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Autor: Plos, Mario / Gylltoft, Kent / Cederwall, Krister

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Full-Scale Shear Tests on two Bridges

Essais de cisaillement in situ sur deux ponts

Querkraftversuche in voller Skala auf zwei Brücken

Mario PLOS
Res. Assist.
Chalmers Univ. Technol.
Göteborg, Sweden

Kent GYLLTOFT
Prof. Dr.
Chalmers Univ. Technol.
Göteborg, Sweden

Krister CEDERWALL
Prof.
Chalmers Univ. Technol.
Göteborg, Sweden

SUMMARY

Full-scale shear tests were performed on two concrete highway bridges constructed in 1980. The test results reveal short-comings in the design models when a combination of shear and moment actions leads to failure. The results show the need for better design models based on a clear physical understanding of failure. Fracture mechanics can be used together with the finite element method to obtain a better understanding of the failure process.

RÉSUMÉ

Les tests de cisaillement concernent deux ouvrages construits en 1980, les essais ayant été menés sur les ponts eux-mêmes. Les résultats montrent des défauts dans les modèles d'étude existants lorsque la rupture est due à l'action combinée des moments et de l'effort tranchant. Il s'agit donc d'établir de meilleurs modèles basés sur une compréhension physique claire du phénomène de rupture. La mécanique de la rupture utilisée conjointenement à la méthode des éléments finis permet d'obtenir une meilleure compréhension dans ce domaine.

ZUSAMMENFASSUNG

Grossversuche zur Schubtragfähigkeit von zwei 1980 erbauten Betonstrassenbrücken wurden durchgeführt. Die Versuche zeigen Mängel am Berechnungsmodell auf, wenn eine Kombination von Querkraft und Biegemoment zum Bruch führt. Die Ergebnisse beweisen die Notwendigkeit von besseren Berechnungsmodellen basierend auf physikalischem Verständnis des wirklichen Bruches. Bruchmechanik wird zusammen mit der Finite Element Methode verwendet, um ein besseres Verständnis des Bruchverhaltens gewinnen.

1. INTRODUCTION

The design rules for shear capacity set out in the European concrete codes is mainly based on laboratory tests on a comparatively small scale. In two full-scale tests we had the possibility to investigate the shear capacity for considerably larger structures than is normal in laboratories. The full-scale tests were performed on two concrete highway bridges, constructed in 1980. Both bridges were loaded close to one of the supports in order to cause shear failure.

The purpose of the tests was to improve knowledge by examine the bearing capacity of the bridges, and to study how these big and complex structures act under shear load leading to failure. The test results were compared with the design model in the Swedish concrete code. The results indicate that the design models are able to predict the shear capacity in cases where typical shear failures are achieved. In more complex cases, however, when a combination of shear and moment actions leads to failure, clear shortcomings were found in the design models of the code.

The tests are also intended to be used to improve methods of analysis. Finite element models of the bridges intended for fracture mechanics analysis are now under evaluation.

2. FULL SCALE SHEAR TESTS

2.1 The bridges

Full scale shear tests were performed on two concrete portal frame bridges. One of the bridges was a non-prestressed slab frame bridge with a free span of 21 m (fig 1 and 2).

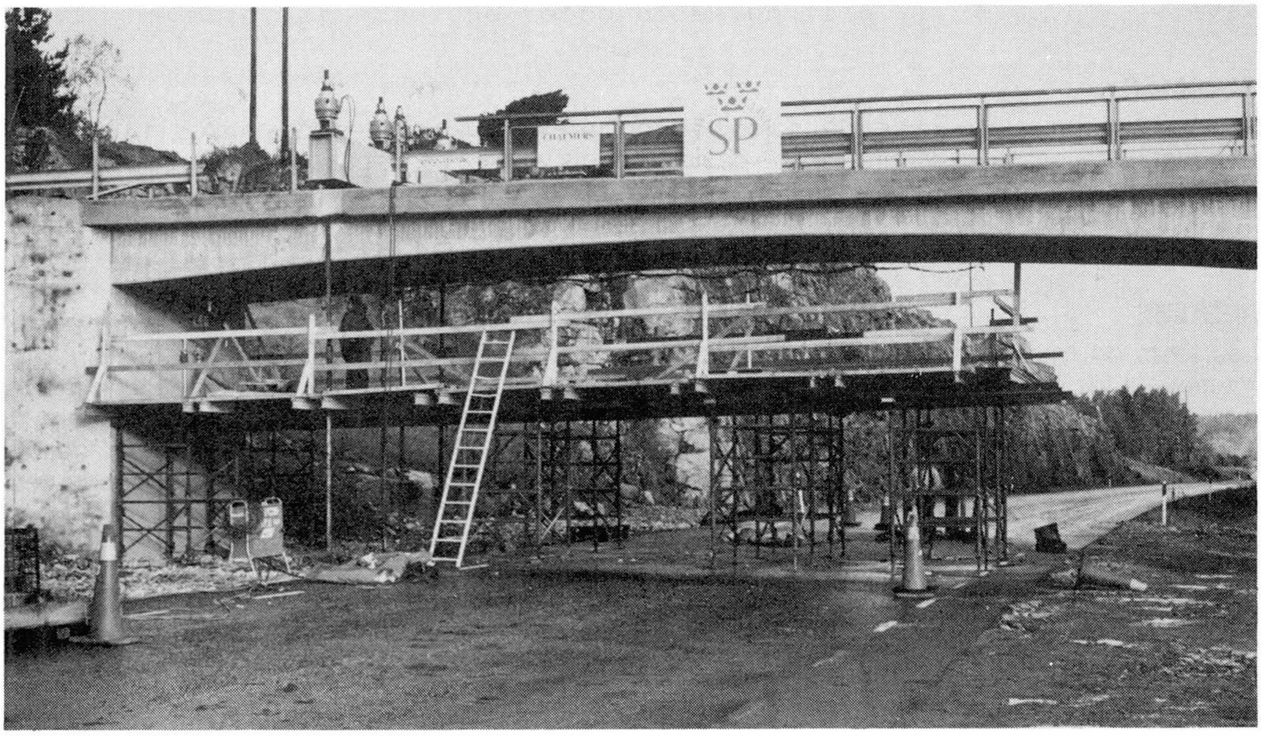

Fig. 1 Non-prestressed bridge during test preparation.

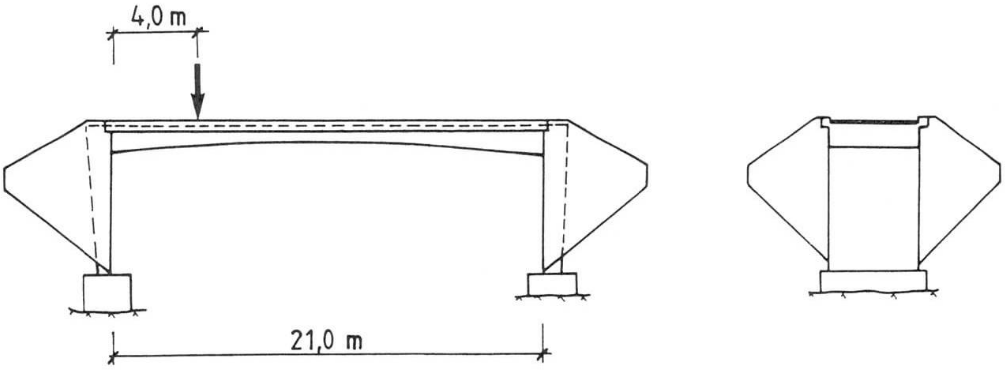

Fig. 2 Non-prestressed bridge

The other bridge was prestressed and had a free span of 31 m (fig 3 and 4). The span consisted of two post-tensioned beams connected by a bridge deck slab. The beams and the slab were connected with the front walls at the supports, forming a frame.

2.2 Test arrangements

The loads were applied through steel bars anchored to the rock under the bridges and transferred to the bridges by hydraulic jacks (fig 5). Loads, deflections and strains were measured during the tests, and crack growth was registered. The concrete strength was tested on cylinders drilled out of the bridges.

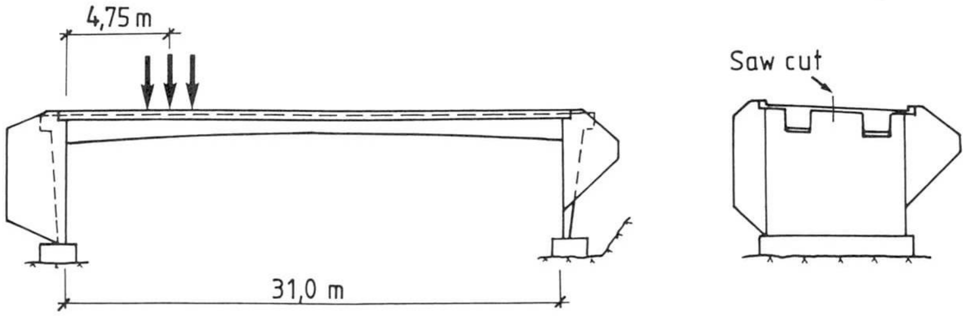

Fig. 3 Prestressed bridge

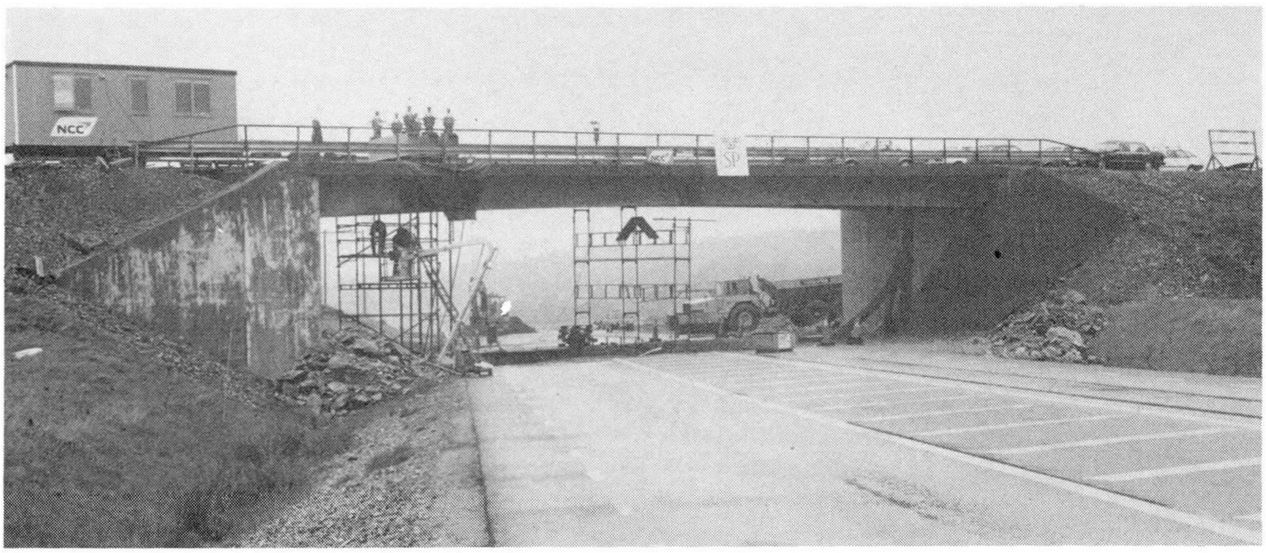

Fig. 4 View of the prestressed bridge

2.3 Test performance

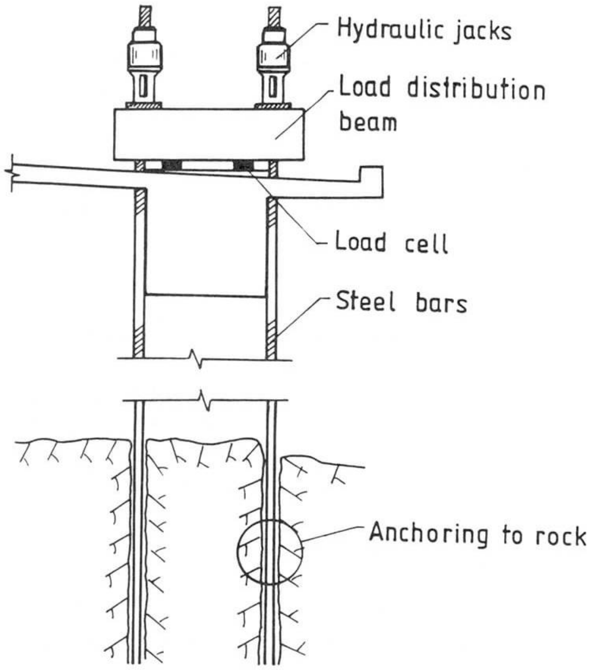

Fig. 5 Loading arrangement

The non-prestressed bridge was loaded 4,00 m from one of the supports and failed at a load of 4,5 MN due to a sudden diagonal shear crack (fig 6). The bridge was substantially cracked due to bending, and some shear-bending cracks were observed close to the loading section before the failure occurred.

The failure of the prestressed bridge was more complicated. Before the test this bridge was cut longitudinally between the two main beams and one of the beams was loaded about 4,75 m from one of the supports. After extensive cracking due to bending, together with a few shear-bending cracks, the support closest to the load unexpectedly failed at a load of 8,5 MN. The support failure lead to a redistribution of the moment, with increasing moment in the loading section.

When the support failed, the load decreased to 6,0 MN. Further loading with the jacks lead to large deformations and several inclined cracks in the shear span. The final failure occurred at a load of 6,3 MN, when the concrete at the upper edge of the loading section crushed due to compression (fig 7).

Fig. 6 Shear failure in the non-prestressed bridge

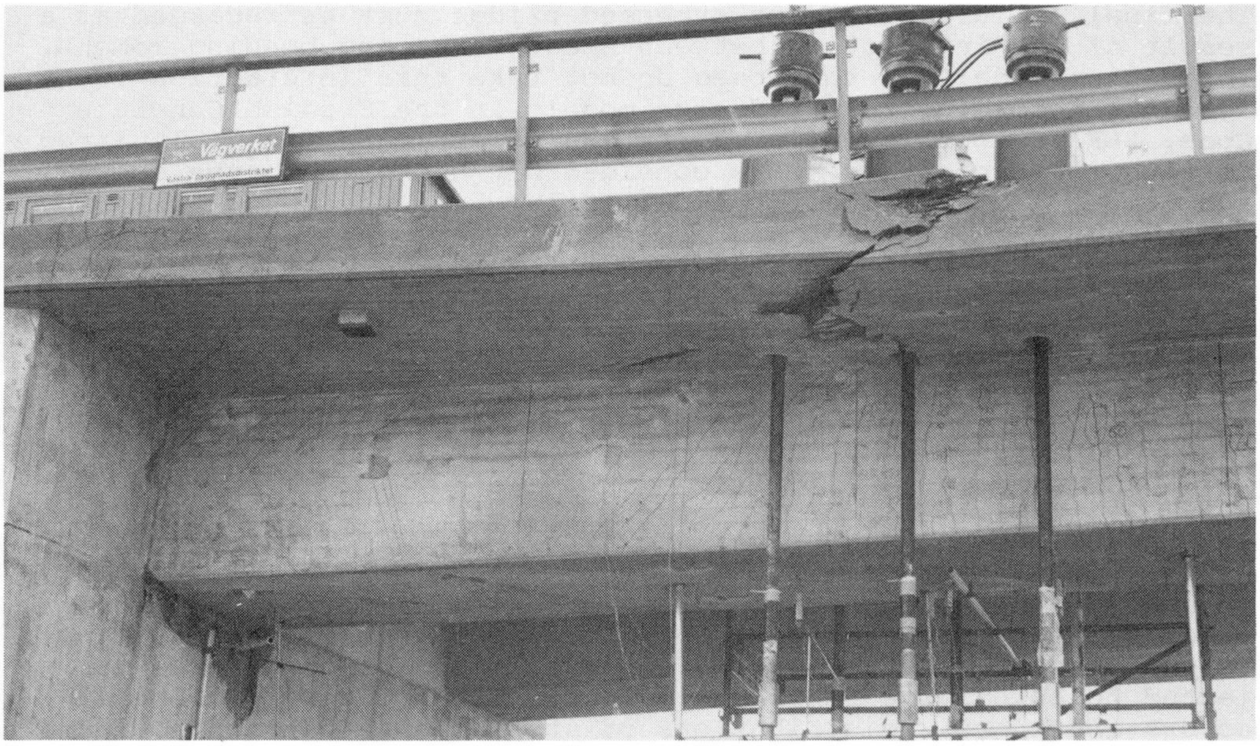

Fig. 7 Failure in the prestressed bridge. Cracking, support failure and concrete compression failure at the top of the loading section can be seen.

3. EVALUATION

The main purpose of the evaluation was to compare the bridges' real shear force at failure with their shear capacities according to the design model in the Swedish Concrete Code, BBK 79 /1/. Both the real shear force along the bridges and their shear capacities are dependent on the stiffness of the bridges and the degree of restraint at the supports. Due to cracking of the concrete and, for the prestressed bridge, failure in the support, stiffnesses and restraint conditions changed during loading.

To determine the stiffnesses and the degrees of restraint, computer programmes based on the finite element method were used. The stiffnesses were approximately calculated from the crack formation registered during the tests. By adjusting the calculated stiffnesses and varying the degree of restraints in the finite element model so that the calculated deflections were the same as the measured deflections of the bridges, proper models of the bridges were created. By analysing the obtained models the bridges moment and shear force distribution were determined. The shear capacities according to codes were then calculated and compared with these shear forces present in the bridges at failure.

4. RESULTS

In the non-prestressed bridge a typical shear failure occurred. The moment and shear distribution of this bridge are under evaluation, but preliminary results indicate good agreement between the capacity according to the model in the code and test results.

The final failure in the prestressed bridge must be regarded as a result of the interaction between shear force and bending moment. The design models in the codes do not take this interaction into account. According to the design models in the Swedish Concrete Code, BBK 79, both shear capacity and moment capacity, calculated as separate capacities, were considerably higher than the shear and moment in the bridge at final failure.

It should however be observed that the final failure was achieved at a load level lower than the maximal. The difference between calculated shear capacity and shear force in the bridge was much smaller at maximum load level than at the final failure. The moment in the loading section, however, increased considerably from maximum load level until final failure occurred. The effect of moment must therefore have a decisive influence on the failure.

5. CONCLUSIONS

To sum up, the design models used in the codes for calculation of shear capacity seems to work well for structures subjected mainly to pure shear action. In more complex cases, for structures subjected to both large shear and moment actions, where prestress occurs and where redistributions of stesses have taken place, the design models are unable to predict capacity. It is therefore not sufficient to modify the design models used today. Instead research should be intensified to find models that better describe what happens when structures are subjected to loading until failure, so that the design can be based on a clear physical understanding of the failure.

Fracture mechanics together with the finite element method will be used to analyse these bridges to obtain a better understanding of the failure process, but also to further develop fracture mechanics as a tool in the analysis.

6. ACKNOWLEGEMENT

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