STRENGTHENING OF ANCHORAGES WITH POST-INSTALLED SUPPLEMENTARY REINFORCEMENT UNDER SHEAR LOADING

LOKALE VERSTÄRKUNG FÜR VERANKERUNGEN MIT NACHTRÄGLICH EINGEMÖRTELTEN BEWEHRUNGSSTÄBEN UNTER QUERZUGBELASTUNG

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SUMMARY

Supplementary reinforcement can be used to increase the concrete edge resistance of the anchorages with headed studs according to current norms. However, the utilization of post-installed reinforcement to improve the behaviour of anchorages against concrete edge failure has not been investigated yet. In this work, experimental investigations are carried out on strengthening of bonded anchors close to an edge using post-installed reinforcement bars under shear loading. Tests were carried out without and with post-installed reinforcement. The results of these tests and the resulting conclusions are summarized here.

ZUSAMMENFASSUNG

Um ein Abbrechen von Betonkanten zu vermeiden, können Kopfbolzen nach den heutigen Regeln mittels einbetonierter Zusatzbewehrung verstärkt werden. Ob Zusatzbewehrung nachträglich eingebaut werden kann und ob sie einen Einfluss auf das Tragverhalten von nachträglich montierten Verbunddübeln haben könnte, wurde bislang nicht untersucht. In der vorliegenden Arbeit wurden nachträglich montierte Verbunddübel am Rand mit nachträglich eingemörtelten Bewehrungsstäben gegen Querzugbelastung verstärkt. Es wurden Versuche ohne und mit Verstärkung durchgeführt. Die Ergebnisse dieser Versuche und die daraus resultierenden Folgerungen werden in diesem Artikel zusammenfassend dargestellt.

KEYWORDS: Bonded anchors, concrete edge failure, shear load, post-installed supplementary reinforcement

1. INTRODUCTION

Anchorages in plain concrete subjected to shear loading perpendicular to an edge may fail by anchor steel failure, concrete edge failure or pry-out failure. In case of anchorages close to an edge, the dominant failure mode is often concrete edge failure. In case of cast-in anchorages with groups of headed studs, supplementary reinforcement also known as anchor reinforcement can be designed according to standards and guidelines such as EN 1992-4 [1], ACI 318 [2] or fib Bulletin 58 [3] to increase the resistance against concrete edge failure. For anchorages close to an edge provided with supplementary reinforcement, under shear loading perpendicular to the edge, concrete edge failure is replaced by stirrup yielding or bond failure, strut failure and node (anchorage) failure [4].

The load-bearing behaviour of an anchor close to an edge with supplementary reinforcement under shear load can be explained with a strut and tie model according to Fig. 1 [1]. The shear load from the anchor plate is transferred by compression in concrete while supplementary and edge reinforcement take up the tension forces. The effectiveness of the supplementary reinforcement depends on the e_s, which is the distance between the line of shear force acting on the fixture and axis of reinforcement, see Fig. 1. Furthermore, the distance, from where the supplementary reinforcement is classified as effective, must be equal or less than to $0.75 \cdot c_1$ according to [1], or $0.5 \cdot c_1$ according to [2, 3].

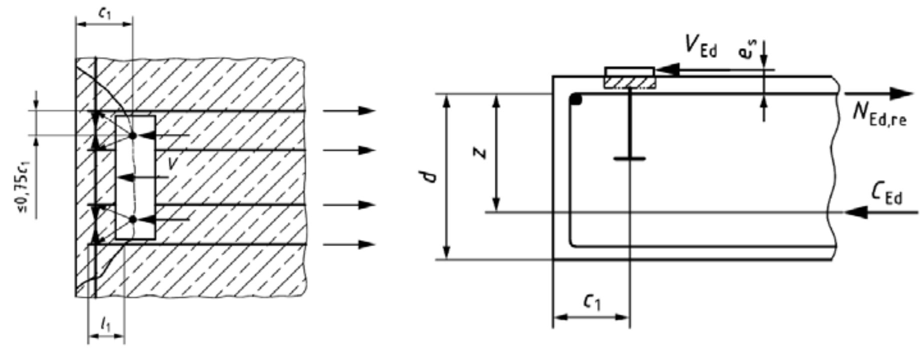


Fig. 1: Strut and tie model for suppl. Reinf. under shear loading according to EN 1992-4 [1]

Researchers have shown an increase in the resistance of the anchorages in case of „cast-in“ anchorages with „cast-in“ supplementary reinforcement under shear loading (Schmid, 2010 [5], Infaso, 2012 [6] Sharma et al., 2017 [4, 7]). However, rather limited information is available on increasing the resistance to concrete edge breakout for an existing anchorage.

Furthermore, very limited research has been performed to investigate the influence of post-installed supplementary reinforcement on the failure load of post-installed anchorages loaded in shear towards the edge. 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 against concrete edge failure under shear loading. Shear tests were performed on single bonded anchors close to an edge without and with post-installed reinforcement. The main objectives were to investigate the influence of the reinforcement arrangement on the ultimate load capacity, on the load-displacement behaviour and failure mode of the anchorages. The bonded anchors were selected considering the ease of installation and freedom to choose the test parameters. 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. TEST PROGRAM

In this study, shear tests on single post-installed bonded anchors without and with post-installed supplementary reinforcement were carried out in normal strength concrete. The main objective was to investigate the effectiveness of post-installed reinforcement to improve the behaviour of anchorages against concrete edge failure. As bonded anchors M24 threaded rods with a steel grade of 12.9 were used to prevent steel failure of the anchor. The edge distance, as well as the effective embedment depth of the anchors was $c_1 = h_{ef} = 180$ mm. High strength epoxy-based injection system from the company fischer (FIS EM Plus) was chosen as the adhesive for bonded anchors as well as for the post-installed reinforcement. Table 1 shows the test matrix. The test program was designed to investigate the influence of the distance between the anchor and the post-installed reinforcement. For that, except the reference tests without reinforcement, three series with the same amount of reinforcement (2 x ϕ10, $A_s = 157$ mm^2) but different distances (50 mm, 90 mm, 135 mm) were carried out. In each series three tests were made.

Table 1: Test program with details of Anchors and Reinforcement

	ANCHOR				REINFORCEMENT					
Serie No.	Geometry [-]	Size [-]	h_{ef} [mm]	c_1 [mm]	Diam. [mm]	Number [-]	Area [mm^2]	Distance *a* [mm]	$h_{ef,Reinf.}$ [mm]	Remarks
S1	Single	M24	180	180	-	-	-	-	-	Ref. series
S2	Single	M24	180	180	10	2	157	50	500	-
S3	Single	M24	180	180	10	2	157	90	500	-
S4	Single	M24	180	180	10	2	157	135	500	-

2.1 TEST SPECIMEN AND MATERIAL PROPERTIES

The shear tests were carried out in normal strength concrete of C20/25 grade. Unreinforced concrete slabs with dimensions of 120/120/50 L/B/H [cm] were used for the tests. The concrete slabs were designed in such a way that in each slab four tests could be carried out. The average cubic compressive strength of concrete at the time of the tests was $f_{cc,150,m}$ = 28.5 MPa. For the post-installed reinforcement, ribbed reinforcing steel with a diameter of 10 mm and with a characteristic yield point of 500 MPa was used.

2.2 INSTALLATION OF THE ANCHOR SYSTEM AND REINFORCEMENT

An injection mortar (FIS EM Plus from company fischer) with relatively high mean bond strength, approx. 35 MPa, which is approved for both bonded anchors and post-installed reinforcement was used to install the anchors and the reinforcement. The installation was carried out according to the manufacturer's specifications, which involve drilling, cleaning, injecting the mortar and installing the threaded rod and reinforcing bar. After required curing time, the shear tests were carried out. The reference tests were performed by simply installing and testing the anchors after observing the required curing time. The schematic and photograph of a typical installation of bonded anchors with post-installed reinforcement is shown in Fig. 2.

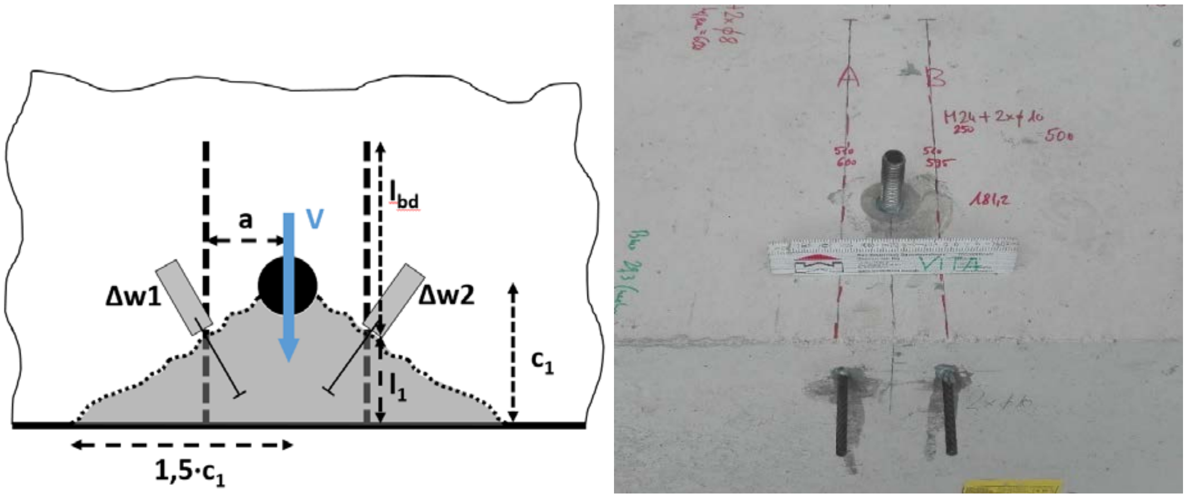
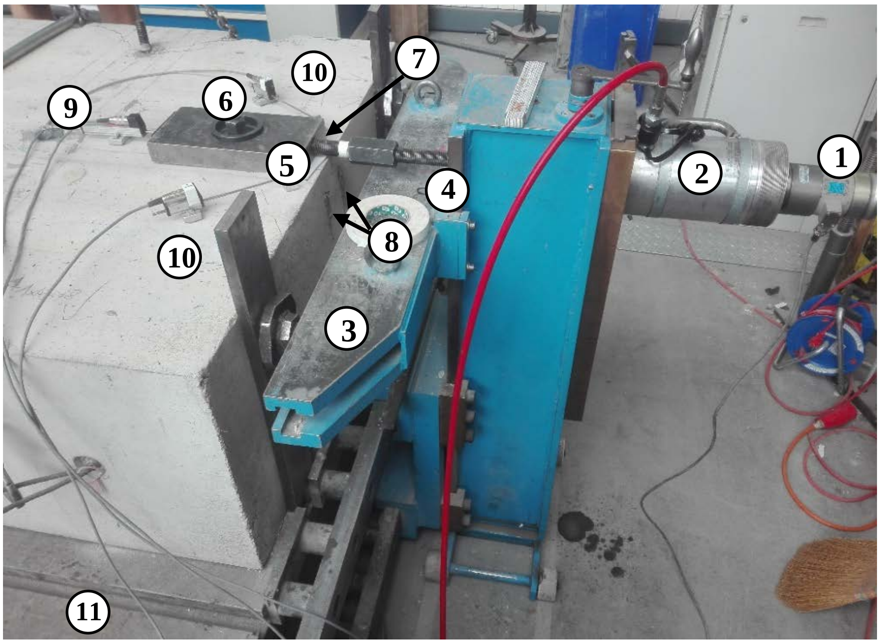


Fig. 2: Schematic (left) picture (right) from the installed bonded anchor with post-installed supplementary reinforcement as a strengthening under shear loading

2.3 TEST SETUP

The shear tests were carried out in acc. with the ETAG 001, Annex A [8]. The typical test setups used for the shear tests on the single anchors are shown in Fig. 3. This consisted of a load cell (1), hydraulic cylinder (2), with wide support (support distance $\geq 4 \cdot c_1$) (3), connecting rod (4), fixture plate (5) and displacement transducers (9-10). The horizontal displacement of the anchor in the direction of the applied load was measured with LVDT placed on the opposite side of the fixture plate (9). Furthermore with two LVDTs the crack width was measured on both side of the anchor (10). Teflon sheets (7) with 2 mm thickness were used between fixture plate and concrete surface to minimize friction. In order to avoid lifting off of the concrete slab, it was clamped to the strong floor (11). According to the expected load, the load ranges of the calibrated load cell and the hydraulic cylinder were chosen. The applied load, anchor displacements and the crack width opening 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.



1) Load cell
2) Hydraulic cylinder
3) Support ($\geq 4 \cdot c_1$)
4) Tension rod
5) Fixture plate
6) Bonded Anchor
7) Teflon under 5)
8) Post-installed supplementary Reinforcement
9) LVDT for anchor Displacement
10) LVDT for crack width
11) Clamp base

Fig. 3: Test setup for shear loading for single anchors with details

3. TEST RESULTS

This section presents the results of the shear tests performed on single anchor according to Table 1. Furthermore, the failure patterns of all series are shown to identify different failure mechanisms. The results of the shear tests on single bonded anchor are summarized in Table 2. This contains the ultimate load obtained in individual tests ($V_{u,i}$), the mean failure load ($V_{u,m}$), the coefficient of variation (CV%) and failure mode for each test series as well as the ratio of the mean load carrying capacity for a test series to the mean load carrying capacity of the reference series without supplementary reinforcement (Series S1).

As seen in Table 2, due to the introduction of post-installed supplementary reinforcement, a significant increase in the load carrying capacity of the anchorages could be achieved, even with a relatively small amount of reinforcement (only two rebar's with 10 mm diameter, A_s =157 mm^2). This increase with small amount of reinforcement is generally not accounted for according to the models in the standards [1-3] for cast-in supplementary reinforcements but is also reported in the work of Sharma et al [4, 7]. The highest load increase was reached in the series S2, when the reinforcement was positioned closest (a = 50 mm) to the anchor, with 57% more capacity reached compared to the Reference Series S1. However, a significant increase in load-bearing capacity could still be observed in case of larger distance in Series S3 with distance of a = 90 mm (1.37 times) and in S4 with distance of a = 135 mm (1.29 times). This is due to the fact that with increasing distance between the anchor and the reinforcement, the crack intercepts the reinforcement later and also the anchorage length of the reinforcement in the breakout body is shorter.

Table 2: Summary of test results

Series No.	ANCHOR		REINFORCEMENT			Ultimate load of individual tests	Mean failure load	CV of load	Relative increase in resistance	Failure mode
	Size	c_1	Diam.	No.	Distance	$V_{u,i}$	$V_{u,m}$		$V_{u,m}/V_{um,Ref.}$	
	[-]	[mm]	[mm]	[-]	[mm]	[kN]	[kN]	[%]	[-]	[-]
S1	M24	180	-	-	-	85.7/87.8/84.9	86.1	1.7	-	C. Edge
S2	M24	180	10	2	50	127.0/128.0/150.4	135.4	9.8	1.57	Mix
S3	M24	180	10	2	90	119.0/118.3/116.8	118.0	1.0	1.37	Strut
S4	M24	180	10	2	135	107.8/111.4/113.1	110.8	2.4	1.29	Strut

In the following sections, the load-displacement behaviour and crack pattern will be discussed.

3.1 DISPLACEMENT BEHAVIOUR

For comparison, all load-displacement curves of the four series are shown in Fig. 4, in three similar diagrams, always the three test from one Series with reinforcement in comparison with the Reference curves (e.g. on the left side S2 with S1). The test results clearly show that not only the amount of the supplementary reinforcement, but also the distance between anchorages and reinforcement have a significant influence of the increasing in the load. When the reinforcement is placed close to the anchor, not only the resistance but the entire load-displacement behaviour improves significantly. Nevertheless, even in case of a relatively large distance of a = $0.75 \cdot c_1$, which is not considered in [2] and [3], an increase in the resistance by 29% is observed due to post-installed supplementary reinforcement. In case of post-installed rebars, the mortar has high bond strength compared to that of cast-in reinforcement and therefore requires smaller bond lengths (l_1) in the breakout body to dissipate the full tensile force until the reinforcement yield, which is the maximum contribution of the rebars. Therefore, even with a short anchorage length in the breakout body, the reinforcing bars can fully be activated.

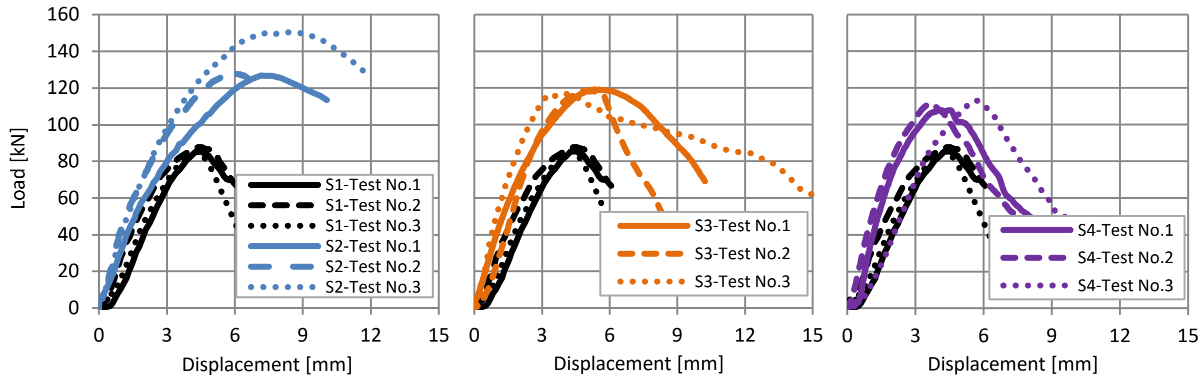


Fig. 4: Load-displacement curves for different Series: S1-Reference (black), S2-with 2 x d10; a = 50 mm (blue), S3-with 2 x d10; a = 90 mm (orange) and S4-with 2 x d10; a = 135 mm (purple)

For better understanding the displacement behaviour of the performed test series with post-installed supplementary reinforcement, the failure modes should be explained in more detail. The typical failure modes are shown in Fig. 5. While in the reference test Series S1 the typical concrete edge failure can be seen, in the Series S2 with close reinforcement the concrete edge breakout was found to be impeded by the reinforcement (Mix). In the Series S3 and S4 with larger distance of the reinforcement a mix of reinforcement and strut failure (concrete compression failure) could be observed.

The change in the failure mode in case of Series S3 and S4 is clearly caused by the increase in distance between anchor and reinforcement, because no other test parameters have been changed. This will be clear, if we understand the mechanism of the strut failure. According to Berger [9], the strut failure (in case of headed stud with cast in supplementary reinforcement) depends only on the geometry of the headed stud (h_{ef}) and reinforcement (*a*). By increasing the distance *a* between anchor and reinforcement, the resistance to strut failure decreases. This indicates that the maximum possible load increase with supplementary reinforcement also decreases, because strut failure is the maximum limitation (failure mode) that can be achieved with supplementary reinforcement [4, 9].

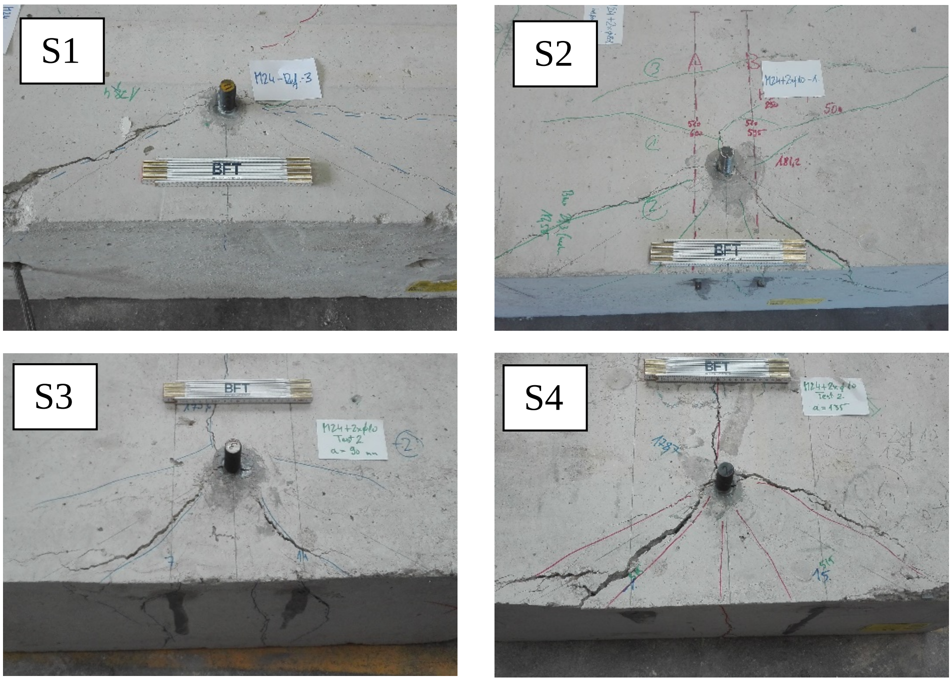


Fig. 5: Typical failure mode obtained from the shear tests on single anchor without and with post-inst. rebars

Normally, in case of cast-in supplementary reinforcement, this failure type is rarely achieved, only in case of high amount of reinforcement. Nevertheless, the results of these tests on bonded anchors with post-installed supplementary reinforcement show a different behaviour. The reason for this behaviour can be found again in the better bond properties of the mortar, because the bars can be fully activated even with a short anchorage length but with increasing distance between reinforcement and anchor, the concrete strut capacity decreases. This means that the limit is provided not by the reinforcement or its bond, but rather the concrete. In test series S2, the reinforcement was sufficiently close to prevent strut failure and to observe mixed concrete edge and partial bond failure of the reinforcement. Comparing the initial stiffness of each Series with supplementary reinforcement and reference curves show 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 edge crack intercepts with the reinforcing bars.

3.2 CRACK DEVELOPMENT

In the shear tests, not only the horizontal displacement of the anchor but also the crack widths on both sides of the anchor (see Fig. 3) were measured during the test. To better visualize and compare the series, Fig. 6 shows for each series (S1 to S4) a typical load-displacement curve of the anchor together with the load-crack width curves (left and right from the anchor). With the help of these diagrams, the crack width can be determined when the maximum anchor load is achieved and a comparison of the crack widths between the series with post-installed supplementary reinforcement and reference series can be carried out. The mean crack width at the failure load for the Reference Series (S1) without reinforcement was 0.26 mm and for the Series with reinforcement S2 = 1.18 mm, S3 = 0.43 mm and S4 = 0.41 mm, respectively. This means that only in series S2 a significant change in crack width was measured. This fact is relatively easy to explain with the types of failures. In both Series S3 and S4 the failure mode strut failure was dominant, which is a quasi-brittle concrete failure, similar to the reference test. In the Series S2, a mix failure, concrete edge and reinforcement failure was observed, which is rather a more ductile failure resulting in more anchor displacement and increased crack widths. Nevertheless, even for this case, when the crack width reaches a value of 0.3 mm (corresponding to serviceability limit state), the load carrying capacity is much higher than 50% of the ultimate resistance. This suggests that the serviceability limit state is well satisfied.

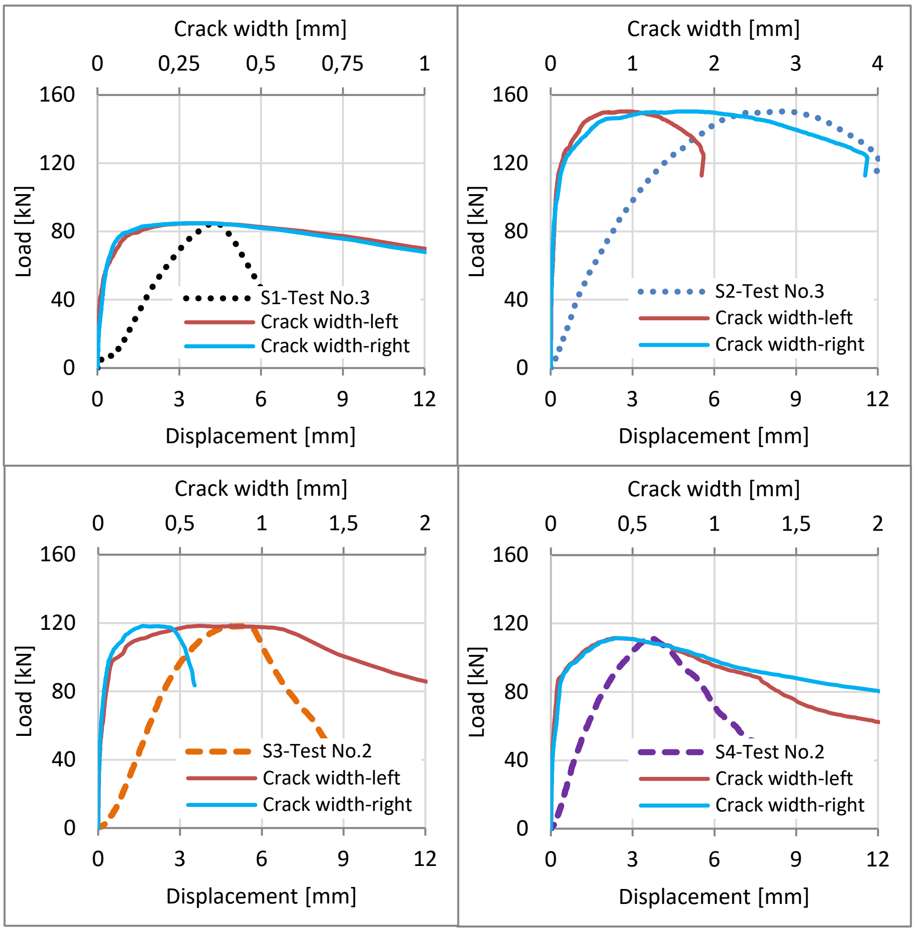


Fig. 6: Load displacement and crack width curves obtained from the shear tests on single anchor without and with post-inst. reinforcement

The crack development in case of supplementary reinforcement can be illustrated much more clearly if the mean crack widths are plotted in a diagram as a function of the distance of the reinforcement, as in Fig 7. The empty triangles are the mean crack widths at the peak load, the full circles are the mean crack widths at the load level of the mean reference load. The full circles show that with supplementary reinforcement, the crack width at the mean load level of the reference test get smaller and there is no significant influence of the distance. As explained previously, the reinforcement is activated only when the concrete is cracked. In the tests with supplementary reinforcement after reaching the reference load level, the concrete get cracks, the reinforcement becomes active, and intercepts and stitches the crack, resulting in smaller crack widths. The reinforcement must be close enough to the anchor so that the initial cracks cross them. Fig. 7 shows well that in the case of series S4 with the greatest distance, smaller crack widths were measured at the reference load level, than in the test. This means the distance was close enough and had no negative influence.

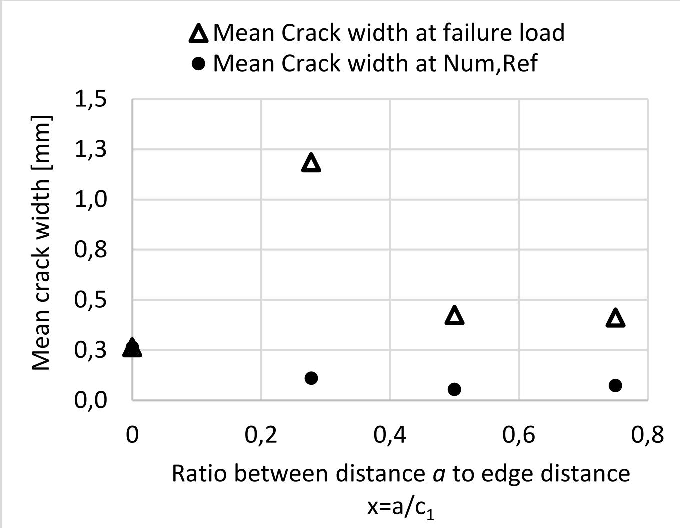


Fig.7: Mean crack width as a function of the ratio between a/c_1

4. CONCLUSIONS

In the present work, shear tests were carried out on single bonded anchors without and with post-installed supplementary reinforcement. The main objectives of the work were the investigation of the influence of the post-installed supplementary reinforcement on the concrete edge resistance, displacement behaviour of the anchorages and crack propagation. Based on the described and detailed evaluation of the performed tests, following statements can be summarised:

The performed shear tests shown clearly, that post-installed supplementary reinforcement has a positive influence on the concrete edge resistance and corresponding behaviour of post-installed anchors. This method could also be used as retrofitting for existing anchors, as well as for new installed anchors.

With a relatively small amount of reinforcement, it is possible to increase the concrete edge resistance of the anchorages.

The distance between the anchor and the reinforcement has a strong influence on the behaviour of the anchorage. Depending on the distance between anchor and reinforcement, the strut failure can be decisive in case of post-installed supplementary reinforcement.

The highest load increase was observed in series with smallest distance between the anchor and the reinforcement. Nevertheless, for the other series with increased distance also, a significant increase in the concrete edge resistance due to added post-installed reinforcement was observed.

Because of the higher bond in case of post-installed rebars, no bond failure of the reinforcement in the concrete breakout body was observed, even at greater distances (S3-S4). Rather, in these series strut failure was the failure mode which occurred.

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