THE MENAI SUSPENSION BRIDGE, 1819-26
and
BRITANNIA BRIDGE, 1845-50

by Elisabeth Beazley

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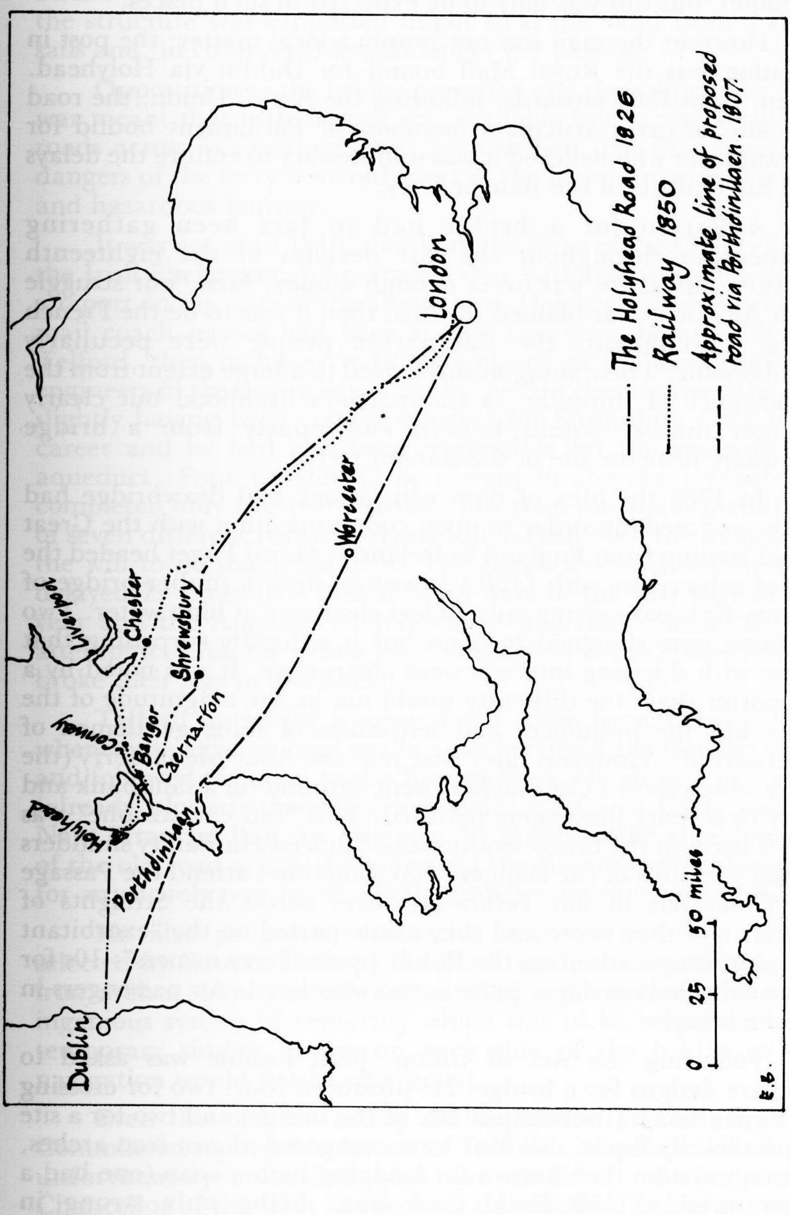
The Menai Strait without its two great bridges is difficult to imagine. They set off the rugged backdrop of Snowdonia as do the temples or bridges of an eighteenth century park. Just as the impact of the gardens of Stourhead, for instance, comes from the contrast between the classical stonework, "natural" landscape and water, that of Menai is compounded of man's intrusion in masonry and iron, marvellously wrought, into one of the most romantic mountain landscapes in Britain. Although minute attention was given to the individual design of each bridge, its relationship to its surroundings was, needless to say, a happy by-product which chanced to be very pleasing to the admirers of the picturesque.

To those who seldom actually see the Strait now, the image stamped on the mind is still that of Robert Stephenson's mighty tubular bridge (1845-50) rather than its arched successor which followed the disastrous fire of 1970. The outline of Telford's marvellous suspension bridge (1819-26), a mile up the Strait was little altered when its wrought iron chains were changed for steel in 1938.

Practically speaking it is equally difficult to imagine the Strait without its bridges. This dangerous channel, eighteen miles or so long, narrowing to about an eighth of a mile wide in the middle reaches, cuts Anglesey off from the mainland. The tides thrust and ebb from both ends, creating peculiar conditions and currents only understood by knowing mariners and interested locals. The height of the tides varies from 10-12 foot at neaps to nearly 30 foot at extreme equinoxials. Six ferries plied across the Strait but determined travellers would risk beating the tide by crossing the Lavan sands, leaving the mainland near Aber and heading for Beaumaris, a ride of four miles over the sands at low water. The route was "sufficiently pointed out by posts, at proper distances" but the sands "are so extremely level, that they are all, in a manner, instantaneously overflown at the rising of the flood: travellers, who intend crossing them, are therefore cautioned to make exact enquiries, concerning the tides, an inattention to which has been fatal to many"[1]. This was the route originally taken by the Post Road (see Ogilby's map, 1675) but later the Post used the ferries. Had the only mail been that destined for Anglesey the matter might have rested. The ferries may have



Map showing the routes from London—Dublin been the cause of grave anxiety not to say inconvenience and rheumatics (Wellington boots and Macintosh coats were luxuries to come), but this was only to be expected in such places.

However the mail was not simply a local matter; the post in question was the Royal Mail bound for Dublin via Holyhead. Then, from 1801 onwards, following the Act of Union, the road was also to carry articulate members of Parliament bound for Westminster who believed it was unnecessary to endure the delays and discomforts of the Bangor ferry.

Agitation for a bridge had in fact been gathering momentum throughout the last decades of the eighteenth century. But there was never enough money. First "our struggle with America" was blamed for this; then it was to be the French wars. Throughout, the Caernarfon people were peculiarly troublesome. Their antagonism derived to a large extent from the importance of shipping[2] to Caernarfon's livelihood but clearly Bangor market would benefit enormously from a bridge anywhere near the site of the Bangor ferry.

In 1783 the idea of dam with a lock and drawbridge had been proposed "in order to open communication with the Great Road leading from England to Ireland"[3]. (Lord Paget headed the list of subscribers with £120.) Drawings show a timber bridge of twenty-five spans giving only 10 feet clearance at high water. Two of these were designed to open but it is hardly surprising that those with shipping interests were obstructive. It was noted by a supporter that "the difficulty would not be the magnitude of the work but the prejudices and selfishness of some gentlemen of Caernarfon". However, later that year the Aber-Menai ferry (the ferry which served Caernarfon) went aground on a sandbank and sixty or seventy passengers perished. This "sad catastrophe" was not wasted on the bridge enthusiasts: "indeed Humanity shudders at the very idea of the Dangers that sometimes attend the Passage of Thousands of our Fellow-creatures across the Streights of Menai. . ." they wrote and they also reported on the "exorbitant Impositions practised on the Public by the Ferry owners": 10s for a fourwheeled carriage, 5s for a two wheeler, 1s for passengers in public vehicles . . .[4]

Following the Act of Union, John Rennie was asked to prepare designs for a bridge. He produced four, two for crossing at Ynys-y-moch (the eventual site of the bridge) and two for a site by the Swelly Rocks. All four were composed of cast iron arches, the only system then known for bridging such a span (one had a clear span of 450 feet). Cast iron, being only strong in compression, had to be used in an arched form and therefore had to be supported by timber centering during construction (like a stone or brick arch). This would have impeded navigation in the Strait. It was also thought that the massive stone piers on which the structure was supported might steal the wind from a ship's sails and, in contrary tides, endanger her passage.

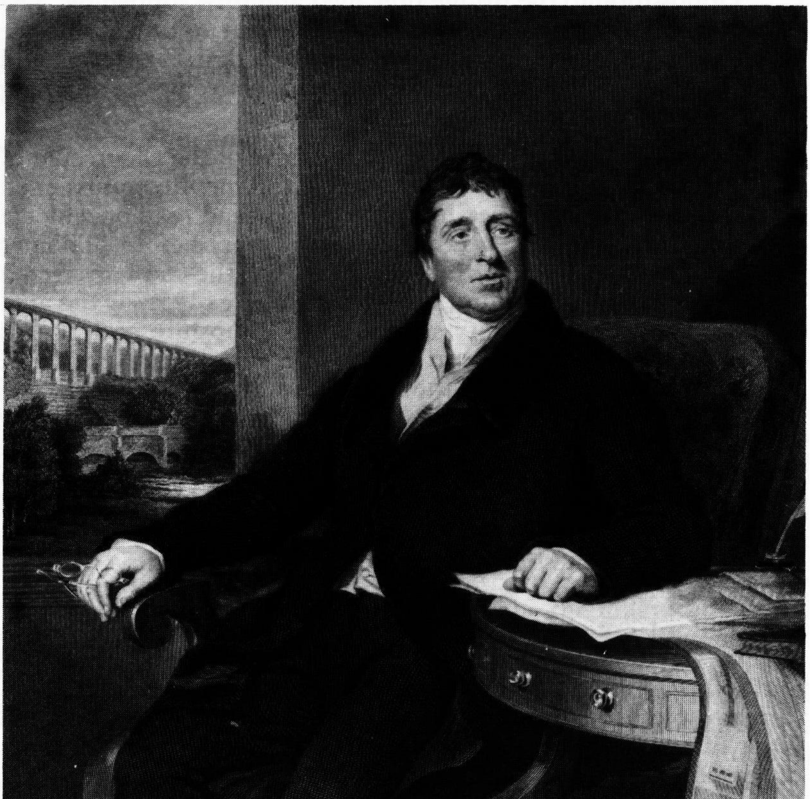
Oppostition to the bridge prevailed and time slipped by. The war meant that little money was available but in any event, the roads across Wales themselves were so bad that the delays and dangers of the ferry were only part of the inconvenience of a long and hazardous journey.

It was not until 1810, thanks to the drive of the Chancellor of the Irish Exchequer, John Foster, that Parliament commissioned a report on the state of the Shrewsbury-Holyhead road on which a mail coach service had been started two years before. Thomas Telford, then in his early fifties and one of the most respected engineers of the day, was put in charge. He already knew the area slightly having been county surveyor for Shropshire early in his career and he had also been responsible for the amazing iron aqueduct, Pont Cysyllte ("the stream in the sky") which was completed only five years earlier. The road was the responsibility of seven different turnpike trusts who lacked both the money and the will to do much about it. The coach was said to have been delayed 79 times in a period of 85 days in the first part of that year and the Anglesey stretch was so bad that coaches did not attempt it. Even the riding post horses were at risk; three fell and broke their legs in one week[5].

Telford opted for a more direct route from Betwys-y-coed whence the existing road made a detour down the Conway valley and followed the coast to the Bangor ferry. He chose a new route (already plotted) through Snowdonia, via Capel Curig and the Nant Ffrancon Pass. In Anglesey, he proposed the abandonment of the old road across the island via the county town, Llangefni, for an entirely new road[6]. (Both stretches are now part of A5.)

He also proposed alternative schemes on the two sites selected by Rennie whereby the Strait was to be spanned by cast iron arches. However the arches were to be constructed on an ingenious system of centering which was to be suspended from temporary timber towers on each side of the bridge so that navigation would not be obstructed.

Even this did not satisfy the opposition and although the Commission reported in favour of Telford's proposals their report unfortunately coincided with the abolition of the post of Chancellor of the Irish Exchequer, thus Telford's chief supporter was removed from the scene. Not surprisingly, a lull of several years was to follow.



Thomas Telford
An engraving by W. Raddon from a painting by S. Lane

Then in 1815, Sir Henry Parnell, another Irish member, took up the cause and Telford was instructed to make a detailed survey of the whole road from London. He was also to include the coast road from Chester to Bangor which took the Liverpool and Manchester traffic. Both roads had a major obstacle: the crossings of Menai and the River Conway. However, in the interim period, Telford had been consulted about spanning the Mersey at Runcorn (1814) and had produced a design for a suspension bridge of 1,000 feet span giving 70 foot headroom at high water. This was an entirely new departure in bridge design since to that date the only suspension bridges were rope foot bridges[7]. The success of Telford's idea was to depend on the tensile strength of wrought iron. Two hundred experiments were made to satisfy himself of this, and a huge model was made of the Runcorn bridge in which the actual span was fifty feet.

Although the Runcorn bridge was abandoned, the knowledge gained was not wasted. When in 1818 Telford was again asked to bridge Menai, he designed a suspension bridge spanning 579 feet and giving 100 foot clearance for the Ynys-y-moch site. Thanks to Parnell's championship, the design was accepted so the Holyhead Road Commissioners petitioned Parliament for an act to authorise the bridge, and preliminary work was put in hand.

However the citizens of Caernarfon made a last bid to prevent is construction. "Explanations satisfied the noble Marquis" who, at yet another public meeting, spoke in favour of the bridge but others ". . . would listen to no compromise whatsoever"[8]. Fortunately the opinion of Trinity House was also given in favour of Telford's design so, after thirty three years discussion and delay the bridge was to begin.

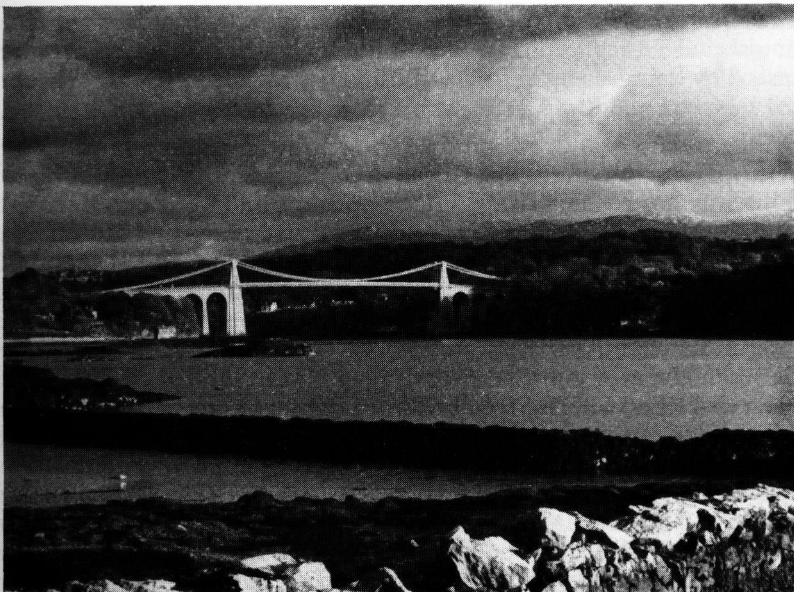
The excitement of a new material (wrought iron) being used in a new way (suspension chains) tends to eclipse the monumental but traditional problems which had first to be solved concerning the construction of the masonry for the bridge: a source of stone, a means of transporting it to the site and a supply of masons and labourers in remote country had to be found. It is easy to forget now that Telford was himself a stone-mason (his first job in the south had been that of a mason working on Somerset House). The stonework of the Menai Bridge suggests the work of a master of that trade.

The search for suitable stone began at once and the coast was perambulated from Beaumaris east round the Penmon peninsular where good hard limestone was located. Quarries had to be opened and quays built. Two ships were purchased but there was difficulty in getting enough masons so "barracks were set up for strangers". Carpenters and smith's shops, storehouses and an office were built on the Anglesey shore.

William Provis, a young man who had been for ten years Telford's pupil and who had assisted on the Runcorn design, was appointed resident engineer. It is from his account[5] of the building of the bridge that much of this has been gleaned. By May 1819 Ynys-y-moch had been blasted level to make a foundation for the Anglesey pier and a causeway was built out to it on which a railroad was laid for sledges drawn by horses. After the Bill received the Royal Assent (July 1819) Provis laid the foundation stone "with the utmost privacy"—diplomatic in view of the recent hostility—and work began on the foundations for the Caernarfon pier. These had to go six foot below low water springs because the surface rock of the beach was found to rest on friable shale. Work went on at night "by lamplight and firelight" when this made best use of the tides. But all was not well with the progress of the stonework. "Frequent remonstrances" were made to the masonry contractors who "were not proceeding with sufficient energy"[9]. After only nine months' work they threw in their contract. Telford recalled John Wilson (who had worked with him on Pont Cysyllte) from the Gotha Canal then under construction in Sweden, and he brought with him his two sons.

By the following June there were different worries. Because of the increase in the number of masons (300) and the unseasonable storms it was difficult to keep up the supply of dressed stones. "Disasters were continually happening to vessels" in stormy weather. Ten were now employed but one ship was stove in on the rocks at the outer quarries, another was only saved by scuttling at the same place. A third was driven onto a reef off Puffin Island. It is hardly surprising that the owners were "very shy in allowing them to work"[10]. They soldiered on and by the end of 1820 the highest pier was 51 foot out of the water but "a severe frost closed the year and for a while put a stop to our proceedings". Refinements were made to the design of the masonry and the method of securing the chains.

The following summer, with the highest pier now 83 feet out of the water, the contract for the ironwork was let to Telford's old colleague, William Hazeldine of Shrewsbury. The iron was first forged at Upton, then carted five miles to Shrewsbury where it was treated against rust. Rust was the great enemy but as William Provis reminded his readers: the bridge was "not necessarily a structure of very perishable nature" if it was kept free of corrosion"[11]. His brother, John, was appointed to take charge of the ironwork in Shropshire and each piece had to bear his stamp of approval before leaving the works. Before immersion in linseed



Menai Bridge from the Anglesey shore
This photograph shows the steel chains which replaced the original wrought iron in 1938. The wall of an old fish trap can be seen in the foreground.
(Photograph: Elisabeth Beazley)

it was heated "to secure it being perfectly dry and to make the oil penetrate further into the pores in the iron". It was then dried again in a stove before being loaded into carts for the next ten miles of its journey to Telford's Ellesmere canal. Here it was loaded onto barges bound for Chester whence it was shipped for Menai.

It was also necessary to joint all the stones of the suspension piers with wrought iron dowells (12ins x 1in diameter) because of the sway of the bridge. The chains were to pass over the piers on cast iron saddles and wrought iron rollers to allow for their expansion and contraction. They were then to be run through tunnels to be anchored deep in the rock on each side of the Strait. The chain within these tunnels was of heavier section than the rest as a further precaution against corrosion. The cutting of these tunnels and their drainage proved to be a "very tedious operation"; the rock was hard and the openings small. It took fourteen months working day and night. During the winter of 1822-23 severe frost and bad weather again meant that little work was done on the masonry. This went on for two months.

About this time it was decided to alter the design to give a two foot rise in the roadway since expansion of the main chains could cause a sag and this "would not look well". The chains were tested by being slung across a small valley on the Angleysey shore.

Naturally enough there was great public interest in the bridge. "The grand question of 'how are the main chains to be put up?' was one that gave rise to much speculation and doubt . " This was hardly surprising since "no plan had yet been decided upon". The original idea had been to construct them on scaffolding but this had long been abandoned. The suspended part of each chain (there were 16 in all, in groups of four) which formed the central span of the bridge was made on a raft 450ft long x 6ft wide. This was to be floated out from the shore to lie between the two piers, and be linked to the landward chains at each end. The Caernarfon landward chain was to hang down the face of the tower so that its end was near water level; the men on the raft would link it to their chain. The other end would then be hoisted to the top of the Anglesey tower where it would be connected to that landward chain. The whole operation had to be geared to give those on the raft as much time as possible when the water would be slack, near the turn of the tide.

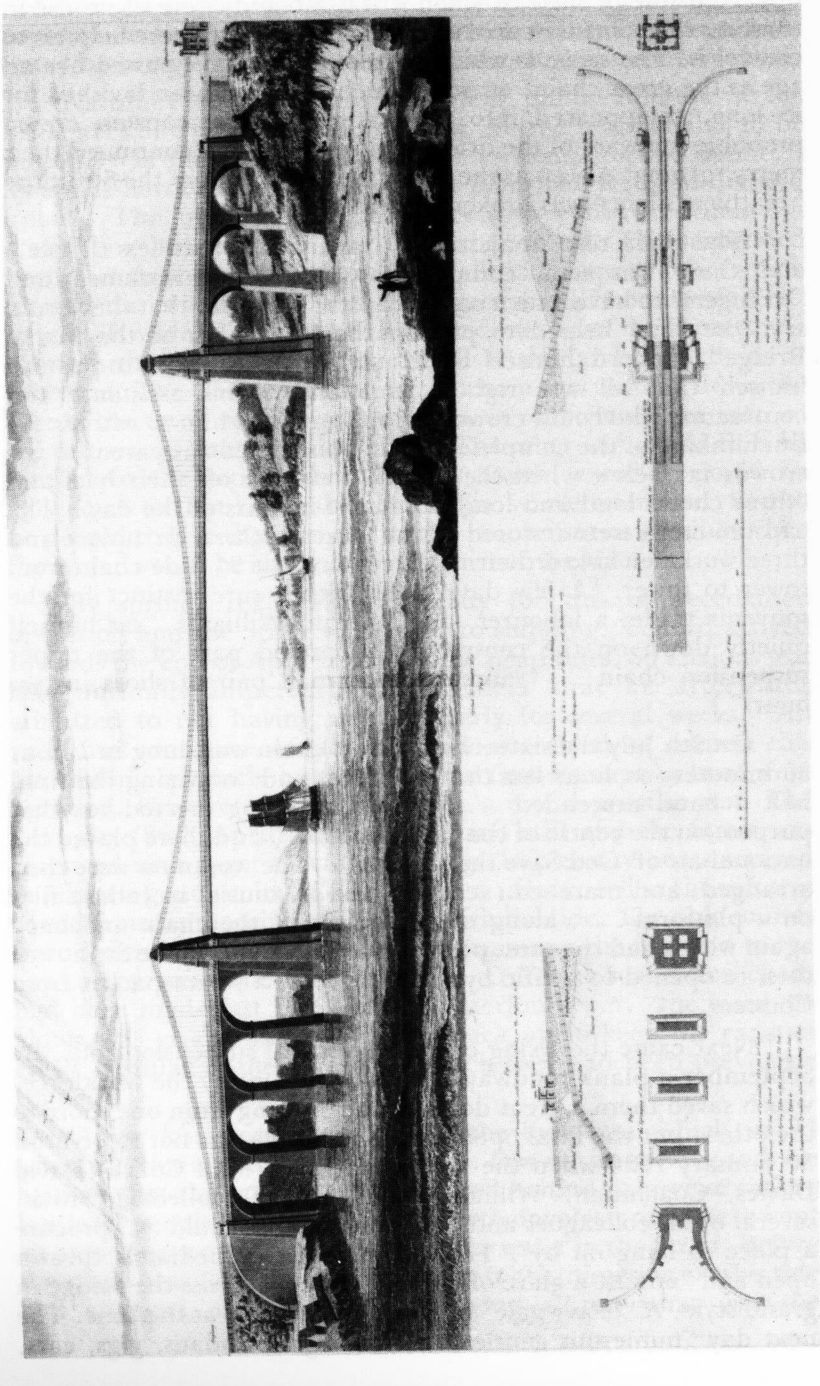
By spring, 1825, all was ready for this unprecedented operation and the Strait was closed to shipping. Telford arrived towards the end of April ready for the neap tides. So anxious was this normally imperturbable engineer that he afterwards admitted to not having slept properly for several weeks. "An immense concourse of people" had assembled to witness this astonishing spectacle but alas, on the first attempt, a boat went aground. However this proved to be a useful practise run. The next day (26th April) dawned fine and still and the Strait was thronged with eager spectators, many "in pleasure boats arrayed in all their gaudy colours". At 2.30 p.m. silence fell as the raft was towed from its mooring to float up with the tide. The only sounds were the orders ringing out to those manning the raft and to the capstan crews on the Anglesey shore. Once the suspension chain had been made fast below the Carnaerfon tower, "the word 'go along' was given" and two fifers struck up to keep the capstan crews "regular in their steps for which they had been previously trained".

All at last seemed set fair for the long haul which would bring the chain to the top of the pier. Few of the crowd can have realised that the operation had slipped behind its precise timing but local people as well as those directly involved must have kept an anxious eye on the exact state of the water in the Strait. Before the chain was "lifted quite off the raft the direction of the tide had changed, and the anchors being all on what was the upstream side of the raft when it was moored, were of no use in resisting the contrary current". Those on the raft were helpless to control it. The seconds which followed must have passed like an age as the great chain, on which such care had been lavished for so long, disappeared into the water. But the capstan crews, probably unaware of the drama below them, had continued their merry turning. At last as the chain rose slowly out of the Strait the breathless silence was broken by a mighty cheer.

The chain rose "majestically" (again in "breathless silence") and there was soon competition from other workmen and "strangers" to have a turn on the capstans in order that they could say "they had helped to put up the first chain of the Menai Bridge". Telford himself then ascended the tower to "satisfy himself that all was right". As many of his assistants and contractors who could crowd on top were with him to witness the final linking of the complete chain. This became apparent to the crowds far below when the tiny figures took off their hats and "three cheers loud and long closed the labours of the day". The capstan crews were restored with a quart of *Cwrw da'* apiece and three workmen risked their necks crossing the 9″ wide chain from tower to tower. (A few days later, with a sure instinct for the souvenir trade, a labourer, one William Williams, "sat himself quietly down on the centre of the curved part of the upper suspension chain . . . and made a small pair of shoes in two hours".)

On 9th July the sixteenth and last chain was slung in 1 hour 30 minutes (an hour less than the first) and "on fixing the final bolt a band descended . . . to a scaffolding erected for that purpose on the centre of the curved part . . . and there played the national air of 'God Save the King' . . . The workmen were then arranged, and marched (accompanied by music) in Indian file, on a platform . . . along the curvature of the chain and back again which had the most picturesque effect . . . " The Strait was then re-opened to traffic by the *St. David,* a steam packet from Chester.

Next came the fixing of the 44 vertical suspension rods. By September a plank roadway was ready for use by the workforce, which saved them a great deal of time crossing from one shore to the other, but the final opening of the bridge was not to be until 30 January 1826 when the 1.35 a.m. Royal Mail Coach (David Davies, Coachman; William Read, Guard) collected Provis, several of his colleagues and "as many more as could . . . procure a place to hang on by". The toll gate was immediately thrown open and "amidst a glare of lamps" it passed across the bridge in grand style. A "heavy gale" of wind was blowing at the time. The next day "numerous gentleman's carriages, landaus, gigs, cars,



Suspension Bridge over the Menai Straits between the County of Carnarvon and Island of Anglesey (plate 70, from the *Life of Thomas Telford* (Atlas) by himself). The section shows the method of securing the chains.

pony-sociables . . . and horsemen innumerable" crossed over and, despite a very slight undulatory motion, the horses crossed "without evincing the least shyness or timidity".

Trouble was still to come. On 1st February there was a "tremendous gale of wind which struck the bridge broadside and increased in the night to tempest truly frightful". Various temporarily fixed pieces of iron railing were blown away and 24 road bearers and 6 suspension rods broken. "The bridge certainly laboured very hard" one of the engineers reported to Telford. Transverse braces were introduced between the main chains, and the roadway strengthened. The undulation was reduced from 18 inches to 6 inches. Even so, on 19th and 20th the guard "durnt not cross" until he was given a lead by a chaise and pair. This is hardly surprising considering "the howling gale through the bars was truly terrific".

Given this lateral strengthening the wrought iron bridge gave satisfaction just as had been predicted. Horse-drawn vehicles had long given way to fast and heavy traffic undreamt of by Telford, when the ironwork was replaced by steel (Engineer: Sir Alexander Gibb) in 1938, one hundred and twelve years later.

Perhaps one of the most astonishing things about this most revolutionary monument of the industrial revolution is the kind of power by which the iron and stone used in its construction were brought to Menai and assembled to form the bridge. Man power for almost everything, not forgetting the capstan crews who hoisted the chains; horse power for the site-railways, for towing the canal barges, for dragging or carrying over the land, and for bringing everyone, including Telford himself, to the site—except for those who walked or came by sea; wind power—most if not all the ships employed were sailing vessels; and the power of the tides without which the construction rafts on which the main suspension chains lay might never have been positioned. Menai must be one of the last great bridges to be constructed thus. Only twenty years later when the bridging of Menai was next undertaken the age of steam had well and truly arrived.

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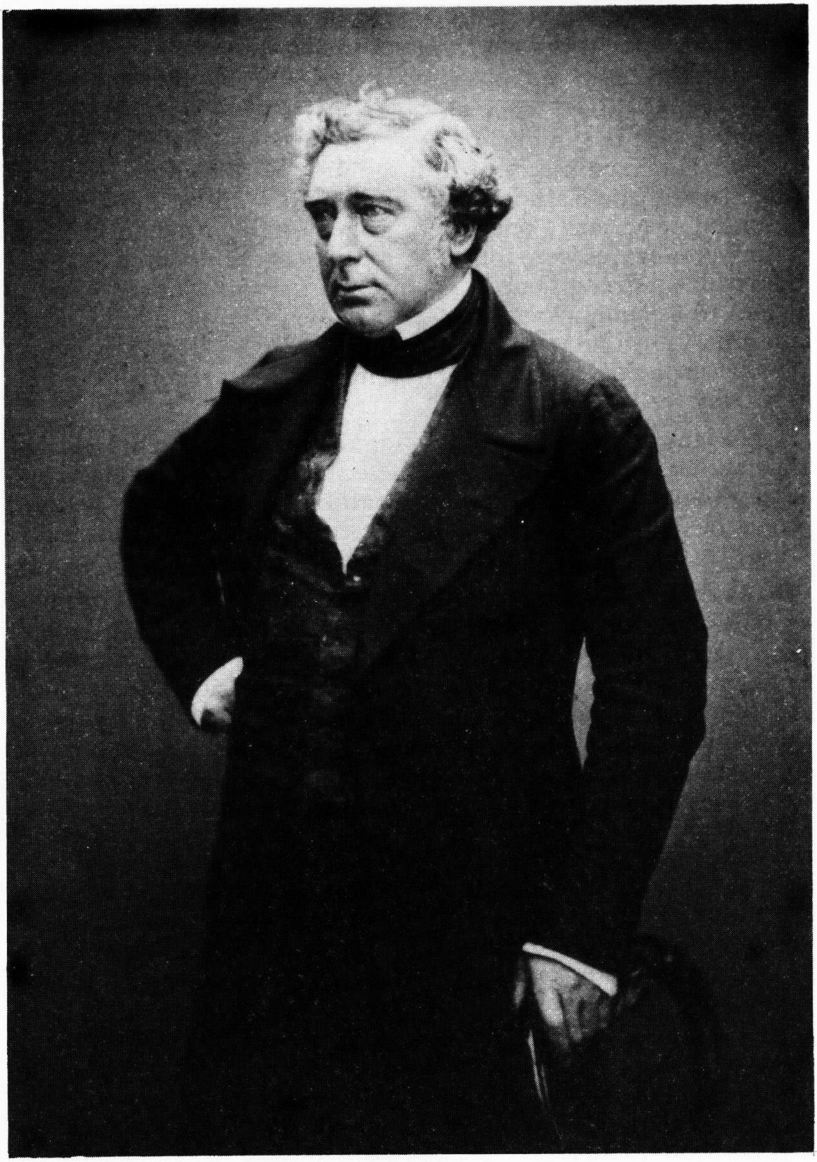
In 1838, only twelve years after the opening of the Menai Bridge, Robert Stephenson was commissioned to survey possible routes for a railway to a port for the Dublin ferry (see map, p.37). Serious consideration was given both to Holyhead, where the harbour was already established, and to Porthdinllaen in the Lleyn Peninsular of Caernarvonshire (at the time of the Act of Union the M.P., W.A. Madocks, had backed Porthdinllaen in preference to Holyhead: it was a direct route which would have



Robert Stephenson
(Photograph: Maull & Polybank)

avoided the problem of bridging the Menai Strait. The site of the proposed harbour is exceptionally sheltered. Incendentally, its choice would have put his new town, Tremadoc, on the coach road).

Stephenson reported in favour of Holyhead despite the great problem of the crossing of Menai (and the River Conway). Progress was again slow but the Chester and Holyhead Railway Act was eventually passed in 1845 and Stephenson was appointed Engineer-in-Chief. He was faced with many of the difficulties which had confronted Telford. Nothing could be allowed which might impede shipping and his first design of cast iron arches again proved to be impracticable on account of the obstruction which would be caused by the centering required for their construction. The movement of a suspension bridge made it quite unsuited to a rigid railway track (surprisingly, Robert's father, old George Stephenson, had proposed laying a single track on Telford's bridge but fortunately nothing came of this).

Like Telford before him, Stephenson had to find an entirely new solution. He then set in motion experiments for a novel form of structure—a tubular bridge constructed of wrought iron. On 9th February 1846 he reported to the Railway Company the results of experiments in the use of tubes of circular, eliptical and rectangular section. "In the whole of these [experiments] this remarkable unexpected fact was brought to light, viz, that in such tubes the power of wrought iron to resist compression was much less than its power to resist tension, being exactly the reverse of that which holds with cast iron"[12]. It had also been discovered that the rectangular "tube" was much stronger than either the eliptical or circular "which should be discarded altogether" (this may account for the rather unexpected adjective "tubular" being used to describe a bridge of rectangular section). Stephenson had consulted two colleagues as to the advisability or not of also including suspension chains in the design (a belt and braces expedient?). Needless to say their advice differed, William Fairbairn, the engineer who was to work closely with Stephenson on later experiments, being the optimist.

At this time, Stephenson had also designed for the same company the Dee Bridge at Chester. It was a three span structure of compound girders. This is not the place to consider its details: suffice to say that the bridge was passed by the Board of Trade Inspector in October 1846 and that one of the outer spans crashed when a train was crossing it the following May. Six people were killed. Stephenson believed that his design was at fault but the Railway Company's solicitor insisted that any admission of failure would be fatal to the Company[13] so he was torn between loyalty and personal honesty—an agonising position for anyone but particularly for a man of Stephenson's calibre and straightforward character. Eventually the jury, though returning verdicts of accidental death, recommended that a government enquiry be held into the safety of all similar bridges. These unhappy proceedings were in train when Stephenson needed maximum confidence not only personally in himself, but also that of his client, the Chester and Holyhead Railway Company who he was about to try to persuade to accept an entirely new form of structure which had no precedent in bridge design. The enormous responsibility which he was about to shoulder was infinitely more daunting in the context of the Dee Bridge disaster.

It then chanced that a most fortunate accident occurred which gave a practical demonstration of the strength of a tubular iron section. A new iron steamship was being launched on the Thames and through some mishap she got stuck so that her hull was supported at each end only, leaving it spanning a gap of 110 feet. This it did without damage. Stephenson and Fairbairn were greatly reassured, but still, Stephenson wrote later, at night he would "be tossing about seeking sleep in vain. The tubes filled my head, I went to bed with them and got up with them". Further experiments made with Fairbairn at his shipyard proved the immense additional strength of a *continuous* beam supported at intervals compared with that of a series of beams of the same dimension spanning the same gaps.

Meanwhile a site had been chosen for the bridge about a mile west of the suspension bridge. Here a small island rock (the Britannia) would make a secure base for a support near mid span. The bridge would consist of two tubes side by side, one for the up line and one for the down. Each would be constructed of two long tubes over the two central spans and two shorter at each end. Once in position these would be rivetted together to make one continuous tube 1,511 ft. long. The continuous tube was to be fixed centrally on the Britannia tower but was to be free elsewhere so that the whole could expand or contract (which it was to do constantly). The central tubes had to be designed to be strong enough initially to be self-supporting until they were rivetted to the adjoining tubes at each side. The shorter land tubes would be supported by scaffolding.

Like Telford, Stephenson too had the parallel but lesser problem of bridging the River Conway, and he too decided to use the same type of structure for each bridge, but in this case the Conway was to be the prototype. Edwin Clark had been appointed to be resident engineer for both bridges.

Foundations began on Good Friday, 10th April 1846, and two long timber platforms on which the central tubes were to be constructed were ready by the following February. Operations covered 1,000 yards on the Caernarfon shore running westwards from the village of timber cottages run up for the workmen below the land tower. Stone again was quarried at Penmon and some was shipped from Liverpool. The design of the masonry is splendidly simple. It is not known to what extent Francis Thompson, architect to the railway company, was involved.

Despite the huge theoretical strength of the tubes, Stephenson had not pressed for a decision about the use of suspension chains. It seems that he and Fairbairn kept their counsel as the masonry of the towers proceeded, but their eventual height above the level to which the tubes were to be raised was to accommodate their lifting mechanism.

On 10th August 1847 Clark inserted the first rivet. Tens of thousands were to follow. Three rivetting machines were brought from the Conway bridge where they had been used with great success but "the men who look with jealousy on any machinery which abridges their labour, were all advocates for hand-rivetting . . . so the whole of Britannia Bridge is consequently hand-rivetted". This created a fantastic spectacle, seven or eight thousand rivets a day being fixed. The rivets were heated to red heat in 48 air furnaces spaced along the length of the platform. "In constructing the bottom of the tube the rivets were handed by the rivet-boys to the workmen, by means of iron pincers. As the work proceeded they were thrown on to the riveting platform; and so dexterous did the boys at length become, by the constant practice of throwing the rivets higher and higher as the work proceeded, that ultimately, although weighing 1¼lbs, these red-hot bolts were thrown with extraordinary precision to the riveters on the top of the tube, at an altitude of 33 feet". The work went on continuously so in the dark the red hot rivets could be seen whizzing through the night — a fine display of fireworks.

The gigantic iron plates used to form the bottom of the tube were hammered flat on site. The din is hard to imagine. The sides were of single plate thickness, but the top and bottom were cellular. (Every five years these cells had to be inspected: it took over an hour for a man to propel himself 1,511 feet through the 1ft 9 inch square cell on a special trolley. A more claustrophobic job is hard to imagine.)

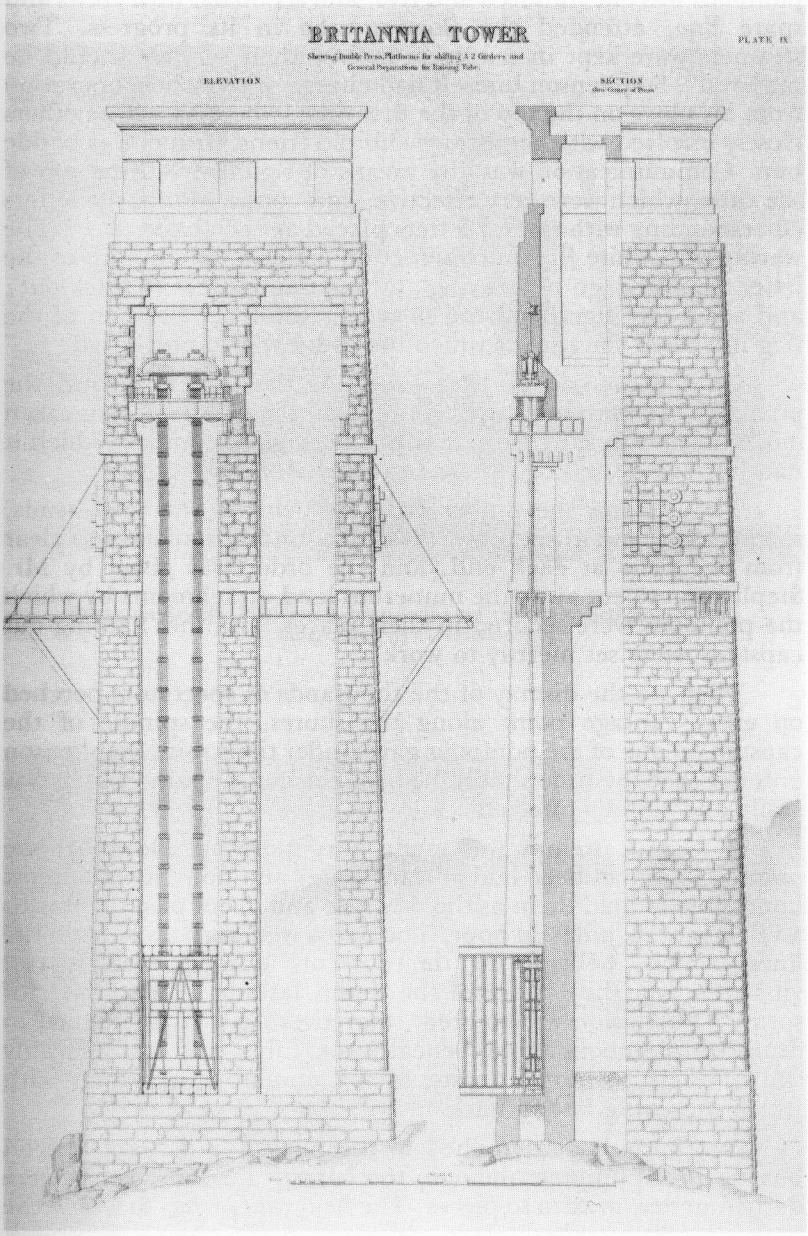
As the tubes grew so did the weight on the platforms. The massive timbers of which they were constructed crushed under the immense weight of iron. The 9 inch camber designed in the tube was lost by this settlement and it could only be restored by lowering the ends on which the tube was supported and putting wedges ("many thousand were consumed") under the centre. The replacement of some of the longitudinal timbers was also to be "a tedious and lengthy process" but it was essential if the tube was to be true.

Although totally different in other respects the central spans of both Stephenson's and Telford's bridges were erected in the same way. Like Telford's chains, Stephenson's tubes were to be floated out on the tide, but whereas each main chain had weighed 23½ tons, each main tube was more than 1,500 tons.

By January, 1849 the stage had been reached when the lengthy transfer of the tubes from the construction platforms onto the pontoons on which they were to be floated out was to begin. Rock had to be blasted away to let in the tide which was to be their great ally in the completion of the manoeuvre. Unexpected setbacks occurred. For example, by great misfortune, on the critical day of the transfer of the first tube, high springs rose 4 inches higher than the most conservative estimate so salt water flooded the lower cells. These "were afterwards with considerable expense, flushed with fresh water to prevent oxydisation".

By the summer the Britannia tower stood 230 feet above the Strait; the lower side towers were also ready. Invaluable experience had been gained at Conway where the first tubes were already in position and the hydraulic presses used to raise them had been brought to Menai. Recesses had been left in the face of the piers to take these presses and guide them vertically upwards. An exact model had been made of the Strait with pontoons, tubes, hawsers and capstans, boats and Bridge piers; and the tides had been calculated precisely. The tides again were to do the work, the giant hawsers being employed to put a brake on the pontoons if they moved too fast. "The velocity of the current at starting [the operation] was estimated at 1.8 miles per hour, diminishing gradually until the moment of tide-turn, when the water becomes perfectly tranquil. The tube is thus carried along by the tide, which is the only moving power . . . the tide, however, continues to rise for some considerable time after the current has changed its direction; so that, provided the tube be moored in its permanent position before the current changes, all danger is over, and abundant time remains for any subsequent adjustment". The tides limited the time to be taken by the whole operation to 1½ hours.

The management of all nautical matters was under the direction of Captain Claxton (as at Conway). The "capstans were fully manned by eleven intelligent superintendents, four hundred and fifty labourers, sixty-five sailors, and twelve carpenters. Each capstan had forty-eight men. The number of hands in each set of



Britannia Tower. Shewing Double Press, Platforms for shifting A 2 Girders, and General Preparations for Raising Tube (From Britannia & Conway Tubular Bridges by Edwin Clark) pontoons was one hundred and five, and six boats, with crews and spare line, attended the floating-tube in its progress. Two steamers were kept in readiness in case their services should be required". Stephenson himself had charge of the whole operation from his place on the top of the first tube, where as well as others closely involved with the Bridge, his old friend Brunel was beside him. Communication was "by means of signals from the top of the tube, which were very effective, and consisted of large letters corresponding with similar letters placed at each capstan. . . The waving of a white flag in conjunction with the holding up of the letter, signified 'go on heaving'; a blue flag indicated 'slack out'; and a red flag signified 'stop heaving'; while the position of the flag indicated the rate at which the order was to be obeyed. . . "

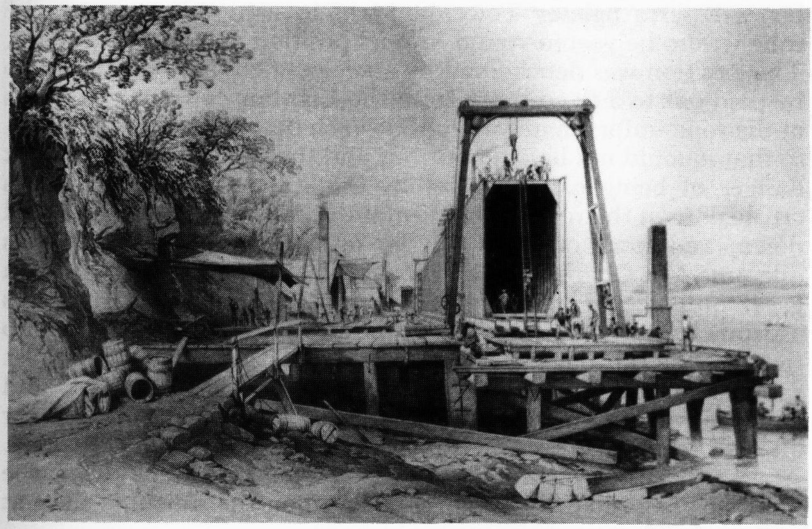
On the evening of 19th June "As the tide rose, and the pontoons began to bear against the tube, the deflection was taken out of it, and it returned partly to the original camber, which it had lost when the supports were removed.

The noise of the timber crushing beneath the rivet-heads, soon ceased, and at six p.m. it was announced that she was clear from the piers at each end, and the order was given by Mr. Stephenson to cut away the numerous land attachments by which the pontoons were secured in their places, and the 'hauling-out capstans' were set merrily to work".

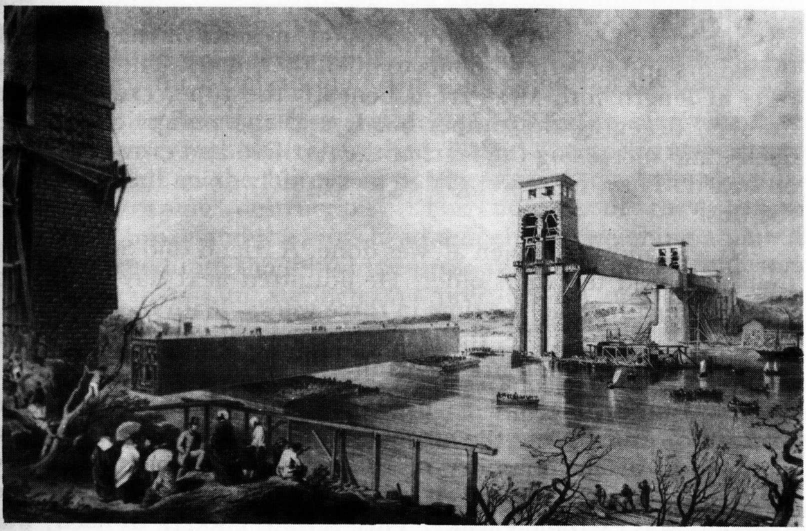
Then, to the dismay of the thousands of spectators perched on every vantage point along the shores, the spindle of the capstan on one of the pontoons gave under the strain. Stephenson ordered that the tube should be brought home again "which was easily and rapidly effected".

A second attempt was made next morning. However, the original lines had been laid at slack water and now "it was almost impossible to hold them as the tide rose and swept past them with a velocity of six miles an hour. The buoys were torn away from the lines, which, bellying in the current, dashed with fearful vibration over the surface of the water, lashing it into clouds of spray. The tension was so great, moreover, that it threatened to draw the pontoons from beneath the tube, and considerably shifted their position in spite of the numerous moorings with which they were lashed back.

The large boats attached to the buoys, with spare line on board, after plunging about in the current for some time, were dashed under, or torn to pieces. The heavy moorings to which the buoys were attached were dragged from their positions". Following "great exertions" throughout the day "by half past seven in the evening, the tube was again ready and the spectators assembled, though "in somewhat diminished numbers". The drama that followed certainly repaid these loyal supporters.



Britannia Bridge. Platform & construction of the tubes, September 1848.
(Engraving by G. Hawkins)



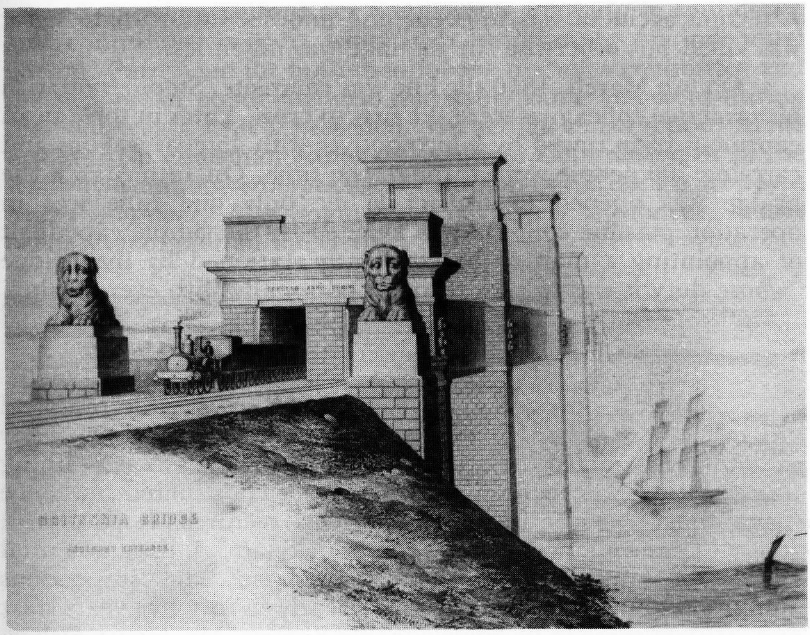
Shewing the Floating of the Second Tube December 3rd 1849
(Engraving by G. Hawkins)

Everything depended "on properly striking the 'butt' beneath the Anglesey Tower, on which, as upon a centre, the tube was to be veered round into its position across the opening. This position was determined by a twelve-inch line, which was to be paid out to a fixed mark from the Llanfair capstan. The coils of the rope unfortunately over-rode each other upon this capstan, so that it could not be paid out . . . and the tube was in imminent danger of being carried away by the stream, or the pontoons crushed upon the rocks. The men at the capstan were all knocked down, and some of them thrown into the water, . . . In this dilemma Mr. Charles Rolfe, who had charge of the capstan, with great presence of mind, called the visitors on the shore to his assistance, and, handing out the spare coil of the 12-inch line into the field at the back of the capstan, it was carried with great rapidity up the field, and a crowd of people, men, women, and children, holding on to this huge cable", hauled and heaved for all their might and eventually "arrested the progress of the tube". At last the tube was in place "and as the tide went down the pontoons deposited their valuable cargo on the welcome shelf at each end."

Trouble was still in store. The freeing of the pontoons "was attended with extreme danger to those on board as the tide had now attained a fearful velocity in the opposite direction, and night was approaching. Many of the men on board, unused to operations on the water, became alarmed at the violence of the stream, and called out to be taken on shore, scrambling for the life-buoys, and in the utmost confusion, in spite of the efforts of the sailors and superintendents to quell their fears. These massive rafts at length tore away from beneath the tube, crushing the timbers, dragging the timber-heads and the pumps out of the decks, and increasing the fears of the terrified and crowded crews on board. They, however, glided away safely down the current in the dusk".

It was midnight when all was done. A friend told Stephenson that he looked ten years older. He admitted next day to having "slept sound" for the first time in three weeks. With the successful floating of the first tube, the tragedy of the Chester bridge was no longer the great landmark of his life.

The tube now had to be raised. The positioning of the hydraulic presses in the recesses on each tower and the completion of the masonry of the towers went on until early August when, on testing, it was discovered that one of the cylinders was extremely leaky. This, serious enough in itself, was to delay the floating of the next tube since navigation could not be held up by its remaining at the base of the piers. Eventually



Britannia Bridge. Anglesey Entrance
(From Britannia & Conway Tubular Bridges by Edwin Clark)

"the press was closed with oatmeal gruel and sal ammoniac . . ." and the Anglesey end raised four feet. Each time the tube was raised timber was packed under it and then the recess was bricked up so that in case of accident the tube could not drop far.

Despite fierce gales everything proceeded to plan when, on 17th August, with the tube raised 24 feet "an accident occurred unparalleled in the history of engineering, the whole structure barely escaping destruction". The bottom of the cylinder suddenly broke and the cross head and chains, weighing about 50 tons, crashed into the top of the press and the tube fell (only 8 or 9 inches thanks to Stephenson's precautions) onto the timber packing. An "unfortunate sailor" was killed but miraculously no one else. The damage to the tube itself "was found to be very serious" but the problems concerning the design and casting of a new cylinder seem to have even been more worrying. This was done "in the incredibly short time of six weeks" during which the tube was also repaired.

On 13th October "the tube safely attained its final elevation". The junction pieces weighing 174 tons each which were to link the landward tubes to the central span were rivetted and preparations for the raising of the second tube went forward.

A second accident was to occur and another unfortunate sailor was killed but otherwise the damage was much less.

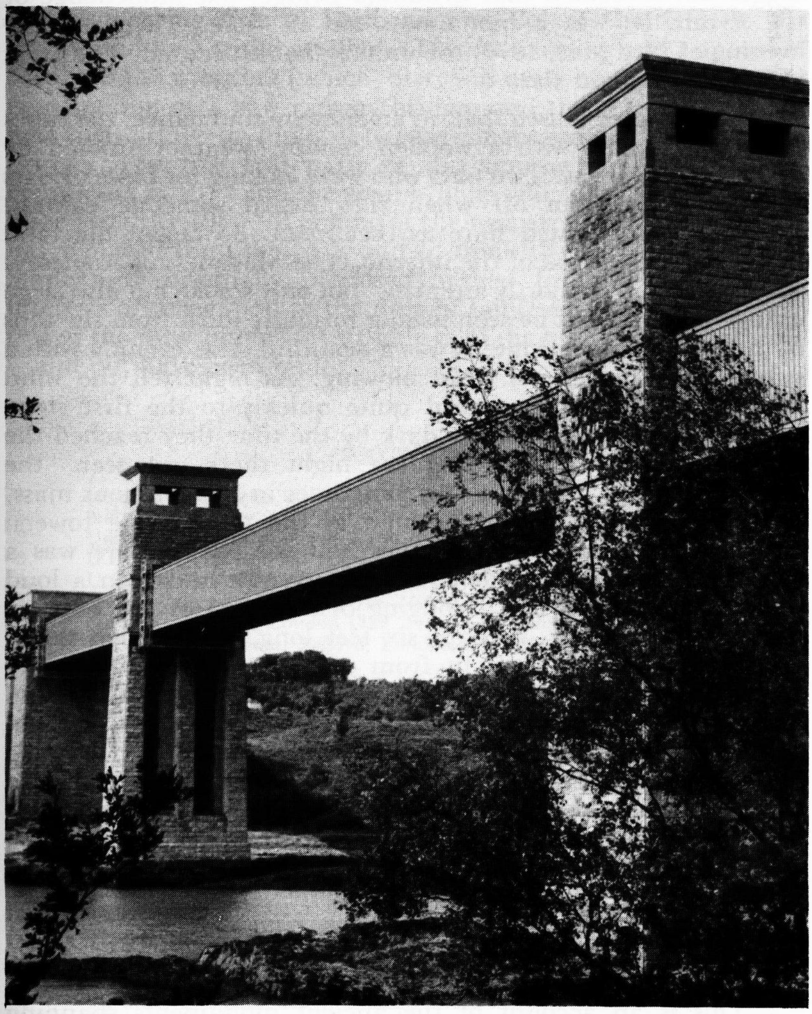
On 5th March, 1850 the line was complete. Stephenson with his principle colleagues were the first to cross. Later in the day an enormous train towed by 3 locomotives with 45 coal wagons and carrying 700 people went through the tube. On 18th March the bridge was opened to traffic. While only one tube was in operation possible collision was avoided by the simple expedient of appointing a man to be constantly stationed by the bridge "whose duty it was to pass through personally with every train".

* * * * * *

The bridges proved to be not only of inestimable practical use but continued to be of tremendous public interest. They would have attracted the lively interest of engineers as astonishing pioneering works wherever they had been constructed but since they happened to be in one of the most picturesque parts of a region already renowned for its romantic qualities, their potential as tourist attractions was quickly appreciated. The "stupendous and elegant" suspension bridge had nearly twenty five years start and was fortunate in its knowledgable Keeper, Mr. Henry Fisher, to whom application could be made to see the fastenings of the main chains in the rock. Visitors could stroll across by the footway[14] in the centre of the bridge to gaze at the activity associated with Britainia Bridge, a mile distant.

The tubular bridge was to attract ever more attention. Some tourists (eg. George Borrow with Henrietta) actually walked through the tube. It was guarded by four huge stone lions designed by George Thomas of Chelford; "the breadth of each paw is two foot four inches" readers of *Parry's Railway Guide*[15] were told. *The Gossiping Guide to Wales*[16] explains how 186,000 pieces of iron were joined by two million rivets and describes a good walk which takes in both bridges. Lanfairpwll, the village nearest the railway station on the Anglesey side, had its name changed by a publicity-minded tailor of that village to Llanfairpwllgwyngllgogerychwyrndrobwllllandysiliogogogoch. The name board on the station platform and the lions were important landmarks for any child travelling on the line (the experience of the bridge itself being of course a disappointment, simply that of travelling through a tunnel).

It has long been recognised that both bridges were pioneering works which were to have a profound influence on all that followed. Their success is so evident that it is easy to forget the long loneliness of their designers before their ideas were proved. Neither Telford nor Stephenson enjoyed the confidence and continuous support which can be given by an individual patron. Patronage for both men meant that of a committee and the support of politicians who inevitably came and went during the long years which preceded the actual construction of the bridges. No chairman either of the Road Commission or of the Railway Company emerges as a champion of the design proposed by its engineer. Any engineer, particularly a pioneer, dearly needs a champion in the chair.



Britannia Bridge, 1970. (Photograph: Elisabeth Beazley)

Both bridges continued to carry more and more, heavier and heavier traffic. Indeed it is now hard to believe that they were not designed with it in mind. The list on Telford's toll-house for Llanfair gate belongs to that other world: droves of Oxen, Cows or other neat cattle are included in addition to the coaches, carriages and curricles which feature in contemporary engravings. Similarly, views such as that included in Clark's account appear faintly absurd; the gigantic tube carries what seems to be little more than a toy train. The toys got bigger and bigger but it seemed that Britannia Bridge, like Stonehenge or the Pyramids, was a monument for all time. Then, on the evening of 23rd May, 1970, the unimaginable occured. The great iron bridge caught fire.

Few people realised that, as an aid to maintenance, the tubes had been topped with a wooden canopy, weather-proofed by pitch soaked canvas. Two boys who were looking for birds or bats on the bridge, ran off when they heard someone calling, dropping their lighted flare as they went. So began the fatal blaze. An eye-witness of the inferno, The Marquess of Anglesey, has described how shortly after this "not only smoke but also large orange flames could be seen issuing furiously forth from the tops of the tubes of the bridge. It was a beautiful clear evening with a strongish south-westerly wind blowing. As night fell the wind increased. The flames spread quite quickly to the first stone tower, but it was completely dark by the time they reached the central tower . . .". During the night there was seen "the terrifying sight of flames rising sometimes in a continuous mass, sometimes singly, at least as high as the tops of the towers. Between the bottom of the tubes and the water there was a continual display of 'golden rain'. Every now and then a loud crack would herald the dislodging of a section of the burning superstructure. This, perhaps six feet long, would then slowly somersault, brilliantly alight from end to end, into the water below, followed by smaller pieces. All the time there was the dull roar of the flames, and a faint smell of burning paint and hot metal. Next morning it was seen that "the paint on the north side of the tubes had been burnt off in some places. Otherwise, except for the blacking of the tall tops of the towers, everything looked uncannily the same as before the fire. In fact, a close inspection revealed that each of the four central tubes had sagged no less than two had a half feet in the middle".

* * * * * *

This is an account of the ancient monuments spanning Menai so does not include a description of the present bridge. A brief account of the result of the fire follows.

The top cells probably behaved like blow torches and the top plates reached red heat. The Caernarfon long span had a sag of 710mm[18]. During cooling a series of loud bangs was heard. Each long continuous tube had split into the four original simply supported tubes of which it was constructed. The breaks occurred at the joints made after the central tubes were lifted into position in 1849-50.

British Rail did not delay. In less than a week they consulted the engineering firm of Husband and Co. of Sheffield. It was confronted by a triple problem. The dismantling and removal of Stephenson's ironwork (which, alas, was quite beyond repair), the construction of a new railway bridge, and the construction of a new road bridge on top of it to ease congestion on the suspension bridge. The first two parts of this unique undertaking were completed in 1973 and the road bridge, which has proved to be a huge asset, by 1980[19]. Looking at the new arched structure which has replaced the tubes it is odd to think that both Telford and Stephenson originally proposed arched bridges. But for the interests of navigation in the days of sail (even then almost over) two of the most important structures in the history of engineering would not have been built.

FOOTNOTES

1. Henry Penruddocke Wyndham, *A Tour through Monmouthshire and Wales,* 2nd ed., Salisbury, 1781, p.138.
2. University College of North Wales, Bangor, KG 117.
3. U.C.N.W. Plas Newydd Papers PN 2312.
4. U.C.N.W. KG 177.
5. William Alexander Provis, *An Historical and Descriptive Account of the Suspension Bridge,* London 1828. Provis was Telford's resident engineer.
6. L.T.C. Rolt, *Thomas Telford,* London 1958. Much of the background comes from this excellent biography.
7. Since writing this my attention has been drawn to R.A. Paxton, Menai Bridge (1818-1826) and its influence on Suspension Bridge Development. *Transactions of the Newcomen Society.* Vol. 49, 1977-78, pp.87-110. A 70 foot span iron suspension bridge had been erected in N. America in 1801.
8. U.C.N.W. Joseph Pring, *Particulars of the Grand Suspension Bridge erected over the Straits of Menai . . .,* 8th ed., 1828. Much lively detail is included in Pring's enthusiastic pamphlet. He lived locally. The Marquis is the Lord Paget who supported the 1783 proposals and was later created Earl of Uxbridge. The Battle of Waterloo, after which he was enobled and became 1st Marquess of Anglesey, occurred before this meeting in Caernarvon.
9. Provis.
10. ibid.
11. The idea seems to have captured the public's imagination. As the White Knight was to remark "I heard him then for I had just / Completed my design / To keep the Menai Bridge from rust / By boiling it in wine". Lewis Caroll was not born at the time of its construction.
12. Edwin Clark, *Britannia and Conway Tubular Bridges,* London 1850. Clark was resident engineer and his account has been used extensively.

13. L.T.C. Rolt, *George and Robert Stephenson,* London 1960. An excellent biography giving much of the background.
14. The small "sun ray" gates to the footway which appear in early engravings were designed and made on the spot. One now opens into Llangaffo churchyard; another probably from the same source, to the garden of the farmhouse on the Isle of Muck.
15. *Parry's Railway Companion from Chester to Holyhead . . .,* London 1848.
16. *Gossiping Guide to Wales,* Pt. 11, London 1893.
17. Elisabeth Beazley and Lionel Brett, *Shell Guide to North Wales,* London 1971.
18. J.B. Wardle and J.C. Lucas, Britannia Bridge: stress and investigation before and after the fire. *Proceedings of the Institution of Civil Engineers.* Vol. 58, 1975, p.185-193.
19. H.C. and R.W. Husband, Reconstruction of Britannia Bridge. Ibid, p.25-66.

Pontydd Menai (The Menai Bridges), published by the Gwynedd Archives Service in association with the Welsh Arts Council, 1980, is a most beautifully illustrated but modestly priced publication which was produced in association with the exhibition of that name. It was still available in 1984 from the Gwynedd Archives Service, Victoria Dock, Caernarfon. Unfortunately I did not know of it until after this article was written.