

HEADED STUDS IN COMPOSITE STRUCTURES WITH LWAC

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SUMMARY

The application of lightweight-aggregate concrete (LWAC) in composite structures was realized recently in a few projects. The development of HSLWAC facilitates concretes with a moderate strength, but extremely low density. Therefore, it is necessary to verify the range of applicability for the existing design rules.

The following report presents the first results of push-out tests with headed studs in solid slabs embedded in a LC 20/25 with an oven dry density $\rho_w=1,25 \text{ kg/dm}^3$. From the tests conducted so far, it appears that it will be necessary to work out new design formulas for the application of LWAC.

1 INTRODUCTION

The design resistance of shear connectors in composite structures is defined in the European standard EC4 [1] only for connectors embedded in normal-density or lightweight-aggregate concrete (LWAC) with a density greater than $\rho=1,75 \text{ kg/dm}^3$. In cases, where the concrete density doesn't satisfy this condition, the design resistance should be determined experimentally from push-out tests.

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2 EXPERIMENTAL PROGRAM

Nowadays the welded headed-stud is the most common form of shear connection adopted in composite structures. When its design is based on experimental evidence, the resistance is usually investigated with push-out tests. Testing procedure and evaluation are regulated in the EC 4.

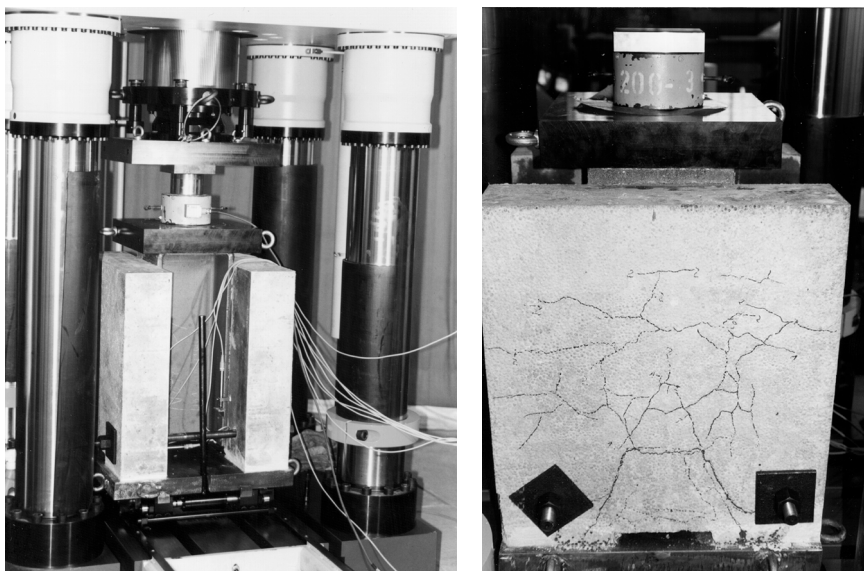


Fig. 1: Test specimen

Every concrete slab was cast in the horizontal position, as is done for composite beams in practice. In the first test series three specimens were manufactured with a LC 20/25 and an oven dry density $\rho_u=1,25 \text{ kg/dm}^3$. The mix composition is given in table 1. While no pre-wetted LWA were used, a good workability could be reached by means of a superplasticizer. The risk of segregation increases with decreasing aggregate density and is often connected with LWA floating on top of the concrete. The applied silica slurry reduced this problem, so that nearly no segregation was observed.

Table 1: Mixture design of the LC20/25 and concrete properties of the mixes of one specimen

Cement CEM I 42,5 - R	380	kg/m ³
Water	201	kg/m ³
Lightweight coarse aggregate - expanded clay, 4/8mm	400	dm ³ /m ³
Lightweight fine aggregate - 0/2mm	233	dm ³ /m ³
Silica fume	35	kg/m ³
Superplasticizer, naphthalene-based	12	kg/m ³
Fresh concrete density	1,45	kg/dm ³
Oven dry density	1,25	kg/dm ³
28/29-day compressive cube strength $\beta_{WN,150}$	31,6	N/mm ²
28/29-day E-modulus (average)	12600	N/mm ²

The test specimens, the cubes and cylinders were covered with wet burlap and plastic foil for two weeks. After that the specimens were air cured up to the day of testing. According to [2], the following relations for the compressive strength apply:

$$f_{cm} (EC4) = \delta_R \cdot \delta_L \cdot \beta_{WN,150} = 0,8 \cdot 1,25 \cdot \beta_{WN,150} = \beta_{WN,150}$$

where: δ_R = coefficient for dimension of test specimen

δ_L = coefficient for curing procedure

$$f_{ck} = f_{cm} - 8 = 23,6 \text{ N/mm}^2$$

The capacity of the shear studs is primarily influenced by the compressive strength and modulus of elasticity of concrete. The choice of a LWAC with an extremely low E-modulus should serve the purpose of verifying the range of validity of the empirical developed design formulas in case of the use of LWAC.

The test specimen is shown in Fig. 2. The flanges of a short piece of steel section are connected to two small concrete slabs by means of eight headed studs ($\varnothing 22$ mm). The slabs are then bedded down onto the bearing plate of the compression-testing machine, with the load being applied at the upper end of the steel member controlled by the displacement. The longitudinal slip between the steel beam and the two slabs is measured at four points on the specimen, and the load per connector is plotted against the average slip. The moment $M=0,5 \cdot P \cdot e$, that is initiated by the eccentric load induction, will be taken by forces D and Z. A steel bar was attached in order to resist this tensile force Z tending to separate the slab from the steel beam.

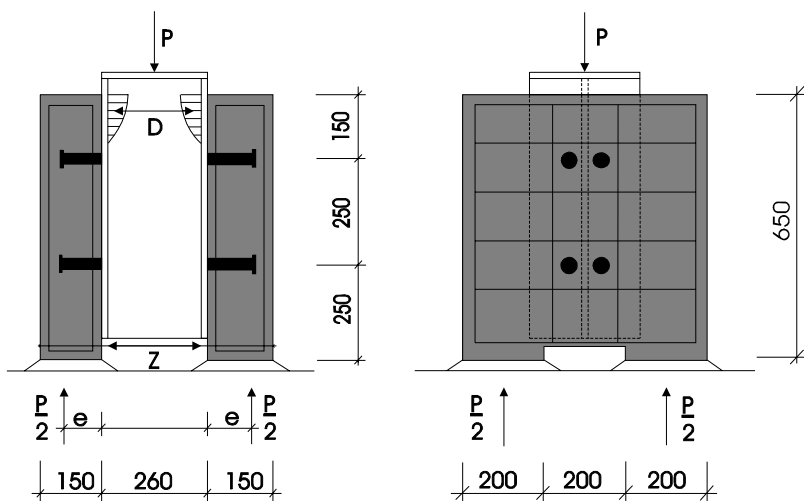


Fig. 2: Test specimen for Push-out test

3 BEHAVIOUR OF HEADED STUDS EMBEDDED IN LWAC

The load-slip curve of the second test is documented in Fig. 3. In comparing the results of this LWAC test with tests of normal concrete, the same favourable mechanical composite behaviour of LWAC is apparent. LWAC demonstrates a great initial stiffness in the serviceability state. It also demonstrates a great deformation capacity of the connectors in the ultimate limit state up to the failure point without a significant loss of the stud resistance. The evaluation of the test series is carried out in accordance with EC 4. The shear capacity is calculated as (related to one stud):

- minimum failure load: **$\max P_e = 131,2 \text{ kN}$**
- characteristic resistance: **$P_{Rk} = \max P_e / 1,1 = 119,3 \text{ kN}$**
- design resistance: **$P_{Rd} = P_{Rk} / 1,25 = 95,4 \text{ kN}$**
- mean initial stiffness: **$0,5 \cdot \max P_e / s_{cor} = 2265 \text{ kN/cm}$**

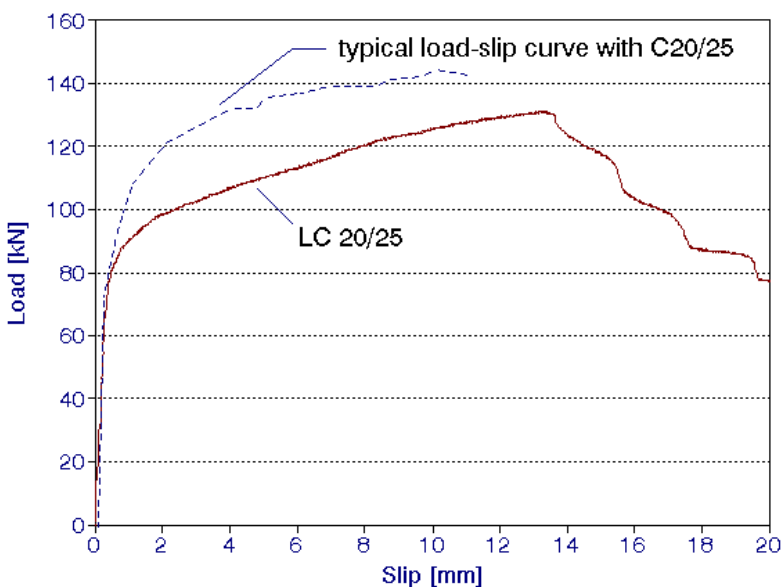


Fig. 3: Load-slip curve for a headed stud embedded in NC and LWAC

Additionally a typical load-slip curve for a C20/25 was exhibited in fig. 3 for comparison. Generally the load-slip curve in case of a LWAC application can be subdivided in three ranges:

First range:

In the serviceability state the load increases almost linearly up to about 60 % of the failure load. The horizontal shear force acting at the steel-concrete interface is transmitted principally by the stud's root. (see Fig.4 and 6 - load part A). Because of the load concentration at the weld collar, only small deformations take place. Therefore it is justified to speak of a full shear connection in the serviceability state. The behaviour of normal concrete under working loads differs only irrelevantly from those of LWAC because of a bigger initial-stiffness of about 50%. This fact is not of great significance considering the small deformations at this load level.

Second range:

The significant, non linear increasing of the deformation is characteristic for the load levels above the serviceability state. This loss of stiffness is caused by the local crushing of the concrete around the foot of the shear connector and thus by a load distribution from the weld collar to the shank of the stud. This results in flexural and shear deformation of the studs (load part B according to Fig. 4 and Fig. 6), which quantitatively depends wholly on the elastic bedding, or on the E-modulus of the concrete, respectively. At this state the first cracks could be observed. This is the reason for the different development of the curve for NC and LC beyond the 60% -ultimate loading limit.

Due to the low bedding value, considerable additional deformations can be observed in the case of LWAC, although the load is only slightly increased. Since the concrete restrains the rotation of the head of the stud, tensile forces are created in the shank of the stud. The equilibrium is satisfied with a compressive force D , that is forced between the underside of the stud's head and the flange of the steel beam (load part C).

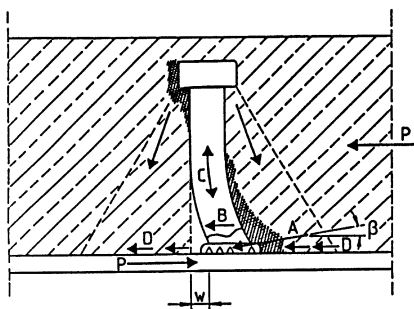


Fig. 4: Composite behaviour of headed studs in solid slabs [1]

With increasing longitudinal slip, the axial force, that results from the geometry of the deformed system, grows in the shank and thus in the compressive force D as well. This reflects a friction force R in the steel-concrete interface (load part D).

The maximum load will finally be reached after several studs failed at the top of the weld collar due to the combined effects of shear and tension.

The deformation in the steel-concrete interface at the point of failure ranges from 10 to 14 mm for the conducted tests. Thus, the criteria of ductility according to EC 4, section 6.1.2.(3) is comfortably satisfied.

Third range:

After exceeding the maximum load, lower load levels were reached step by step. A ductile behaviour was detected; when one stud fails, there was enough capacity in the neighbouring studs to absorb the load shed. This result was confirmed by the steel sections uncovered after the tests (see Fig.5).

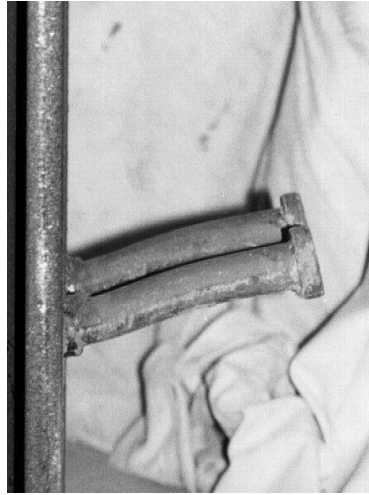


Fig. 5: Uncovered specimen after the test

Fig. 6 exhibits the load parts A to D for NC and the probable distribution for LWAC in quality according to [2]. The effects of the low bedding in case of LWAC appear in a different distribution of the load parts B to D. The larger deformations increase the load parts C and D and simultaneously reduce the load part B [3]. Further information will be expected after the numerical evaluation of the experimentally determined data.

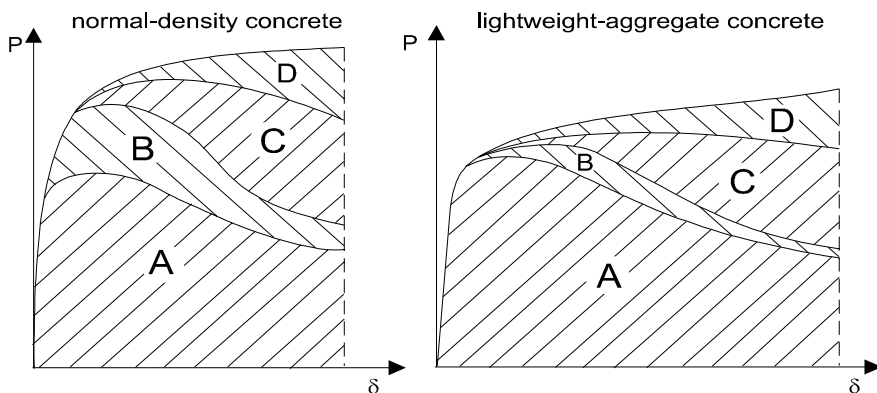


Fig. 6: Qualitative representation of the load parts A to D (acc. to Fig.4) for NC [2] and the probable distribution in case of LWAC

An extrapolation of the basic design formulae presented in EC4 (Eq. 6.14) for the here employed LWAC gives a characteristic stud resistance of $P_{Rk}=75,2 \text{ kN}$.

$$E_{cm} = \eta_E \cdot 9500 \cdot \sqrt[3]{f_{ck} + 8} = 12160 \text{ MPa}$$

$$\text{where: } \eta_E = (1400 / 2200)^2$$

$$P_{Rk} = 0,29 \cdot d^2 \cdot \sqrt{f_{ck} \cdot E_{cm}} = 75,2 \text{ kN}$$

The measured values exceed the calculated ones by about 50%.

4 CONCLUSIONS

The following conclusions were reached in this study so far:

- The first test series with LWAC confirms the known favourable mechanical composite behaviour of headed studs in NC. One significant difference was observed in comparison to NC beyond the 60%-ultimate loading limit regarding the deformations of the shear connectors because of the lower bedding of the studs. After reaching the ultimate load, several studs failed at the top of the weld collar due to the combined effects of shear and tension. A very ductile behaviour was observed.
- An extrapolation of the empirical basic design rules given in EC4 for headed studs in solid slabs embedded in NC seems to underestimate the real shear resistance considerably in the case of LWAC.

These results have to be confirmed in further investigations, including the shear resistance of shear studs used with profiled steel sheeting as well, to develop new formulas for the application of LWAC in composite structures.

Literature

- [1] Eurocode 4, Part 1-4, German Draft ENV 1994-1-1: 1992
- [2] Roik,K.; Hanswille,G. et al.: Hintergrundbericht zu EUROCODE 4 - Abschnitt 6.3.2: Bolzendübel
- [3] Lungershausen,H.: Zur Schubtragfähigkeit von Kopfbolzendübeln - Institut für konstruktiven Ingenieurbau - Ruhr Universität Bochum Mitteilung Nr. 88-7 , Oktober 1988