LOAD TESTING IN BRIDGE ASSESSMENT

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Bridges in the United Kingdom are being assessed to bring allowable gross vehicle weights in line with other European countries. Lower original design loads, corrosion of reinforcement and prestressing tendons, poor concrete quality and bad detailing have all contributed to a number of bridges failing assessments. Design of these bridges was normally based on conservative analytical methods. Therefore, assessment load ratings can often be increased by using other load paths. These include membrane action, surface stiffening and bearing restraints. As quantifying these effects is not straight forward, instrumented load tests have been used to calibrate analytical models. This paper describes the assessments, load tests and instrumentation carried out on several bridges that had corroded prestressing cables.

INTRODUCTION

Bridges in the United Kingdom designed before the introduction of BD37/88 loading are being assessed for live loads including 40 tonne vehicles. The assessment programme started in the mid-1980's and will bring allowable gross vehicle weights in line with other European countries. A number of bridges have failed assessments mainly as a result of less stringent design loads or because of strength deterioration. In concrete bridges strength reductions have been mainly due to corrosion of reinforcement and prestressing tendons. In extreme cases poor concrete quality, coupled with defective waterproofing and bad detailing, has permitted the ingress of water and de-icing salts and this has resulted in severe corrosion.

HIDDEN STRENGTH

Analytical methods used in the original designs of these bridges were often based on safe and conservative assumptions. However, with the advent of higher loads or reduced strengths, additional load paths must be proven to demonstrate safety. It is well established that there are a number of other factors that help to resist load in bridge decks. Amongst these factors are membrane action, surfacing stiffening, composite action and bearing restraint. Quantifying these effects is not straight forward and often cannot be based solely on better analytical models. However, instrumented load tests have been used to calibrate analytical models.

PRESENT CONDITION

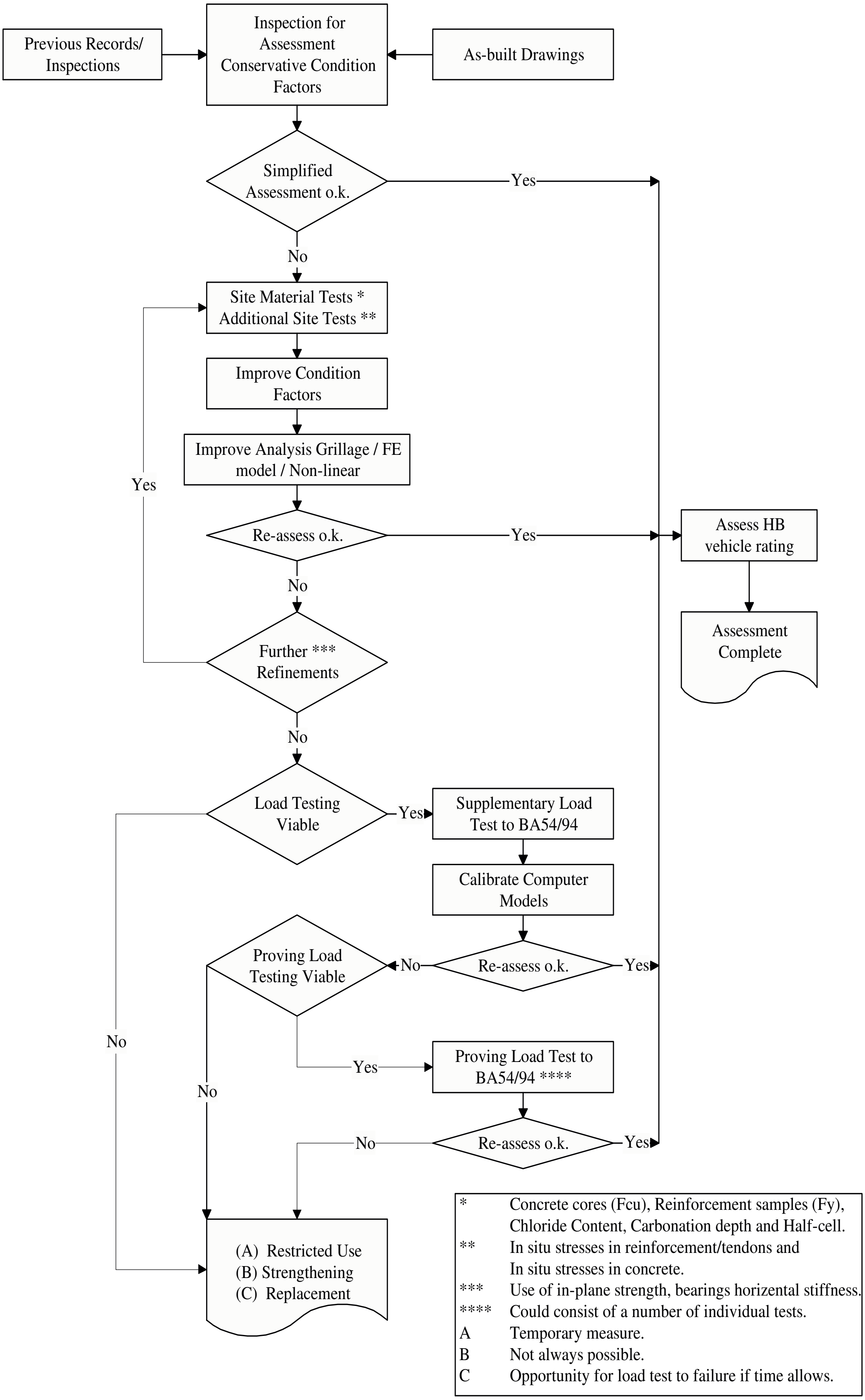
A bridge assessment normally starts by a simplified structural analysis using the information on the as-built drawings, including dimensions and characteristic strengths, following a visual site inspection to allow for any deterioration since construction. Condition factors are considered to allow for any deterioration [1]. If this simplified approach fails, further steps are required to improve the load rating of the bridge. Figure 1 shows a flowchart for a typical bridge assessment.

The additional steps include physical tests to establish the characteristic strength of concrete, reinforcement and prestressing tendons and chemical tests such as carbonation depth, chloride content and cement content which along with covermeter and half-cell potential surveys indicate the likely degree of corrosion vulnerability of the structure [2-3]. On certain occasions in situ stress determination in steel [4] and concrete [5-7] could also improve the understanding of the degree of prestress loss in the prestressed bridges. The overall results of the site tests and measurements can then be used to obtain a more accurate condition factor for the bridge. Additional steps may also include improved analytical methods such as grillage or finite element analyses.

When further refinement in the bridge analysis or material understanding is not achievable or when it becomes uneconomic, load testing should be considered. Load testing has been categorised by BA54/94 [8] as “Supplementary Load Test” or “Proving Load Test”. The former is used to improve the theoretical modelling of the bridge whereas the latter is used as a complete assessment by itself in place of the theoretical assessment in the context of an assessment flowchart such as Figure 1.

The authors have carried out Supplementary Load Tests and the computer model calibrations which followed. Load tests have been applied either by static or moving loads. The static loads included jacking against a support and using concrete or steel weights. Moving loads included using pre-weighed aggregate lorries or a single axle of 45 tonne similar to the HB vehicle in BS5400.

The Proving Load Test in principle is a high risk approach for the assessment. It has been used apparently with success by some research workers and certain organisations inside and outside the UK. Basically, Proving Load Tests should not be used unless the bridge is fully instrumented to measure strains in steel and concrete, and rotation and deflection at critical positions. When shear strength of the bridge is suspect, consideration should be given to the use of a displacement control loading system. In addition, diagonal strain in concrete and strain in stirrups must be measured.



*	Concrete cores (Fcu), Reinforcement samples (Fy), Chloride Content, Carbonation depth and Half-cell.
**	In situ stresses in reinforcement/tendons and In situ stresses in concrete.
***	Use of in-plane strength, bearings horizental stiffness.
****	Could consist of a number of individual tests.
A	Temporary measure.
B	Not always possible.
C	Opportunity for load test to failure if time allows.

Figure 1. Flowchart of Bridge Assessment including Load Tests

There is a risk that as a result of the Proving Load Test structural damage is inflicted to the bridge which may not be evident initially, but may lead to a rapid deterioration and sudden collapse. Therefore, bridges which have been the subject of a Proving Load Test should be monitored periodically.

TEST PROCEDURES

Improved analysis of the bridge deck is normally carried out either by the use of a grillage or a finite element computer model. This step happens before any consideration to load testing is given, see Figure 1. Therefore, it would be possible to determine a safe level of load to be used on the bridge as a Supplementary Load Test. Instrumentation used normally includes strain gauges and dial gauges to measure deflection at midspan. Loads are applied asymmetrically and gradually made symmetrical both with respect to midspan and longitudinal axis of the deck. If a static load is used, some form of partial or total lane closure is required. If a moving load is used, the test could be carried out with minimum disruption to traffic, preferably at early hours when temperature effects are minimal. Typical instrumentation and a loading regime are detailed in [9].

CALIBRATION OF COMPUTER MODELS

Results of the Supplementary Load Tests are normally in the form of variation of midspan soffit strains for the load at specific locations or variation of the longitudinal strains along a beam in the span direction. The former would help to define the degree of transverse load distribution and the latter reflect the existence of any bearing restraints. In addition, the summation of the total moment applied compared to those induced would indicate the degree of the composite action between the structural deck and the surfacing layers. However, it is not straight forward to isolate the effect of each individual item. Any composite action and bearing restraint could change with the level of loading and the ambient temperature. However, the lateral load distribution capability is less influenced by the above factors. Therefore, computer models are calibrated to produce similar lateral load distributions as the load tests by introducing orthotropic behaviour and varying the ratio of the elastic moduli in the two directions.

CASE STUDIES

Over 50 deck-spans have been load tested by Mehrkar since 1989 using a variety of loading systems. Construction varied from reinforced or prestressed concrete, filler deck and trough decks. In this section three types of prestressed decks are discussed.

- Single span decks, load tested with pre-weighed vehicles.
- Multispan simply supported decks, load tested with 45 tonne HB axle.
- Multispan complex deck structures, load tested with 45 tonne HB axle.

Single Span Decks, Load Tested with Pre-weighed Vehicles

The decks of these bridges consist of a number of precast pre or post-tensioned concrete beams which were transversely post-tensioned to provide load distribution. The overall assessment of these structures included material testing, in situ determination of concrete stresses by stress-relief coring [5,6], slot cutting technique [7] and Supplementary Load Tests. The material testing provided an improvement on the value of f_{cu} (Characteristic strength of concrete) and in situ stress determination helped to establish the level of prestress loss. In these cases the transverse distribution of the Supplementary Load Test were directly combined with a strip method of analysis to calculate the ultimate loads due to assessment loads. Some examples of this type of approach is detailed in reference [9].

Multispan Simply Supported Decks, Load Tested with 45 tonne HB Axle

The Hayling Island bridge was built in 1955 to replace an old timber bridge, which connected the island to the mainland at Langstone. The present bridge is in prestressed concrete and consists of 29 simply supported spans of 9.75m. In addition, four spans of 2.14m occur at roughly the fifth points. The decks are supported at each end by five reinforced concrete piles. A reinforced concrete capping beam cast in situ is supported on the piles. The 9.75 m spans consist of 16 rectangular prestressed concrete beams 457mm deep, placed side by side, jointed with a dry packed mortar and transversely stressed with twelve 5mm diameter Freyssinet wires. Each beam was post-tensioned with two 28.6mm diameter Lee-McCall bars laid to a parabolic profile. A full description of the construction procedure was published by Melrose and Eyre in 1957[10].

The first span from the mainland side of the bridge was load tested by the Cement and Concrete Association in 1957[11]. In addition, two precast beams were load tested to destruction, one at an age of 3 months and one at an age of 2 years. These tests indicated prestress losses of 3% and 22% respectively.

In 1989 further work was carried out by Gifford and Partners. In situ concrete stresses were measured by taking 3 instrumented stress-relief cores[5,6] and 3 instrumented slot-cuts[7] in spans 1,4 and 14. These spans were chosen after getting a finger print of all the spans under a 45 tonne axle similar to HB vehicle performed over night to reduce disruption to traffic. Each span was instrumented with 12 vibrating wire gauges on the soffit at midspan. Strains were measured in the longitudinal and transverse directions of the deck and across the longitudinal joints between the beams.

The estimated prestress loss in the longitudinal direction ranged between 5% to 33% which was comparable to those of 1957[11]. The results of the load test was also compared with those of 1957[10], a Morice and Little[12] load distribution and an isotropic finite element computer model, Figure 2. The loss in transverse prestressing was about 44% with a remaining compressive stress of 1.7N/mm^2 across the longitudinal joints between the beams. The joints were full of dry packed mortar.

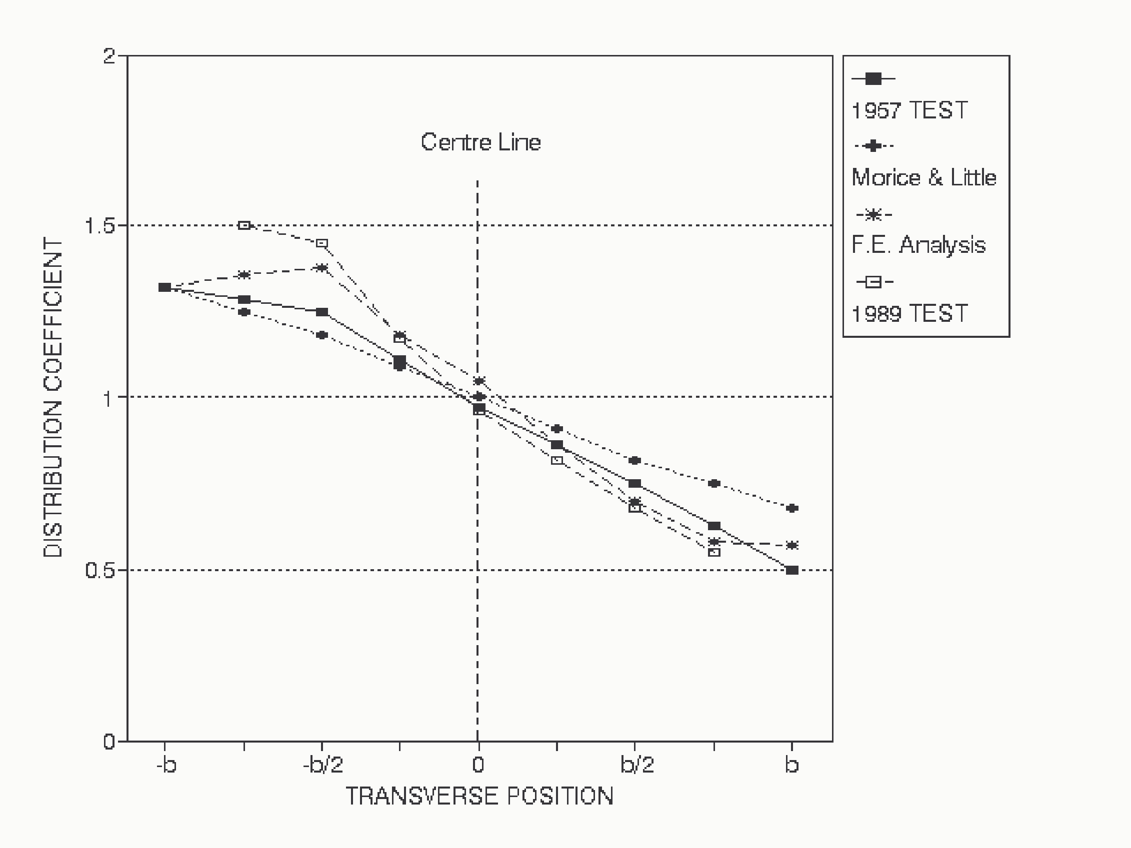


Figure 2 Lateral load distribution

Figure 2 shows that the lateral load distribution characteristics of the bridge have deteriorated since its construction. This is not unexpected considering the aggressive environment of the bridge. The results of the load test were then used to calibrate a finite element model of the deck using orthotropic elements which gave a ratio of 0.25 between the transverse and longitudinal elastic moduli. The remaining compressive stress of 1.7N/mm^2 across the longitudinal joints between the beams was adequate to provide some degree of lateral load distribution. The bridge is still being monitored and its condition was improved by providing a water proofing membrane and repairing the concrete cover to the transverse prestress anchorages.

Multispan Complex Deck Structures, Load Tested with 45 tonne HB Axle

The Angel Road Railway Bridge was built in 1960 to replace an earlier road bridge constructed in 1908. It is situated in the London Borough of Enfield, about six miles north of the centre of London, and carries the North Circular Road, A406. The construction details of the bridge were described by Mason in 1962[13]. It consists of three traffic lanes per carriage way, a central reserve and a wide footway either side of the deck.

The decks of the ten span bridge are made of 59 rectangular pre-tensioned beams 610mm deep and 381mrn wide, placed side by side. The width of the beams reduce to 362mm at the top, allowing a concrete topping to infill between the beams. The decks are post-tensioned in the transverse direction by Freyssinet cables positioned every 1.5m along the length of the bridge.

The first seven spans of the bridge from the west are of continuous construction. In these spans, precast beams are supported by half joints at the end of pier cantilevers. The continuity is provided by post-tensioning of the beams through the pier cantilevers. The remaining three spans are simply supported.

In the early 1980's, corrosion of the longitudinal post-tensioning was noticed at the anchorage points. Gifford and Partners were commissioned to strengthen the bridge and in 1982 a series of steel frames were added to the support ends of the precast beams in the continuous spans. The authors became involved in the latter half of 1990 to make a present condition assessment of the bridge as part of the Department of Transport assessment programme. It was decided, due to the complex nature of the structure, that a direct approach was required to establish the load distribution of the bridge and the actual level of prestress left in the structure. The former was achieved by running a 45 tonne axle similar to an HB vehicle over the bridge and monitoring longitudinal strains on the soffit of the precast beams at midspan using 11 vibrating wire gauges per span. The latter was achieved by taking 6 instrumented stress-relief cores[5,6] and 2 instrumented slot-cuts[7] on the soffit of precast beams in the main railway span over a 30 hour weekend possession. In addition, material tests were carried out on the cores retrieved from the structure. The load test was performed after midnight to minimise any disruption to traffic. The HB axle was run along the fast lane of one carriageway and the slow lane of the other.

The measured values of in situ stresses indicated a residual compressive stress between 0.5 and 2.5N/mm^2 in the longitudinal direction and 1.5N/mm^2 in the transverse direction. The load test results used to calibrate a full 3D finite element model of the deck. The final calibration concluded that there should be no continuity in the transverse direction between the beams. This result was not unexpected as almost all the packing mortar between the beams was missing in the middle part of the deck. In addition, calibration indicated that the topping concrete should be an orthotropic plate with a ratio of 0.5 between the transverse and longitudinal elastic moduli. Almost a perfect match between the analysis and the Supplementary Load Test was obtained for the distribution of the load at the slow and fast lanes of the bridge.

The 3D model was then used to calculate all the internal forces in the bridge. The bridge was found to be capable of carrying the 40 tonnes Assessment Loading to BD21/93. In addition, the HB rating and Abnormal Indivisible Load rating of the deck was assessed to be 45 units and 280 tonnes, respectively.

CONCLUSIONS

It has been demonstrated that Supplementary Load Tests enable improved assessments to be made. The tendency to extrapolate from the results of this type of load test to ultimate limit state in the wake of a possible loss of effects such as composite action of the deck, stiffness of the surfacing layers and bearing restraints could be minimised if the lateral load distribution characteristics of the deck is calibrated in the computer model. Occasionally, for single simply supported spans a combination of the load test distribution results and a strip method of analysis is adequate to finalise the assessment. Assessment ratings of a number of bridge have been increased with the combination of in situ stress determination, Supplementary Load Tests and calibrated computer models.

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