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Newport Transporter Bridge—an historical perspective

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Exactly 100 years ago French suspension bridge expert Ferdinand Arnodin was commissioned to design the Newport Transporter Bridge in south Wales, one of the world's few surviving aerial ferries. Completed in 1906, the crossing was substantially refurbished in 1995 and is now a grade I listed structure. This paper reviews the historical development of this rare and unusual bridge—which uses both cable-stayed and parabolic suspension systems—and shows that Arnodin was right at the cutting edge of civil engineering development at the beginning of the last century.

> *'A giant, with the grace of Apollo and the strength of Hercules'*
> (Alderman Canning, 12 September 1906)

The Newport Transporter Bridge has been both loved and loathed by many over its 90 year life, but the importance of this unusual structure (Fig. 1) cannot be denied and is recognized by the grade I listed building status conferred on it following its refurbishment.

Essentially an aerial ferry and originally designed to carry two four-wheeled vehicles, each with axle loads of 7·5 t, and a footway load of 3 kN/m², the bridge is today capable of carrying up to six light road vehicles and 120 pedestrians across the river Usk at 15 min. intervals.

Fig. 1. Newport Transporter Bridge following refurbishment

> Tunnels and high-level bridges were rejected for financial reasons, and traditional moving bridges were considered unsuitable because of the obstruction they offered to the free use of the waterway.

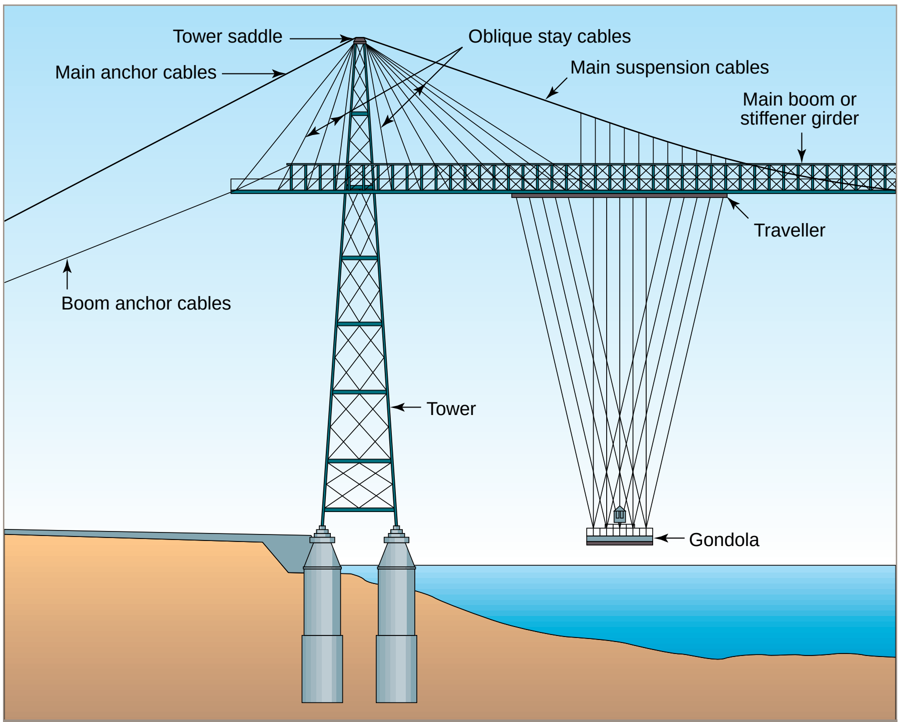

Fig. 2. Newport Transporter Bridge—part elevation

At a maximum speed of 11 km/h, journey time for the 196·6 m crossing is typically about 5 min and operations are only suspended if winds exceed gale force 6 (50 km/h). The height to the underside of the boom is 53·95 m and the towers reach a further 19·65 m above the boom. The ferry or 'gondola' measures 10 m long by 12·2 m wide and is suspended by cables from a high-level travelling frame. This spreads the live load over a 32 m length of the stiffening boom which, in the central portion of the bridge, was designed in such a way so as to distribute the load as evenly as possible to the 16 suspension cables. Closer to the towers, oblique stay cables fan out from the tower top saddles to provide a more direct support, and it is the interaction between these two support systems which characterizes the response of the structure (Fig. 2).

At the towers, both the main suspension cables and the stay cables are attached to roller-mounted saddles. These are in turn held in place by a further 16 main anchor cables connected to masonry anchorages on both sides of the river, each of which have a design weight of over 2200 t.

The towers are of lattice construction, giving an open portal, through which the gondola and traveller can pass (Fig. 3), and the foundations for the towers are on bed rock some 25 m below the river bank, with each pier containing around 550 m^3 of masonry and concrete.

Origins

The town of Newport in south Wales is divided into two parts by the relatively wide, swiftly flowing River Usk, renowned for its exceptionally high tide. Crossed at the northern end of the town from as early as the 12th century, and in stone from 1800, the adequacy of the Town Bridge was forever being questioned. It was widened in 1866 and then partly reconstructed in 1892–3 following the rapid development of the east bank of the river along the then new Corporation Road (Fig. 4).

Between 1869 and 1889, various schemes were proposed for joining the two sides of the river at the southern end of the town but, although a ferry and foot-passenger subway were authorized, the latter was never started because of a lack of finance and the former ended following a number of fatalities on what was undoubtedly an extremely risky crossing.[1]

In 1896 John Lysaght of Wolverhampton announced his intention to build a steelworks in the south west and, so as to attract him to a site on the east bank of the river, proposals for a crossing were again resurrected. Tunnels and high-level bridges were rejected for financial reasons, and traditional moving bridges were considered unsuitable because of the obstruction they offered to the free use of the waterway. The borough engineer of Newport, R. H. Haynes, had however heard of the work of the French engineer Ferdinand Arnodin and his 'aerial ferry', which appeared to meet Newport's needs. This was therefore the proposal and, following a visit to Rouen to inspect a similar Transbordeur designed by Arnodin, the borough elected to proceed without delay.

Parliamentary approval was obtained in 1900; Haynes and Arnodin were appointed joint engineers and detailed design was undertaken during 1901. In 1902 a contract was let to Alfred Thorne of Westminster and the bridge was opened on 12 September 1906 by Viscount Tredegar at a cost of £98,124.

From construction to closure

Construction 1902–1906

Prior to construction, two separate and independent site investigations were carried out, the agreement between which was remarkably good. The anchorages were founded on timber piles driven into the underlying sands and gravels, whereas the tower foundations penetrate the marl and reach a depth of 26·2 m. Because of the tendency for this material to be soft in its upper layers, particularly on the east shore, it was also thought necessary to examine these foundations carefully before the piers were capped.

Caissons were therefore used, excavated by hand under compressed air at up

Fig. 3. Bridge towers and gondola

"Arnodin used 'witness cables', a technique on which he wrote several theses. A small cable of similar material was hung alongside the main cable and its tension adjusted until it assumed the same profile."

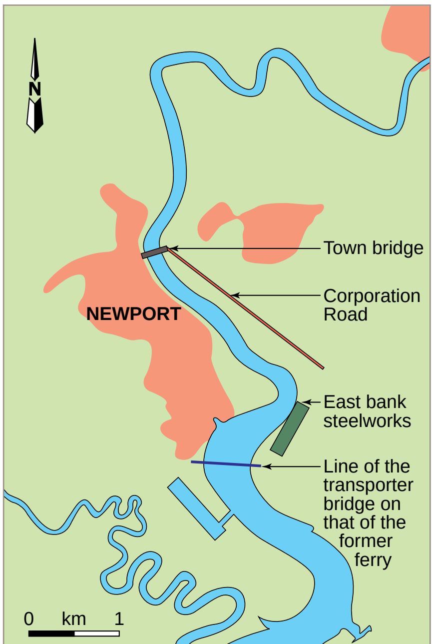

Fig. 4. Newport, circa 1900

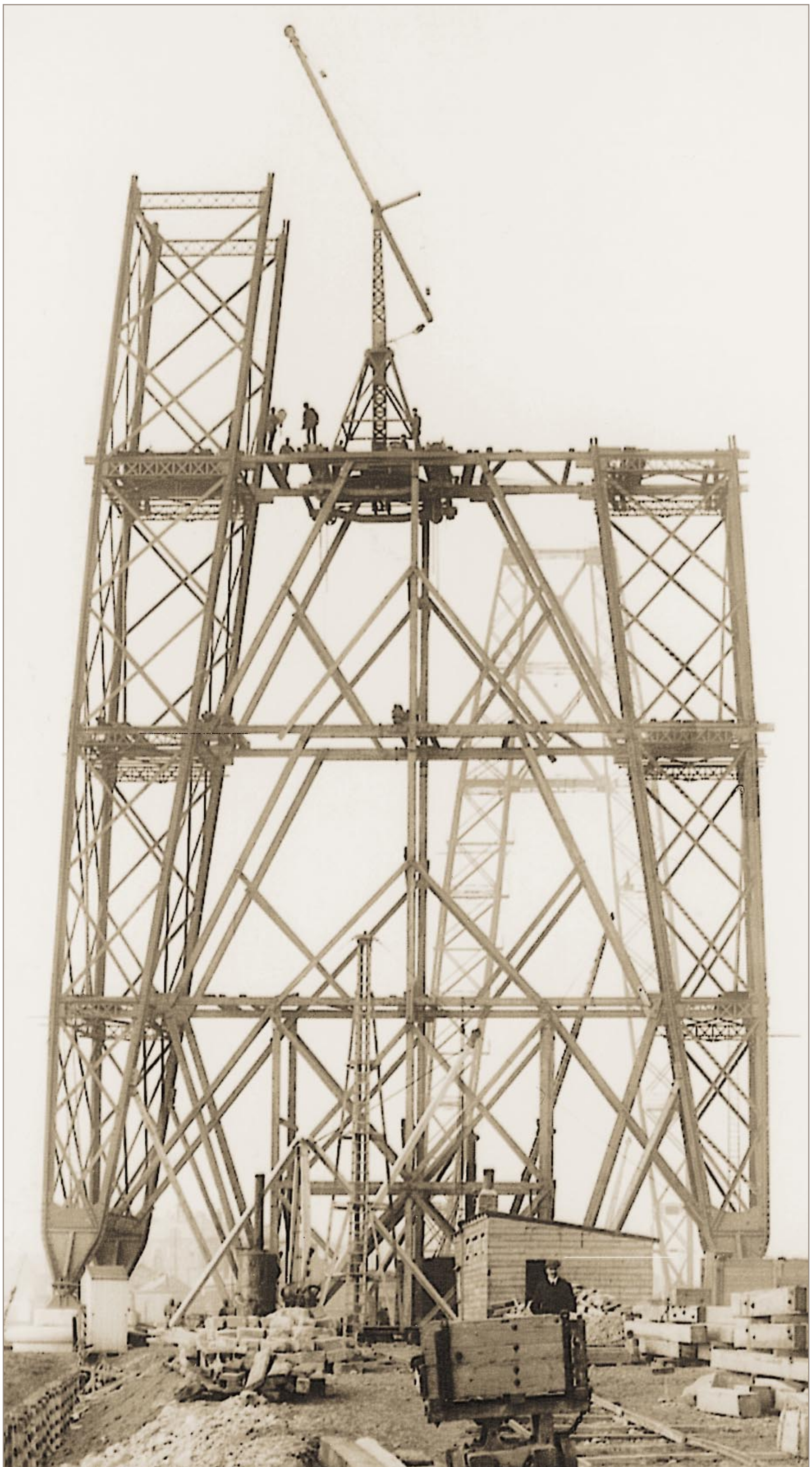

Fig. 5. Tower construction

to 2·5 atmospheres, the working chamber being de-pressurized at the end of each shift to aid sinking of the steel shoe.

The towers were constructed using a considerable amount of temporary bracing and electrically-driven derrick cranes (Fig. 5), the economy of which was proudly boasted when it was noted that

> 'Less than 1,000 units of electricity, costing under £8 10s, were sufficient to lift and place in position the whole of the temporary scaffolding and staging, as well as the permanent steelwork in both towers, a total weight of about 880 tons'.[2]

On completion of the towers, the main and anchor cables were installed between the tower saddles and the anchorages, and the lower part of the boom incorporating the rail–bearing girder was lifted into position piecemeal from barges. The remaining elements of the boom were then simply placed on this lower part so as to establish a uniform dead load profile for the suspension system before assembly of the girder as a whole.

Commissioning August–September 1906

Tests to prove the load carrying capacity of the bridge were carried out on the completed structure between 29 August and 5 September 1906. Supervised by Arnodin, they consisted of applying a series of test loads to the gondola while stresses were measured in the cables. To do this Arnodin used 'witness cables', a technique on which he wrote several theses. A small cable of similar material was hung alongside the main cable and its tension adjusted until it assumed the same profile. This tension was then measured and the stress in the main cable was assumed to be the same as that in the witness cable. No mention is made of the accuracy of this technique, the results simply being recorded as satisfactory despite an apparent standard deviation of as much as 30%.

As well as Haynes and Arnodin, the tests were attended by the contractor Alfred Thorne, his son John (who had supervised the construction) and Arnodin's assistant and son-in-law

> "Although tolls were charged the bridge never paid its way and by 1919 was costing the borough around £6000 a year."

Fig. 6. Main cable wire breakages

Gaston Leineklugel-le-Cocq. On the second day, however, it was reported that

> 'the platform of the bridge weighed in round figures 23 tons more than originally calculated through the necessity of adopting English steel sections.'

The French drawings had called for metric sections, and the nearest equivalent oversize section had been used. It was therefore discussed whether to proceed to the full test load or to reduce it by the 23 tons. Two more quotes then follow

> 'The contractors expressed their opinion that it was not wise to load a structure with a weight superior to that for which it had been designed'
> 'The Engineers, sharing the contractors' opinion ...'.

A wise decision no doubt. What is more, on the following day it was noted that testing up until then had been based on English tons of 1016 kg, whereas the calculations were based on French tonnes of 1000 kg. The problems of communication it would seem were just as bad in 1906 as many believe them to be 90 years on. It was however finally agreed that the structure should be tested with an applied load of 45 tons, which it carried satisfactorily.

Operation 1906–1985

Arnodin was a great believer in maintainable structures and, with the design, produced what amounts to a maintenance manual for the bridge. In this manual he proposed a programme of replacement of parts so that the life of the structure could be extended indefinitely, including the systematic replacement of all cables such that the cost could be spread over time. He acknowledged that this meant initially replacing parts that still had a useful life.

We can only conjecture as to whether, had his advice been taken, there would have been no problem with the structure today, or whether the whole life costs would have been significantly different. Arnodin was 60 when the Newport Transporter Bridge was opened in 1906 and he died in 1924. As the bridge lost money from the beginning his programme was not, and perhaps could not, be followed and certainly a lower standard of maintenance than he expected was applied.

From 1906, the bridge generally operated from dawn to dusk every day, with Sunday morning reserved for routine maintenance. The bridge was manned on a shift system, each shift requiring a driver, conductor and at least one maintenance engineer, all of whom were responsible to the bridge superintendent. By the time of its closure in 1985 the total workforce on the bridge numbered eleven. Although tolls were charged the bridge never paid its way and by 1919 was costing the borough around £6000 a year.

To reduce the cost of collection the tolls were therefore dropped in 1946, although a charge for pedestrians who wished to cross by the high-level walkway and tower stairs was continued until the bridge was closed. As the bridge was classed as a transport facility, the costs of routine maintenance and the occasional repaint have been borne by the local highway authority throughout its life.

The last full repaint before the 1990s refurbishment work was in 1957, when the cables supporting the gondola from the traveller were also replaced. Moving parts needed regular repair and the winding ropes were changed approximately every three years. The main suspension and anchor cables received little attention apart from some paint and an inspection of the anchor bolts in the 1930s.

The need for refurbishment as opposed to maintenance was first addressed in the early 1960s when broken wires in the cables were identified. In 1961 Sir Alfred Pugsley inspected the bridge and commented on the slackening of the main cables as well as recommending replacement of the boom anchor cables, which was eventually undertaken in 1969. Further concern was then expressed in 1979 over the condition of the main suspension cables and the oblique stay cables. The latter were judged to be in such bad condition that their renewal was undertaken immediately.

In 1985 yet more wire breakages were reported (Fig. 6) and non-destructive testing suggested that there may also be problems within the body of the cables. Closure was therefore the only sensible course of action.

Fig. 7. Stiffening girder

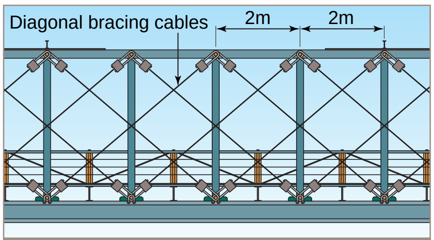

Fig. 8. Part elevation of stiffening girder

Background of suspension and transporter bridges

In order to appreciate the historical significance of the Newport Transporter Bridge it is appropriate to view its design against the background of the development of suspension bridges and transporter bridges during the last century.

Theoretical work on the behaviour of suspension bridges appears to have been first addressed at the end of the 18th century. The problem then was the form and design of the hanging cable or chain, with the decking simply being seen as a beam-like structure suspended from it. Many problems associated with excessive deflections were therefore experienced and even Telford's Menai Bridge suffered from vertical oscillations excited by the wind until it was stiffened by Rendel after damage in 1839.[3,4]

There was also a number of disastrous collapses, most notably in the context of Arnodin's future career, at Angers. Here, on 16 April 1850, two battalions of French troops were crossing the 102 m span of Pont Suspendu de la Basse-Chaine when it failed, sending 487 of them into the River Maine with the loss of 226 lives.[5] Such events led to what was effectively a moratorium on the construction of major suspension bridges in Europe and, although work continued under the direction of Roebling and others throughout America, an improved understanding of such structures was required before they would again really be popular in Europe.[6,7]

To reduce the flexibility which was characteristic of early suspension bridges it was recognized fairly early on that the decks of such structures were required to be stiffened in some way, but that it was not required to such an extent that the cables and suspension system might be dispensed with altogether.[8] There was, however, no real evidence of this until Barlow demonstrated it by a series of model tests and Rankine published his approximate theory for two- and three-hinged stiffening girders in 1858.[9]

The development of suspension bridges in the 19th century, like many of the engineering developments of that time, was therefore due both to engineers who were progressing their knowledge on the basis of this theoretical work and those who relied on their experience developed under the supervision of the pioneers from the early part of the century.

Ferdinand Arnodin was born in 1845 and lived in Chateau Neuf sur Loire, where his father worked for Marc Seguin and his brothers.[10] He studied at Orleans and then Paris, before joining his father as an inspector in the Companie Seguin. Then, in 1872, he set up his own business with a view to reviving suspension bridge construction in France with the development of his Systeme Arnodin. This was first employed on the Pont de Saint Ilpize (70 m main span) in 1879[5] and with it he pioneered the use of spirally wound steel cables arranged so that the central portion of the main span was hung from groups of parabolic cables while the outer portions were supported directly from the towers by oblique stay cables (Fig. 2). This enabled him to feel much more confident about assuming that the main cables were carrying a uniformly distributed load.

In France, it was the work of Navier that laid the foundations for the elastic theory of suspension bridges, and it was in 1886 that the theoretical basis of the system proposed by Arnodin was examined by Professor M. Levy, details of which are set out in his treatise *La Statique Graphique et ses Applications aux Constructions*.[11,12]

Initially, Arnodin used timber for the decks of his structures but later turned to steel, experimenting with various forms. The boom or stiffening girder used at Newport is a double-intersection Whipple truss (Figs 7 and 8). In America it was as early as 1847 that for long-span truss bridges Whipple recognized that a deep truss was required to minimize the material used.[13,14] He was also aware that for the diagonals to be most effective they should be placed at 45° and that if the panel length was too long, then the cost and flexibility of the deck structure would be excessive. To meet all of these criteria he therefore came up with the idea of having the diagonals cross over two panels.

It is uncertain just how much of Whipple's work Arnodin was familiar with, or how much was being developed concurrently in France, but what is clear is that Arnodin was at the forefront of the engineering developments of his time.

It was because his reputation as an expert on suspension bridges that Arnodin was first approached in connection with a transporter bridge. Although the idea of a person-carrying 'basket ferry' operating on the cable-car principle had been in use for many centuries, the first recorded proposal for a modern vehicle carrying structure is that of Charles Smith of Hartlepool. In 1873 he published his proposal to cross the Tees at Middlesbrough in the journal *Engineering*[15] and, although the idea was not immediately taken up, the bridge finally erected at Middlesbrough in 1911 is similar.[16]

By the end of the 19th century the growth in traffic, both on land and water, had generated a need that appeared to be met by the ability of the transporter bridge to provide a low-level vehicular crossing while providing the clearance required for shipping. The period from 1893 to 1911 saw the construction of a considerable number of these structures before traffic demands reached a point well in excess of the essentially limited capacity they provided.[17,18]

The first to be opened was in 1893 at Portugalete in Spain.[19] A leading Spanish architect, Alberto del Palacio, was commissioned in 1885 to provide a crossing of the Nervion to be known as the Puente Vizcaya. Palacio considered

Fig. 9. Boom refurbishment

> The cables were replaced, one at a time, by transferring the load from the cable to be replaced to a jacking assembly and then detensioning it to allow the cable to be removed.

Fig. 10. Vehicles using the bridge

the span large enough to warrant using a suspended structure and so engaged Arnodin as a specialist. Arnodin produced the successful design and, realizing its potential, went on to promote the form, taking out a number of patents. He designed another seven, although the last at Bordeaux was never completed and is believed to have proposed a very long span crossing of the River Seine not far from the current location of the Pont de Normandie.[10,20,21] The Newport Transporter Bridge was the last of his designs to be realized and was one of his largest.

Refurbishment 1991–1995

Another full condition survey of the Newport Transporter Bridge in March 1991 identified the stairs and walkways as being in a critical condition, with the result that access had to be severely restricted and even holding maintenance became virtually impossible. It was therefore recognized that a decision on the future of this much loved, listed, local landmark could be deferred no longer.

A £3 million financial package was therefore assembled, with contributions coming from Gwent County Council, the European Regional Development Fund, Cadw (Welsh Historic Monuments), the Welsh Development Agency and the European Architectural Heritage Fund. Work on phase I, using a bill of rates, began in the summer of 1992. Due to the critical condition of the stairs and access ways, it was these items which were tackled first, as were the towers to ensure that they were in good condition before disturbing the equilibrium of the cable loads. Details of this and subsequent phases of the work are described in full elsewhere.[22]

A fixed-price contract for phase 2 was let in the spring of 1994 and involved replacing all the main anchor and suspension cables and refurbishing the cable anchorages. The cables were replaced, one at a time, by transferring the load from the cable to be replaced to a jacking assembly and then detensioning it to allow the cable to be removed. Replacement cables were installed by reversing this operation. More correctly described as spiral strand, there was evidence that they had originally been protected by using a coal tar/pitch oil mixture, but the amount which remained was minimal. Replacement cables are basically of the same construction but are composed of a higher grade of galvanized wire (1570 N/mm^2, class A zinc coated) protected both internally and externally with Metalcoat, a proprietary protective treat-

> this has generated a tremendous respect for those engineers who were undoubtedly working close to the edge of their engineering knowledge.

ment supplied by the cable manufacturers. Prior to commencing the replacement of the cables, all damaged and broken cable hangers were renewed, as were some of the hanger pins and all the U-bolts connecting the cables to the hanger pins.

Phase 3 included structural steelwork repairs, surface protection, and major refurbishment of the main boom, gondola and motor house. Work to the boom was carried out from an enclosure built on the traveller from which the gondola is normally suspended (Fig. 9), but as extensive refurbishment was also required to the gondola itself, it was removed from its cables and stationed on temporary supports on the west bank. A major overhaul of the electrical and mechanical systems and the renewal of the unusual counterweighted fender system at the east and west gondola docking points were also undertaken in this phase.

A new beginning—1995

The bridge was reopened on the 15 December 1995, operates from 8 a.m. to 6 p.m. Monday to Saturday and from 1 p.m. to 5 p.m. on a Sunday, and since April 1996 there has been a charge of 50p per vehicle (Fig. 10). The re-opening attracted a considerable number of enthusiasts, but its use is never likely to be great and its contribution to the highway network will always be insignificant. Nevertheless, the unusual nature of this historic structure and the difficulties posed by its restoration have led the authors to research the works of Arnodin, and his contemporaries, and this has generated a tremendous respect for those engineers who were undoubtedly working close to the edge of their engineering knowledge. The structure has therefore already served as a teaching tool for many—surely a fitting tribute.

Acknowledgements

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Discussion

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