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Numerical comparison of concrete columns strengthened with layer of fiber concrete and reinforced concrete

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Abstract

Concrete structures that are influenced by degradation, overloading, the thawing and freezing cycles, abrasive damage, corrosion of reinforced bars, should be repaired or strengthened. Each of those mentioned influences lead to decreasing the load-carrying capacity of the structure or its member. The damaged structure stops to fulfil the serviceability limit states (SLS) and ultimate limit states (ULS). For this reason, the structure has to be strengthened to increase the load-carrying capacity and elongation of remaining lifetime. One of new method for strengthening vertical members (columns of frame structures) is the using fiber concrete layer and utilization its increased tensile strength in comparison to common concrete.

Keywords: fibre concrete, strengthening, column, numerical

1. Introduction

Geometry of structures result from architectural solution. In the last decades, the structures of buildings were changing from low wall structures to higher frame structures stiffened with stiffener walls or cores. The load-bearing system consisted of massive main walls in the past, the floor slabs were supported with these massive walls and created a difficult static system. The main goal was to replace massive structures to subtle structures as skeletal structures or concrete frames, which lead to enlarging utility area (Hruban, K., 1950). The columns are very loaded on the edges of the frame structure, where is the highest bending moment and axial load. The exceeding the design values of

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structure´s/member´s resistance can be by reasons of the design loads exceeding, mechanical damage (due to explosion, impact load, etc.), change of the structure function and so the increasing of considering loads.

Aim of this paper is to show possibility of strengthening the columns by fiber concrete. Distribution and orientation of fibers in fiber reinforced composites are essential for the structural performance of elements and structures (Vítek at all, 2017, Rehacek at all, 2014) and using this method we can achieve the optimal strengthening and technological approach.

2. Method of strengthening

Basic principles of the concrete column´s strengthening is based on increasing the cross-section of column. It can be done by adding a layer around column´s cross-section (encasement, min. requirements of thickness is 60 mm) of normal concrete with reinforcement or by layer of cement mortar with min. thickness 30 mm, adding rigid steel members with thin concrete encasement, or near-surface mounted reinforced steel bars into cross section. Wrapping with the FRP sheet (Sonnenschein at all, 2016) and also near surface mounted (NSM) or externally bounded reinforcement (EBR) with FRP lamellas are the methods, which belong to new technologies. Using the layer of fiber concrete encasement is also new technology, which is investigated at Department of Structures and Bridges, Civil Engineering Faculty, University of Žilina. In this case, the column´s cross-section is also enlarged by new layer of fiber concrete, but without new reinforcement and not so high thickness as in the case of normal concrete with reinforcement. The new layer can by only 30-40 mm because the fiber concrete has not protective function of new reinforcement. By this manner of the strengthening, we want to use the tensile strength of fiber concrete, which increase the resistance instead of steel reinforcement. The tensile strength is depending on the fiber profile, amount, size, and shape, strength of fiber and on the location of fibers in the crack. In the fiber concrete, where the ratio between water and cement is higher than 0.40 and fiber diameter is 0.10 mm or more, the mechanical anchoring is needed. The various profiles were developed on this purpose.

The next step, which should be considered, is the angle of fiber orientation concerning to the load. The mechanical properties are influenced by orientation of fibers (Thrane at all, 2013). The fibers, which rotate around the cracks in the different angles, are shown in the Fig. 1. Fibers are oriented in the one direction and cracks are crossed through them. Experimental results show that influence on the mechanical properties of the fiber reinforced constructions is mainly dominant by their amount of the fibers, which are crossed through the crack.

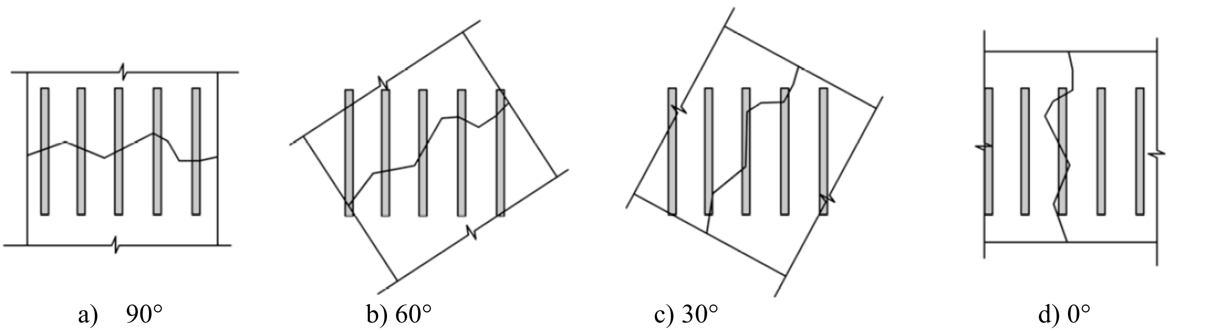


Fig. 1. Orientation of fibres to crack.

In the last decades, a lot of researches engage manners how to strengthen concrete members effectively and simply and such maximally increase the load capacity and extend the remaining lifetime. The result of researches is extremely increasing of load capacity, but from the technological point of view not all these variants are applicable in practice nowadays. Using high performance concrete, as well as fiber concrete on the strengthening existing structures, is advisable choice in term of lifetime and strength.

Aim of the article is to show the increasing resistance of the cross-section of column, which is loaded by the combination of axial force N_{Ed} and bending moment M_{Ed} by using fiber concrete layer around column for strengthening. In this way, the tensile force in the fiber concrete is used for increasing the column cross-section resistance. Strength of the fiber concrete at the crack mouth opening displacement f_{ft} grows approximately linearly with mass density of fibers m_{fl} until the value, which is difficult for manufacturing the concrete mass (in the magnitude 100-150kg/m^3) (Krátky at all, 1999).

3. Numerical modeling

Using experimental program on real specimens is the best way how to investigate the increase of strengthened column´s resistance. But firstly, it is recommended to do numerical modeling of prepared experiment specimens in order to verify the expected results, justify and improve the experimental program etc. That is the reason why the numerical modeling was used and was foregone the experimental program.

In the numerical modeling, three methods of strengthening were modeled and compared. The experiment was based on the reference sample, thus reinforced concrete column with parameters 240 x 240 x 2500 mm were considered. Concrete of lower class C16/20 was used. The characteristic cylinder strength in the compression was 16.0 N.mm^{-2} [MPa], the tensile strength was 1.9 MPa and modulus of the elasticity was 29 GPa. The steel class B 500B was used as the reinforcement. The column was reinforced by 4 bars of diameter 10 mm in the corners and stirrups of diameter 8 mm (as a shear reinforcement), the distance between stirrups´ axes was 100 mm. It was assuming that the minimal and maximal ratio of reinforcement $\rho_{min} = 0.002 \leq \rho = 0.00545 \leq \rho_{max} = 0.04$ was complied. Slenderness of the column equals to $\lambda = 36.084$. According to code (STN EN 1992-1-1, 2015), the limit values of the compression force and bending moment were calculated. The column, according to Eurocode, is able to carry the compression force $N_{Ed} = 214$ kN and the bending moment $M_{Ed} = 19$ kNm. Based on these values, the eccentricity was determined at 101 mm from the centre of the gravity.

3.1. Alternatives of strengthening

First alternative was the strengthening by the fiber concrete layer around the column´s cross-section (encasement) of thickness 30 mm. It was necessary to do the parametric studies of the comparison of real measured values (Sajdlová, 2011) for the input data of the fiber concrete material characteristics into program ANTENA and subsequently made modification of material properties in the program ATENA. The parametric study was performed on examinational beams (real experiment) with dimensions 150 x 150 x 700 mm. The examinational specimens consisted the fibers Arcelor HE 75/50, which were added in amount of 40 kg/m^3. The concrete mixture reached cube strength in the compression 46 MPa after 28 days. Thus the class of concrete was type of C35/45.

Realization of the experiment with fiber concrete was performed on the four-point bending flexural test and the results were used for comparison with the program Atena – calibration of model (Sajdlová, 2011). It was necessary to adjust the parameters of the compression strengthening, particularly critical deformation in compression for the correct response of the material. In the resultant value, the value of the fracture energy was increased 500-times of the original value and as well as the critical compression deformation was increased 500-times of the basic value. The tensile strength of fiber concrete was decreased on the 66 percentage of the original value.

Second alternative of strengthening was strengthening by encasement reinforced concrete layer with steel reinforcement. The new concrete layer of thickness 30 mm was reinforced by the four bars of diameter 10 mm in corners and stirrups of diameter 8 mm with the axial distance of stirrups 100 mm. According to previous recommendations, the minimal thickness of new concrete layer should be 60 mm, but for reason of enormously enlargement of cross-section and better possibility of comparison with first method of strengthening (firer concrete), there was considered thickness only 30 mm in the numerical modeling. Class of the used concrete was C50/60. The design principles of the minimal cover was not fulfilled for environment XC1, for reason of enormously enlargement of cross-section, how it was previously mentioned.

The encasement by layer of plain concrete C50/60 without any reinforcement was the last third alternative of strengthening. The characteristic values of materials, like in the previous cases, were used. The thickness of the layer for reinforcing was established on the value 30 mm. Bonding between the materials (original old concrete cross-section and new encasement layer) was not especially modified in all the cases.

All type of strengthening are shown in Fig. 2.

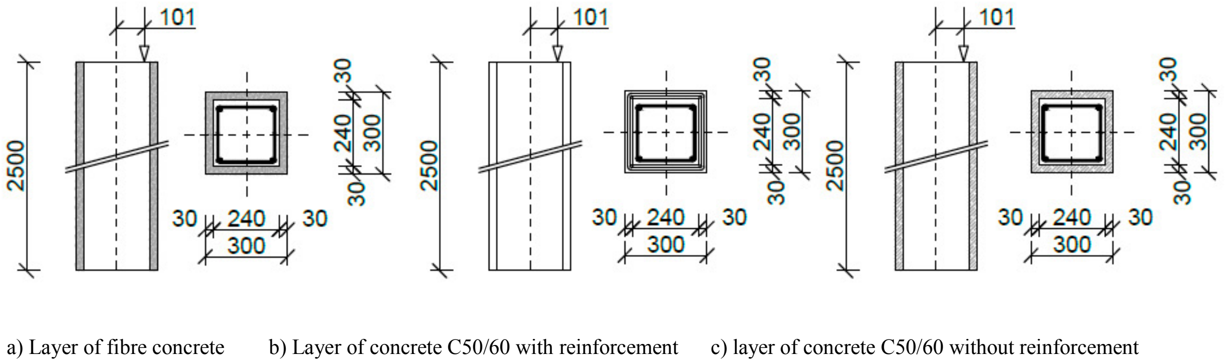


Fig. 2. Type of strengthening.

3.2. Results from numerical modeling

In the Fig. 3, there is shown the comparison of all three types of strengthening. Resistance of the reinforced column without strengthening is shown with dashed line. The load carrying capacity (normal force) of non-strengthened column is equal to 314.7 kN.

The figure shows that the least effective way is strengthening only by plain concrete (third type of strengthening). The layer of plain concrete is not able to carry the high level of load in the tensile parts of column area, it is useful only in compression parts. However this type of strengthening increase the load carrying capacity up to value of normal force equal to 400.6 kN. In this case, the load carrying capacity of column greatly depends on bonding between old concrete and new concrete layer, but this effect was not investigated.

According to results, second alternative of strengthening is the best way. The load carrying capacity of column´s cross-section increases up to 542.4 kN. Comparing to the third strengthening (layer of plain concrete), the load was increased about 141.8 kN. Comparing the first alternative of strengthening (layer of fiber concrete) with the others, we can see that this method of strengthening has very good results. The load carrying capacity is equal to 490.6 kN. Compared to the strengthening by plain concrete, this type was increased about 90 kN, but compared to the reinforced concrete with reinforcement, the value is lower about 52 kN.

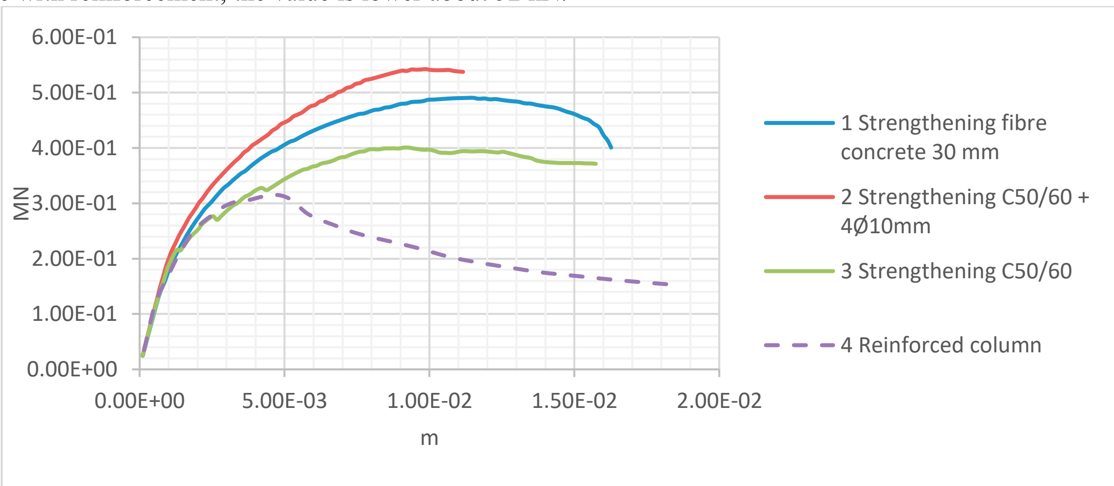


Fig. 3. Comparison of strengthening methods.

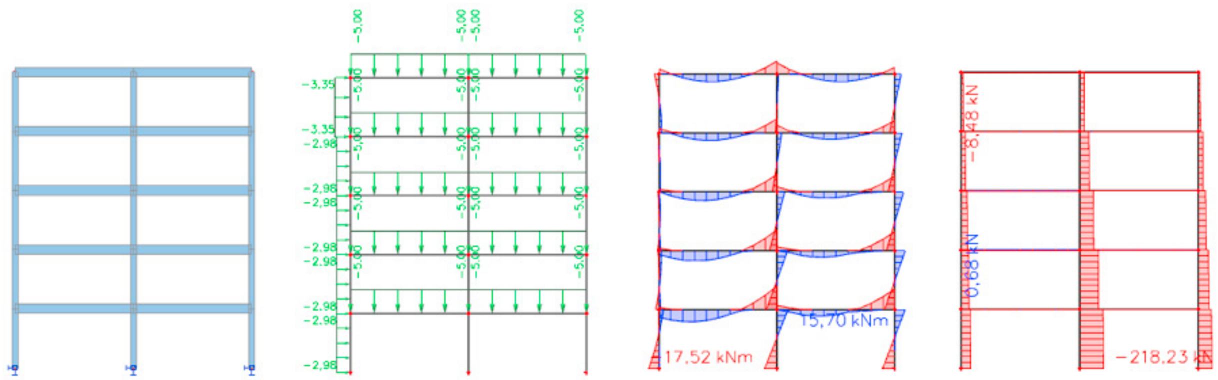
The accurate results are shown in Tab.1, where is illustrated comparison of percentage increasing towards to the reinforced concrete column and also calculation of the bending moment to pertaining axial load.

Table 1. Methods of strengthening and utilization.

Type	Axial force (kN)	Bending moment (kN/m)	Increasing axial forces (kN)	Increasing axial forces (%)
1. Strengthening by layer of fiber concrete	490.6	49.5	175.9	55.8
2. Strengthening by layer of concrete C50/60 with reinforcement	542.4	54.7	227.7	72.3
3. Strengthening by layer of concrete C50/60 without reinforcement	400.6	40.4	85.9	27.3
4. Not strengthened reinforced column	314.7	31.7	-	-

3.3. Demonstration on the concrete frame structure

The utilization of strengthening columns was demonstrated on the outer columns of frame structure with five stores. Structure consisted of vertical columns with dimensions 240 x 240 mm and horizontal beams of dimensions 240 x 400 mm. Concrete frames were made with class of concrete C16/20. The frames were loaded by self-weight of varying members and permanent load 5 kN/m on every floor. The imposed load was neglected. Horizontal load represents the wind load and was applied for the reason to increase only bending moments in columns without increasing of vertical internal forces. The wind load was calculated according to code (STN EN 1991-1-4, 2008). The value 2.98 kN/m was applied for floors from 1 to 4 and value 3.35 kN/m was applied on the last 5th floor as it is shown in Fig. 4b. In this solution, there were considered two combinations – the partial safety factors equal to 1.0 were used for the characteristics combination SLS_C01 and the partial safety factors for the permanent loads 1.35 and for the variable load 1.5 were used for the second design combination ULS_C02.



a) Superstructures b) Load c) Internal forces – max. bending moment d) Internal forces – max. axial force

Fig. 4. Internal forces from initial loads.

The maximum results of the bending moments and axial forces were gained from the both combinations (shown in Tab.2) and there was established percentile utilization of columns´ cross-section resistances. The result show that all columns on the ground floor are not satisfactory from the combination ULS_C02. Utilization of the middle column is about 115% and column on the edge is about 113% in the case of Ultimate Limit State (ULS), what is over 100%. Utilization of the columns in Serviceability Limit State (SLS) from combination SLS_C01 is about 80% for all columns. All results are showed in Tab.2. From the gained result is clearly, that columns need strengthening.

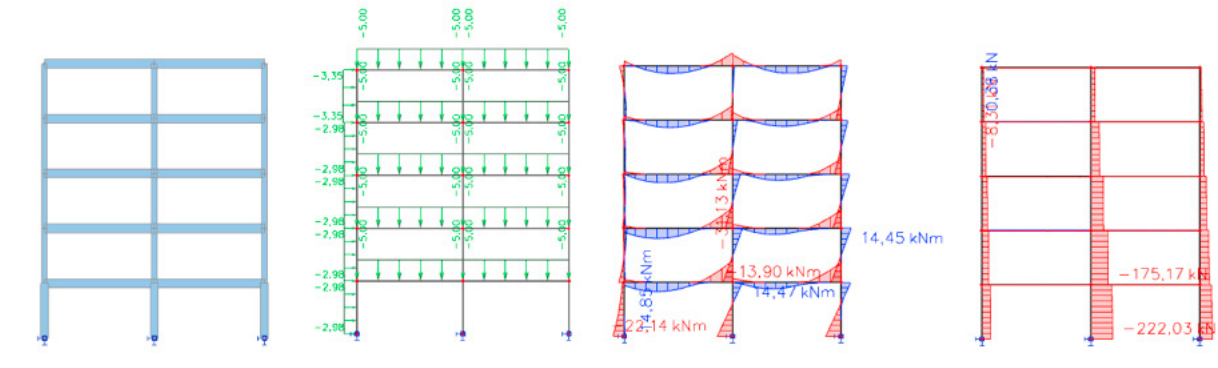
Table 2. Internal forces on the first floor with utilization.

	SLS_C01			ULS_C02		
Column	M_{Ed} (kN/m)	N_{Ed} (kN/m)	Utilization (%)	M_{Ed} (kN/m)	N_{Ed} (kN/m)	Utilization (%)
Column on the edge	17.12	-125.30	80.4	25.58	-118.80	115
Column in the middle	17.52	-218.23	81.8	26.37	-314.62	113

For the application and using the results from the program Atena into program SCIA Engineer, it was necessary to do the reverse calculation. The axial pressures forces about value 419 kN was gained from the strengthened column model from Atena and the bending moment about value 49.591 kNm was established from the original eccentricity e = 0.101m. On the basis of these values, there was designated theoretical cross-section with dimension 350 x 350 mm, which resistance was utilized on 99 %. It was for the reason that into program SCIA Engineer is not possible to enter strengthened cross-section. It was necessary found equivalent cross-section adequate to values from Atena. Subsequently, there were made changes in SCIA Engineer, thus original cross-section 240 x 240 mm was changed to 350 x 350 mm how is showed in Fig. 5a). The values are shown in Tab.3.

Table 3. Internal forces on the first floor with utilization for strengthening columns.

	SLS_C01			ULS_C02		
Column	M_{Ed} (kN/m)	N_{Ed} (kN/m)	Utilization (%)	M_{Ed} (kN/m)	N_{Ed} (kN/m)	Utilization (%)
Column on the edge	21.96	-127.85	62.4	32.75	-184.07	79.4
Column in the middle	22.14	-220.03	60.6	33.21	-319.77	76.2



a) Superstructures b) Load c) Internal forces – max. bending moment d) Internal forces – max. axial force

Fig. 5. Internal forces from strengthened frame

Comparing the results from the Tab. 3 and Tab. 2, it is clear that the resistance of bottom (1^{st} floor) columns increase (utilization decrease). The columns´ resistances were increased about 21.2% for the characteristic combination and for the design combination occurred increasing about 36.8% in the middle column and 35.6% in the outer of column. Next step was determining what value can increase the horizontal wind load so that structure will be still satisfactory. The increasing horizontal load to the utilization of bottom columns equal to 99.9% using iteration was the way how to find maximal horizontal load. From the result follows that the horizontal load can increased about 25%.

4. Conclusion

Different variants of the strengthening give different results as shown in this paper. In this article, three ways of strengthening were used: strengthening by the layer of fiber concrete, layer of reinforced concrete or plain concrete. The highest strengthening was achieved by using of reinforced concrete, but in this case, it is considerably technologically difficult due to using and preparing reinforcement around the column and using formwork. So, the best method seems to be strengthening by fiber concrete layer, which showed higher load-carrying capacity compared to plain concrete layer and very comparable values to the reinforced concrete layer. It is needed to highlight that the tensile force in fiber concrete is dependent on to amount of the fibers in the concrete mixtures and the fibers in concrete decrease the ductility and fragility during failure of member.

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