Impact of the Degree of Concrete Cracking on the Pull-out Resistance of Steel and Plastic/Metal Sleeve Anchors

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Abstract. Areas affected by seismic and mining disturbances are tied to a risk of damage to engineering structures. The problem may result in permanent damaging of fasteners installed in buildings. Such damage may affect the strength of different types of construction fasteners and connectors. The technical condition of fastening elements should be assessed, and conclusions formed regarding the causes of damage and ways to secure those elements. In order to determine the pull-out resistance of fasteners set in a concrete base, the effects of disturbances were simulated as cracks in the concrete. Additionally, the influence of tolerances for openings made using drills with diameters $d_{\text{min}}$, $d_{\text{nom}}$, and $d_{\text{max}}$ presented in the study was also determined. Introduction of the variables described may influence the pull-out resistance of the steel and plastic/metal anchors. The article presents the results of tests for specific pull-out resistances of steel and plastic/metal anchors installed in a concrete base in normal-weight non-cracked concrete and normal-weight cracked concrete where crack initiation was at 0.20 mm and 0.35 mm. All tests were carried out for the purposes of this paper at normal temperature and with C20/25 concrete, without factoring in influence of concrete or air moisture content.

1. Introduction
Contemporary fastening technology offers many ways of constructing structural and non-structural connections. In structure bases, depending on the intended function and assembly methods chosen by the designer, typical choice of fasteners include steel torque controlled wedge anchors and plastic anchors with a steel screw. Every structure should be designed in such a way as to fulfil its function throughout its entire life in regard to serviceability, strength and stability, without any significant loss of functionality and without incurring any excessive, unpredicted maintenance costs [1]. When permanent connections are installed in areas affected by seismic and mining-related disturbances, this may impact the pull-out strength of the fasteners or some premature damage to the connection. This paper presents an analysis of changes in strength of steel anchors and plastic anchors with a steel screw in a cracked base as compared to a non-cracked base; the aim is to simulate the performance of the anchors before and after structure damage.

2. Material and methods

2.1. Materials
The research concerning the strength changes was carried out on a base made of C20/25 concrete without taking into account the impact of moisture content in the concrete or air. The anchors selected for examining the strength of anchors in cracked concrete were steel torque-controlled M10 wedge anchors.
made of galvanised carbon steel with $R_m \geq 500$ MPa and plastic anchors with a steel screw $\varnothing 10$ mm, made of PA6.

Figure 1. Anchors used for the research: a) steel, torque-controlled M10 wedge anchors, b) plastic anchors with a steel screw

2.2. Methods
The research was carried out in compliance with EAD guidelines [3, 4]. The concrete base was prepared in wooden forms with the following dimensions: 4000x1000x300 mm. During concreting, samples of the concrete were taken for strength tests, in accordance with the applicable methodology [5]. The concrete class was determined after 28 days [6]. The anchor testing was carried out with the use of: Quantum HBM device, HBM software, force sensors with the capacity of 0–20 kN and 0–200 kN, and displacement sensors in the range of 0–100 mm. Test preparation methodology was as follows: holes were drilled into the C20/25 concrete using an impact drill and SDS-Plus bits with a diameter of 10.3 mm. The diameter of the drill hole was controlled with the use of an electronic calliper in order to obtain repeatable installation holes in the C20/25 concrete base. The holes were cleaned by blowing air from a compressor four times, in order to remove the swarf. The anchors were installed in these openings and then pulled out of the base in order to determine their pull-out strength.

2.3. Aim and scope of the test
The aim of the laboratory test was to determine the change of average strength of anchors in a cracked concrete base, as compared to a non-cracked base. The test involved the process of determining the average pull-out strength of anchors installed in the C20/25 concrete with crack widths of 0.00 mm, 0.20 mm and 0.30 mm.

3. Results
Table 1 contains list of installation parameters of steel wedge anchors and plastic anchors with a steel screw.
Table 1. Assembly parameters of anchors

| Anchor                                      | Nominal Embedment Depth h₁ [mm] | Effective Embedment Depth hₑf [mm] | Installation Torque Tₑst [Nm] | Drill Hole Diameter dₑ [mm] |
|---------------------------------------------|----------------------------------|-----------------------------------|------------------------------|-----------------------------|
| Steel M10 wedge anchor (TA)                 | 80                               | 70                                | 50                           |                             |
| Plastic anchor with a steel screw (TM)      | 70                               | 50                                | 16                           | 10.30                       |

3.1. Pull-out strength in concrete base

Based on the forces measured, the pull-out strength of the anchors was calculated from formula (1). Average pull-out strength is presented in figures 2 and 3. Detailed values of pull-out strength of anchors is shown in figure 4.

\[
N_{Ru,m} = F_{Ru} \cdot \left( \frac{f_c}{f_{c,\text{test}}} \right)^{0.5}
\]

Where:

- \( N_{Ru,m} \) – average pull-out strength [kN],
- \( F_{Ru} \) – average failure force [kN],
- \( f_c \) – characteristic compressive strength of concrete [MPa],
- \( f_{c,\text{test}} \) – characteristic compressive strength of concrete [MPa].

Figure 2. Relation between failure force (\( F_{Ru} \)) and the width of the crack (\( w \)) for steel wedge anchors (TA) in C20/25 concrete.
4. Conclusions

Based on the laboratory tests and analysis of the pull-out strength of the tested anchors, it can be concluded that the drop in strength for steel M10 wedge anchors (TA) in cracked C20/25 concrete stands at 24% with embedment depth of $h_{ef} = 70$ mm, and with embedment depth of $h_{ef} = 50$ mm the drop in strength it equals 36%. In the case of plastic anchors with a steel screw, the embedment depth has no impact on the drop in strength, which stands at 50%. Further development of cracking causes a drop of strength of c. 30%. For cracked concrete with crack width of 0.3 mm, the decrease in strength was found to be equal to 50% for steel wedge anchors and 70% for plastic anchors with a steel screw. Therefore, the cracking of concrete does not preclude usage of either steel anchors or plastic anchors with steel.
screws. The average values of pull-out strength determined based on the failure force exhibit significant drops with the increase of crack width in C20/25 concrete. This drop is dependent on anchor type and displays different behaviour for each of them.

References
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