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8075 DISCUSSION

The strengthening of Hammersmith Bridge

B. G. R. HOLLOWAY & H. J. WADSWORTH

Mr Holloway

The actual strengthening scheme adopted was only conceived after a number of early proposals had been developed, discussed with the GLC at numerous meetings and constructively criticized. At these same meetings a number of useful suggestions were made by the GLC engineers, among them the proposal to use a temporary footway, which was the key to the adopted scheme.

62. I should like to enlarge upon the effect of the interaction of all parts of the bridge in providing the enhancement of the stiffening effect, although such enhancement was of course ignored in the design of the reconstructed stiffening girders. The lattice balustrades contributed significantly to the overall stiffness; as a result the rivets through the joints in the top flanges failed from time to time. Since the balustrades, now repaired, have been retained, it is essential that the new stiffening girders should be adequate to prevent this failure recurring. The stiffness of the new girders is about twice that of the old.

63. The contract documents and drawings included a fairly detailed erection scheme, but which, if accepted by the contractor, would in no way relieve him of his responsibility. This procedure ensures that tenders are on a common basis, and helps in pricing accurately.

Mr Wadsworth

The make-up of the stiffening girder presented a problem in welding, because of the three plies of the vertical stalk. Trial welds subjected to ultrasonic examination showed signs of cracking propagating from the ends of the interfaces of the plies. It was therefore necessary, before commencing the main weld, to weld up the interfaces so that the weld preparation presented a solid surface rather than a surface in three plies.

65. In the Paper the back-up trough of the expansion joint is shown as being filled with mastic asphalt, but in the event, we were a little concerned about the use of mastic because of the difficulty of removing it for maintenance. After trying alternatives we decided that the best solution was to fill most of the trough with a fine cold asphalt after having primed it with bitumen, and to put a mastic asphalt topping on it to provide a hard surface for the traffic. This seems to have been satisfactory.

66. When the old tower top rollers were lifted out, it was interesting to see they had signs of line contact along them, and had not flattened out as expected. Had we known this, it might have been possible to free the rollers by water blasting.

Mr T. L. G. Deuce, Greater London Council

The whole project was characterized by attention to details in every aspect of the work. For instance not only were new glass fibre bases cast for the replica lamp columns but

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even replica plastic rosettes were made for the cross-links of the lattice girders on the footbridge.

68. The bridge has been given a new lease of life at a fraction of the cost of a replacement bridge, and will now be able to play an important part as one of London's river crossings for many years to come. It is the second Thames bridge to undergo major repairs in recent years the other being the Albert Bridge. Both had wood blocks as a running surface underneath a thin coating of asphalt before they were repaired. Rather than providing a protective wearing surface, these wood blocks contributed to the deterioration of both decks by allowing water to pass through to the underlying timber, and then repeatedly punching the wet timber as traffic passed over them.

69. So far only one panel of the Acme panelling put down on Albert Bridge in 1972 has had to be replaced. There have been some repairs of minor mechanical damage, but otherwise there is no sign of deterioration of the plywood and I confidently expect a life of the order of 15 years. Hammersmith Bridge will carry heavier traffic but a life of a similar order is hoped for. On Hammersmith Bridge it was necessary to prefabricate the deck timbers into panels in order to reduce traffic closures to a minimum. It is preferable, however, to build the decks in situ as the resulting monolithic construction provides the plywood panels with a marginally better foundation.

70. I should like to take up the point on the interactive stiffness of various components of a bridge. Before repair, Albert Bridge had no lateral bracing system and relied entirely on the longitudinal deck timbers to provide lateral stiffening. A bracing system was therefore introduced as part of the strengthening works. Loading tests on the bridge during the course of the work showed that the vertical stiffening effect of the deck altered the behaviour of the bridge much more than would have been expected of a timber deck with a total construction depth of 14 in.

71. Glass fibre has been used for replica repair work on other Thames bridges. Some 300 covings on Battersea Bridge have been replaced in this material by the GLC staff who have achieved a saving of £100 000 over the cost of cast iron equivalents.

Mr J. E. G. Palmer, Consultant, Rendel, Palmer and Tritton

In §§ 18 and 21 there are references to traffic. Of London's bridges, 15 are under the control of the GLC, from Kingston in the west to Waterloo Bridge in the east. The total traffic in the summer of 1976 carried by those 15 bridges averaged nearly 600 000 vehicles/24 h. Putney Bridge carried 60 000 and Albert Bridge under 20 000; over Hammersmith there were about 30 000 vehicles/24 h.

73. What would be the cost of doubling the width of Hammersmith Bridge and improving its approaches so that this bridge could handle 75 000 vehicles/24 h? Secondly, would the Authors consider making a complete survey of all 15 GLC bridges across the Thames so that each one could carry its proper share of the 600 000 vehicles/24 h?

Mr D. Dennington, Bullen and Partners

While involved in drafting the terms of reference (§ 18), I left the GLC before the work started, though I well remember the bridge. It was an unnerving experience to sit inside the casing listening to the squeaking of the wrought iron tower as the loose rivets accommodated the movement which the rollers would not. I am pleased to see that access is provided at a more convenient level into the casing.

75. I also remember the snapping of a hanger in 1967. I believe some of the short hangers were replaced and I am interested in how tempted the Authors were to replace them throughout, in view of the necking. Did any particular problem occur with the short spans, or were these minor, once the problem of the main span was solved?

76. The Paper mentions the loading on the bridge, the calculations of stress, and the strain measurements which were conducted. Mr Palmer mentioned traffic loading on bridges. I am doubtful whether engineers know enough about the true loading on

bridges that occurs during the general period of their life or throughout the day. Albert Bridge has been mentioned. That had similar characteristics and during one inquiry there was some attempt to show that I was incompetent and negligent. At one time the GLC was interested in the traffic loading on that bridge. In the morning enough traffic is held up by the lights at the north end to identify all the vehicles on the bridge at that time. The resulting calculation showed that on the carriageway alone the average loading was only 14 lb/sq. ft, which was surprising.

77. The bridge was particularly unfortunate with the gradients of the roadways, especially at the towers, where it was level. This produced a switchback effect, particularly when buses going south left that small bit of flat and bounced down on to the short span. The long hangers on that side were a great cause of concern because of this.

78. The work described in the Paper called for much engineering judgement and the Authors are to be congratulated.

Mr J. M. Fenton, formerly Bridge Engineer, East Indian Railways

Rendel, Palmer and Tritton have specialized in the past in awkward jobs. One with which I was associated was the regirdering, under traffic, of the Dufferin Bridge—later renamed the Malaviya Bridge—across the River Ganges at Benares. One of the first steel bridges, constructed in the early 1880s, it consisted of seven spans of 356 ft and nine approach spans of 111 ft, and carried a single broad-gauge railway track. The regirdered bridge, undertaken immediately after the end of World War II, carries two broad-gauge tracks with an overhead roadway.

80. Following the dynamiting of the 360 ft span of the Lower Ganges Bridge at Sara the crippled span, with a completely severed lower chord, stayed in position, supported by the torsional resistance of the remaining chords and the wind bracing. In situ repairs at low cost were possible and the 'generous' design by Rendel, Palmer and Tritton was amply justified. The Willingdon Road–Rail Bridge, a little upstream of Calcutta, also had 'generous' treatment, and was criticized by some as unnecessarily heavy. In these turbulent days there is something to be said for designs not wholly angled to the competitive forces in play when they go to tender.

Mr E. L. Barron, Peter Fraenkel and Partners

I was interested to read that waterblasting had been used on the mild steel chains. I wanted to try this in 1972 on a bridge over a river, but was unable to do so because the river authority objected to the lead based paint falling into the river.

82. I would like to know how the standard of substrate cleanliness was specified, if abrasives were included in the water, and if the drying was by flame or solvent. Would the Authors consider waterblasting advantageous for new structural steelwork, and would they use other than red lead primer?

Mr W. I. J. Price, Transport and Road Research Laboratory

On the question of the contribution of secondary members to the stiffness of primary members, the universal law seems to be that bridges, or any other complex structures, hardly ever behave as the relatively simple idealization that designers envisage. Invariably there are various degrees of redundancy, and interaction both within and between components, even when the form of the structure itself is statically determinate. This is perhaps no bad thing in terms of the contribution of the secondary members to the primary strength, and hence to enhancing the factor of safety of main elements. Perhaps the danger to be recognized in design is the risk of overloading a secondary member which might lead to some unfortunate local failure. In the case of Hammersmith, it was apparent that the parapet upper chord was sharing the load with the stiffening girder. In past field trials, we at the Transport and Road Research Laboratory have come across several examples where secondary behaviour tends to alter the general mode of the stress and strain regime in primary members. A common example is the effect of the deflexion of a supporting member on the bridge deck.

84. I applaud the provision by the designers of manuals for the future maintenance and inspection of the bridge. This practice should be followed more generally in civil engineering to enhance service performance and to minimize problems that arise when repair or restoration has to be done. Having been involved in some inspections, I know how difficult it can be to get information relating to the actual structure as built. It is sometimes not possible to find working drawings, and very rarely are the designer's thoughts about the intended performance transmitted. The idea might be extended with advantage to record those features of the construction work, as well as of the design, which might be relevant to future maintenance.

85. I wonder how much the inspections of major structures of this type cost and how comprehensive they can be? Even though the inspections in this case were thorough, nevertheless the last one did not spot the trouble with the balustrade underneath the footpath. This highlights the difficulty of detecting deterioration in hidden components without dismantling parts of the structure to a degree which would only be acceptable in reconstruction work. Another example is given by the links of the anchorage chains and I wondered how well the internal links could be inspected, especially around the holes for the connecting pins? It was a very small stress corrosion crack, 2 mm long, in that location which precipitated the catastrophic collapse of the Point Pleasant Bridge in West Virginia.

86. Did the Authors consider a steel orthotropic deck as a possible alternative to timber? This might have given scope for increasing the live load capacity of the bridge, as I believe was the case with Marlow Bridge.

87. It is certainly interesting to see how long two versions of Hammersmith Bridge have lasted; almost 60 years for the Tierney Clark design and over 80 years for the Bazalgette design, without any major repairs. They might serve as examples, whereby, with hindsight, the overall economics of bridges could be worked out, taking account of the total life cycle cost. With reference to § 52 and a particular aspect of durability, how were the lanterns made 'vandal resistant'?

The Chairman (Mr P. F. Mead)

I have been concerned with both London Bridge and Albert Bridge. Regarding the latter, I congratulate the GLC on their courage in surfacing it with ply plus a skim of epoxy and a dusting of grit. I am delighted to hear that it has lasted so well.

89. London Bridge was different in that it involved the complete demolition and rebuilding in four consecutive longitudinal slices. The contractor was required to do a large amount of critical temporary works design and had overlapping responsibility with the engineer's permanent works design, particularly on such items as deflexion. Was there a similar overlap of design responsibility at Hammersmith?

90. There were also problems with navigational clearances which meant all building and demolition had to be supported from above. Were there similar problems of clearance with the three cradles at Hammersmith, and did this restrict the programme?

91. I agree with the Authors about the difficulties of dealing with statutory authorities. At London Bridge we were told some time after the start that the GPO required 6 months to divert their cables, all on the critical path. It took a lot of engineering thought and continuous pressure to reduce this to 2 months in practice.

92. A phrase I found of great significance occurs in § 33: 'It will be seen therefore that the final simple and satisfactory solution was arrived at only after a considerable period of progressive development.' That, I think, is the essence of this sort of engineering. One has to look at a problem, try to understand it, work out a solution, discuss it with people concerned, revise ideas and have another go. It suggests a motto for our younger engineers: 'Flashes of brilliance only come after a lot of hard polishing.'

Mr A. G. Osborne, Carter Horseley Engineers Ltd

As Chief Engineer to the Contractor during the course of the work, I have two comments to make.

94. With hindsight, a form of steel battle deck as used on many recent suspension bridges, and indeed for the earlier rebuild of Marlow Bridge, could well have been employed, instead of merely replacing the existing heavy deck timbers with some 16 000 cu. ft of jarrah. This method would probably have been cheaper, lighter and less disruptive in installation. Was this considered, and if so why was it not adopted?

95. Secondly, referring to the figures quoted in § 58, the contract was tendered in May 1973 on the basis of net increases on certain items only being recoverable. The effect of the unforseen rapid rise in inflation which followed the oil crisis, coupled with the financial failure (also due to inflation) of the principal designated sub-contractor for the timber deck and other non-steelwork items unfortunately resulted in costs in excess of the quoted figure of about £250 000 being incurred.

Mr S. McConnel, Fellow (retired)

To all interested in the development of suspension bridges this Paper dealing with the replacement of stiffening girders is of outstanding interest. Both Telford and Capt. S. Brown RN appear to have been unconvinced as to their necessity, but Marc Brunel in his short-lived Isle de Bourbon (Reunion) bridges of 1822 provided underdeck catenary chains to deal with hurricane conditions.

97. Tierney Clark in his original Hammersmith Bridge made a crude but positive move in the right direction in 1827, and illustrations of Navier's Pont des Invalides (1826) and Chaley's Fribourg Bridge (1833–34) indicate the provision of substantial stiffening girders. Stiffening by means of auxiliary cables also came into use and pictures of Roebling's Niagara Bridge resemble a spider's web.

98. From my own experience I have found suspension bridges will continue to function when subjected to very serious damage due to faulty design or a complete lack of maintenance. In the 1890s a cast iron cylinder forming part of a pier in a multi-span bridge at Rockhampton, Queensland, settled about 4 ft due to scour, but the superstructure suffered so little damage that the bridge was put back into use within a matter of days. One of the piers and an anchorage of the 240 ft span suspension bridge carrying a pipeline near Mombasa moved forward several feet but continued to function. On numerous occasions bent or broken suspenders were found.

99. Short span suspension bridges, generally very attractive in appearance, although no longer fashionable are still strongly competitive in cost. The rusting of the joints in the links does not appear to be a matter of moment as one Swiss bridge has chains of flats rivetted together at the joints.

100. Possibly the Authors might consider providing a cross section showing the stiffening and splint girders in position, as this would clarify the description.

Messrs Holloway and Wadsworth

In reply to **Mr Palmer**, it would not be practicable to increase the width of the existing bridge since it is only capable of taking $\frac{7}{22}$ of HA loading in two lanes. Further, to widen the approaches to give four lanes of traffic would involve phenomenal cost.

102. As to the hangers to which **Mr Dennington** refers, the trouble with the short hangers was that they were not properly articulated and so were subject to bending stresses. When we replaced them we made sure that they were articulated. There was no point in replacing all the hangers because they were of comparable strength to the chains and other major parts of the structures, with due allowance made for the necking.

103. Mr Dennington raises a point with regard to the engineering of the short spans. We are not sure of the drift of the question, but if it was a case of deciding on sections required for the stiffening girder, it is a fact that the bending moment which occurs at the centre of the approach spans is almost the same as the maximum bending moment which occurs in the main span, at about the fifth point of the span. So the stiffening girder scantling is the same for both spans.

104. As regards the calculation of stresses, our earlier calculations were made first on the classical elastic theory of suspension bridges, and then modified to use the

deflexion theory, and we made use of the semi-tabular method for working out the necessary results of the deflexion theory which was put forward by Professor Asplund. It does save quite a lot of time although there is nothing revolutionary about it. It is merely that Asplund works out several factors which are required to be known in order to develop functions, and these are tabulated and shorten the procedure a little.

105. As far as strain measurements are concerned, to determine actual stresses in the bridge, in our investigation in 1960 we used a grand old instrument known as the Fereday Palmer stress recorder, which we think Mr John Palmer's father was instrumental in developing. It is an optical instrument which is clamped to the member of which you are trying to determine the strain. The degree of extension which occurs is magnified through a lever system to rotate a mirror, and as this mirror deflects a line of light along the length of the tube of the instrument, which is about 12 in., you get a considerable magnification. The trace is recorded on a roll of film which is wound through the instrument either electrically or by hand, so that as the vehicle runs over the bridge you construct an influence line for the point at which the instrument is mounted. It has been a very useful instrument. Nowadays we tend to use something a little less cumbersome such as the Demec strain gauge, which is just a simple mechanical device for measuring the extension of a bar between two points. The movement is magnified slightly and registers on a dial gauge. We took readings such as this on the stiffening girder flanges, the cross-girder flanges, the hangers and the chains.

106. Mr Dennington mentions that it was found that under crowded conditions on Albert Bridge the actual load on the deck was 14 lb/sq. ft. There was a similar situation noted on Hammersmith Bridge on one occasion where both lanes were full of traffic during the peak period. We think there were four buses and one other heavy vehicle on the bridge and the remainder consisted of taxis, light vans and motor cars, and it was calculated that the loading on the bridge carriageway was about 19 lb/sq. ft. That is, of course, nothing like the loading that the Department of Transport requires us to put on.

107. When we were dealing with the surfacing under the arches we adjusted the profile to avoid this taking off of traffic.

108. We refer to the help we had through discussing a problem, and you can usually solve a problem if you can discuss it with people of like minds. The solution was arrived at in discussions both in the firm and with the Client's engineers. In the work we did for the Indian Railways we always had scheme drawings coming over showing their ideas of temporary works, special erection gear, and all sorts of things to allow the service spans to carry the rail traffic while the old girders were taken out and the new ones rolled in. In the same way we had tremendous help from expatriate engineers, most competent engineers from the Indian Railways, so we must return the compliment to **Mr Fenton.**

109. As to **Mr Barron**'s question on waterblasting, the exercise of blasting under the confined conditions in the chain tunnels obliged us to get the best we could and put up with that. The standard achieved was about SA 2½, not perhaps the best, but it was quite a good standard. We did not use any abrasive grit because of the problem of cleaning it up afterwards under these conditions. We did not dry it either. We had intended to blow a hot air blast through the tunnel while painting was being carried out, but we realized that with the humidity that obtained in the tunnels we should merely have been blowing moisture on to the chains rather than off. So we allowed them to dry naturally and then coated them with red lead. We would use red lead on a new structure in the right circumstances, because we do not think anybody has found a better rust inhibitor. But the problem of course is that present legislation will mean that some local authorities would ban its use, and others would be very cautious about it, and you might have a great deal of popular protest against it because of its toxic nature.

110. We agree with **Mr Price** on the question of interaction. It can help; on the other hand it may be a menace. The instance of the rivets breaking in the top chord of the lattice balustrade illustrates how a secondary member will pick up stresses it is not supposed to deal with and suffer as a consequence.

111. With reference to the cost of inspections, the answer is really how long is a piece of string. A thorough investigation and report on a major structure these days would not be done for less than £10 000, and might well cost much more.

112. As far as the cracks in the eye-bar links are concerned, these old bridges built by the old engineers were not put in on the basis of any sort of guesswork. They took an eye bar and actually broke it, and proved that it was several times as good as it needed to be. We would have thought that that, together with a careful inspection of the links, is the only safeguard against the sort of failure Mr Price mentioned.

113. As to whether we could have increased capacity if we had put in a steel deck, really the answer is that the timber deck was like Topsy: it just grew. We started off with the intention of replacing only those timbers which we knew to be rotten and, shortly before the contract was due to be put out to tender, an investigation was made of some of the other timbers. It was found, by boring into the end, that some of them had a rotten heart while appearing quite sound on the outside. So at the last minute a decision was made by the GLC to replace all the timbers. In considering the best way of doing this, it was concluded that some economy could be effected by making up a deck which was not as solid as the previous one and structurally a better job, and something which could be made up in a form which could be bolted together in sections. So rather at the last minute the present arrangement was devised.

114. Although a steel deck would probably have been lighter than the timber deck, little if any increase in carrying capacity would have resulted since the capacity is controlled by the stiffening girders and these, if anything, would be adversely affected by a reduction in dead weight. We cannot agree with **Mr Osborne** that a steel deck would have been cheaper, and we doubt whether it would have been less disruptive in installation in view of the amount of welding which would have been required, necessitating night possessions.

115. As to making the lanterns vandal-resistant, the lanterns themselves were not strictly our concern, but we understand that polycarbonate was used for the window.

116. **Mr Mead** raises the question of the extent of the temporary works. In this particular case, where the bridge has to be kept open to traffic, it was necessary in our view to design the majority of the temporary works before we went out to tender so that we could be sure we had a basis for tendering which would be equitable to all tenderers. Had we allowed them to design their own temporary works either during the tender period or after the job had been let, we should have had such a variety of different schemes that it would have been difficult to assess them. On a new bridge built from scratch with no traffic on it, then in common with most other consultants we would have left the temporary works almost entirely to the contractor.

117. There were of course many details of temporary works settled jointly between Contractor and Engineer as the work proceeded.

118. On the question of navigational clearance, we did have a long discussion with the PLA as to what would be permitted. We were not allowed to make our stiffening girders any deeper because we were right on the limit of the lowest bridge on that part of the river, and even an extra rivet head would have drawn forth a protest. So we had to do what we were allowed, and they allowed us to use this travelling cradle at certain states of the tide. It had to be pulled into the side whenever the tide was above a certain level and parked against the pier. There was no question of it being a permanent arrangement. Now that the bridge is finished, the PLA will not allow the cradle to remain over the river at all. It can only be parked over the towpath at the Barnes end of the bridge.

119. We are sorry that **Mr McConnel** had difficulty in following the description of the stiffening girders and splint girders, but perhaps a further look at Fig. 4 would help. The splint girder is on the left, and rests on the cross girders (which cannot be seen) and the stiffening girder is just to the right of it, the old girder visible in the left foreground, and the new girder in the background.