Bridge strengthening without traffic disruption

Autor(en): **Pritchard, Brian**

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Bridge Strengthening without Traffic Disruption

Renforcement de ponts sans interruption du trafic

Brückenverstärkung ohne Beeinträchtigung des Verkehrs

Brian PRITCHARD
Consultant
WS Atkins Consult Ltd
Epsom, UK

Brian Pritchard obtained his civil engineering degrees at the University of Wales, UK and Washington University, St Louis, USA. Formerly the Director in charge of Bridging for Atkins, with over 30 years experience of international bridge design, construction, maintenance and research, he now acts as a Consultant to the firm.

SUMMARY

The paper describes several new techniques for strengthening existing bridges to withstand increased loading by imposing dead load relief or load sharing. The techniques cover beam load sharing and external prestressing, the installation of extra shear connectors and the use of shock transmission units. They all benefit from requiring minimum, if any, traffic disruption.

RESUME

L'article expose diverses techniques nouvelles pour le renforcement de ponts existants, dans le but de supporter un accroissement de surcharge tout en imposant à l'ouvrage une réduction du poids propre ou une répartition des charges. La technique comporte la répartition des charges sur les poutres avec précontrainte extérieure, la mise en place de goujons de cisaillement supplémentaires et d'éléments de transmission de chocs. Le procédé ne nécessite qu'une interruption de trafic minimale.

ZUSAMMENFASSUNG

Der Beitrag beschreibt verschiedene Techniken zur Verstärkung bestehender Brücken für höhere Nutzlasten durch Verminderung der Eigenlasten oder durch Lastaufteilung. Es handelt sich dabei um Lastaufteilung auf mehrere Träger und aussenliegende Vorspannung, Einbau von zusätzlichen Schubverbindungsmitteln und Verwendung von Stoss-Übertragungselementen. Der Vorteil dieser Massnahmen liegt in der minimalen Beeinträchtigung der Verkehrs.

1. INTRODUCTION

An ever-expanding world demand for highways means a world stock of bridges not only increasing in numbers but also in age. At the same time, traffic and the bridge loading demands of design codes are also increasing, leading to associated expansions of bridge strengthening programmes.

Bridge strengthening inevitably requires changes to the deck structure, often accompanied by upgrading of the substructure. With associated traffic disruption costs so high, a considerable amount of ingenuity has been expended by designers of late to minimise or even eliminate these costly disruptions.

The paper initially sets out the important characteristics sought of such strengthening methods to allow traffic to flow freely. Following this, new traffic disruption-free strengthening procedures are described for:

- Deck beam bending capacity
- Composite deck beam fatigue life extension
- Substructures

2. REQUIREMENTS FOR BRIDGE STRENGTHENING WITHOUT TRAFFIC DISRUPTION

To avoid traffic disruption during the bridge strengthening operations, the following characteristics are required:

- Strengthening work to the deck should take place under the deck and away from the trafficked upper surface.
- Strengthening should be confined to adding to the existing structure, with only minor cutting or removal to acceptable safety factors.
- Strengthening materials should generally exclude wet construction such as insitu concrete, guniting, grouting or glueing to avoid separation effects due to traffic vibration during setting.
- Strengthening attachments to existing steel bridge decks should be fixed by bolting rather than welding and the attendant dangers of overheating steel under service loading.
- Strengthening procedures involving the use of relieving loads should not overstress the existing structure during application.

3. STRENGTHENING DECK BEAM BENDING CAPACITY

Two innovatory construction procedures developed in recent years allow strengthening of the deck beams of an existing bridge to give additional bending capacity without traffic disruption.

3.1 Load Sharing Strengthening

The first technique uses new steel beams placed directly under the existing beams. The new beams may be supported off the existing piers or off newly constructed piers and foundations. The design analysis is based on the new and existing beams acting together, although not compositely, along their full lengths such that applied loading is shared in proportion to their stiffnesses. The innovatory technique developed related to the establishment of the structural filling of the small gap between the new beams and the in-service beams.

This technique, initially used on a reinforced concrete beam deck, had to take account of the fact that the gap depth varied between 30 and 75mm because of the undulating nature of the existing beam soffit. There was also lack of accessibility, with the narrow gap extending over the 250mm width of the new steel beam flange.

The solution was to use circular nylon reinforced grout bags, with circumferences ranging between 700 and 500mm, initially laid flat over the steel beam top flange. The bags were then pressure filled with sand/cement grout to take up the varying gaps and left to harden. The pressurised grout was not only contained but unaffected by any vibrations arising from traffic during setting.

Several uses of this technique were made on bridges in Wales, Figure 1. The technique could also be extended to the filling of the very variable gaps between old masonry arches and new strengthening steel arch frames.

3.2 Self Weight Relief Strengthening

Conventional prestressing of a bridge deck imposes a permanent direct compression together with a bending moment which counters, or relieves, the applied dead load moments. The bending moment reduction effect of added prestressing can also be used to advantage in relieving dead load bending in existing overloaded decks of reinforced concrete, steel or composite concrete deck-steel girder structures. This dead load bending relief can be sufficient to reduce the deck bending under full dead and live loading to permissible limits. Alternatively, a bridge deck can be upgraded to carry increased superimposed dead and/or live loading.

In general the direct compression effect of the added prestressing is not helpful. Reinforced concrete allowable compressive stresses are usually lower than with prestressed concrete and extra compression in steel structures can lead to plate stability problems. It is therefore beneficial to mobilise as much of the prestressing bending moment reduction as possible and there is every advantage in locating the prestressing tendons at the beam extremities or even beyond.

Rakewood Viaduct carries the M62 motorway between Lancashire and Yorkshire across a 36m deep valley, Figure 2. The 256m long six span continuous deck, completed in 1969, consists of ten 3, deep steel plate girders carrying and composite with an insitu reinforced concrete deck slab.

The Viaduct required upgrading to cater for a proposed increase in traffic lanes carried and the more onerous requirements of the newly introduced BS5400 bridge code. The main shortfall was identified as an approximate 40% overloading in the steel girder compression flange over the piers. Upgrading by 'unloading', using external prestressing, was found to provide an economical strengthening procedure with minimal disruptions on this heavily trafficked motorway. Figures 2 and 3 indicate the strengthening procedure, which first requires the attachment of fabricated steel anchors to the locally stiffened underside of each steel bottom flange by HSFG bolting. Three pairs of 50mm or 36mm diameter Macalloy prestressing bars of overlapping lengths are then attached under each flange between piers. Upon stressing, hogging bending is set up in the mid span regions of the beam. However, it is the parasitic sagging moment over the piers, caused by deck continuity, which performs the required 'unloading' to acceptable stress limits in the bottom girder flanges over the piers.

Figure 4 shows how a similar external prestressing technique was used to 'unload' the rectangular beams of an understrength two span continuous reinforced concrete deck in South Wales. In this case prestressing was by plastic sheathed cables located on the sides of the beams anchored and deflected by steel assemblies attached by epoxy grouted bolts passing through the beams.

4. COMPOSITE DECK BEAM FATIGUE LIFE EXTENSION

Existing composite bridge decks often require strengthening or fatigue life enhancement of the shear connection between the concrete deck slab and steel girders. This can be undertaken by installing additional new shear connectors. The innovation comes with how to do this without traffic interference.

The existing new viaduct decks of the London Docklands Light Railway, completed in 1987, are generally of continuous composite construction with an insitu reinforced concrete deck slab supported by and composite with twin steel universal or plate girders. The original design of the decks to BS5400 established that fatigue considerations were a critical factor, particularly in the deck shear connectors. As a result of an unforeseen increase in weight and frequency of trains after 1991, the fatigue life would suffer considerable reduction. Strengthening measures to restore the fatigue life back to the originally designed 120 years were required. Additional shear connectors installed between the original 19mm welded stud connectors would relieve the loads on these connectors sufficiently to accomplish this.

The provision of new shear connectors by drilling-in from under the top flange of the steel girders was examined. Several types of connectors were considered, including 20mm diameter spring steel pin fasteners. These offered the advantage of a readily achieved force fit into the hole drilled through the steel flange and lower section of the concrete deck slab with no requirement for grouting, glueing or welding.

Strength and fatigue testing were carried out on push-out samples by the Welding Institute at Cambridge. Samples were shown to have superior strength and fatigue properties to the 19mm studs. The pins obtain their force fit by jacking the lead-in chamfer into drilled holes with slightly smaller diameters, Figure 5. The spring mechanism is generated by the compression of a 2 turn spirally coiled strip of steel. Good interface shear connection is established, with a degree of pullout resistance afforded by the spring loaded friction between the pin and the hole face. In the event, the spiral pins were successfully installed with no interruption to the train services.

5. SUBSTRUCTURE STRENGTHENING

Existing substructures can be strengthened without traffic disruption by the simple procedure of load sharing using Shock Transmission Units (STUs). STUs are mechanisms which are connected across movement joints between structural elements. They transmit slow acting joint movements like temperature and shrinkage with negligible resistance and, when required, transmit momentary impact forces like traction, braking & earthquake with negligible movement.

A simple, economical and minimum maintenance bridge STU was developed in the UK some years ago. Instead of oil the STU utilises the peculiar properties of 'bouncing putty', a silicone compound which will readily deform under slow pressure but becomes rigid under impact. The unit consists of a steel cylinder containing a loose fitting position fixed to a transmission rod, the void round the piston being filled with the silicone putty. Under slow movement this putty is squeezed around the piston and displaced from one end of the cylinder to the other.

As described earlier, the London Docklands Light Railway viaducts will require heavier and more frequent trains, which will add braking and traction effects in excess of those originally catered for.

Figure 6 shows a typical as-built seven span deck unit, continuous between expansion joints. Train traction and braking loads are currently shared among the slender piers, which generally support the deck via rubber bearings. STUs have been installed, Figure 7, at rail level between joints such that, when the new increased longitudinal traction and braking loading is applied to one particular seven span unit, load is beneficially transmitted and shared with adjacent seven span decks sufficient to require no pier and foundation strengthening in any substructure. This simple procedure represents a tremendous saving in cost and interference with the existing train service.

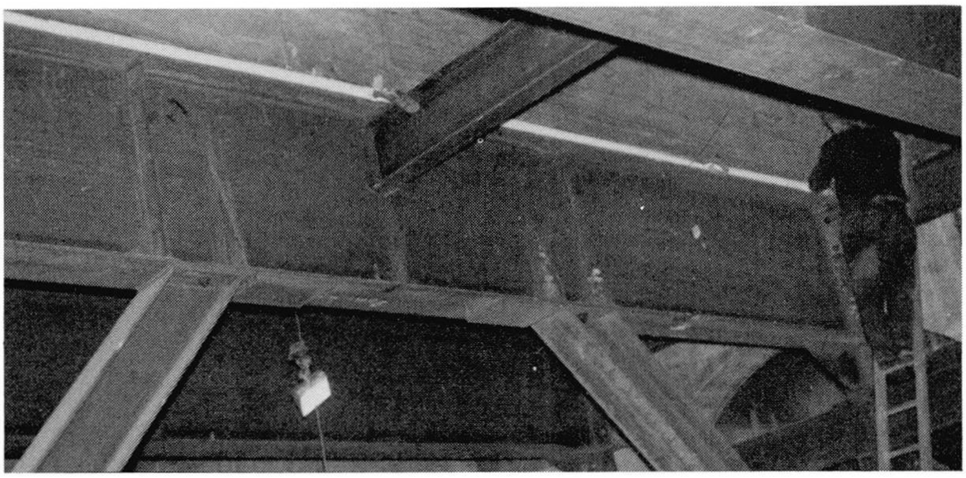

Fig. 1 Grout Bags Being Pressurised

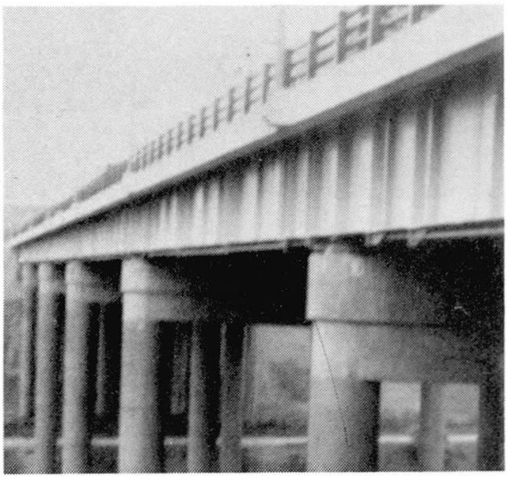

Fig. 2 Rakewood Viaduct

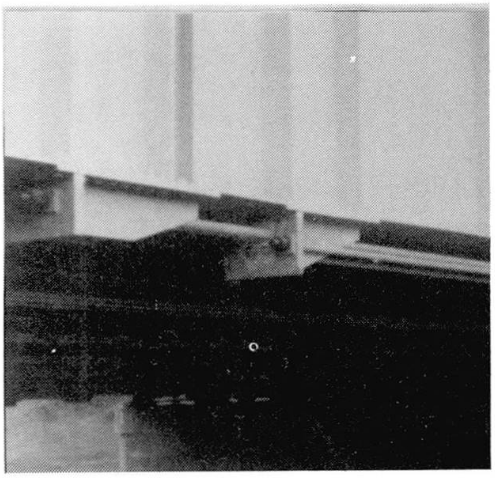

Fig. 3 Anchorages

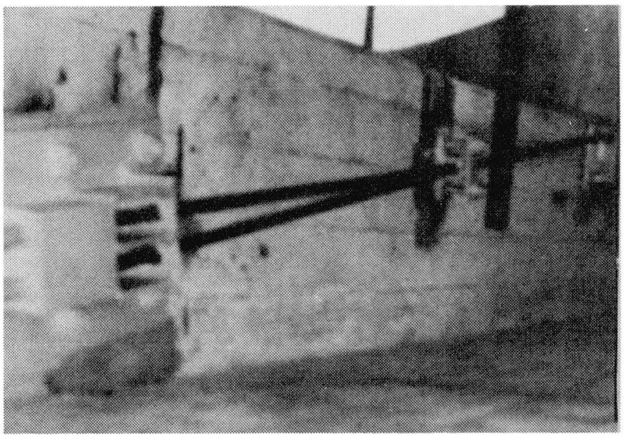

Fig. 4 Strengthened R C Beam

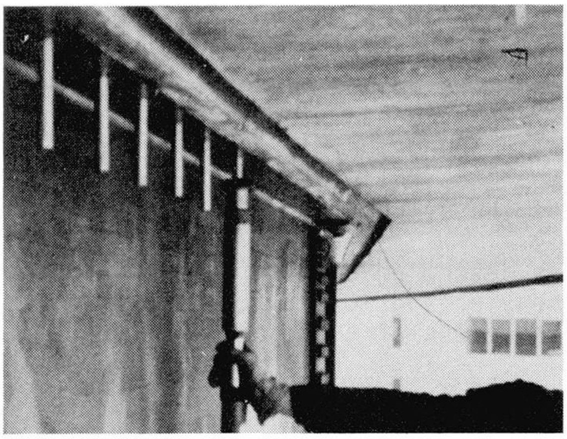

Fig. 5 Tension Pin Jacking

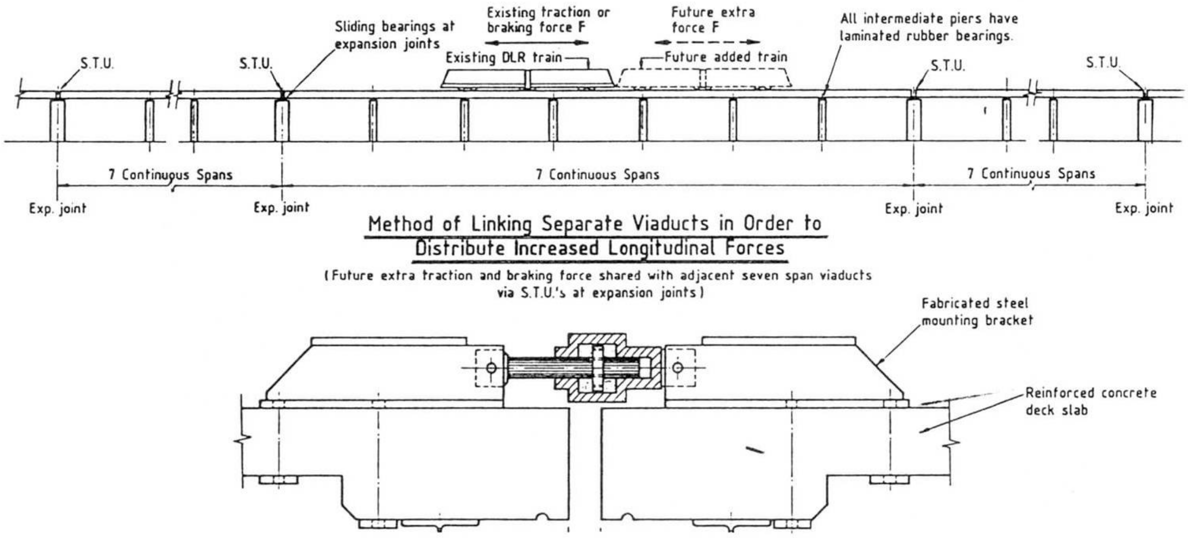

Fig. 6 Substructure Load Sharing Using STUs

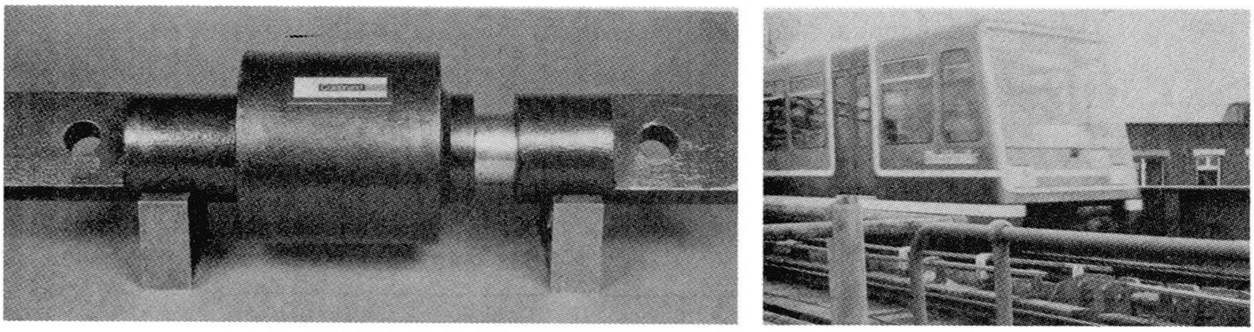

Fig. 7 STUs Installed