ANCHOR CHANNELS UNDER FATIGUE SHEAR LOADING

ANKERSCHIENEN UNTER ERMÜDUNGSRELEVANTER QUERBELASTUNG

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SUMMARY

The fatigue design of anchor channels is currently limited exclusively to centric tensile loads, so that the use under shear loads is not allowed. One reason for this limitation is the product-specific clearance between the channel bolt and both the anchor plate and the channel profile, which can lead to non-permissible impact loads in case of alternating shear.

In order to investigate the fatigue behavior of anchor channels under shear loading, cyclic tests under pulsating and alternating shear perpendicular to the channel axis were carried out. Therefore, a newly developed product solution for gap filling was used. Based on the test results, the principle suitability of anchor channels under fatigue-relevant shear loading was established.

ZUSAMMENFASSUNG

Die Ermüdungsbemessung von Ankerschienen ist zurzeit ausschließlich auf zentrische Zuglasten beschränkt, sodass sie unter Querbelastung nicht eingesetzt werden dürfen. Ein Grund dafür liegt u.a. in dem produktspezifischen Lochspiel zwischen Anbauteil, Schraube und Schiene, das bei wechselnden Querlasten zu unzulässigen schlagenden Beanspruchungen führen kann.

Zur Untersuchung des Ermüdungsverhaltens von Ankerschienen in Querrichtung wurden zyklische Versuche unter schwellender und wechselnder Querbeanspruchung rechtwinklig zur Schienenlängsachse durchgeführt. Hierbei kam eine neu entwickelte Produktlösung zur Spaltverfüllung zum Einsatz. Anhand der Ergebnisse konnte die grundsätzliche Eignung von Ankerschienen unter ermüdungsrelevanter Querbelastung festgestellt werden.

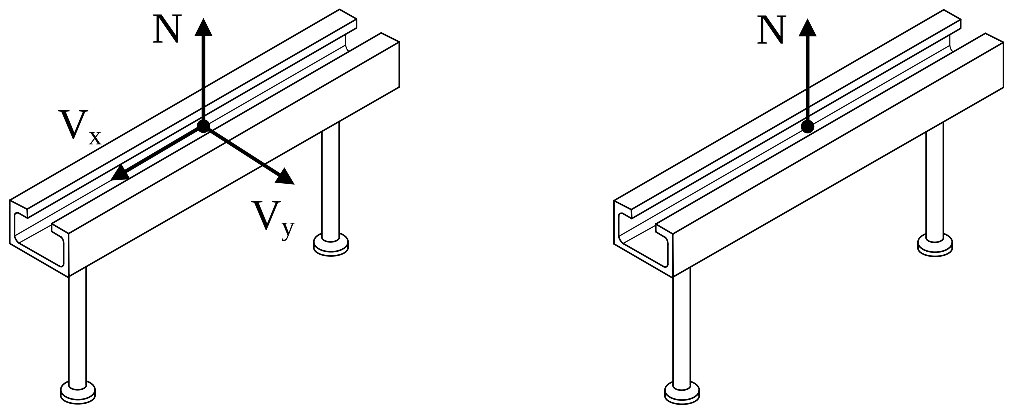
1. INTRODUCTION

Anchor channels are a widespread fastening system in today’s building industry for the realization of connections between steel and concrete components. Their use is not only limited to static or quasi-static load conditions, but they can also be applied under cyclic actions.

Typical applications of anchor channels where high cyclic loads can occur are e.g. fastenings of guide rails for elevators, crane girders, installations in tunnel systems, rotating machines but also façade elements with temperature variations. In such cases, a fatigue verification is required to prevent progressive damage which can lead to sudden failure of the anchorage and the connected structure.

Anchor channels can be subjected to tension loads, shear loads acting perpendicular to the channel axis and shear loads acting longitudinal to the channel axis as well as any combinations thereof. The transfer of shear loads in longitudinal direction is realized by using either smooth channel profiles with notching channel bolts or serrated anchor channels with matching channel bolts.

The design of anchor channels under static and quasi-static loading is specified in EN 1992-4 [1] or TR 047 [2] for tension loads and shear loads perpendicular to the channel axis. Design rules for shear loads in longitudinal direction are available in Annex B of TR 047 or CEN/TR 17080 [3]. In contrast to the static provisions, where all load directions are covered, the fatigue design is currently limited to tensile forces (see Fig. 1).



(a) Static loads acc. to EN 1992-4 or TR047

(b) Fatigue loads acc. to TR 050

Fig. 1: Permissible load directions for anchor channels: tension load (N), shear load longitudinal to the channel axis (V_x) and shear load perpendicular to the channel axis (V_y)

Since the fatigue verification of anchor channels is not included in EN 1992-4, separate design rules are provided in TR 050 [4]. However, fatigue relevant shear loads are not regulated in this guideline and therefore they are not permitted for anchor channels. One reason for this limitation is the product-specific clearance between the channel bolt and both the anchor plate and the channel profile. As alternating shear loads can lead to unintended impact effects, a permanent level of prestressing force and the elimination of the annular gap between fastener and fixture is required according to EN 1992-4.

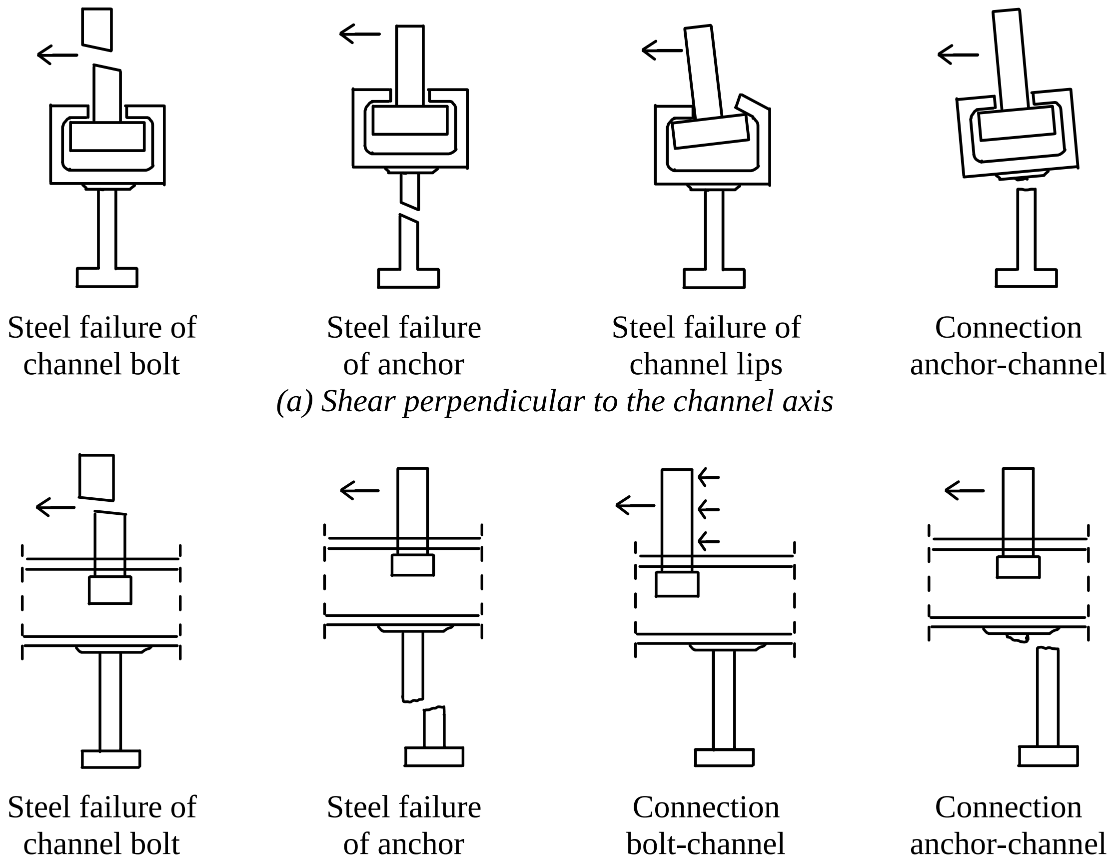
Within the scope of this contribution, a constructive measure is to be examined in order to check the suitability of anchor channels under fatigue relevant shear loads. This contains the investigation of a patented gap filler set, which is intended to be used for the elimination of the hole clearance by the injection of epoxy mortar. Preliminary filling experiments are conducted to study the suitability of various mortars under different temperatures. Afterwards fatigue tests under perpendicular shear load are performed to investigate the fatigue resistance of anchor channels in transverse direction including the impact of alternating loads.

2. SHEAR RESISTANCE OF ANCHOR CHANNELS

The load-bearing behavior of anchor channels is characterized by the complex interaction between the channel bolt, channel profile and channel anchor in the concrete. As a result, the resistance is governed by different failure modes both under static and cyclic loading. In contrast to static loading, the fatigue resistance is time dependent and the failure mode can vary with the number of load cycles. Comprehensive studies have been carried out on the static resistance under shear load so far. In contrast, the current knowledge about the fatigue resistance is very limited.

2.1 Failure modes

The failure modes of anchor channels are distinguished according to the load direction. The possible failure modes under shear loading are steel failure, concrete edge failure and concrete pry-out failure. In case of steel failure, the failure can occur at different locations of the anchor channel depending on whether the shear load is acting perpendicular or parallel to the channel axis as shown in Fig. 2.



(a) Shear perpendicular to the channel axis

(b) Shear longitudinal to the channel axis

Fig. 2: Steel failure modes of anchor channels under shear load

2.2 Static behavior

Previous studies on anchor channels mainly focus on the load-bearing capacity under monotonic loading. Initial studies on the behavior of anchor channels close to an edge and subjected to shear load towards the edge were performed by Wohlfahrt [5]. Potthoff [6] investigated the load transfer mechanism under perpendicular shear. In contrast to tension loading, shear forces are mainly transferred via the channel profile into the concrete. Nevertheless, the anchors are also subjected to tensile forces under shear due to the occurring moment. Hence, the model for the distribution of the shear loads is proposed similarly to the triangular method for tension loads based on Kraus [7]. Schmid [8] addresses the application of anchor channels in reinforced concrete. It could be shown that the resistance to concrete edge failure can be increased by placing supplementary reinforcement. The interaction between tension load and perpendicular shear load was studied in Wohlfahrt [5] and Oluokun & Burdette [9]. The load transfer for serrated channels subjected to longitudinal shear was investigated by Schmidt [10] and Konertz et al. [11].

2.3 Fatigue behavior

The fatigue behaviour of serrated anchor channels of type 38/23 loaded in various directions was investigated in Güreş [12]. In addition to the centric tensile direction, fatigue tests were carried out under shear load in longitudinal and perpendicular direction to the channel axis as well as with different load angles of 30°, 45° and 60°. The tests indicated a higher fatigue resistance under shear load compared to centric tension as exemplary shown in Fig. 3. The presented results were obtained in uncracked concrete C20/25 at constant upper load of 17 kN. The main cause of failure observed in the shear tests was steel failure. The failure occurred either in the channel profile or in the connection between anchor and profile. However, the results under perpendicular shear are very limited. Due to the limit ed upper load, all tests were stopped at $4 \cdot 10^6$ or more load cycles without failure, except for one test with a load range of 15 kN, where failure occurred at $1.9 \cdot 10^6$.

For combined tension and shear loads, the results indicated that a linear interaction between the directions can be assumed on the safe side. The exponents of the interaction equation were obtained as α = 1.3 to 1.7 for tension and longitudinal shear and α = 1.1 to 1.2 for tension and perpendicular shear. However, no tests were performed on the interaction between longitudinal and perpendicular shear loads. The findings by Güreş are limited to the pulsating range. The impact of alternating shear loads on the fatigue resistance of anchor channels have not been investigated so far.

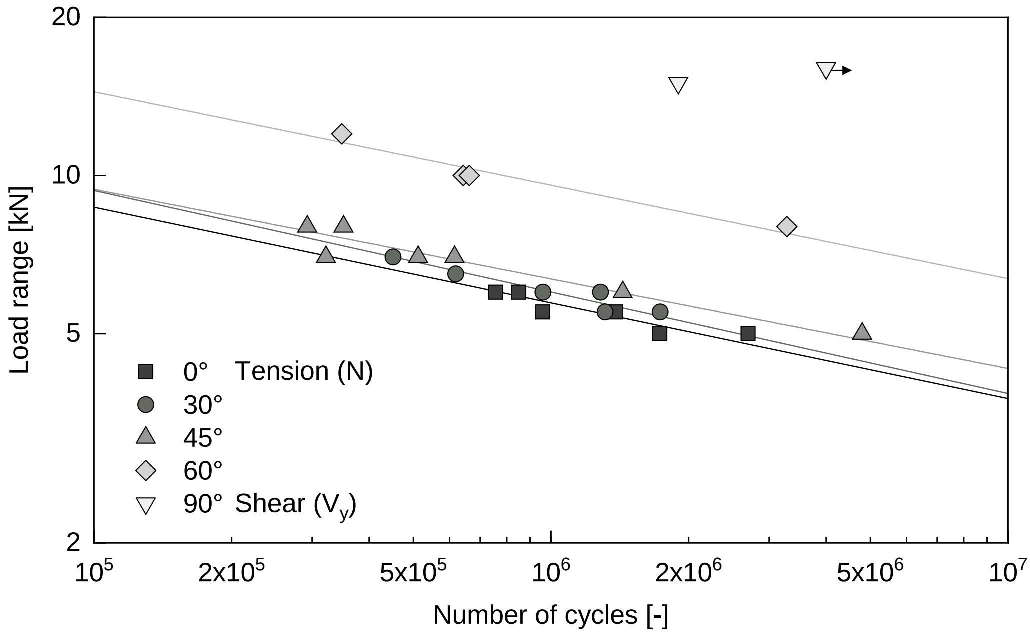
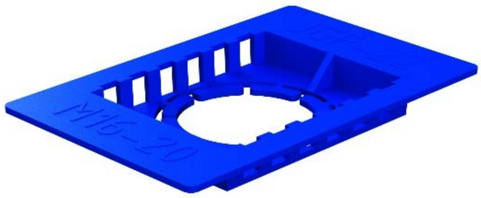


Fig. 3: Fatigue resistance of anchor channel 38/23 under different load directions [12]

3. GAP FILLER SET FOR FATIGUE LOADS

For the elimination of hole clearance, a gap filler set [13] of the company Jordahl® was used. The set consists of a plastic insert and a special nut as shown in Fig. 4. The nut is provided with an opening for the injection of epoxy mortar to fill the hole clearance. The insert of the set is made of an organic polymer. It prevents uncontrolled penetration of the injected mortar into the channel profile so that the annular gap between the channel bolt and the fixture as well as the gap between the bolt and the channel lips is properly filled.



(a)

(b)

Fig. 4: Gap filler set including plastic insert (a) and special nut (b) (Figure: Jordahl®)

The installation procedure of the gap filler set is shown schematically in Fig. 5. The plastic insert is slid onto the channel bolt and placed directly on the channel lips. After assembling the fixture, the special nut including a standard washer is screwed onto the bolt and the specified installation torque is applied. Finally, the epoxy mortar is injected through the hole until the hole clearance is filled. After hardening of the mortar, the anchor channel can be loaded.

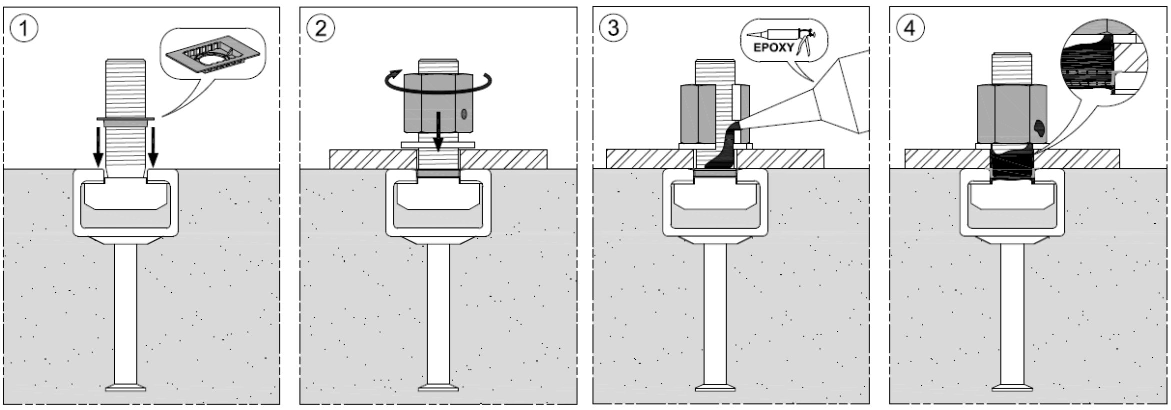


Fig. 5: Installation procedure of gap filler set (Figure: Jordahl®)

4. SELECTION OF INJECTION MORTAR

In general, the filling of the hole clearance can be provided with various types of injection mortars available on the market. However, the chosen product should be suitable for the intended use. The injection mortar needs a sufficient viscosity to obtain a uniform filling without producing air pores or voids on the one hand and should not be too liquid and flow out of the insert on the other.

In order to achieve reliable results in the fatigue tests, preliminary filling experiments have been performed for the selection of the injection mortar as shown in Table 1.

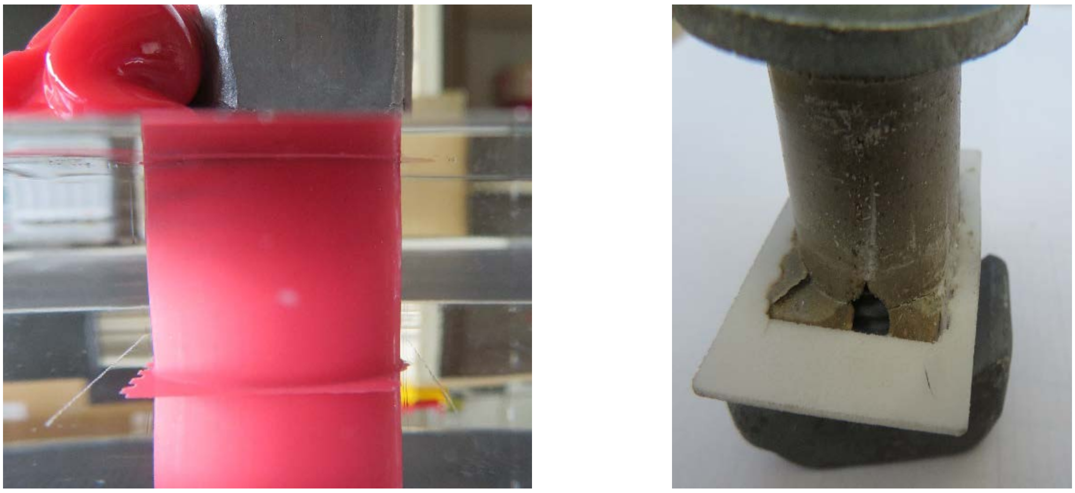
Table 1: Filling tests for the selection of the injection mortar

Purpose of the test	Number of tests	Storage	Hardening	Time of hardening
Type of mortar	4	20°C	20°C	24h - 528h
Low temperature	1	5°C	5°C	24h
High temperature	1	40°C	40°C	24h

In the first step, the mortar type was investigated on the basis of four different products. Two types of vinylester based mortars and two epoxy resins were chosen. They were stored, filled and hardened at a room temperature of 20°C. Afterwards, the most suitable mortar was further studied under the influence of different temperatures in the range between 5°C and 40°C.

The filling tests were carried out on a hot-rolled channel profile of type 53/34 in combination with a hooked channel bolt of size M20, as used in the fatigue tests. The installation of the gap filler set and the injection of the mortar was executed as described in Section 3. A plexiglass plate of 100 x 100 x 20 mm with 22 mm of clearance hole was used as an attachment to observe the filling of the injection mortar in the insert.

As exemplary shown in Fig. 6, the tests with the epoxy mortar have provided better results than with vinylester. The epoxy filling was evenly distributed in the insert so that no cavities could be observed. The epoxy mortar tested also proved to be suitable at the different temperature levels, although changes in viscosity properties were noticed. The use at more extreme temperatures can therefore not be recommended so far.



(a) Results with epoxy mortar *(b) Results with vinylester mortar*

Fig. 6: Photographs of filling tests

5. FATIGUE TESTS

The test program comprised three test series at different load levels with either constant lower load, upper load or mean load. The test specimens were subjected to shear load perpendicular to the channel axis. Series 1 and 2 were performed in the pulsating range to investigate the influence of the static load level. The impact of alternating loads on the fatigue resistance was investigated in Series 3. For each series four fatigue tests were carried out as constant amplitude tests with various load ranges of $\Delta F_{1\text{-}4}$ = 60, 40, 30, 25 kN. The static resistance of the tested specimens was determined as F_{stat} = 130.9 kN, while steel failure of the channel bolt was observed.

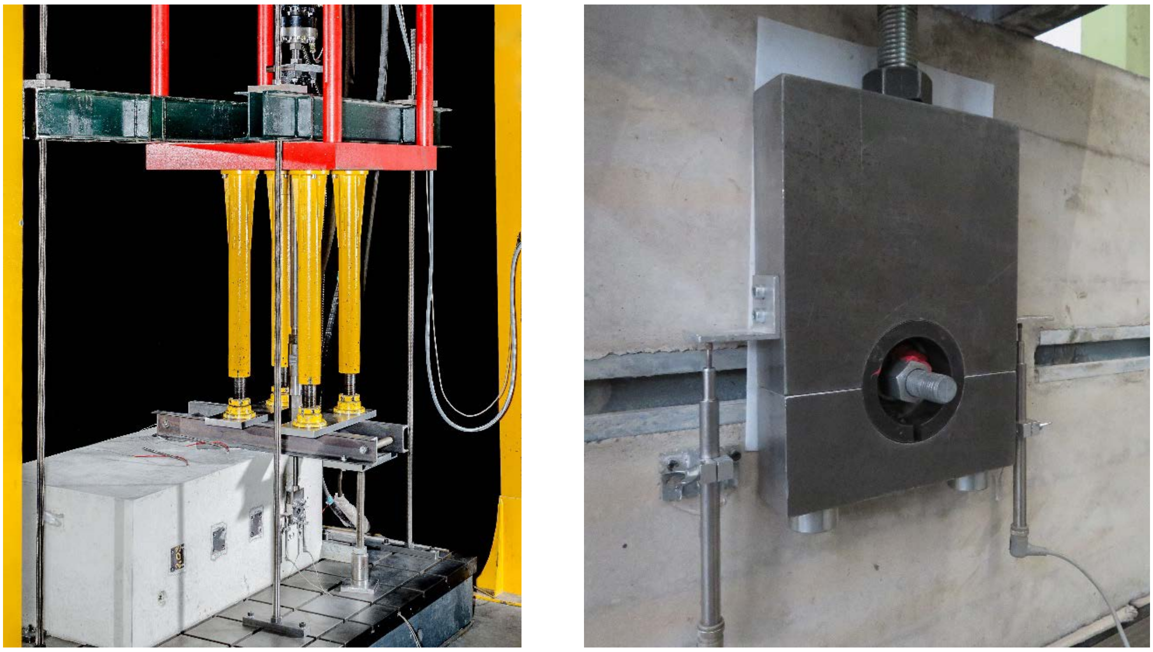
Table 2: Test program

No.	Test description	Load level	Number of tests
Series 1	Pure fatigue load	Lower load F_{lo} = 1 kN	4 (V01-V04)
Series 2	High load level	Upper load F_{up} = 78 kN	4 (V11-V14)
Series 3	Alternating load	Mean load F_m = 0 kN	4 (A01-A14)

For the fatigue tests, the same anchor channels of type 53/34 as in the filling tests were used. Specimens with two anchors and an anchor centre distance of 250 mm were embedded in non-cracked concrete specimens of strength class C20/25 with sufficient large edge distance to achieve steel failure. The load was applied via the channel bolt M20 of strength class 8.8 located directly over one of the two anchors. In all the tests, the bolt was provided with the patented gap filler set described in Section 3. The installation torque of T_{inst} = 120 Nm applied to the channel bolt was reduced to 20% to account for time-dependent relaxation of the prestressing force. Afterwards, the epoxy mortar selected in Section 4 was injected through the special nut in the injection insert and was hardened for at least 10 hours until testing.

The tests were carried out using a test stand with a servo-hydraulic 250 kN cylinder of type MFL as shown in Fig. 7. The shear load was applied parallel to the concrete side surface via a 50 mm thick steel plate with an insert sleeve having a thickness of 20 mm. One Teflon layer was placed between the loading plate and the concrete surface to reduce friction. A pendulum rod with two spherical joints was provided between the cylinder and the fixture to avoid unintended bending.

The loading frequency was chosen between 1 Hz and 7 Hz depending on the respective load range. The load of the cylinder was measured by means of a calibrated load cell. Two linear variable differential transformers (LVDTs) were used to capture the displacements of the anchor channel relative to the concrete surface in the direction of the applied load.



(a) Overview of test setup *(b) Detail of load introduction*

Fig. 7: Experimental setup for fatigue shear tests

6. TEST RESULTS

The test results comprising the fatigue resistance, failure modes and displacement behavior obtained in the fatigue tests are summarized in the following section.

6.1 Fatigue resistance

In Fig. 8, the results of the fatigue tests are shown in an S-N diagram with double logarithmic scaling. In addition, the regression line for each series is provided, which were determined by the least square method taking the number of load cycles as dependent variable.

It can be seen that both test series under pulsating shear load show comparable results. However, the slope of the S-N curve for Series 1 at F_{lo}=1 kN is m=4.5 and thus somewhat flatter than for Series 2 at constant upper load of F_{up}=78 kN, which corresponds to 60% of the static resistance, with a slope coefficient of m=3.4. This indicates that the static load level has a slight impact on the fatigue resistance.

All tests performed under alternating shear result in a higher number of load cycles for the tested load ranges than under pulsating shear. Hence, no negative effect on the fatigue resistance could be observed in these tests, if there is no hole clearance within the anchor channel system.

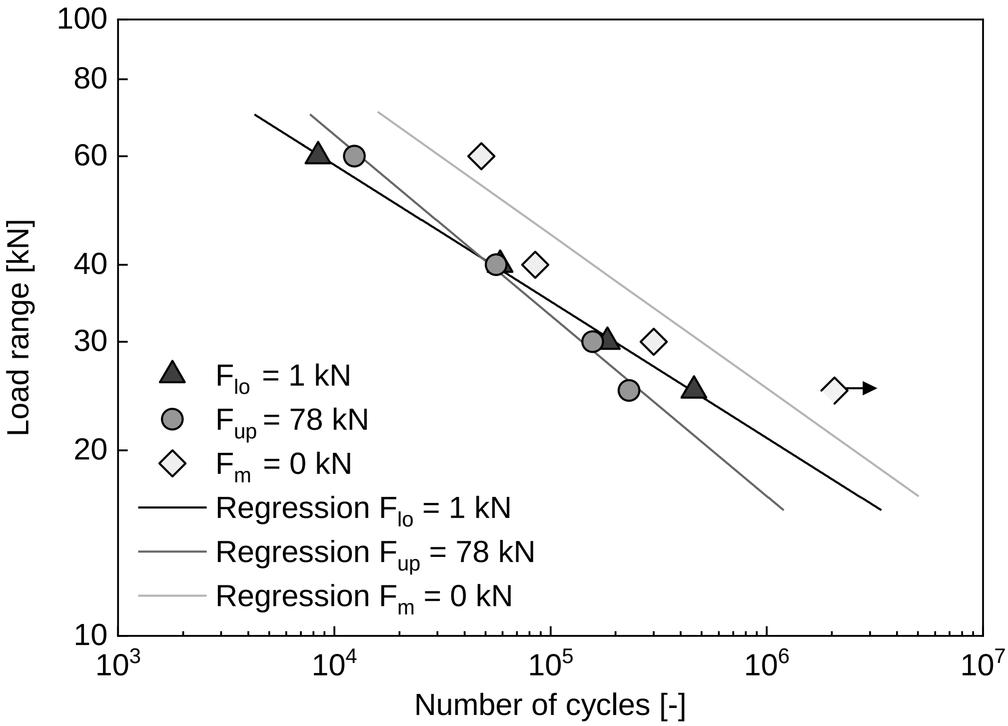


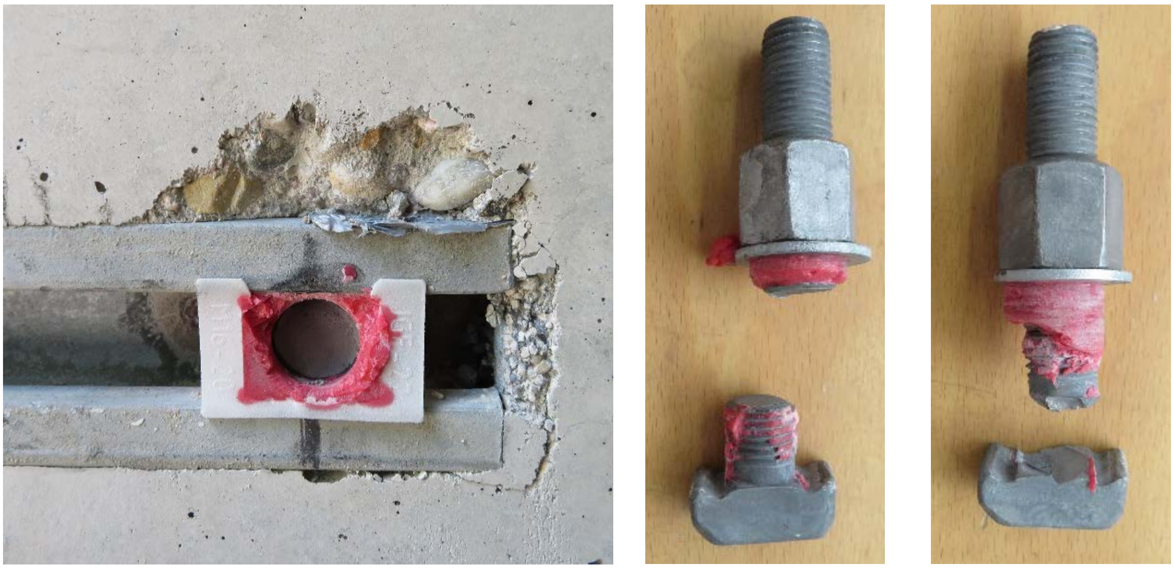
Fig. 8: S-N diagram of fatigue tests under perpendicular shear load

6.2 Failure mode

In all tests, steel failure of the channel bolt was observed as exemplary shown in Fig. 9. The failure was accompanied by slight local bending of the channel lip and associated concrete damage close to the surface in the direction of loading.

The failure of the channel bolt was caused by fatigue cracks initiated at typical notch details. Hence, the failure was located either in the thread of the bolt in the area of the fixture or in the transition area between the shaft and the head of the bolt. Furthermore, in the tests with a low load range of ΔF = 25 kN a combination of both failure locations was observed.

Under alternating shear, a deterioration of the injection mortar was apparent, which leads to an increase of the displacement values obtained in these tests as shown in the following section.



(a) Steel failure of channel bolt *(b) Bolt thread* *(c) Bolt head*

Fig. 9: Typical failure modes observed in the fatigue tests

6.3 Displacement behavior

The measured data of the two LVDTs was evaluated to analyze the damage progress of the anchor channel under shear load leading to failure. Fig. 10 shows the displacement range in shear direction between upper and lower load for all tests. For better comparability, the results obtained for each test are plotted as function of the related number of cycles to failure.

In general, the displacement behavior during the tests can be described by an almost constant rate up to about 75%-90% of the fatigue life. The beginning of failure was characterized by a progressive increase of the maximum displacements, which can also be seen by the increased values of the displacement ranges.

In both test series under pulsating shear, an increase of the displacement ranges was identified with increasing load ranges. The damage behavior in Series 3 was somewhat different, where noticeable displacement growth was found even at lower load levels. The alternating tests tends to show larger displacement ranges than the other two series, which can be explained by the damage of the injection mortal. As can be seen in the diagram, the displacement values at 98% of the number of cycles to failure were up to about 3 mm, which corresponds to 16% of the maximum displacement observed in the static test at ultimate load.

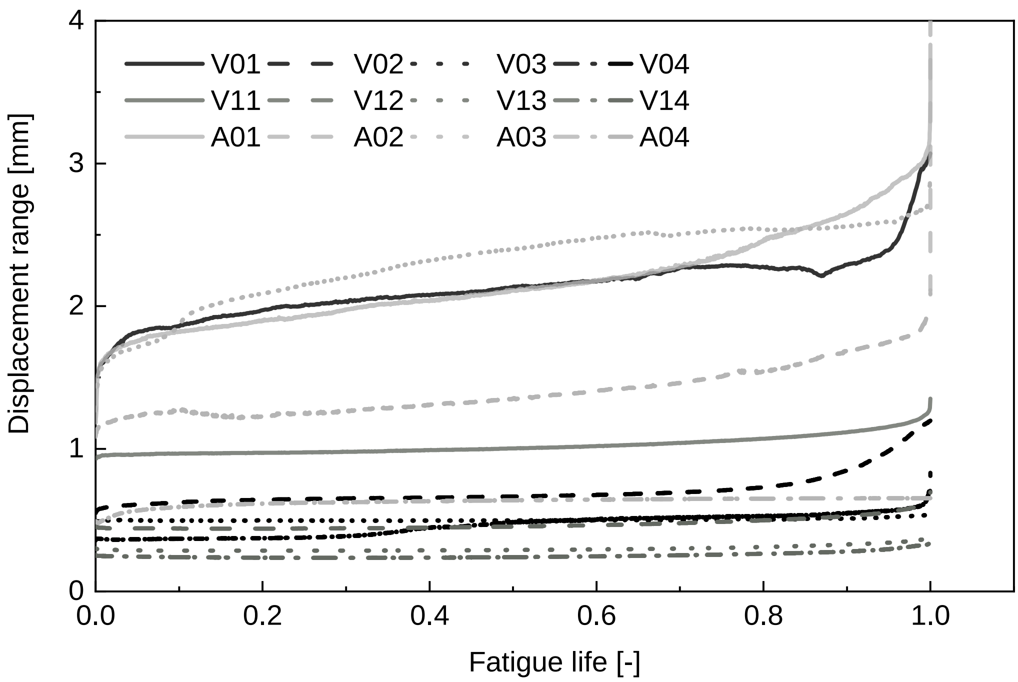


Fig. 10: Displacement range during fatigue life

7. CONCLUSION AND OUTLOOK

Anchor channels are used in many different areas in the construction industry. They are subjected to different loads in various directions. Thereby, fatigue relevant shear loads or combinations of tensile and shear loads can occur. However, the current provisions for fatigue design are limited to tensile forces due to the fact that the existing hole clearance within the anchor system can cause non-permissible impact loads in case of alternating shear.

Based on the results presented in this study, it could be shown that anchor channels can also be used to transmit fatigue relevant shear loads, if the hole clearance is eliminated by suitable constructive measures. Even though the investigations focus on tests under perpendicular shear, the findings can serve as a basis to extent the fatigue design of anchor channels in both directions under shear load and thus also the interaction under combined tension and shear loads becomes relevant.

Anchor channel close to the edge and subjected to shear can also exhibit concrete related fatigue failure. These cases have not yet been investigated in detail. Furthermore, the distribution of shear loads to the anchors is still an open question, as the previous knowledge has been limited to static investigations.

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REFERENCES

[1] EN 1992-4: *Eurocode 2 - Design of concrete structures-Part 4: Design of fastenings for use in concrete*. Beuth Verlag, Berlin, 2018

[2] EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT (EOTA) TR 047: *Design of Anchor Channels*. Brussels, Belgium, 2018

[3] CEN/TR 17080: *Design of fastenings for use in concrete - Anchor channels – Supplementary rules*, Beuth Verlag, Berlin, 2018

[4] EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT (EOTA) TR 050: *Calculation Method for the Performance of Anchor Channels under Fatigue Loading*. Brussels, Belgium, 2018

[5] WOHLFAHRT, R.: *Tragverhalten von Ankerschienen ohne Rückhängebewehrung*. PhD Thesis, University of Stuttgart, 1996

[6] POTTHOFF, M.: *Tragverhalten und Bemessung von Ankerschienen unter Querbelastung*. PhD Thesis, University of Stuttgart, 2008

[7] KRAUS, J.: *Tragverhalten und Bemessung von Ankerschienen unter zentrischer Zugbelastung*. PhD Thesis, University of Stuttgart, 2003

[8] SCHMID, K.: *Tragverhalten und Bemessung von Befestigungen am Bauteilrand mit Rückhängebewehrung unter Querlasten rechtwinklig zum Rand*. PhD Thesis, University of Stuttgart, 2009

[9] OLUOKUN, F.; BURDETTE, E.: *Behavior of channel anchors in thin slabs under combined shear and tension (pullout) loads.* ACI Struct J. 1993, 90(4), 407-413

[10] SCHMIDT, T.: *Tragverhalten von Ankerschienen unter Querlast in Schienenlängsrichtung*. PhD Thesis, University of Stuttgart, 2017

[11] KONERTZ, D.; KOCUR, G.K.; HÄUSLER, F.; MARK, P.: *Longitudinal shear transmission of anchor channels into concrete–An experimental approach.* Structural Concrete 2020, 1-13

[12] GÜREŞ, S.: *Zum Tragverhalten von Ankerschienenbefestigungen unter nicht ruhenden Beanspruchungen*. PhD Thesis. Ruhr University Bochum, 2005

[13] JORDAHL GMBH: (2017). *Injektionseinsatz. Utility model No. DE202017005582 U1*. München, Deutsches Patent- und Markenamt, 2017