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LOAD TRANSFER MECHANISM OF CONCRETE SCREWS

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Abstract. Even though the market and development for concrete screws has been increasingly rising in recent years, the load transfer mechanism of concrete screws has not yet been fully investigated. Therefore, different tests of concrete screws made of galvanized and stainless steel were performed in concrete C20/25 and C50/60. The main aim is to measure the strain along the embedment depth. This will be achieved by using strain gauges that get placed in a centrically drilled borehole through the concrete screw. To get a comparison to the mechanism of the screws the same process will be executed in threaded rods used as a part of bonded anchors. Due to the fact that the threaded cuts of concrete screws have geometrical similarities to bonded anchors, it was examined if the load transfer of both fasteners is related and may be compared. The results of the testing have shown that the load transfer mechanism of both fastener types is similar in low-strength concrete showing a concrete cone failure. In high strength concrete due to the mainly occurring steel failure the maximum measured strains at the maximum load step are not comparable. However, at lower load steps where the steel does not exceed the yield strength the results show a similar load transfer mechanism, too.

Keywords: Anchorage to concrete, concrete screw, deformation behaviour.

1. Introduction

In fastening technologies there are three basic principles of load transfer mechanisms: friction-based, bond-based and mechanical interlock-based load transfer. The load transfer mechanism of post-installed concrete screws is based on the principle of the mechanical interlock as shown in [1, 2]. Concrete screws typically consist of five different segments: the head, the shaft, the run-out of thread section, the main load-bearing section and the thread cutting section. To provide the form locking function, the specially hardened thread cutting section is liable for cutting the threads for the following ones into the base material. The research presented in this paper is based on the question of how the load transfer behaviour behaves from the tip of the concrete screw to the upper edge of the concrete. This has already partially been examined by Lechner et.al. [3] for concrete screws with a larger diameter used as retrofitting for shear force strengthening. Therefore, a hole was drilled through the concrete screws along the embedment depth. In this manufactured hole, strain gauges got placed in specified intervals to measure the strain along the screw during a defined load situation. Furthermore, to compare the load transfer mechanism of concrete screws with bonded anchors, the same process was done for threaded rods that get placed in the borehole with an injection mortar.

1.1. Scope

In the European Assessment Document EAD 330232-00-0601 - "Metal Anchors for use in Concrete" [4], concrete screws have different segments with specified tasks, see Figure 1. The head (1) for transferring the load into the thread sections. The shaft (2) is for attaching components. It is dimensioned that it can be completely sunk into the borehole. The runout area where the thickness of the thread is running out to zero. The main load bearing section (4) is supposed to bear the main load into the base material and the thread cutting section (5) cuts the threads into the base material. So, every section has its specific task, however the detailed load transfer behaviour is not fully examined yet. It is assumed that the load transfer mechanism is similar to them from bonded anchors because both systems are transferring the loads into the basement almost over the entire embedment depth. The tests of the concrete screws presented in this contribution have been performed with an unconfined setup for an unrestricted concrete cone failure according to Technical Report TR 048 "Details of tests for post-installed fasteners in concrete", [6]. This paper wants to provide a look into the segments of a concrete screw and their reaction with an applied load.

1.2. Load transfer mechanism of concrete screws and bonded anchors

The mechanical interlock principle is providing the load transfer between the fastener and the base material. This principle is used by different fastener systems, for example drop in anchors, headed anchors, undercut anchors, concrete screws and any type of

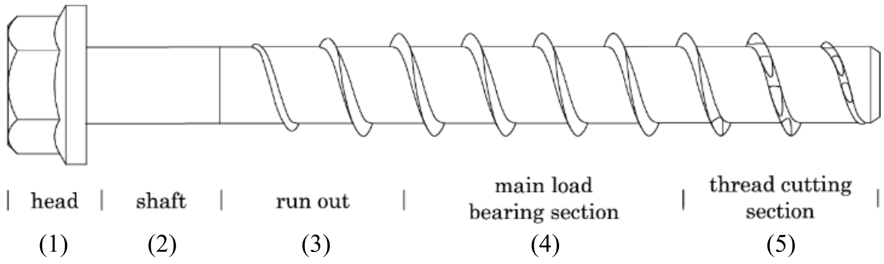

FIGURE 1. Sections of a concrete screw; modified according to [4].

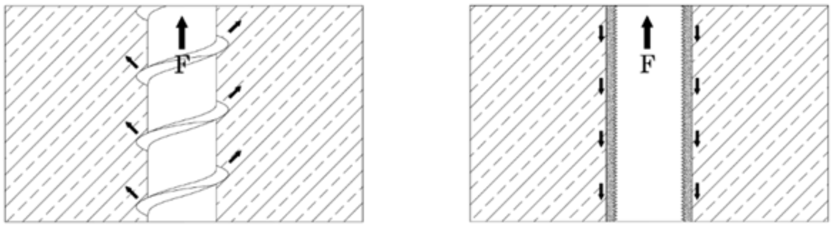

FIGURE 2. Load transfer mechanism of concrete screws (left) and bonded anchors (right) based on the approach of [5].

cast-in anchorages. Concrete screws in general are cutting the thread in the concrete through the hardened thread cutting section. Figure 1 shows a main load-bearing section ((4) in Figure 1) in which the main load is supposed to be transferred into the base material. Furthermore, it is estimated that every single helix is contributing to the load transfer because all threads are fixed in the concrete. However, it is still not completely clear how much each thread is included in the load transfer mechanism. The question is which threads are contributing more to the load transfer into the base material. The strains of the two concrete screw types and the bonded anchor may differ from each other because of different material characteristics like E-Modul, yield strength, tensile strength and fracture strain. The mechanical and the chemical interlocking principle are depicted in Figure 2 schematically based on the approach given in [5]. The left picture in Figure 2 shows the concrete screw interlocked in the base material loaded with a force and transferring the load through the threads. The picture on the right shows the bonded anchor and the theoretical load transfer through the bond stress.

The failure modes are well described in the relevant literature [1, 7]. Two of the failure modes for mechanical post-installed fasteners are concrete cone failure or combined failure. In this research there have been used single concrete screws with a nominal embedment depth of $h_{nom} = 85\,\text{mm}$ and an effective embedment depth of $h_{ef} = 68\,\text{mm}$. The calculation for the design situation of a single concrete screw follows the concrete capacity design (CCD) approach [8] where the ultimate strength of the anchor is mostly based on the square root of the concrete compressive strength and the embedment depth to the power of 1,5 [7, 9]. The load transfer mechanism of bonded anchors is working with chemical interlock. The different types of bond systems and how to work with them are well described in [1, 7]. The effective embedment depth of the bonded anchors has been $h_{ef} = h_{nom} = 85\,\text{mm}$ in this research. The main bond models are the uniform bond model and the elastic bond model [7]. The uniform bond model is mainly dependent on the strength of the anchor (the anchor itself and the injection mortar), the embedment depth and the diameter [7]. It assumes a constant stress distribution along the embedment depth. If the bond stress surpasses the bond strength, then failure occurs. For high loads and strength design methods this model is more appropriate than the elastic bond model [7]. The bond stress τ can be derived by testing based on the following equation.

$$N_u = \tau \cdot \pi \cdot d \cdot h_{ef} \tag{1}$$

where

- $N_u \ldots$ ultimate strength of the anchor,
- $\tau \ldots$ bond stress,
- $d \ldots$ diameter of the fastener,
- $h_{ef} \ldots$ effective embedment depth.

Cook et. al. [7] showed that for low loads the elastic bond model is more appropriate than the uniform bond model to describe the anchor behaviour. A finite element analysis made by McVay, Cook and Krishnamurthy [10] also showed that bonded anchors following the elastic bond model at low load levels and the uniform bond model at peak loads. Following calculation can be made based on these results.

$$N_u = \tau \cdot \pi \cdot d_0 \left[\frac{\tanh(\lambda \cdot h_{ef})}{\lambda}\right] \tag{2}$$

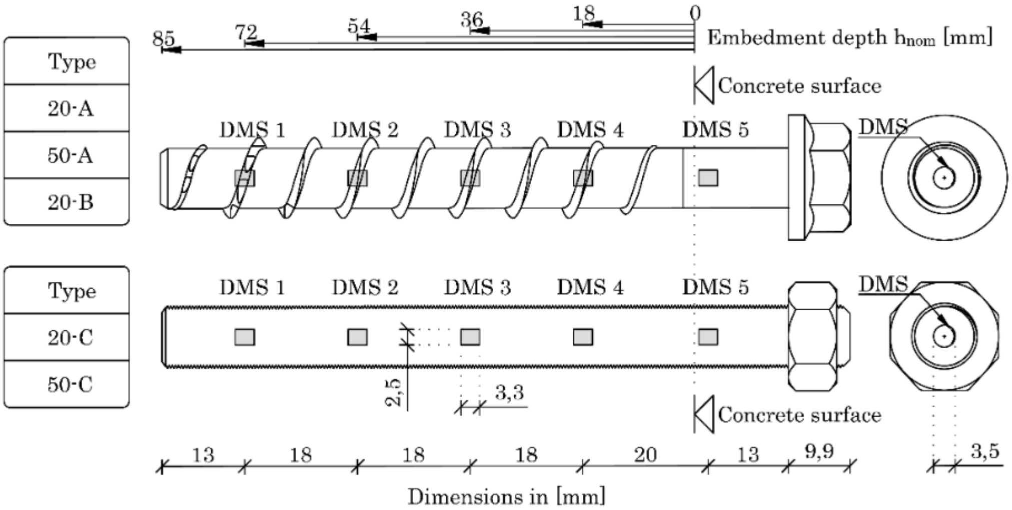

Figure 3. Test samples and position of the strain gauges.

Type	Concrete strength	n	Test samples
20−A	C20/25	5	Galvanized steel concrete screw
20−B		3	Stainless steel concrete screw
20−C		3	Threaded rod 10.9
50−A	C50/60	5	Galvanized steel concrete screw
50−C		3	Threaded rod 10.9

Table 1. Overview of the testing program.

where

- d_0 ... diameter of the borehole,
- λ ... stiffness characteristic of the bond anchor system.

Davis and Cook showed with a finite element analysis of an elastic model that the behaviour of a bonded anchor with a low short term load has a stress distribution relationship like an hyperbolic tangent curve [4]. This hyperbolic tangent curve approaches a distribution of the bond stress like the uniform bond model as the load is increasing or the duration of the test increases at a specific load level [11]. The load transfer behaviour of the bonded anchors that was found in this research seems to reflect the behaviour of the elastic model also approaching a hyperbolic tangent curve. The load transfer principle and the calculation approaches are different from form-locking systems like concrete screws. However, through the threads along the screw it is assumed that bonded threaded rods have a similar bearing behaviour like concrete screws.

1.3. Tested concretes

The tests shown within this contribution have been performed in non-cracked concretes of strength classes of C20/25 and C50/60 from the same supplier, with a concrete compressive strength measured at cubes of $f_{c,cube} = 29,4\,\mathrm{N/mm^2}$ for the C20/25 and $f_{c,cube} = 68,2\,\mathrm{N/mm^2}$ for the C50/60 at time of testing. The maximum aggregate size (round aggregate) was defined by $d_g = 16\,\mathrm{mm}$ following the grading curve given in TR 048 [8] which is based on DIN 1045-2 [5]. The resistance to fragmentation of the aggregates is at a Los Angeles abrasion value of 28 and an impact value of 21 for the considered low strength concrete, according to [12].

2. Test program and description

2.1. General

In standard pull-out tests the result is usually force-displacement relationship. But there is a lack of information about the behaviour of the screw segments along the whole anchoring depth and to what extent they are involved in the load transfer process. This paper aims to examine how the load transfer behaves and makes a comparison to the behaviour of bonded anchors. In order to make this behaviour visible, the strains along the concrete screws and the bonded anchors are measured by means of strain gauges. To develop the test rig, a centrically arranged hole with a diameter of 3,5 mm has been drilled through the concrete screw. The strain gauges (short called DMS) are placed in the borehole through the testing samples as shown in Figure 3.

Table 1 shows the test program and the test samples. Therefore, the testing program consist of five centrically drilled concrete screws made from galvanized steel, three centrically drilled concrete screws

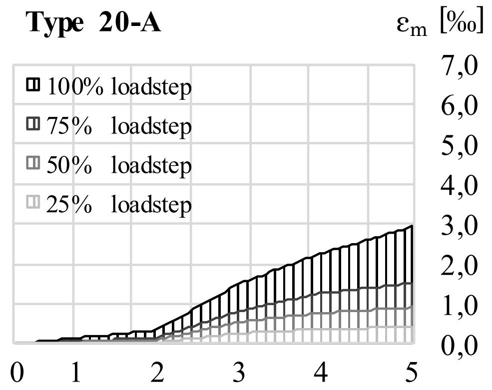

FIGURE 4. Type 20−A ε_m[‰] in 25 % loadsteps with concrete screws made of galvanized steel in C20/25; [$n = 5$].

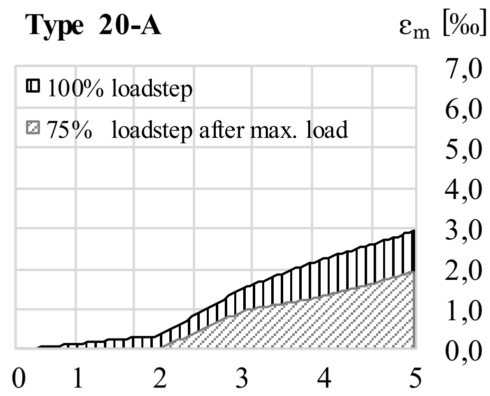

FIGURE 5. Type 20−A ε_m[‰] of 100 % and 75 % loadsteps after max load with concrete screws made of galvanized steel in C20/25; [$n = 5$].

made from stainless steel and three centrically drilled threaded rods with a steel strength of 10.9 in the concretes of C20/25 and C50/60. The measurements of the concrete screw are 9,4 mm for the core diameter, 12,5 mm for the total diameter including the thread and about 110 mm for the total length. The threaded rod has a nominal diameter of 10 mm. The exact value of the diameter for a M10 without the threads is 8,6 mm. The nominal embedment depth for all tests was set to 85 mm with $h_{nom} \approx 9d$ with a diameter $d = 9,4$ mm. For the hammer a medium drill bit size of the diameter was used. This means for the concrete screws $d_{cut} = 10,25\,\text{mm} - 10,35\,\text{mm}$ and for the bonded anchors $d_{cut} = 12,25\,\text{mm} - 13,25\,\text{mm}$. The used cement-based injection mortar has a nominal bond strength of 18 N/mm^2, the bonded anchors have been installed following the manufacturerťs product installation instruction.

The strength of the screws has been tested on samples out of the middle part of the cross section. The measured tensile strength of the galvanized concrete screws was 960 N/mm^2. Therefore, to provide aăgood comparison between concrete screws and bonded anchors, threaded rods of strength class 10.9 with a tensile strength of 1000 N/mm^2 have been chosen for the bond test sample. The screw made of stainless steel was chosen out of the same product line as the galvanized one, tests have shown that the tensile strength of the inner part is 780 N/mm^2.

3. EVALUATION OF THE TEST RESULTS

3.1. TEST RESULTS

In this section the results of the performed tests are provided. In the evaluation of the results, the measured strains of the 5 strain gauges are depicted. These strain curves are arranged in loadsteps of 25 % in the order of 25 %, 50 %, 75 % 100 %. For the type 20−A and 20−B a descending strain curve is depicted in Figure 5 and Figure 7. These are showing the strain at a load level of 75 % after the maximum load of 100 % was reached. The analysis is based on mean values of the measured data, not considering the scatter. For further results, see [13]. The scattering of the strain values is wide. Though, with an increasing distance from the tip to the head of the test samples the data shows more consistency as a result of lower scatter.

3.2. RESULTS OF THE CONCRETE SCREW MADE OF GALVANIZED STEEL IN CONCRETE C20/25

In this section the results of the tests of galvanized concrete screws in concrete C20/25 are provided (Type 20−A in Table 1). Figure 5 is showing the strain ε [‰]] along the embedment depth of the screw. On the left side, depicted are the strains in 25 % steps beginning with 25 % up to 100 % of the maximum load. The graph shown on the right is depicting the 100 % step and the 75 % step after the peak load of the fastener. The x−axis is providing the position of the strain gauges. For the positioning, see Figure 3. The maximum mean load ($n = 5$) is $F_m = 46,50$ kN with a CV = 9,08 %.

All fasteners in this test series failed with concrete cone failure. Each thread of the concrete screw seems to be included in the load transfer with a specific amount. Most of the load transfer appears to take place at positions 3 and 4, therefore, these measurements are consistent with the assumptions in Figure 1 that the main load is transferred into the base material at the "main load bearing section". Beginning with position 2, it can be stated that there is a linear increase in the strain up to the strain gauge at position 5.

3.3. RESULTS OF THE CONCRETE SCREW MADE OF STAINLESS STEEL IN CONCRETE C20/25

The strain of the concrete screw (Type 20-B) has higher values than that from the galvanized concrete screws (see the following graph shown in Figure 6).

At the same load level, the stainless steel screw stretches nearly double the size compared to the gal-

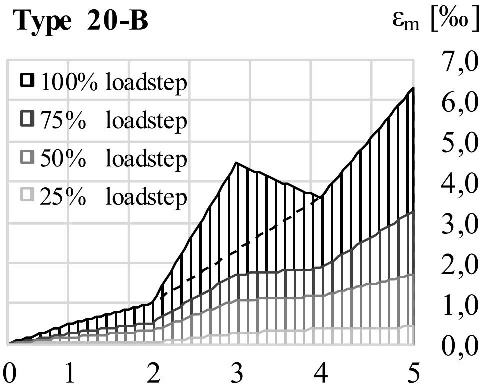

FIGURE 6. Type 20−B ε_m[‰] in 25 % loadsteps with concrete screws made of galvanized steel in C20/25; [$n = 3$].

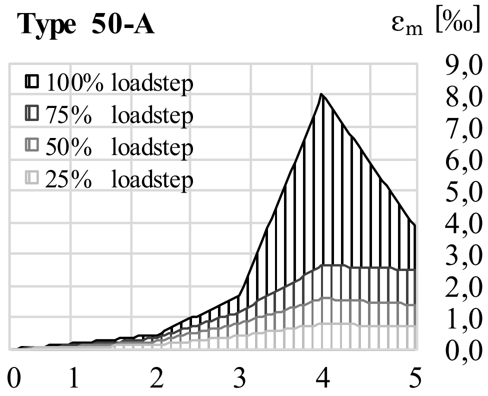

FIGURE 8. Type 50−A ε_m[‰] in 25 % loadsteps, galvanized concrete screw in C50/60; [$n = 5$].

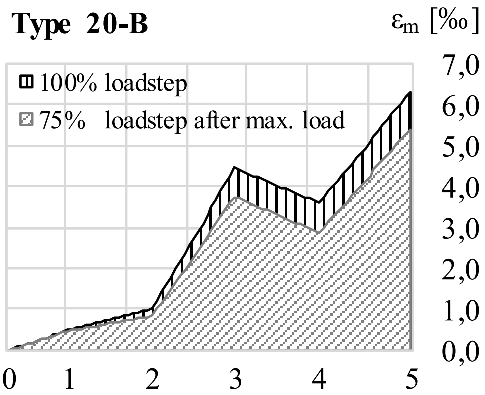

FIGURE 7. Type 20−B ε_m[‰] of 100 % and 75 % loadsteps after max load with concrete screws made of galvanized steel in C20/25; [$n = 3$].

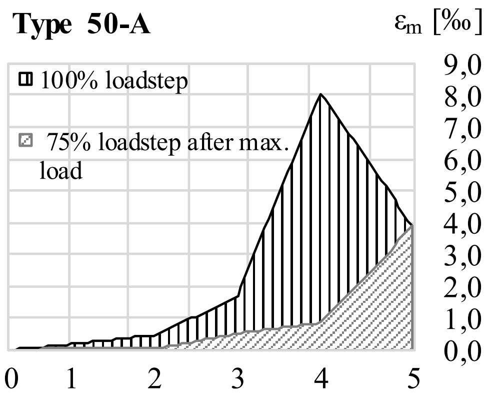

FIGURE 9. Type 50−A ε_m[‰] of 100 % and 75 % loadsteps after max load with concrete screws made of galvanized steel in C50/60; [$n = 5$].

vanized version. The maximum mean load at these tests is $F = 45,47$ kN with a CV = 9,83 %. Based on the characteristics of both steels, the higher strain of the stainless steel screw is a result of the higher fracture strain up to $\varepsilon_b = 40$ %. The failure mode of this test series was concrete cone failure too. Furthermore, the cutting tip failed in the middle of the thread cutting section in 2 out of 3 tests. The graph is showing a test sample $n = 3$ and after analyzing the data, the peak at position 3 is due to the result of one experiment at a loadstep of 100 %. The other tests show an almost linear behaviour (dotted line in Figure 7). With a higher number of tests, the strain curve could be harmonized (like the curves at Type 20-A).

3.4. Results of the concrete screw made of galvanized steel in concrete C50/60

The results of the concrete screw in a C50/60 concrete (Type 50-A) show that up to the 75 % loadstep the distribution of the measured strains have a similarity to the Type A tests in low strength concrete C20/25. The strain values are slightly higher, this may be caused due to a higher stiffness of the concrete. After the 75 % loadstep, 3 out of 5 tests failed due to steel failure of the concrete screw. The tensile force exceeded both, the yield strength and the tensile strength, which is the reason for the peak at position 4 in Figure 8. The screws with steel failure broke at position 4 with a maximum load of 58,33 kN with a CV = 5,26 %. The 75 % loadstep after the maximum load in the graph shown on the right are the strains of the screws with concrete cone failure ($n = 2$), which show also a similar behaviour as the tests in low strength concrete.

3.5. Comparison to the bond model

In this section the results of concrete screws made of galvanized steel and the bonded anchors with threaded rods steel class 10.9 in a concrete C20/25 will be compared. The values of the measured strains of the bonded anchors (Type 20-C) are higher than the strains at the galvanized concrete screw (Type 20-A), see Figure 10. But it turns out that the strain development over the embedment depth can be assumed as quite similar, as shown in Figure 10. Figure 10 is showing the strain curves of the Type 20A and 20-C tests compared at each 25 % loadstep. Up to thew 75 % loadstep the strain curves showing a similar behaviour (except the specific strain values

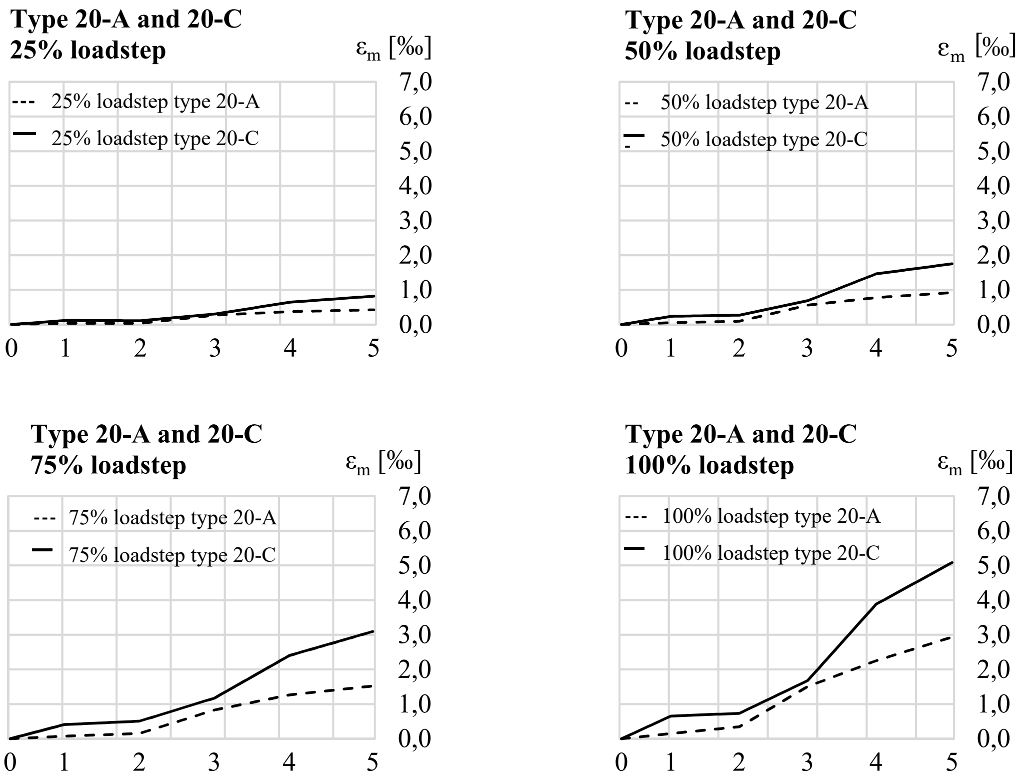

Figure 10. Comparison of ε_m[‰] each 25 % of galvanized concrete screws (denominated as type 20-A) and bonded anchors (type 20-C).

at positions 4 and 5). At the maximum load (the 100 % loadstep), shortly before the fasteners failed the strain curves of the 20-A and 20-C types differ from each other. But there are two different failure modes developing. The bonded anchors (Type 20-C) failed by steel failure with a maximum load of 49,43 kN (CV = 11,13 %) where the maximum load of the concrete screws (Type 20-A) was 46,50 kN (CV = 9,08 %) by concrete cone failure.

As discussed previously, the elastic bond model is a good approach for low load levels before the peak [7]. This is also confirmed in Figure 10. These strain curves increase evenly like in the elastic bond model. Regarding the similarity of the steel strength and the yield strength of both anchor systems (960 N/mm^2 to approximately 1000 N/mm^2), the difference in failure modes can be a reason for the higher strain values in the bonded anchor. However, the graphs in Figure 10 compared may represent an indication that the mechanical behaviour and the load transfer behaviour of concrete screws can be assumingly similar to bonded anchors. Lastly, the shape of the curves shown in test series Type 20-A and 20-C is a confirmation of the elastic bond model discussed before. The comparison between the results of the bonded anchor (Type 50-C) and the concrete screw (Type 50-A) in a C50/60 will be left out. The strain curve of the bonded anchor (Type 50-C) is similar to the bonded anchor (Type 20-C), and the strain values are slightly higher. However, the different failure modes of the concrete screw (Type 50-A) in a C50/60 does not allow a practical comparison.

4. Conclusion

In this study, tests with concrete screws and bonded anchors were performed in uncracked concrete C20/25 and C50/60. All tests had a nominal embedment depth of $h_{ef} = 85$ mm. Regarding the results of the concrete screws, the main load bearing section is carrying most of the load into the base material. In this test series the main load bearing section of concrete screws made of galvanized steel transferred $90 - 95$ % of the load into the concrete, depending on the concrete strength. The higher the strength of the concrete is, the more strains got measured in the main load bearing section. This is confirmed by the measured strains at DMS positions 3 and 4. This also reflects the failure mode of the Type 50-A tests where steel failure only occurred at DMS position 4. The thread cutting section seems to be included in the load transfer mechanism. The values of the measured strains at DMS positions 1 and 2 are low compared to the DMS positions 3 and 4, but nevertheless this section is also able to bear a part of the load into the base material. ($5 - 10$ %) The amount seems to be influenced by the screw material. The stainless-steel screw has higher strains at the tip as the galvanized concrete screw. In this test series the concrete screw made of stainless steel was with up to 15 % included in the load transfer mechanism.

The results of the data indicate that the load transfer behaviour of concrete screws in concrete C20/25 are similar to bonded anchors. The strain curves of the tested bonded anchors are comparable to the elastic bond model [7]. Therefore, as seen at the strain curves, concrete screws can be assumed to react like a bonded anchor (a threaded rod) with the elastic bond model. The behaviour of concrete screws investigated in this test series is only valid for the parameters used to perform these tests. Therefore, the failure modes should be considered. The compared threaded rods have failed with steel failure and the concrete screws with concrete cone failure. However, before the steel failure occurs, the measured strains or at least the form of the curves can assumingly be compliant. The results themselves appear to be satisfactory, but additional tests should be performed to (1) enlarge the number of samples and (2) observe additional load transfer mechanisms of different concrete screw anchors made from different materials.

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