Impact of assembly parameters on the resistance of steel anchors

Daniel Dudek¹

¹Instytut Techniki Budowlanej, Warszawa
d.dudek@itb.pl

Abstract. In the current research practice, there is no documented influence of factors on load-bearing resistance and durability of joints by using steel anchors fasteners for fastening structural elements. The basic factors that may affect the load resistance are in particular various assembly parameters of steel anchors/connectors, the condition of the substrate (possible cracks), the grain size of concrete substrates, and additional reinforcement in the form of dispersed admixtures. The work determines changes in the load-bearing resistance of M12 steel anchors, depending on the anchorage depth used and the tightening/installation torque applied. The tests were carried out on cracked and non-cracked C20/25 concrete substrates. As part of the load resistance analysis, the correction coefficients of the load capacity of pulling-out of the steel anchors, which can correct the design loadings for pulling out of concrete substrates in the C20/25 ÷ C50/60 class range and correlations of these resistance, were determined. Two types of steel anchors: ring and sleeve on diameter M12 were selected for the tests, as commonly used structures of steel anchors in the construction industry. The article presents the results of tests for specific pull-out resistances of steel anchors installed in 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

According to the current guidelines [1-4] for the steel anchors installed in concrete substrates, the determination of the pull-out resistance is required. For this purpose, appropriate tests of the suitability of steel anchors for use and the determination of acceptable conditions of use should be performed [3, 5]. The pull-off resistance, in accordance with the mentioned guidelines, depends mainly on the anchorage depth for single types of steel anchors, regardless of the assembly parameters. In fact, these connectors work in various assembly systems, provided by system operators (manufacturers), which translates into the final load resistances of the steel anchors. In addition to different anchorage depths, the assembly systems are also characterized by different diameters of drilled holes caused by installation moments and cracks zones. Anchor pull-out strength is determined based on laboratory tests or using calculation method CCFM [6]. For strengths determined through tests in which steel anchors are subjected to static or quasi-static loads, mean pull-out resistance [6, 7] is calculated using the formula (1):

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

Where:

- \( F_{Ru,cone} \) – average pull-out resistance [kN],
- \( F_{Ru} \) – load capacity of pulling out of the steel anchors [kN],
- \( f_c \) – characteristic compressive strength of concrete [MN/m²],
- \( f_{c,test} \) – characteristic compressive strength of concrete [MN/m²].
FRu,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 non-cracked C20/25 – C50/60 concrete is calculated according to formula (2) [6, 7]:

\[ N_{Ru,m} = 13.5 \cdot h_{ef}^{1.5} \cdot f_{c,test}^{0.5} \]  \hspace{1cm} (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].

Mean pull-out resistance determined based on CCFM method calculations, for cracked C20/25 – C50/60 concrete is calculated according to formula (3) [6, 7]:

\[ N_{Ru,m} = 9.5 \cdot h_{ef}^{1.5} \cdot f_{c,test}^{0.5} \]  \hspace{1cm} (3)

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
Steel anchors on M12 diameters, selected in Figures 1 to 2, were selected for the tests. The tests were carried out on C20/25 concrete substrates. Tests of steel anchors consisted in determination of maximum destructive forces, fasteners fastened under the action of static tensile forces, in scratched and non-cracked concrete substrates in which steel anchors were installed.

Figure 1. Steel anchor – ring/expansion: a) construction, b) installation

Figure 2. Steel anchor – sleeve/expansion: a) construction, b) installation
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. The anchors were installed in accordance with installation parameters specified in Table 1 to 2.

**Table 1. Installation parameters of ring anchors M12**

| Combination | Concrete | Nominal Embedment Depth $h_1$ [mm] | Effective Embedment Depth $h_{ef}$ [mm] | Installation Torque $T_{inst}$ [Nm] | Drill Hole Diameter $d_{cut}$ [mm] |
|-------------|----------|-------------------------------------|------------------------------------------|-------------------------------------|----------------------------------|
| I           | $f_{c,\text{test},C20/25} = 30.0$ MPa | 80                                  | 60                                       | 80                                  | $d_{cut,nom} = 12,30$            |
| II          |          | 60                                  | 40                                       | 80                                  | $d_{cut,nom} = 12,30$            |
| III         |          | 80                                  | 60                                       | 40                                  | $d_{cut,nom} = 12,30$            |
| IV          |          | 60                                  | 40                                       | 40                                  | $d_{cut,nom} = 12,30$            |

**Table 2. Installation parameters of sleeve anchors M12**

| Combination | Concrete | Nominal Embedment Depth $h_1$ [mm] | Effective Embedment Depth $h_{ef}$ [mm] | Installation Torque $T_{inst}$ [Nm] | Drill Hole Diameter $d_{cut}$ [mm] |
|-------------|----------|-------------------------------------|------------------------------------------|-------------------------------------|----------------------------------|
| I           | $f_{c,\text{test},C20/25} = 30.0$ MPa | 95                                  | 60                                       | 80                                  | $d_{cut,nom} = 20,30$            |
| II          |          | 75                                  | 40                                       | 80                                  | $d_{cut,nom} = 20,30$            |
| III         |          | 85                                  | 60                                       | 40                                  | $d_{cut,nom} = 20,30$            |
| IV          |          | 75                                  | 40                                       | 40                                  | $d_{cut,nom} = 20,30$            |

Correlation coefficient is a measure of the correlation between one of the variables and the other variables treated together. It is experimentally assumed that the research data have a normal distribution (Figure 3).

![Normal distribution curve](image)
The probability of the value of a random variable with normal distribution is in the range \((\mu - \sigma x, \mu + \sigma x)\) and is 0.682. The double-wide range corresponds to a confidence level of 0.954 and a compartment three times greater 0.997 [8, 9].

The correlation coefficient \((r)\) describes the relationship between data \(x\) and \(y\), which maps \(x\) in \(y\) without the occurrence of any residue (error). The tightness of the relationship between data is less important than the information whether a given relationship is statistically significant. Otherwise, the obtained value is more a result of error than the real dependence.

3. Results and discussions
Initial results of mean ultimate loads obtained for ring and sleeve anchors M12 are presented in Figure 4 to Figure 6.

![Figure 4. Mean ultimate load in a test for concrete non-cracked C20/25 for M12 ring anchor](image-url)
On the basis of the conducted tests, additional correction factors were determined to estimate the design resistance to peeling from concrete substrates of class C20/25 using calculation formulas. Certain correction factors for estimation of new pull-out resistance are shown in Figure 7 to 8 and Table 3, depending on the tests combination determining the pull-out resistance of steel anchors.

**Figure 5.** Mean ultimate load in a test for concrete non-cracked C20/25 for M12 sleeve anchor

**Figure 6.** Mean ultimate load in a test for concrete cracked C20/25 for M12 sleeve anchor
Figure 7. Correction factors for estimating the pull-out resistance for non-cracked concrete substrates of class C20/25 for M12 ring anchors

Figure 8. Correction factors for estimating the pull-out resistance for non-cracked concrete substrates of class C20/25 for M12 sleeve anchors

Table 3. Correlation coefficients of steel expansion joints for pull-out concrete substrates of class C20/25, from the combination of assembly parameters of anchors

| Anchor     | Combination I | Combination II | Combination III | Combination IV |
|------------|---------------|----------------|-----------------|----------------|
| ring/sleeve| 1,00          | 0,99           | 0,87            | 0,95           |

Based on laboratory tests determining pull-out strength of ring sleeve anchors in C20/25 concrete as well as comparative analysis of the values, it can be concluded that:
assembly parameters affect the bearing resistance of the fasteners,
high pull-out resistance for steel sleeve and ring anchors, obtained at the first test combination regarding the anchorage depth and the set tightening / installation torque,
to estimate the lifting resistance for concrete substrates M12 ring anchors, it is proposed to apply the determined correction factors for the third combination,
all determined on the basis of resistance pull-out tests are higher or equal to the load capacity determined on the basis of the CCFM calculation method,
the deadweight specified for the tests combinations II and III are at a similar numerical level,
there was a decrease of the load-bearing resistance for pull-out steel anchors by about 48%, depending on the assembly parameters of the combination I, for extreme changes in assembly parameters,
• decrease of the load resistance by about 35% was found for combinations II and III, depending on the assembly parameters of the combination I.

4. Conclusions
The article presents own experimental tests and load resistance analyses of steel anchors providing new, significant data on the behavior of steel ring, sleeve anchors in C20 / 25 class concrete substrates, depending on the assembly parameters. A reference to the determined average load-bearing resistance for pull-out steel anchors was the calculation methods for the load resistance of the anchors. The own tests of steel anchors were carried out in accordance with the applicable test principles. Steel ring and sleeve anchors were used in construction for structural fasteners the most commonly. The tests carried out together with the analyses clearly indicate a statistically significant influence of the assembly parameters on the average pull-out resistances for concrete substrates of the C20/25 classes. Based on the conducted tests, there was a decrease in lifting resistance, steel anchors subjected to change of assembly parameters, in comparison with fixtures in reference concrete (combination I). Correlations of the above relationships in all cases were above 0.87, with a confidence level p less than 0.05.

References
[1] D. Dudek, ”Influence of cyclic loading on pull-out strength of expansion anchors in cracked concrete,” ITB PhD thesis, 2017.
[2] PN-EN 1992-4:2018-11, “Design of concrete structures. Design of fastenings for use in concrete”, Eurokod 2, 2018.
[3] ETAG 001, “Metal anchors for use in concrete”, EOTA Annex C, 2013.
[4] Fib Model, “Code for Concrete Structures”, Ernst&Sohn, 2013.
[5] T. Prepartner T, J. Asmus, R. Eligehausen, “Behavior of bonded expansion anchors in cracked and non-cracked concrete,” Beton und Stahlbetonbau, 2008.
[6] T. Pregartner, “Bemessung von Befestigungen in Beton. Einführung mit Beispielen”, Ernst&Sohn, 2009.
[7] R. Eligehausen, R. Mallee, J. Silva, “Anchorage in concrete construction”, Ernst&Sohn, 2006
[8] J. Jóźwiak, J. Podgórski, “Statistics from scratch,” State Economic Publishing House, 1994.
[9] J. Greń, ” Models and tasks of mathematical statistics,” PWN, 1968.