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SOME ASPECT OF NONLINEAR ANALYSIS OF TIMBER-FIBRE CONCRETE COMPOSITE

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Abstract

Accuracy of the numerical analysis of the timber – fibre reinforced concrete composite structures fully depends on material models used in the analysis. Therefore the implemented material models were verified on the basis of experimental results and they were used for non-linear analysis of combined timber-fibre reinforced structure after successful verification of validity.

Keywords: fibre reinforced concrete, timber, combined structures, non-linear numerical analysis

1. Introduction

The technology of combined timber-concrete structures has been known since thirties of the last century. The significance of the technology increased in the beginning of eighties when proportion of reconstructions and redevelopments grew up.

The timber – (fibre reinforced) concrete combines advantageous properties of both load-bearing elements thanks to shear-rigid connection. Application of this technology can bring economically effective structures with high effectiveness both in reconstructions and strengthening and in newly build structures.

The condition of correct design and successful application of the combined structure primarily is detailed knowledge of behaviour of the structure from moderate loads until the failure. The knowledge can be gained from experiments but the expenses of manufacturing of test specimens for full-scale test in sufficient amount are rather high.

Analysis of behaviour of structural element or structural system in nonlinear analysis can partly replace expensive experiments and become a virtual testing laboratory. The condition is implementation of material models accurately simulating real properties and implementation of simplifying assumptions that do not negatively affect results of numerical simulation with respect to the real structural behaviour.

The results of numerical simulations must be verified by experiment or on the contrary the performed experiments can help to calibrate parameters of the numerical models and implemented material models. Here are the experiments inevitable. As late as the numerical model is verified it can be used for case studies, optimisation, probabilistic and

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reliable analyses. The aim is effective utilisation of used materials together with providing of required reliability.

2. Nonlinear analysis of timber-fibre concrete structure

The response of timber – fibre reinforced concrete combined structure is nonlinear after a certain level of loading is reached. The reasons are in physical character of the interconnection, behaviour of FRC and viscous-plastic behaviour of timber. In terms of long-term behaviour of the timber – FRC structures nonlinear effects as decrease of the timber strength in time and creep and volumetric changes of concrete plays an important role.

Implementation of all these nonlinearities in the complex model of the structural model or system without verification and confirmation of their plausibility on simple models can result in non-realistic simulation of the real structural behaviour.

Below analysis of nonlinear model of interconnection and material model of fibre reinforced concrete will be demonstrated. The calculations were performed in finite element programs ATENA 2D and ATENA 3D.

2.1 Modelling of the interconnection

Nonlinear response of the interconnection is evident in the record of the extrusion test [1].

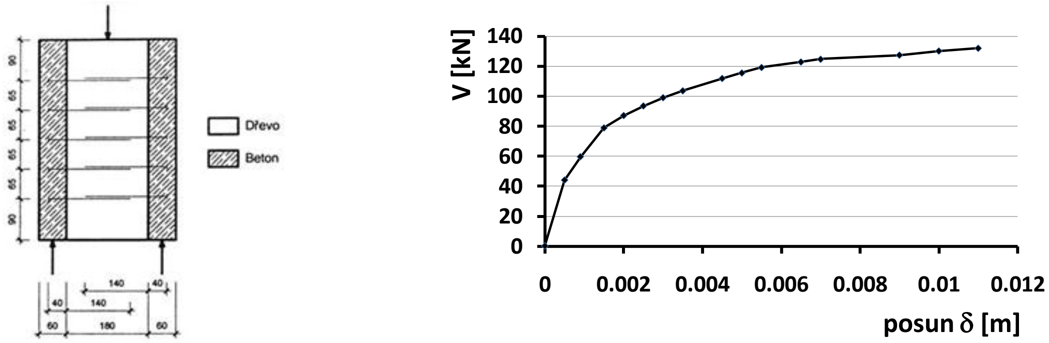

Fig. 1: The test specimen and record of the experiment according to Koželouh [1]

The connection is realised by smooth nails with ϕ6,3 mm and length 180 mm, depth of the slab is 60 mm.

The aim of the numerical simulations of the extrusion test is determination of a suitable numerical model and verification of material parameters of interconnection which will be applied in numerical analyses of the combined girder and complex models of combined structural systems.

Modelling of the connection by discrete elements (nails) has many difficulties and it can lead to exceedingly many finite elements in numerical model what is an unmanageable problem even though the capacity and efficiency of current computer technique is high. The simplification was adopted: the interconnection would be smeared uniformly over the whole contact of the timber and FRC components. The simplification is necessary in simulation of the whole structure or structural element and the results are sufficiently accurate in terms of the global response of the structure; of course it cannot describe the local stress state and failure in the area close to the connector elements.

The objective is identification and verification of parameters of contact elements that represent the connection so that they can be used in complex numerical models of structural systems. The material model of the contact is based on Mohr-Coulomb theory. The relationship and table with material parameters that were derived from the performed test [1] shows the figure 2.

K_{tt} [MN/m^3]	834
K_{nn} [MN/m^3]	330
c [MPa]	1.25
R_t [MPa]	1
ϕ [-]	0

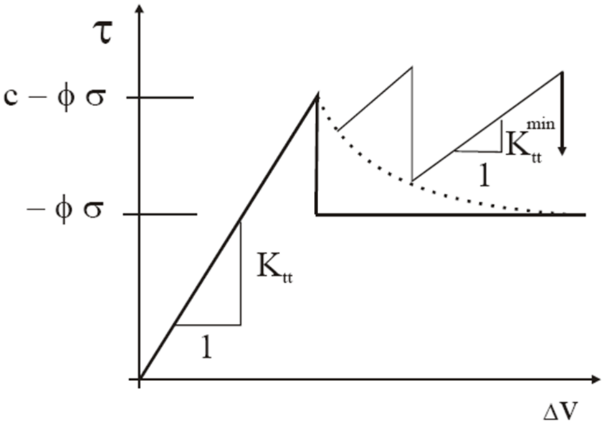

Fig. 2: Model of the contact material and its parameters

The zero inner friction corresponds to the fact that contact area is strained with shear; the friction is activated only if normal compressive stress perpendicular to the contact plane is present. The compressive stress does occur in a beam loaded with vertical load; but the effect of friction cannot be determined from the test; that why in the material model the friction equals to zero. The implemented tangential stiffness of the contact K_{tt} represents the slope (gradient) of the line that runs through points [0,0] and [0.0005, 44], see fig. 2. The normal stiffness of the contact equals to the elastic modulus of the timber perpendicularly to fibres. Cohesion c is the shear stress at failure of the test specimen. Material models of the concrete slab and the timber beam are assumed as isotropic and linear elastic.

The numerical model is loaded by deformation in 70 steps so that the resulting displacement equals 11 mm what corresponds with the test result. Figure 3 shows the numerical model and result of numerical analysis (curve NA1).

Although the initial stiffness corresponds with the experiment with increasing load the defined stiffness differs. To identify the reasons of the difference the elastic modulus of wood and FRC were modified (increased several times). After increasing the model of the contact behaviour was identical to the diagram in the figure 2 including the stiffness (curve NA2, fig. 3). The reason is obviously tangential stresses caused by transversal expansivity in the transverse direction τ_2; due to this transversal stress the total tangential stress

$\tau = \sqrt{(\tau_1 + \tau_2)}$ is not constantly distributed across the height (what is common engineer assumption).

The difference of initial stiffness in numerical simulation and reality apparently has not physical explanation; it is probably caused by the choice of finite element size or some other reason from the numerical mechanics field.

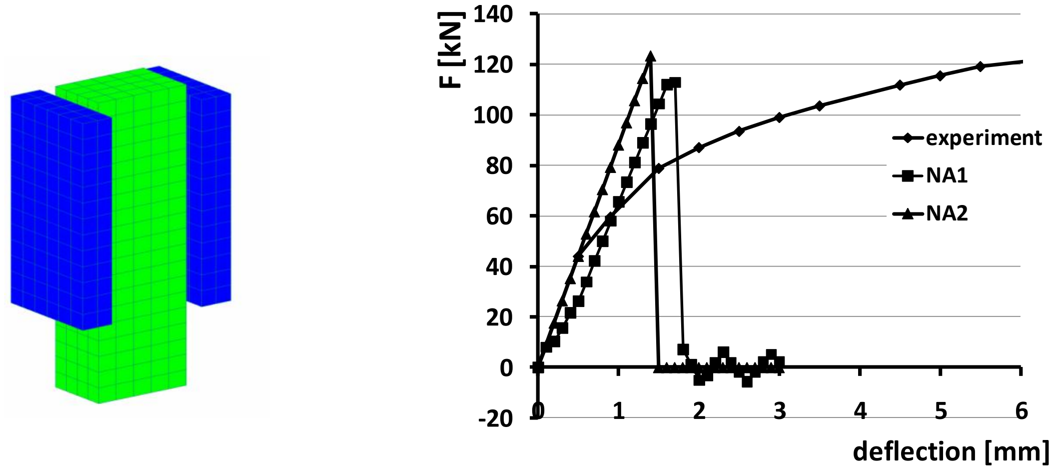

Fig. 3: FE-model and result of the simulation with material model according to figure 2

The material characteristics of FRC and wood are for the numerical simulation decisive thus the lower initial stiffness of the contact shall be adopted.

Furthermore the material model of the contact must be modified to respect the decrease of stiffness for increasing load. This can be adopted by the function softening or hardening of the cohesion (see fig. 4).

d [m]	c/c0
0	1
0.0016	1.86
0.0056	2.4
0.011	2.5

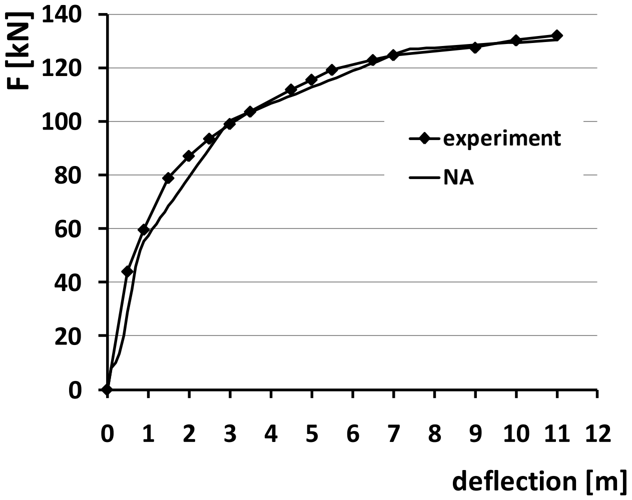

Fig. 4: FE-model and result of simulation with function cohesion stiffening

In this case the function of cohesion hardening with initial cohesion $c_0 = 0.5$ MPa was chosen. The approximation of the experiment can be considered excellent despite the small differences of the stiffness in the lower part of load – deflection diagram.

2.2 Material model of fibre reinforced concrete

Derivation of the stress-strain diagram of FRC from the results of bending test is performed in inverse analysis. The curvature of the deflection line is determined of the FRC test specimen, the stress-strain diagram of FRC derived and parameters of implemented material model identified and subsequent verification by the numerical simulation of the experiment carried out in the procedure of inverse analysis. Details about inverse analysis are in [3], [4].

Verification of derived constitutive relations of Fibre reinforced concretes was performed in numerical simulation of a four-point bending test in programs ANSYS and ATENA. Details and results of analyses – see [3], [4].

The derived and verified material model of FRC will be used for the simulation of combined beam behaviour.

2.3 Analysis of the combined girder

Material models of the contact and fibre reinforced concrete were applied in the numerical model of combined timber – FRC T –section. The spanning of the beam was 6.5 m. The dimensions of the timber section were 0.14 x 0.24 m, depth of the FRC slab was 0.06 m and the width 0.94 m. The wood was assumed as linear elastic material. The model of the combined beam and load – deflection curves are in the figure 3.

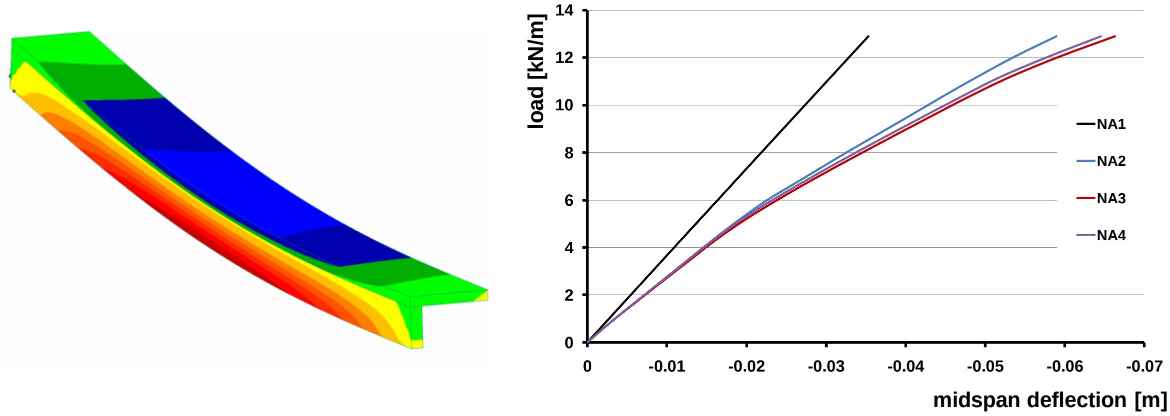

Fig. 5 Numerical model of composite beam and results of the analysis

The model was loaded with constant linear load and loaded in increments so that the tensile edge of the beam reaches the mean value of the tensile strength of wood. The calculations were performed in alternatives according to table 1.

The results of numerical analysis show that the magnitude of the tangent slip modulus and the load-deformation curve of connecting elements according to extrusion test are decisive for the layout of stress in the composite section and on the layout of the load – deflection diagram (Fig. 5, curve NA2). The increase of deformations after cracking in the tensile part of the FRC component can be noted. Application of FRC can enhance the bending of the composite beam thanks to ability to resist tensile stresses after cracking. The enhancement of the bending stiffness depends on the value of residual tensile strength of FRC; in analysis NA4 the FRC with pronounce tensile softening was used.

Numerical analysis	**Contact**	**Concrete**	**Timber**
NA1	rigid	elastic	elastic
NA2	nonlinear	elastic	elastic
NA3	nonlinear	plain concrete, nonlinear	elastic
NA4	nonlinear	fibre concrete, nonlinear	elastic

Tab. 1 Table of used materials

3. Conclusions

The accurate analysis of behaviour of combined structural systems until the failure is possible only if nonlinear behaviour of material and interconnection are considered. Modelling of the interconnection using suitable material parameters of the smeared contact of the timber beam and FRC component is an acceptable alternative to discrete modelling of particular connecting elements. Verification of implemented material models by numerical analysis of experiments shall be an integral part of the nonlinear analysis of the structural system as it increases probability of correct simulation of the combined structure behaviour.

Acknowledgement s

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4. References (separated by one lines from the conclusion)

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