*Proc. Instn Civ. Engrs*, Part 1, 1990, **88**, Feb., 149–154

9425 DISCUSSION STRUCTURAL ENGINEERING GROUP

# Prestressed concrete road bridges in Great Britain: a historical survey

K. Sriskandan

**Mr P. J. Andrews,** *Northamptonshire County Council*

The paper is a good balance indicating the way development occurred and the manner in which codes were changed as a result of research and model analysis. These developments led to the modern analytical and construction techniques which are now so common. Civil engineers design to build and often ignore the need to demolish. What procedures can be used to take down prestressed concrete bridges and how is demolition balanced against strengthening? How can bridges be strengthened when some for example have cables that are incorrectly prestressed or not covered in grout? Knowledge has been developed project by project. If a bridge has not been designed for differential temperature further work is needed to adapt it to modern load criteria rather than demolish the structure. Such additional work is expensive; however, knowledge and methods must be developed to enable existing bridges to be strengthened.

72. Ease of maintenance has been mentioned. I do not agreee with the Author that the use of external cables is inadvisable. In prestressing they are of considerable use not least of which is to enable easy maintenance. One particular problem which has to be kept in sight is that if something goes wrong with prestressing in a structure there is a situation that a catastrophic failure could occur. It is fundamental to the design of prestressed concrete that this is remembered because failure cannot be seen to be occurring in the same way as it can on reinforced concrete or steel bridges. The failure of Ynys-y-Gwas Bridge in South Wales was a classic example. One minute it was there, the next it was not—there was no warning of impending collapse.

73. The building-in of the M-beams has been mentioned. Many of these have been built in various locations and are an extremely successful method of construction. However, with a heavily curved structure there is an enormous problem when the ends are built in—that of accounting for the changing direction of force, where there are often major transverse stressing problems.

74. British Rail have high containment barriers which have a major effect on design as they not only require the ability to resist large movements but they have a detrimental environmental effect. The former case cannot easily be accommodated in old bridges which have to be substantially strengthened to carry these new parapets.

75. A much more co-operative approach is needed in bridge design and construction. There has for instance been the disparity of approach between British Rail and Highway Authorities. There is an interface beween the two in that rail-

Paper Published: *Proc. Instn Civ. Engrs*, Part 1, 1989, **86**, Apr., 269–303.

ways and roads cross each other and this crossing needs to be successfully accommodated. Historically this has not been the case—as Engineers we need to ensure in the future that these mistakes are not repeated.

**Mr D. J. Lee,** *G. Maunsell & Partners*

The Author correctly pointed out the importance of prefabrication and precasting. There are two distinct aspects of prestressing. One is the long line system, where bars are stretched and concrete is placed around them. If properly made in the factory these products are extremely reliable, although there can be quality problems in the precast factory controlling production cycles and slack use of steam curing. However, the Author is correct to think of a return to prefabrication, as it is one of the most effective ways of casting concrete, not only for beams but also in the precasting of segments. There has not been much development in the design of beams in the UK. The inverted T is an effective design and worthy of its place unlike the M-beam which has taken a long time to phase out. There is talk of producing a Y-beam: a revised type of I-beam. The Y-beam has promise for medium spans (i.e. between the inverted T range and the longer U-beams). Other beams could be thought of for certain circumstances, such as Z-beams, channel beams and various types of box beams.

77. It is regrettable that there is so little feedback from the government, particularly from the Department of Transport, on the performance and performance standards of structures. It is only in recent years, with involvement in refurbishment work, reports and inspections, that those outside the government have found out how other people's bridges, or even their own, are performing. This secrecy is not good for the profession.

78. Prestressing has always required good duct technology, accessibility, robust construction and good workmanship generally. Prestressing is only part of the story. Detailing is all important. Difficult parts of a bridge are not necessarily the prestressed concrete parts but the reinforced concrete elements such as the end blocks, the bearing ledges, abutments and columns. The Department of Transport requires so-called 'full prestressing'. In certain circumstances a reinforced concrete bridge very lightly prestressed would be more desirable. Designers should be given a chance to use light prestressing.

79. Overseas countries, which do not have problems of de-icing salt and atmospheric pollution to the same extent as the UK, make far more durable prestressed concrete. How are these problems overcome? Reliability analysis is showing up various pointers. Replaceable tendons are the only way that prestressed concrete can be made equally reliable as a steel bridge. This requirement would change the form of bridges to allow tendons to be replaced just as bearings have had to be replaced.

80. Fibre tendons—such as Polystahl, glass fibre tendons and carbon fibre tendons—may also need to be replaced as their future durability history is untested in bridge construction. With very big structures which can be very heavily prestressed it is important not to over-stress them because there will be serious problems with deflexion.

81. There are restrictions to prestressing because the shape of various elements can affect how they are prestressed and how they are reinforced. Although a skew bridge can be prestressed in three directions, it is still not fully prestressed everywhere in the concrete deck for all load conditions.

**Mr B. Pritchard,** *WS Atkins Consultants Limited*

My career goes back to the late 1940s and early 1950s when prestressing was really quite an exciting business. I recall working on the Baur Leonhardt system mentioned by the Author, where continuous tendons were wrapped around semi-circular end blocks which were then pushed out to stress the deck. The jacks were pumped full of grout and held at pressure while the grout set to permanently hold the prestress. Dr Leonhardt was most anxious to make these buried jacks very cheap. At one time he was using concrete-backed aluminium saucepans which fitted inside each other.

83. On another occasion there was great excitement because a new larger diameter wire cable was being tried out. Each wire had to be prestressed individually. Unfortunately, 10% of the new and larger anchors were shattering violently during prestressing. The protective system of prestressing developed involved a person doing the jacking behind a steel shield and myself, a safe 50 yards away, measuring the wire being extended through a theodolite. I think things have improved since then.

84. I was concerned at the Author's response to the business of continuity for deck beams. He says that he prefers the flexible slab which is debonded at the end of the beam, and that there is not much advantage to be gained in making beams continuous. Atkins has successfully developed systems of building-in prestressed precast beams, offering many advantages.

85. Only two types of precast beam were required for the large six-viaduct Woodford interchange constructed 15 years ago at the end of the M11. The beams were built into 2·5 m wide in situ concrete integral crossheads for continuity, which allowed not only the curvature to be taken up but also deck drainage pipes to be put into the in situ section at each pier position. There was also a depth saving in using this continuity, which applied to the slab, surfacing and live loads. If the deck had been simply supported, M10 beams would have had to have been used. However, only M8 beams were required, saving 160 mm in depth, which made the depth/span ratio go up from 1 : 20 to 1 : 24. This type of construction is to be recommended.

86. As mentioned, salt corrosion is a cause for great concern. A 25-year-old prestressed concrete flyover had to be pulled down in Berlin because of the excessive salt corrosion which had badly affected the prestressing cables. It had been considered at one time that, with so many cables, they were not all liable to corrode at the same time. In fact, every single one of those cables was very badly pitted and corroded, and a new flyover had to be built.

87. Other examples are the Heads of the Valley road bridge in Wales, which had to be demolished and rebuilt, and the Ynys-y-Gwas bridge, also in Wales, which collapsed suddenly 18 months ago. They were due to chloride corrosion arising from road de-icing salt assisted in the latter case by chloride in the mix for the segment jointing concrete. Both Welsh bridges were around the 25 year critical age.

88. A lot of small box beam type bridges, which were transversely prestressed, were built in the UK in the 1960s. The mistake with these bridges was that they did not have deck slabs on top of them, just pre-tensioned boxes transversely stressed together, then waterproofing and surfacing. A lot of people had the misguided idea that stressing across a joint stopped deck water coming through. If there are joints, prestressed or otherwise, water will usually penetrate. Once the waterproofing fails, water goes down the joints and attacks reinforcement or prestressing.

89. On a bridge Atkins examined recently, stalactites of salt water were forming at the joints between the prestressed concrete beams. When the box beams were drilled into, 3in. of water was found inside, with a significant chloride containment, all lying above the pretensioning cables which are in the boxes. A parlous state which takes a lot of work to put right when the cables cannot be seen without removing concrete, and associated structural integrity. The Germans and the French currently say that all prestressing cables must be accessible, inspectable and replaceable—that must be the lesson for the future.

90. When the Author spoke of the Charolle Viaduct in France, he did not have time to explain that the bottom pipe flange, which is concrete filled, is used to push the structure out. The deck is initially a steel structure with a steel permanent form for the deck slabs. It is made up into a triangular space truss, pushed out and the deck slab concreting follows, the whole thing being prestressed internally. All of the cables used are inspectable, accessible and replaceable. This principle is being followed for the stay cables on the new Severn Bridge. It is a requirement of the tenders now out that the cables shall be removeable without interrupting traffic.

91. A comment about the future use of special inert cables. The Germans are already commercially producing a glass fibre prestressing cable. The cable is delivered to site on an 8 ft dia. drum with the anchors already attached. This system has already been used experimentally in three bridges in Germany. They have been in place now for more than three years and are performing well. Even these supposedly non-corroding cables should remain accessible, inspectable and replaceable.

92. To conclude, I have painted a rather gloomy picture of the state of some prestressed concrete bridges, due to salt corrosion, particularly at the age of 25 years. To add to that the University of Surrey has done some recent research into cable losses in existing prestressed concrete bridges by measuring the actual loads in cables. The results have been sobering—with losses of up to 50–100% more than designed in some cases. Having said all that, I want to make the more uplifting comment that a recent inspection undertaken by Atkins and Maunsell established that the prestressing cables in the large A40(M) Westway box girders, now within 5 years of the critical 25 year span, were in good condition.

**Mr T. Sketch,** *Buckinghamshire County Council*

Very little of the bridge work in Glamorgan was published so it is not surprising that Mr Skriskandan has not included any description in his Paper. By 1953 the first prestressed bridges were going up in Glamorgan—they were ex-Ministry of Transport stock, coming from Harmondsworth.

94. By 1955 there were twin 55 ft spans over the Neath, and many other bridges were prestressed slabs. At that time it was discovered that if a box section bridge was built it needed a hole in the bottom, and if the box was separated out into many sections many holes were required in the bottom—otherwise the excess of water in the bridge would lead quickly to failure. We are still relearning the same lesson.

95. An interesting bridge which was built in 1962 was Penarth Road Bridge over the Ely. This is literally overshadowed by one of the viaducts in Cardiff which has been built recently of segmental construction. It was 180 ft span and was unique. It had 1 in $14\frac{1}{2}$ cross fall. There were a number of friction and stressing problems that the designer went to France to talk to Guyon about. Where there are very tight radii at anchorages followed in the length of the main beam by a

very flat radius, if there is any slippage in anchoring all the loss occurs around the anchorage. This problem occurred at that bridge.

96. One of the advantages of standard T-beam bridges was that a lot of research had been done by the Cement and Concrete Association on load distribution, so that design could be extremely quick with literally one page of calculations for each deck.

97. A computer was used to design the reinforcement at Cowbridge Viaduct in 1963 as a mathematical exercise rather than a need, but the spin-off from these exercises was that the computer group brought bridge engineers in counties together, and a lot of information was thus swapped, before the road construction units were formed in England.

98. Three major prestressed multi-span viaducts were designed by Glamorgan County Council and are significant. They were at Cowbridge, Glynneath and Kenfig. They followed the tradition of simply supported bridges in Glamorgan where ground conditions are so very variable.

## Mr Sriskandan

*Mr Andrews* asked a question about demolishing and strengthening. Much work has been done on demolishing prestressed concrete and many articles have been published about it. One bridge deck that was demolished recently was that of Taf Fawr bridge in Wales and the procedures that were adopted have been described in reference 58. Mr Andrews also asked about strengthening bridges, particularly those that were not designed for temperature difference. As mentioned in the Paper, this has not been a problem in Great Britain so far. However, bridges in France have had to be strengthened to cope with this problem, by adding prestress using external tendons. Britain may be faced with similar problems when longer span bridges are assessed against the new and greater loading.

100. British Rail's approach to bridge installation may have been different because many of their recent bridges have been replacements which have to be erected with minimum disruption to services. I feel sure that if a road bridge had to be replaced a similar approach would have to be adopted in order to avoid traffic delays.

101. Mr Andrews has perhaps misunderstood my statement about external prestressing tendons. I thought I had said that external tendons should be used. To quote *Mr Pritchard*, there should be inspectable, accessible and replaceable tendons. That is what I meant to say although I did not say it in so many words.

102. Mr Pritchard referred to continuity by building in of the beam ends. On over bridges, spans are usually about 15 m. With this system temporary staging will be required at each pier. In the case of the normal over bridge, if one beam can be landed on to its pier and the slab debonded the total costs may be less. Unless it is tried one does not know. I am sure that the design for Woodford viaduct was economical, but the spans there were nearly 30 m. At these spans continuity can provide structural advantages.

103. Mr Pritchard also mentioned the use of pre-tensioned boxes without a concrete slab on top. I thought with the C&CA standard box one had to have some amount of in situ concrete on top. We were told that one of the reasons for the failure at Ynys-y-Gwas was that those beams were all precast post-tensioned beams laid side by side without an in situ slab on top and that if there had been an in situ slab, it would have afforded some protection to the precast beams. Clearly

what Mr Pritchard was saying was exactly the same thing. When the water gets to the beams it can get to the longitudinal and transverse cables.

104. *Mr Lee* spoke about the scope for various shapes of beams. There is no scope for a large number of national standards. Every precast manufacturer would be forced to have moulds, because if one of them had it others would feel compelled to have it also. This cannot be a economical solution when considered nationally. I agree with what he said about feedback on things that go wrong. We outside the Department should join together and ask the Department to make the feedback available.

105. There are very few countries who yet have partial prestressing in their codes. Switzerland is probably one. Things are moving very gradually. In UK a certain amount of tension is allowed under some load combinations. Maybe with a little more experience one might permit some cracking as well, but I would not go towards that yet. There is a danger of fatigue in tendons if crack widths exceed a certain amount. Experience is not yet wide enough in Great Britain to jump to class 3 as it is called. My feeling is that we should go step by step and permit cracking when more experience has been gained with the present code.