**Zeitschrift:** IABSE reports = Rapports AIPC = IVBH Berichte

**Band:** 999 (1997)

**Artikel:** Composite slabs with and without end anchorage under static and dynamic loading

**Autor:** Bode, Helmut / Minas, Frank

**DOI:** https://doi.org/10.5169/seals-979

# Composite Slabs with and without End Anchorage under Static and Dynamic Loading

**Helmut BODE**
Professor Dr.-Ing.
Kaiserslautern Univ.
Kaiserslautern, Germany

Helmut Bode, born 1940 in Dresden, received his Ph. Degree at Bochum Univ. Since 1980 he is Professor of Civil Engineering at the Steel Construction Chair, Kaiserlautern Univ., Germany.

**Frank MINAS**
Research Assistant
Kaiserslautern Univ.
Kaiserslautern, Germany

Frank Minas, born 1963, received his civil engineering degree in 1991 and since this time he investigates the behaviour of composite slabs at the Steel Construction Chair, Kaiserslautern Univ., Germany.

## Summary

This report deals with strength and behaviour of composite slabs with three typical, but different profiled steel sheet geometries used with and without end anchorage means (headed studs and bent rib anchors). A brief survey of slab design up to a modified global plastic analysis is given. Furthermore an improved partial shear connection method based on the results of small scale slip-block tests is introduced. In addition some results of slab tests with static and dynamic loadings are presented.

## 1. Introduction

This paper deals with the behaviour and design of composite slabs. Composite slabs consist of particular profiled metal deckings with concrete topping. They permit an easy and high speed construction of steel framed or even concrete buildings, whereby the steel sheet acts during erection among other things as safe working platform, permanent shuttering and horizontal bracing. After the concrete has hardened the profiled steel sheet is part or all of the tensile reinforcement. Their efficiency and advantages in combination with flexibility lead to an increasing use of composite slabs. Therefore the development of many different shapes all over the world is going on.

Numerous slab-, pull-out- and slip-block -tests with different types of composite slabs have also been carried out in the laboratory for structural engineering of Kaiserslautern University, Germany, in order to determine design values for their load carrying capacity and to investigate their behaviour. Till now in Germany in most cases Holorib-type metal decking is used. The new generation of these sheetings has embossments in the top flanges at least. But it shall be pointed out that trapezoidal composite slabs show also a similar ductile behaviour and high resistance in bending and longitudinal shear, if end anchorage means are applied. This end anchorage can be provided by throughwelded headed studs, which are anyhow necessary for the composite beam action. Objectives of our work and this paper are therefore

1. to enhance the resistance and behaviour of composite slabs with trapezoidals,
2. to improve the partial connection method which can be applied in designing composite slabs with ductile horizontal shear failure,
3. and to expand the range of application to cyclic loadings under fork lift trucks.

## 2. Ductile composite slabs

Basically three different types of metal decking are normally used on our construction sites:

- profiles with re-entrant shape (dovetail ribs, Holorib-type) without embossments, but together with end anchorage means, to create sufficient composite action,
- the Holorib-type sheeting with embossments (e.g. Cofrastra 40, Haircol, Super Holorib, SupeRip)
- and the trapezoidal profiles with embossments or idendations and with or without end anchorage means.

Trapezoidal shapes lead to a consumption of steel per m² flooring smaller than re-entrant profiles. However the vertical separation of the two composite partners is not efficiently prevented and therefore the longitudinal shear resistance is only about one tenth of the new generation of re-entrant profiles. The $\tau_u$ - values [1], [3] permit an easy comparison of the different metal decking types, see table 1.

| profile geometry | failure mode without end anchorage | $\tau_u$ [kN/m²] (mean test value) |
|---|---|---|
| trapezoidal with embossments (Cofradal 60 $t_N$ = 0.88 mm) | brittle | 40 |
| plain re-entrant (Holorib $t_N$ = 0.88 mm) | brittle | 120 |
| re-entrant with embossments (Super Holorib $t_N$ = 0.88 mm) | ductile | 520 |

*Table 1: Longitudinal shear resistance - Comparison for typical metal deckings*

One outstanding advantage of re-entrant steel profiles is the fact that these composite slabs can attain a fire resistance of R90 without any supplementary reinforcement.

The load-deflection curves in figure 1 are test results, but they illustrate the typical behaviour of these three different types. Cross-sections, test set up and descriptions are in agreement with Eurocode 4 and quite similar for all curves: span length 3.0 m, shear span length $L_S$ = L/4 = 750 mm, depth of composite slab $h_t$ = 140 mm and nominal sheet thickness $t_N$ = 0.88 mm.

Re-entrant profiles of the original generation (Holorib, without embossments) show a brittle failure mode. As soon as the pure shear bond is destroyed (increasing bending moment, cracking of concrete in tension, shear stresses on both sides of these cracks exceed the pure bond strength, end slip occurs) the load decreases suddenly and considerably. Due to clamping forces in the shear span length the re-entrant geometry makes somewhat higher loads possible.

Composite slabs with trapezoidal profiles (e.g. Cofradal 60) show also a brittle failure mode. But end anchorage means, in this case Cofradal 60 with throughwelded headed studs ∅ 3/4" (19 mm), lead to a clear improvement of the slab behaviour up to failure, particulary with regard to bending resistance and ductility. Almost no end slip occurs, and the sheet fails in load bearing at the headed studs at the panel ends.

The re-entrant shapes with embossments (new generation, e.g. Super Holorib) show however a very ductile behaviour, after first end slip has been recorded, together with high load carrying capacities. In this case significant slip occurs at the steel-concrete interface before the maximum load is reached (longitudinal shear failure). As an alternative, the ribs at the panel ends can be bent to provide another type of end anchorage and to prevent the wet concrete from flowing through the dovetail ribs.

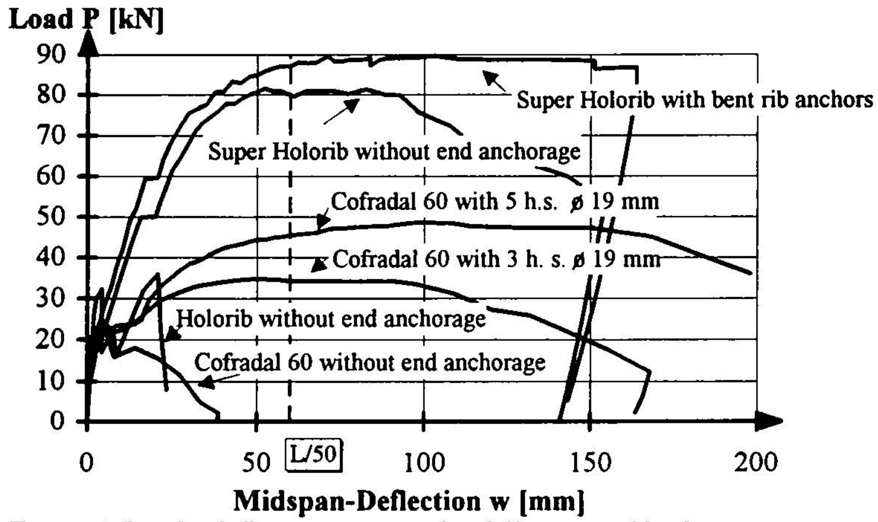


*Figure 1: Load - deflection - curves for different profile shapes with and without end anchorage*

A statistic evaluation of seven Cofradal 60 slab tests with throughwelded headed studs ∅ 3/4" leads to the characteristic shear strength $P_{pb.Rk}$ = 25.1 kN per stud. Eurocode 4 [1], 7.6.1.4 proposes for the load bearing capacity of headed studs corresponding to our test conditions the conservative value $P_{pb.Rk}$ = 19.6 kN. The evaluation of 23 earlier pull-out tests without concrete yields a load bearing capacity of such headed studs ∅ 3/4" being about 15.7 kN. The strengthening effect of the surrounding concrete results in about twice the value: from five pull-out tests with concrete a characteristic value of 31.3 kN per stud can be deduced.

A good approximation for the strength of one bent rib anchor is the area of the anchored rib times the yield strength of the steel sheet. For the Holorib 51/0.88 shape this leads to $P_{pb.Rk} = A_{Rib} \cdot f_{yp} = (3.6 + 2 \cdot 5.1) \cdot 0.88 \cdot 32.0 = 38.9$ kN.

## 3. Design methods for horizontal shear

Eurocode 4 offers two different design methods to check the horizontal shear strength of composite slabs.

The m+k - method - slightly modified from the original North Amercian version - is the standard method for the longitudinal shear verification.

The partial connection method ($\tau_u$ - method) with incomplete interaction and considerable relative displacements at the steel concrete interface is in accordance with the well known partial connection design for composite beams with flexible connectors. Therefore it can be used to design composite slabs with enough ductility even in case of horizontal shear failure. The same mechanical model is being used for the test evaluation and for design purposes (fig. 2a, b). This

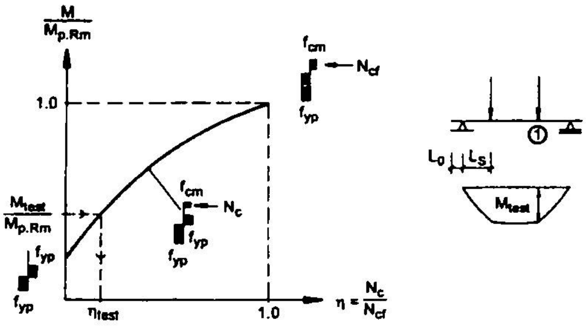

*Figure 2a:Determination of the degree of shear connection from slab test*

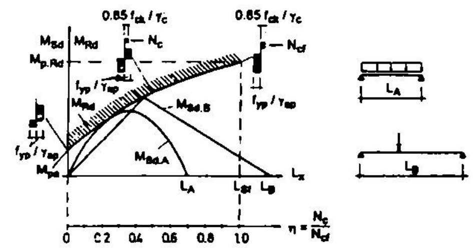

*Fig. 2b:Design with partial interaction diagram*

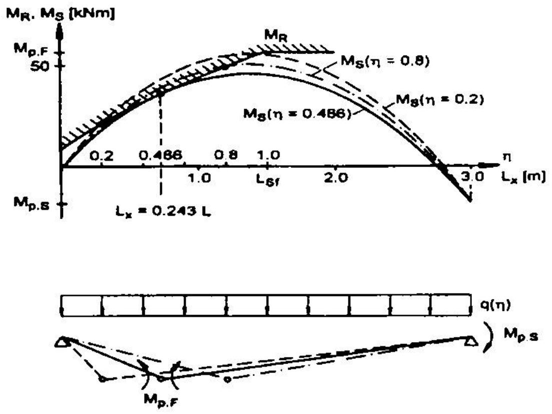

*Fig. 2c:Design of continuous composite slabs*

method leads to a very good agreement between theoretical solutions and test results. It is easy to take into account additional (fire) reinforcement and end anchorage measures. Even the determination of the ultimate loads of continuous composite slabs by means of a modified global plastic analysis is possible [5], [6]. Figure 2 shows this design method applied to a two span slab indcluding the critical cross section for $\eta$ = 0.486 (degree of shear connection).

# 4. Improvement of the $\tau_u$ - method by means of slip-block tests

The evaluation of standard tests according to EC 4, annex E, results in the determination of $\tau_u$ as shown in figure 2:

$$\tau_u = \eta_{Test} * N_{cf} / (b * (L_S + L_0)) \qquad (1)$$

This shear strength $\tau_u$ consists mainly of the overriding resistance, but also of friction over supports and clamping forces, if there are any. Line 1 in fig. 3 indicates the overestimation of longitudinal shear resistance for small $L_S/h_t$ values. The filled round marks in fig. 3 indicate the $\tau_u$ - values of 13 full scale slab tests over the ratio shear span to depth ($L_S/h_t$). The tests with Super Holorib sheets were carried out and evaluated as shown in fig. 2 according to EC 4. Line 1 is a linear approximation throughout these 13 values. Results of the so called slip-block tests [8], [13] can be used to improve this method. Fig. 4 illustrates the test arrangement with a little composite

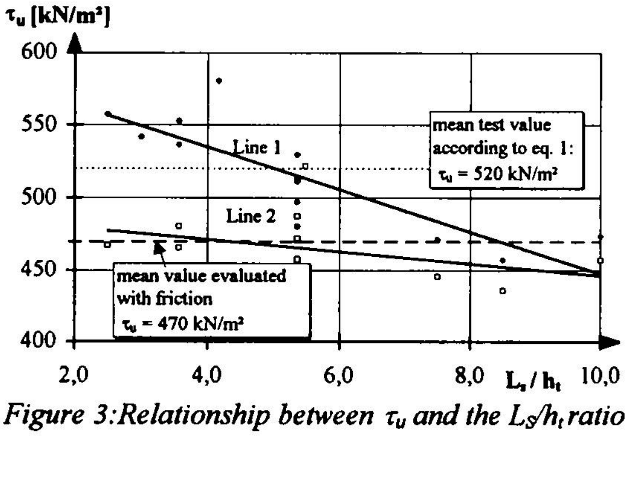


*Figure 3:Relationship between $\tau_u$ and the $L_S/h_t$ ratio*

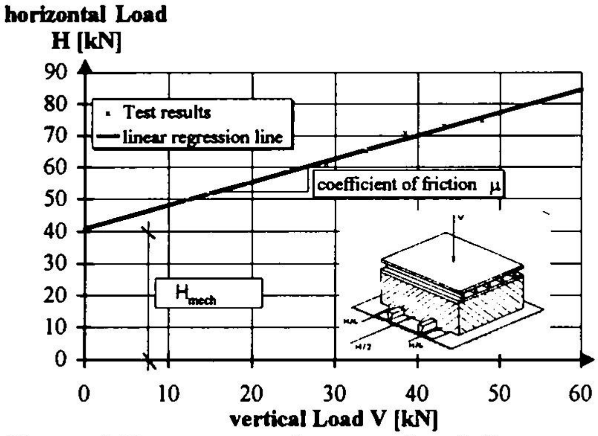


*Figure 4: Test set up and test results of slip-block tests*

slab specimen (e.g. length 300 mm, width 300 mm, high 200 mm) under vertical (V) and horizontal (H) loading. By means of this small scale test the contributions of friction (friction coefficient $\mu$) and mechanical interlock ($H_{mech}$) can be separated. Fig. 4 contains test set up and test results of such slip-block tests carried out at Kaiserslautern University, and this with the same metal decking as used in the full scale slab tests. A linear regression analysis yields the corresponding friction coefficient. The remaining longitudinal shear resistance (after the contribution due to friction has been substracted) $\tau_u'$ results in line 2 in fig. 3. The square marks indicate the evaluation according to eq. 2. The influence of the shear span length is obviously clearly reduced, if friction over the supports is taken into account.

$$\tau_u' = \eta_{Test} * N_{cf} - \mu * V_{Test}/(b * (L_S + L_0)) \quad (2)$$

## 5. Behaviour of composite slabs under cyclic loading

Load-deflection and load-slip curves of two identical slabs (Super Holorib 51/0.88) with preloading of 5000 cycles in the static test and with 2 Million load cycles in the dynamic test are compared in figure 5. In this case the maximum load itself, the midspan deflection at this load and the corresponding end slip are obviously independent of the number of load cycles. The major part (2/3) of midspan deflection increases along with concrete cracking and end slip during the first 5.000 cycles. The behaviour of this type of composite slab even under cyclic loading (from fork lift trucks) is very good, and no fatigue damage occurs as long as the stresses in the profile sheet are clearly lower than the yield strength. For the considered test the stress range $\Delta\sigma$ was 120 N/mm², and the top stress 75% of the yield strength. Tests with concentrated point loads are not described in EC 4. At the moment a research program with composite slab tests under static and dynamic loading (up to wheel loads of 7to forklift trucks) is carried out at Kaiserslautern University. As it can be seen from fig. 5, there is no difference between the static and dynamic tests regarding the maximum load. For fatigue design purposes it is proposed to assume rigid connection with full interaction

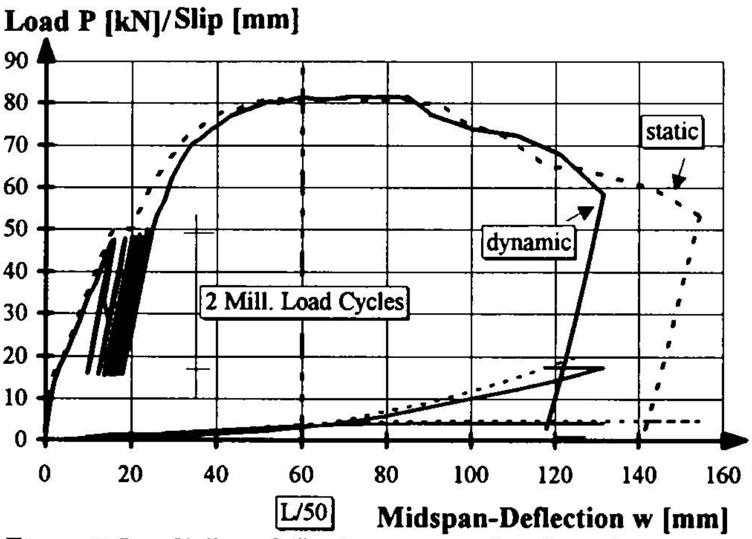


*Figure 5: Load/ slip - deflection curves of static and dynamic slab tests*

between concrete and profiled steel sheeting, in order to evaluate the stress range $\Delta\sigma$ in the steel part.

Now we are carrying out coupon tests with varying stress ranges $\Delta\sigma$ to derive values for further improved S-N-curves.

## 6. Conclusions

Composite slabs with ductile horizontal shear failure - such as re-entrant profiles with embossments or trapezoidal profiles with throughwelded headed studs as end anchorage means - show a very high load carrying capacity and good servicability properties under static and dynamic loading. This has been proved by means of composite slab tests. In addition a procedure has been outlined to improve the partial connection method by means of so called slip-block tests. This scientific work was financially supported by DFG (German Research Foundation). This support is gratefully acknowledged.

## References

[1] Eurocode 4: Design of Composite Steel and Concrete Structures - Part 1-1: General Rules and Rules for Buildings. ENV 1994-1-1:1992

[2] National Application Document for Germany, DASt-Richtlinie 104

[3] Bode, H.; Sauerborn, I.: Modern Design Concept for Composite Slabs with Ductile Behaviour. Engineering Foundation Conference on Composite Construction II, Potosi, USA. June 1992.

[4] Crisinel, M.; O' Leary, D.: Composite Floor Slab Design and Construction. IABSE, Stuctural Engineering International Vol. 6, No. 1, 1996.

[5] Bode, H.; Minas, F.; Sauerborn, I.: Partial Connection Design of Composite Slabs. IABSE, Stuctural Engineering International Vol. 6, No. 1, 1996.

[6] Sauerborn, I.: Zur Grenztragfähigkeit von durchlaufenden Verbunddecken. Ph.D Thesis Kaiserslautern University, 1995.

[7] Stark, J.W.B.; Brekelmans, J.W.P.M.: Plastic Design of Continuous Composite Slabs. IABSE, Stuctural Engineering International Vol. 6, No. 1, 1996.

[8] Patrick, M.: The Slip Block Test - Experience with Some Oversea Profiles (Part A). Melbourne, Australia, June 1990.

[9] Porter, L.: Two-Way Analysis of Steel-Deck Floor Slabs. Ninth International Specialty Conference on Cold-Formed Steel Structures St. Louis, Missouri, USA, 1988.

[10] Crisinel, M.; Fidler, M.J.; Daniels, B.: Flexural Tests on Composite Floors with Profiled Steel Sheeting. École Polytechnique Féderal de Lausanne, March 1986.

[11] Veljkovic, M.: Behaviour and Resistance of Composite Slabs. Experiments and FEM-Analysis. Ph.D Thesis, Lulea University, 1996.