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Resistance of Metal Anchors on Territories Covered under Seismic Actions

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Abstract. In areas affected by the threat of the substrate's influence, in the form of its movement, it is advisable to estimate the load-bearing resistance of metal anchors by testing in areas affected under seismic actions. These tests involve determining the load resistance for pull-out metal anchors of cracked concrete. Cracked concrete can take place in cycles. In the international literature, tests are conducted on metal anchors for various classes of concrete substrates, including cycles of initiation of cracked $w_c = 0.10 \div 0.30$ mm. The tests was carried out with the assumption of determining the reduction coefficient $\alpha_{N,seis}$, C1. The coefficient can lower the determined final load capacities of the fasteners to scratch out of scratched concrete substrates. Depending on the scale of the occurrence of the amplitude of the gravitational acceleration, able to cause seismic actions influences greater than 0.05 g, C1 or C2 categorization was adopted, giving European Guidelines to determine the load resistance for pull-out metal anchors from cracked concrete. In the case of a seismic action of less than 0.05 g (gravitational acceleration), it is not required to determine the ultimate lifting capacity including reduction factors for seismic activity. The occurrence of amplitude from 0.05 to 0.1 g requires testing, for initiation of scratches in concrete $\Delta w = 0.50$ mm for category C1 or $\Delta w = 0.80$ mm for category C2. In the case of interactions of amplitudes greater than 0.1 g, tests for the initiation of scratches in concrete $\Delta w = 0.80$ mm, for the regions of southern Europe and Asia are required. The article presents the results of tests for specific pull-out resistances of metal anchors installed in a cracked concrete. All tests were carried out for the purposes of this paper at normal temperature, without factoring in influence of concrete or air moisture content.

1. Introduction

Pull-out resistance [1],[2],[3] is among basic characteristics describing the behaviour of anchors in construction elements. Apart from compliance with installation parameters quoted by manufacturers, the anchor should be installed in its base in a way which allows it to perform its load bearing functions. Real technical conditions on construction sites, in the form of installation of fixings and compressive strength of concrete bases, should be planned, starting with design of fasteners, their installation and specific usage in their intended location. Fasteners should operate correctly in all concretes intended for use in construction. Correct installation of steel anchors should be accompanied by proper technical supervision on the site and technical training of the installation team. These actions are intended to eliminate basic factors [4],[5] which may influence the final values of the anchors' pullout resistance, in particular use of drill bits with tolerances exceeding those specified in [6].



Proper cleaning of drill holes and correct axial installation of anchors are also important elements of the process, and may influence final pull-out resistance. By constantly monitoring these actions, so-called major installation errors can be avoided. Steel anchors should be able to transfer loads, without factoring in the influence of temperature, which acts on the concrete bases between -40°C and $+80^{\circ}\text{C}$. Anchor pull-out strength is determined based on laboratory tests or using calculation method CCFM [7]. For strengths determined through tests in which steel anchors are subjected to static or quasi-static loads, mean pull-out resistance [8],[9] is calculated using the formula (1):

$$F_{Ru,cone} = F_{Ru} \cdot \left(\frac{f_c}{f_{c,test}}\right)^{0.5} \quad (1)$$

where:

$F_{Ru,cone}$ – average pull-out resistance [kN],

$F_{Ru,m}$ – test failure force [kN],

f_c – standard compressive strength of the concrete base [MPa],

$f_{c,test}$ – compressive strength of the concrete base from tests [MPa].

Mean pull-out resistance determined based on CCFM method calculations, for cracked C20/25 – C50/60 concrete is calculated according to formula [7]:

$$N_{Ru,m} = 9,5 \cdot h_{ef}^{1,5} \cdot f_{c,test}^{0,5} \quad (2)$$

where:

$N_{Ru,m}$ – average pull-out resistance [kN],

h_{ef} – effective embedment depth of the fastener [mm],

$f_{c,test}$ – compressive strength of the concrete base from tests [MPa].

2. Scope and aim of the research, analysis

Tests of sleeve anchors consisted in determining maximum failure force for anchors installed under static tension in concrete. The fasteners were installed in accordance with installation parameters specified in table 1. Three diameter sizes of fasteners were installed (M8, M10 and M12), using minimal, nominal and maximal drill hole diameters d_{cut} .

The fasteners were tested in cracked and non-cracked bases, where crack width was 0.10 to 0.50 mm and cyclic crack width change from 0.10 to 0.30 took place over 100 cycles. During research cycles the fasteners were loaded with constant or variable forces, depending on the test combination. A constant load is understood to mean load determined using formula (3), while variable – load in the min-max range over 100 crack cycles of 0.1 to 0.3 mm, calculated from formulas:

$$N_{p,min} = 0,1 \cdot N_R \quad (3)$$

$$N_{p,max} = 0,4 \cdot N_R \quad (4)$$

where:

$N_{p,min}$ – minimum load on a fastener in a cycle [kN],

$N_{p,max}$ – maximum load on a fastener in a cycle [kN],

N_R – mean pullout resistance of a fastener [kN].

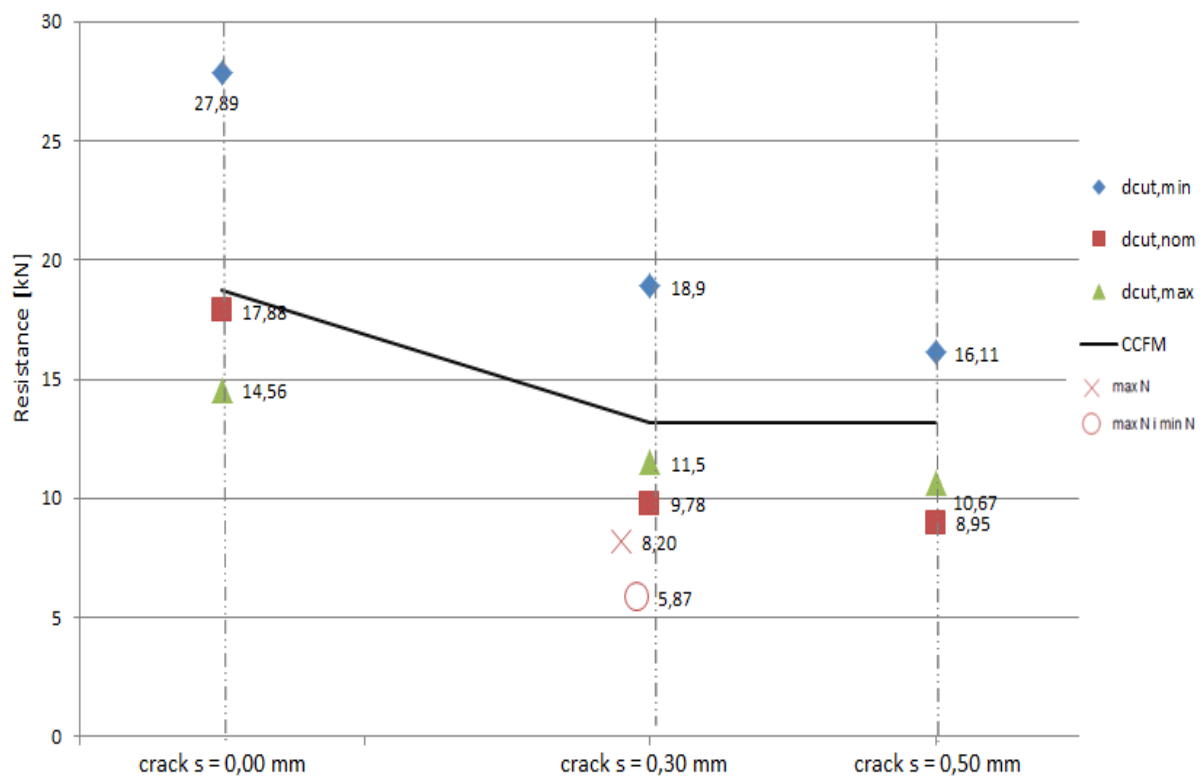
The comparative analysis of the strength of steel anchors used as construction fasteners covered mean pullout resistance of structural fasteners for C20/25 concrete, both cracked and non-cracked, for different research combinations. Test results were distributed in the range 7–15%. Number of trials carried out $n = 5$.

Table 1. Installation parameters of sleeve anchors

Anchor	Concrete $f_{c, \text{test}, C20/25}$ [MPa]	Nominal Embedment Depth h_l [mm]	Effective Embedment Depth h_{ef} [mm]	Installation Torque T_{inst} [Nm]	Drill Hole Diameter d_{cut} [mm]
M8	30.0	50	40	15	$d_{\text{cut}, \text{min}} = 12,15$ $d_{\text{cut}, \text{nom}} = 12,30$ $d_{\text{cut}, \text{max}} = 12,45$
M10	30,0	65	50	50	$d_{\text{cut}, \text{min}} = 15,15$ $d_{\text{cut}, \text{nom}} = 15,30$ $d_{\text{cut}, \text{max}} = 15,45$
M12	30,0	70	60	80	$d_{\text{cut}, \text{min}} = 20,15$ $d_{\text{cut}, \text{nom}} = 20,30$ $d_{\text{cut}, \text{max}} = 20,45$

3. Results and discussions

Initial results of mean ultimate loads obtained for sleeve anchors are presented in figure 1 to figure 3; the data refers to crack width s and drilled hole diameter d for C20/25 concrete. Results of mean failure loads for anchor M8 are presented on figure 1.

**Figure 1.** Mean ultimate load in a test for concrete C20/25 depending on s and d for M8 anchor

The results of mean ultimate load tests for M10 anchor and for C20/25 concrete are presented on figure 2.

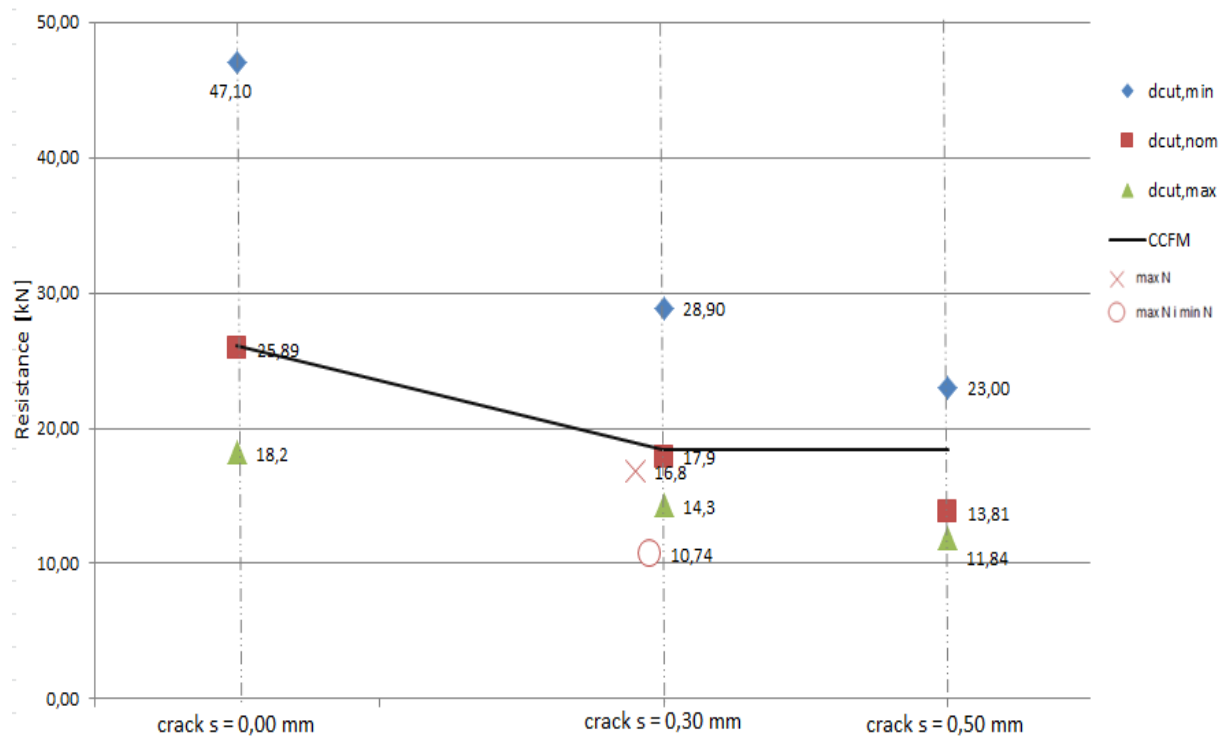


Figure 2. Mean ultimate load in a test for concrete C20/25 depending on s and d for M10 anchor

The results of mean ultimate load tests for M12 anchor and for C20/25 concrete are presented on figure 3.

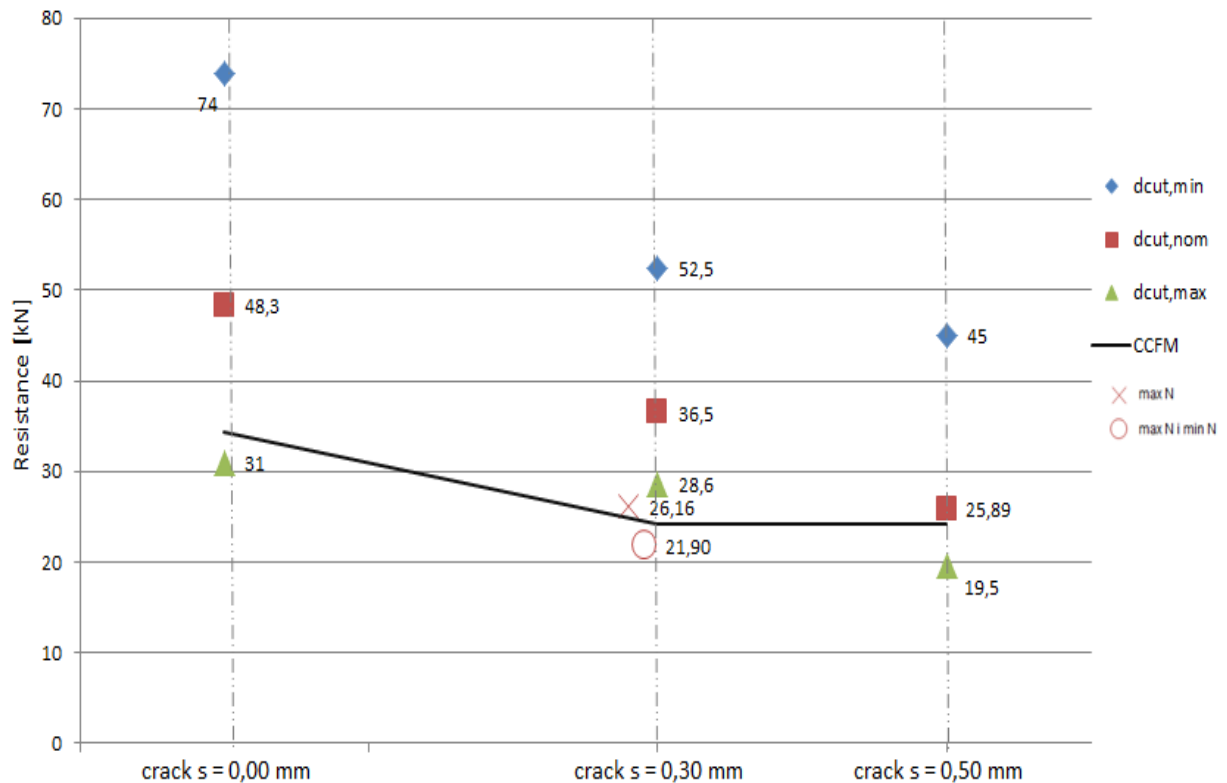


Figure 3. Mean ultimate load in a test for concrete C20/25 depending on s and d for M12 anchor

Based on laboratory tests determining pull-out strength of sleeve anchors in C20/25 concrete as well as comparative analysis of the values, it can be concluded that:

- variable loads present when crack width changes affect the quality of the connection, damaging it, as a result of the fastener sliding out of its base,
- constant load with variable crack width in C20/25 concrete, for all types of tested fasteners, adversely affect the final pullout resistance; the pullout resistance was determined at the crack width of up to 0.30 mm,
- the minimum tolerance of the drill holes for sleeve anchors yielded highest pullout resistance,
- installation openings for M8 and M10 anchors drilled with nominal and maximum tolerance for drill holes do not show the impact of the variables caused by tolerances of drill holes and the type of anchor loads,
- loss of anchor resistance was reported in cracked concrete by 30% as compared to non-cracked concrete; the loss for concrete with cracks wider than 0.30 mm was equal to 20%,
- in the analyses of test results, a clear difference was found between the strength of anchors in cracked C20/25 concrete and those in non-cracked concrete; this evidences that cracking impacts the strength of anchors installed in such concrete,
- it was found that the chosen form and diameters of the anchor were impossible to use in areas with potential seismic actions; long-term variable loads for which no ultimate load was determined were characterised by the anchor sliding out of the base at maximum load before the designed 100th crack cycle, with crack width of 0.10 to 0.30 mm,
- in areas not subjected, or only partially subjected, to seismic actions, using this type and diameter of anchor will not affect the strength and quality of structural connections made with the use of steel sleeve anchors installed in C20/25 concrete elements.

4. Conclusions

The article presents own tests and analyses of pull-out resistance of steel anchors, providing new, significant data concerning the behaviour of steel sleeve anchors with a ring in C20/25 concrete, depending on the tolerance of drilled holes, crack width and load on the anchor, also considering seismic actions. Own tests of steel anchors were carried out according to the relevant research rules and self-developed guidelines for loads from cyclically varying cracking. The anchors chosen for the research were of the most common type used in construction for structural connections – steel sleeve anchors.

Based on the tests, loss of pull-out resistance was found in steel anchors subjected to constant tension installed in cracked C20/25 concrete, as compared to anchors installed in cracked concrete for cracks of 0.30 mm by c. 15%. Moreover, the tests showed that this type of anchor subjected to cyclic variable loads (at a rate of up to 20% of the ultimate load) will experience visible displacement in relation to the cracked concrete they were installed in. Anchor strength loss of c. 35% was found, as compared to fasteners installed in cracked C20/25 concrete, at the crack width of 0.30 mm.

Long-term variable loads simulating seismic actions resulted in the fastener sliding out of the base at maximum loading force before the 100th crack cycle with crack widths between 0.10 to 0.30 mm. It was found that the chosen form and diameters of anchor were impossible to use in areas with potential seismic actions; however, in areas without such seismic activity, using this form and diameter of the anchor will not affect the strength of the connection.

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