# NUMERICAL SIMULATION OF BEHAVIOR OF TIMBER-FIBRE CONCRETE COMPOSITE FLOOR

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## Abstract

*Numerical simulation of the behaviour of composite concrete floor, consisting purely SFRC, i.e. without reinforcing bars, supported by solid timber beams. Comparison with conventional technology of execution (capacity, load, cost of the structure). Simulations were carried out in the program Atena 3D.*

**Keywords: fibre reinforced concrete, timber, numerical simulation, composite slab structures**

## 1. Introduction

Application of a fibre reinforced concrete slab in timber beam floor structures can eliminate some of the shortcomings of wooden structures (stiffness, heat capacity, fire resistance, impact noise) or it can be effective in reconstruction of existing floor structure (permanent load reduction, simplification of the construction technology).

Compared to "classical" technology of reinforced concrete panels the thickness of floor slab will be dramatically reduced (if the position of reinforcement is in the middle of the slab the minimum thickness of the slab is 60 mm). The reinforced concrete slab can be substituted by the FRC slab with thickness 40 mm what is proved by numerical simulations. The reduction of the slab depth and simplifying of execution (reinforcing by rebar reinforcement and delivering of the reinforcement to the site) decreases the costs related to erecting of the structure (about 40-50%).

## 2. Numerical simulation

The following text provides a comparison of the reinforced concrete and the fibre reinforced concrete slabs in a composite floor structure; influence of material components (wood, connectors, amount of fibres) on the behaviour of the structure as such. The computer program was developed the that uses the iterative steps to calculate the relation of the curvature changes in the cross-section and the bending moment; after derivation of this function the graph of changes of the bending stiffness related to the rotation is

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obtained and the first crack and the diagram of the stiffness of the changes after cracking are exactly determined.

## 2.1 Effect of particular material components

Fibre reinforced concrete

Material models for the simulations were determined in inverse analysis. Simulations of a four-point bending test were performed for FRC 0,25% (20 kg/m$^3$), 0,35% (30 kg/m$^3$), 0,50% (40 kg/m$^3$), 1,0% (75 kg/m$^3$), 2,0 % (155 kg/m$^3$).

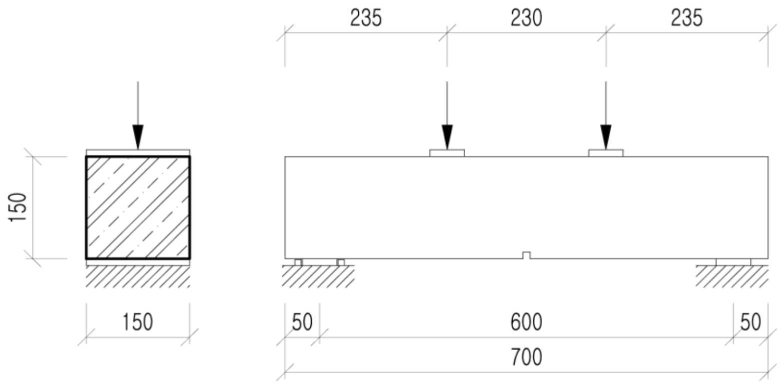



Fig 1 – FRC specimen

For further modelling FRC with 1.0% of dispersed fibres was chosen, i.e., about 75 kg/m$^3$. With higher content of fibres there is the so-called deformation hardening and ductility is greatly increased. This was reflected in the behaviour of the investigated T-section (length of the beam 4.90 m, section 220/270 mm, timber class C14, cross-section of the FRC slab 800/50 mm) cut of from the model of the structure (see Fig 2, 3 and graph 1). Figures show how plastic hinges were created at the point of load application for the lower amount of fibre reinforcement (fig. 2) and ductile behaviour of the FRC slab with higher reinforcement ratio (fig. 3).

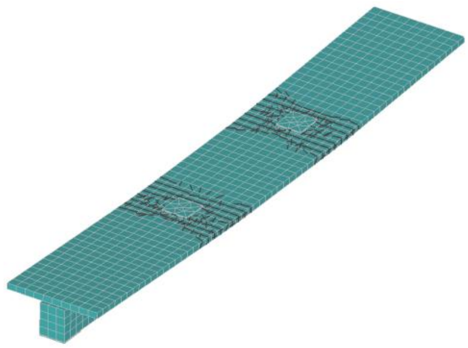


Fig. 2 FRC level of reinforcement 0,35%

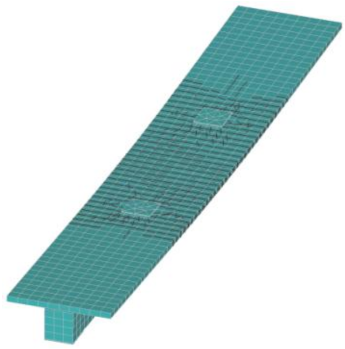
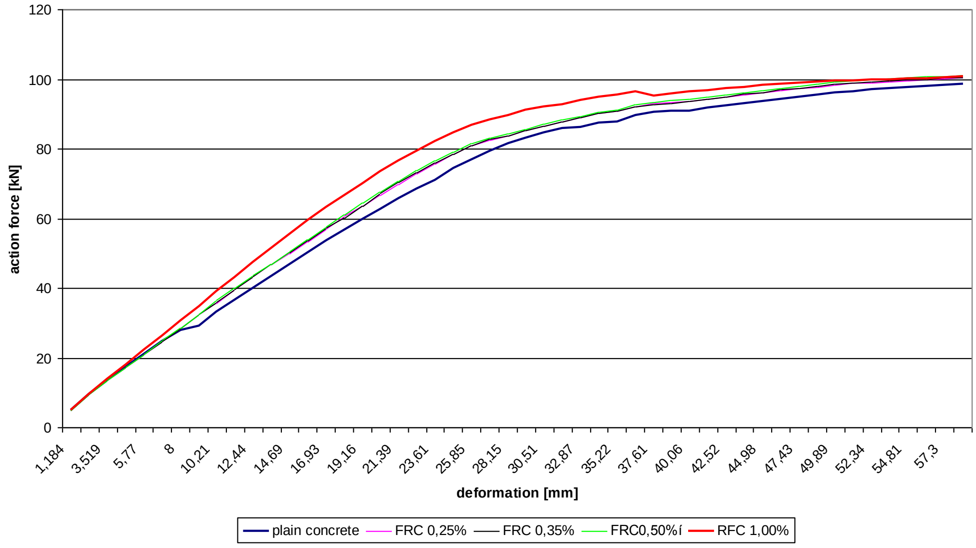


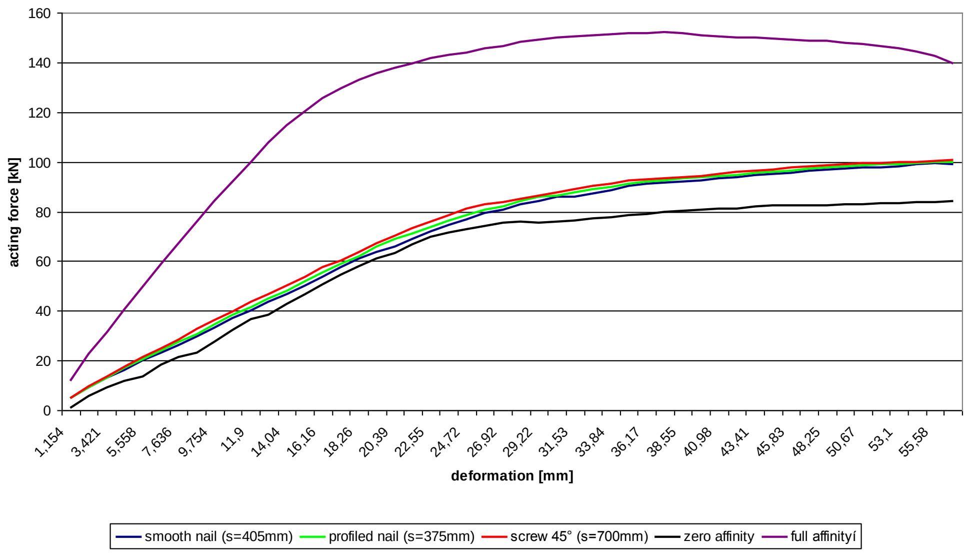
Fig. 3 FRC level of reinforcement 1,00%

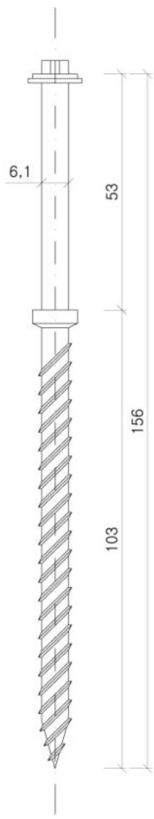



Graph 1 – Influence of the reinforcement ratio of the slab on the behaviour of the T-section (interconnection with screws 45 degrees to the beam axis)

Connectors

The first idea was that the connectors will be modelled discretely (i.e. detailed modelling of the connector, slip and deformation in the beam and slab), however, this model was too demanding on the computer capacity. Therefore, the connectors were modelled by a contact between two materials. Three types of dowels were examined (nail with a smooth and profiled shank and screw at angle 45 degrees to the beam axis).




Graph 2 – Influence of the connector type on the behaviour of T-section

The best results are obtained with the screws inclined 45 degrees to the beam axis; due to the inclination of the screw the forces are distributed in the normal and tangent direction; the normal component prevents the development of pronounced delamination of the beam and plate and provides better interaction and greater load-bearing capacity. Properties of the connectors were adjusted with respect to possible slip and deformation of the timber based on extrusion tests (see Prof. Koželouh, Bratislava, 1978)

| | | |
|---|---|---|
| resistance of a nail | $R_d$ | = 1,628 kN |
| spacing of nails | s | = 700 mm |
| number of elements in the beam | n | = 14 ks |

Increased resistance of a nail (+20%, Koželouh)

$R_{d+20\%}$ = 1,954 kN

The contact surface of the wood and FRC slab

A = 0,14x4,9 = 0,686 m$^2$

Shear stiffness of joints:

$$K_3 = \frac{n \cdot R_{d+20\%}}{A} = \frac{14 \cdot 1954}{140 \cdot 4900} = 0{,}040 MPa$$

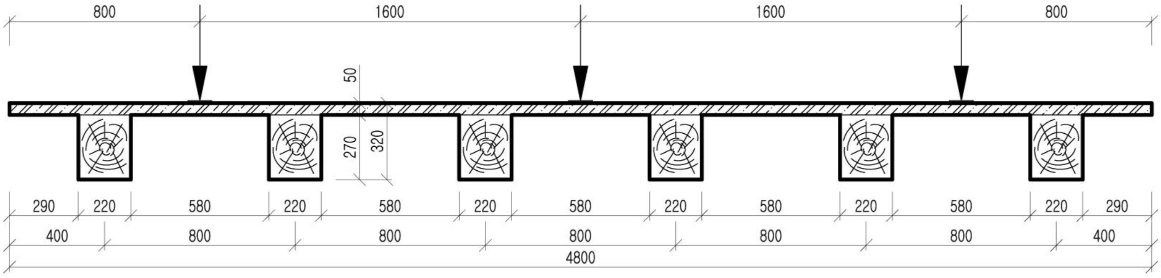
<u>Timber</u>

Timber was introduced using a bilinear stress-strain diagram. The influence on the overall grade of timber carrying capacity of T-section was studied. For the overall model class C14 was chosen (taking into account the weakened section in the reconstruction – cracks due to drying, etc.).

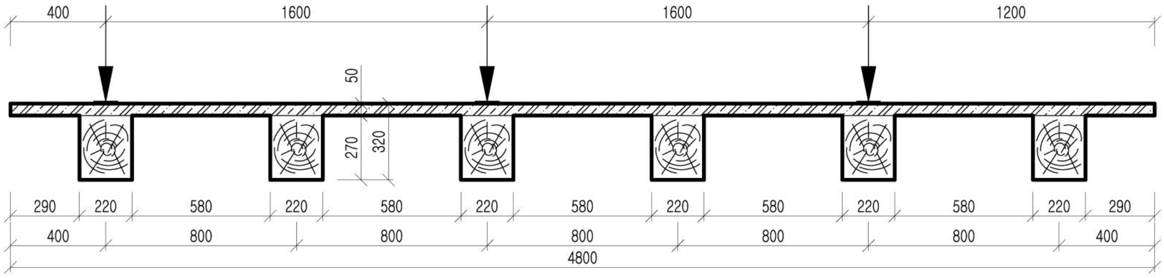
## 2.2 Behaviour of the complex model of timber-fibre concrete slab

The complete model consists of six beams (C14 220/270 mm) 4.9 m long in spacing 0.8 m. Screws at 45 degrees to the beam axis were used as connector elements (two screws in one row with inverted orientation of inclination; distance of rows 0.7 m). FRC slab was considered 50 mm thick; the amount of dispersed reinforcement was 1.0% of volume content (75 kg/m$^3$). Two load cases were analysed:

Load case A




Load case B




A reference model was created with RC slab with the same geometry as FRC slabs. The RC slab had depth 60 mm and the reinforcement was provided by weld mesh 8/150x150 mm.

Deformation of the FRC floor structure:

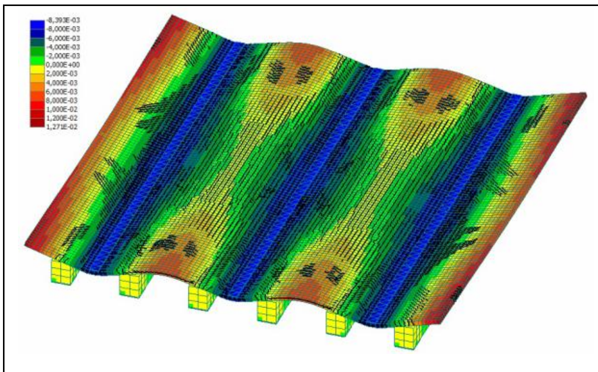


Fig. 4 Vertical deformation – load case A

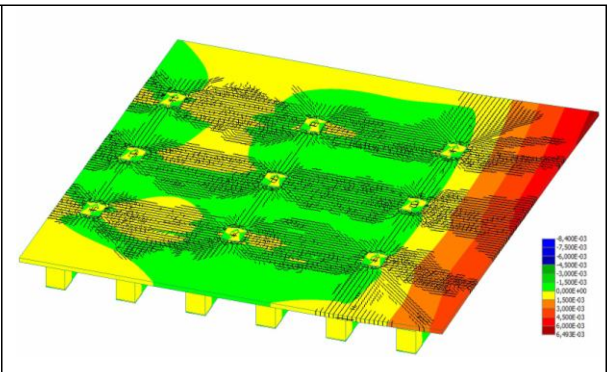
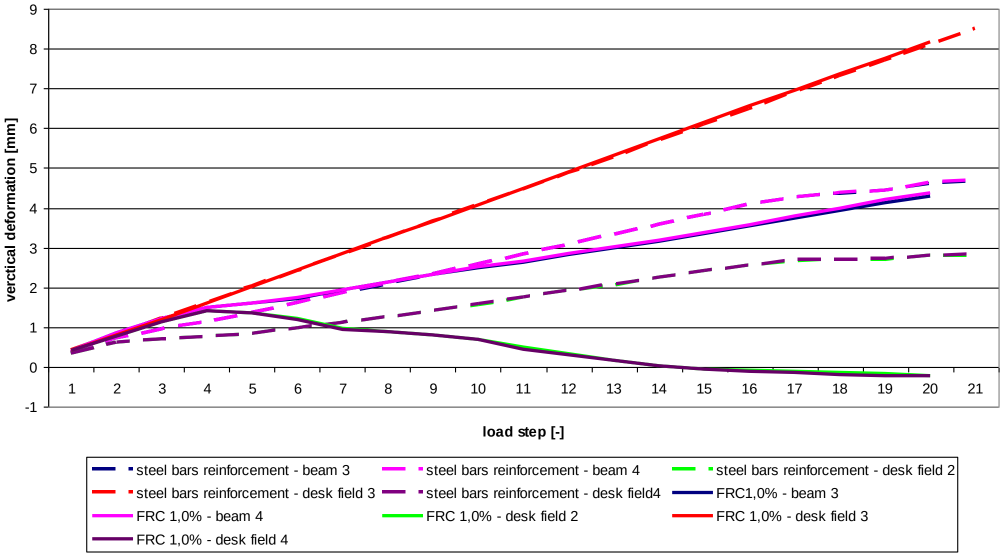
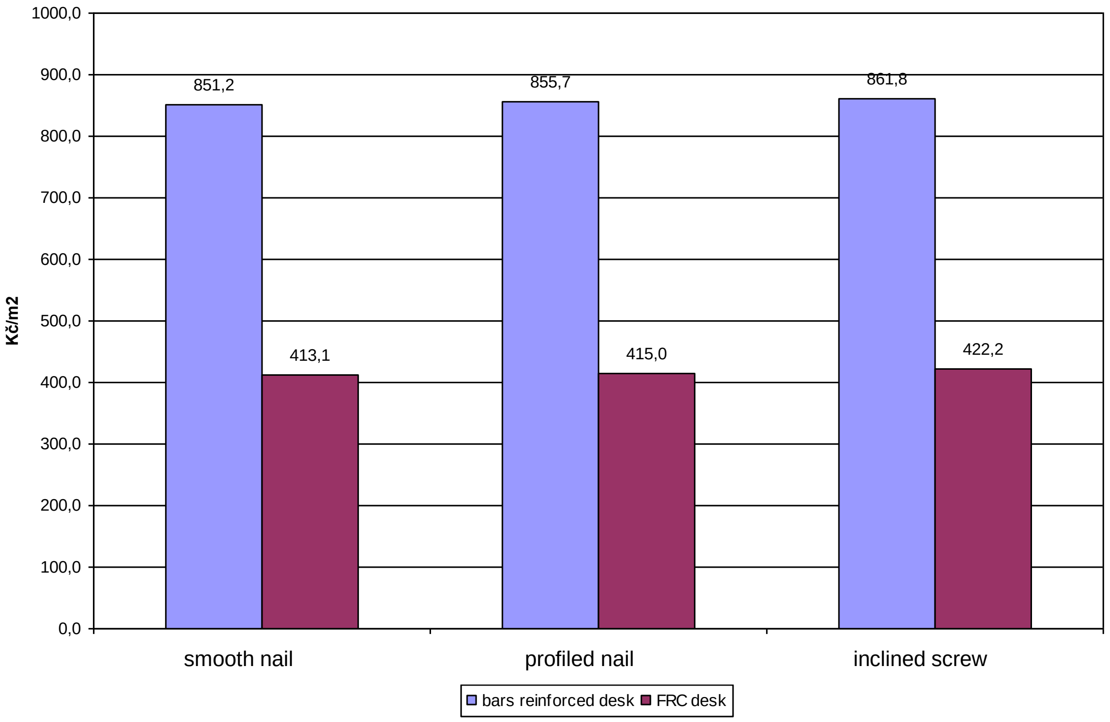


Fig. 5 Vertical deformation – load case B

The graph 3 shows the reduction of the slab deformation for the FRC slab.




Graph 3– influence of progress vertical deformation of bars reinforced slab and FRC slab – load case A




Graph 4 – Comparison of cost efficiency

### 2.3 Comparison of the cost effectiveness of a reinforced concrete and FRC slab

If the slab does not comprise classical rebar reinforcement it is not necessary to prevent the reinforcement from corrosion and provide the reinforcement cover. Thus the depth of the slab can be decreased. Hence the volume of the concrete is lower and the self-weight decreases.

## 3. Conclusions

Numerical simulations of the composite timber – FRC slab demonstrated that fibre reinforced concrete can fully substitute the classical reinforced concrete slab. The feasibility of the FRC is underlined by the cost reduction. The condition for utilisation of the FRC component is the technological discipline that ensures the homogeneous distribution of fibres in the concrete matrix.

### Acknowledgements

*The contribution has been achieved within the project GAČR 103/09/2097*.

## 4. References

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