INVESTIGATIONS ON THE INFLUENCE OF THE FASTENER TYPE ON THE SHEAR BEHAVIOUR IN CASE OF CONCRETE EDGE FAILURE

UNTERSUCHUNGEN ZUM EINFLUSS DES BEFESTIGUNGSMITTELS AUF DAS TRAGVERHALTEN BEI BETONKANTENBRUCH UNTER QUERLAST

Stefan Castridis, Thilo Fröhlich

Materials Testing Institute (MPA), University of Stuttgart, Otto-Graf-Institute

SUMMARY

Experimental investigations of concrete anchors located close to the edge were performed to study the behaviour of fastenings under shear load towards the edge associated with concrete edge failure. Three different fasteners, namely post-installed anchors (Pi anchors), headed studs and anchor channels, were tested under static loads as well as under high-cyclic loads. The test results were compared to each other in order to discuss the influence of the fastener type on the concrete edge resistance. The study focuses not only on the maximum load capacity in relation to failure but also provides insights on the displacement behaviour and the anchor stiffness, as well as the increase in deformation and the change of hysteresis loops caused by fatigue damage.

ZUSAMMENFASSUNG

Es wurden experimentelle Untersuchungen an randnahen Befestigungen im Beton durchgeführt, um deren Tragverhalten unter Querlast bei Versagen durch Betonkantenbruch zu untersuchen. Drei verschiedene Verankerungselemente, nachträglich montierte Dübel, Kopfbolzen und Ankerschienen, wurden sowohl unter statischer als auch unter hochzyklischer Belastung zum Rand geprüft. Die Versuchsergebnisse wurden miteinander verglichen, um den Einfluss des Befestigungsmittels auf den Betonkantenbruchwiderstand zu diskutieren. Der Fokus der Studie liegt dabei nicht nur auf der maximalen Traglast im Versagensfall, sondern gibt auch Aufschluss über das Verschiebungsverhalten und die Ankersteifigkeit sowie die Verformungszunahme und die Veränderung der Hystereseschleifen infolge der Ermüdungsschädigung.

1. INTRODUCTION

1.1 General

In structural engineering, fasteners provide an efficient and economical solution for the connection between steel and concrete components. The recent trend to build sustainable, material-saving and filigree constructions requires that these connections have to be realized in concrete structures with a small edge distance.

In case of applications close to an edge, the resistance of anchors subjected to shear loads towards the edge is usually governed by failure of the concrete edge. The current design provisions offer a calculation model of the load capacity for different types of fasteners by considering various boundary conditions. The design approach delivers conservative results that may deviate considerably from the real anchor behaviour depending on the level of knowledge or experimental background.

1.2 State of the art

The verification of anchorages against concrete edge failure is generally required, if fasteners are loaded under shear towards an edge with a distance smaller than the maximum value of 10 times the anchorage depth or 60 times the diameter of the fastener. The basic static capacity of a single anchor against concrete edge failure may be calculated using the following equation acc. to EN 1992-4 [1]. The resistance depends mainly on the edge distance c_1, which determines in conjunction with the anchorage depth l_f the size of the concrete failure body. In addition, the anchor diameter d_{nom} as well as the concrete strength f_{ck} and the condition of the concrete have an influence.

$$V_{Rk,c}^{0} = k_9 \cdot d_{nom}^{\alpha} \cdot l_f^{\beta} \cdot \sqrt{f_{ck}} \cdot c_1^{1,5} \tag{1}$$

with:

$k_9 = 1{,}7$ for cracked concrete $(= 2{,}4$ for uncracked concrete)

$\alpha = 0{,}1 \cdot \left(l_f / c_1\right)^{0,5}$

$\beta = 0{,}1 \cdot (d_{nom}/c_1)^{0,2}$

f_{ck} characteristic concrete compressive strength (cylinder 150 mm x 300 mm)

Equation (1) is applicable for Pi anchors and headed studs but also for anchor channels under shear load in the direction of the longitudinal channel axis acc. to CEN/TR 17080 [2].

The fatigue resistance for all concrete related failure modes is given in the standard EN 1992-4 by using a simplified approach of 50% of the static value for $2 \cdot 10^6$ load cycles. For concrete edge failure, only a few studies have been performed so far [3]. The test results indicate that the related capacity of the concrete cone under shear load is somewhat lower than under tension. Consequently, the fatigue design rules for Pi anchors acc. to EOTA TR 061 [4] consider a reduction factor of up to 40% for the concrete edge resistance. It should be noted that the fatigue design of anchor channels is not covered by EN 1992-4, the application is currently limited to fatigue tension loads only as defined in EOTA TR 050 [5].

The static load capacity of anchors close to the edge may be increased by supplementary reinforcement, which is usually present in concrete structures. In fatigue design, however, the beneficial effect of the reinforced steel may not be taken into account due to the lack of sufficient test data.

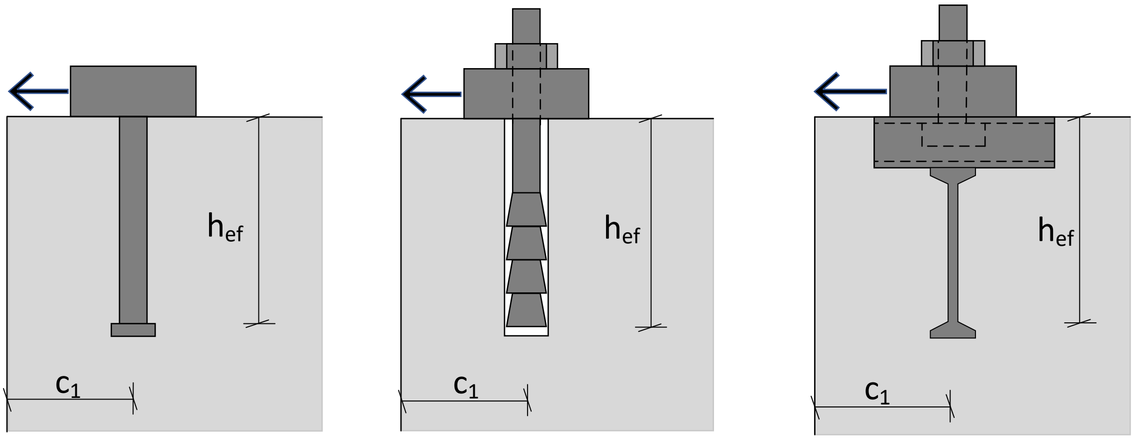
1.3 Objective of the investigations

The fatigue resistance of concrete-steel connections located close to the edge and subjected to shear loads is currently being investigated within the scope of the research project IGF 22283 N at the University of Stuttgart (Materials Testing Institute and Institute of Structural Design).

The purpose of the experimental investigations presented in this paper is to better understand the influence of the fastener type on the concrete edge failure of anchors under both static and cyclic loads.

2. SELECTED FASTENERS

For the experimental investigations, three different fasteners were chosen, which had a similar anchorage depth and comparable diameters. The selection contains one type of headed studs, post-installed anchors and anchor channels as shown in Fig. 1. Head studs and anchor channel are cast-in parts and were therefore inserted into the formwork before concreting. A bonded expansion anchor was chosen as Pi anchor type, which was installed into a borehole drilled in the hardened concrete. The parameters of the selected fasteners are summarized in Table 1. Since the tests were planned on single fasteners, anchor channels with only one anchor with an axial distance of x=35 mm to the loaded channel end were used. The distance to the concrete edge was chosen equal to or larger than the minimum edge distance given in the corresponding product approval. It should be noted that the applied installation torque specified by the manufacturer was reduced to 20% (Pi anchors) and 10% (anchor channels) before the tests. Both the Pi anchors and the anchor channels were tested with a so-called dynamic set, which implied that the gaps within the anchor system were eliminated by filling mortar. The tests were performed in uncracked concrete of low strength class C20/25.



Headed stud Ø22 *Post-installed anchor M20* *Anchor channel 64/44*

Fig. 1: Graphic of tested fasteners located close to the edge

Table 1: Parameter of the fasteners and concrete

	h_{ef} [mm]	c_1 [mm]	d_{nom} [mm]	b_w x t_w [mm]	$f_{cc,150}$ [N/mm²]
Headed stud	165	80;100;120	22	-	36,0
Pi anchor	180	120	22	-	36,0
Anchor channel	179	100	-	46 x 7,6	31,4

3. EXPERIMENTAL SET-UP AND EXECUTION

The scope of experiments included static and fatigue tests on single anchors under shear load towards the free concrete edge with the above-mentioned fasteners. An illustration of the experimental set-up and the measurement equipment used for the tests is shown in Fig. 2.

The load was applied by a 100 kN hydraulic cylinder connected via a pendulum rod to a 40 mm thick steel plate, which served as anchor plate to transfer the force into the fastener. In the tests with Pi anchors and anchor channels one teflon layer was placed between the anchor plate and the concrete surface to reduce friction. The concrete block was supported at the front and at the top to avoid movement or uplift of the specimen during loading. In order to ensure an unrestricted formation of the concrete cone break-out, the clear distance of the lateral support was chosen to be at least $4c_1$. During the tests, the force and displacement signal of the cylinder was measured. The anchor displacements in the direction of the acting shear load were recorded by means of a displacement transducer centred behind the attachment. In addition, the crack propagation of the concrete cone was captured using two displacement transducers located at the side of the anchor.

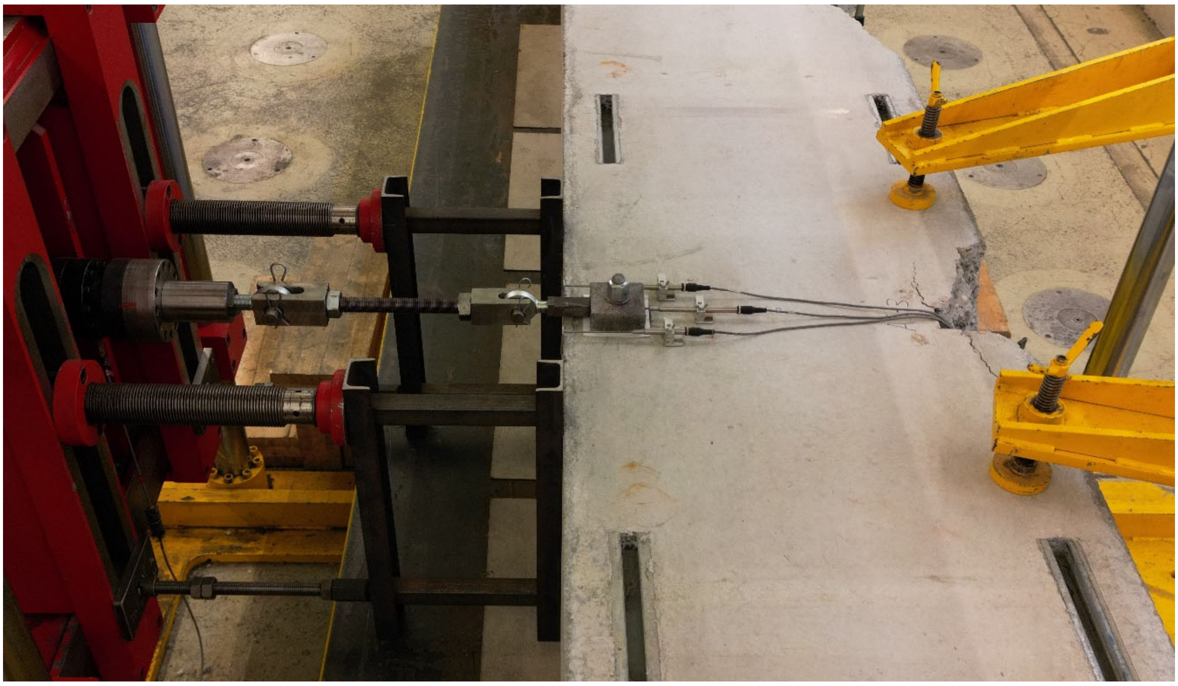


Fig. 2: Test set-up and measuring equipment of the shear load tests

4. RESULTS OF STATIC TESTS

4.1 Load-displacement behaviour

The static tests were performed displacement controlled with a constant speed of 1 mm/min. The load-displacement curves of the static tests obtained for headed studs (c_1 =80 mm), Pi anchors (c_1=120 mm) and anchor channels (c_1=100 mm) are shown in Figure 3. The ultimate loads and the displacements measured are quite different for the tested fasteners. The average failure loads were 25,2 kN for the headed studs, 47,0 kN for the Pi anchors and 41,9 kN for the anchor channels. The differences in the ultimate loads can be explained by the different edge distances and geometrical parameters of the fasteners. The curves show that the maximum load is achieved at different displacements. However, after reaching the maximum load, a slow decrease in load with a simultaneous increase in displacements is observed in all the tests before failure.

4.2 Anchor stiffness

Using the load-displacement curve data obtained from the static tests, the stiffnesses of the individual fasteners were evaluated at different load levels. The load levels were defined at 40%, 80% and 100% referred to the above-mentioned mean failure loads, whereby 100% corresponds to the ultimate load of the respective test. Fig. 4 compares the stiffnesses of the shear tests for the different load levels. In addition to the test results for headed studs with an edge distance of c_1=80 mm, the results of further tests with c_1=100 mm and c_1=120 mm were also added.

The evaluation shows a decrease in the stiffness of all fasteners with increasing load level. Independent of the edge distance, the headed studs have a significantly higher stiffness than the other fasteners. The stiffness of the anchor channel is lower than that of the other fasteners, which can be attributed to additional displacements of the anchor plate caused by the interaction of the serration between the channel bolt and the channel profile. The headed studs show a significantly higher variance of the individual test results with an edge distance of 80 mm compared to the other two edge distances. The differences of the stiffness of all test series decreases slightly with increasing load and reaches a comparable level at ultimate load.

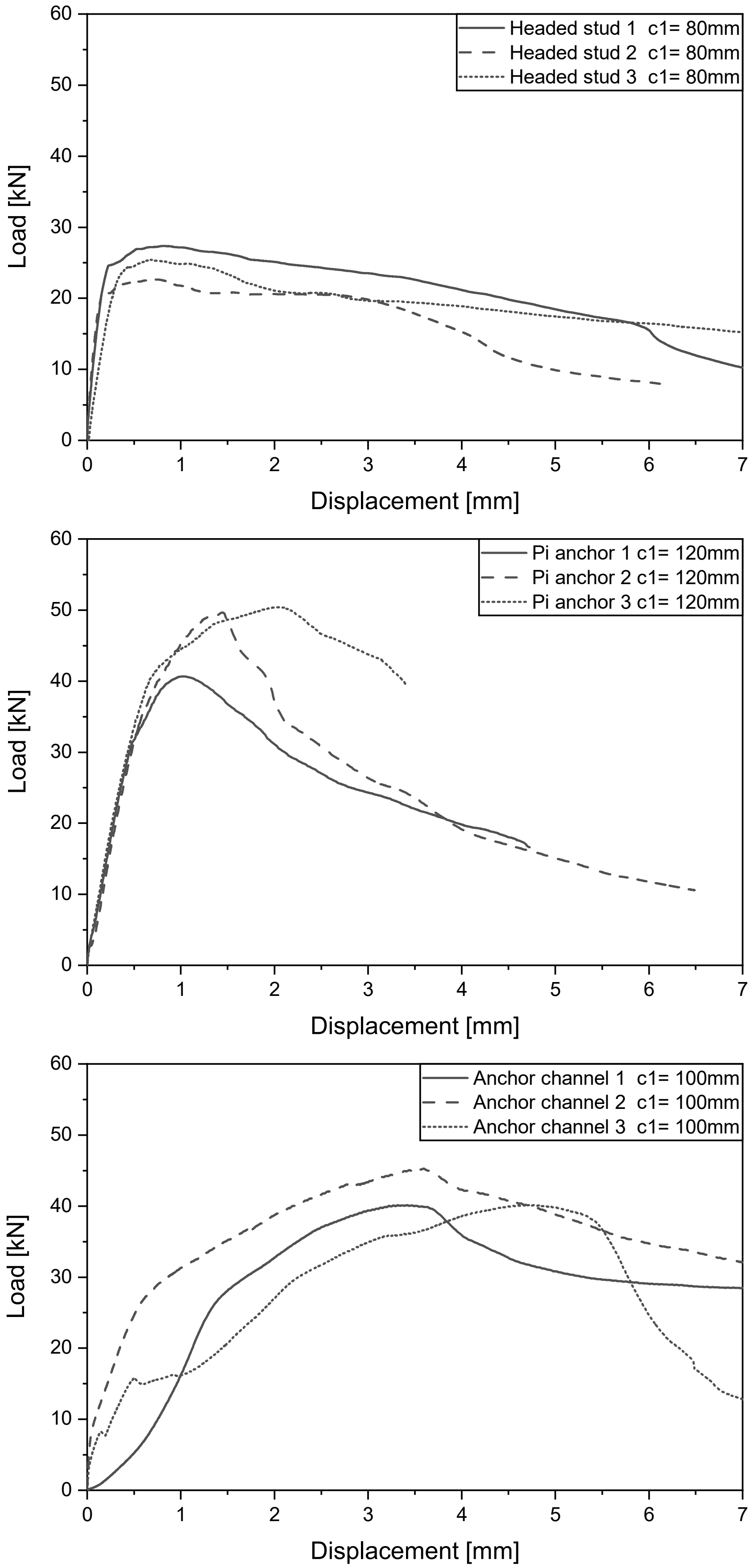


Fig. 3: Load-displacement curve of the static tests

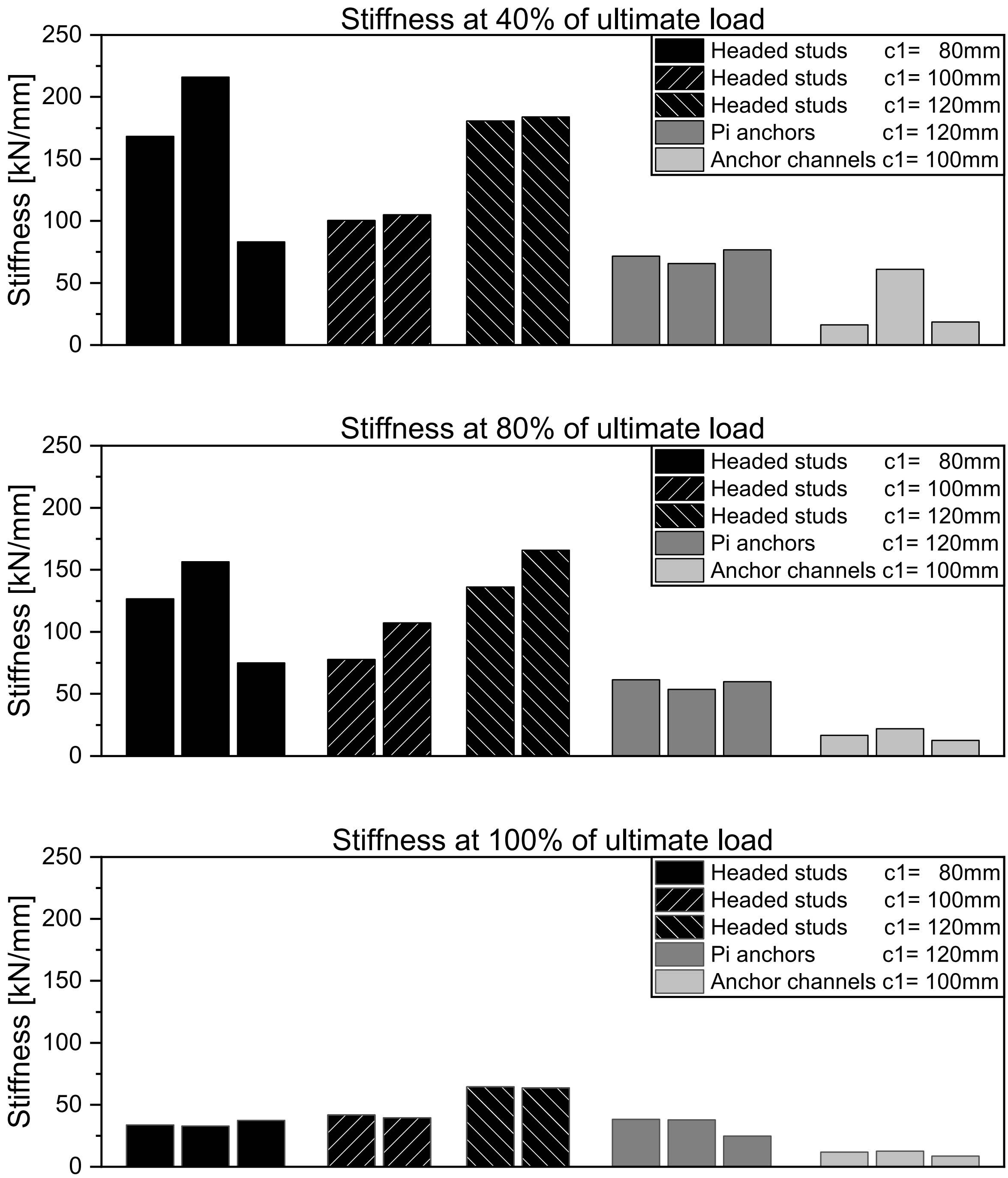


Fig. 4: Stiffness of the individual static test series at 40%, 80% and 100% of the ultimate load

4.3 Ultimate loads

In Fig. 5 the ultimate loads obtained in the tests are plotted versus the calculated failure loads for an undisturbed single anchor. As the calculation in Equation (1) is related to characteristic values, a modified approach with k_9 =3,0 and $f_{cc,200}$ acc. to [6] was used to obtain more realistic average values for concrete edge failure. The straight line in the diagram marks the points at which the ultimate loads measured in the tests correspond to the calculated values.

The results show that the measured values agree quite well with the calculated mean values. The measured failure loads tend to lie slightly below the calculated failure loads. However, the failure loads obtained in the tests are clearly above the calculated characteristic values.

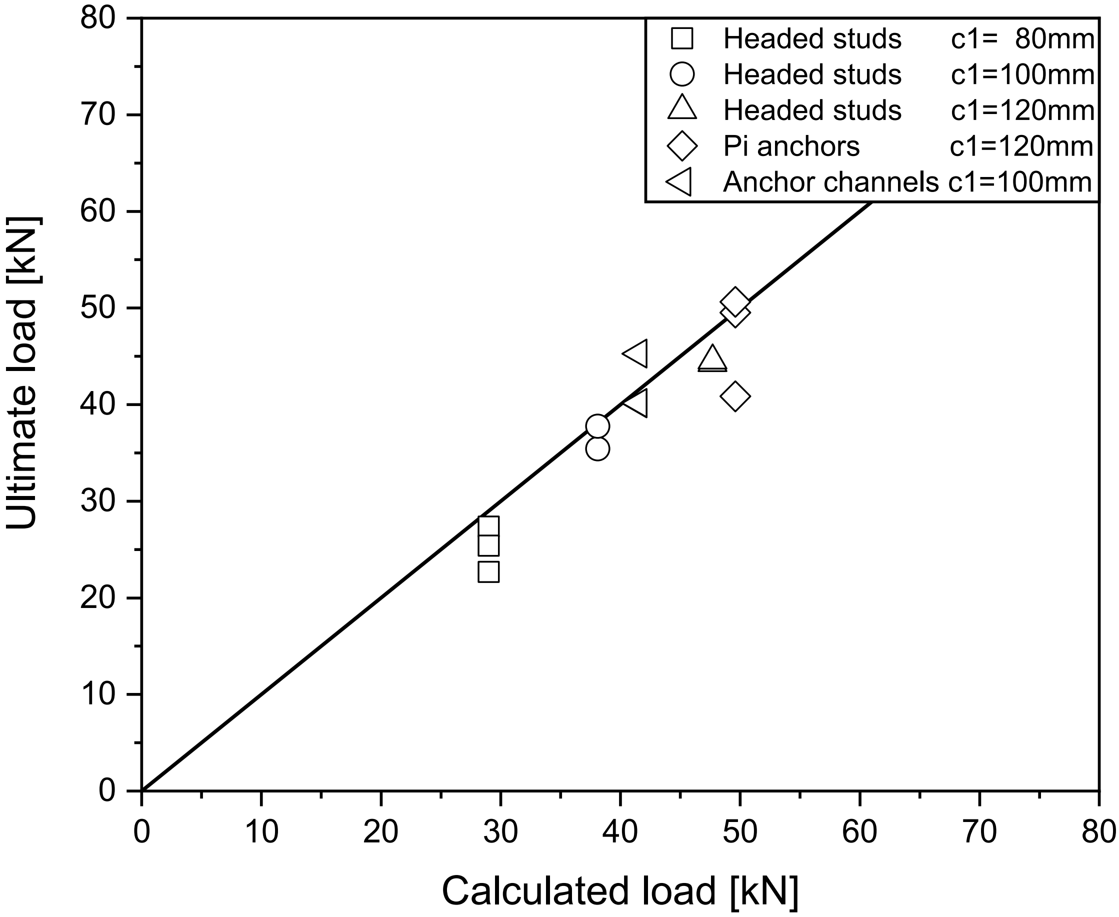


Fig. 5: Ultimate test loads compared with calculated average loads

5. RESULTS OF FATIGUE TESTS

5.1 Test parameter

Based on the results of the static tests, the loading conditions and parameters for the fatigue tests were defined as given in Table 2. The level of the load range was chosen with 65% of the mean maximum load of the respective fastener determined in the static tests. The lower load was kept constant with 10% of the ultimate load. The tests on headed studs with an edge distance of c_1=100 mm and c_1=120 mm were chosen to directly compare the results with the tests on Pi anchors (c_1=120 mm) and anchor channels (c_1=100 mm). The fatigue tests were carried out load controlled with a sinusoidal load regime and a frequency of 3Hz. The number of load cycles to failure ranged from $N=9\cdot10^3$ to $N=3{,}5\cdot10^4$.

Table 2: Test parameters of the cyclic tests

	c_1 [mm]	F_{ult} [kN]	ΔF [kN]	$\Delta F/F_{ult}$ [%]	F_{up} [kN]	F_{lo} [kN]
Headed stud	100	36,6	23,8	65	27,5	3,7
Headed stud	120	44,4	28,9	65	33,3	4,4
Pi anchor	120	47,0	30,6	65	35,3	4,7
Anchor channel	100	41,9	27,2	65	33,5	4,2

5.2 Displacement behaviour

Fig. 6 shows the displacements obtained in shear direction at upper and lower load until failure. For better comparability, the test results of each fastener are plotted as function of the related number of load cycles. The observed deformation curves are similar for all fasteners, but differ in the amount of displacement. In all the tests, a quasi-linear increase in displacement was observed between 20 and 80% of the fatigue life, which then changed to a non-linear increase in displacement until failure. The transition from linear to non-linear deformation increase occurs earlier for the headed stud and the anchor channel than for the Pi anchor.

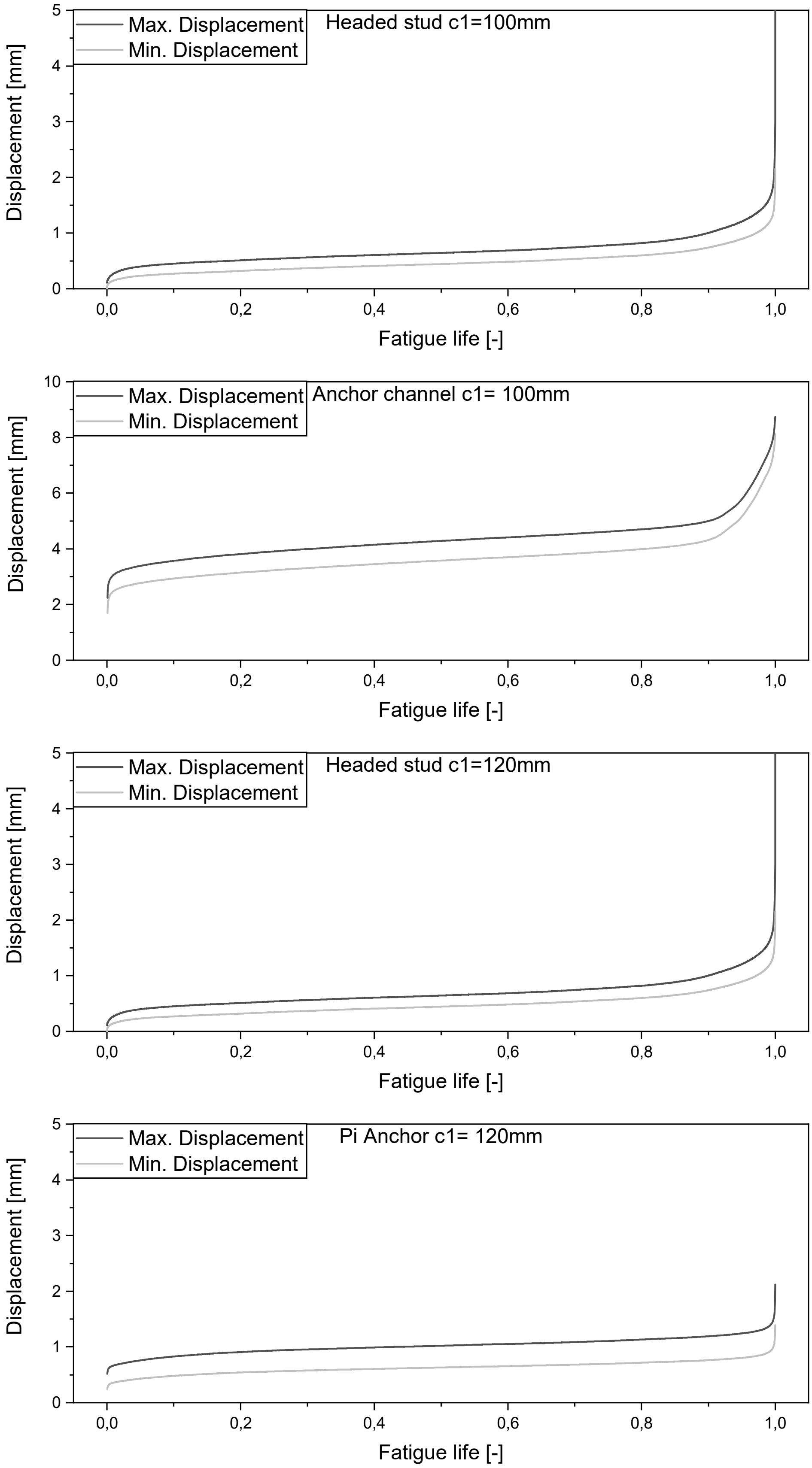


Fig. 6: Displacements of the fatigue tests at a load range of 65% of the ultimate load

5.3 Degradation of stiffness

In order to better illustrate the increase of deformation during the fatigue tests, the stiffness curves were established over the life time as plotted in Fig. 7. Similar to the static tests, the cyclic tests also show a comparable stiffness distribution. The headed studs provide a significantly stiffer behaviour during the fatigue life than the other fasteners. Both tested headed studs have an almost identical stiffness course during the fatigue test. The low stiffness of the anchor channel is also accompanied by the lowest decrease in stiffness over the service life of the three fasteners compared. As with the static tests, the cyclic tests showed almost the same stiffness values when the ultimate load was reached.

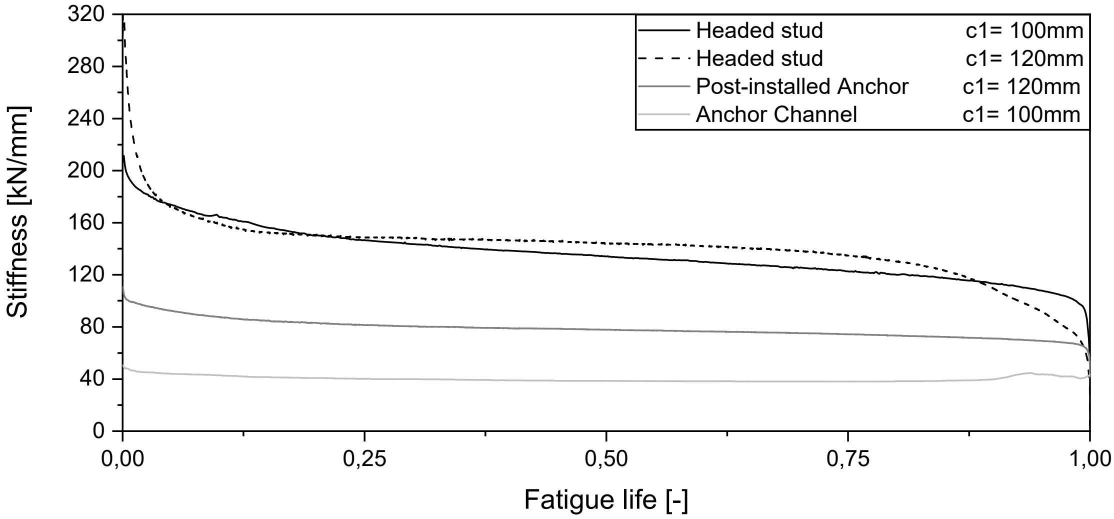


Fig. 7: Course of the stiffness over the fatigue life of the individual fasteners

5.4 Hysteresis loops

In Fig. 8 the hysteresis loops of the fatigue tests at a load range level of 65% were evaluated. For this purpose, the hysteresis were plotted in 10% steps of the fatigue life. In addition, the first as well as the last recorded hysteresis were added.

The results show that the hysteresis of the fasteners differ both in area and shape. It can be seen that the area of the hysteresis increases during the fatigue test. However, the area of the hysteresis of the headed stud remains relatively small compared to the other two fasteners. The largest hysteresis area is provided by the anchor channel. The increasingly flatter slope of the hysteresis show that the stiffness decreases over the time.

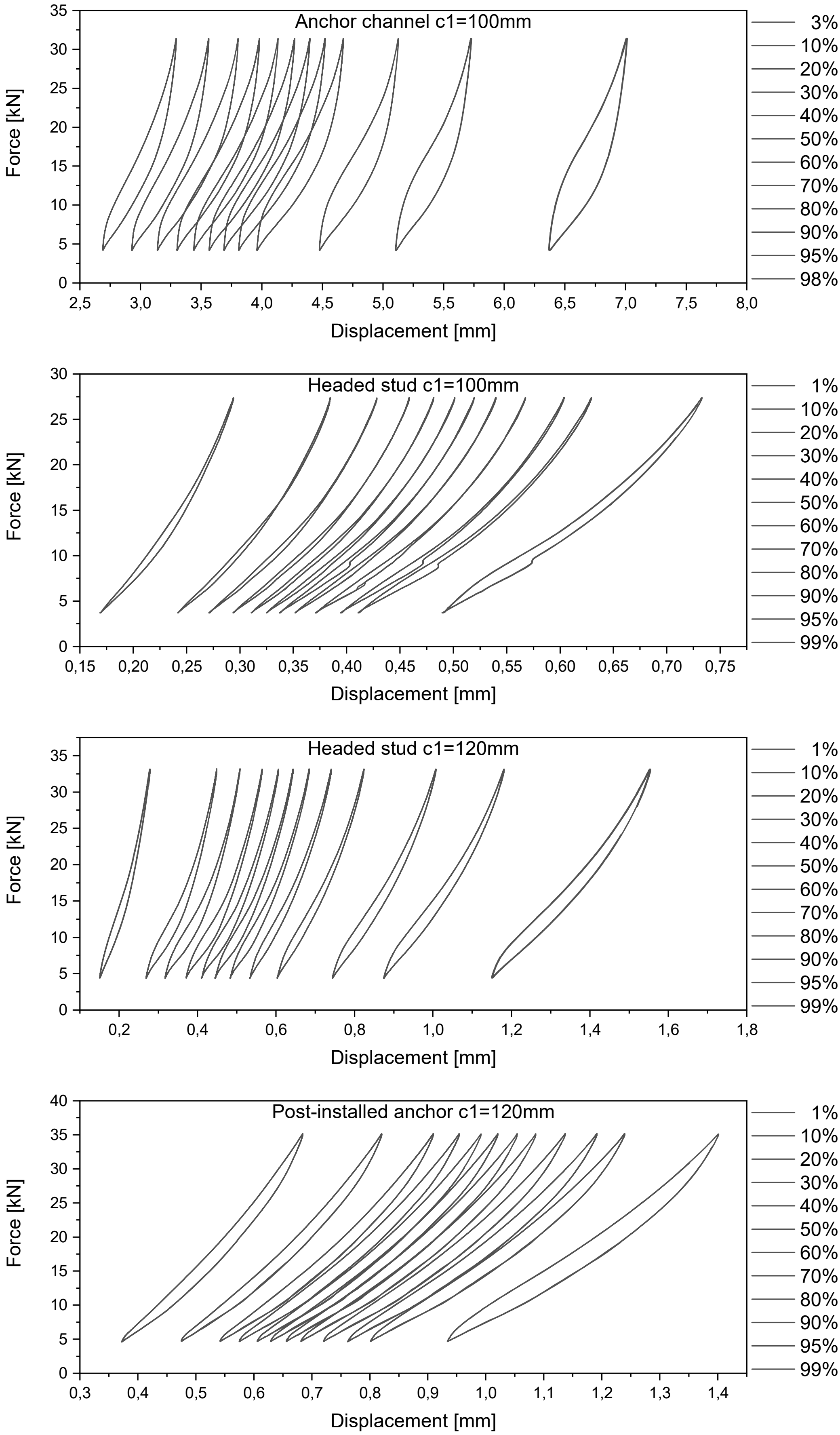


Fig. 7: Hysteresis of the fatigue tests at a load range of 65% of the ultimate load

6. CONCLUSIONS

The experimental investigations demonstrate the behaviour of different types of concrete anchors in case of concrete edge failure. The ultimate loads in the static tests varied in the range of about 25 kN and 50 kN. All static test results show good agreement with the current calculation approach for the concrete edge resistance. However, the displacement response of the investigated anchors differs significantly under both static and fatigue loads. The tested headed studs generally exhibit much stiffer behaviour compared to the other fasteners. The anchor channels provide the lowest stiffness among the fasteners investigated. The results so far are based on a small data set, which will be expanded in the future.

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