Local strengthening of anchorages with post-installed (supplementary) reinforcement

N Vita, A Sharma and J Hofmann

Institute of Construction Materials, University of Stuttgart, Pfaffenwaldring 4, 70569 Stuttgart

norbert.vita@iwb.uni-stuttgart.de

Abstract. The existing anchorages in reinforced concrete structures may need strengthening due to an increase in the applied load during its lifetime. In certain cases, due to limited dimensions of the structural member (e.g. concrete slab or beam), the size of the anchorages that can be used is also limited and the standard design of anchorages may not be enough to provide required load-carrying capacity. In these above-mentioned cases, a method to strengthen the anchorage may be needed. In the present work, it is attempted to develop a method for strengthening of anchorages under tension loads by using post-installed reinforcing bars. Tests were performed on anchorages using bonded anchors (single anchors) without and with different configurations of post-installed reinforcement for strengthening. The main objectives were to investigate the influence of the reinforcement arrangement on the ultimate load capacity and on the load-displacement behavior of the anchorages. The bonded anchors were selected considering the ease of installation and freedom to choose the test parameters. The tests were performed on anchorages away from the edge. The test parameters were determined in a way that in the case of reference tests, concrete breakout was the dominant failure mode. The reinforcement was placed relatively close (with a distance of approx. 0.4·hef) to the anchor. The results clearly show that the post-installed reinforcement can result in a considerable increase in the load and deformation capacity of the anchorage. Depending on the amount and arrangement of the reinforcement, a change in the failure mode from concrete cone breakout to strut-failure could be observed. It was also shown that for the same amount of reinforcement provided, the arrangement of the reinforcement had a considerable influence on the effectiveness of the strengthening. To understand the mechanics better, in certain tests, strain gauges were applied on the reinforcing bars, which showed the interaction between the contribution of concrete and that of reinforcement in resisting the applied loads.

1. Introduction

For the design of anchorages, e.g. according to EN1992-4 [1] or ETAG 001 [2-4], different failure types are calculated separately and the smallest value of the calculated resistances is deciding for the anchorage and is valid for the complete service life of the fastening. However, for various reasons, the load to be resisted by the anchorage might increase during its lifetime. In such cases, the fixing must be recalculated and, if possible, replaced.

For cast-in as well as post-installed anchors subjected to tension loads, concrete cone breakout often leads to the minimum resistance. For new designs, the concrete cone resistance can be increased either by increasing the concrete strength (base material) or by increasing the effective embedment depth of
the anchors [5]. Another way of increasing the tension resistance of an anchorage is by providing supplementary reinforcement also known as anchor reinforcement (Berger, 2015 [6]; Sharma et al., 2017 [7-8]). In such cases, once the concrete cone crack intercepts the supplementary reinforcement, the reinforcement takes up the tension forces, while the compression is transferred by a network of concrete struts (figure 1). The effectiveness of supplementary reinforcement in increasing the resistance of the anchorages have been shown by various researchers in the past (Berger, 2015 [6]; Sharma et al., 2017 [7-8], Schmid, 2010 [9], Infaso, 2012 [10]). However, rather limited information is available on increasing the resistance to concrete breakout for an existing anchorage.

![Strut-and-tie mechanism for load transfer in case of anchorages with supplementary reinforcement (EN1992-4 [1]).](image)

Weber (2012) [11] attempted to increase the tension load-bearing capacity of headed studs, by using post-installed reinforcement bars as supplementary reinforcement. In the tests, an increase in the resistance of approx. 30% to 70% compared to plain concrete was achieved.

For the first time, in this work, the authors have attempted to perform the strengthening of post-installed anchors (bonded anchors) with post-installed reinforcement. Tests were performed on anchorages using bonded anchors (single anchors) without and with different configurations of post-installed reinforcement for strengthening. The main objectives were to investigate the influence of the reinforcement arrangement on the ultimate load capacity and on the load-displacement behavior of the anchorages. The bonded anchors were selected considering the ease of installation and freedom to choose the test parameters. The tests were performed on anchorages away from the edge. The test parameters were determined in a way that in the case of reference tests, concrete breakout was the dominant failure mode. This paper discusses the details of the test program as well as detailed evaluation of the tests results.

2. Experimental investigations

2.1. Overview

In this study, tension tests on single anchors (bonded anchors) without and with post-installed supplementary reinforcement were carried out in normal strength concrete to study the influence of post-installed reinforcement on the load-bearing capacity and behavior of anchorages in case of concrete cone failure. For the bonded anchors as well as for the post-installed reinforcement, a high strength epoxy-based injection system from the company Fischer (FIS EM Plus) was chosen. The test parameters were selected in such a way that in the reference tests concrete cone breakout would be the dominant failure mode. The test program was designed to investigate the influence of the number, area and arrangement of the post-installed reinforcement.
2.2. Test specimen
The pull-out tests were carried out in normal strength concrete with a grade of C20/25. Unreinforced concrete slabs with a dimension of 190/190/40 L/B/H [cm] were used. The average cubic compressive strength of concrete at the time of the tests was between 33 N/mm² and 36 N/mm².

2.3. Anchor system and installation
For the installation of individual anchors for the tensile tests without and with post-installed reinforcement, an injection mortar (FIS EM Plus from company fischer) was selected which is also suitable (approved) for post-installed reinforcement bars. The injection mortar has a relatively high mean bond strength (~35 MPa), which helps preventing the pull-out failure. Threaded rods of size M24 and with a steel grade of 8.8 were used for the bonded anchors. For the post-installed reinforcement, ribbed reinforcing steel with a characteristic yield point of 500 MPa was used. The installation of bonded anchors, as well as the post-installed reinforcement, was carried out according to the manufacturer's specifications. The schematic of a typical installation of bonded anchors with post-installed reinforcement is shown in figure 2.

Two different paths were investigated for the installation process of single anchors. The first method involves drilling, cleaning, injecting the mortar and installing the threaded rod and reinforcing bar in a single work step (Example, see figure 2). After curing of both the anchor and the reinforcement, the tension tests were carried out. This method results in saving of time for the tests and could be used for new anchors that have not yet been loaded. However, in cases where anchors had already been installed and loaded, the possibility of strengthening with post-installed reinforcement should be investigated. Therefore, in the second method, only the bonded anchor was installed in the first step. After complete curing, they were loaded with the 5%-fractile (characteristic) value of the concrete breakout load resulting from the reference tests. For strengthening, the anchors were first unloaded. After unloading the bonded anchor, the reinforcement bars were installed, i.e. drilled, cleaned, injected and set (see figure 3). After curing of the reinforcement bars, the pull-out tests were carried out. A detailed comparison of the different installation methods can be found in table 1.

To obtain the information about the load distribution among the reinforcement and concrete, in a few tests, strain gauges were installed on the reinforcement bars before setting them in. The strain gauges were installed at the locations where the theoretical concrete cone crack should meet the rebar under test.

| Steps | Method 1 - „new“ Anchor | Method 2 - „existing“ Anchor |
|-------|-------------------------|-----------------------------|
| 1     | Drilling holes for anchor and reinforcement | Drilling the hole for anchor |
| 2     | Cleaning holes for anchor and reinforcement | Cleaning of anchor hole |
| 3     | Installation of anchors and Rebars | Installation of the anchor |
| 4     | Waiting for curing (all elements) | Waiting for curing (only Anchor) |
2.4. Test program
Unconfined tension tests were carried out on individual anchor without and with post-installed reinforced bars with various arrangements. The diameters of the reinforcement (d=8 mm and d=12 mm) and the number of the reinforcement bars (n=1, 2, 4, 6) were varied, which resulted in different total cross-sectional area of the reinforcement \((A_s=50, 101, 113, 226, 452, 679 \text{ mm}^2)\). The effective embedment depth of the anchors was kept as \(h_{ef}=100 \text{ mm}\) or \(h_{ef}=140 \text{ mm}\). All the tests were performed without edge influence, with an edge distance of more than the critical edge distance \((c>c_{cr,N})\). The distance between the threaded rod (bonded anchor) and the post-installed reinforcement was maintained as \(a=50 \text{ mm}\) for all series. In one series, the influence of a preload on the bonded anchor (according to the installation method 2 given in table 1) was investigated. The test program is summarized in table 2. In principle, two tests per series were made.

### Table 2. Test Program with details of Anchors and Reinforcement.

| Serie No. | ANCHOR  | REINFORCEMENT |
|-----------|---------|---------------|
|           | Geometry| Pre-load | Diam. | Number | Area  | Distance | Remarks       |
|           | Size    | h_{ef}   | [mm]  | [mm]   | [mm^2] | [mm]     |               |
| S1.1      | Single  | M24      | 100   | No     | -     | -        | Reference series |
| S1.2      | Single  | M24      | 100   | No     | 12    | 2        | 226 50 210     |
| S1.3      | Single  | M24      | 100   | Yes    | 12    | 2        | 226 50 210     |
| S2.1      | Single  | M24      | 140   | No     | -     | -        | Reference series |
| S2.2      | Single  | M24      | 140   | No     | 8     | 1        | 50 50 315      |
| S2.3      | Single  | M24      | 140   | No     | 8     | 2        | 101 50 315     |
| S2.4      | Single  | M24      | 140   | No     | 12    | 1        | 113 50 315     |
| S2.5      | Single  | M24      | 140   | No     | 12    | 2        | 226 50 315     |
| S2.6      | Single  | M24      | 140   | No     | 12    | 4        | 452 50 315     |
| S2.7      | Single  | M24      | 140   | No     | 12    | 6        | 679 50 315     |

2.5. Test setup
The tension tests were carried out in accordance with the ETAG 001, Annex A [3]. The test setups used for tension on the single anchors are shown in figure 4. This consisted of a tension rig with wide support \((\geq 4 \times h_{ef})\), calotte, load cell, hydraulic cylinder, fixture plate and displacement transducers. According to the expected load, the load ranges of the calibrated load cell and the hydraulic cylinder were chosen. The applied load, the anchor displacements and the strains in the post-installed rebars (for tests with strain gauges) were recorded at a frequency of 5 Hz by using the commercial data acquisition software DiAdem. The peak loads were reached within 1 to 3 minutes.
3. Test results

3.1. Overview
This section presents the results of the tests performed according to the test series given in table 2. For clarity and ease of visualization, the load-displacement curves of similar series (e.g. single anchors with d_s=8 mm reinforcement) as well as the reference tests without any reinforcement are presented and discussed in the same graph. Besides, the failure patterns of all series are shown to identify different failure mechanisms. The results of the pull-out tests are summarized in table 3 in terms of the ultimate load obtained by individual tests, the mean failure load for the test series and the ratio of the mean load carrying capacity for a test series to the mean load carrying capacity of the corresponding reference series without supplementary reinforcement (Series S1.1 and S2.1). As seen from table 3 due to the introduction of post-installed supplementary reinforcement, a significant increase in the load carrying capacity of the anchorages could be achieved, with the highest increase of more than 100% in case of series S2.7 (single anchor with 6 bars of 12 mm diameter). Also, comparing the results of series S1.2 and S1.3, it can be seen that the influence of pre-loading on the anchor prior to the installation of supplementary reinforcement is nominal. This is discussed further in the following section.

Table 3. Test Results.

| Serie No. | ANCHOR REINFORCEMENT | Ultimate load of indiv. tests N_u,i [kN] | Mean failure load N_u,m [kN] | Relative increase in load capacity N_u/m/N_u,m,Ref. [ ] | Remarks |
|-----------|-----------------------|---------------------------------------|-----------------------------|------------------------------------------------------|---------|
| S1.1      | M24 100 - - -          | 82,0/82,9                             | 82,5                        | -                                                    | Reference series |
| S1.2      | M24 100 12 2 226       | 160,4/156,8                           | 158,6                       | 1,92                                                 |                     |
| S1.3      | M24 100 12 2 226       | 156,6/146,2                           | 151,4                       | 1,84                                                 | with pre-loading   |
| S2.1      | M24 140 - - -          | 123,3/129,3                           | 126,3                       | -                                                    | Reference series |
| S2.2      | M24 140 8 1 50         | 144,6/147,1                           | 145,9                       | 1,15                                                 |                     |
| S2.3      | M24 140 8 2 101        | 173,1/180,4                           | 176,8                       | 1,40                                                 |                     |
| S2.4      | M24 140 12 1 113       | 181,2/184,6                           | 182,9                       | 1,45                                                 |                     |
| S2.5      | M24 140 12 2 226       | 219,6/238,2                           | 228,9                       | 1,81                                                 | *w. strain gauge   |
| S2.6      | M24 140 12 4 452       | 245,7/230,9                           | 238,3                       | 1,89                                                 |                     |
| S2.7      | M24 140 12 6 679       | 272,8/263,6                           | 268,2                       | 2,12                                                 |                     |

Figure 4. Test setup with details.
3.2. Tests on anchorages under tension load

3.2.1. Single Anchor with pre-loading and with post-installed reinforcement, $d_s=12$ mm. In the preliminary test series, the influence of a possible preloading of the bonded anchor was investigated. For this purpose two test series with the same parameters (2xd12 with distance $a=50$ mm) and a reference test without reinforcement were conducted. In the case of the Series without pre-loading (series S1.2), the bonded anchors and rebars were installed in one work step, as shown in table 1. For the series with pre-loading (series S1.3), the tests were prepared according to Method 2, with the pre-loading being 5%-fractile value of the reference tests (approx. $0.75 \cdot N_{u,m,\text{Reference}}$). The reference tests were performed by simply installing and testing the anchors after observing the required curing time.

![Figure 5. Load-displacement curves from tension tests on single anchor without and with post-install rebars, $d_s=12$ mm.](image)

For comparison, all load-displacement curves of the three series are shown figure 5. The mean failure load was $82.5; 158.6; 151.4$ kN for series S1.1 (Reference), S1.2 (without pre-load) and S1.3 (with pre-load), respectively. Comparing the initial stiffness of series S1.1 and S1.2 shows indicates that the presence of reinforcement does not influence the initial stiffness of the anchorage. This is understandable since the reinforcement gets activated only after the concrete cone crack intercepts the reinforcing bars. However in the series S1.3, where the tests were performed after the application of preload and subsequent unloading, the initial stiffness becomes slightly smaller, which can be attributed to the initiation of local damage in the concrete due to the applied pre-load. Nevertheless, there is only a marginal difference in the load-displacement behavior, failure loads as well as the failure modes (see figure 6) observed for series S1.2 and S1.3. Not only the load-carrying capacity but also the displacement behavior of the anchorages was significantly improved due to the introduction of the post-installed supplementary reinforcement. The typical failure modes are shown in figure 6. While in the a) reference test the typical concrete cone breakout can be seen, in both series with reinforcement the concrete breakout was found to be impeded by the reinforcement.
Figure 6. Typical failure mode obtained from the tension tests on anchor without and with post-installed rebar, ds=12 mm.

3.2.2. Single Anchor with post-installed reinforcement, ds=8 mm. Figure 7 presents the load-displacement curves for the anchorages with ds=8 mm post-installed reinforcement with 1x (Series S2.2) and 2x (Series S2.3) rebars, as well as the reference-curves (Series S2.1). The mean value of the failure load for the tests performed in plain concrete (series S2.1), Reinforcement with 1xd8 rebar (series S2.2) and 2xd8 rebars (series S2.3) was 126,3; 145,9; 176,8 kN, respectively. This shows that even a relatively small amount of supplementary reinforcement results in a significant increase in the load carrying capacity of the anchorage. The relative increase in the load carrying capacity (1.15 times for S2.2 and 1.40 times for S2.3) is not linearly proportional to the cross-sectional area of the supplementary reinforcement. This might be due to the fact that the presence of reinforcement only on one side of the anchor results in an unsymmetric behaviour of the system after the concrete cone crack intercepts the rebar, which results in an unstable strut formation. With the reinforcement placed symmetrically on both sides of the anchor, a stable strut formation takes place and the supplementary reinforcement contributes more efficiently to the load-resisting mechanism. Figure 8 shows the typical failure patterns of these series.

Figure 7. Load-displacement curves from tension tests on single anchor without and with post-inst. rebars, ds=8 mm.
3.2.3. Single Anchor with post-installed reinforcement, \( d_s = 12 \) mm. The test results, load-displacement curves of the series with different number \( (n=1, 2, 4, 6) \) of the rebars \( d_s = 12 \) mm (Series S2.4 to S2.7) and the reference-curves (Series S2.1) are shown in Figure 9. For simple illustration the conditions of the Series, the pictograms in Figure 9 symbolize the different arrangement of the reinforcement bars, which also refers to the different amount of the reinforcement (see table 3). The results with 12 mm diameter rebars show similar behavior to the results with 8 mm diameter rebars, which in this case is much more significant. Not only the failure load, but the displacement at the failure load and thus the ductility of the anchorages are influenced positively, if the reinforcement quantity is increased. The initial stiffness of the load-displacement curves is quite identical with the series with and without reinforcement, due to the aforementioned reasons. The average failure loads of the Series with post-installed supplementary reinforcement depending on the number of bars (S2.4=1x, S2.5=2x, S2.6=4x, S2.7=6x bars), were as follows: 182.9; 228.9; 238.3; 268.2 kN respectively, and for the reference series 126.3 kN. In case of the Series S2.7, an increase of more than 100% in the load capacity can be observed. However, this relative increase in the load carrying capacity is again not proportional to the amount of reinforcement. The reason for this is not only the asymmetrical/symmetrical arrangement of the rebars, but also the fact that from a certain amount of reinforcement the failure type changes to the so-called strut failure. Consequently, the maximum achievable increase in the load carrying capacity is limited by the strut failure [6, 7]. The change in the mode of failure can also be seen in the typical failure pictures of these series in figure 10.
3.3. Evaluation of the test results

In certain tests on bonded anchors with post-installed supplementary reinforcement, strain gauges were installed on the post-installed reinforcing bars in order to measure the strains, generated in the reinforcement. The strain gauges were installed on the place of the rebars, where the theoretical crack should intersect the reinforcement during the tests. Two strain gauges were installed on each
reinforcement bar. The strain induced in the reinforcement, measured by the strain gauges, was converted into stresses assuming perfect elastic-plastic behaviour (yield point 550 MPa) of the steel. By multiplying these stresses with the reinforcement area, tensile forces generated in the reinforcement could be calculated. The calculated tensile forces in the reinforcement were deducted from the total applied force to determine the contribution of the concrete.

Figure 11. Segregated contributions of concrete and reinforcement in carrying the total tension force in case of tests performed on bonded anchor M24 with 2xd12 reinforcement under tension load.

Figure 11 plots the total anchor force (orange line), the tensile forces in the two d=12 mm rebars (dark and light blue) and the calculated contribution for concrete (grey line), as a function of the anchor displacement tested under tension load (Series S2.5, Test 1). At the beginning of the test, at relatively small anchor forces, the reinforcement takes up negligible forces, i.e., the curve of total anchor forces and the curve of the force carried by concrete are identical. This is due to the fact that the reinforcing is only activated after the concrete has cracked. When the contribution of concrete reaches almost the value of the failure load without reinforcing (Reference-tests), the reinforcement begins to increase the load significantly and the contribution of concrete decreases. In this case (S2.5-2xd12 rebar), at the peak load, the reinforcing bar has not reached the yield point, but in case of the Series with low amount (for example 1xd12 rebar) of post-installed supplementary reinforcement, at the peak load, the reinforcing bars have yielded.

Furthermore, when the peak load is reached, it is clearly shown that a high percentage of the anchor load still can be taken up by the concrete. This load-bearing behaviour was also observed and reported in the work of Berger [6] and Sharma et al. [7-8] for cast-in headed studs with supplementary reinforcement.

4. Conclusions
In this study, the influence of post-installed reinforcement for the concrete cone capacity of post-installed anchorages was investigated for the first time in non-cracked normal concrete. The test program included pull-out tests on single anchors without (as reference) and with post-installed reinforcement nearly to the anchorages, as a supplementary reinforcement.

The test results show clearly, that post-installed rebars installed close to the anchorages (in this work using bonded anchor) increases significantly not only the load-bearing capacity of the anchorages in
tension, but also the displacement at the peak load. In case of relatively small amount of reinforcement yielding the reinforcement was observed as the failure mode, which shows a significantly more ductile displacement behaviour. By increasing the amount of the reinforcement, the load may be increased further, however up to a certain limit. This limitation consists of the failure of the concrete, the strut failure, which was observed in the works of Berger [6] and Sharma et al [7, 8]. Furthermore, the evaluation of the tests with strain gauges showed that when reaching the peak load, not only the reinforcement supports the load, but a part is absorbed by the concrete. The same load-bearing behaviour was determined at Berger [6] and Sharma et al. [7, 8] for cast-in supplementary reinforcement.

By comparing the results of the tests on unloaded and preloaded bonded anchors strengthened with post-installed reinforcement, it could be concluded that this method will work for newly installed anchors as well as for existing anchors (with possible pre-damage of the concrete). In addition, it has to be taken into account that this study focused only on the influence of the number, diameter and amount of the post-installed rebars. In all tests the distance between bonded anchors and rebars was constant and relatively small (50 mm). For this reason, future studies need to be performed with different distance to clarify the influence of this parameter and the effectiveness of the reinforcement in that case.

Acknowledgements
The test presented in this paper was supported by the fischer GmbH company.

References
[1] EN 1992-4 2015 Eurocode 2 Design of concrete structures – Part 4 Design of fastenings use in concrete European committee for standardization, CEN/TC 250, Brussels, FprEN 1992-4
[2] ETAG 001 2013 Guideline for European Technical Approval of Metal Anchors for Use in Concrete, Edition 1997, Part one: Anchors in general Brussels, EOTA, 2nd Amended April 2013
[3] ETAG 001 2013 Guideline for European Technical Approval of Metal Anchors for Use in Concrete, Edition 1997, Annex A: Details of tests Brussels, EOTA, 3rd Amended April 2013
[4] ETAG 001 2013 Guideline for European Technical Approval of Metal Anchors for Use in Concrete, Edition 1997, Part five: Bonded Anchors Brussels, EOTA, 3rd Amended April 2013
[5] Eligehausen R, Malle R, Silva J F 2006 Anchorages in Concrete Construction (Berlin: Ernst&Sohn)
[6] Berger 2015 Trag und Verschiebungsverhalten sowie Bemessung von Kopfbolzenankerungen mit und ohne Rückhängebewehrung unter Zuglast PhD Thesis, IWB
[7] Sharma A, Eligehausen R and Asmus J 2017 Experimental investigation of concrete edge failure of multiple-row anchorages with supplementary reinforcement Structural Concrete 18 153-163(a)
[8] Sharma A, Eligehausen R and Asmus J 2017 A new model for concrete edge failure of multiple row anchorages with supplementary reinforcement Reinforcement failure Structural Concrete 18 1-9(b)
[9] Schmid 2010 Tragverhalten und Bemessung von Befestigungen am Bauteilrand mit Rückhängebewehrung unter Querlasten rechtwinklig zum Rand PhD Thesis, IWB
[10] Kuhlmann U, Hofman J, Wald F, da Silva L, Krimpmann M and Sauerborn N et al. 2012 New market chances for steel structures by innovative fastening solutions between steel and concrete (INFASO) Final report, Report EUR 25100 EN, European Commission
[11] Weber 2012 Verstärkung mit eingemörtelten Bewehrungsstäben bei Kopfbolzenankerungen unter Zuglast Diploma thesis, IWB (not published)