FULL SCALE SHEAR TESTS ON MODERN HIGHWAY CONCRETE BRIDGES

Mario Plos, M.Sc., Research Assistant,
Division of Concrete Structures, Chalmers
University of Technology, Sweden

Kent Gylltoft, Dr., Adjunct Professor
Division of Concrete Structures, Chalmers
University of Technology, Sweden

Krister Cederwall, Dr., Professor
Division of Concrete Structures, Chalmers
University of Technology, Sweden

ABSTRACT

Full-scale shear tests were performed on two concrete highway bridges constructed in 1980.

The purpose of the tests was to improve present knowledge by examining 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 codes. The intention was also to improve methods of design and analysis in terms of shear capacity of concrete structures.

The results indicate that the design models are capable of predicting the shear capacity with some underestimation 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 codes.

Key-words: Full scale test, shear capacity, concrete bridges

1. INTRODUCTION

In the next ten years about 1300 highway bridges in Sweden will be replaced or strengthened to carry heavier vehicle loads, partly due to new regulations within EEC. The bearing capacity for many of these bridges is limited by their shear capacity.

When road E6 between Gothenburg and Uddevalla was converted to motorway standard some highway bridges, constructed in 1980, had to be demolished. In connection with this, Chalmers University of Technology, in cooperation with the Swedish National Testing and Research Institute, was entrusted to do full scale shear tests to failure on two of the bridges.

At the Division of Concrete Structures at Chalmers the shear capacity of concrete structures is one of the main research areas and the division has been involved in developing the design rules that are referred to in the European concrete codes. These design rules have been developed from laboratory tests at a comparably small scale. In the two full-scale tests it was possible to investigate the shear capacity for considerably greater structures than is normal in laboratories. The tests can therefore give an indication of whether the structure size is reasonably taken into consideration.

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). The depth of the slab varied from 1.15 m at the supports to 0.65 m at midspan. The main reinforcement in the bridge slab was of the quality Ks 600, while the secondary reinforcment was of the

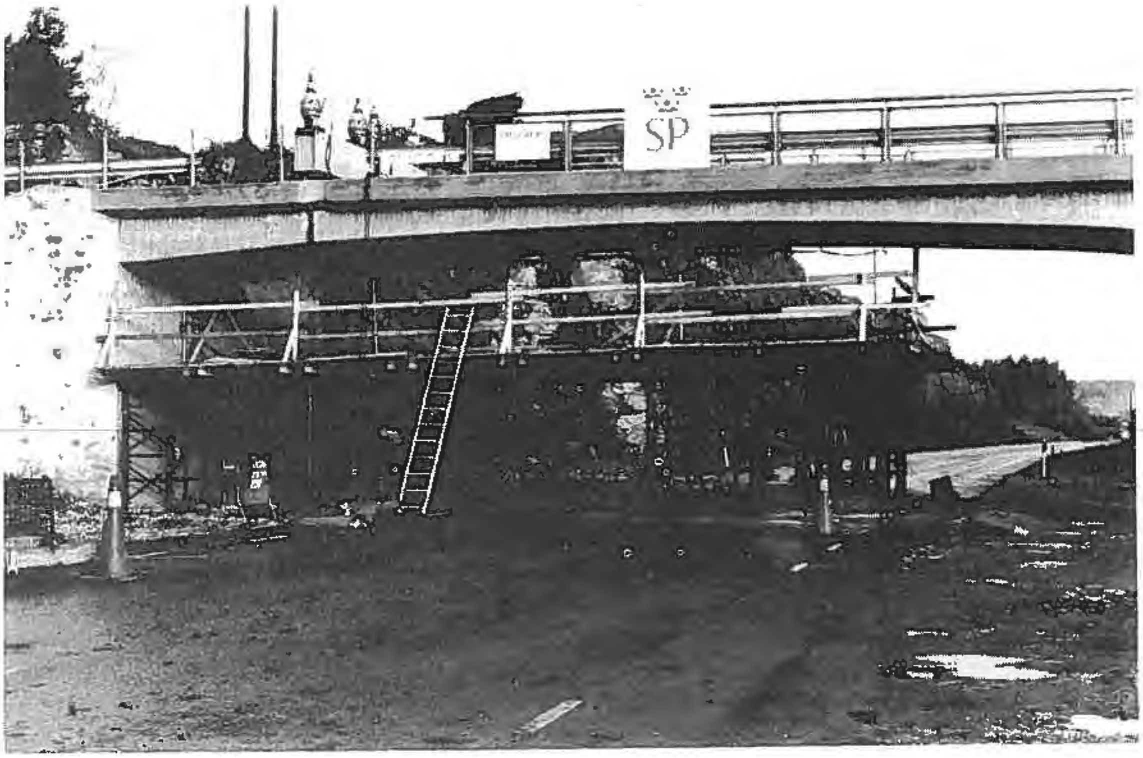

Fig. 1. Non-prestressed bridge during test preparation.

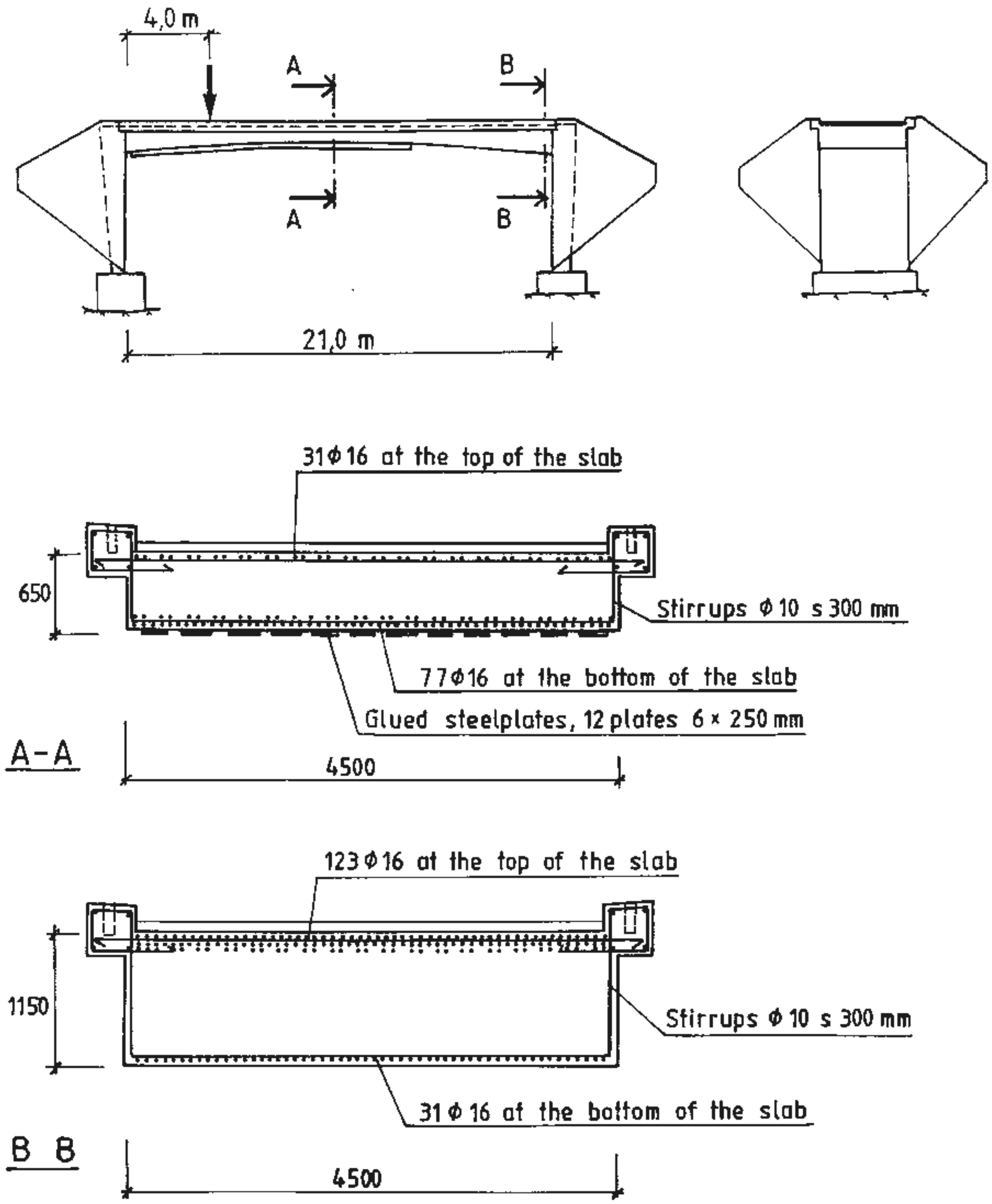

Fig. 2. Non-prestressed bridge

quality Ks 400. In the original design of the bridge the reinforcement was anchored with respect to the bending moment due to vehicle loads. In the test, however, the bridge had a different moment distribution, and to make shear failure possible the moment capacity of the bridge was increased by longitudinal steel plates glued to the underside of the bridge slab.

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 to the front walls at the supports, forming a frame. The bridge beams had varying depths, 1.64 m at the supports and 1.16 m at midspan. The prestressing reinforcement was of type BBRV and consisted of 12 tendons per beam. The tendons consisted of 44 wires, each of 6 mm diameter. The profile of the tendons was parabolic, so that they were located at the top of the cross-section at the supports and at the bottom at midspan. The mean effective prestressing force in each beam was calculated to P_{eff} = 12.4 MN. The bridge was also reinforced by non-prestressed deformed bars of quality Ks 600 in the longitudinal direction and by stirrups of quality Ks 400. Before the test, the bridge deck slab was cut longitudinally between the two main beams, and the test was performed on one beam only.

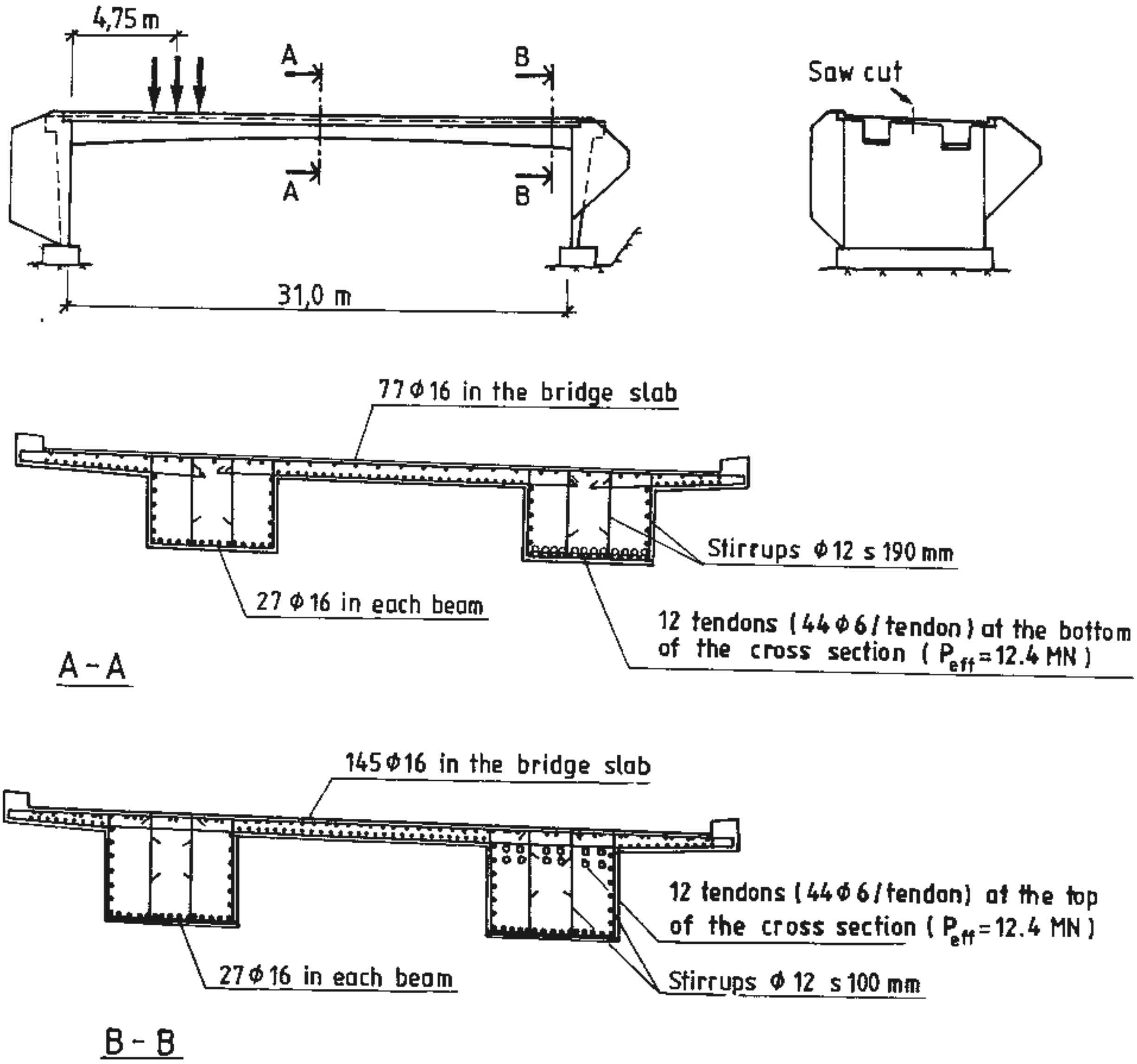

Fig. 3. Prestressed bridge

Fig. 4. View of the prestressed bridge

2.2 Test arrangements

The bridges were both loaded close to one of the supports to induce shear failure. The loads were applied through steel bars, placed in holes drilled through the bridges and anchored to the rock beneath (fig 5 and 6). The loads were transferred to the bridges by hydraulic jacks and load distribution beams, each beam placed between a pair of bars.

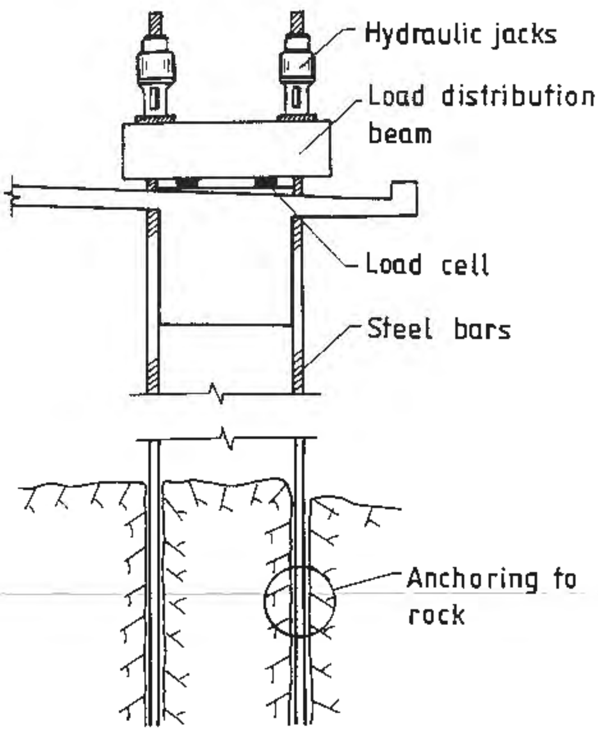

Fig. 5. Loading arrangement

Loads were measured using load cells placed between the load distribution beams and the bridges. Deflections were measured by electronic position gauges fixed to specially stayed and anchored scaffolds. Strain gauges were used to measure the longitudinal strains in the steel plates and the strains at some locations at the topand bottom of the concrete sections. To be able to determine the main strain direction, strain gauges were placed in a rosette pattern on the side faces of the bridges.

The crack growth was continuously monitored and photographed.

The concrete strength was determined through tests on cylinders drilled out of the bridges. The test cylinders were of equal diameter and length, and the measured mean value of the compressive strength was 53 MPa for the non-prestressed bridge (ϕ 150 mm) and 72 MPa for the prestressed bridge (ϕ 108 mm)

Fig. 6. Loading equipment on top of the prestressed bridge

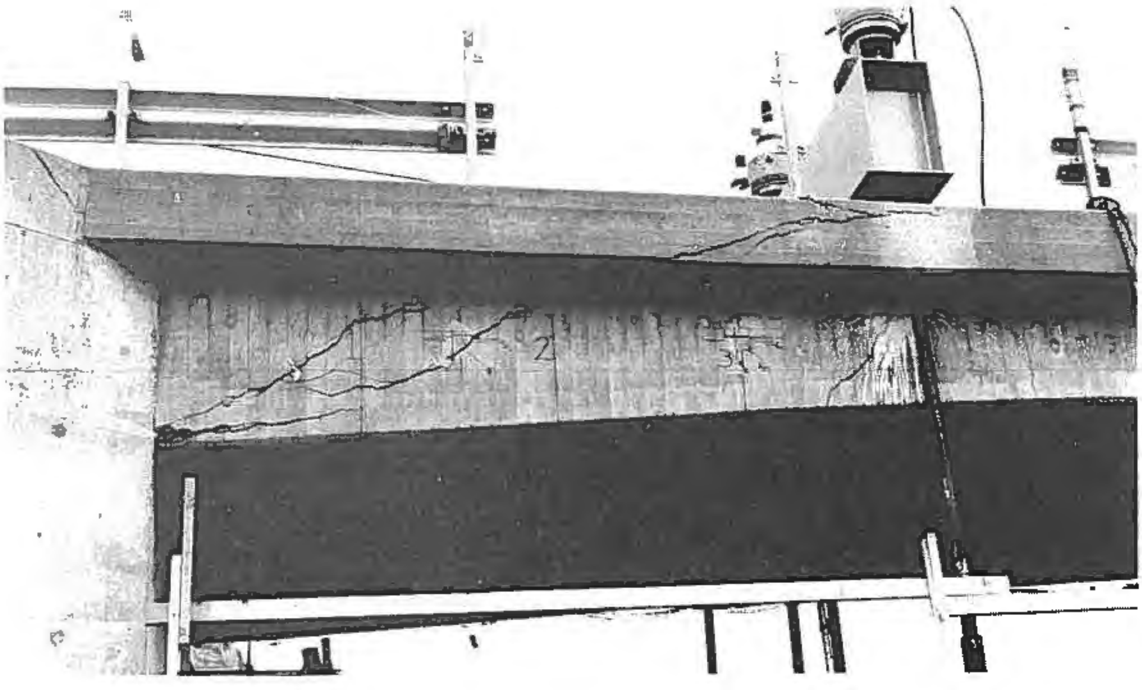

Fig. 7. Shear failure in the non-prestressed bridge

2.3 Test performance

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 typical shear crack (fig 7). The load-deflection relations are shown in figure 8. 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 shear failure was determined by a diagonal crack from the bottom of the cross-section at the support to the upper edge of the loading section.

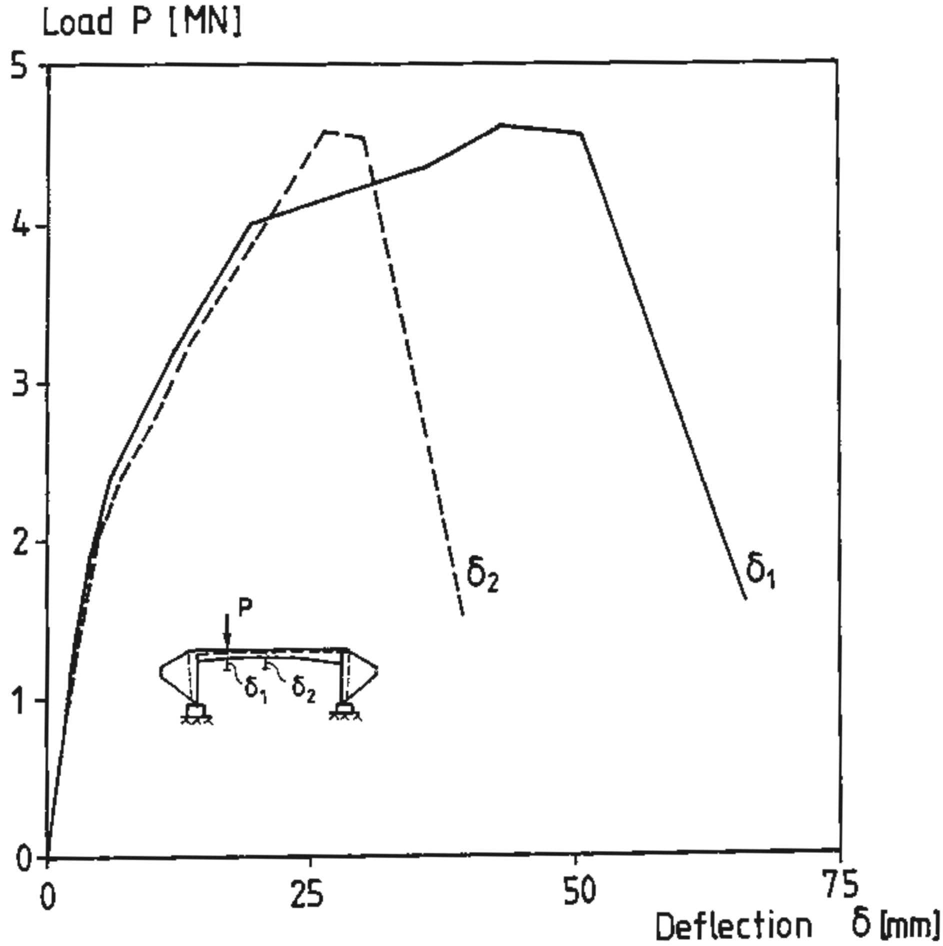

Fig. 8. Relation between load, P, and deflection, δ, for the non-prestressed bridge. δ_1 is the deflection of the loaded section and δ_2 is the deflection at midspan.

The prestressed bridge was cut longitudinally between the two main beams, and one of them was loaded with the load resultant acting 4.75 m from one of the supports in the same way as the non-prestressed bridge was. Failure was more complicated for this bridge. At a load of about 8 MN, extensive cracking due to bending together with some shear-bending cracks were observed. When the load reached 8.5 MN the support unexpectedly failed. The bottom part of the bridge beam moved into the front wall and the whole beam was displaced downwards. The support failure led to a redistribution of the moment as the degree of restraint changed. Due to this redistribution the moment in the loading section increased.

When the support failed, the load decreased to 6.0 MN. Further loading with the jacks led to large deformations, with only a minor increase of the load. The large deformations resulted in 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 8). This failure is probably best explained as an interaction failure caused by simultaneous bending and shear. The load-deflection relations are shown in figure 10.

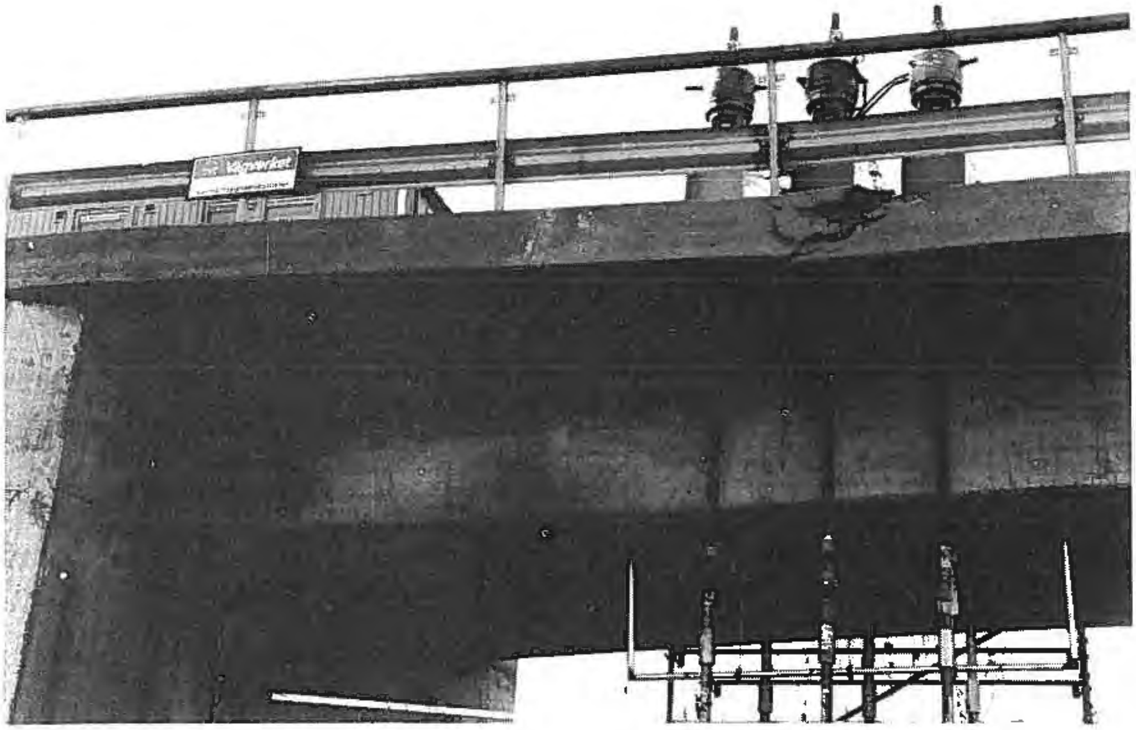

Fig. 9. Failure in the prestressed bridge. Cracking, support failure and concrete compression failure at the top of the loading section can be seen.

3. EVALUATION

The main purpose of the evaluation was to compare the bridges' shear forces due to load effect with the shear capacities in accordance to the design model in the Swedish Concrete Codes, BBK 79 /1/. Both the shear forces due to load effect and the shear capacities of the bridges depend on the stiffnesses and the degrees of restraints at the supports (the frame corners' resistance against rotation). Due to cracking of the concrete, and for the prestressed bridge, failure at the support, stiffnesses and restraint conditions changed during loading.

The stiffnesses and the degrees of restraint were determined by theoretical analyses based on the finite element method, FEM. The stiffnesses of the bridge slab and the bridge beam

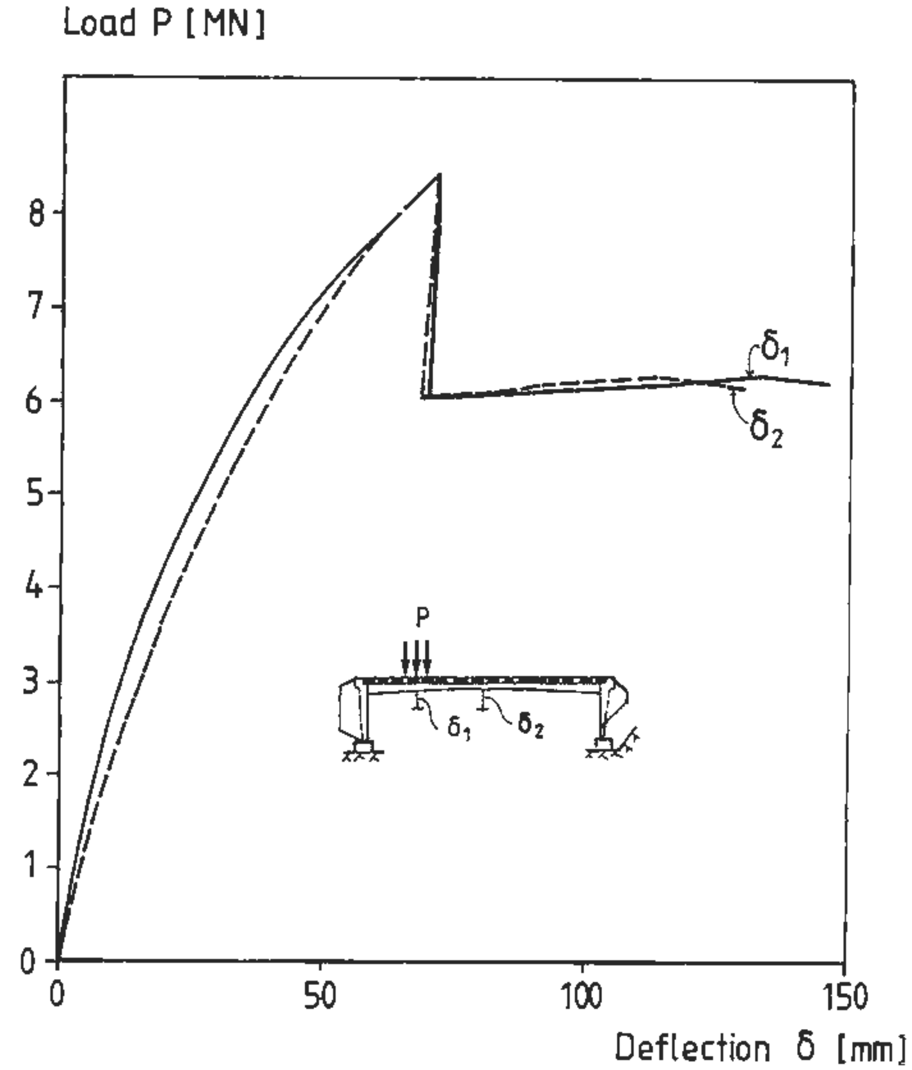

Fig. 10. Relation between load, P, and deflection, δ, for the prestressed bridge. δ_1 is the deflection of the loaded section and δ_2 is the deflection at midspan.

were approximately determined from the crack formation registered during the tests. By adjusting the stiffnesses and varying the degree of restraints in the finite element model so that the calculated deflections were about the same as the measured deformations of the bridges, proper models of the bridges were obtained (fig 9). Both stiffnesses and restraints were nonlinear and decreased with increasing load. They were therefore determined through an interactive process where the load was gradually increased in the analysis.

By analysing the obtained models the moment and shear force distributions were determined. The shear capacities according to the design model in the codes were then calculated using the measured material properties, transformed to corresponding standardized properties, and compared with the shear forces present in the bridges at failure.

4. RESULTS

4.1 Non-prestressed bridge

In the non-prestressed bridge a typical shear failure occurred. The moment and shear distribution of this bridge are still under evaluation, but preliminary calculations show that agreement is good between the test results and the capacity according to the model in the codes. The shear force at failure was about 40 % higher than the characterstic shear capacity calculated using the Swedish Concrete Code, BBK 79, and measured material properties. This is a normal underestimation according to the comparison made by Hedman and Losberg /2/, where 1099 test beams were compared with the authors' proposal for BBK 79 concerning shear capacity.

4.2 Prestressed bridge

At the maximum load level the shear force in the bridge was almost the same as the characteristic shear capacity calculated using BBK 79. Shear cracks and decreasing stiffness close to maximum load level indicates that a shear failure probably wuold have appeared in the bridge beam for a load not much higher than the maximum if the support had not failed. This shows that the design model probably is capable of predicting the shear capacity for this case within the normal scatter according to /2/.

After the support failure the shear force decreased and the moment gradually increased untill the final failure in the beam occured. The effect of moment must therefore have a decisive influence on the failure.

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 BBK 79 neither shear nor moment failure should appear when the final failure was achieved in the bridge beam. According to the design models both shear capacity and moment capacity, calculated as separate capacities, were higher than the shear and the moment in the bridge at final failure.

5 CONCLUSIONS

To sum up, for structures subjected mainly to pure shear action the design model that is used in the codes seem to work well. 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 better understanding of the failure process, but also to further develop fracture mechanics as a tool in the analysis.

6 ACKNOWLEGEMENT

The tests were performed in cooperation with The Swedish National Testing and Research Institute (SP), the Swedish Road Administration (Vägverket) and Luleå University of Technology.

7 REFERENCES

/1/ Statens betongkommitte', "Bestämmelser för betongkonstruktioner, BBK 79, Utgåva 2 (Regulations for concrete structures, second edition)", The Swedish concrete codes, AB Svensk Byggtjänst, 1988 (in Swedish).

/2/ Hedman O. and Losberg A., "Dimensionering av betongkonstruktioner med hänsyn till tvärkraft (Structural design of concrete construction based on shear failure)", print-off from Nordisk Betong nr 5:1975, Division of Concrete Structures, Chalmers University of Technology, Publication 75:9, Göteborg 1975 (in Swedish).

/3/ Kjellgren L. and Bergström G., "Skjuvförsök på spännarmerad rambro (Shear test on prestressed concrete frame bridge)", Division of Concrete Structures, Chalmers University of Technology, Diploma work 90:1, Göteborg, February 1990 (in Swedish).

/4/ Plos M., "Skjuvförsök i full skala på plattrambro i armerad betong" (Full-scale shear test on concrete slab frame bridge), Division of Concrete Structures, Chalmers University of Technology, Report 90:3, Göteborg, December 1990 (in Swedish).

/5/ Vo Minh H. and Plos M., "Skarvning av armering i ramhörn (Splicing of reinforcement in frame corners)", Division of Concrete Structures, Chalmers University of Technology, Diploma work 88:2, Göteborg, April 1988 (in Swedish).