Investigation of shear connection between new and old concrete layers

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Abstract. The structure and all its elements must be load-bearing, safe and serviceable. Due to time and external factors such as wind, thawing and freezing cycles, seismic activity, the structure of the concrete is disturbed and this leads to a reduction in the load-bearing capacity of the element. For vertical elements (columns), this usually means that the member’s strengthening must be used. The most common way of strengthening a concrete column is to use a new reinforced layer of concrete. In this case, great emphasis is placed on the contact between the original and the new layer of concrete. This article deals with two ways of surface treatment, such as notches and indents using different types of strengthening.

1. Introduction
Due to the aggressiveness of the environment, the materials itself degrades over time in concrete structures and also reduces the load-bearing capacity. We can extend the life-time of the structure by regular inspections and maintenance. Early detection of the causes of structural damage and subsequent proper selection of strengthening can restore the structure’s ability to satisfying operational requirements [1], [2], [3].

In the case of corrupted elements, or the entire structure, it is needed to take into account how to proceed with strengthening. In order to achieve the required level of reliability, the correct amplification method must be chosen. Nowadays and with today’s technologies, we have a huge variability of strengthening. Adding concrete reinforcement to the new enlargement cross-section is one of the most traditional ways of reinforcement (figures 1 a, b). If this method is used, there must be sufficient space around the column where the cross-section is increased, which is not possible in many cases. The recommended minimum thickness of the reinforced concrete layer according to [4] is 30 to 60 mm.

Using this method, it must be ensured that the original and new concrete do not slip, so it is considered the full co-operation. A state where the tensile force is transmitted to the pressed concrete [5] by shear forces is considered to be a full co-operation. It follows that the resistance depends on the concrete-concrete connection (contact between new and old layers). With such a joint, it is assumed that the newly added layer will has the same concrete quality or higher.
Shear resistance [6] in the shear joint is able to transmit shear forces to a certain level of resistance. After this level, the cross-sectional resistance is ensured by the action of several factors such as the strength of individual materials, technological processes or constructional arrangements. In the case of concrete structures, 3 factors contribute to the shear resistance when using concrete reinforcement [7], [8]:
- cohesion,
- friction,
- shear reinforcement.

These factors act simultaneously, only after overcoming a certain level of stress does cohesion cease to work. After overcoming cohesion, there is no collapse of the element, but a reduction of stresses in the cross section, which means that the element can no longer be considered monolithic [9], [10]. The standard STN EN 1992-1-1 [11] states the values of the coefficients of cohesion and friction for various surface treatments from very smooth to roughed. These factors are essential for calculating the load-bearing capacity of a composite element.

In practice, we often encounter the fact that the new additional reinforcement is anchored with hooks, which is quite laborious [12], [13]. Therefore, the article deals only with surface treatment for notches and indents by means of fibre concrete concreting. It follows that there is no need for concrete reinforcement and also no anchoring. The relevance of cohesion will also be demonstrated by inverse calculation from experimental measurements for notches and also the cohesion for notches will be determined which is not given in [11].

2. Experiments
Push tests consisted of a central column and an encasement. The cross-section of the column was chosen with floor plan dimensions of 0.16×0.16 m and a height of 0.35 m. The column (core) was reinforced with 4Ø10 mm, the length of the bars is 0.3 m. The stirrups of diameter 8 mm were placed at an axial distance of 85 mm (figure 2a). The concrete grade was used C 16/20. Samples after concreting were treated for 28 days. Subsequently, the samples were modified according to figure 2b and c. The samples were encasement with a layer of 35 mm thickness.

Temporary polystyrene was placed on the samples on the lower part (the polystyrene was removed after the encasement hardened). Subsequently, the samples were placed in the formwork where they were centered with spacer screws (figure 2d). Prior to concreting, the samples were cleaned, moistened and then the samples were concreted with fiber concrete. The composition of the concrete mix was based on previous research [14], where they compared the amount of fibers added to the concrete mix and their effect on the flexural tensile strength (table 1).
Figure 2. Reinforcement of concrete column and modification of surface.

Table 1. Results of the modify materials characteristics.

| Concrete mixture                      | 1 kg/m³ |
|---------------------------------------|---------|
| CEM II/B-S 32.5R (Ladce)              | 400     |
| Aggregate 0/8 mm                      | 910     |
| Aggregate 8/16 mm                     | 685     |
| Fly ash (USS Košice)                  | 80      |
| Water                                 | 200     |
| Fibers DRAMIX 3D                      | 40      |

Cubes with an edge length of 150 mm were cast to determine the compressive strength of the concrete. The average cube strength of fiber-reinforced concrete was 45.6 MPa.

The samples were loaded with axial force. The deformation between the core and the encasement was measured. Trajectory sensors were used for sliding. It was loaded by deformation at a speed of 0.5 mm/min. Theoretical load capacities of samples were calculated according to STN EN 1992-1-1 [11] and they are shown in table 2.

The results of measurements showed shear resistance for individual types of surface treatments. The six samples (three in two series) were tested and the test results are shown in figure 3 for indent and figure 4 for notches.

After analysis of the indent tests (ZZ), it was clearly visible that the indent in the core was filled with the concrete mixture and were slipped after reaching the shear resistance (figures 5a and d). Using fiber concrete, one or two major longitudinal cracks were formed, which occurred at the time of shear resistance. After reaching the maximum shear force, cracks were formed and opened (figures 5b and c). The average value transferred by the surface treatment to the indent was 262.17 kN.

The notches (ZR) samples showed the high shear resistance. In the analysis of the cladding, it was visible that the formation of cracks was situated more on the corners of the core, but the effectiveness of the notch was also clearly visible (figures 6 a, b, c). The mechanism of the violation was the same as for the indent. The average value transferred by the surface treatment to the notches was 250.58 kN.
**Figure 3.** Load-deformation, fibre concrete – indent.

**Figure 4.** Load-deformation, fibre concrete – notches.

**Figure 5.** Sample after load – indent.
For comparison, the characteristic values of shear strength $\tau$ [11] were calculated according to equation (1 and 2). For the indent, the shear resistance was calculated at 105.0 kN. A coefficient of friction of 0.45 was used for the notches and the value of shear calculated according to STN EN 1992-1-1 [11] was 94.5 kN.

\[
\tau_n = c + \mu \sigma_n
\]  \hspace{1cm} (1)

\[
\tau = \tau_n \cdot S
\]  \hspace{1cm} (2)

where:
- $\tau_n$ is the shear stress [MPa],
- $\tau$ is the shear resistance [kN],
- $\sigma_n$ is the normal stress [MPa],
- $S$ is the contact shear surface [$m^2$].

**Table 2.** Determination of the coefficient of cohesion.

| Series | Average shear resistance from experiment $\tau$ [kN] | Shear resistance standard $\tau$ [kN] | Shear stress from experiment $\tau_n$ [MPa] | Calculated cohesion $c$ [MPa] | Standard cohesion $c$ [MPa] | Cohesion difference calculated-norm [%] |
|--------|---------------------------------------------------|-----------------------------------|------------------------------------------|----------------------------|----------------|----------------------------------|
| ZZ     | 262.18                                            | 105.0                             | 1.248                                    | 1.25                       | 0.50           | 40.05                           |
| ZR     | 250.58                                            | 94.5                              | 1.193                                    | 1.20                       | 0.45           | 37.50                           |

From the obtained results (table 2) the calculations from equations (1) and (2) were confirmed, where the values of the tests in some cases exceeded the calculated results for indent and notch many times. As the standard [11] does not specify the coefficients of friction and cohesion for the notches surface treatments, it was necessary to calculate these values by back-calculation and compare them with the standard values.

However, it should be noted that the results came from large differences between the individual samples. The diversity of the results is largely due to the concrete mix and the air cavities at the contact surfaces of the encasement.
3. Conclusions
If is necessary to strengthen the vertical load-bearing elements by using a new layer concrete, the emphasis is placed on the slippage between the original and the new concrete and also on the load-bearing capacity of this new layer. This contact is influenced by the type of surface from which cohesion depends. The mechanism ensures the cohesion of the cement composite through porosity and also by surface treatment. The article proves that the values of cohesion are several times on the side of the security side compared to the measured and calculated values of up to 40.05% for indent and 37.50% for notches. They also point out that by surface treatment we achieve higher shear resistance. In our case, the modification of notch indicates a higher shear capacity than notches but smaller by only 11.6 kN.

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References
[1] Koteš P. 2012 Reliability of existing bridge structures and possibilities of its increase (Žilina)
[2] Vičan J and Koteš P 2018 Evaluation of existing bridge structures (Žilina: EDIS)
[3] Tomica V, Sokolík A, Zemko Š 1992 Maintenance and reconstruction of bridges (Bratislava)
[4] Bilčík J and Dohnálek J 2003 Rehabilitation of concrete structures (Bratislava: JAGA)
[5] Priganc S and Bahleda F 2007 Reinforcement of concrete structures (Košice)
[6] Sadowski L 2019 Adhesion in Layered Cement Composites (Switzerland: Springer)
[7] Wall J S and Shrive N G 1988 Factors affecting bond between new and old concrete ACI Materials 95 pp 117-125
[8] Czarnecki L and Chmielewska B 1993 Factors affecting adhesion on building joints Proc. of Fifth Int. Conf. on Structural Faults and Repair
[9] Vavruš M, Koteš P and Bahleda F 2019 Analysis of shear contact between wrapped layout of fiber reinforced concrete POLLACK PERIODICA Int. J. for Eng. and Information Sciences
[10] Bakhsh K N 2010 Evaluating of Bond Strength between Overlay and Substrate in Concrete Repairs (Master of Thesis, Stockholm)
[11] Standard 2004 STN EN 1992-1-1: Eurocode 2. Design of concrete structures-Part1-1: General rules and rules for buildings
[12] Čítek D, Kolísko J, Řeháček S and Mandlík T 2015 Concrete cover effect on bond behaviour of UHPC 22nd Int. Conf. Concrete Days (Litomysl; Czech Republic) 249 pp 273-7
[13] Čítek D, Huňka P, Řeháček S, Mandlík T and Kolísko J 2014 Testing of bond behavior of UHPC 11th Int. Conf. on Special Concrete and Composites 1054 pp 95-98
[14] Vítek J L and Smiřinský S 2010 Interaction of classical and diffuse reinforcement BETON