

Numerical Analysis of Rigid Frame Joint with Textile Carbon Reinforcement

Jiří ŽALSKÝ^{1,a*}, Tomáš VLACH^{1,2,b}, Lenka LAIBLOVÁ^{1,2,c},
Zuzana JIRKALOVÁ^{2,d}, Jakub ŘEPKA^{1,2,e} and Petr HÁJEK^{1,f}

¹Building Structures, Faculty of Civil Engineering, CTU in Prague, 166 29 Prague, CZ

²University Centre for Energy Efficient Buildings of CTU in Prague, 273 43 Buštěhrad, CZ

^ajiri.zalsky@fsv.cvut.cz, ^btomas.vlach@cvut.cz, ^clenka.laiblova@cvut.cz, ^dzuzana.jirkalova@cvut.cz,
^ejakub.repka@cvut.cz, ^fpetr.hajek@fsv.cvut.cz

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Abstract. Benefit of textile reinforced concrete (TRC) is absent of necessary concrete cover because of the durability. It allows creating concrete slabs only about 10 mm thick. Therefore, TRC going to be very popular, and more often used in design and load-bearing structures. Big problem in designing of load-bearing structures are rigid frames. The aim of this paper is clarify behavior of thin concrete rigid frames with carbon textile reinforcement by numerical analysis and influences of carbon reinforcement anchoring to the crack opening. Model was created as 2D model and necessary parameters were determined by experimental tests.

Introduction

Textile reinforced concrete starts to be used very often for load-bearing structures, but the design low, standards or Euro codes haven't been created yet or they are not clear. For that reason is necessary quality numerical analysis based on the experimental tests. [1,2] This paper explains problems of reinforcing rigid frames from thin concrete slabs reinforced by carbon rovings [3]. Rigid frame is one of most critical area in concrete structure, specially design of the shape of reinforcement. And this paper explains possibility use of different shapes of reinforcing using numerical analysis. There is presented crack opening in rigid frames during different types of loading, different types of reinforcement shapes and different types of surface treatments. It clarifies possibilities for load-bearing structures where is rigid frame used.

Shapes of reinforcement are similar to ordinarily used shapes of steel reinforcement. Each of these types rigid frame was computed and analyzed by Atena Science. Software Atena is one of few software which can determinate crack opening and crack width during loading [4]. Quality of analysis was based on correct results from experimental tests. There was determinate basic mechanical parameters of carbon textile reinforcement and also basic mechanical properties of high performance concrete - compressive strength of concrete, tensile strength of concrete, tensile strength of carbon roving, and cohesion between concrete matrix and carbon roving. Validation of material parameters for numerical modeling was made on real four point bending test. After calibration of parameters were created six different shapes of reinforcing and each of them was analyzed. Numerical analysis clarified crack opening, internal forces and deformation of rigid frames during loading in two opposite directions and with rovings used different type of surface treatments.

Materials

The HPC mixture used in this experiment was developed and optimized in last years at the CTU in Prague for different applications. It is the self-consolidating fine grain concrete without any fibers. Materials used for experiment are primarily from local sources and components are: CEM I 42.5 R cement, silica sand with two particle sizes and maximum grain size 1.2 mm, silica flour with one particle size, microsilica and one type of the PCE superplasticizer. Developed mixture reduces the

amount of water on water/cement ratio only 0.25 and therefore significantly improves the mechanical properties. Direct tensile strength of used HPC is experimentally determined to 6.7 MPa respected the CSN 73 1318 standard. Tensile strength in bending and compressive strength are presented in next chapter about performed experiments. Static modulus of elasticity is 49.2 GPa on prisms 100 x 100 x 400 mm according to CSN ISO 6784 standard. [5]

Textile reinforcement was produced by our team from combination of carbon roving and epoxy resin because of required surface treatment. Larger quantity of epoxy resin of low viscosity 60 % in cross sectional area was due to experimental manual production in the lab, but it was an advantage during the technical sand application as a surface treatment. Used roving was from the company Toreyca® with a length weight (titer) of 1600 g/km (= 1600 tex), tensile strength 4400 MPa and modulus of elasticity 230 GPa according to technical data sheet. As an epoxy resin was used SikaFloor 156 from the company Sika®.

Experiment

For correct setting material parameters was necessary determining values of compressive strength of concrete, tensile strength of concrete, tensile strength of carbon roving and cohesion between concrete matrix and impregnated carbon roving. All experiments were created in laboratories of University Centre for Energy Efficient Buildings (UCEEB) in Buštěhrad. All experiments of composite were created in two variants for comparison of cohesion influence. The first type with smooth surface treatment and the second type with the surface treatment using silica sand [6].

Compressive strength of concrete. Material parameters of concrete were determined by experiments according to ČSN EN 731302. Compressive strength f_c was determined using concrete cube test and tensile strength f_t using three point bending test. For each experiment were prepared three specimens for creating average values. All specimens were made at the same time and were tested after 28 days. Cubes for concrete cube test had dimensions 100x100x100 mm and three-point bending test prisms had dimensions 40x40x160 mm.

Average compressive strength was determined as $f_{cc} = 138.2$ MPa and average tensile strength as $f_{tc} = 8.54$ MPa.

Tensile strength of carbon roving. Carbon yarns were laminated by epoxy resin (for creating roving, where all yarns are cooperating together). In the next step were created two different types of surface treatments. One smooth and the second type was with silica sand on the surface. Five specimens were created with both surface modifications. Rovings were placed into the steel sleeve for necessary anchoring of specimens in testing machine.

Specimens were placed into the testing machine and to the middle of roving were placed potentiometer for determining of elongation during the loading process. Specimens were loaded until the failure with constant speed of loading 1 mm/min [5].

Table 1: Summary of results from tensile test.

	Theoretical value	Surface treatment	Measured value
Tensile strength	4 400 MPa	Smooth	3 506 MPa
		Silica sand	3 423 MPa
E modulus	240 GPa	Smooth	247 GPa
		Silica sand	267 GPa
Bearing capacity	3 977 N	Smooth	3 169 N
		Silica sand	3 094 N

Final tensile strength of roving depended on the quality of lamination. There was visible cracking of yarns during loading which were badly laminated. Due to these inaccuracies happened little deviations in results from theoretical value of tensile strength 4 400 MPa as presented in Table 1.

Cohesion between roving and concrete. In the same way as in tensile strength experiment were created also two different type of surface treatment. Each impregnated single roving was placed in the middle of concrete slab sized 100x100x20 mm. Length of roving cohesion was 20 mm. On the other site of roving was paled same steel sleeve as in tensile test. Specimens were placed into special steel extension and were loaded by loading speed 1mm/min. During loading was really important to catch start of movement of the roving and record all loading curve. Loading force depending on the movement of roving was modeled in Atena preprocessor. [7,8]

Four point bending test of the TRC composite. These experiment determined the behavior of composite material and it was used for validation and calibration of the numerical model. Concrete slabs with dimensions 360x100x18 mm were created with carbon textile reinforcement. Textile reinforcement was placed on the both of surfaces and load bearing reinforcement consisted of four carbon impregnated rovings.

Loading of the slabs in four point bending test was created according to the ČSN EN 12390-5 standard. Loading was applied by two steel plates with distance between supports 100 mm. Specimens were loaded until the failure with speed of loading 0.02 mm/s [9].

Numerical Analysis

First of all were validated properties of materials which were measured by experiments. For calibration of material properties and model type was used 2D model of four-point bending test presented in Fig. 1. It was necessary to catch most similar shape of loading curve to real bending test. [10] All material parameters acquired from real experiments were not change, just another parameters were changing to improve shape of loading curve. Parameters like fracture energy G_f , critical compressive displacement W_d , etc. There was further modified size of mesh and fast of loading until shape shown in Fig. 2 was captured.

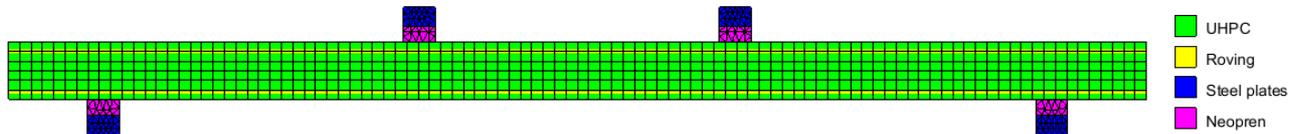


Fig. 1: Model with finite element mesh and material parameters set in preprocessor GiD [11]

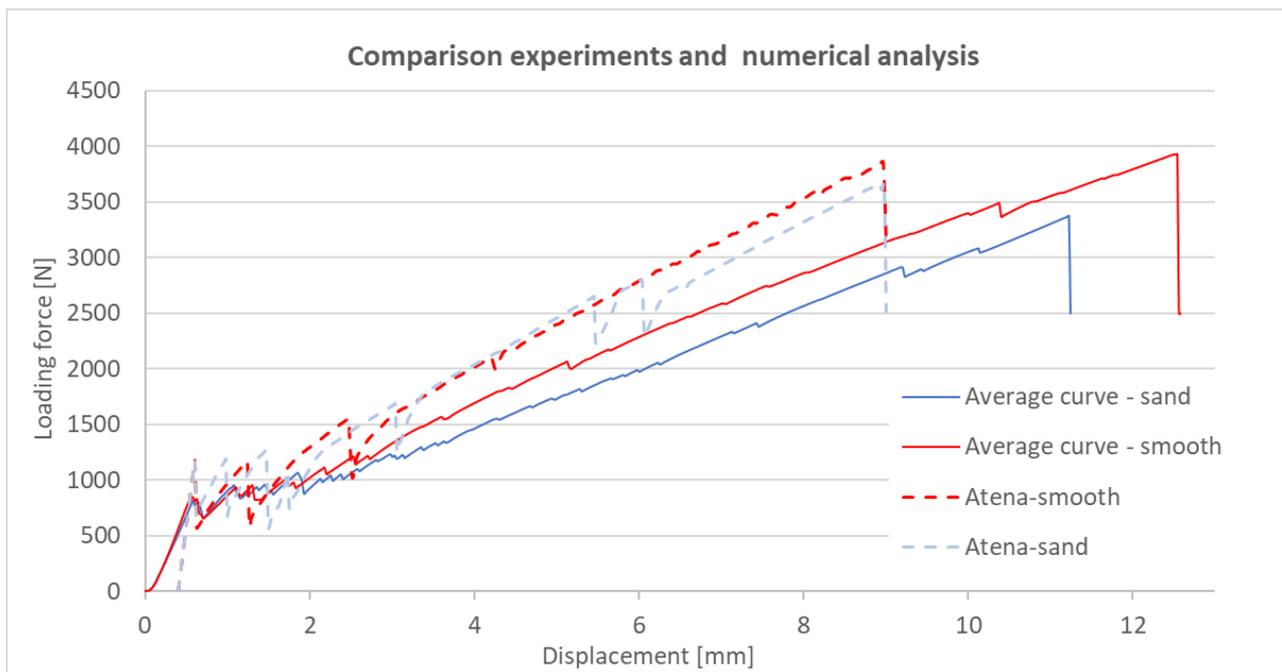


Fig. 2: Comparison of average curves from experiments and curves from calibrating models from Atena Science [11]

For quality numerical analysis was necessary capture the crack opening at the beginning of loading in 2D model. At curve shown in the Fig. 2 is visible dropping of load related to the crack opening. Curves of numerical model corresponding to experiments, it could be declared as a good model results. With same materials parameters, size of mesh and speed of loading were created theoretical models of rigid frames. Models were loaded in two directions. First from above as is visible in Fig. 3 and from the bottom opposite part. All models were created with two types of reinforcement and with six different shapes of reinforcement. Presented version with easy shaped textile reinforcement and good load bearing capacity results.

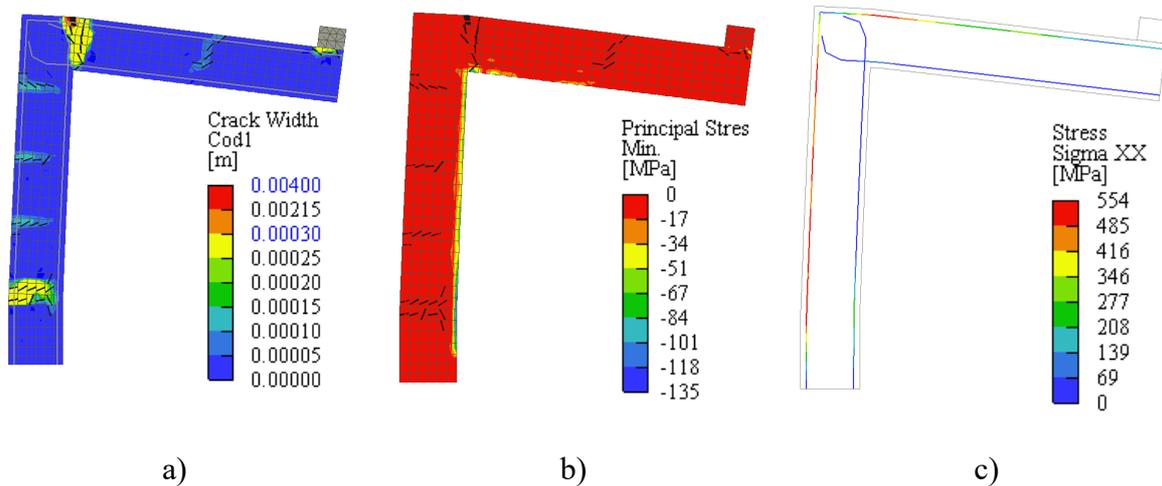


Fig. 3: Example of rigid frame with good behavior before collapse. a) There is shown crack width b) There is shown principal stress before cracking of concrete (138 MPa) c) There is shown stress in carbon reinforcement with tensile capacity 3500 MPa [11]

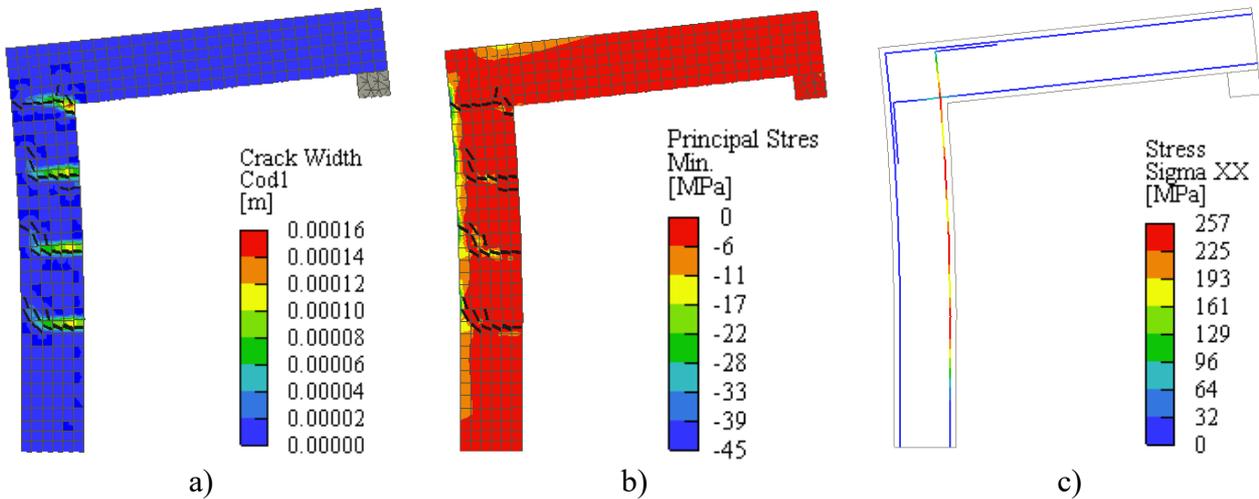


Fig. 4: Example of rigid frame with good behavior of crack opening. a) There is shown crack width b) There is shown principal stress before cracking of concrete (138 MPa) c) There is shown stress in carbon reinforcement with tensile capacity 3500 MPa [11]

Conclusion

After numerical analysis was captured behavior of rigid frame under the loading by bending moment and there was declared that thin concrete TRC slabs as rigid frames are able to bear loading. Very important is calibration of model included exactly bond parameters, which can be used for later numerical analysis structures from textile reinforced concrete.

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