those visiting the works. Any more minute details, either of the very interesting history of the invention or of the actual construction of the bridges, would be inadmissible within the limits of a hand-book; this, and all other information connected with these novel and extraordinary structures, will be treated on at large, in a work to be shortly published by Mr. Edwin Clark, a notice of which will be found at the end of this pamphlet.

Britannia Bridge, 1st *May*, 1849.



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THE

BRITANNIA AND CONWAY

TUBULAR BRIDGES.

THE present age is remarkably distinguished from all that have gone before it, by the extraordinary energy manifested during it in all regions of thought and action. Other centuries, as the sixteenth and seventeenth, have been characterized by vast activity and vigour, but neither so widely extended nor so intense as in this. Among the Continental nations, the particular direction in which this energy has displayed itself is that of those great political and social questions which, happily for us, were in great measure settled by our forefathers during the former period; while, among ourselves, progress hitherto has shewn itself mainly in a material and mechanical direction. The thirty-five years which have passed since the Peace have seen—not, it is true, the invention, but the almost universal application of machinery and the power of steam to the processes of manufactures and of agriculture; whilst the electric telegraph, probably only the commencement of our mastery over this mysterious agent, is of much more recent invention. Of this energy and progress, railroads are at once the most prominent embodiment and the fittest symbol; and it is of the greatest railroad work yet achieved—offering in itself a striking and interesting specimen of that energy—that in the following pages an explanation and description is attempted.

The Tubular Bridge at the Menai Straits, called the Britannia, and that at Conway, do not differ materially in anything. They were designed at the same time, and the principle and details of construction are identical in both; but as the size of the former is greater than that of the latter, and the difficulties of the site more numerous and insurmountable, our description will chiefly apply to the Britannia, with allusions by the way to any small points of difference which are worthy of notice in the Conway Bridge.

The line of road connecting London with Holyhead has been long esteemed, and with reason, the principal road in the country. In 1822, Telford, the most eminent engineer of his day, was employed by the government to improve or reconstruct the old mail-coach road; and he did so, leaving it the most perfect piece of road-engineering then known, constructing, in the course of it, the two beautiful suspension bridges at Conway and the Menai, which have deservedly immortalized his name. The latter of these bridges was quite as great a work in that day as the Britannia is now, and like it presents an instance of a new and untried method of construction daringly developed at the first effort almost to its ultimate capabilities.

But railroads came, and superseded the turnpike road, even in its improved and matchless state; and, Chester having been reached, the remaining part of the highway to Ireland was too important to be allowed to continue long in its old condition. In 1844, the Chester and Holyhead Railway Company was formed, and it was soon perceived by their engineer that the grand difficulty of the line was, how to carry it over the estuary of the Conway and the Menai Straits. As it is impossible to make use of the Chain Suspension Bridge for the passage of heavy railway trains, its flexibility rendering it wholly unfit for cases where a stiff inflexible roadway is required, some other mode of accomplishing the object was necessary; and the difficulties in the way of this arose from the following causes:—At both places there is a considerable traffic, carried on by vessels of large size, to avoid any interference with which, it was requisite that, in the building of the bridges, no scaffolding or centering should be used, since that, if employed, would of course obstruct the passage. In the case of the Menai Straits, Mr. Stephenson met this requirement by a design for a bridge, of two cast-iron arches, the span of each to be four hundred and fifty feet; the height of the crown of the arch one hundred feet, and of the springing fifty feet, from the water; the use of centering being with great ingenuity dispensed with, by connecting by tie-rods the half-arches on each side of the centre pier with each other. The site intended for this was that on which the present bridge is being erected.

But the first difficulty having been surmounted, another and far more serious one presented itself. The Commissioners of the Admiralty, on this design being submitted to them for approval, insisted on a height of one hundred feet above the water, not merely at the crown of the arch, but also close to the piers; thus giving but two alternatives—to retain the arched form, but increase its height by fifty feet; or, relinquishing the arched form, to construct, in some entirely new method, a beam, which should depend for its stability simply on the strength of its parts; the first requirement, moreover, rendering it necessary, that it should be either constructed in its ultimate position on a suspending scaffolding, or else lifted *entire*, and *at once*, into its place, after having been put together elsewhere. The latter alternative was the one chosen by Mr. Stephenson. His proposition of a tube or girder, four hundred and sixty feet in clear length, strong enough, not only to carry a railway train, but to bear its own weight, was received by the public, on its first announcement, with almost universal incredulity. However, though the public doubted, the railway company had confidence in their engineer; and his labours and investigations have resulted in the present tubular bridges, which, from their stupendous magnitude, the singularity of their form, and the gigantic nature of the operations by which entire bridges of such unexampled weight are transported and raised into their position, have excited more interest, both in the scientific world and the public, than any other engineering works of the present day.

We have said that the Arch and the Chain Bridge being unavailable, Mr. Stephenson was driven to adopt the third possible form—that of a Beam; and we would impress on our readers that these tubes are nothing but gigantic beams; they derive no strength from any transmission of horizontal pressure to the abutments, as is derived by the arch; nor from any mode of suspension, as in the chain bridge, but resist incumbent pressure on exactly the same principles as the short plank does by which the village brook is crossed. But their form and the method of employing the material of which they are composed, is so novel and beautiful, and so very different to those of a simple beam or girder, that we would willingly draw the attention of our readers to a few of these points before proceeding to a detailed description of the tubes themselves.

The word "tube," as applied to these bridges, is certain to give those who are unacquainted with them a wrong impression of their form and method of construction. By a tube is commonly meant a round pipe, of no very considerable size; whereas these—as our detailed description will afterwards more fully show—are of square shape, and of great breadth and height. But still, it would be not easy to find any one word which would describe their construction so well as this of "tubular": for not only are they hollow from end to end, and closed in all round in manner of a tube, but their roof and floor—as will also be more fully explained afterwards—are each formed of a row of smaller square pipes or tubes, side by side, all firmly connected together, adding most materially and essentially to the strength and stiffness of the main body. Indeed, on a close scientific investigation, its whole strength will be found to reside in the tubular top and bottom.

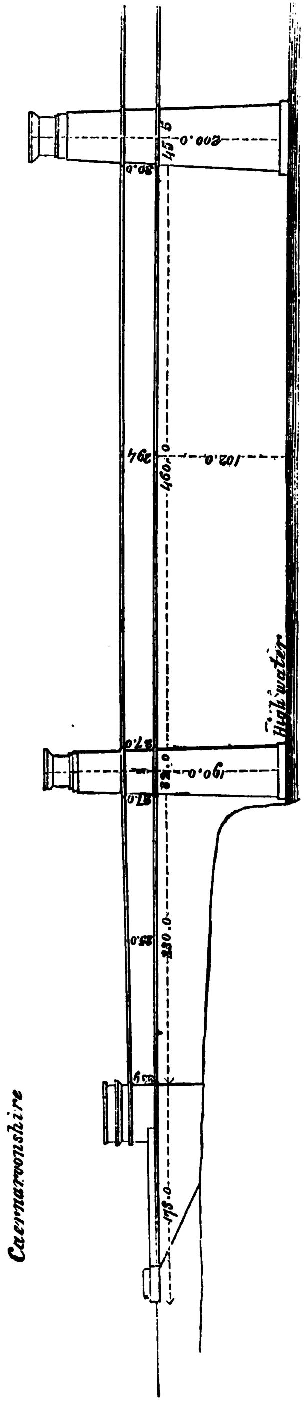
Now, on reading this description, or looking at the tubes themselves, many persons may be tempted to ask what necessity there is for all this intricacy, why it is necessary not only to have the tubular shape in the main body, but also these smaller tubes at the top and bottom, and why these beams should not have been made of a similar shape, but with breadth and height correspondingly enlarged, to those which they have often seen across openings of fifty or sixty feet. Such questions are at once answered by merely stating the fact, that after a certain size has been reached a solid form is the most inefficient way of employing a given quantity of material. To those who are conversant with mechanics, the demonstration of this is not difficult—to those who are not so we would explain, that a thin tube of any material is far stronger than the same quantity tightly rolled up into a solid rod of less diameter than the tube: of this they will at once call to mind many examples—how strong are quills, reeds, or straw in proportion to the very small quantity of material employed in them. Paley has noticed this in speaking of the bones of birds, which, while lighter than those of animals of equal size, are quite as strong from their hollow or tubular form. In the case of the tube bridges, it is easily ascertained, by a simple calculation, that a solid bar of iron—could such a thing be made—of the same length, breadth, and depth as one of the large tubes, would not even bear its own weight.

The particular spot at which the Britannia bridge crosses the Menai Straits is, as will be seen from the map on the frontispiece, exactly a mile nearer to Carnarvon than the Suspension bridge; the railway, after leaving the end of the bridge, passing close under the Anglesey column. The shores are of the same precipitous and shelving character at both places, but the stream is wider here than at the Suspension bridge, being about eleven hundred feet across at high water. It is divided nearly exactly in the middle by the Britannia Rock, which at high water is covered to a depth of ten feet. The rise and fall of the tide is ordinarily twenty feet, and its velocity very great, often as much as eight miles and a quarter an hour. It is from the Britannia Rock that the bridge takes its name, the centre pier being based upon it. It and the Anglesey shore consist of chlorite schist, a very hard and intractable kind of rock, worked with great difficulty: from this and the circumstance that no coffre-dam was used, and therefore few hours only could be consecutively spent on the Rock, some months were passed in laying the bottom course of the tower. It was commenced in May, 1846, the first stone being laid without ceremony by Frank Forster, Esq., acting engineer of the portion of the railway between Conway and Holyhead, and of the masonry, scaffoldings, &c., of the Britannia Bridge.

The stone of which the towers are built is a hard carboniferous limestone, or marble, called Anglesey marble; it abounds in fossils, and is capable of receiving a very high polish. Some specimens of it are very handsome. It is obtained from quarries expressly opened for the purpose on the sea shore at Penmon, at the northern extremity of the island, where it occurs in great abundance and in convenient strata of every thickness, from three or four feet downwards. The stones are split off with great dexterity by iron wedges, and wrought into shape with heavy steel picks. Some of the stones in the work are no less than twenty feet in length, and others weigh from twelve to fourteen tons. A great portion of the interior masonry, however, is built of red sandstone, from Runcorn, in Cheshire. This is a very soft stone, and easily worked, but at the same time very durable, especially when not exposed. The stones in the towers are all left with a rough or quarry face, except at the angles, and in the recesses, and the entablature at the top. This circumstance, coupled with their immense size and height, gives the towers a truly noble appearance. The approaches to the bridge are ornamented on each side by colossal statues of lions, in the Egyptian style. They are each composed of eleven pieces of limestone, and, although in a couchant attitude, are twelve feet in height. Their length is twenty-five feet, and their weight about thirty tons. Being associated with so many other large objects, their real size is not apparent. They were sculptured by Mr. Thomas, of the new Houses of Parliament. It was once contemplated to surmount the centre tower with a figure of Britannia, in stone, sixty feet in height, by the same artist; but the idea is for the present abandoned. The designs for the masonry, both for this and the Conway, were furnished by F. Thompson, Esq., of London.

When the whole structure is completed, it will consist of two immense wrought-iron tunnels or tubes, each considerably upwards of a quarter of a mile in length, placed side by side, through which the up and down trains respectively will pass. The ends of these tubes rest on abutments, the intermediate portions being supported across the Straits by three massive and lofty stone towers. The centre tower, as has been just observed, stands on a rock, which is covered by the tide at high water. The side-towers stand on the opposite shores, each at a clear distance of four hundred and sixty feet from the centre tower. The abutments are situated inland, at a distance of two hundred and thirty feet from the side towers. (*See the Figure in the next page.*)

The Britannia tower is sixty-two feet by fifty-two feet five inches at the base; it has a gentle taper, so that where the tubes enter it is fifty-five feet by forty-five feet five inches. Its total height from the bottom of the foundations will be, when completed, nearly two hundred and thirty feet; it contains 148,625 cubic feet of limestone, and 144,625 of sandstone, weighing very nearly 20,000 tons, and there are three



hundred and eighty-seven tons of cast iron built into it in the shape of beams and girders.

The land towers are each sixty-two feet by fifty-two feet five inches at the base, tapering to fifty-five feet by thirty-two feet at the level of the bottom of the tubes; their height is one hundred and ninety feet from high water; they contain two hundred and ten tons of cast iron in beams and girders. The chief dimensions of the masonry, as well as of the tubes, will be seen upon the figure, which shews an elevation of the Carnarvon half of the bridge.

The scaffolding, both for the erection of the masonry and for the support of the small tubes during their construction, is of the same description as that employed at the Nelson Column, Trafalgar-square, London, and at the new Houses of Parliament. It is that known to builders as "whole timber scaffolding;" its name distinguishing it from the old kind, which was constructed in a most cumbrous manner, with round poles and cords. The timbers here are "whole balks" —logs of from twelve to sixteen inches square, and some of them as long as sixty feet, and the method of uniting them is such, that when taken down, the timber is uninjured—nay, often increased in value from being more thoroughly seasoned by exposure to the weather. The scaffold below the land tube on the Anglesey side is, from the form of the shore, very lofty—more than one hundred feet in height at its outer end. As a piece of construction, it is most admirable; and from the multitude of cross struts and bracing timbers, interlacing each other, its appearance is very picturesque. That on the Carnarvon shore is not so lofty, but is of the same excellent construction. It will be seen presently that the weight which these scaffolds will have to support, when the small tubes are completed, is about thirteen hundred tons. The framing round the Britannia tower rises to the vast height of nearly two hundred and fifty feet, and at this elevation, stones of many tons weight are transported over all parts of the tower with perfect ease, by means of travelling windlasses, called gantries, which roll upon rails laid on the top horizontal timbers. Notwithstanding the constant and very heavy winds that it has been exposed to, this scaffolding, which looks so light and slender, has stood hitherto without injury. The contractors for the masonry and scaffolding are Messrs. Nowell, Hemmingway, and Pearson.

The bridge, as we have seen, is divided into four spans—viz., the two small spans at each end, which are over the land, and are each two hundred and thirty feet wide; and the two principal spans which are over the water, and are each four hundred and sixty feet wide. The small tubes, as they are termed, or those which cross the land, being constructed on the platforms, at their ultimate level, do not require any removal. Although called the "small tubes," their span is vastly greater than that of any other railway bridge in existence, the Conway tubes alone excepted. But the large tubes, which are to cross the water, are constructed on timber platforms along the beach, on the Carnarvon shore, just above the level of high water. These have consequently to be removed, and elevated to their final position on the towers; and to these the principal interest attaches.

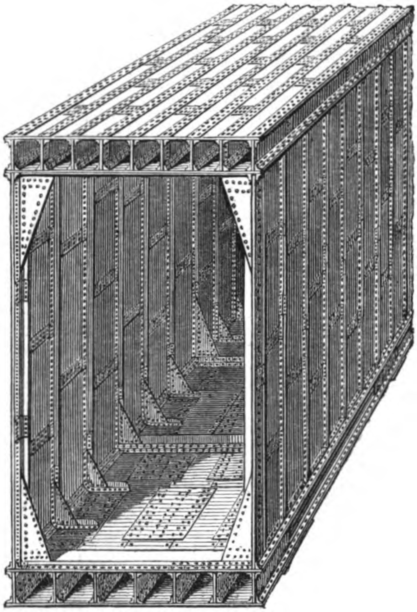
The length of one of these tubes, as constructed on the platform, is four hundred and seventy-two feet; that is, twelve feet longer than the clear span between the towers. This additional length is intended to afford a temporary bearing of six feet at each end, after they are raised into their places, until there is time to form the connexion between them across the towers. Our London readers will better appreciate the great length of these tubes by remembering, that if one of them were placed on end in St. Paul's Churchyard, it would reach one hundred and seven feet higher than the top of the cross! The span, in fact, is much greater than has ever before been attempted, except in bridges on the suspension principle. The length of the iron arch of Southwark bridge, in London, the largest rigid span in this country, is but two hundred and forty feet.

The height of the tubes is not the same at all parts of their length. It is greatest at the centre, in the Britannia tower, where it is thirty feet outside, and diminishes gradually towards the ends, at which, in the abutments, the external height is only twenty-two feet nine inches; the top forms a regular arch, (a true parabolic curve,) and the bottom is quite straight and horizontal. The clear internal height is, on account of the double top and bottom, less by four feet than the external; being twenty-six feet at the centre, and eighteen feet nine inches at the extreme end; the land tubes are, outside, twenty-seven feet, and, inside, twenty-three feet high at their smaller ends. The intermediate heights will be seen on reference to the figure, page 14. The internal width from side to side is fourteen feet, though the clear space for the passage of the trains is but thirteen feet five inches; the whole width outside is fourteen feet eight inches.

The general method of the construction of the tubes is readily seen. They consist of sides, top, and bottom; all formed of long narrow wrought-iron plates, varying in length from twelve feet downwards, and in width from two feet four inches to one foot nine inches. The direction in which these plates are laid is not, as may at first sight be supposed, arbitrary or immaterial, but is governed by the directions of the strains in the different parts of the tube.

Thus, in the top and bottom, where the strain is in the direction of the length of the tube, the plates are laid lengthwise, whilst in the sides they run up and down. The plates, which are of the same manufacture as those used for making boilers—"boiler-plate"—are of the best quality, principally from Staffordshire. They vary in thickness, from three-eighths to threefourths of an inch: some of them weigh nearly seven hundred weight, and are among the largest that it is possible to roll with any existing machinery. In the sides, the plates are alternately six feet six inches and eight feet eight inches in length, two feet in breadth, and half an inch thick, except at the ends, where they become somewhat thicker. They are joined together, and greatly strengthened and stiffened at the joints by **T** shaped iron both inside and out, reaching from the top to the bottom, and forming a complete pillar at every two feet, in the same manner as the frames in a window sash form a pillar between each two panes. It is the projection of this **T** iron inside the tubes that reduces the clear space to thirteen feet eight inches.

The longest plates are in the bottom. They are twelve feet long, by two feet four inches in width, arranged in double layers, each layer being nine-sixteenths of an inch thick at the centre of the large tube, and seven sixteenths at the ends. Those forming the top are each six feet in length, and one foot nine inches in breadth. In the middle of the tubes they are three-quarters of an inch thick, diminishing to five-eighths at the ends. These thicknesses are all dependent on the amount of the strains in the tube, as the direction of the plates was before noticed to be. In the top and bottom will be seen the cells or flues of which slight mention has been before made. Of these there are eight at the top, each one foot nine inches square; and six at the bottom, of the same depth, but wider—viz., two feet four



inches, from their number being smaller. The vertical partitions which form these cells are connected to the horizontal plates at top and bottom, and the horizontal plates themselves to the sides by angle-iron, **L** fitting into the corners, and riveted through both. This **L** iron weighs in the top forty-five lbs. per yard, and in the bottom twenty-seven lbs.

The connexion between the top and bottom and the sides is made much more substantial by triangular pieces of thick plate, which are riveted in across the corners. These are technically called "gusset-pieces;" they are intended to enable the tube to resist the cross or twisting strain, to which it will be exposed, from the heavy and long-continued gales of wind that will assail it in its lofty and unsheltered situation. They will be seen on the figure on the preceding page, showing an end view of the tube.

The rivets are placed in rows, at distances of four inches apart in the top and bottom, and three inches in the sides. They are rather more than an inch in diameter, and are put into the holes red hot, and a head formed by beating up the projecting end of the hot rivet with heavy hammers, the operation being finished by a steel tool, with a cup-shaped end, which gives the head of the rivet a round and neat appearance. In cooling, they contract strongly, and draw the plates together so powerfully, that it requires a force of from four to six tons to each rivet to cause the plates to slide over each other; this resistance being due solely to the force of contraction, and independent entirely of the strength of the rivet itself. Each of the large tubes contains 327,000 rivets, and the whole bridge about 2,000,000.

In all cases, great care has been taken so to distribute the joints of the plates, that they may never come near together; and wherever they occur, a thick plate is carefully riveted over the joint, on each side, so as to maintain an equal strength in every part. The same rule is observed at the joints of the angle-iron. The rivet-holes in the plates are formed by a machine which punches out a piece of iron the exact size of the required hole. The plates are fastened upon a sliding-table, which advances at every stroke double the required space between each rivet. Two punches then descend through the plate, and form the holes.

In this way about forty holes are punched per minute.

Each tube contains about ten miles of angle and T-iron, and the whole bridge sixty-five miles. The weight of the wrought iron in one of the large tubes is estimated at about one thousand six hundred tons, of which five hundred are in the bottom, six hundred in the sides, and five hundred in the top.

The chains by which the tube is lifted will be attached to it at two feet from the end, and in order to get sufficient attachment at this part, three strong frames of cast iron are built into each end of the tubes; the innermost frame is intended only to stiffen and support the sides while the tube is resting on its ends; the two outer frames are the lifting frames; the chains are attached to these by three sets of massive cast-iron beams, placed across the inside of the tube, one above another, their ends fitting under deep shoulders or notches in the lifting frames, where they are secured by screw-bolts; as an additional security, two very strong wrought-iron straps pass over the upper pair of beams, and descend into the bottom cells beneath the frames, where they are strongly keyed. The weight of these lifting frames and cast-iron beams will be about two hundred tons, so that the whole weight of one large tube, when complete and ready for floating, will be, as nearly as possible, one thousand eight hundred tons. To those unaccustomed to the estimation of weight in tons we may observe, that this weight is fully as great as that of thirty thousand ordinary men. It is not easy to conceive how machinery can be made strong enough to raise such a ponderous burden. The weight of each of the small tubes, when quite complete, will be six hundred and sixty tons, so that the weight of iron in the whole eight tubes amounts to very nearly 10,000 tons.

As soon as each of the four large tubes is complete, the platform on which it has been constructed will be cut away, and the ends allowed to rest, for a distance of six feet, on the stone piers placed beneath them.

In order to provide for the deflection which must occur in beams of such extraordinary length as these, the platforms are not constructed level, but have a rise of nine inches in the middle of the length of each tube—being exactly what the deflection from its own weight is calculated at—so that when the platform is away from below the tube, and it is merely resting on the stone piers as it will ultimately on the towers, its bottom will be a perfectly straight line. These platforms, which are built of whole balks of timber covered with planks, extend along the beach on the Carnarvonshire side for a distance of about half a mile, and together with those for the small tubes, cover an area of three and a half acres.

The appearance of the interior of the large tubes, as seen from the end, is very striking, from the regularly diminishing perspective of so many vertical and horizontal lines, the large gusset-plates in the corners making an approach to the form of an arch, so that there is really no very distant resemblance to the "long drawn aisles" of a cathedral. Should the sun happen at the time to be shining into the end, the strong shadows from the projecting strips at the sides add much to the striking effect.

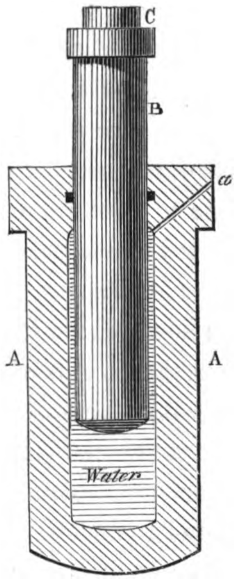
One of the large tubes was constructed by Messrs. Garforth, of Dukinfield, Manchester; the other three, and the small tubes, by Mr. Chas. Mare, of Blackwall. The first rivet was put in on the 10th August, 1847.

The tubes will be transported from the position they now occupy, to that between and at the base of the towers, upon large flat bottomed close barges, called pontoons; of which eight will be used to a tube. Six of these pontoons are of wood, and were built at Conway, and used in floating the tubes there; the other two, which are of iron, were built at the further end of the tube platforms; they are each ninety-eight feet long, twenty-five feet wide, and eleven feet deep, and are capable of supporting four hundred tons; when carrying the tube they draw five feet of water. They will be arranged under the tube in two groups of four, one near each end. Large valves are placed in the bottom of each boat, which are kept constantly open, and in this state the tide enters and leaves them daily without producing any buoyant effect. The operation of floating the tube will be commenced by closing all these valves at low water; as the tide rises the pontoons will begin to float, and shortly afterwards to bear the weight of the tube, which will be at last raised by them entirely off its temporary supporting-piers; about an hour and a half before high water, the current running about four miles an hour, it will be dragged out into the middle of the stream by powerful capstans and hawsers, reaching from the pontoons at each end to the opposite shore. In order to guide it into its place with the greatest possible certainty, three large hawsers will be laid down the stream, one end of them being made fast to the towers between which the tube is intended to rest, and the other to strong fixed points on the two shores, near to and opposite the further end of the tube platforms: in their course they will pass over and rest upon the pontoons, being taken through "cable stoppers," which are contrivances for embracing or gripping the hawser, and thereby retarding, or if necessary, entirely destroying the speed induced by the current.

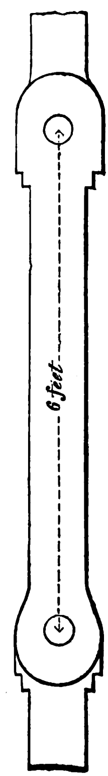
Thus these hawsers answer exactly the same purpose as the ropes of a ferry boat, and the tube slides down them just as the ferry boat does. Their entire length is rather more than two miles, and they are four inches in diameter. With a view to a still greater power of retarding or accelerating the speed, and for the convenience of guiding and "coaxing" the monster into its resting-place, a number of other smaller ropes will be made fast to the pontoons, and hauled upon by capstans at divers convenient points on the shores: the capstans being each worked by fifty men. Steam-boats will also be in attendance to give their assistance if required. The speed and time of floating will be so arranged that when the tide becomes stationary, before turning, which it does for fifteen minutes, the tube shall have just reached the towers, and in this interval it has to be deposited on the projecting shelves at the foot of the towers, exactly under its final position: this is the most difficult part of the whole operation.

As before mentioned, (p. 16,) the tube is twelve feet longer than the distance between the towers; in order to receive this additional length, recesses or grooves are left in the face of each tower, six feet deep, and of sufficient width to allow the end of the tube to slide up easily within them. These recesses extend from the bottom to the top of the towers. Now, in order to get the tube within these recesses, the low end of it, which is near the land tower, has to be thrust twelve feet past the side of the tower, thus allowing the opposite end of the tube to be inserted into its recess. In order to deposit the low end in a similar manner, a portion of the masonry at the side of the recess is left out, to allow the tube to pass under it into the recess; this will be subsequently built up before the tubes are raised. As soon as this operation is accomplished, the valves in the pontoons are opened, the water enters, destroying their buoyancy, and the tube settles quietly down upon a bed of soft timber placed to receive it.

The next operation is that of elevating the tube to its permanent level: the machine used to effect this is the hydraulic press—a contrivance invented by Bramah, and extensively used in this country, in expressing oils, packing soft materials, and in many operations where an intense pressure is required. Its construction is so simple, that it may be readily understood by any person, however unacquainted with machinery. It consists only of an exceedingly thick and heavy iron cylinder, like a mortar, marked A in the annexed figure; a strong piston or plunger B, also of iron, called the ram, works up and down inside this cylinder, and is fitted with a leather collar at the shoulder, so as to be water-tight. Water is forced into the cylinder, by a force-pump, through a small hole, *a*, which we may compare to the touch-hole of the gun, and this water gradually forces the piston up. Now the whole secret of the immense power of these machines consists simply in the prodigious force with which the water is driven into them, and which, in the present instance, is



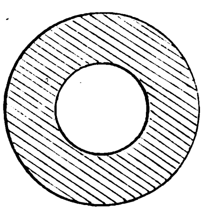
so great, that it would throw the water to a height of nearly twenty thousand feet, which is more than five times as high as the top of Snowdon, and five thousand feet higher than the summit of Mont Blanc! The whole affair, in fact, exactly resembles the piston of a steam-engine; but, instead of using *steam*, at thirty or forty pounds pressure on the inch, *water* is used, at a pressure of eight or nine thousand pounds. The cylinder requires, of course, to be very strong to withstand this pressure. The sides of the largest of the presses used in raising the Britannia tubes are eleven inches thick, and the weight of the cylinder alone sixteen tons; it is of cast iron, in one piece. The ram, or piston, which works within it, is twenty inches in diameter. The whole machine, complete, weighs above forty tons. It is the largest press in the world, and is, indeed, the most powerful machine ever constructed, and, if worked to its utmost power, would be alone quite capable of raising one of the tubes. *Its action, nevertheless, is guided and controlled by one man, with the most perfect precision and ease.* It was constructed by Messrs. Easton and Amos, of Southwark, by whom the lifting apparatus at Conway was also made.



This press stands on two beams, composed of wrought iron plates, rivetted together, at the top of the side towers, about twenty-nine feet above the level to which the bridge has to be raised; and two smaller presses, with rams eighteen inches in diameter, the same that were employed in raising the Conway tubes, are placed, side by side, at a similar level in the Britannia tower, and act in conjunction. The chains, by which the power exerted by the presses in their lofty position is communicated to the tubes lying at the base of the tower, resemble the chains of an ordinary suspension-bridge, and are very similar in appearance to those of Hungerford Bridge, in London. They are made by the patent process of Messrs. Howard and Ravenhill, of London. They consist of flat links, seven inches broad, one inch thick, and six feet in length, with an eye at each end, and are bolted together in sets of eight and nine links alternately; the eight links are made somewhat thicker than the nine, so as to make their strength equal at all parts. Their weight is about one hundred tons—far exceeding that of the statue of the Duke of Wellington, recently erected at Hyde Park, which was justly regarded as one of the greatest lifts ever made. The manner in which they are connected with the press is easily understood:—An exceedingly thick and heavy beam of cast iron, strengthened by wrought iron ties across the top, rests like a yoke upon the shoulder C of the ram, on the figure page 26; it is called the *cross-head* of the press. The two chains pass through square holes at either end of the cross-head, and are securely gripped on the top of it by an apparatus, called the *clams*, consisting of two strong cheeks of wrought iron, drawn together by screws, like a blacksmith's vice—the shoulders of the links being made square, as is shown by the figure on the preceding page, so as to afford a secure hold between the clams.

Now the stroke of the presses is six feet; that is, they are only capable of raising six feet at one lift; the tube, when lifted that height, has consequently to be sustained while the presses are lowered, and a fresh hold obtained; this is effected, not by building up under the tube, which is left wholly unsupported below, but by gripping the chains between another set of clams at the foot of the press, twelve feet below those on the top of the cross-head; these sustain the weight while the press is lowered, the upper set of links taken off and laid aside, and arrangements made for another hoist. The upper clams are then again closed, and the operation repeated as before. Each six-feet stroke of the press is performed in about thirty minutes; but an additional half hour is occupied in adjusting the machinery for taking another stroke; the tube has to be lifted one hundred and one feet, so that the whole operation may be performed in about eighteen hours, and will probably be completed in one day.

The water is forced into the presses by two steam-engines of forty-horse power each, with tubular boilers, as in a locomotive. The steam cylinder is horizontal; a continuation of the piston rod, which passes through both ends of the cylinder, forms the pistons of the force pumps, which are placed one at each end, in the same line as the cylinder. The diameter of the pumps is one inch and one-sixteenth; that of the ram of the hydraulic press twenty inches, their respective areas being in the proportion of one to three hundred and fifty-four. The pipe through which the water is forced into the press is of wrought iron, and is much smaller than would be expected. The annexed diagram shows its exact size.



The tube having been pulled up to its proper level, three large cast iron keys or beams are thrust in at each end, across the opening up through which the tube has ascended, and it is finally lowered upon them. These key-beams are each twenty-four feet long by four feet high, and weigh eleven tons. They have been previously drawn back from over the opening on to a projecting scaffold, through cast iron boxes built into the masonry, so that they can be readily moved backwards or forwards. To ensure perfect security while lifting, a contrivance is adopted, by which the chains as they rise, are continually followed up by wedges, so that, in the event of any accident arising to the lifting machinery, no injury would happen to the tube. The beams on which the presses stand, the cross-heads, and all parts that are subjected to a very severe strain, are either constructed of, or strengthened by, *wrought iron*, which is found to be less brittle, and much more trustworthy than cast iron.

When all the tubes have been raised, and the small ones completed, their ends, which come together in the towers, will be joined; so that, as we before stated (p. 13) there will be two tubes "each upwards of a quarter of a mile long." The exact length of each will then be one thousand five hundred and thirteen feet, and weight *five thousand tons*—in size far surpassing any piece of wrought iron work ever before put together, and in weight nearly double that of a hundred and twenty gun ship ready for sea.

The junction of the tubes will add most materially to their strength—so much so, indeed, that, startling as it may at first appear, the bridge would stand securely, even if the large tubes were to be each cut through in the middle of the span. The parts which pass through the towers are very much strengthened, with this view.

The entire length of the bridge at rail level is one thousand eight hundred and forty one feet, a number easily recollected from its approximation to the date of the present year. The expansion and contraction of so great a mass of metal, from changes of temperature, will of course be very considerable; the extreme variation in the length of one of them between summer and winter being nearly twelve inches. It is therefore necessary to make provision for this constant alteration of length, which would otherwise endanger the stability of the whole structure. It is effected in the following manner:—The middle is fixed in the centre tower, and cannot move, but, on either side, where it passes through the land-towers, and in the abutments, it travels on rollers of cast iron, six inches in diameter; a portion of the weight being also supported at the top on balls of hard gun-metal, of the same size, working in channelled beams, and acting in the same way as the rollers; at the extreme ends, where the rails in the tube are joined to those on the land, a simple contrivance is used to prevent a gap from being formed by the contraction, which might endanger the safety of the trains.

The resident engineer of the iron-work of the Britannia and Conway Bridges, and of the floating and lifting operations connected with them, is Mr. Edwin Clark; the immediate command during the operation of floating being at both places entrusted by Mr. Stephenson to Captain Claxton, R.N., who so distinguished himself by extricating the Great Britain from her perilous position in Dundrum Bay.

The height of the bottom of the tube above high water is 102 feet, being the same as that of the Menai Suspension Bridge.

There are three large workshops at intervals along the tube platforms provided with forges and machinery for cutting, punching, and straightening the plates. A great deal of the machinery is quite novel, having been invented expressly for this work. There are five wharfs and landing cranes for unloading the stone, iron, and other materials, and six steam-engines are constantly employed in raising the stone for the towers, blowing fires, and working the machinery. The number of men employed upon the work, when in full operation, averages about fifteen hundred—seven hundred on the stone-work, and eight hundred on the iron-work. The operation of floating will engage about seven hundred men; the raising, only thirty-six. The accidents that have occurred on the work have, fortunately, not been numerous, seven persons only have lost their lives. In the vicinity of the bridge, on the Anglesey side, may be observed a monument in stone, erected by the masons of the work, to the memory of those of their companions who have been killed during the progress of the undertaking.

Temporary wooden cottages have been erected upon the ground, which afford accommodation to about five hundred workmen with their families. There are also shops for the sale of provisions, the prices of which have much increased since the work commenced. They have also the advantages of a daily school, and a clergyman; and a medical man is constantly on the ground, in case of accidents.

Several points might be mentioned as commanding views of the entire bridge. The road leading from the Suspension Bridge to the Llanfair Station, in Anglesey, has the advantage of being at such a distance that the bridge forms part of the landscape, so that its true proportions can be better judged of and criticised than at a distance from which the details can be more made out. These proportions, when the whole is completed, will be of a much lighter and more airy character than can well be conceived by one who has become acquainted with their huge bulk only from a close approach. Those immense masses, when raised to their ultimate height of one hundred feet above the water, and viewed in connexion with the towers and abutments, will undoubtedly appear far more slender and graceful than will now be imagined.

From the outside of the platform of the second and third tubes, a very good whole view of the opposite side is obtained, and the scaffold below the Anglesey Land-tube is seen thence to great advantage.

Those who can, should ascend one of the land towers, and go as near as possible to the edge of the stone-work in the opening to be filled by the tube, so as to look down and across the great gulf between their standing-place and the Britannia tower. No one who does this for the first time can help being impressed by the sight.

The Conway Bridge stands close beneath the old castle walls of Conway, and within a few feet of the beautiful Suspension Bridge of Telford. The design of the masonry is in keeping with that of the castle, the whole forming a very picturesque group. It is similar in its construction to that over the Menai Straits, but consists only of one span of four hundred feet clear, which is sixty feet less than that of the Britannia, its height above high-water being but eighteen feet. The tubes have not the advantage possessed by the Britannia, of end tubes counterbalancing them over the land, but have, nevertheless, proved themselves to be of abundant strength. The weight of each tube, with castings, &c., as lifted, is thirteen hundred tons. The first tube was tested with a load of three hundred tons of iron, which is many times greater than can ever be required to pass through it, and with this load its deflection was nearly three inches; and, immediately on the weight being removed, it rose again to its former position uninjured: similar results were obtained with the second tube. The first stone of this bridge was laid on the 15th June, 1846, by Alexander M. Ross, Esq., acting engineer of the line from Conway to Chester; the contracts both for the masonry and tubes were executed by Mr. Evans. The first tube was commenced in March, 1847; it was floated on the 6th March, and raised to its position on the 16th April of the following year, and on the 1st May the trains were passing through it; thus exemplifying one of the advantages of bridges of this construction—viz., that both the bridge and its support can be completed at the same time, and when ready, it can be erected and used at once. The second tube, which was built on the same platform, was floated on the 12th October, 1848, and raised on the 30th of the same month. The trains have now been passing daily through these tubes for many months, without any injury or effect whatever, and no motion can be detected by the eye during the passage of a train, although instrumental observations detect a deflection of about the eighth of an inch. The noise produced by a train in passing through them is not at all greater than in an ordinary bricked tunnel. The rails are laid on longitudinal balks of timber, which rest on transverse plates of iron, placed on edge across the bottom of the tube, at intervals of six feet, as in the Britannia; like it, too, one end of each tube rests on cast iron rollers below, and on five metal balls at the top, to allow freedom for expansion with changes of temperature, the other end being fixed; the variation in length from this cause is about one inch. Their exterior is painted a light stone-colour, and is protected from the weather by an arched roof of thin corrugated zinc.

To return to the Britannia Bridge:—at the time at which we write, the four large tubes and one of the land tubes are nearly complete. The land tubes on the Carnarvon side have been commenced; the pontoons are complete. The masonry is also complete, excepting the Britannia tower. The floating and raising of the first tube will probably take place in the course of June.

Supposing that the bridge be completed by the summer of 1850, the work will have been four years in execution, a fact of which those concerned on it may justly be proud, when they remember that the Menai Bridge was nearly eight years in building; the weight of the iron work being to that of the Britannia Bridge as 644 to 10,000, or as one to fifteen nearly, and the stone work being in a very similar proportion.

P.S. It will interest our readers to know, that since the foregoing pages were written, the platform beneath one of the large tubes has been cut away, and the tube brought to its bearing on the stone piers (see page 22)—the deflection being found to be ten inches. In this situation its sensibility to changes of temperature —owing to its large surface—is very remarkable, and coincides exactly with the result obtained under similar circumstances from the Conway tubes. By being expanded on that side, the tube becomes curved towards the point from which the sun shines, so much so, that between sunrise and sunset, the centre is lifted fully an inch, as well as drawn sideways through an equal space.

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INCLUDING

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The express train at 2 o'clock, P. M., from Holyhead, and which started ten minutes after the experimental train arrived there, would have been sent through the tube, and thus have saved an hour, but this could not be done without the consent of the Railway Commissioners, unless under heavy penalties. It is understood that Capt. Symonds, the Government Inspector, will inspect on the 9th inst., and report to Government; and the public inauguration for every day traffic may be expected on the 15th inst. The inauguration was to have taken place on the 17th, St. Patrick's day, out of compliment to the natives of the sister isle, but that day happening to fall on a Sunday, this could not be accomplished. It may be interesting to know that the general opinion of the numerous engineers present yesterday appears to be that the Britannia tube bridge is as trustworthy as any tunnel on *terra firma*.—[London paper.

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MENAI STRAITS, TUESDAY AFTERNOON.—*pening of the Britannia Tubular Bridge.*—The ening of this magnificent structure, looked forward ith so much interest, came off this day at dawn, the grandest success. At half past 6 o'clock M., three powerful engines (the Cambria, the St. vid, and the Pegasus) of from 50 to 60 horse wer each, decorated with flags of all nations and ion jacks, steamed up, and harnessed together, rted from the Bangor station, carrying Mr. Stephen-, who drove the first engine through the tube, and following gentlemen:—Mr. Bidder, engineer, Mr. evethick, locomotive manager of the London and rth Western Railway; Mr. Edwin Clark, Mr. timer Clark, Mr. Appold, and Mr. Lee. At pre-ly 7 o'clock the adventurous convoy, progressing speed of seven miles an hour, were lost sight of he recess of the vast iron corridor. Instead of ig driven through with a despatch indicative of a ire on the part of those who manned it to get in out with the utmost expedition, the locomotives e propelled at a slow and stately pace, with the of boldly proving by means of a dead weight calibre of the bridge at every hazard. The total ght of the locomotives was 90 tons. The appear-e of the interior of the tube during the interesting eriment was of a novel and remarkable character. pauses that occurred during the progress of the sit furnished an imposing view of the interior of gigantic structure, which, as contrasted with that tunnel of similar length, was rendered compar-ly cheerful by the recurrence at intervals of holes of light, which serve the three useful pur-s of ventilating, and lighting, and divesting the of steam from the passing engines. The loco-ves were brought to a standstill in the centre of of the great spans, without causing the slightest n or deflection. The first process—that of going ough the tube and returning—occupied altogether minutes.

he second experimental convoy that went through isted of 24 heavily laden wagons, filled with blocks of Brymbo coal, in all, engines included, aggregate weight of 300 tons. This was drawn erately through, at the rate of from eight to ten an hour, the steam working at quarter power, n the engines of this train, besides the gentle-already enumerated, there were Mr. Hedworth the resident engineer, Mr. Charles Rolfe, Mr. J. aran, Mr. Bothwick, Mr. T. L. Gooch, Mr. k Forster, engineer, Mr. Dinger, manager of the Mr. J. C. Mare, maker of the tubes, and a number of scientific gentlemen. During the ge of this experimental train through the tube, athless silence prevailed that was almost sol-until the train rushed out exultingly, and with flying, on the other side of the tube, when acclamations, followed at intervals by the rattle illery down the straits. Upon the return, which ied about seven minutes, similar demonstrations d, and during the progress of the train those stood on its top to ascertain any possible vibra-reported they could detect no sensible deflection. this, Mr. Stephenson and his staff steamed up is Llanfair, Mr. Foster's seat, and partook of dsome repast. Meantime the Locomotives were ng up and down the interior of the tube without ng the slightest manifestation of strain. An stronger still was then resorted to: a train of tons of coals was allowed to rest, with all its t, for two hours in the centre of the Carmarth-re tube, and at the end of the time, on the load removed, it was found to have caused a deflec-f only four tenths of an inch. It is remarkable

re, it being moreover calculated with confidence at the whole bridge might with safety and without ijury to itself be deflected to the extent of 13 inches. These loads it is most material to remember are im-iensely more than the bridge will ever be called on to ear in the ordinary run of traffic, though the engin-ers are of opinion that it would support with ease, nd without much show of deflection, a dead weight n its centre of 1,000 tons. Twelve miles an hour the limit of speed at which Mr. Stephenson intends iat trains shall at first go through, more particularly s there are sharp curves at the termini of the tube. During the trial of the dead weights a very inter-sting episodical proceeding took place in the interior f the Carnarvonshire land tube—that of putting the ist rivet into the plates, making exactly the 2,000-00th that have been used. The rivet having been put by Mr. Mare, was driven home and fastened by Mr. Stephnson with successive strokes with a huge iammer. This ceremony was followed by the waving f hats and the deafening acclamations of the work-people.

Mr. Stephenson, in a brief address, eulogized he industry of these men and their devotion to their work. He could never forget the ingenuity and the abor exhibited in the humbler sphere of the great operation, nor the masterly manner in which the work had been carried out under the superintendence of Mr. T. Fleet, who had distinguished himself as a sterling and honest workman. It being now nearly 12 o'clock another testing train was prepared to be taken through the tube. It consisted of the three engines, the 200 tons of coal, and from 30 to 40 railway car-riages containing between 600 and 700 passengers packed together as closely as figs in a basket, all so clamorous and eager to "go through the tube," that it became impossible to accommodate them. At length, obediently to a long wild whistle, the train, which was almost long enough to cover the extent of tube, glided slowly into the interior, saluted by a loud burst of "Rule Britannia," from an array of Liverpool seamen up aloft in the towers at the en-trancé, on the front of which, cut deeply in the stone, were the words "Erected Anno Domini, 1850: Robert Stephenson, Engineer." As the huge train trailed slowly through the tube successive salvos of artillery were fired at each end. This accom-plished, the steam was got up, and the company as-sembled proceeded at the rate of 35 miles an hour, amid the magnificent scenery and snow-capped hills of Wales, to Holyhead, where they were received by all the principal townspeople, and with salutes from the steam ships in the harbor.

The effect of the recent hurricane on the calibre of the tube has proved that its lateral surface strength is sufficient, and far more than sufficient, to resist the strongest wind. It is calculated that, taking the force of the wind at 50lb. on the square foot—an excessive supposition—the resistance offered by the bridge would be 300 tons + 2 = 600 tons, which is not two thirds of its own weight. The wind going at 80 miles an hour, the rush of a hurricane would only press in the ratio of 128 tons on the side. It is intended, when both tubes are up, to brace them together with stays so as to counteract any possible oscillation.

The great work has now been four years in hand, and is nearly complete, while Telford's suspension-bridge took eight years. The floating and actual transference of the tubes has occupied since June last —a short period when the bulk of the fabric is ta-ken into consideration. Great fears were entertained for its safety during the late gales, from the recollec-tion in this part of the country of the damage do to Telford's suspension bridge.