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# Analysis of shear behavior between old concrete and fiber concrete

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## ABSTRACT

Concrete structures that are influenced by degradation, overloading, the thawing, and freezing cycles, corrosion of reinforced bars, should be repaired or strengthened. Each of the mentioned influences lead to decreased load-carrying capacity of the structure or its member. Exceeding the load-carrying capacity leads to mechanical damage of members or excessive deformation. The damaged member has to be strengthened to the required level of reliability and load-carrying capacity. There exist many types and methods of strengthening the columns. This research work deals with strengthening of columns by concreting a new layer of fiber concrete. When applying that type of strengthening, it is necessary to assure the contact between the old layer and the new one. The paper deals with analysis of different types of contacts and determination of their parametric values.

## KEYWORDS

fiber concrete, strengthening, column, surface, contact

## 1. INTRODUCTION

Exceeding the load-carrying capacity leads to mechanical damage of members or excessive deformation. The damaged structure ceases to fulfill the Serviceability Limit State (SLS) or the Ultimate Limit State (ULS). The damaged member has to be strengthened to the required level of reliability and load-carrying capacity. Many types and methods of strengthening for the column are existing in practice, like encasement of a layer reinforced concrete of fiber concrete [1–3], pre-stressing, adding the rigid steel members, wrapping by the Fiber Reinforced Polymer (FRP) etc. [4, 5]. Strengthening and increasing of the concrete member load-carrying capacity, especially by adding a new layer of concrete, puts enormous emphasis on the connection (contact zone) between the old concrete and a new layer. The main factors, ensuring the shear bonds, are cohesion ( $c$ ) and friction ( $\mu$ ) [6]. Those parameters are necessary for calculation of the cross-section resistance. It is possible to increase the member's resistance by relating the tensile forces from the fiber concrete layer and shear parameters of a contact.

The main advantage of using the steel fibers lies in their crack-bridging ability, and the fact that after the cracking the tensile strength does not fall down to zero, but is stabilized at a nearly constant value [7, 8]. The fiber concrete has the better tensile properties; thus it is possible to remove the reinforced bars and accelerate time for placing of concrete layers [9, 10]. However, this level of resistance is influenced by modification of the surface of original material – reinforced concrete. Nowadays, a lot of surface modification methods exist that provide the bigger shear resistance. This article deals with experimental and numerical analysis of a contact between the Reinforced Concrete (RC) column and a new fiber concrete layer around the column (ring layer) by using the push tests. The three methods of the surface modification: smooth surface, using indents and notches, were compared. The increasing load-carrying capacity was investigated, using a layer of fiber concrete in the experimental tests and results were compared to the numerical model. Modification of the

input parameters of the fiber concrete in numerical models was performed, as well as comparison and evaluation of individual surface modification types. There is a possibility of using other types of fibers, as well [11, 12]. Very close to that problem are also works, which are dealing with strengthening columns by using the RC jacketing or the Carbon Fiber Reinforced Polymer (CFRP) laminates [13–16], but the fiber concrete was not used, like shown in this paper.

## 2. EXPERIMENTAL MEASUREMENTS AND NUMERICAL MODEL

The experiment was conducted at University of Žilina, Faculty of Civil Engineering. It included the three groups of samples with different modification of the surface – contact between the concrete of the column and a new layer of fiber concrete. The modified surfaces were a smooth surface, surface with a notch and surface with indents. Each type of modification was done on the two samples; the sample was composed of the core (reinforced concrete column) and an encasement (layer of the fiber concrete). The core was reinforced by 4 bars of diameter of 10 mm and stirrups of diameter of 8 mm. The axial distance between the stirrups was 100 mm. The steel reinforcement of type B 500B was used. For the core, a concrete type of C16/20 was used in realization. The cover of reinforcement was 25 mm, due to assumed exposure class XC1. Subsequently, a modification

of surface on the samples was done (see Figs 1 and 2), the first type was the smooth surface of concrete, the surface was not especially modified and it was only cleaned from the particulate of dust and humidified. The second type used a notch that was 100 mm long. The notch was situated at a height of 100 mm from the bottom page. The indents were used as the third modification, depth and width of indent were 5 mm, and the axial distance between indents was 50 mm.

### 2.1. Realization of samples

Samples (the cores represented columns) were cleaned from the particulates of dust and humidified. There was an affixed temporary pad on the bottom surface, which was removed after the concrete hardening. The height of the pad was 50 mm. Subsequently, samples were inserted into the formwork. The position of samples was modified by using the distance bolt (Fig. 3). The distance between the core and framework was 40 mm. Design of a mixture for the fiber concrete is shown in Table 1.

Samples were treated for 3 days. Cubes for testing the strength in compression (see Fig. 4), of dimensions  $150 \times 150 \times 150$  mm and specimens for 3-point bending dimensions  $150 \times 150 \times 700$  mm were made, as well. The fiber concrete was mixed in a mixer twice, so the samples 1A, 1B, and 1C were from the first mixer and samples 2A, 2B, and 2C were from the second mixer (the second set). Results of the compression strength test are shown in Table 2.

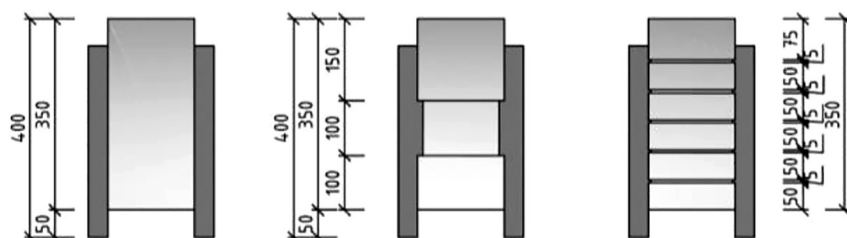


Fig. 1. Methods of surface modification: smooth surface (left), notch (middle), indents (right)

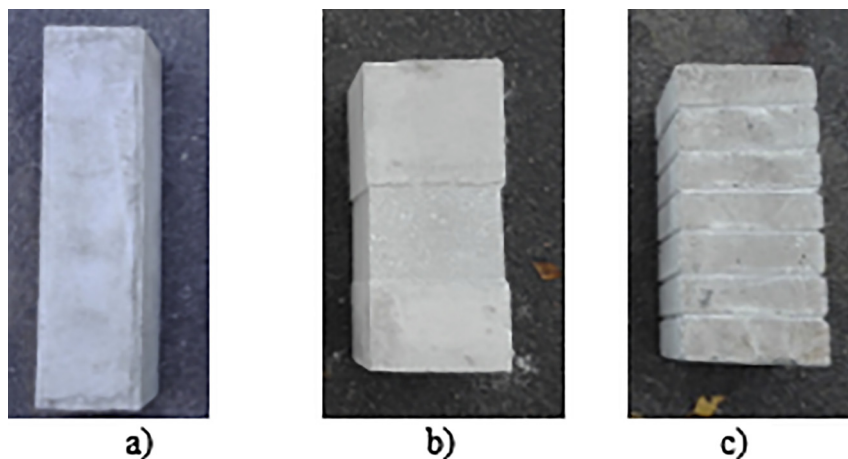


Fig. 2. Realization of samples and their surface modifications, a) smooth surface, b) notch, c) indents

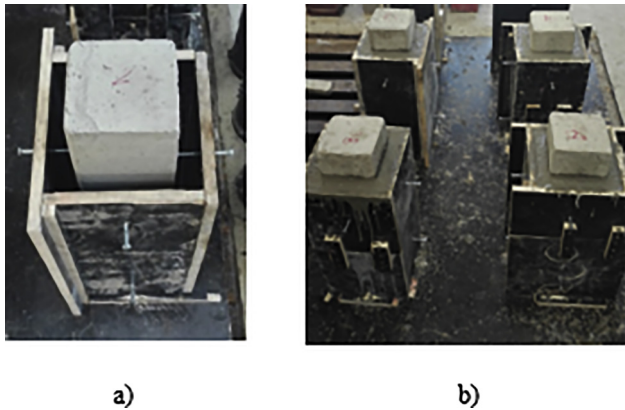


Fig. 3. Realization and modification by using the distance bolt, a) sample in the cast, b) samples after concreting

Table 1. Design of fiber concrete mixture

Name	[kg/m <sup>3</sup> ]
Cement CEM II/B-S 32.5R	400
Aggregate 0/8	910
Aggregate 8/16	685
Fly ash	80
Water	172
Fiber Dramix 3D	40
Superplasticiser Berament HT5621	3 [L]

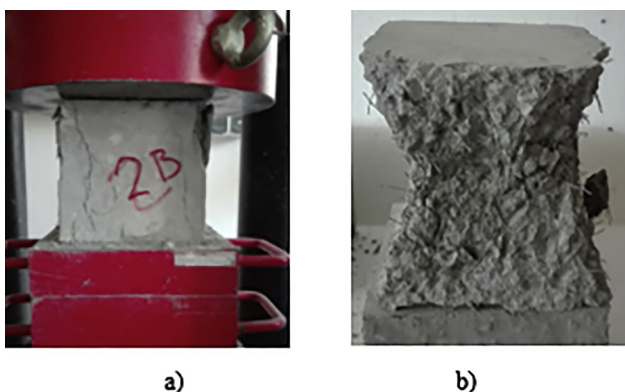


Fig. 4. Strength in compression of fiber concrete cubes, a) testing in jack, b) sample after failure

Realization of the 3-point bending tests was executed according to the EN 14651 standard [17]. An axial distance of support was 500 mm. The notch in the middle of the span is important for the test for the 3-point bending moment. Dimensions of the notch were: depth 25 mm and width 5 mm.



Fig. 5. Realization of the 3-point bending test of fiber concrete before testing

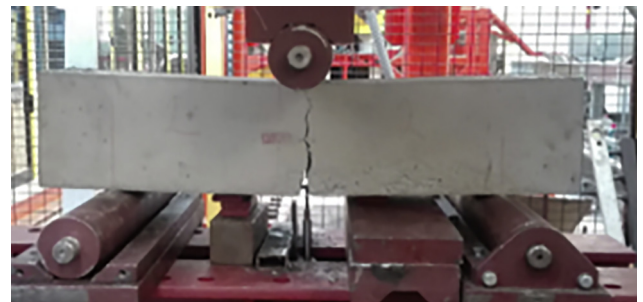


Fig. 6. Realization of the 3-point bending test of fiber concrete after failure

The testing of samples was performed after 28 days. The loading rate of the test specimens was 0.5 mm/min. Two specimens were tested and results are shown in Figs 5 and 6.

In Fig. 7 results from the 3-point bending test are shown. Dash-dot thin line (Specimen 1) and solid thick line (Specimen 2) curves are results of the experimental test and the dashed thin line curve is obtained from the numerical model for comparison, which is explained in the next section.

## 2.2. Realization of the push-test

The test was executed by the axial force load. To obtain the load distribution a steel desk of a height of 25 mm was placed on top of the concrete core. A movement between the core and encasement was measured, as it is shown in Fig. 8. Results of the maximal forces, obtained in the push-test, for different types of modification, are shown in Table 3.

In Fig. 9 it can be seen that the deformation is equal to zero almost until coming to a specific level of load when the encasement is not able carry the load any more. In Fig. 8c it can be seen that all the samples were damaged in the same

Table 2. Cube compression strength of fiber concrete

	1A	1B	1C	2A	2B	2C
A (mm <sup>2</sup> )	22626.42	22432.50	22350.19	2223.31	22627.68	22492.17
$f_c$ (MN m <sup>-2</sup> )	43.617	39.942	40.277	52.296	47.874	47.994
Average values $f_c$ (MN m <sup>-2</sup> )		41.278			49.388	

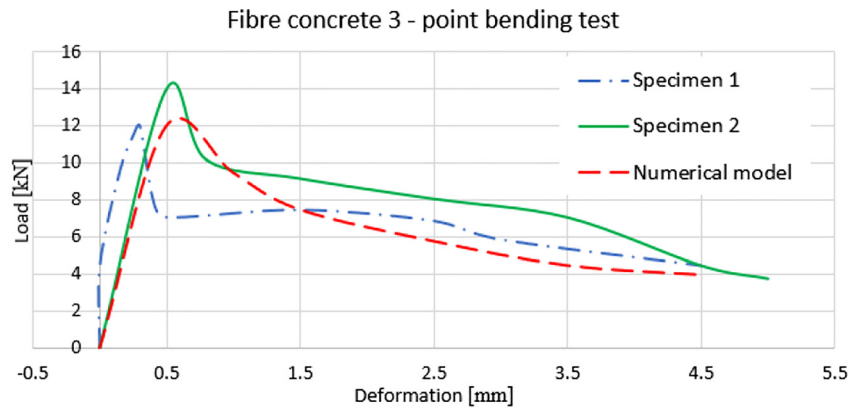


Fig. 7. Results from the 3-point bending test

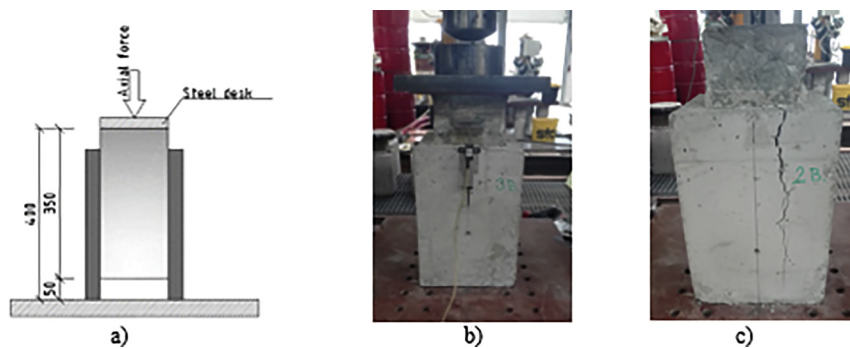


Fig. 8. Realization of the push-test, describe of test a), sample before load b), sample after load c)

Table 3. Results of the push-tests, maximal force [kN]

Specimen #	Smooth surface – A	Surface with notch – B	Indents – C
1	625.20	819.82	755.20
2	663.85	586.40	572.10

way, only the two main cracks were created in the encasement. That occurs due to pushing the core into the encasement. The encasement has a certain tensile resistance as a ring. During the pushing the core to encasement, the tensile forces arise around the perimeter. If those forces are bigger than the tensile strength of the fiber concrete that would lead to appearance of a crack in the encasement. Increasing the load force would lead to increasing the cracks' lengths.

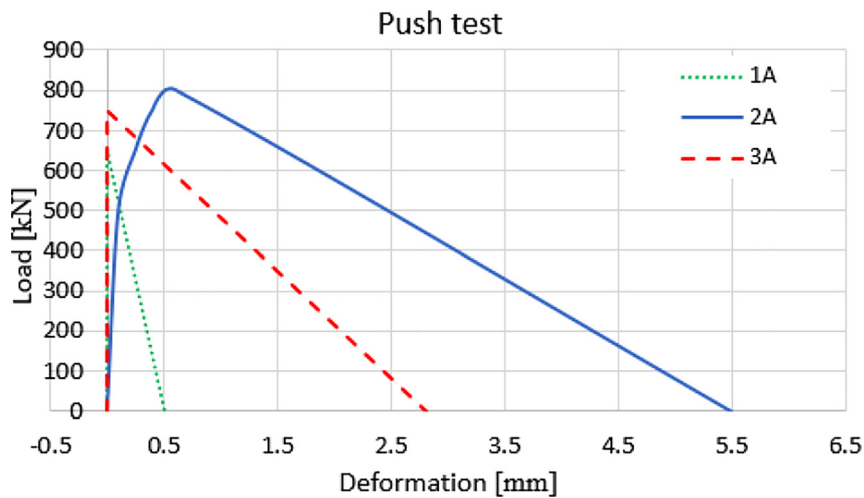


Fig. 9. Comparison of the push test results of individual contact methods



### 2.3. The numerical model

Numerical models were created in the ATENA program [18]. In the first step, the 3-point bending model from fiber concrete was developed for the input data into the numerical model and subsequently the modified properties were verified by the experimental test, as it can be seen in Table 4. The curve obtained from the numerical model is shown in Fig. 7 (dotted red line curve).

The push-test model consisted of the core and encasement. The most important factors were the modifications of the shear contact between the old layer and the new layer of concrete. The contact is defined between the two parallel surfaces with a fictitious gap between them. The surface can be modified by 8 or 16 joints, according to choices approximation. The rigidity of the contact is influenced by the two parameters  $K_{nn}$  and  $K_{tt}$  [18]. Those parameters are the initial elastic and shear stiffness, respectively. The main objective was to find values of the input data for the further research.

The model (push-test) was developed as the 3D model (Fig. 10). Material CC3DNonLinCementitious2 was used as a material for the core, with basic properties of the concrete C16/20. The element of a mesh was in a form of a brick, where the relative coefficient of the mesh element was 0.25 [-]. The material from the 3-point bending moment was used for the encasement, as it is shown in Table 4.

The models were modified according to the experimental test. Parameters  $K_{nn}$  and  $K_{tt}$  for individual models are shown in Table 5. In Figs 11–13 results obtained from the numerical models with comparison to results obtained from the experiment are shown.

Table 4. Input data of properties for numerical modeling

Property	Values
Elastic modulus $E$ (MPa)	4.44E+04
Tensile strength $F_t$ (MPa)	2.16E+00
Compressive strength $F_c$ (MPa)	-4.21E+01
Fracture energy $G_f$ (MN/m)	4.66E-04

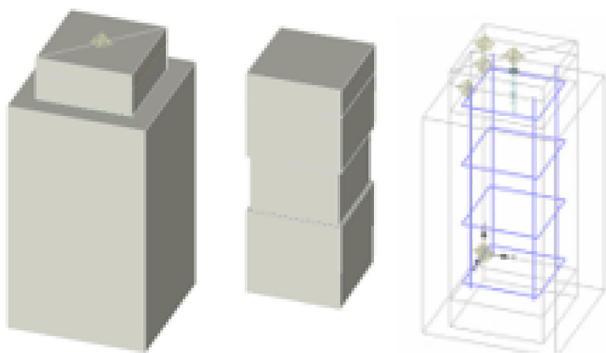


Fig. 10. 3D numerical model of push-test in ATENA, 3D model core and encasement (left), core (middle), reinforced 3D model (right)

Table 5. Contact properties GAP in numerical models

Models	$K_{nn}$ (MN/m <sup>3</sup> )	$K_{tt}$ (MN/m <sup>3</sup> )	$K_{nn,min}$ (MN/m <sup>3</sup> )	$K_{tt,min}$ (MN/m <sup>3</sup> )
A – Smooth surface	6.190E+06	2.275E+05	8.500E+04	1.021E+03
B – Notch	2.550E+06	2.600E+06	2.000E+04	2.000E+04
C – Indents	4.890E+06	1.775E+05	8.400E+04	1.021E+03

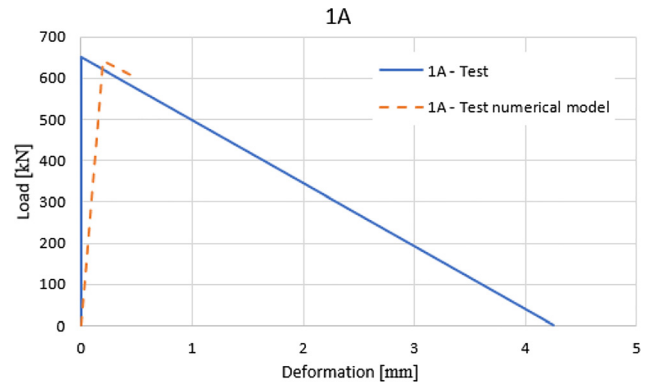


Fig. 11. Relationship between axial forces and deformation for the smooth surface

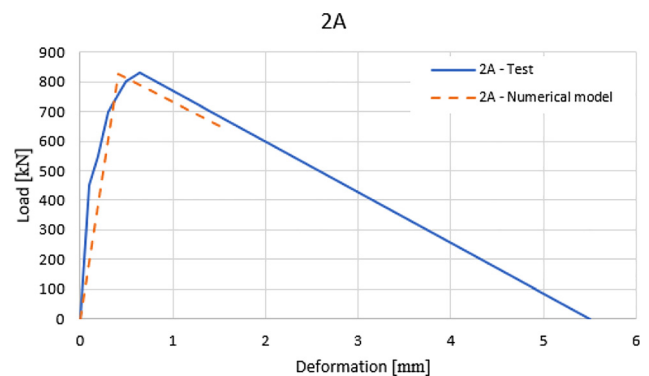


Fig. 12. Relationship between axial forces and deformation for the surface with a notch

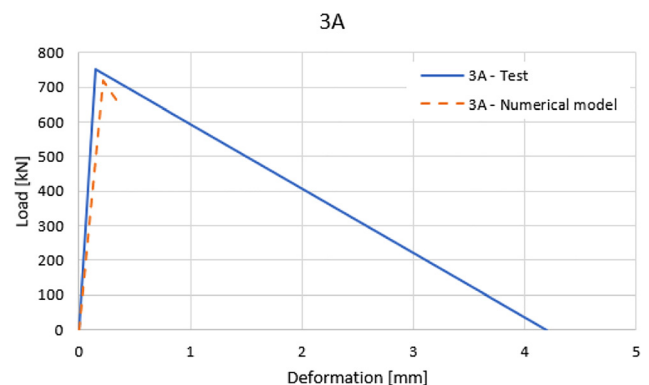


Fig. 13. Relationship between axial forces and deformation for the contact with indents

In Table 5 the final values of  $K_{nn}$  and  $K_{tt}$  are shown. It can be seen that the load values are dependent on rigidity  $K_{nn}$ . If the value of  $K_{nn}$  was higher, the contact would be able to carry the lower the load, only.

### 3. CONCLUSIONS

The objective of this paper was to find out which is the best method for modification of the surface and to obtain the numerical properties of the shear contact. Three types of the surface modification were used. From the results it follows that the best method of the surface modification is the using of the notch. That method enabled a load of about 820 kN to be carried. The second best method was using indents. The maximum value, which that specimen could carry, was 755 kN what is about 92% of that for the first type of surface. The weakest modification of the surface was using the smooth surface. The maximum load was only 660 kN, which represents about 80% of a value using the notch. These types of the surface modification are recommended for members, which are extremely loaded. For the practical use and members, which are not extremely loaded, it is recommended to use the simple smooth surface for strengthening of columns. However, for clarification, the term “smooth surface” means a surface without notches and indents, but slightly roughened. Sometimes it is recommended that the surface should be clean and the additional anchoring steel hooks should be used in that modification. Advantage of this type of modification is that there is no need for difficult surface modifications like notches or indents.

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