Design of Channel Bars under Shear Load

Dipl.-Ing. Michael Potthoff
Institute of Construction Materials, University of Stuttgart, Germany

Dipl.-Ing. Yvonne Grewin,
Institute of Construction Materials, University of Stuttgart, Germany

Prof. Dr.-Ing. Rolf Eligehausen,
Institute of Construction Materials, University of Stuttgart, Germany

ABSTRACT: In engineering practice Channel Bars are very often used to transfer loads to concrete structural elements such as foundations, beams etc. Channel Bars may be loaded by tension, shear or combined tension and shear loads. There are principally three different kinds of failure loads by loading in shear: Steel failure, pry-out failure and edge failure. In the present paper the behavior of Channel Bars located at an edge and loaded in shear towards the edge with concrete failure is discussed.

Keywords: Channel Bar, shear load, finite element studies, design model

1 INTRODUCTION

Channel Bars, which consist of a steel channel with welded or forged anchors, are often used to transfer loads into concrete. The assembly of channel and anchors are cast into the concrete. Loads are transferred by special attachments to the channel and then into the concrete via the anchors. Presently no generally accepted method for the design of Channel Bars exists. The aim of the FE-analysis was to investigate the load transfer mechanism of Channel Bars by loading in shear.

2 FINTE ELEMENT STUDIES

To study the behavior of Channel Bars loaded in shear extensive numerical investigations were carried out with the non-linear three-dimensional finite element code MASA (Ožbolt et al. 2001) developed at the University of Stuttgart. The program is well suited to simulate the behavior of concrete under arbitrary loading conditions. In the present study the edge distance, the size of the Channel Bar and the number of anchors was varied. In all investigated cases, the failure was caused by concrete break out.

2.1 Concrete model

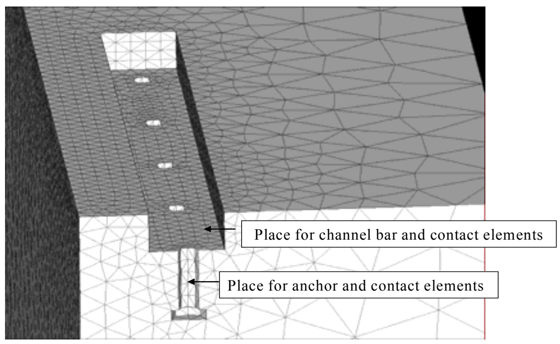

Figure 1. Finite element model of concrete

The concrete quality used in the study was C20/25 with:
Young's-Modulus: E = 28.000 N/mm²
Poisson's ratio: $\upsilon = 0.18$
Tensile strength: $f_t = 2.0$ N/mm²
Uniaxial compressive strength: $f_c = 20$ N/mm²
Fracture energy: $G_F = 80$ N/m

2.2 Steel model

To assure concrete failure, the steel behavior was assumed to be linear elastic. The Channel Bar and the special screw have the same material properties. Figure 2 shows a Channel Bar (profile 50/30) with a screw above the second anchor. Because of the symmetry only a half of the specimen is modeled.

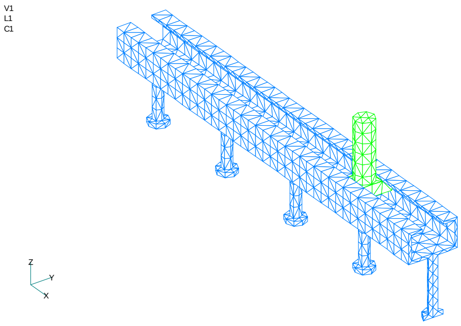

Figure 2. Finite element model of Channel Bar with screw

The steel properties were taken as: Young's-Modulus: E = 210.000 N/mm² and Poisson's ratio $\upsilon_s = 0.33$

2.3 Contact elements

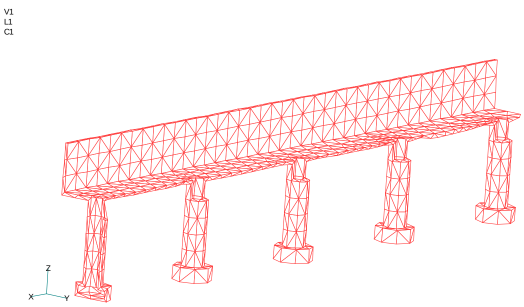

Figure 3. Finite element model of contact elements

The contact elements are placed between steel and concrete. These elements can take up only compressive stresses and no tensile stresses. The material model of these elements is based on the microplane model.

2.4 Comparison of the FE-analysis with test results

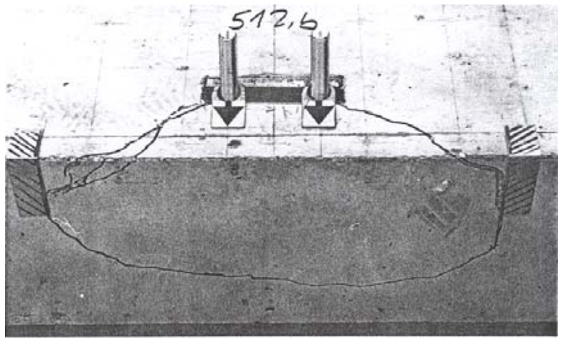

Figure 4. Concrete break-out of Channel Bar with 2 anchors (test)

Figure 4 shows a concrete break-out of a short Channel Bar with 2 anchors under shear load. The load was applied over the both anchors. The crack opening starts from the edge of the Channel Bar and follows the way to the bearings. From the tests it is difficult to conclude weather the crack opening starts from the Channel Bar or from the anchor. To clarify this question FE-calculations were carried out.

To verify the finite element model, the tests of Wohlfahrt (1996) with short Channel Bars and load over both anchors were calculated with finite element analysis code MASA (Ožbolt et al. 2001).

The concrete edge failure shown in Figure 4 can also be seen in Figure 5 where only half of the specimen is modeled (symmetry). The black areas in Figure 5 show principal concrete strains that correspond to the critical crack opening of 0.1 mm. The crack pattern after peak load is reached as shown in Figure 5.

The crack starts between the underside of the channel and the top of the anchor. Figure 6 shows the peak loads from test and FE-analysis for 3 different Channel Bars with 2 anchors. The anchor spacing was varied from 100 mm to 400 mm.

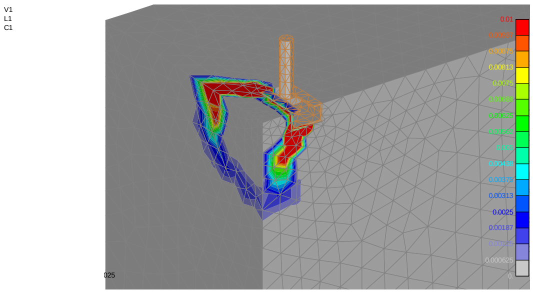

Figure 5. Concrete break-out of Channel Bar with 2 anchors (FE-analysis)

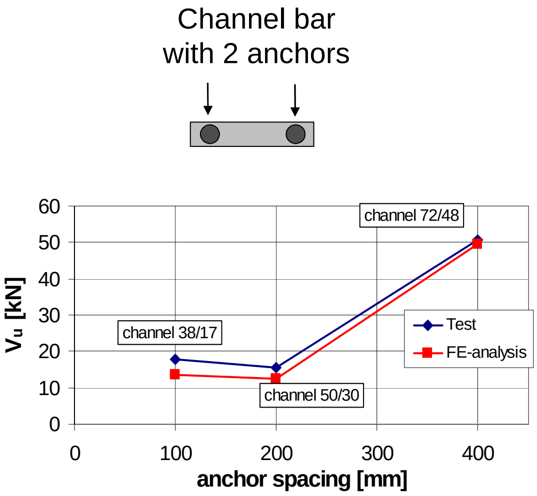

Figure 6. Comparison between FE-analysis and test results (2 anchors)

The comparison between FE-analysis and test results show that there is almost no difference in the peak loads. Furthermore, Wohlfahrt (1996) performed tests using Channel Bars with 4 anchors in a thin specimen. Figure 7 shows the concrete failure after loading in shear. Failure of a concrete member was obtained.

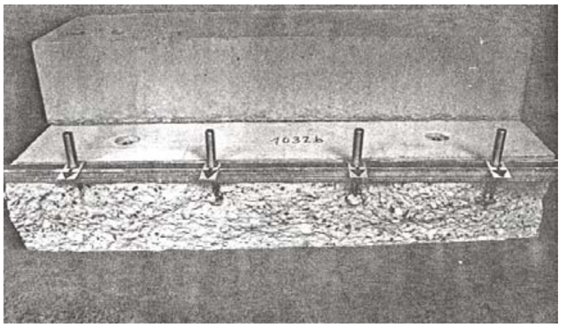

Figure 7. Concrete break-out of Channel Bar with 4 anchors (experiment)

The FE-analysis of the same specimen was performed. The same as in the test, the analysis shows the failure of a concrete specimen.

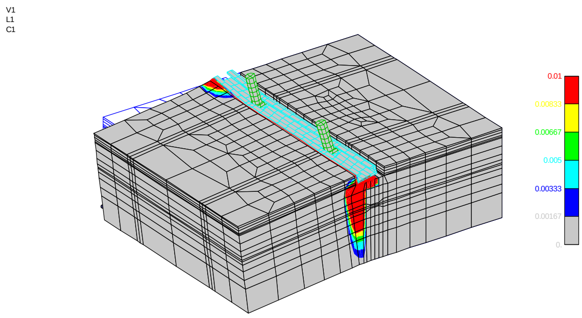

Figure 8. Concrete break-out of Channel Bar with 4 anchors (FE-analysis)

Figure 9 shows the calculated crack pattern. As can be seen the failure mode is the same as in Figure 7. There is no doubt, that the member thickness is the most important influencing factor in this investigation.

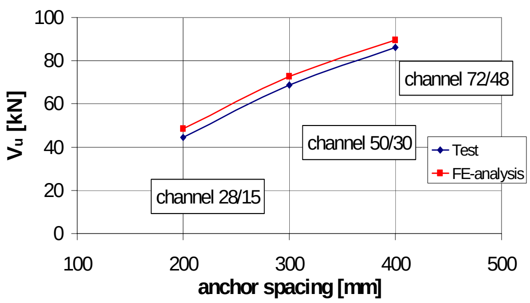

Figure 9. Comparison between FE-analysis to test results (4 anchors)

The comparison between numerical and test results of the Channel Bars with 4 anchors loaded over all anchors is relatively good because the difference between the peak loads is less than 10 %.

Furthermore, Channel Bars with 1 anchor have been tested by loading in shear by Wohlfahrt (1996). The length of the Channel Bar was varied from 0 mm (only anchor) to 600 mm. The result of the performed tests was that the length of the Channel Bar has almost no influence on the ultimate load.

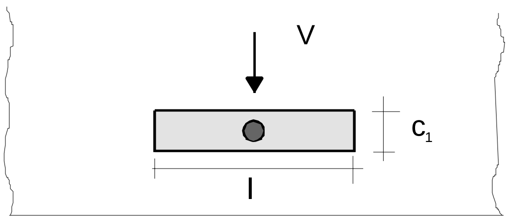

Figure 10. Geometry of the anchor with one anchor

Figure 11 shows the test results and the results of the FE-analysis. The comparison shows a very small difference between ultimate loads. The results also indicate that there is almost no influence of the length of the Channel Bar on the peak load.

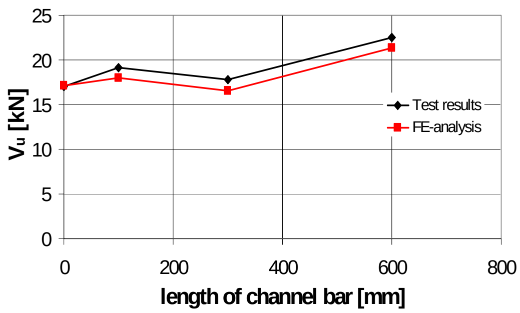

Figure 11. Comparison between FE-analysis to test results for channel bar with one anchor

3 LOAD TRANSFER MECHANISMS OF CHANNEL BARS LOADED IN SHEAR

To investigate the load transfer mechanisms of channel bars, several FE-calculations have been performed. The load against the edge was applied over one anchor. Figure 12 shows a design of the Channel Bar with one load over the middle anchor.

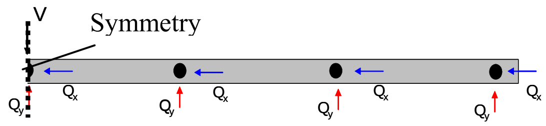

Figure 12. Channel bar with 7 anchors

Due to symmetry, shown is only half of the model with 7 anchors. The edge distance was 75 mm and the anchor spacing was 100 mm. The vertical arrows show the resistance of the concrete in load direction. The horizontal arrows show the resistance orthogonal to the load direction. The load was applied by displacement control. Each load step in the FE-analysis corresponds to a displacement of 0.01 mm.

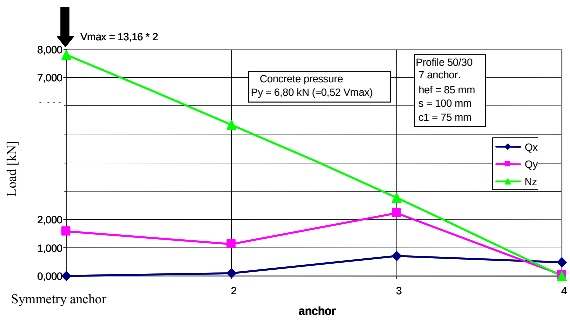

Figure 13. Distribution of shear and tensile anchor loads for the channel bar with 7 anchors with load over the middle anchor

Figure 13 shows distribution of the shear and normal (tensile) forces at peak load. The tension load in anchor is initiated by the moment that exists because of the distance from load inserting and the concrete surface. The tension load in the anchor is the highest load. The shear load in the middle anchor is only 25 % of the tension load. That means, that the head of the anchor is necessary for the Channel Bar to stay in the concrete.

The shear load resistance of the anchor is quiet small and is getting even smaller over the last anchor. A higher shear load resistance of the third anchor is caused by the torsion of the Channel Bar

The load distribution of the Channel Bar was investigated by a FE-calculation with 7 anchors and load applied over 2 anchors. Figure 14 shows the design of this investigation.

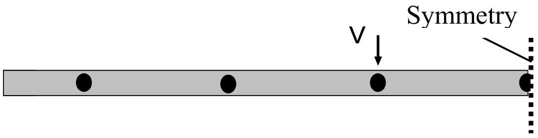

Figure 14. Channel bar with load over 2 anchors (symmetry)

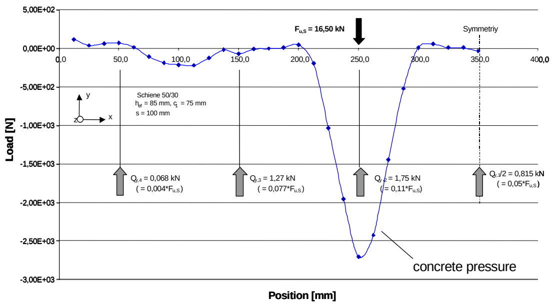

Figure 15. The distribution of the anchor shear loads and concrete pressure over the length of the channel bar

Figure 15 shows that the Channel Bar transfers the largest part of the load into the concrete. Altogether 66 % of the load is distributed over the Channel Bar and only 34 % over the anchors.

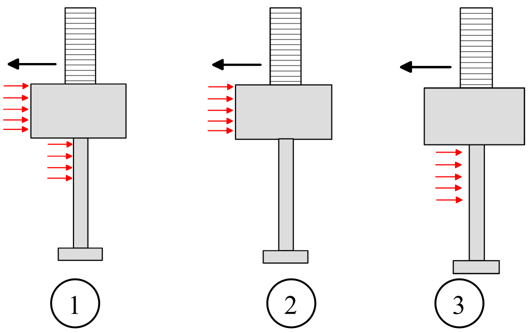

Figure 16. Three possible load transfer mechanisms

For proposing a design model, three possible mechanisms of the shear load transfer are considered.

Mechanism 1 in Figure 16 describes the load transfer over the Channel Bar and the anchor. The mechanism is shown in a realistic way. If the design model would refer to mechanism 1, it would be rather complicated, since one would help to couple tensile and shear resistance. Another disadvantage of such a model is due to the fact that it is not clear how much load will be transferred over the Channel Bar when parameters like edge distance, anchor spacing and member thickness are varied.

Mechanism 2 in Figure 16 shows the load transfer only over the Channel Bar. The advantage of neglecting the anchors is that the model for shear load itself would not be very complicated. However, similar to the mechanism 1, two transfer mechanisms seem to be complicated what would again complicate the design model.

Mechanism 3 in Figure 16 describes the load transfer over the anchor. In this load transfer mechanism the Channel Bar is neglected. This is an important advantage concerning the interaction of tension load and shear load because both design models would transfer the load over the anchor. In this case the design model for interaction would verify only the anchor. The mechanism for transferring the load from the screw over the Channel Bar to the anchor is not clear yet. This transfer mechanism has to be investigated by further FE-studies.

4 CONCLUSION

The finite element analysis, using FE code MASA is able to model the behavior of channel bars realistically. Therefore, the code is used to study the load transfer mechanism of channel bars with a large number of anchors. When Channel Bars are loaded in shear, most of the load is transferred into the concrete over the Channel Bar. Small parts of the load are transferred over the anchors. It would be a complicated model to describe the load transfer for shear load over the Channel Bar and the anchor. Even if just small parts of the load were transferred over the Channel Bar it would be difficult to perform the interaction of shear and tension load in concrete. Therefore, it would be useful to formulate a design model, which would be formulated on the assumption that the complete load is transferred only over the anchors.

5 REFERENCES

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- Wohlfahrt, R (1996).: „Tragverhalten von Ankerschienen ohne Rückhängebewehrung“, Dissertation am Institut für Werkstoffe im Bauwesen der Universität Stuttgart