Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 999 (1997)

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DOI: https://doi.org/10.5169/seals-1072

The Influence of Slab Bending Moments on the Load Bearing Behaviour of Headed Studs

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Summary

The results of push-out tests, carried out with stud shear connectors and with simultaneously acting slab bending moments, are presented. The influence of the slab bending moments on the load-carrying capacity of the studs is described by means of interaction curves. The effect of varied ratios of transverse reinforcement and of sheet geometry is pointed out this way. Models that describe the transfer of stud shear forces in profiled concrete flanges are shown.

1. Introduction

The problems of longitudinal shear and simultaneously acting slab bending moments in the concrete flanges of composite beams were investigated in a project of a research group 'composite action' at the University of Kaiserslautern. In the scope of this project sixteen full-scale beam tests were carried out. The results of these tests were presented in detail in [5] and [6]. In the tests with composite beams in sagging moment regions an influence of the transverse slab bending moments on the load bearing behaviour of the beams was observed. In these beam tests smaller as well as higher ultimate loads occur in connection with smaller and higher slab bending moments. On one hand this influence can be caused by changes in the load-slip-behaviour of stud shear connectors as result of the simultaneously acting slab bending moments. On the other hand this effect can be caused by the influence of the transfer of stud shear forces on the load-bearing behaviour of the composite slab.

Figures 1 to 6 separately demonstrate the different stress effects acting together in the small area of concrete flange above the steel girder. Hereof figs. 3 to 5 show different truss-models, that describe the transfer of the stud shear forces from the bottom areas of the studs to the concrete plate above the sheets.
The transverse tensile forces created by the spreading of the compression forces of the longitudinal shear are shown in fig. 1. These tensile forces were described in detail by different authors, too, for example by Johnson et al. [3]. As shown in the picture shows a distribution of these tensile forces is possible among the reinforcement (T_{reinf}) and the profiled sheet (T_{sheet}) in the case of sheets with composite action.

Finally the internal forces in the profiled sheet and in the reinforcement due to the slab bending moments are plotted in fig. 2. In the lower regions of the ribs compression forces act in the sheets (C_{sheet}) and in the encased concrete (C_c). These compression forces will have effects on the load-carrying capacity of the studs. Tensile forces act in the upper regions of the sheet (T_{sheet}) and in the reinforcement (T_{reinf}). They lead to cracks at the upper side of the slab. These cracks influence the load carrying capacity of the studs, too.

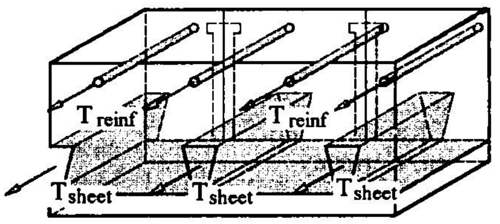

Fig 1: Tensile forces due to the longitudinal shear

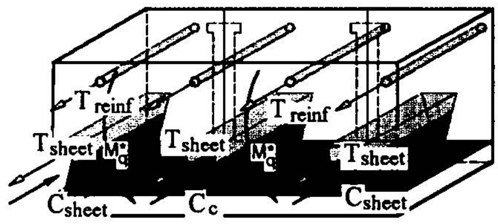

Fig 2: Internal forces as a result of the slab bending moments M_q^*

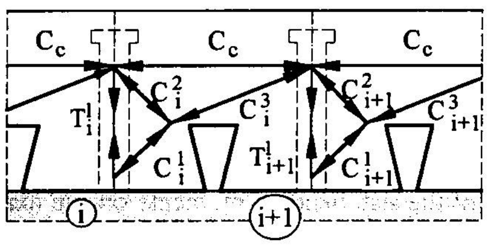

Fig 3: Truss-model for direct transfer of stud forces

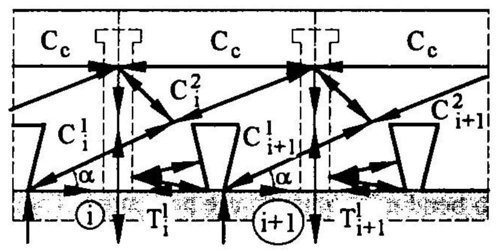

Fig 4: Truss-model for indirect transfer of stud forces (1. alternative)

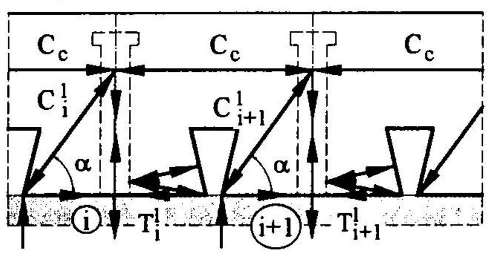

Fig 5: Truss-model for indirect transfer of stud forces (2. alternative)

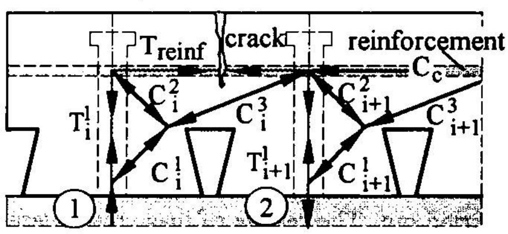

Fig 6: Truss-model for direct transfer of stud forces for the last stud of a beam

The figs. 3 to 5 demonstrate, that different models basing upon the truss-model theory can be used to describe the transfer of stud shear forces in profiled concrete flanges of composite beams. Figure 3 gives a model for a 'direct' transfer of the stud shear forces. This model does not consider possible tensile forces in the sheet. For the situation of the first stud at a beam or in push-out tests with two studs, see fig 6, transverse cracks occur in the upper region of the concrete flange due to tensile forces between the studs. In fig. 4 and 5 models for an 'indirect' transfer of the stud shear forces are plotted. In these models the profiled sheet is used in transmitting the stud forces to the concrete above the sheets. In reality all three models are acting together in transferring the stud shear forces. Because of this there are tensile forces in the sheets, described in the models of fig. 4 and 5 as well as transverse cracks between the studs, described in the model of fig 6.

More information about this transfer of stud shear forces and the influence of the transverse slab bending moments on this transfer was needed for the analysis of composite beams, especially for the investigation of the interaction of slab bending moments and longitudinal shear in the concrete flanges.

First sporadic push-out tests with simultaneous slab bending moments carried out by Bode and Künzel [1,2] and Lloyd and Wright [4] have also shown the above mentioned influence of the slab bending moments on the load-bearing behaviour of the studs. Therefore additional and more detailed examinations about these problems were required.

2. Test Arrangement of Push-out Tests

Figures 7 and 8 show the test arrangement for the carried out push-out tests. Two independent loads were applied. The first load caused shear forces in the steel-concrete interface, the second load produced simultaneously and independently acting slab bending moments.

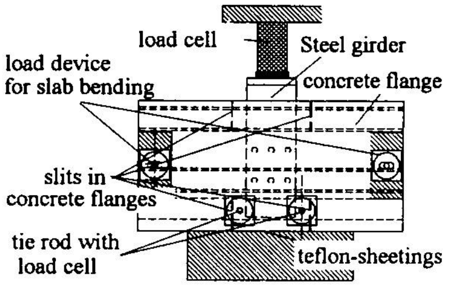

Fig 7: Test set-up and test specimen for push-out tests

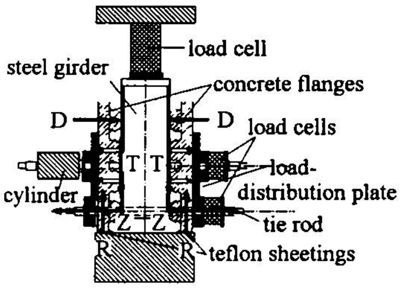

Fig. 8: Sectional view of test set-up and specimen for push-out tests.

Different ratios of slab bending moments and stud shear forces were examined with constant test parameters for the rest to determine interaction curves. For this purpose, load conditions defined in figs. 9 to 12 with the points A to G were tested.

The ribs without studs were slit to obtain clearly defined constant bending moments in the ribs with stud shear connectors. The test specimens were based on teflon sheetings to minimise the friction between the support and the test specimens.

The separation of the concrete flanges from the steel girder in the bottom regions of the specimens was prevented by using tie rods. With a load cell at each tie rod, the forces in the rod were measured.

In all tests the strains were measured at the transverse reinforcement, at two stud shear connectors, at one rib of the profiled sheet in one direction and at an other rib in three directions. With both flanges the slip between the steel girder and the profiled sheet, the middle of concrete above the sheets and the surface of the concrete flange was measured.

Tests were carried out with two extremely different types of profiled sheets. First SUPERHOLORIB 51 sheets with a wide and low rib were used. Secondly COFRASTRA 70 sheets with a narrow and high rib were tested. Both types of sheets had holes for stud shear connectors and were 0,88 mm thick.

Three series with SUPERHOLORIB 51 sheets each including seven push-out tests and one series with COFRASTRA 70 sheets including five tests of the wide range of 48 totally planned tests, have been carried out already. The different types of profiled sheets were examined in these tests with one and the same cross-section area of transverse reinforcement and in varying the slab bending moments.

3. Test results

In the following some selected results are presented about the influence of cross section area of the reinforcement and of the sheet geometry on the interaction between the slab bending moments and the load carrying capacity of stud shear connectors. Further results are shown to verify the described above truss-models.

The figures 9 to 12 show two interaction curves where related loads P^m of studs are plotted versus related bending moments of the slabs. Stud loads P^m are related to the bearing capacity P of the studs without slab bending moments, bending moments of the slab are related to ultimate bending moment with out stud forces. The first curve gives the yield loads P_y^m of the studs. In this case the yield load of the stud is defined as the smaller value of the maximum load multiplicated with 0.9 and the minimum load $P^m_{Ru,10mm}$ reached up to a slip of 10 mm. Therefore this curve is relevant for the design of composite beams. The second curve gives the maximum load reached up to a slip of 10 mm. It is needed for an exact calculation of composite beams for example with FEM. These two interaction curves were plotted for three series of tests with SUPERHOLORIB 51 sheets and one interaction curve for the series of COFRASTRA 70 sheets.

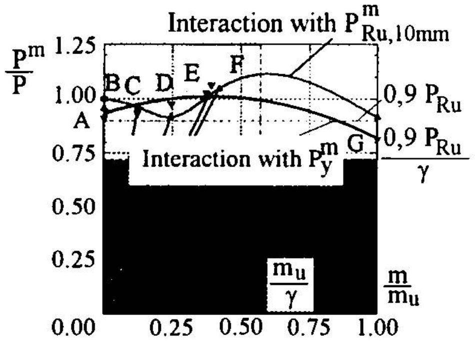

Fig. 9: Interaction curves of tests of series HOL339

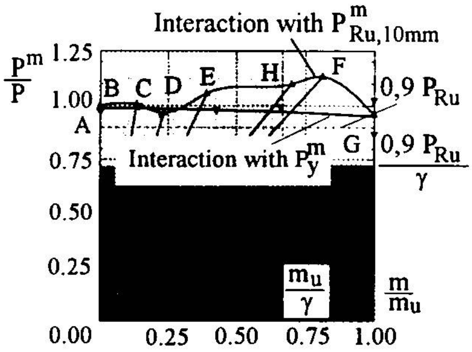

Fig. 10: Interaction curves of tests of series HOL785

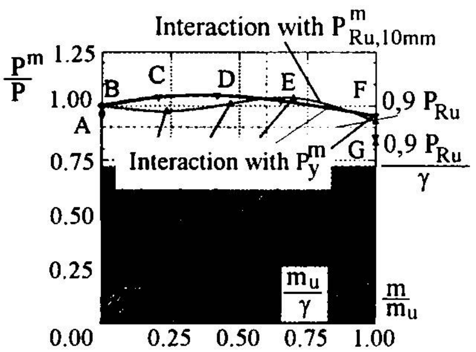

Fig. 11: Interaction curves of tests of series HOL1589

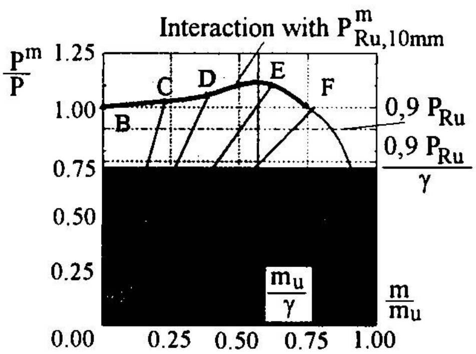

Fig. 12: Interaction curves of tests of series COF785

The mentioned figures show no change in yield loads by small slab bending moments in the tests of series HOL339 (A_s = 7,85 cm^2 of transverse reinforcement, fig. 9) and of series HOL785 (A_s = 7,85 cm^2, fig. 10). In the tests of series HOL1589 (A_s = 15,89 cm^2, fig. 11) there was a small increase of yield load by small slab bending moments. With high slab bending moments a decrease was observed in all series. The magnitude of the decrease of yield loads depends on the ratio of reinforcement. The tests of series HOL339 show the largest and the tests of HOL1589 the smallest decrease. In all tests the ultimate load of the studs exceeded the design loads of studs without slab bending, obtained from test B ($\frac{0,9 * P_{Ru}}{\gamma}$).

Comparing the maximum loads reached up to a slip of 10 mm different curves of interaction were observed, too. In all tests there was a decrease of the load-carrying capacity of the studs by small slab bending moments and an increase with higher slab bending moments. The effect of slab-bending moments depends on the ratio of transverse reinforcement too.

The comparison of tests with SUPERHOLORIB sheets (fig. 9 to 11) with the first tests series with COFRASTRA 70 sheets (fig. 12) demonstrates the influence of the rib geometry. In this figure only maximum loads are plotted, as they were reached nearby 3 mm slip, as loads decreased afterwards. In these tests an increasing of the ultimate loads of studs with increasing of slab bending moment and an estimated decrease of load carrying capacity with higher slab bending moments. This decrease has a greater influence on load bearing behaviour of studs than in tests with SUPERHOLORIB sheets. Further tests will give more detailed information about this problem.

This load-bearing behaviour of the studs is a result of compression stresses in the bottom region with small slab bending moments, and of wide longitudinal cracks with high slab bending moments. For more information about this problem see [5,6].

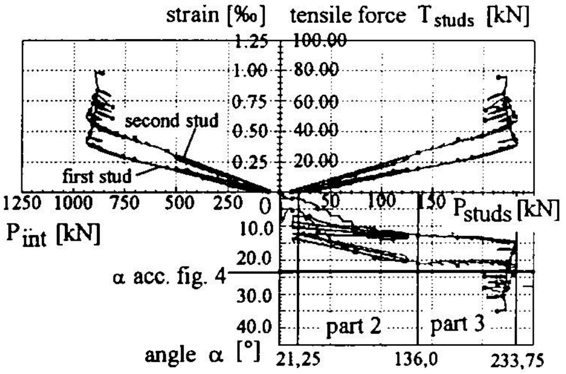

Fig. 13: Strain, tensile force in stud shear connectors and angle α of a test with free possible separation between slab and steel girder

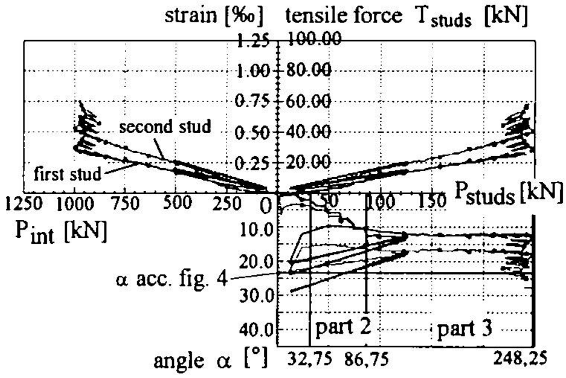

Fig. 14: Strain, tensile force in stud shear connectors and angle α of a test with hindered separation between slab and steel girder

In figures 13 and 14 the measured strains of the stud shear connectors are plotted for two studs obtained from a test with free possible separation of the concrete flange from the steel girder and a test with hindered separation but with slab bending. In the upper left part of the pictures the strains measured at the lower and the upper stud are plotted versus the load in the interfaces P_{Int} between the steel girder and the profiled flange. In the upper right part the calculated tensile forces T_{stud} in the group of two studs are plotted versus the shear force P_{studs} of the group. Finally in the lower right part the calculated angle α of the compression forces of the in fig. 4 described truss model are plotted versus the shear force of the group of two studs.

The comparison of these pictures shows common effects in both tests. On one side the strains and tensile forces increase linearly with growing force in the interface between steel and concrete up to the maximum load reached up to a slip of 10 mm. Thereafter the strain increases without an increase of the stud shear forces. On the other side the curve of the calculated angles α of the compression force can be divided in three parts. Part one is a horizontal line at small stud shear forces, which can be described as a uncracked situation of transfer of stud shear forces. Part two shows increasing angles α with increasing stud shear forces. In this part the cracks occur in the concrete flanges. In part three the calculated angle α has a constant value up to the maximum load reached up to 10 mm slip. Beyond this point the angle increases without an increasing of stud shear forces.

The transverse crack described in fig. 6 occured in all push-out tests at a load range corresponding to part two. Further the strain measured in the lower stud was greater than in the upper stud. This corresponds to the truss-model described in fig. 3. According this model higher tensile forces can be calculated in the second stud (lower stud in the push-out tests). Different from this model but in accordance with the other models described in figure 4 and 5 tensile strains were observed in upper flange of the sheets. These strains that occur between the studs and beside the steel girders are influenced by the slab bending moments. Furthermore the principal strains are also influenced by the slab bending moments. As a consequence it can be said that both models of 'direct' and 'indirect' transfer of stud shear forces act simultaneously.

Finally it should be mentioned, that the slab bending moments have an influence on the stiffness of the interface between steel girder and concrete flange, too. More detailed information will be presented by the authors in further papers.

3. Conclusion

The carried out push-out tests have shown the following results:

The load-carrying capacity of the studs is influenced by the slab bending moments. The influence depends on the ratio of reinforcement and the geometry of the sheets.

The transfer of stud shear forces in profiled concrete flanges can be described as a combination of the presented models based upon the truss-model theory.

4. Acknowledgement

The authors are grateful to the Deutsche Forschungsgemeinschaft for sponsoring the research work presented in this paper. Further thanks are given to the Holorib GmbH, Germany and the Solac Socie Social, France for the contribution of the profiled sheets and to TRW Nelson GmbH, Germany for the stud shear connectors.

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