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IX

Investigation and Failure Test of a Prestressed Concrete Bridge

Examen et essai de rupture sur un pont en béton précontraint

Untersuchung und Bruchbelastungsversuche an einer vorgespannten Betonbrücke

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SUMMARY
A 20 years old continuous prestressed concrete slab bridge was investigated and tested to failure to verify the assumptions generally used in bridge calculations. The failure load was nearly as predicted using the theory of plasticity, but the failure mechanism indicates, that the theory of plasticity must be used with caution, especially for concrete slabs, where the absence of stirrups leads to a rather small rotational capacity.

RESUME
Un pont dalle de vingt ans, en béton précontraint, a été examiné et chargé jusqu'à la rupture pour vérifier les hypothèses généralement utilisées dans le calcul des ponts. La charge de rupture était à peu près celle prévue suivant la théorie de plasticité, mais l'évolution de la rupture a démontré que la théorie de plasticité doit être utilisée avec précaution, surtout en ce qui concerne les dalles en béton où l'absence d'étriers conduit à une faible ductilité.

ZUSAMMENFASSUNG
Eine 20 Jahre alte, durchlaufende, vorgespannte Betonplattenbrücke wurde untersucht und bis zum Bruch belastet, um die Voraussetzungen für die Brückenberechnung zu überprüfen. Die Bruchlast war nahe dem erwarteten Wert entsprechend der Plastizitätstheorie, doch zeigte der aufgetretene Bruchmechanismus, dass die Plastizitätstheorie mit Vorsicht anzuwenden ist, besonders bei Betonplatten, wo das Fehlen von Bügelbewehrung eine sehr begrenzte Rotationskapazität zur Folge hat.

1. INTRODUCTION

Bridges in Denmark and in many other countries are subjected to increasing traffic volumes, heavier loads and different environmental conditions, which for both steel and concrete bridges in time can give weaknesses and deterioration of the structures. Therefore it is important for bridge engineers to investigate older and apparently "healthy" bridges, to test the bearing capacity and to verify design criteria. However, reports on loading tests to failure with such bridges are few.[1, 2, 3, 4, 5, 6 and 7].

In connection with the extension of the Copenhagen-Hørsholm motorway to Elsinore in 1974, a bridge became redundant, as the new part of the motorway were to by-pass the bridge. The bridge was one of the first prestressed concrete bridges in Denmark, designed by Chr. Ostenfeld & W. Jønson (now Cowiconsult) in 1955 and built in 1956. [8] . It was a unique opportunity to carry out a loading test on a rather old bridge, to verify the design assumptions applied such as ductility and rotational capacity, to study the influence from the environment on concrete and reinforcement in the bridge deck, and finally to see how effective the cement grout in the tendon ducts had protected the prestressing reinforcement against corrosion.

Based on a proposal from Cowiconsult, Vejdirektoratet (the Danish Road Directorate) decided in 1977 to grant the necessary funds for a loading test and investigations of concrete and reinforcement etc. of the bridge.

The loading test and the investigations were planned and supervised by Cowiconsult in collaboration with Vejdirektoratet and Statens Vejlaboratorium (The National Danish Road Laboratory).

This paper, which is a translated condensation of the test report published by the Danish Road Directorate [9], gives the basic test results, test procedures used and compares the measured ultimate load with the theoretical load according to the theory of plasticity.

2. DESCRIPTION OF BRIDGE AND PREPARATIONS FOR TEST

In fig. 1 is shown a plan of the bridge.

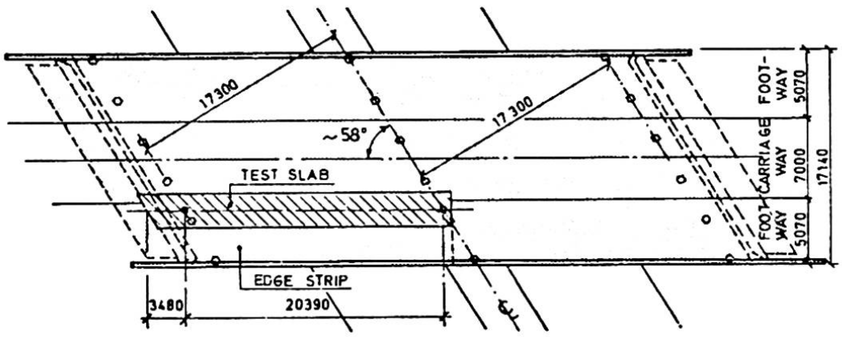

Fig. 1. Plan of the bridge. Test slab indicated.

The superstructure was a solid continuous slab over two spans. It was reinforced longitudinally with 12 Ø 7 mm post-tensioned Freyssinet cables placed in groups of 9 and with mild steel Ø 12 at 700 mm.

The substructure was reinforced concrete. The supports were hexagonal columns fixed at 3 continuous foundation beams, founded directly on firm soil.

The connection between column and bridge deck was a semi-concrete-hinge.

As the bridge was skew, testing of the entire bridge would give a rather complicated stress-strain picture, which would be difficult to measure and interpret. Furthermore the wide bridge deck would require a large and expensive load arrangement. Therefore it was decided to cut up the bridge deck into a slab strip over one span length. The width of the slab strip (2.8 m) was chosen so that the slab strip would contain 2 cable groups.

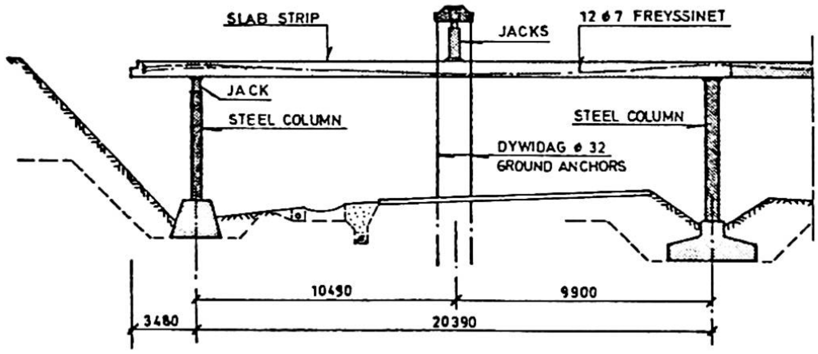

Fig. 2. Slab strip. Elevation. Load arrangement.

As the concrete columns were placed excentrically to the groups of posttensioned cables, it was decided to replace the two affected concrete columns with temporary steel columns, placed in such a way that the test slab would be subjected to bending and shear only.

As the slab strip was statically indeterminate, a hydraulic jack connected to a pressure gauge meter was placed at top of the end steel column to measure the end reaction of the slab strip. The arrangement is shown in fig. 2 and 3.

The top surfacing and the edge strip (see fig. 1) of the bridge deck were removed.

3. INSTRUMENTATION AND TESTING PROCEDURE

The slab strip was instrumented for strain and deflection measurements. The surface strains were measured with a "Pfenderruler" over a gauge length of 300 mm giving a precision of 3.3×10^{-6} mm/mm.

The deflections were measured to 18 levelling staves suspended in pairs under the slab strip. All deflection readings were taken from 2 levels.

The test load was transmitted from a ground anchor system through a steel structure and two jacks to two base plates on the slab strip.

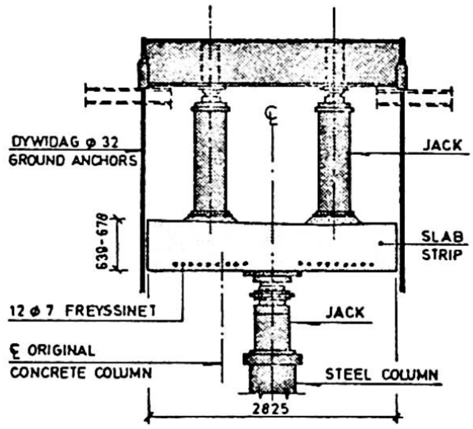

Fig. 3. Slab strip. Cross section at midspan. Load arrangement

The ground anchor system consisted of DYWIdag MONOanchors drilled 10 m into the ground and grouted over a length of 4 m. In each anchorbar was inserted a 1 m long bar provided with strain gauges.

The two jacks on the bridge slab were double action hydraulic jacks, installed in parallel. Each jack had a max. stroke of 900 mm and a max. jacking force of 2000 kN at 320 bar. The applied load was measured at each load interval by strain gauge readings on the 4 Dywidag bars.

The load was applied in increments of 150-200 kN with a loading rate of 100 kN per minute. At each load increment, the recordings were taken 10-15 minutes after the load had been increased.

The slab strip was first loaded up to one load increment above the theoretical flexural cracking load, then the slab strip was unloaded at a rate of 400 kN per minute to approx. 300 kN, then reloaded to the former load level and unloaded again to approx. 300 kN. After 3 load cycles, the development of new cracks stopped and existing cracks became stable in length and width.

4. EXPERIMENTAL RESULTS

The load-deflection curve at the midspan is shown on fig. 4, and the curvatures at sections at midspan and at interior support are shown in fig. 5.

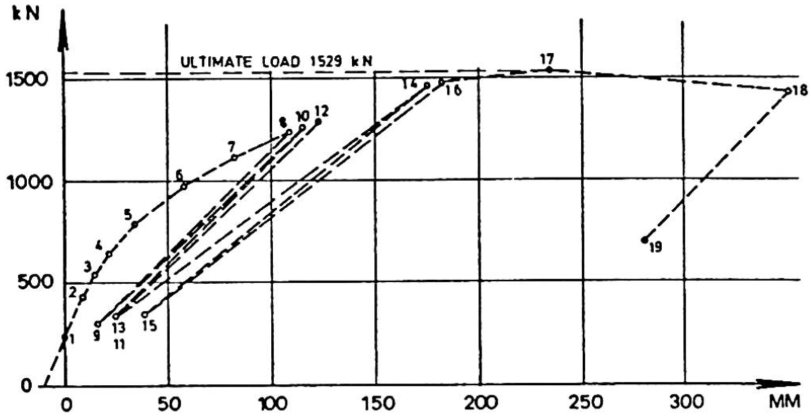

Fig. 4. Load-deflection curve for point at midspan.

In fig. 5 is indicated when the first crack in the area became visible. Furthermore are shown the theoretical curvatures based on that plane sections remains plane; besides the measured tensile strength of the concrete is taken into account - also during the crack development - and the measured stress-strain relationship for the concrete and the reinforcement is used.

The first sign of distress was observed in the compression zone near midspan for an applied load equal to 1464 kN. The load was maintained for about 10 minutes without any measurable effect on the load-deflection behaviour.

After the load was increased to 1529 kN the slab strip collapsed. Fig. 6 shows the failure mechanism.

No yielding at the interior support (point b) was observed; after the test all cracks at point b were closed again. Fig. 7 shows the collapsed slab strip.

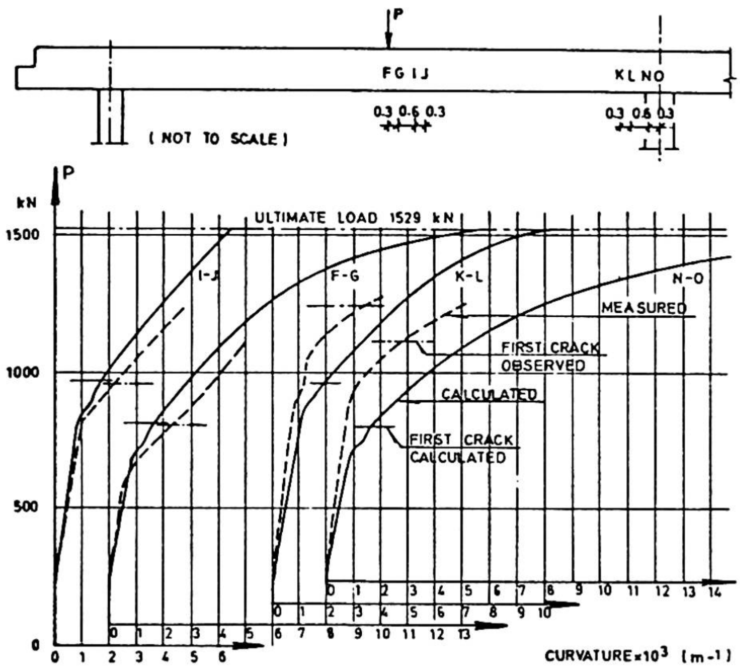

Fig. 5. Curvatures at sections at midspan and at interior support.

5. THEORETICAL CONSIDERATIONS

After the bridge deck was cut up into a slab strip and the new steel columns were installed, an almost fixed/simply supported beam system was obtained.

Based on the measured mean strength for the concrete and the measured stress-strain curve for the reinforcement the theoretical ultimate moments at midspan and at interior support were determined.

$$M_m^{u,t} = 6796 \text{ kNm} \quad \text{and} \quad M_i^{u,t} = -6401 \text{ kNm}$$

To have a proper plastic mechanism, two hinges must be formed, one at midspan (at the applied load) and one at interior support.

We found, that the theoretical ultimate load was

$$P^{u,t} = 1569 \text{ kN}$$

where the failure test showed $P^{u,r} = 1529$ kN.

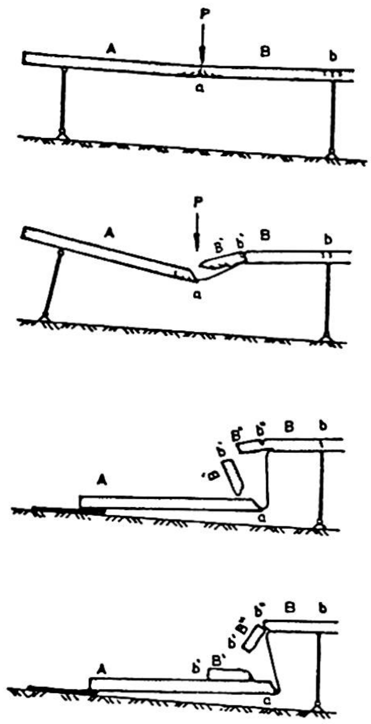

Fig. 6. Failure mechanism.

Fig. 7. The collapsed slab strip.

6. CONCLUSIONS

The real bearing capacity of the slab strip corresponded well with the calculated bearing capacity based on the theory of plasticity, although the failure mechanism showed that the bearing capacity of the concrete section at the interior support was not reached. In this connection it must furthermore be kept in mind that the relatively rigid fixed support should give excellent conditions to utilize the full bearing capacity in this section. For the entire bridge with live load placed in one span only, the relation between moments at midspan and at interior support would have been more disadvantageous for the section at midspan than at the tested slab strip.

The test results therefore point out to be cautious, when using the theory of plasticity for continuous slabs, where the absence of stirrups leads to rather small rotational capacity.

The midspan deflection of the slab strip at failure was 1/70 of the span length. This corresponds reasonably well with findings from similar failure tests.

The investigation of concrete samples taken from the bridge deck showed that the concrete was sound with no signs of damaging alkali-silica reactions or deterioration from freeze-thaw cycles, although the coarse aggregate contained flintstones and the air-content of the concrete did not satisfy the requirements, which - with today's knowledge - are specified for a frost-resistant concrete.

The reinforcement was as for a new bridge and the cement grout in the cable ducts had protected the prestressing steel extremely well.

The prestressing force in the cables was found to be slightly larger than assumed in the original design calculations.

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