Eighty highway bridges in Kent

J. A. BERGG

Mr Bergg

I feel that there has been a distinct gap in the published material on bridges in the medium-to-short span range: these are, after all, the most common bridges to be built. Having said that, I would be the first to admit that there is little that is original about the structures described in this Paper, nor is the sample of data which I have been able to collect on these 80 structures wide enough statistically to enable firm conclusions to be drawn.

61. The data in the Paper are related to the third quarter of 1972, when the constant for the construction cost index was 160. As will be seen from Table 2, this figure has been up-dated for two or three further periods, and I have just heard from the Department of the Environment that the constant for the third quarter of 1973 is 202.

Mr R. M. Tiller, Advisory Division, Cement and Concrete Association

One of the forms of construction which the Author has shown is voided slab in simply supported and continuous form, and using both reinforced and prestressed concrete. It is interesting to see the upsurge of interest in this form of construction over the last five years. This is attributable in some respects to the three commercially available types of void former.

63. The first former was a steel tubular construction, made of light gauge steel strip, helically wound and continuously welded to produce a tube which could be blanked off at each end with diaphragms. This presented a reasonably priced product but it has certain shortcomings. For example, it tends to collapse when treated roughly on site. It also has a tendency to spring leaks, so that in order to make the best use of it, as I think the Author would agree, some sort of rudimentary plumbing has to be installed so that water which collects in this tube may be drained off.

64. The other point is that, like all other void formers, it is buoyant, and during construction is inclined to rise through the wet concrete unless restrained properly. The method of restraint is rather critical, as it is with most of these formers. The best principle is probably to think of the spacing as determined, halve it, and put restraints in at those centres. The type of support and the restraints used should also be of the banded rather than the cable type. Otherwise a crease may be introduced in the former which could be followed by progressive collapse.

65. Another type of former which appeared fairly soon was one in expanded polystyrene. This does not suffer from the same drawbacks as the light gauge steel one. It does not have the tendency to collapse progressively and does not take up water as it is made up of a series of discrete cells of air. Thus the damage is usually localized.

66. The most recent addition to the range of proprietary formers consists of chip-board wrapped round formers. They are composed of timber rings with triangular cut-outs round the perimeter. Longitudinal stringers are passed over these formers to produce a box rather like an aircraft fuselage, and then the polythene impregnated chipboard (which is claimed by the manufacturers to be capable of immersion in water almost indefinitely) is wrapped round these formers and stapled where they overlap. The ends are blanked off to form the void.

67. One of the problems with all void formers, with the exception of the last, is that when transporting them it is largely air which is being carried. But this last

type is intended to be delivered flat. However, it is true to say, I think, that they have not appeared in such large numbers as the polystyrene or light gauge steel sheet.

68. I should like to know whether the Author has any further comments to make on the use of the voided slab form of construction, with particular reference to the relative costs, comparing reinforced concrete and prestressed concrete construction.

Mr D. Janes, Anglian Building Products Ltd

Analysis of the cost figures in Table 1 together with the Author's comments would appear to be conclusive as to the relative economics of the various types of precast deck, particularly if reference is made to the graphs plotting overall cost/overall length and overall cost/maximum span. However, it is equally apparent that other considerations not noted in the Paper affect the ultimate choice of the deck. For example, invariably underbridges involve the crossing of road, rail, river or canal, and the use of falsework in these circumstances could not only affect the overall economy of in situ decks but also provide considerable practical difficulties of construction. This is illustrated by reference to bridge 65, where segmentalized precast beams provided a comparable economic answer. The one example of in situ construction, bridge 36, does not provide a reliable basis for comparison with the precast decks used in the majority of underbridges, for the reasons stated by the Author—the scatter of individual bridge costs.

70. It is also apparent from the definition of terms, that the relationship between overall cost and overall lengths plotted graphically, is significantly affected by the bridge configuration, a factor that has only an incidental relationship with the costs of single span in situ or precast decks for underbridges.

71. Whilst it is noted with regard to overbridges that in the 65–80 m range precast bridges were considered to be more expensive, it is also interesting to note that a comparison of all overbridges shows that the average 'overall' and 'deck' costs for the precast deck bridges are £67.5 m² and £52.5 m² respectively as against the average 'overall' and 'deck' costs for the in situ deck bridges of £77.0 m² and £57.0 m² respectively. As there can be little doubt as to the economies offered by in situ reinforced concrete slab construction for subways, figures for this form of construction were not included in the 'average' summary.

72. With regard to the pretensioned trough 'Bergg' beam, I note with considerable interest that the analysis of costs clearly shows that of the nine decks built using the trough beam (two overbridges, four underbridges and three 'combination' underbridges) the average 'deck' cost was £52.0 m². Bearing in mind that the trough was evolved as an alternative to the post-tensioned inverted T beam (average overall 'deck' cost of £61.0 m²) it would appear that the development of the beam was successful insofar as deck economy is concerned, although it is also noted that the overall cost of these bridges is at the upper end of the cost scale. From the manufacturing point of view the cost of the Bergg beams produced, economic though they may have been, reflected not only the development process to produce a standard component, but also the wide variation in beam configuration (lengths, depths, skews, etc.) all within a limited production run. The projected short run of production dictated a certain prudence of expenditure, which in turn affected the system and to some degree the efficiency of manufacture. Anglian's decision for example to cast the beams over a solid core incorporating the stress heads and also to use individual moulds to cater for the interchangeability dictated by the variation in beam depths, lengths and projecting reinforcement position, undoubtedly affected the overall cost efficiency. It is my firm's opinion that with standardization of requirements the cost efficiency of the beam, with all the advantages of its 1.5 m width for bridge decks, would produce an even better comparison than that quoted earlier. Certainly recent experiences involving the manufacture of pretensioned trough beams prompts me to forecast a more efficient production system than that previously employed. However, a word of caution on the question of tolerances. Experience showed that whilst the beams

were within the requirements of CP116, the construction of the deck required much stricter tolerances for dimensions, particularly beam depth and bar projection, than had been envisaged in the design, a case of the dimensional tolerances not being quite what the designer required in practice.

73. It would seem to me that a further significance of the Paper is that it highlights two basic problems; first, the obvious limitations that precast elements have in respect of transporting and handling large components, and second the 'inefficiency factor' that is introduced when elements are not used to their full capability. I refer particularly to multi-span underbridges where the side span beams are of similar section to the main span beams but invariably of a different length. The greater the standardization of beam detail, the greater the economies that can be offered by the manufacturer, and there would seem to be a case for suggesting a standardization of lengths for each span; or if this were not possible a revision of the side span beam section consistent with a standardization of the beam lengths would possibly yield further economies. With regard to the size of elements, it would seem also that there needs to be a much greater acceptance by designers to design for segmentalization, perhaps even on a hollow box principle as this appears to offer significant advantages in situ decks. This would not only eliminate costly transport and handling but also allow the manufacturer to use his expertise to a greater degree by manufacturing smaller, more accurate, components. Whilst it may be hypothetical, it is also interesting to reflect on the comparative deck costings that might have been produced, had the M beam range now in production been considered as an alternative; certainly the design span range would have allowed a greater flexibility of choice.

74. In conclusion, I would like to comment on the question of footbridges and particularly on the question of standardization. As manufacturers it is a matter of concern that so many local authorities elect to formulate their own designs for footbridges, as the mould costs for these 'one-off' designs are extremely high. In this instance I must disagree with the Author, because I firmly believe that in the case of footbridges, standardization is synonymous with economy; reference to bridges 22 and 81 clearly shows this and there can be little doubt that a well-designed aesthetically acceptable footbridge either on the principles illustrated by the Kent County Council or a similar system approved by the Department of the Environment or Council of Industrial Design or both, provides an economic answer for both existing roads and new carriageways.

Mr J. Ford, Department of the Environment

I notice that bridge 19 seems to be a rogue, being the only one where steel gets a mention. It also seems to be one of the most expensive decks. Was this a steel/concrete composite deck, or was it of some other form, perhaps joists in concrete, and has the Author any explanation for its expense? Was this one isolated instance which frightened him off ever trying steel again?

76. Might there be some advantage in comparing spans by weight of reinforcement and volume of concrete per square metre of deck? This sometimes gives a lead as to the efficiency of design, which of course need not necessarily be the same as economy of design. The material may be used slightly inefficiently, but because a very simple form of construction results, it could be economic.

Mr K. Sriskandan, Department of the Environment

In looking through Table 1, I feel it would have been useful if the skew angles had been given, in order to see how these affected the costs.

78. In § 3 reference is made to inclined abutments. I have had some experience of using these abutments in the West Riding of Yorkshire. When the skew angle

became large and also when the height of the abutment varied along its width due to the fact that the deck was on a super elevation, there were problems of geometry. I wonder whether the Author has come across this problem, and if so how he overcame it.

79. In § 8 the Author says: 'There are aesthetic and safety justifications for omitting the piers in the central reserve.' He goes on to say: 'Fig. 2 shows that these bridges, spanning between 35 m and 40 m, were cheaper overall than the equivalent precast beam four-span bridges with maximum spans of 17–20 m. The average overall cost of bridges 31, 32, 33, 39, 40, 45 and 46 was £73·5/m².' These are all in situ slab bridges.

80. Looking back at § 7 the two four-span in situ reinforced concrete slab bridges 49 and 53 are quoted as £60·6/m²—cheaper by something like £13 for the four-span as opposed to the three-span bridge.

81. The DoE did a survey some time ago to find out whether there were any accidents involving vehicular collision with the centre pier, and came across only two, so I do not think there can be much benefit from the safety point of view, and £13/m² seems a high price to pay for aesthetics.

82. I have one other point to make on these three-span bridges. On one bridge I found the centre spans were long compared with the two side spans. The proportioning of spans did not appear to be balanced. If one wants to provide a three-span bridge, I think the side span has got to be long enough to provide the classical three-span type of solution.

83. Continuing to § 15, the Author suggests that the trough beam was more economical over spans of 15 m. But on Fig. 14 the cross-over point seems to be about an 18 m span, and below that is the range where one uses the inverted T beam. So that in fact, below 18 m span, it seems to me that the inverted T beam was cheaper than the trough section.

84. Another point about the trough section was that it had reinforcement projecting from the sides. I would like to ask the Author what the precast manufacturer's reaction was. Mr Janes said earlier that his firm would like to cast these again. In this connexion the DoE has recently had discussions with the major precast manufacturers and they are all against any kind of reinforcement projecting from the sides of precast beams, and any form of cast in sockets. If something like that is to be introduced into the beams they would prefer it to be shot in rather than cast in with the beams. So it seems to me that this is a drawback with this type of construction.

85. Going on to § 17, segmental post-tensioned T beam construction can obviously be used, but I think it must be made clear that the beam sections must of necessity be non-standard because most standard beams are designed and produced for the span range up to 27·4 m which is the normal transportable length. I would like to ask the Author whether any form of initial prestress was put into these beam sections, or was the reinforcement providing the strength? I agree entirely with his statement that the ends of the sheathing should be in recesses. I was engaged in the design of a bridge of this form where the ducts were left exposed and they were so badly damaged during transit and other construction operations that it was quite a job to try to connect them up.

86. On pier costs, I should like to know the actual width used in calculating the pier envelope. Does this include the whole width of the deck, i.e. including side cantilevers, or merely the structural width?

87. In his conclusion the Author states that there is only a small variation in the prices of various forms of construction, but it appears that in the overbridges the in situ construction certainly came out cheapest. Since these bridges were constructed and priced there has been a tremendous increase in the cost of timber, and people have been talking about the non-availability of carpenters. I should like to know from the Author whether there have been any other tenders received since then in Kent and whether there has been any change in the trend shown in the Paper.

Mr F. A. Sims, West Riding County Council

I agree with the Author that it is the standardization of components which is to be encouraged. Rigid standardization over any long period will be in the long term more costly owing to the inhibition of the normal processes of design refinement and the failure to incorporate technical innovations or reflect construction trends. What is the best solution in current circumstances may not be so tomorrow.

89. The point may be demonstrated by reference to Fig. 14. The cost of decks consisting of simply supported precast beams agrees reasonably well with decks of this type constructed in the West Riding.

90. In recent years, however, as a result of the processes to which I have referred (spurred on by the fact that continuous cast in situ decks are rarely possible in the West Riding because of possible mining subsidence) simply supported precast beam decks have become considerably more economic. Post-tensioned beams have been superseded by pretensioned deflected tendon beams, widely spaced to work at their maximum capacity where this would reduce the number of beams in a deck. Transversely prestressed or reinforced intermediate diaphragms have been omitted. The result has been a saving on this type of construction of up to 30% giving costs comparable with in situ decks.

91. I share the Author's view that the forward leaning abutment can give a more pleasing appearance at no extra cost. The West Riding CC has used this style of abutment, where appropriate, during the past six years, and is at present looking at ways of reducing substructure costs, which (excluding piling) may amount to 40% of the total bridge cost. One field being examined closely is the use of reinforced earth. At the moment this is being used for retaining walls and appears to be economically attractive. The next step will be to incorporate it into bridge substructures.

Mr J. F. Davies, Berkshire County Council

It would be interesting to hear the Author's views on the maintenance of the bridges, and how they affected his choice of a particular type. I am prompted to raise this issue in the light of the reference, for example, in § 28, to the provision of access to bearings at 'step' joints—too often this is inadequate or non-existent!

Mr David Lee, G. Maunsell & Partners

With reference to Fig. 17 showing beams transversely post-tensioned, current cost analyses suggest that for normal UK loading it is marginally more economical to stiffen up the longitudinal beams and dispense with transverse diaphragms except at the supports. It is certainly easier for the contractor. Similarly, in Fig. 18, inverted T beams were shown with the bottom slab connexion. Although this confers the benefit of 'pseudo-box' action, I think that current practice suggests that the benefit is offset by the additional concrete deadweight and to proportion and reinforce the top slab suitably is adequate in normal cases. *Perhaps the Author would comment.*

94. I would like to comment on the handrail with vertical balusters. It is handsome, but one has to be careful about the flicker effect of two rails. The moiré banding can be seen even in a photograph such as Fig. 45. Seen head-on at over-bridges the effect is lively but not distracting but at certain acute angles at intersections, the flicker can interfere with the driver's concentration.

95. Fig. 42 shows the jointed type of construction with an in situ portion over the support or a side span and then a drop-in span. I tend to prefer a continuous connexion between those elements so that deflexion is distributed giving merely a difference in a curve rather than a dog's hind leg effect. That is not present on the bridges that I have seen, and I compliment the Author on that, but it is a problem where there are articulations, certainly on longer thin spans. The weight is balanced by high prestress, and there is a small difference between large quantities. *Perhaps the Author would care to comment on his allowances for camber and creep.*

DISCUSSION

96. Coming to costs, I applaud the up-dating of the information given. Many papers refer to noteworthy costs achieved a good many years ago, which has little relevance. I would sound a note of caution on interpreting cost analyses because contractors do not reveal everything in their tenders, and they do not necessarily reveal it in their final settlements.

97. My firm has been looking at various types of double webbed beam used in Britain, one of them being the trough beam shown in Fig. 16 compared to various types of box beam and U beam. The form of the trough and U beam allow all surfaces of the beam to be easily inspected after casting. There is also a similarity in that the U and trough beams have a ratio of in situ concrete to precast concrete volume in the completed deck between 1 and 2, whereas standard box beams require less in situ concrete.

98. Fig. 49 shows typical examples of the weight of tendons per unit area of deck against span and gives a good indication of the efficiency of the Kent trough beam in terms of prestressing steel. Fig. 50 is similar in showing the web area against span. The Author might like to comment on whether the economy of the trough beam in this respect is related to requirements regarding ultimate shear capacity, which have been made more onerous in recent years. The patches surround the areas in which the points derived from various structures actually lie but it should not be inferred that they fully envelop all possible designs for each type of beam.

Fig. 49.

99. Mr Bergg has made a point about the number of beams used in the width of deck. The width of beam and their spacing is relevant to the number of beams needed for each bridge and hence the total production batch for each contract. The Paper provides confirmation that the trough beam is economical and compares with similar figures for contracts awarded with U beam decks. Taking practical and theoretical aspects together, the Author's firm has considered the U beam preferable to other types of double webbed beam and in forming that view the interesting and successful use of the trough beam has certainly played a part.

100. On the comparison of the trough beam and the U beam, one big difficulty with the trough beam is the edge detail. One has got a precast edge, but it is an ungainly object in my opinion. The inverted trough or U shape seems to be slightly

Fig. 50.

more advantageous, and if necessary the top slab can be cast on as well. I wonder whether the Author would like to comment on the choice of the trough rather than the U?

Mr Bergg

101. In relation to continuous reinforced and post-tensioned three and four span bridges I would underline **Mr Tiller's** comments on the need for adequate restraint to prevent void formers from floating. Ties should preferably be taken through the soffit shutter and the tendency can be minimized by a steady rather than fast rate of pour, with the concrete kept at a steep face to avoid a long 'tongue' of concrete under the voids. This may also assist in reducing pour-line blemishes on the fascia. With regard to the relevance of voided slab construction to reinforced and prestressed construction, I would not have thought that the use of voids was merited for the majority of reinforced construction, where one would merely be reducing dead weight. With prestressed construction one is also reducing the area to prestress, and this double advantage is the justification for the additional cost of forming the voids. **Mr Sriskandan** refers to the economy of the two 4 span continuous reinforced slabs and doubts the justification for omitting the central reserve pier and using 3 span post-tensioned continuous structures. I should point out that the main span for the 4 span bridges averaged 15.2 m; the equivalent span for the sites where 3 span structures were used would have been 19.3 m. This would inevitably have led to some increase over £60.6/m² at 15.2 m, probably to about £70/m²; hence 3 span construction was adopted with little increase in cost over 4 span construction but with an undoubted benefit to drivers in relaxed driving, particularly at night.

102. **Mr Janes** refers to the relative economy of the trough beams in spite of short production runs and high initial mould costs. Fig. 49 and 50 produced by **Mr Lee** appear to bear this out, and it is interesting to consider what might have happened had not the M-beams appeared at about the time the trough was introduced. It might even have been worthwhile patenting the design! **Mr Lee** comments on the shear capacity of the trough beam webs. I do not think the more onerous requirements introduced in recent years would have affected the 'placing' of the troughs, since the webs are generally fairly lightly stressed owing to the relatively small proportion of dead weight due to in situ infilling.

103. I am sorry he does not like the parapet beam. To produce a precast parapet beam with the minimum of site work to the fascia was, in fact, one of the objectives in producing the trough beam design, and although it is rather unwieldy due to its lack of symmetry, I think it looks quite well in place. Of course for multi-span construction a light in situ coping is required to even out any differential hogging of individual beams, but the precast parapet beams certainly simplified construction. **Mr Sriskandan** asks how the subcontractors reacted to the projecting steel. The heavy steel is at the top, and a lift-off portion to the mould side is therefore possible. The bottom steel is only 10 mm in diameter, and can be bent up in the mould. This keeps perforation of the mould side to the minimum. I agree, however, that is one of the disadvantages of the design.

104. I agree with Messrs Janes and Lee that costs are to be treated with caution since site conditions, bridge configuration and the contractor's method of pricing his tender inevitably lead to variations. Had I had time to analyse the lowest four tenders for each structure the results might be more reliable but this was not possible. Similarly, like **Mr Ford**, I would have liked to compare concrete volumes and steel weights per square metre, although this only leads to an indication of efficiency of design rather than economy. (Mass concrete retaining walls are 'inefficient' in this respect, but are becoming increasingly economical, whilst 'efficient' counterfort walls are anathema to a contractor.)

105. **Mr Janes** takes me to task on the relative economies of precast versus in situ, quoting average figures for overbridges. I do not quite agree with his arithmetic,

since I make the average of the eleven precast overbridges listed to be £80/m² overall cost, whilst that for 22 in situ overbridges is £76·7/m², but I fully agree with him that on many sites precast decks are the only solution. I would not have thought that segmental construction would have been used widely other than in one-off structures. To me it appears to combine the worst aspects of precast and in situ construction for short- and medium-span bridges. Bridge 65 was undoubtedly a special case. In answer to Mr Sriskandan, there were in fact five segments, so that the normal secondary steel was sufficient for lifting stress on individual segments.

106. Mr Sims and Mr Lee refer to the greater economy with precast construction of stiffening up the longitudinal beams, spacing them out, and letting the slab look after transverse distribution. I agree, but would mention that one has then lost the concept of the precast elements acting as in situ shuttering for infill concrete, and the longitudinal members can become somewhat congested owing to their high loadings.

107. I share Mr Sims' liking for inclined abutments, but agree with Mr Sriskandan that they can look distorted if the skew exceeds about 15°.

108. Mr Ford asks whether the cost of Bridge 19 put me off steel bridges. This structure was originally to be temporary, hence the decision to use steel. Originally it was to have steel troughing with lightweight infill to support the paving but became 'permanent' shortly before contract, and so the troughing was replaced by a composite-acting concrete slab. Surrounded as we are in Kent with cement works and ballast pits and now even a producer of steel reinforcement, it ought to be possible to make concrete bridges economically and I suppose this explains the absence of more steel structures.

109. Mr Janes refers to the desirability of standardizing footbridges. I agree, and have done so for multiple uses in urban areas, but doubt the need in the case of individual rural structures where any extra cost of non-standardization is insignificant compared with the total contract price.

110. In answer to Mr Sriskandan, the width of deck taken to determine the 'pier envelope' used for pier costs is that on the axis of the pier over the structural width, i.e. excluding cantilevered parapets or copings.

111. Mr Davies asks how the future maintenance of the structure affected my choice of type. There is scope here for another paper, but sufficient to say it is in my opinion more a question of detail rather than overall concept. Drainage, waterproofing, and sealing are the chief sources of difficulty, together with adequacy of bearings and expansion joints. Where the overall concept implies a possible increased maintenance liability, such as with 'stepped' joints, it is necessary to take increased precautions in detailing. I would not have thought that the detail should necessarily determine the overall concept.