Sir Ove Arup: The design of bridges

Foreword

Jørgen Nissen*

Ove Arup (1895-1988) once said in a BBC interview that the two structures that had given him most satisfaction were the Highpoint flats in North London (1935) and the Kingsgate footbridge, Durham, Yorkshire (1963), as “both are rather perfect examples of the complete integration of architecture, structure and method of construction”.

But before Kingsgate Ove had designed other bridges. Although they were for real none was built, for reasons unconnected with their design, but he wrote about them. The article that begins overleaf appeared in the Arup London Newsletter, nos 21 and 22, February and April 1964, though it was written a few years earlier so that Kingsgate only comes in with a few final lines, almost as an afterthought.

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It is a fascinating article, well worth studying even now almost 50 years later, and not only by bridge engineers. In it Ove lucidly describes what he meant by what he would later call “total architecture” – which, whatever we call it now, is very much what we are about. He wrote extensively about “total architecture” throughout his career, but usually in the abstract, almost philosophically. Here, uniquely in his writings, he is addressing the subject in specific contexts, with real if unbuilt examples, revealing step-by-step how his thoughts progressed. He says it all at the start, emphasising that he is writing about bridges – “…a more rewarding field for the study of unity between architecture and structure. A bridge is architecture with a clear and simply formulated function. All one has to worry about is the stability, durability, cost, and appearance.” And as for appearance: “there will always remain a number of more or less arbitrary decisions, which have to be made on purely aesthetic or sculptural grounds. I suggest, however, that the best result is obtained if there are very few of such arbitrary decisions to be made, in other words, if decisions affecting proportion and form at the same time make structural and constructional sense”.

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In spite of writing for an audience of architects – or perhaps because of it – he did not offer any thoughts on how these decisions should be taken. He did not need to. He was writing about the engineering. In the earlier Casabella version he had included a small footbridge at Bowring Park, St Johns, Newfoundland, but he almost apologises for it at the end of the paper: “It does not really belong in this series because the method of construction is not in any way out of the ordinary and in fact, the whole object is small and insignificant and presents no structural and constructional difficulties. But the appearance was important – it always should be anyhow. This is therefore a case of satisfying function and structure in a pleasing and neat manner – construction is of lesser importance.”

And when he refers to Kingsgate at the end he adds: “Although appearance was of major importance in this case, the form was largely influenced by structural and constructional considerations”. He did work with the architect Yuzo Mikami on this bridge and it is a great pity that he could not include a full account here and so close the argument.

A few years later, in 1971, Ove was asked by the Institution of Civil Engineers to advise on “how to improve the appearance of engineering structures… if architects are not to muscle in on the Engineer’s domain” (sic)... and “please write a paper which will teach engineers how to design beautiful and efficient structures”. True to character, he wrote a fairly long paper explaining why he could not write such a paper, concluding: “you cannot make rules or principles for what is beautiful, but you may be able to learn by examples of good design – by studying it in statu nascendi”. He does just that in this article.

All four bridges were to be built over water and therefore called for particular engineering expertise. Ove had that expertise; he had been chief designer for contractors specialising in marine structures for nearly 20 years: “We were designers and contractors in one, design and construction were naturally integrated. Now the bulk of designers are mostly unacquainted with the problems on site.”

The construction methods he proposes are complex, but as ever Ove explains them in simple direct language. He is aware of the danger of writing ex post but he writes about it as it is, not leaving out ideas that had to be aborted and only including the successful ones. The construction methods are all quite sophisticated and would have been innovative at the time but feasible. His partner Geoffrey Wood (1911-2007), who had a great deal of experience of working in Africa, did argue that the Ghana bridges required technology not then available in Africa. But Ove insisted that they had been “designed down to the last detail”. So they had, but then maybe the local contractors did not yet have an Ove.

Would we do the same today? We might. But technology has moved on; we now have at our disposal stronger and more durable materials, more precise controls and better methods of analysis and forecasting, more sophisticated construction methods, etc. The limits of what we can now do have expanded. And society has greater expectations; environmental and social issues are significant and Ove’s “more or less arbitrary decisions” now weigh heavier in the balance sheet.

He would have approved. His approach is as relevant now as it ever was, even if the input to the process and therefore the outcomes may be different. It is a pity that these four bridges were never built, but he did at least leave us the best: the delightful Kingsgate bridge and our approach to “holistic design”.

After the article was written, the Ministry of Transport, then England’s main client for bridges, announced its first-ever design competition, for the Calder Bridge in Yorkshire. 110 designs were submitted, five of them from Arup (London Newsletters 19-22, January- May 1964). A team from Povl Ahm’s group including Yuzo Mikami as architect won a special prize. This led directly to the award in 1965 of our first bridge project by the Ministry, the Gateshead Viaduct, and the Highways and Bridge group in London was born. Ove took an interest – and sometimes more than an interest – in many of our subsequent bridges, particularly the Jesmond Dene Bridge in Newcastle, close to his birthplace. The design was almost ready for tender when the project was cancelled following public pressure not to demolish the existing wrought iron Armstrong Bridge built in 1878. This is in fact a striking bridge and is now listed.

* Jørgen Nissen joined Arup in 1962, at first designing shell structures. He was one of the prize-winning Calder Bridge competition team and later in attendance at the birth of the Highways and Bridges group. He was made a director in 1977, a main board director in 1984 and a trustee in 1992. He retired from the board in 1999 and as a trustee in 2004. He is now a consultant to Arup. Throughout his career Jørgen has maintained his interest in bridge design. Of his many bridge projects his favourites are, from the beginning, the Bishopthorpe and Berry Lane bridges in England, in the middle the Kylesku Bridge in Scotland, and at the end the Oresund Bridge between Denmark and Sweden.
The design of bridges

Sir Ove Arup

This article is about the design of bridges, and tries to show why in a number of cases certain designs were chosen, and how they were developed. That most of these bridges will probably never be built is regrettable but does not defeat my main purpose, which is to probe into the nature of architecture by showing how in the case of bridge design the architectural form results mainly from the choice of structure and the method of construction. I say mainly, because there will always remain a number of more or less arbitrary decisions about proportions or detail design which do not greatly affect economy or functional efficiency, and which have to be made on purely aesthetic or sculptural grounds. I suggest, however, that the best result is obtained if there are very few of such arbitrary decisions to be made, in other words, if decisions affecting proportion and form at the same time make structural and constructional sense.

When everything thus "comes naturally", there will be the greatest possible unity between architecture and structure – they will in fact be one and the same thing, which is as it should be. I know that this kind of unity is not always possible, and that it can be perfectly justified to do violence to the structure or to add to the difficulties of construction in the interest of architectural values, but most people agree that such unity is worthwhile striving for. As is well known, what in the end "comes naturally" is the most difficult thing to attain. It has the best chance of emerging if one mind controls the design process. That is why the great bridges are created by engineers with a feeling for form, but thinking mainly in engineering terms.

Unity between architecture and structure, or perhaps rather "Unity" in general, has since Aristotle been valued as a mark of great architecture. However, in the case of buildings filled with technical equipment and housing a multitude of human activities – as for instance a teaching hospital – such unity is difficult to obtain or even define. The needs to be harmonised are multifarious and perhaps even conflicting, and structure anyhow comes rather low on the list of priorities. That is why bridges and large engineering structures seem to me a more rewarding field for the study of architectural unity. That a bridge is a form of architecture will probably be conceded; in fact it can have a very powerful architectural impact.

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This brings me to the crux of my argument, which is that to study architecture – I am talking about bridges, but suspect that it applies to all architecture – one should study it in statu nascendi.* One should be privy to the working of the minds of the creators. Creating architecture – good or bad – consists of making a great number of choices. One should get to know what these choices were, what was rejected as well as what was adopted, and why. If one selected as example designs of acknowledged merit – and there is much more agreement about what is good, once it has been created, than about architectural theory – then one would come nearer to an understanding of how good architecture was produced and one might perhaps even get an inkling of what good architecture was. One would derive a benefit akin to that accruing to the pupil who watches his master at work. It would serve the dual purpose of exploring the nature of good architecture and of teaching the making of it. It would be nice to think that that this was generally conceded and that henceforward we would be spared the tedious descriptions of what the work looked like, how many tons of cement and acres of glass were used, how the contract was administered and so on, and that we instead would witness through information "straight from the horse's mouth", the exciting battle going on in the designer's mind to find the right answer amongst the scores of possible solutions. But I am afraid these are pipe dreams, and that for several very good reasons.

The main reason is this, that it is extremely difficult to get hold of what exactly happens during the largely intuitive process of designing. The material would at any rate have to be edited and drastically reduced. It is also difficult to remember unless immediately recorded. Designers are not authors; they are bent on designing, not on recording. When much later, a reconstruction of the process is attempted, the result is probably a rationalisation more Dichtung than Wahrheit**. And then in order even to attempt to describe the design process to the reader, it is necessary that he should understand the problem as it presents itself to the designer. The latter will have spent some time and effort getting acquainted with the problem as it relates to the site and other conditions, and only when it has been thoroughly absorbed into his system will he be able to survey the field of three-dimensional possibilities in his head.

* "In its original form".  **From Goethe's autobiography Aus meinem Leben: Dichtung und Wahrheit ("From my Life: Poetry and Truth").
Considering the method of construction, however, it was very soon found that to provide a temporary staging for the whole bridge would be far too expensive. The best method seemed to be to drive piles from a floating plant for the construction of the piers and then cantilever both ways from these piers, delivering all the materials or precast units to these piers by barge (Fig 1). This would not be easy, considering the depth of water and the skewness of the pier; at the least it would require very heavy and expensive piers. It would obviously facilitate matters enormously if each of the two piers was replaced by two narrow piers relatively close together (Fig 2). These two twin piers would then form natural harbours for supplies by barge and would, when connected, form a stable base from which to cantilever in both directions. Further, it would then be possible to arrange floating spans connecting the bridge with the shore, thus diminishing the height of construction over land, and solving the problem of temperature changes.

However, there was still the skewness to consider. The narrow piers would have to follow the direction of the current, forming an angle of 60˚ with the centreline of the bridge (Fig 3). If we, in order to preserve the symmetry and the logic of the system, were to cut the floating spans on the skew as well (Fig 4), all sorts of problems would arise. The system would work if the bridge consisted of parallel strips, but that would be wildly uneconomic because each

Perth Narrows Bridge

The first design, for a bridge over the Narrows at Perth, Australia, never got further than an early sketch stage, but the fundamental decisions about how to build the bridge had been taken and, as will be seen, these decisions, logically applied, resulted in a bridge of a somewhat unusual form.

The task, as presented to us by the clients at the time, was to build a low road bridge 92ft wide and 1300ft long – of which 900ft were over water – between the mainland and a large island. The special feature of this bridge was its skewness – the line of the bridge formed an angle of 60˚ with the channel it had to span, and consequently with the current. The clients at one time expressed the hope of spanning the bridge in one span, but that could only be done by having the main structure above road level – suspension bridge – and that was not considered desirable for other reasons – landscape. The best that could be hoped for with the construction height available was three spans: a long middle span with two cantilevers and a floating span, and two shore spans.
It will be seen that the elevation is not symmetrical about the centre of the bridge but follows a rhythmic but syncopated movement from left to right of deep dip, low dip, deep dip, low dip. Seen from the other side, the movement is again the same from left to right, not from right to left, as one would expect. A perspective is shown in Fig 8.

This is as far as we got.

There were of course hundreds of questions left to consider – whether to construct the bridge in situ as a hollow box section or a ribbed construction, of precast and prestressed units – probable – and the size and shape of units, the treatment of the joint between bridge and pier, cantilevered footpaths, if any, railings, lighting, etc, all of which would have influenced the architecture in varying degrees, but none as much as the basic design decisions described above, taken on purely structural and constructional grounds, which really determined the architectural character of the bridge for better or worse. I must confess I felt a bit doubtful myself, when I had drawn an outline of the elevation resulting from my structural thinking, and an architect friend, who came in and saw the thing, thought it looked awful. But after a few days of looking at it I came to like it more and more, and I was very grateful for the skewness of the bridge that made it possible and even sensible to produce something with a distinct character, different from the ordinary run of bridges. But that feeling may of course be peculiar to me.

5.

6.

7.

The elevation of the bridge will then look like Fig 6, with short cantilevers AC and long cantilevers BE, the latter following an identical curve to AC on the stretch BD and then dipping down further to E. From E to C, that is between the twin piers, the soffit is formed by two curves, each being symmetrical to the corresponding cantilever curve and meeting in F. The resulting contour lines of the soffit are shown in Fig 7. The soffit in the area between the piers will then consist of a vault with horizontal lines running parallel to F - F, a direction still more skew than the piers.

8.
Bridge in Scotland – over the Tay

The next sketch design is for a bridge in Scotland (Figs 9-11). The bridge is about 8070ft long, of which 5510ft is over not very deep water. The roadway is about 110ft above high water level, because the roads on both sides of the firth are at that level, and because shipping requires a free height of 82ft. There are 11 piers in the water, spaced 475ft apart.

The main consideration in this case was to keep the cost down. It was thought that the height of the bridge above water level would make this very difficult, but in the proposed design this difficulty has been largely overcome by extracting the greatest possible advantage from this extra height. Greater height means of course that there is more room available for the supporting structure, which makes it possible to employ arches, deep cantilevers, or raking struts thus reducing moments, increasing spans, and reducing the number of supports. But the fact remains that more structural material has to be used to raise the road level to this height, and more important still, work at this height and far out over the sea is very expensive.

The aim of the designer must therefore be to reduce this extra material to a minimum, and to avoid work in situ.

In this case conditions for prefabrication were favourable, insofar as the length and uniformity of the bridge involved a lot of repetition. This would make it economically possible to invest a fair amount of capital in specially designed floating cranes and other plant that could be used for sinking cylinders and landing prefabricated units. There was also available, near the site, a rather underemployed shipyard, which could be used for constructing and launching floating units, if structural steel were used for the bridge.

These considerations led to a form of cantilever-construction almost on the lines of the old Forth Bridge, with floating spans between balancing cantilevers supported on central piers. Arches were considered, but rejected because of the one-sided thrust they would exert on the piers during construction, but mainly because the chosen system seemed to offer greater opportunities for almost complete shore-fabrication.

The first problem was to establish stable bases from which to work without going to the expense of constructing heavy solid piers. This led to open piers, consisting of four cylinders placed at the corners of an 18.5m square, and connected by precast concrete bracing, as roughly indicated on Fig 10(a) (next page). The lower “ring” would be cast or assembled at the top and lowered down, the diagonal bracing lowered into pockets at the connection of the piers with the lower ring, and fixed by pouring concrete in the pockets under water, etc – enough to say here that it would be possible, at a reasonable cost in view of the repetition, to provide 18.5m wide bases able to resist forces and moments in all directions, and therefore each able to support a portion of the bridge independently of the other piers.

The next problem was then to use the available height to spread out the support as much as possible in the most economical way, and the method chosen, with four A-frames that together with the deck provide maximum stability with a minimum of material and minimum wind resistance, could hardly be improved upon.

Having established a desirable static system, there still remained the question of how to build it and what materials to use. I am not suggesting that this happened exactly in that order. When you are designing, the mind is let loose amongst a lot of possible combinations of statical systems, methods of construction, until an idea emerges for closer examination. Anyhow the idea emerged, based on the preferred statical system, to form the bridge of floating units - which I will call “barges” - which could be completely finished with paving, lighting, railings, etc, on shore, and which could be lifted up to their final position by making use of the supporting structure of A-frames. If the main A-frames supporting the barges are hinged top and bottom by simple open hinges and the barges are pulled towards each other, they will automatically rise from the water at high tide to the required level, and can be secured to the other A-frames which provide the longitudinal stability (Fig 9).

It would take too long to describe in detail the various problems involved in this operation, but the forces were all calculated and the necessary plant designed in principle. The winches and hoisting gears were to be fixed to a temporary steel frame formed as a pyramid, which from a couple of barges could be transferred to each pier in turn. A floating crane would transfer the A-frames to the piers and the bridge barges would be guided towards each side of the pier by temporary guides fixed to the piers.

It is obvious that the use of structural steel for the bridge would favour these operations, as the weight of barges, etc, would be much less. There was actually no time to investigate a prestressed concrete scheme as well, but had it been decided to proceed with the construction of the bridge, this should have been done. It would have reduced maintenance problems - but actually these were not too bad in the case of the steel structure, because it was to be constructed of hollow units presenting a smooth surface to the outside.

Actually, later a probably somewhat better way to erect the bridge was thought of. According to this the lifting up of the barges from the sea would take place at the dockyard, and the whole section of bridge resting on one pier, including A-frames but excluding the floating spans, would be brought to the bridge pier on two large barges or ships.
This was done in the simplest possible way (Fig 9). The concrete approach was designed as a completely plain hollow slab, on plain walls which were spaced closer together as the height became less. This is logical enough – although it may not lend itself so easily to prefabrication – but at any rate I think it is justified aesthetically. This slab was bent down at an angle to form the front leg of an A-frame at the junction with the bridge proper, which automatically enabled the bridge to resist a pull from the “barge” at this point.

This account is of necessity very brief, dealing only with the basic idea. In fact, all the many detail problems were only solved to the extent required to make sure that the scheme was workable and economic.

total weight about 900 tons. This would mean that the steel pyramid including hoisting gear could remain in one position all the time and would not have to be transferred from pier to pier. The bridge section would be brought to the pier at high tide and guided so that when the tide went out it would come to rest on the pier.

The “floating span” would of course also be floated out and lifted up in position.

How to design the railing is always a most perplexing problem for the engineer – and I suppose the architect too – because of the danger of its becoming a mere additional ornament not logically or organically part of the bridge. In this case this problem was solved very neatly and naturally by making the railing part of the hull of the barge (Fig 11), thus assisting the floating and acting as a useful windbreak protecting cars and pedestrians.

Also in this case, the “architecture” is essentially dominated by the structural and constructional idea. What remains is to look after the main proportions, the detailing of the structural members and their joints, and the design of the two land approaches at each end.

As far as the main proportions go, these are actually largely dictated by the need to strike a reasonable balance between the forces in the members and the distance between piers, but this balance is in my experience arrived at more by eye than by calculation. In other words what looks right, both structurally and aesthetically, is likely to make structural sense. But of course such judgments must be checked by calculation.

The two land approaches were difficult to deal with, because these portions of the bridge, which would best be built in concrete, would be entirely different in character, and the junction between the steel structure and the concrete abutments was obviously of the greatest importance from an aesthetic point of view – in fact it is on points such as these that so many bridges go wrong. To obtain a satisfactory transition it seemed best to complete the “arch” in steel (Fig 9). This meant, however, that the last “barge” and A-frame would not balance against another barge, as in the case of the 11 centre piers, and it would be necessary to provide a counter-thrust to take the reaction from the cantilevered “barge”.

10. Stages in the bridge erection.
The need to avoid staging suggested cantilevering out from the two shores. The normal method of cantilevering by adding small sections and tying them back did seem to be rather complicated, making high demands on constant good workmanship to ensure that the many joints would not be sources of weakness. I did not feel certain that this procedure would in the given circumstances yield the high quality that I was after. So I was groping for an idea on the lines of the previous bridge with the “barges” constructed in prestressed concrete instead of steel, but in this case there was not the same height to play with, and there were no two balancing barges. The structural system could easily enough be envisaged, with inclined struts supporting the “barges” in the centre, so as to reach as far out into the river as possible and an A-frame with a counterweight at each shore end (Fig 12) but how to get the “barge” into position? Sliding them out seemed a possible solution, and that is in fact the solution which was finally adopted, but it proved to be much more difficult than at first realised, and the design went through many stages before reaching its final form. It would be very instructive to retrace the many alterations made and the reasons for making them, because it would show very clearly that aesthetic conceptions must not be imposed at a too early stage; the final form cannot be determined before the structural and constructional requirements have been met in a direct, clear, and simple manner. But it would require a book rather than a short article to bring that out.

The first scheme (Figs 12-14) was completed in outline before the structural problems had been properly resolved, because the model was needed for presentation to the clients. Visually, this scheme is satisfactory enough, and brings out very clearly the main components of the scheme: the cradle along which the “barges” are slid out, the counterweight, and the suspended span in the centre. And this appearance of the bridge could have been kept, the details were actually solved, but the solution was too complicated to be really satisfactory. In this scheme, the inclined forward strut was permanently anchored back to the A-frame and counterweight, and afterwards the three barges on each side were slid out, using the ties as tracks. Naturally the ties would have to be supported during the sliding, and that

Ankobra bridge, Western Ghana
The next bridge on the list is the Ankobra bridge in Western Ghana, over the river Ankobra, close to the sea. This bridge has been designed down to the last detail, including the temporary staging and apparatus for sliding the main units into position, and tenders have been received, but owing to lack of funds the bridge has not yet been built and it now looks as if it never will be.

The conditions we have to deal with here are: a road, 24ft wide, with two footpaths of 6ft each, to be carried over about 302ft of river, giving a clearance at the centre of about 24ft over high water. Subsoil is poor, until rock is reached 90ft down on one side, and about 33ft down on the other. To provide temporary staging in the river would be expensive and should if possible be avoided.

There is often a salt spray from the sea nearby, and this salt, humid, and warm atmosphere would corrode steel, aluminium, and even concrete, unless the latter were in fairly smooth, solid sections of high-grade concrete, preferably compressed to avoid cracks. So prestressed concrete was the obvious material to use, especially as it would not be justified to rely on proper maintenance in this fairly remote spot.

The desire to produce a bridge which would withstand the ravages of time without maintenance was therefore a major factor in the design. Another was the desirability of avoiding staging in the river. And not least, there was the expressed wish of the government that this should be a beautiful and impressive bridge worthy of the new era in Ghana. A design on the lines of many of the Public Works Department bridges with frequent pile trestles supporting steel or concrete girders was definitely not wanted.
Here the connection between the inclined strut and the “barge” is direct and simple, and the “barge” itself acts as the tie – and is anchored back to the counterweight at the back by prestressing cables. This means that there is no redundancy of steel, and the statical system is clear. On three rows of piles on each side of the river, a reinforced concrete slab and an A-frame are erected, with a retaining structure at the end which is filled up with boulders and concrete to form a counterweight sufficiently heavy to ensure a reasonable distribution of weight over the pile groups under all conditions of loading. The retaining walls also form a finish to the embankments on both sides but are independent of any settlements of these embankments. How this is achieved will be apparent from Fig 16.

These two structures can absorb the forces transferred to them by the inclined strut and the anchorage of the “barge”. But this means that the temporary loads induced by the sliding of the “barges”, which incidentally have been reduced to two on each side, will have to be taken up by a temporary structure, made of structural steel. When this temporary structure was gone into, it was found that the slots required to accommodate it in the A-frame weakened the latter to such a degree that it could not act as the anchorage for the “barges” without considerable complications of
So in the end I went back to basic requirements. I had been considering various combinations of concrete and hardwood – the only two materials which might do the job – but now on the advice of my West African collaborators I ruled out timber and decided to stick to prestressed precast concrete. This meant the units had to be long, preferably able to be produced by the long bench method. Further, I decided against bolts or joints in situ, which would be liable to deteriorate. The units would have to be placed in prepared holes and fitted together so that they stayed put by their own weight – each unit being completely self-contained, and with rounded corners. This led to the design shown on Fig 22 (next page) which can be produced from three forms. The design now at least has a raison d’être.

The temporary steel structure used for sliding is shown in Fig 19. In order to save steel, the 3ft high joists used for the sliding are later used in the permanent structure for the suspended centre span. The “barges” are built on formwork supported on this temporary structure, and when completed, the formwork and supports have been removed, rest on a 10ft cradle that slides on the joists on ball-bearing tracks. Calculations showed that the friction could by this arrangement easily be reduced to a figure that would allow the barges to slide down the ramp by their own weight. All that would be required in the way of plant was a hand winch with a brake arrangement to control the movement. The inclined strut is also suspended from the temporary steel structure in a slightly lower position (Fig 20), and after the sliding of the barge has been completed, this strut is pivoted into position and Freyssinet flatjacks are then placed between the strut and the “barges”. When the “barges” have been anchored and the flatjacks blown up, the weight of the “barge” is taken by the strut and the temporary steel structure is released (Fig 21).

This explanation is, of course, far from complete but will have to suffice here.

The design of the railings proved to be a very difficult job. Dozens of designs were drawn up, and several of them might have served, but none of them produced in me the feeling of rightness. This was a purely architectural matter, and my architectural training or ability was obviously no match for my critical sense. On one occasion I showed about 20 of these designs to an audience of architects during a lecture, and asked them for their criticisms and advice. The result was disappointing. Although some were able to argue fairly convincingly in favour of one design or another, the favours were more or less evenly distributed over the various designs.

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Again, it is desirable to have as few obstructions as possible between the outer embankments, because the river can rise right to the top of these embankments and the current may be very swift. For the same reason it would obviously be cheaper to avoid staging in the river.

The design should be clear from Fig 23.

In cross-section the bridge consists of two 12ft high hollow prestressed concrete girders, with steel joists stuck through holes in the girders at 2ft centres to support the roadway and the cantilevered footways. These are timber decking with a covering of asphalt.

There are only four main piers, two on each side, the span between the centre piers, where practically all the loads are concentrated, being 581ft. On these piers A-frames of hollow steel construction support two main cables which run from the outer piers or counterweights at the back over the A-frame and then to the outer end of each concrete girder. These cables in turn support a second set of cables as indicated. Between these two cantilever systems a centre span of aluminium construction is suspended.

The girders are, to begin with, interrupted at the main pier and at the point where the secondary cables support the girders. This makes the system statically determined for the dead load and when the cables have been stressed – by jacks under the main counterweights – and the length of cable adjusted to ensure that the different portions of concrete girders form a straight line. Then the joists

The Black Volta Bridge, Ghana

The next scheme, so far only a sketch design, is also for a bridge in Ghana, but in the northern part of the country where the atmosphere is dry, and where steel and aluminium are possible materials to use. The bridge is to span the Black Volta, which is approximately 505ft wide at this point, but runs in a valley 984ft wide, which is flooded for three months of the year. The profile is as indicated in Fig 23, with a 36ft drop from the outer embankments to the flat valley and further 25ft embankments down to the river, when it is not in flood.
The guiding principle has been economy of construction, and this has certainly been achieved in this case, if one adheres to the decision that it is undesirable to have supports in the river.

The principle of constructing the two halves of the bridge on the banks of the river and then turning them out would in this case cut the cost of the bridge considerably as it would make construction independent of the yearly floods. If the four piers were built in one season, and the steel A-frames, formwork and cables were brought to the site, then in the next nine months’ season the prestressed concrete girders and the supporting cables could be constructed, and probably the decks finished as well, because this is only a matter of sticking the joists through the holes in the concrete girders and laying the hardwood roadway.

Conditions here are therefore almost ideal for this method, but there must be many cases where it could be used with advantage, and I am surprised that I have never heard of it being used before. It is at present being used for a footbridge over the river at Durham Cathedral, one of the most beautiful settings in England. Fig 26 shows one half of the bridge nearing completion along the river bank. Although appearance was of major importance in this case, the form was largely influenced by structural and constructional considerations.

Credits
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