Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 3 (1948)

Artikel: Preservation of the Menai suspension bridge

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DOI: https://doi.org/10.5169/seals-4032

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Reconstruction du pont suspendu de Menai

Umbau der Hängebrücke über die Menai-Strasse

Preservation of the Menai suspension bridge

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The work here described was started about a year before the outbreak of the war and was carried to completion in a period of some difficulty, but before the period of acute stringency in labour and materials which occurred during the latter part of the war had reached its full development.

Before being started the work to be performed had been closely studied in all its aspects and the design was most carefully framed so as to take advantage of the latest ideas and to make use of the best materials procurable. Although the work happened to coincide with the war period there was, therefore, nothing in its composition or execution of inferior quality. It was, in fact, one of the last important public works undertaken in Britain which can be said to have been carried out in the best tradition and unspoiled by the influence of war.

The work was performed under the direction of the British Ministry of Transport, the Roads Department of which nowadays exercises ownership and control of the principal highways in the country.

Sir Alexander Gibb, with whom the author collaborated, was employed by the Ministry to prepare the designs and supervise the work of reconstruction.

The Menai Bridge forms the only road passage across the Menai Straits, a narrow branch of the sea which separates the Island of Anglesey from the Welsh mainland. The principal route to Ireland passes via the bridge across the Island of Anglesey to the Port of Holyhead, and in the early part of the 19th century, in the old coaching days before the railway was built, the road to Holyhead was naturally a route of great importance. During the latter half of the century, the main traffic was by railway and the road fell into partial disuse, but the advent of the motor car at the beginning

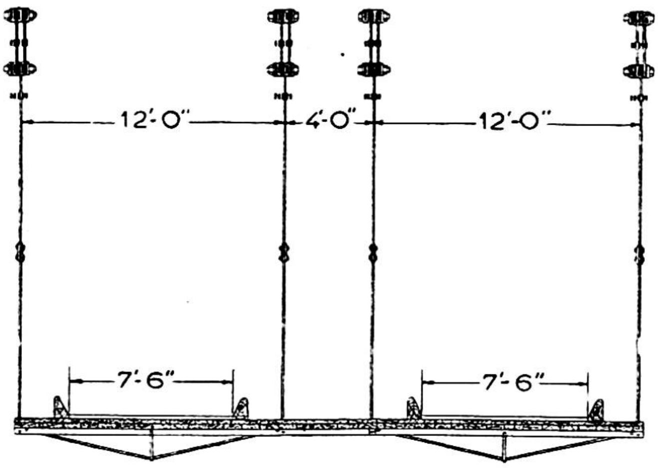

Fig. 1. Cross section of Telford's original deck.

of the present century revived its importance not only as a bearer of local traffic but also as a national highway connecting England and Ireland. Every year up till 1938 saw a steady increase in the volume of mechanically propelled vehicles crossing the Menai Straits and the weak condition of the old suspension bridge, then more than a hundred years old, made it necessary to impose restrictions not only upon the weight and speed of the motor vehicles which passed along its two independent tracks but also a restriction upon the interval between successive vehicles. Such restrictions were irksome to travellers and were found to be difficult of enforcement.

Right from its inception in 1825, the suspension bridge was a toll bridge, every vehicle and for most of the time every pedestrian, having to pay a fare to the collector of tolls posted upon the bridge both by day and by night. These toll collectors were in the tradition of the old Roman publican in that having made an annual lump sum bid to the Government

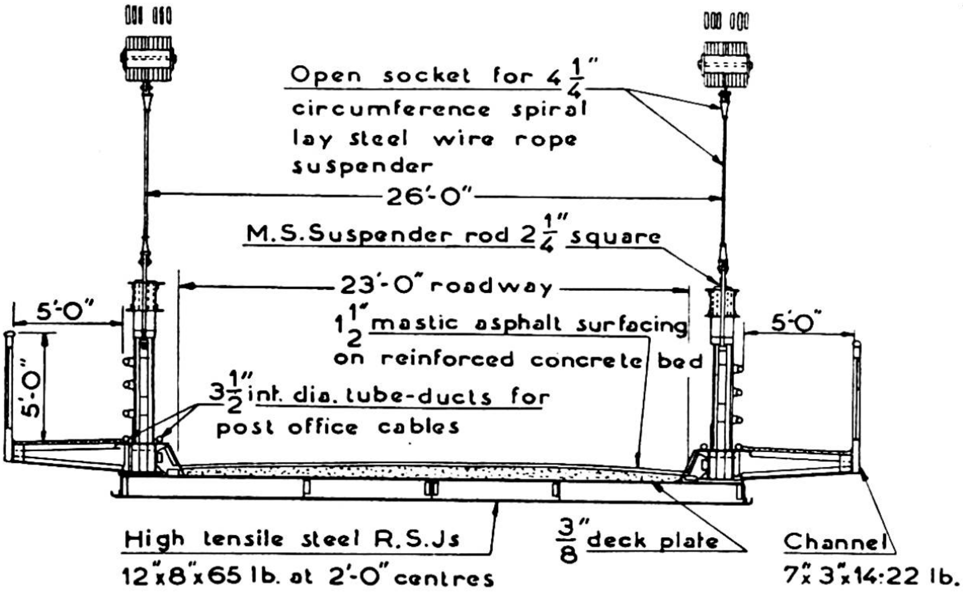

Fig. 2. Cross section of deck as reconstructed in 1940.

for the privilege of farming the tolls and being restricted by Government to the rate of tolls they might charge, they were subsequently dependent upon the volume of traffic to recoup themselves.

After the reconstruction in 1942 the bridge was thrown open to the public for use free of charge and without restriction as to the weight, speed and spacing of vehicles using the route, a benefit which the inhabitants of these islands will no doubt appreciate more amply if and when the free use of motor spirit may permit the resumption of pleasure motoring.

The land approaches and bridge abutments on both sides of the Menai Straits were built in a hard limestone masonry, the blocks of stone having been hewn from local quarries. The work had been very well performed by skilled masons and standing securely upon sound rock foundations the whole of the masonry structure still remains in excellent preservation.

It had originally been designed with an ample margin of safety so that it was found to be capable of carrying without alteration the much heavier loads imposed by the renovated superstructure and by modern transport.

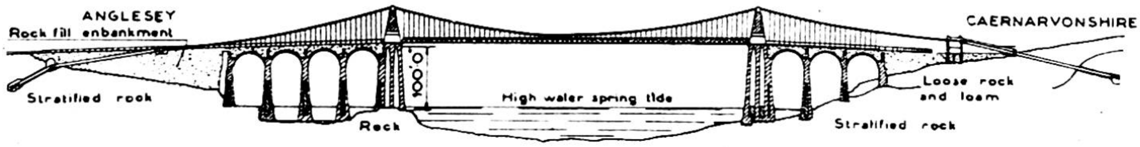

Fig. 3. General longitudinal section.

During the first century of its life the deck of the bridge had been entirely renewed on three occasions and the main suspension chains and hangers had been repaired, numerous defective links of the chains having been taken out and replaced from time to time.

This notwithstanding, the general scheme of chains, hangers, deck, roadway and footways, were found to be totally inadequate for purposes of modern traffic and the whole superstructure of the bridge had to be redesigned on a more liberal scale and in accordance with modern standards, entirely new steelwork being substituted in place of the antique ironwork of the chains and in place of the less antique but still old steelwork of the deck structure.

The work involved in these renovations has several claims to attention which make it of special interest.

There is, firstly, the fact that this bridge, originally built complete in 1826, was one of the earliest iron chain suspension bridges. When first built the clear central span of 580 feet was greater than the spans of any one of the few earlier suspension bridges that had been erected in England, the United States, Germany, Switzerland, and France prior to 1825, indeed, this bridge had then the greatest span ever built. It was also a very handsome bridge and had been designed and built by an Englishman whose reputation as a Civil Engineer surpassed that of any other person so engaged in any other country at that period, and indeed there has probably been no other Civil Engineer in our country since then whose reputation and achievements have equalled those of Thomas Telford, he being one of the founders, and the first President of the British Institution of Civil Engineers.

Apart, therefore, from its utilitarian value, the Menai Suspension Bridge has possessed for British people a unique sentimental attachment standing as a remarkable monument to the industrial revolution of the nineteenth century—a monument moreover which happens in itself and in its natural setting to be a thing of beauty unmarred by the noise, the smoke, the dirt, and the general atmosphere of squalour which has too often been the accompaniment of so many of the other manifestations of the scientific era.

It would be fair to say, therefore, that the principal merit of this bridge during the nineteenth century lay in the fact that it was a spectacular novelty of impressive beauty, full of charm, dignity, interest and utility, and as such that it was an inspiration to the youth of the country.

Apart from such general considerations there are, of course, technical lessons deriving from the long period of its service to be learnt and there are also quite a number of technical features in the design of the restoration work which are of interest to engineers.

Among the latter may be mentioned the ingenious methods which had to be adopted so as to carry out the complete replacement of the suspension chains with their anchorages, their roller bearings and their hangers and also the replacement and widening of the bridge deck and footpaths without any interruption of the traffic crossing the bridge either by day or by night.

Other technical features of interest were the manufacture of the eye bar links of which the chains are composed, and the method of protecting them against rust corrosion. There was also the method which had to be employed for cutting away, underpinning and replacing the central limestone wall between the two roadway tracks where they pass beneath the arches of the principal abutments supporting the suspension chains.

In the space of a short paper such as this it is not possible to go into much detail but some of the main outline of the technical features may be mentioned.

Dealing first with the scheme of operations whereby the whole reconstruction work was effected without stopping the traffic, it would, of course, have been easy to achieve this result by throwing a temporary suspension bridge across the straits and then closing the old bridge to traffic and diverting the latter to the temporary structure. Such procedure would, however, have been very costly.

To understand what was actually done it is first necessary to realise that the old bridge was suspended from four separate chains, one chain on either side and two close together in the middle between the two carriageways. The four chains rested on top of two main piers flanking the main span. Upon each of these two main piers a temporary steel girder or cap was erected and mounted above the old chain seatings and on top of this cap were slung two steel wire rope suspension cables capable temporarily of replacing the outer two sets of the old chains above mentioned.

In the reconstructed bridge the four chains each composed of a tier of eyebar links five abreast and four deep were to be replaced by two chains each composed of a tier of six eyebar links two deep and the new chains had perforce to occupy very nearly the same physical position on top of

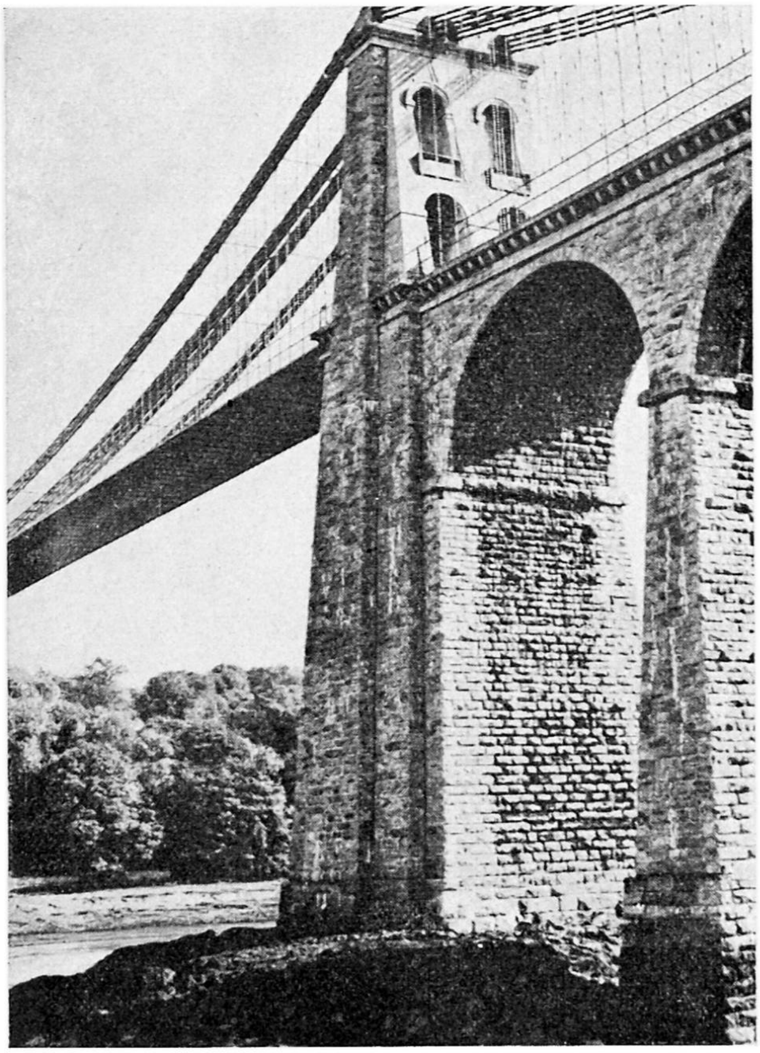

Fig. 3. One of the main masonry piers showing the four chains deck and roadway arches of the original structure.

the piers as had originally been occupied by the two outer tiers of the four original chains. It will be seen, therefore, that it was necessary to remove the two outer tiers of old chains before the new permanent chains could be erected in their place and explains why it was necessary to provide temporary cables for supporting the outer edges of the roadway deck while the work of chain replacement was in progress. The cables were mounted directly above the chains that were to be removed and replaced by new chains and were supported by the temporary cap girders above mentioned. After the cables had been strung across and anchored to the hillsides they were connected by temporary hangers so as to support the outer edges of the old bridge deck and after that the old outer chains were removed and were replaced by the new chains. While this was going on the old inner central tiers of chains were left in service, and traffic continued to use the deck of the bridge without any interruption or interference.

When the new chains had been mounted upon their new roller tracks and carried back through the old anchorage tunnels to deep anchorages in the virgin rock in the hillsides behind, the new suspended deck was erected from the new chains by means of hangers which hung just outside the parapets on either side of the old roadway deck.

The new deck had eventually to occupy the same spatial position as the old deck and as our present state of knowledge does not permit us to make two material objects occupy the same identical spatial position at the same time it was necessary to build the new deck in a position just about 4 feet vertically underneath the old deck which continued to be used by traffic all the time while the new deck was being pieced together.

When the new deck had been built in that position and was itself ready to carry traffic the old deck was demolished, demolition being done in two stages, the old carriageway on one side the bridge being broken up and removed first while the old carriageway on the other side continued to bear traffic. Traffic was then diverted back to run upon the freshly exposed new carriageway at a level four feet below the demolished roadway and the second old carriageway was closed to traffic, broken up and removed in its turn. After this the whole width of the new carriageway was available for the use of traffic which was made to run down temporary wooden ramps on to the new deck. Finally, the new deck had to be raised bodily through a distance of 4 feet so as to bring it up into its proper position and this raising process was done by screwing it up inch by inch on the suspender hangers, all of which had been designed with long screws and nuts for this purpose.

Described in this way the whole operation appears fairly simple but there were a great many minor difficulties and intricacies brought about partly by the rather irregular nature of the old work. The old chains did not lie in one vertical plane but had been made to change direction in plan as well as in elevation and in order to make the new superstructure fit into the old masonry framework the new chains had to be made to do the same. Then there was the stretch of the suspension members, old chains, new chains, and temporary cables which had to be taken into consideration at all times and during all phases of the operations.

The stretch of the wire rope temporary cables supporting the outer edges of the old bridge deck was, of course, quite different to the stretch of the original chains and had to be allowed for. Then the new eyebar link chains had themselves to be supported during erection. On the two side approach spans the new chains were erected on scaffolds supported upon the old masonry arches beneath and there was very little elastic distortion

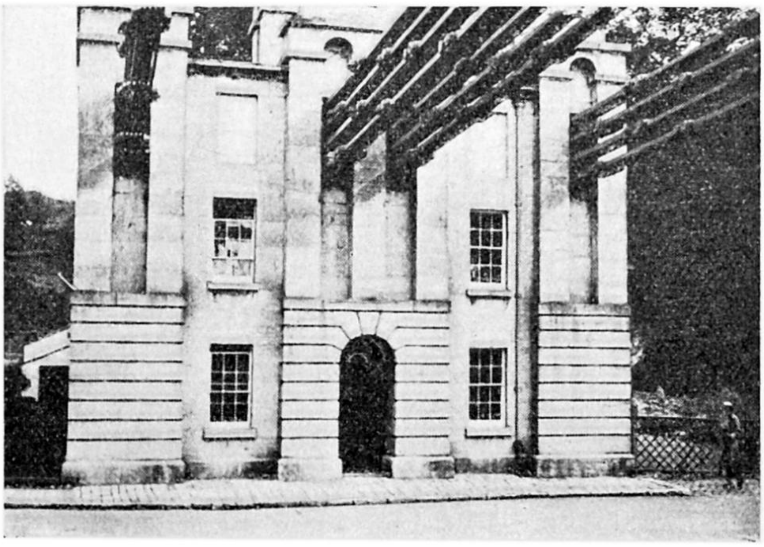

Fig. 4. Old chains entering the anchorage on the Welsh side.

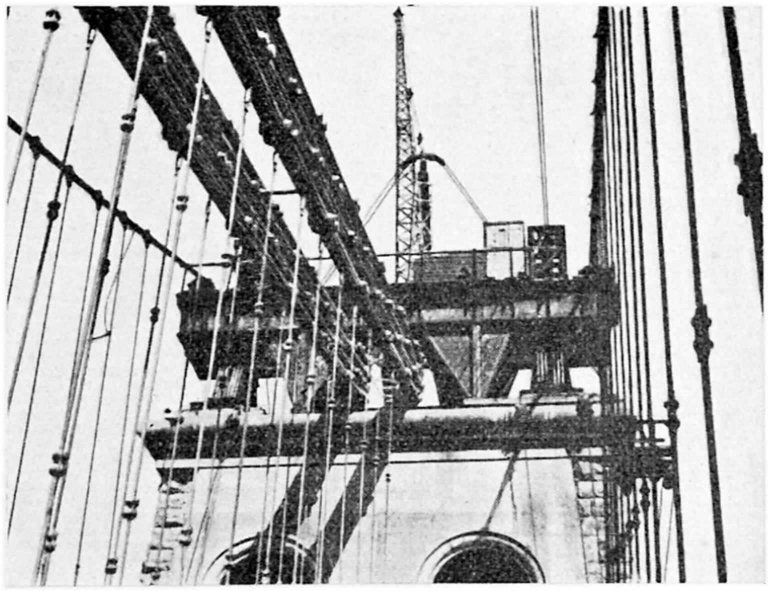

Fig. 5. Top of one of the main piers during reconstruction. The two old central chains are seen in position but the two old outer chains have been removed and the roller bearing saddles for supporting the new chains have been erected on top of the pier. Above the pier is the temporary steel horsehead girder supporting the temporary wire rope cables and suspenders and above them the blondin wires. The suspended walkways for supporting the new chains during erection have not yet been set up.

to be allowed for, but where the two new chains traversed the main span they had to be put together link by link upon two suspended walkways, each of which consisted of five catenary wire ropes hanging side by side and decked over without any stiffening. The stretch of these ropes when the weight of the chain links came upon them was considerable and the sequence in which the chain links were assembled upon the walkway also created distortion away from the catenary. In the stage when the eyebar links were being assembled and before they were connected at both ends to the links on the side spans there was a period of some instability when wire rope walkways tended to twist out of line from under and capsize the load. All these tendencies had to be taken into consideration as the work progressed. The new chains were assembled on the suspended walkways by means of blondins rigged above them.

Perhaps the most instructive technical feature introduced in this design was the method of protecting the new chains against rust. The eyebar links composing the suspension chains had in the original bridge been made of wrought iron—a material which is generally considered to be not very susceptible to rust. They had, moreover, been repainted at regular intervals with the high qualtiy white lead and linseed oil paint which was procurable in those days of plenty. In the course of one hundred years exposure to the salt bearing winds that blow over the Menai Straits, individual links had, however, suffered severely and there were places where a considerable amount of corrosion had occurred, this rusting being usually most marked in or near the eyes of the links, fishplates and hangers where they were pinned together. As the old links were known to contain a number of hidden flaws and as the dead load working stress alone to which they were subject lay between 6 and 7 tons per square inch, the added deterioration due to rust was a serious matter and gave rise to some anxiety. It was decided, therefore, in the new design to do everything possible to eliminate corrosion and with this end in view each link was shot blasted before erection and afterwards spray coated with hot zinc about five thousands of an inch in thickness. Over this was applied a priming coat of red lead followed by three further coats of paint on a linseed oil base. A thick plastic

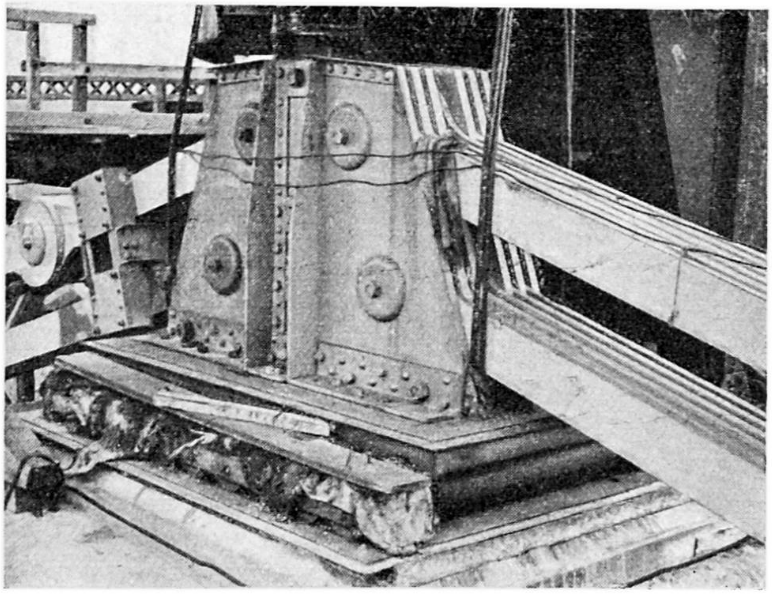

Fig. 6. One of the new roller bearing chain saddles in course of erection on top of the pier and before its enclosure in an oil bath. The new chains have been erected and connected upon the saddle.

paste built up on a petroleum basis was inserted between the meeting faces where the links were pinned together so that the percolation of moisture between links and pins was thereby prevented.

An examination carried out recently, that is about five years after the erection, disclosed no trace of rust anywhere on the eyebar links. While it was apparent that the outer coats of paint had deteriorated in places there was not a trace of rust anywhere so leading to the conclusion that the zinc coating beneath the paint was impervious and was providing perfect immunity against rust.

Owing to the great expense of the shot blasting and zinc coating, this costly process could not be adopted for protecting the steelwork of the stiffening trusses, handrailings and so forth, the protection given here being no more than the ordinary wire brushing, removal of loose rust and mill scale and application of three coat paintwork, the undercoat being red lead paint. In the parts so protected there was considerable evidence of rusting although no more so than could reasonably be expected to occur after five years in such an exposed position.

The underside of the deck structure which consisted of mild steel joists laid as cross beams with continuous steel plating over was in the first instance painted in the ordinary way with three coats of linseed oil and lead paint of good quality.

The lower flanges of the cross beams are, of course, very much exposed to wind and being shielded from sun tend to remain damp and to collect drops of water in misty weather and after five years of this exposure became rusty and some of the paint on the edges of the flanges flaked off. For repainting this part of the structure after the five years it was decided by the Ministry of Transport to employ a black bitumastic paint overcoat, the behaviour of which will be the subject of close observation in future.

While on the subject of corrosion and painting it is interesting to note that Thomas Telford when designing the original wrought iron structure in or about the year 1820 conceived that corrosion of the chains inside the anchorage tunnels would be much more severe than outside in the open air, and he accordingly stiffened up the sizes of the links where they traverse the underground tunnels making them nearly twice as thick as those in use outside so as to allow a margin for rusting. The tunnels consist of narrow passageways cut in the virgin rock where the humidity is considerable and the temperature does not vary very much summer or winter. Telford's conception that rusting in such conditions would be much more active than in the open air has been entirely falsified in the result, experience having proved the exact opposite, there being practically no rusting of the ironwork anywhere in the tunnels during a period of 120 years whereas rusting outside was considerable.

It was observed that the rusting of mild steelwork in the reconstructed bridge after five years exposure was most pronounced in those parts which were most exposed to wind and rain, the worst rusting of all having occurred on the side of the bridge which was exposed to the prevailing south westerly rain bearing wind, and especially was this the case on the outer parapet steel footway railing on that side where the $\frac{5}{8}$ inch diameter upright rods composing the railing were blistered with rust and had the paint stripped off on their exposed western side, the other side of the rods next to the footpath being scarcely blistered at all. It seems as if this question of rust prevention stands today very much where it did fifty or a hundred years ago but with the difference that in earlier times there was always available a sufficient supply of low paid labour to carry out work like painting maintenance whereas today with higher rates of pay and shorter hours of work the onus of maintaining steel and timber structures by means of painting is more than it was, so serious in fact as may actually create some restriction in the use of both steel and timber.

It might have been supposed that the large sums expended in many different countries upon the establishment and maintenance of Building Research Institutions, University Laboratories and the like organisations would have led to a rapid improvement in method and to the solution of problems of this kind, but such does not seem to have occurred. Improvements and solutions when they do appear seem usually to derive in these days, as in earlier times, as the result of the efforts of private traders, firms or individuals, and not as the outcome of the communalised wisdom of State Institutions. The true role of the latter would appear to lie in the

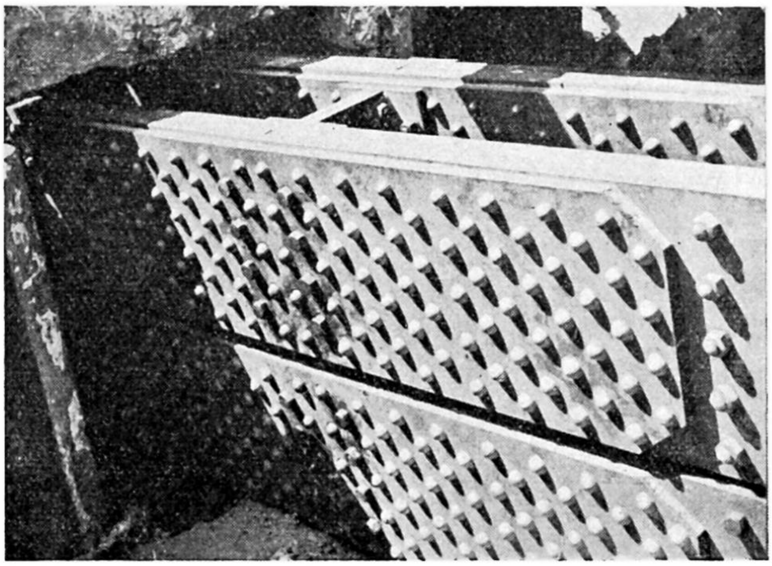

Fig. 7. Steel plate extension of the new eyebar chains which were designed to slide down the anchorage tunnels and to be concreted in solid instead of painted and left exposed as were the underground eyebar extensions in the old structure.

dessemination of knowledge and organisation of improved methods rather than in their origination.

The roadway of the bridge was surfaced with a layer of Trinidad mastic asphalt into the surface of which were rolled clean $\frac{5}{8}$ inch cubical granite chippings applied hot. A special white mastic line $4\frac{1}{2}$ inches wide and in three foot lengths laid at nine foot intervals was embedded in the original asphalt surface to mark the centre of the roadway on the main span.

The asphalt $1\frac{1}{2}$ inches thick was laid on a plain screeded concrete base six inches thick and the concrete base beneath was rather heavily reinforced with a steel mesh and was itself laid directly upon the steel plating of the deck structure. The traffic surface obtained in this way appears to be in almost perfect condition after six years use.

Where the main chains rest upon the piers roller bearings permit of horizontal movement and the ten steel rollers each ten inches in diameter and seven feet long in each of the four main bearings are submerged in an enclosing oil bath from which air is totally excluded so as to prevent water from condensing inside the bath.

The vertical suspenders connecting the deck of the spans to the chains are formed of steel spirally laid wire ropes about $1\frac{1}{4}$ inches in diameter socketed at both ends and each fitted with a turnbuckle tension adjustment. These suspenders have a very clean light appearance and being very flexible are believed to be secure against the deterioration caused by wind vibration.

The reconstruction of Menai Suspension Bridge has naturally given rise from time to time to a number of criticisms and suggestions from engineers, from public bodies and individuals.

It has been pointed out that the high tensile steel eyebar links made up 30 per cent of the total suspended weight in the main span and that a considerable saving in weight, and possibly some saving in cost, could have been effected by the use of wire cables instead of eyebar links, also that cables when wrapped round with protective sheating material are less vulnerable to attack by rust. The reason why the eyebar links were made use of was because these links albeit of different size and arrangement and of different material to that used in the original links were nevertheless similar in conception and appearance to the original design, the character of which it was most earnestly sought to preserve.

Another criticism related to the disposition of the steel lattice stiffening girders which flank to roadway on either side where it traverses the main span of the bridge. The criticism has not been levelled against these stiffening girders based on the aesthetic ground that they spoil the externally viewed appearance of the structure because actually they do not have this effect, but the criticism is that the girders obstruct the view of passengers in motor vehicles crossing the main span. The suggestion has been made that the girders might have been disposed partly or wholly below deck level and it must be admitted that a slight lowering of the girders might have been effected advantageously without trenching seriously upon the navigational headroom, but whether it would have been possible to lower the girders sufficiently to permit unrestricted lateral vision to motorists without detracting from the external appearance is more doubtful.

It has also been suggested that the retention of the two narrow carriage-way openings in the masonry of the two main piers ought to have been avoided and it is actually a fact that the designers prepared a project for substituting a single archway opening of the full roadway width in place of the two arches. The reasons against the adoption of the single archway project were, firstly, that it involved a very expensive rebuilding and widening of the old masonry piers, and, secondly, that it destroyed the rather quaint effect and architectural character of the old roadway viewed from the approaches.

There were others who considered that the reconditioning of the old structure was altogether a mistake and that the old structure should rather have been entirely demolished and replaced by a wide modern bridge supported upon an arch span, and it cannot be denied that the locality lends itself to arch treatment and that a very fine and impressive design, either in steel or in reinforced concrete, could no doubt have been produced on these lines at or near the site of the old suspension bridge. In Britain, however, we prefer not to destroy old institutions unless and until the proposed replacement has established an undeniable superiority which in this case was hardly proved.

There is every indication that the reconstructed bridge can meet all reasonable traffic requirements at the present time and unless there be a further melancholy increase in the density of population, also in the future.

Résumé

Description de la reconstruction du célèbre pont suspendu de Menai, construit en 1826 par Thomas Telford, l'un des ingénieurs les plus remarquables de son époque. Il est à noter que le remplacement du système porteur fut réalisé sans interruption du trafic. Le vieux pont comprenait quatre chaînes en fer forgé; le remplacement des deux chaînes extérieures nécessita l'emploi provisoire de deux câbles porteurs au-dessus des anciennes chaînes jusqu'à la mise en place des nouvelles chaînes. Les chaînes intérieures furent remplacées en second lieu. Le nouveau tablier fut construit à 10 cm en dessous de son niveau définitif puis remonté au fur et à mesure de la démolition de l'ancien tablier. L'auteur décrit les mesures prises pour éviter la rouille des chaînes.

Zusammenfassung

Es wird der Ersatz der berühmten 1826 von Thomas Telford, einem der hervorragendsten Ingenieure seiner Zeit vollendeten Kettenhängebrücke über die Menai-Strasse beschrieben. Bemerkenswert ist, dass dieser Umbau mit vollständigem Ersatz der alten Tragkonstruktion ohne Verkehrsunterbruch durchgeführt wurde. Die alte Brücke besass vier Ketten aus Schmiedeisen; über den beiden äussern Ketten wurden, um diese zu ersetzen, zwei provisorische Drahtkabel verlegt, bis die zwei neuen Ketten eingebaut waren. Nachher konnte auch das innere Kettenpaar entfernt werden. Die neue Fahrbahn wurde um 4′ unter ihrer endgültigen Lage unter der bestehenden Fahrbahn montiert und nach deren Abbruch sukzessive durch Hochschrauben an den Hängern in ihre endgültige Lage gehoben. Besondere Massnahmen für den Rostschutz der neuen Kette werden beschrieben.

Summary

A description is given of the substitute of the famous chain suspension bridge built in 1826 by Thomas Telford, one of the most brilliant engineers of his time.

It is worthy of note that this reconstruction of the old supporting structure was carried out without any interruption of traffic. The old bridge had four chains of wrought iron. Over the two outer chains, and for the replacement of them, two temporary wire cables were laid, until the two new chains were built in. After that, they were able to remove the inner pair of chains. The new track was erected 4′ below its ultimate level, beneath the existing track, and after breaking down the latter it was successively raised by jacks to its suspension rods, into its final position. Particular measures for prevention of rust to the new chain are described.