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EFFECT OF PRESTRESSED EMBOSSMENTS UNDER VARIOUS TYPES OF LOADING USING FEM ANALYSIS

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Abstract. Composite slabs of trapezoidal steel sheeting and concrete are widely used for ceiling structures in all types of buildings. Prestressed embossments can serve as a meaning to ensure the composite action without need of other load bearing reinforcement. Design of the composite slab according to valid codes is governed by semi-empirical methods using bending tests to obtain unique parameters for each type of sheeting. Smaller and less expensive shear slip-block tests are considered as a meaning to obtain shear characteristics of the sheeting, which could be used for design of the sheeting. In our laboratory bending tests with different load arrangements and shear test were performed. The key role in load bearing capacity of the slab has the shear connection between steel sheeting and concrete. The FE (Finite Element) modelling of the connection must deal with a complicated geometry of the embossments and several possible failure mechanisms. Three types of numerical models are being created using Atena software. 2D and 3D models of shear test serves to describe the failure mechanism of embossments. Bending model of one rib over the whole span serves to include effects curvature due to bending. Influence of elevated temperature on shear bearing capacity is observed as well. The models are being set, calibrated and compared regarding data from the experiments performed in our laboratory.

1 INTRODUCTION

Composite slab with prestressed embossments presents a suitable solution for horizontal structures. Its load bearing capacity is mainly determined by its horizontal shear bearing capacity. The bearing capacity is determined using four-point bending tests. Research works are carried out on possibilities of determination of shear characteristics using small-scale slip-block tests, which present a less-expensive alternative to the bending tests [1]. Unfortunatelly final load bearing capacity of the sheeting is influenced by bending effects and loading arrangenent, which cannot be covered by shear tests.

Numerical models presented in this paper has its aim in both, modelling the behaviour of sheeting in small-scale shear tests and modelling of the bending effects in bending. Models are being set and calibrated regarding data from the tests performed in our laboratory. The simulation is realized using Atena software for computing because of its advanced nonlinear concrete analysis possibilities. GiD is used for pre/post processing, because of the complicated geometry of the sheeting with embossments. 2D model is used for correct setting of shear parameters of the task and observe the effect of local bending of the sheeting. 3D model of one embossment is set to observe spacial deformation of sheeting. Finally a bending model of one rib of the slab is modelled to include effects of curvature.

The tests performed in our laboratory consists of small-scale shear test and bending tests using vacuum loading developed by prof. Melcher [2]. Finally an effect of elevated temperature on the shear bearing capacity is modelled.

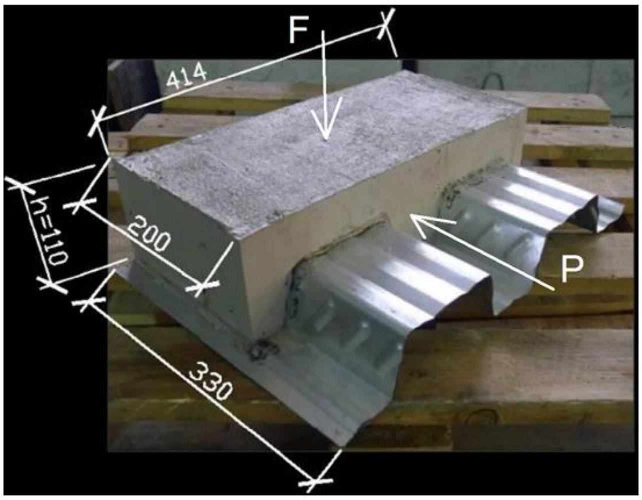
All the tests and models mentioned in this paper are related to the type of sheeting Cofraplus 60 (galvanized surface, 1 mm thickness) and the thickness of the slab 110 mm.

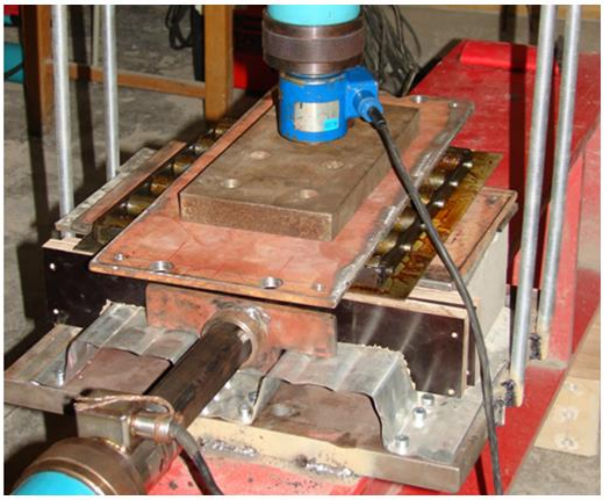
2 SHEAR TEST

2.1 Tests performed in laboratory

A special loading device has been constructed in our laboratory to perform shear slip-block tests. The specimens are bolted to a base plate in the overlapping part of the sheeting. Two jacks are installed to apply loads. One of them is placed vertically to produce a clamping force and the second is placed horizontally to push the concrete block out of the sheeting. A roller bearing is placed between the vertical jack and concrete block to allow sufficiently horizontal movement of the block. The specimens have width of two waves of the sheeting, which allows placing the horizontal load into the centroid of the sheeting cross-section. Mutual slip between steel sheeting and concrete block is measured.

When the slip occurs the sheeting starts to deform and bends in the area of the embossments. The concrete stays almost unimpaired; there is only small abbrasion around the indentations and longitudinal edges of sheeting.





(a) **(b)**

Figure 1: (a) Specimens dimensions (b) roller bearing placed on the top of the concrete block [3].

2.2 Numerical modelling

2.2.1 2D model

2D model of one embossment was created. The embossments resist to mutual slip by its stiffness in bending in combination with contact properties of the interface between steel and concrete. The modelled problem is therefore a combination of contact and bending tasks.

Length of the model is 102 mm, height of concrete is 50 mm and height of the embossment is 3 mm. The inner spacing between supports is 82 mm. Thickness of all the materials is 10 mm. Mesh is refined over the area of steel sheeting to form enough layers of elements for calculation of bending (at least 6 over the hieght). A complementary line is created between steel and concrete and is bonded with the line of the concrete to enable turning on a moving gap function. The complementary line is also an advantage because of possibility of using larger elements for concrete surface.

Figure 2: 2D model: deformed sheeting corresponding to slip 2 mm; displayed stress in longitudinal axes [kPa].

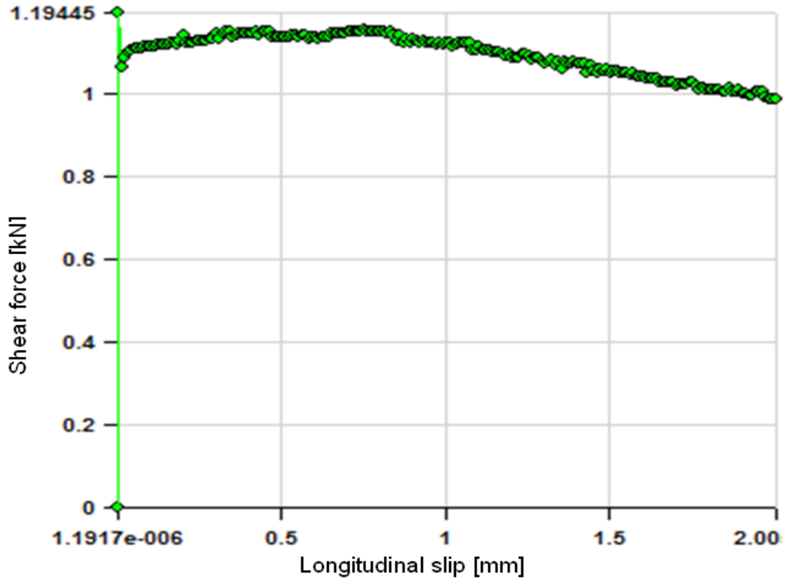
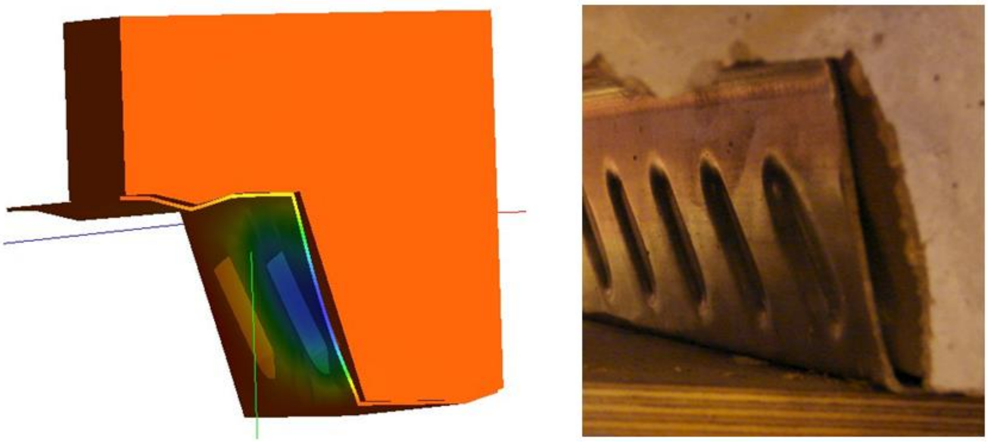


Figure 3: Load-slip dependence of 2D model.

Newton-Rhapson method used to compute in shear test models [4]. The loading is applied in two intervals. In the first interval vertical displacement 1e-7 m is assigned to the top line of the concrete block. In the second interval longitudinal displacement is assigned to left line of the concrete block. Friction was estimated to be 0.2, cohesion 1.0 Mpa and tensile strength 0.4 Mpa [5].

2.2.2 3D model of shear test

Because of the complexity of the embossment action one cannot describe the behaviour of the embossment in real test by the 2D model idealisation. Therefore 3D model of the shear test is being created in the length of one embossment of concrete and overlapping steel sheeting. The final shear bearing capacity of the embossment is influenced by distance of its end from longitudinal edge of the sheeting [6], as show the peak values of stress around the ends of the embossment in fig. 5.



(a) (b)

Figure 4 (a) Deformed sheeting in 3D model with displayed displacement in horizontal axes (b) deformed sheeting in real test.

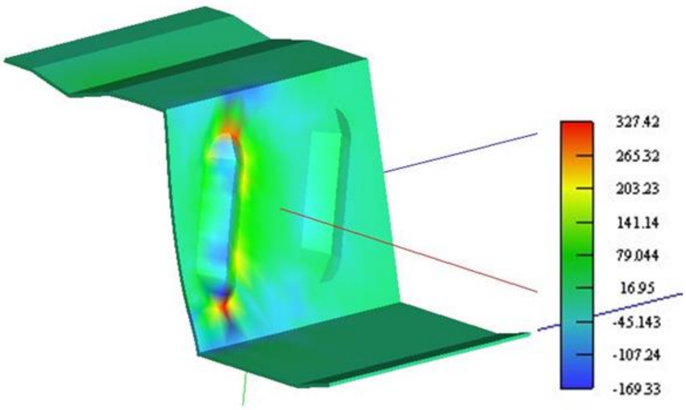


Figure 5 Deformed shape of the steel sheeting with depicted peaks stresses around the ends of embossment.

In order to obtain correct results in bending perpendicular to the plane of the sheeting there is a need to use several layers over the thickness of the sheeting. Atena enables to use Ahmad element developed by reducing of quadratic 3D bricks elements with 20 nodes. These elements include layers inside; therefore its usage significantly reduces required number of elements and time for computation [7].

2.2.3 Combination of thermal and static analysis

Design bearing capacity of the composite slab in fire according EC4 can be determined using theory of plasticity and reduced material properties without specifying the shear bearing capacity at elevated temperatures [8]. Moreover composite slabs behaviour in fire can be transformed to membrane action considering large deflections and proper supporting [9].

Thermal and static analysis was combined on 2D model to observe the sheeting behaviour at high temperatures. At first the thermal analysis was performed to obtain stationary temperature field. The field was then applied to static analysis. The same boundary conditions and material properties were used as in the normal temperature analysis. The temperature loading leads to deformation of the sheeting and subsequently reducing of shear bearing capacity (Fig. 7) in compare to normal temperature analysis (Fig. 3).

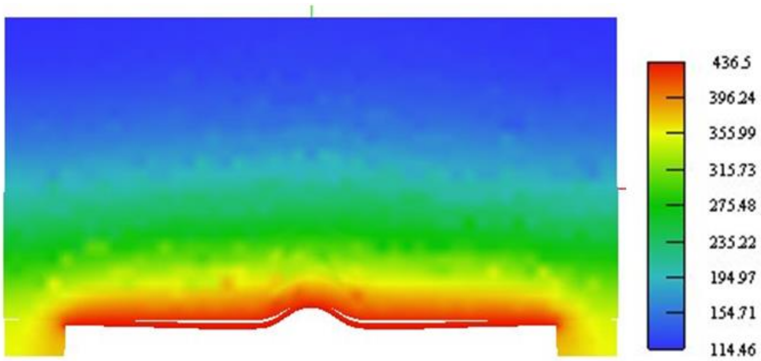


Figure 6 Deformed shape of the steel sheeting subjected to temperature load.

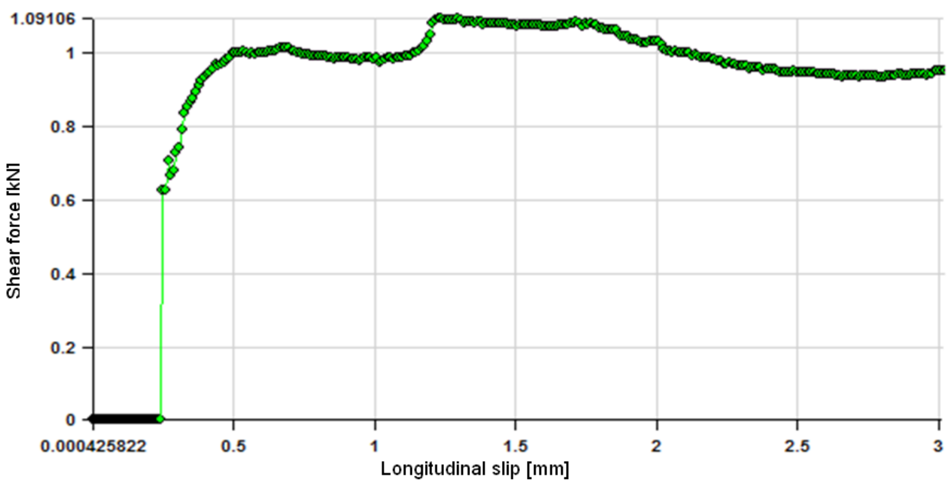


Figure 7 Load-slip dependence of 2D model subjected with temperature load.

Figure 8: Uniformly distributed cracks in concrete after finishing the test and removing of steel sheeting.

3 BENDING TESTS

3.1 Tests performed in laboratory

Ideally uniform area loading was produced using special vacuum loading device [2]. The specimens were simply supported with span 2 m and width 1.08 m. The concrete class was C20/25 and the yield strength of the steeting was 350 MPa. Slabs were loaded by almost 50 kN/m^2 using a common plastic foil. The uniformly distributed load results in uniformly distributed crack pattern over the length of the specimens. The cracks can be seen after finishing the test when the steel sheeting is removed.

3.2 Numerical modelling of bending

Model of one rib as a simply supported beam has been created. Shell elements are used for modelling the sheeting. The bending model is simplified because of the difficulties with detailed modelling of shear behaviour of embossments. The steel sheeting is plain and the effect of embossments is simulated by hardening/softening function of cohesion in Interface material.

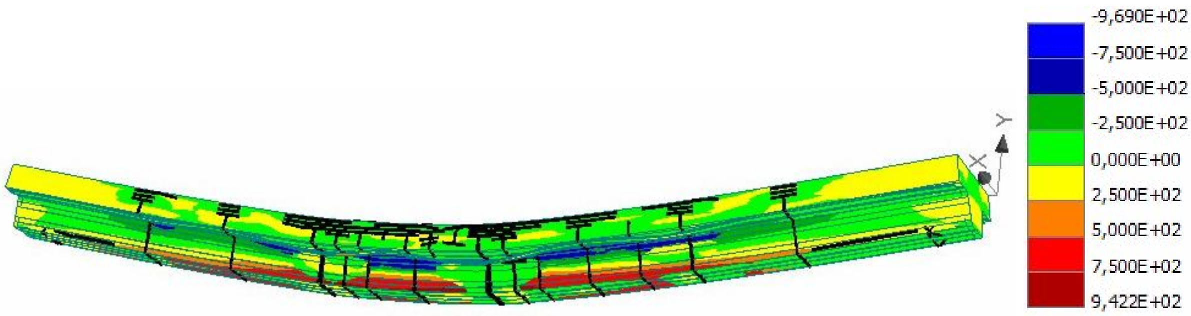


Figure 9 Stress in concrete in longitudinal axes [MPa] with crack pattern.

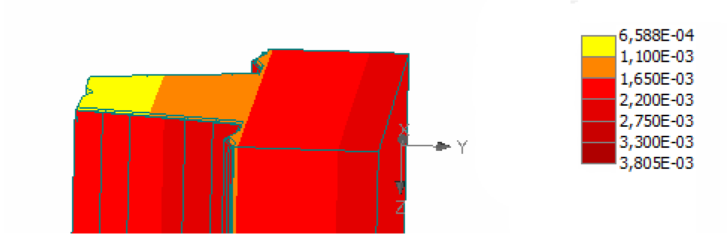


Figure 10 Mutual slip between steel and concrete at the end of the slab; longitudinal displacement [m].

Loading is realized by force applied on the top surface of concrete. Supports are realized by bricks from 3D elastic material. Arc-length method is used for computing.

The resulting bending model crack distribution and end slip development show good accordance with the real results for uniformly distributed load.

4 CONCLUSIONS

The paper presents numerical modelling of composite action of composite slabs with prestressed embossments. Models simulate the real behaviour of sheeting and concrete in slip-block test and bending test. The carried out research lead to the following conclusions:

- Numerical modelling of the embossment shear behaviour can adequately describe the real test behaviour. Both the detailed models and bending models, respectively, can present an effective tool for parametrical studies of sheeting geometry of material properties. However its correct setting is influenced by many factors and must be compared with the tests results.
- Prestressed embossments stiffen the plane parts of steel sheeting and thus present a sufficient tool for ensuring partial composite action. Distance of the ends of the embossments from sheeting longitudinal edges belongs to the most affecting factors of the final shear bearing capacity.
- The thin layer of steel sheeting can be effectively modelled using shell elements. This approach reduces the number of elements needed for analysis and enables to perform bending test simulation. The bending test modelling is realized using plain sheeting and the effect of embossments is substituted by cohesion function. Future works on the models can lead to the inclusion of embossment effect to the bending task.
- Determination of changes in stress state and shear bearing capacity at elevated temperature can be estimated using the FE analysis. Detailed model boundary conditions can be different from those in the real slab; this must be taken into account when interpreting the results.

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