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Cast Screws as Shear Anchors for Composite Slabs

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Abstract

Composite slabs consist of trapezoidal steel sheeting and concrete cover. The steel sheeting serves as both, a lost framework and a tension bearing member after hardening of concrete. The longitudinal shear between the sheeting and the concrete must be ensured by a mechanical interlock, for example shear studs or prepressed embossments in the sheeting. The traditional massive shear studs have to be welded to the supporting construction of the slab. Alternatively, thin screws can be drilled through the sheeting and cast into the concrete to ensure the composite action or to strengthen the composite slab in reconstructions locally. The usage of the screws is not limited to the steel supporting frames. This paper describes laboratory tests of the composite slabs with cast screws of various diameters and the effect of the screws on the bending capacity of the slab in combination with prepressed embossments.

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Keywords: Cast screw; composite slab; concrete; embossments; longitudinal shear; shear anchor; steel.

1. Introduction

The global failure mode of composite slab can be bending, longitudinal shear or vertical shear. The longitudinal failure mode is typical for composite slabs. In that case, the shear bearing capacity of the connection between steel sheeting and concrete is crucial to determine the overall bending resistance of the slab. The shear connection can be realized by prepressed embossments in the sheeting. Screws drilled into the sheeting and cast into the concrete can be used as an alternative and local reinforcement of the shear connection.

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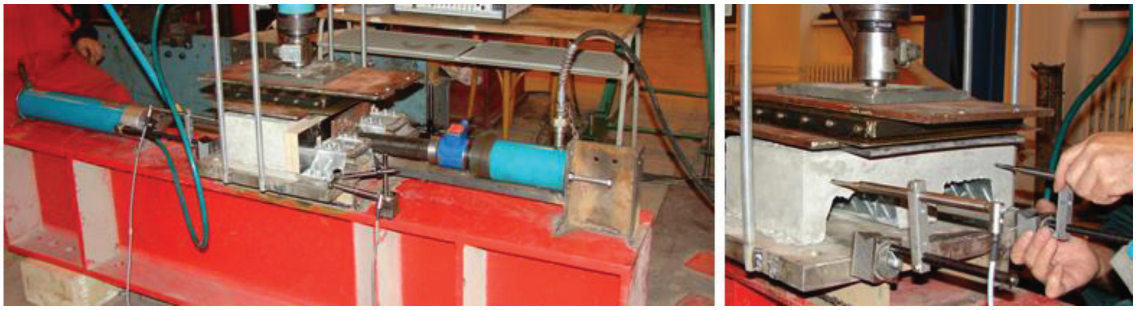
The nowadays codes present two design methods for composite slabs: m-k method and partial connection method. Both methods require bending tests. Alternatively, several design methods using small-scale shear tests have been proposed in scientific literature [1, 2]. Both the bending tests and the shear tests of the slabs with cast screws have been performed. This paper uses the results of the shear test set-up to estimate shear bearing capacity of the screws. The contribution of the screws to the bending resistance of the slab was compared using Built-up bars method [3, 4], Force equilibrium method [5] and using the results of the performed vacuum loading bending tests.

2. Experimental investigation

2.1. Small-scale shear tests

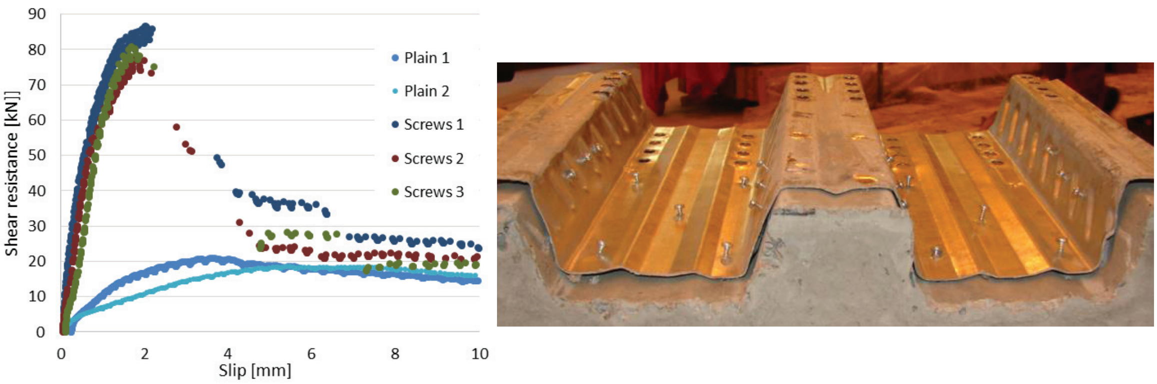
The test arrangement can be seen in Fig. 1. The length of the sheeting of the specimen was 0.33 m, the length of the concrete 0.20 m, width of the specimen was 2 waves (0.41 m) and the thickness 0.11 m. The load was applied by two hydraulic cylinders. The vertical clamping force was transmitted through roller bearing to enable the movement of the concrete block. The concrete block was pushed out of the sheeting by the second cylinder through load distribution plates. The movement of the concrete block and the sheeting and the magnitudes of the forces were measured.



(a) (b)

Fig. 1. (a) Small-scale shear test set-up; (b) concrete block movement measuring devices.

The shear test was performed using Cofraplus 60 sheeting, thickness 1 mm, galvanized surface, material S350GD. The test was performed using plain sheeting as well as sheeting with screws 3.5 x 50 mm which were drilled into the sheeting and cast. Each specimen had 28 screws (Fig. 2). The average concrete compression strength $f_c = 61.2$ MPa and the average concrete elastic modulus $E_c = 31$ GPa. The shear bearing capacity of the specimens with screws was on average 65 kN higher than the shear bearing capacity of the plain specimens. The contribution of one screw was then 2.32 kN. The contribution was mainly at small magnitudes of slip (Fig. 2a). After reaching small slip the screws were cut or bent (Fig. 2b) and the shear capacity was decreased suddenly.



(a) (b)

Fig. 2. (a) Comparison of shear resistances of the specimens with screws and without screws; (b) the specimen with screws after the test.

2.2. Vacuum loading bending test

The special loading device (Melcher/Karmazinova/Schmid – Vacuum test method) was used to perform the tests. The specimens were put into an air-proof chamber and covered by plastic foil. The air was sucked out of the chamber so the specimens were loaded by the difference between the air pressure in the chamber and the atmospheric pressure (Fig. 3a) [6]. The specimens were supported as a simple beam and the deflection was measured in midspan, ¼ of the span and above the supports.

The specimens of the composite steel and concrete slab with Cofraplus 60 sheeting (thickness 1 mm, galvanized surface, with embossments) of the length 2 m, width 1.08 m and the thickness 110 mm were compared using various end anchorage: no end anchorage, cast screws of small diameter (60 screws 3.5 x 40 mm on each side) or cast screws of big diameter (5 screws 10 x 40 mm on each side of the slab); see Fig. 3b. The average concrete compression strength f_c = 25.4 MPa and the average concrete elastic modulus E_c = 20.7 GPa. The reinforcing mesh ø6/100/100 (material B490B) was used to prevent the shrinkage cracks.

(a) (b)

Fig. 3. (a) Comparison of shear resistances of the specimens with screws and without screws; (b) the specimen with screws after the test.

(a) (b)

Fig. 4. (a) The failure mode of small diameter screws; (b) the failure mode of big diameter screws.

The big diameter screws were chosen to change the failure mode to screw in bearing which is more ductile. The difference in failure modes can be seen in Fig. 4. The resulting diagram of the vacuum bending test can be seen in Fig. 5. The maximum values of bending resistances are influenced by reinforcing mesh which is in compression zone in common range of loading but progresses to tension zone as the deflection rises because the neutral axis moves upwards.

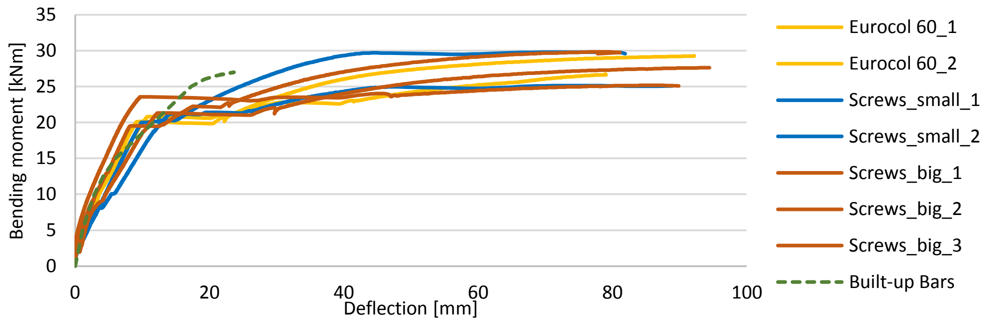


Fig. 5. The bending moment deflection diagram obtained by vacuum bending test.

3. Theoretical investigation

3.1. Built-up bars method

The Built-up bars method uses analytical derivation of the partial connection in combination with the shear characteristics obtained from the shear tests to calculate the bending resistance of the slab and the deflection during loading [3, 4]. The cross section of composite slab is divided into two parts: the steel sheeting and the concrete layer. The bending resistance of the cross section M_R is then the sum of bending resistance of steel sheeting M_{pa} and the bending resistance of concrete layer given by longitudinal force in partial action $T(x)$ and lever arm z_{eff}:

$$M_R = M_{pa} + T(x) \cdot z_{eff} \, . \tag{1}$$

The shear resistance obtained by the shear tests of the plain specimens was 4.8 kN for initial phase corresponding to slip 0.5 mm. The maximum shear resistance was 13.8 kN corresponding to slip 4.9 mm. The shear resistance was increased in the calculation by the effect of screws considering the increase of the shear resistance of 60 screws on each side of the slab. The calculated diagram can be seen in

Fig. 5. The bending moment deflection diagram obtained by vacuum bending test.

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3.2. Force equilibrium method

The force equilibrium method uses the measured data of the deflection in ¼ of the span δ_1, δ_2 and the end slip of the slab s to calculate the increments Δ of bending moment in the steel sheeting when the slip is reached M_r, the vertical shear force V, the longitudinal force T and the shear resistance of the slab τ. The longitudinal force T at the instant i is calculated using:

$$T_i = T_{i-1} + \frac{\Delta T_i}{2} = \frac{\left(\frac{V_{i-1}}{2} + \frac{\Delta V_i}{4}\right)\left(\Delta\delta_{1i} - \Delta\delta_{2i}\right) - \left(M_{ri-1} + \frac{\Delta M_{ri}}{2}\right)\left(\frac{\Delta\delta_{1i} + \Delta\delta_{2i}}{L_s}\right)}{\Delta s_i}, \tag{2}$$

where L_s is the shear span of the slab. Whole the procedure of calculation is presented in [3].

The method can be used for the slabs with ductile behaviour only. The shear resistance (average value on the shear span) is calculated for the chosen specimens where the measured slip and ductility was sufficient. The resulting dependence can be seen in Fig. 6 (the moving average function was used to simplify the diagram).
The contribution of small diameter screws to the shear resistance acts mainly at the initiation of the slip unlike the contribution of the big diameter screw which acts at higher values of the slip.

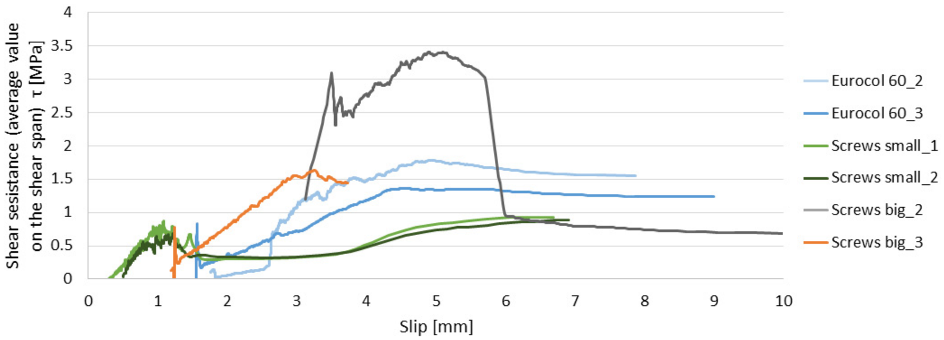

Fig. 6. Shear resistance calculated by force equilibrium method using data from the vacuum bending test.

4. Conclusions

The small diameter screws contributes to the longitudinal shear resistance at the small magnitudes of slip. In higher values of slip the contribution is small. The slab behavior therefore tends to be brittle. The usage of big diameter screws on the other hand increases the shear bearing capacity of the composite slab for higher values of slip. The slab behavior tends to be ductile. The big diameter screws are more suitable for combination with the prepressed embossments. The ductile behavior of the slab is more convenient for the ultimate bending moment. However, when higher slips are reached the deflection can exceed the maximum allowable deflection of serviceability limit state.

The Built-up bars method was used to calculate the bending resistance of the slab with small diameter crews which has been testes previously on the longitudinal shear resistance. The maximum bending resistance fits well with the measured values of the tests. The measured values of deflection were significantly higher than those calculated. The difference was probably because of the reinforcement mesh which occurred in tension zone just before the slab failed and caused increase of deflection.

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