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The Use of Model Analysis and Testing in Bridge Design

Application des essais sur modèles à l'étude des ponts

Über die Anwendung von Modellversuchen zur Bemessung von Brücken

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Introduction

Model testing techniques have been employed in research into the structural behaviour of bridges for some considerable time and, in particular, have been used by the Cement and Concrete Association in virtually all its research on this subject. In recent years attention has been paid to the application of model testing as a logical and economical aid to design, being used either to verify assumptions made in a formal analysis or, where no such analysis is possible, to supply the fundamental design data.

This paper describes briefly three model tests on bridge structures which indicate the usefulness of model testing as a design aid with reference to the entire range of structural behaviour. Two of these tests were aimed at studying the elastic behaviour of the bridge superstructures and the third was concerned essentially with the ultimate load behaviour having regard to the proposed method of construction.

Huntley's Point Overpass, Australia [1]

This overpass forms part of the complex of roads associated with the Gladesville Bridge scheme and was designed by G. Maunsell and Partners. It is a prestressed concrete bridge with a multi-cell, varying section hollow spine beam and cantilevering deck slab; in plan the bridge is curved to a radius of 350 ft. along its centre-line. The main span of 165 ft. is a propped cantilever which has an anchor span of 57 ft.; the remaining spans are all of 80 ft. and form a continuous beam. At each support, two bearings are provided on a single column.

The design required the cantilever and anchor spans to be constructed first and then the reactions adjusted by jacking, to reduce certain critical bending moments in the completed structure, before the remaining spans are built and made continuous with the cantilever span; thus the main span is a propped cantilever for the live load and only a portion of the dead load. The information required to complete the design was (1) the self weight deflexions and reactions during the first stage of the construction; (2) the change in the reactions and deflexions caused by jacking or tying down at various supports; and (3) the live load influence lines for deflexion and reaction in the completed structure.

To provide the above information a Perspex model to a $^1/_{48}$th scale was constructed of three spans as shown in Fig. 1; in this figure $A B$ is the anchor

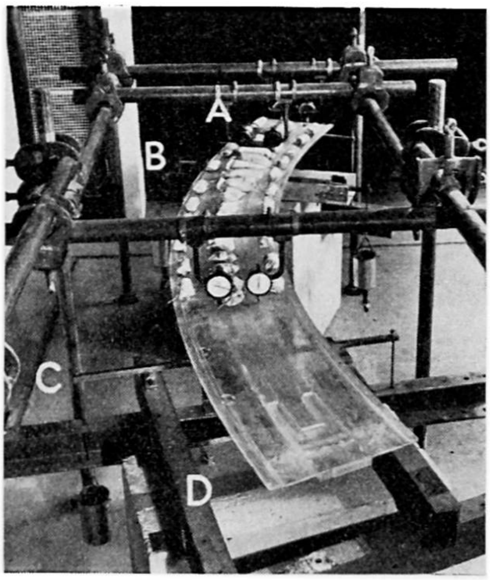

Fig. 1. Huntley's Point Overpass — Model showing application of simulated self weight.

span, BC the main span and CD the first of the series of 80 ft. spans. Perspex was chosen as the model material because information was required only on deflexions and reactions, which are not sensitive to the value of Poisson's ratio, and the scale could be considerably reduced. At support A the model was tied to the reaction frame through threaded rods which could be replaced by tins of lead shot when recording the tie down forces; at B ball supports were provided for most tests these giving the required freedom to rotate but fixing the model in a horizontal direction; at C two lever supports were provided acting on the model through push rods thus enabling lateral movement to take place and adjustable supports for the levers enabled a rigid support condition to be attained when required.

In the tests, the self weight of the structure was simulated by the use of small bags of lead shot as shown in Fig. 1; these were arranged to give the correct distribution of self weight and deflexions of sufficient magnitude for accurate measurement. When the deflexion distribution was being determined, 0.0001 in. dial gauges were placed at five points across the width of the model at selected transverse sections. The reactions due to the self weight were simply determined by adjusting the reactions being weighed until the positions of the six points of support were the same as those prior to the application of the self weight.

In the tests to study the effect of live load a point load of 4 kg was applied at points lying on selected transverse sections and on six longitudinal sections; these were the centrelines of the edge beams (lines *a* and *b*) sections 2 ft. from edge beams (lines 1 and 4) and above the external webs of the spine beams (lines 2 and 3). Deflexion and reaction influence lines were found in a similar manner to those in the self weight tests. A typical reaction influence line, as found from the model, is given in Fig. 2.

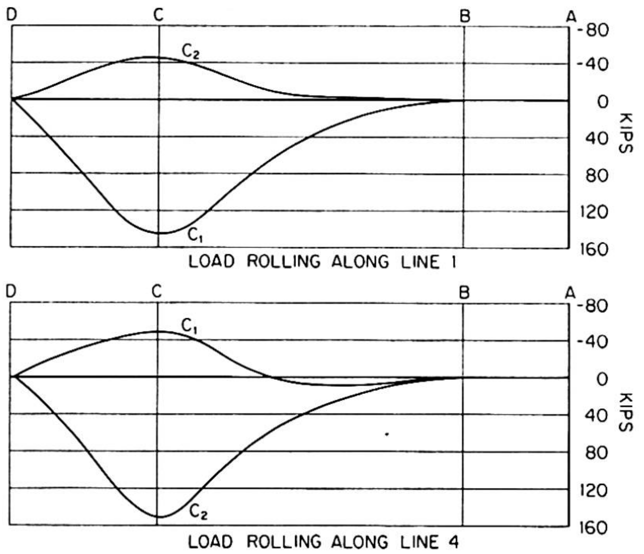

Fig. 2. Huntley's Point Overpass — Influence lines for reaction C1 and C2 due to point loading of 100 Kips.

Cumberland Basin Slab, Bristol [2]

The bridge is part of a complex intersection of elevated roads, and is formed of a 24 in. thick, continuous reinforced concrete slab with edge thickening. The slab is supported by uniform section columns in lines of three across its width; the arrangement of columns to allow a road to pass underneath, at a considerable angle of skew, is shown in Fig. 3. The information required by the designers (Freeman, Fox and Partners) concerns the slab stresses and

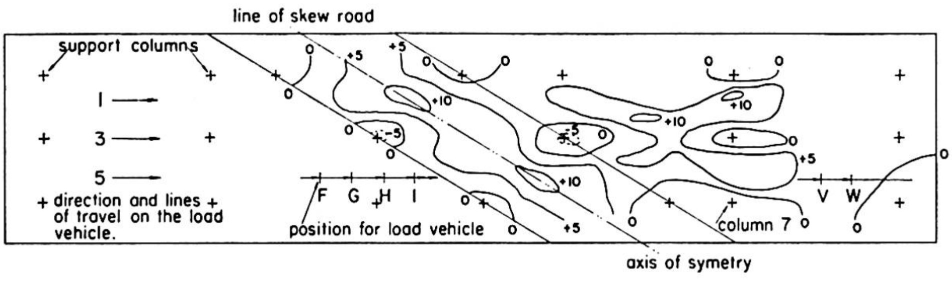

Fig. 3. Cumberland Basin Slab — Transverse strain contours due to uniform loading.

column reactions under the action of uniform load and *H B* loading (a 180 ton, 16 wheeled vehicle). The model was made of concrete to ensure a similar value of Poisson's ratio to that in the actual structure since this ratio affects the distribution of load very considerably. The model was 120 in. long, 27 in. wide and 1 in. thick and was uniformly prestressed in two directions to allow larger strains (which are easier to measure) in the concrete without cracking and consequent loss of stiffness. It is thought that, up to working load on the actual structure, the behaviour of the reinforced structure will approximate closely to that of a prestressed slab since the fairly low value of stress (18,000 lb./in.^{2}) which is allowed in the reinforcement will give rise to only small cracks and little loss of stiffness will result.

The supports for the columns of the model were formed of small, but stiff, load cells for measuring the reactions, and 38 rosettes of electrical resistance strain gauges were attached to the surface of the slab. The strain gauge readings were obtained with a 100 channel digital recorder producing punched paper tape enabling the readings to be processed directly on a Ferranti "Sirius" computer. The speed with which the results were obtained was considerably increased by this means and as a result over 250,000 readings from 20 reactions and 38 rosettes for uniform loading, 54 vehicle positions and 36 individual point loadings were obtained in 15 weeks.

Fig. 3 shows the contour lines for transverse stress (in units of 100 lb./in.^{2}) caused by a uniform load of 1250 lb./ft.^{2}. These figures would also apply to the actual structure. The transverse stresses were generally the critical stresses for point and vehicle loadings. Fig. 4 shows the influence line for the reaction on column 7 (see Fig. 3) due to a 4000 lb. vehicle load moving down each edge and the centre of the road-way.

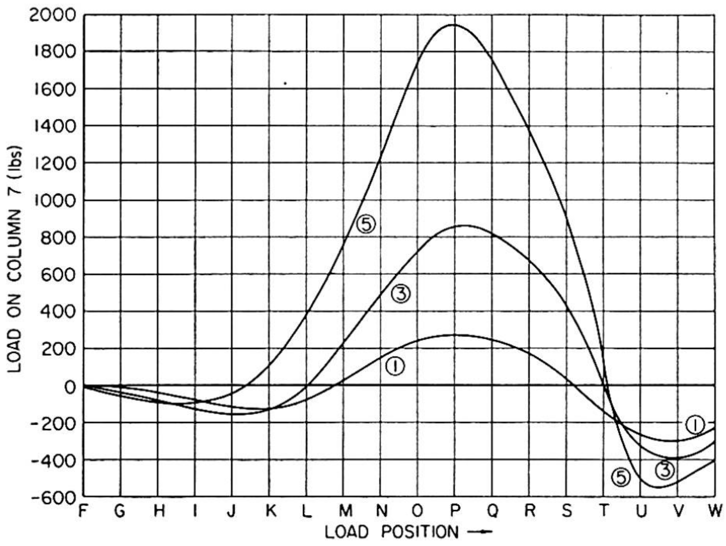

Fig. 4. Cumberland Basin Slab — Reaction on column 7 for vehicle loading.

Hammersmith Flyover, London [3, 4]

This bridge is an elevated road, carrying four traffic lanes, over a total length of 2,054 ft. with the majority of the spans being 140 ft.; the structure is comprised of a varying section hollow box spine beam, precast in 8 ft. 6 in. sections, and precast cantilever diaphragm units 12 in. thick, which are jointed together and post-tensioned to form two beams continuous over 1,237 ft. and 817 ft. with an expansion joint between them. Precast reinforced concrete slabs span between the cantilever arms of the diaphragms and these are connected by in situ reinforced concrete edge beams and joints over the diaphragms and with the spine beams.

In the design, the consulting engineers, G. Maunsell and Partners, wished to check the ultimate load characteristics of the main structural member, the spine beam, at an intermediate support under the required condition of combined bending, torsion and shear and, in particular, to study the behaviour of the jointed structure under these conditions. A model in reinforced and prestressed micro-concrete or mortar was considered to be the only means of obtaining this information.

A model to a $^1/_{12}$th scale was built using the precast reinforced concrete units shown in Fig. 5; it consisted of an in situ reinforced concrete column and

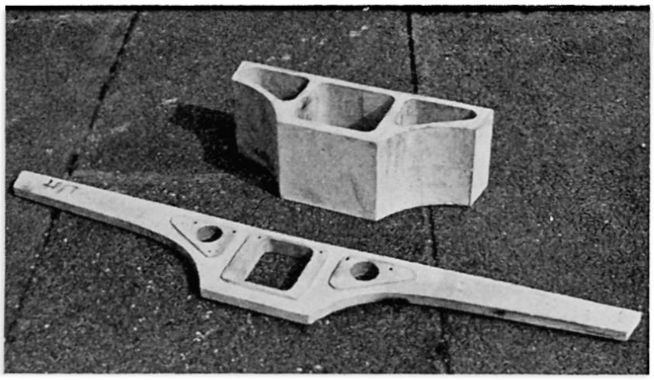

Fig. 5. Hammersmith Flyover — Basic units used in construction of model.

column head on both sides of which were jointed two spine beam units, two diaphragms and two further solid spine beam units thus forming a balanced cantilever system. The joints in the model were $^1/_4$ in. wide and were made with a dry packed mortar; when these had attained the required strength the balanced cantilever was post-tensioned to scale. It should be noted that only the critical section adjacent to the column was reproduced in the model and that the quality of the micro-concrete was the same as that of the concrete to be used in the actual structure.

In the tests two loading conditions were considered; these were:

(1) a load factor of 1.5 on dead load, a load factor of 2.5 on the live load in two traffic lanes and 1.0 factor on that in the remaining lanes; and

(2) a load factor of 1.5 on dead load and a load factor of 2.5 on the live load in the two traffic lanes on one side of the spine beam, the remaining lanes being unloaded.

Loading was applied by two jacks in increments of one ton to a maximum load of 7 tons, the required ultimate load for condition (1) being 6.81 tons. Cracking became apparent at a load of 5 tons and consisted of bending and torsion cracks in the units with some rotational movement in the joints adjacent to the column head. At 7 tons the torsion cracks had penetrated into the column head itself. The load was removed and re-applied with no worsening of the cracking.

The loading condition (2) was then applied to failure; a maximum load of 5.9 tons was attained at which load crushing of column head, under the combined stresses, occurred. The critical section at failure is shown in Fig. 6; the rotational permanent set shown in the figure was about 5 degrees.

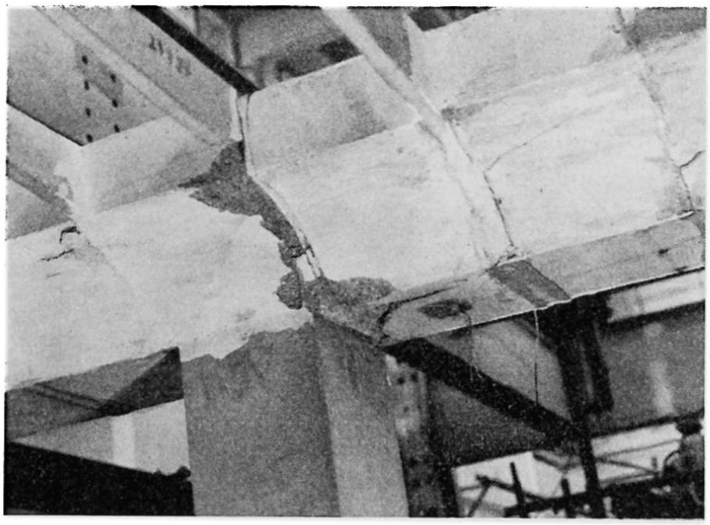

Fig. 6. Hammersmith Flyover — Detail of Failure.

This model test showed the adequacy of the structure from an ultimate load point of view and also gave information on the stress distribution in the spine beam units prior to cracking which confirmed the relaxation approach used in assessing the torsional stresses.

Conclusions

Model analysis and testing, although an established technique in many engineering fields, has not been employed widely in bridge design. Its usefulness as a design aid is clearly illustrated by the, necessarily brief, descriptions given in this paper of model tests relevant to three specific bridges. In these, the model tests gave only a part of the data necessary for the designs to be completed; in future applications it is likely that model testing will be used to provide all or nearly all of the necessary data, particularly in the more complex bridge structures where no rigorous analysis is possible and an approximate analysis can, at best, give only an indication of the true behaviour.

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Summary

Tests on models of three bridge designs are briefly described; the material and scale of the models were selected having regard to the information required from the model test. These tests illustrate some of the uses of models as a design aid in obtaining information concerning the elastic and ultimate load behaviour of bridge structures which cannot be obtained by analytical procedures.

Résumé

Les auteurs décrivent brièvement des essais effectués sur les maquettes de trois projets de ponts; on avait choisi le matériau et l'échelle de ces maquettes en fonction des renseignements que l'on désirait en obtenir. Ces essais illustrent quelques-unes des utilisations des maquettes comme instrument d'étude permettant d'obtenir des informations sur le comportement des ponts sous les charges de service et celles de rupture, informations que ne sauraient donner des méthodes analytiques.

Zusammenfassung

Es werden Modellversuche für drei verschiedene Brücken kurz beschrieben; Modellmaterial und Maßstab wurden jeweils den vom Modellversuch verlangten Aufschlüssen angepaßt. Diese Untersuchungen zeigen, wie auf dem Wege des Modellversuchs in Fällen, die sich ihrer Kompliziertheit wegen einer analytischen Behandlung entziehen, sowohl das (elastische) Verhalten unter den Gebrauchslasten als auch das Verhalten im Bruchzustand untersucht werden kann.

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