TESTING OF FASTENERS UNDER STATIC LOAD WITH REPEATED CRACK OPENING

ÜBERPRÜFUNG VON BEFESTIGUNGSMITTELN UNTER STATISCHER BELASTUNG BEI WIEDERHOLTER RISSÖFFNUNG

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SUMMARY

In the building industry, planning is often delayed due to long construction periods. For this reason, post-installed fasteners on buildings are used. Tensile and compressive zones in reinforced concrete components are often not exactly determinable and also cracks that occur cannot be foreseen or planned. Since the load and the resulting crack width vary in the course of the lifetime of reinforced concrete components, tests are carried out with crack width changes under a static permanent load. Suitability tests are not always clearly regulated or the limit conditions are not clearly defined. Some scope is then possible in the execution of the test.

In this article, suitability tests are presented in which anchors are stressed under cyclic crack opening in concrete with a static load.

An alternative test control system is described to the usual test execution, which is possible under the limit conditions. It is shown that a different interpretation of the test performance of the qualification test, according to ETAG 001, Table 5.1/line 5, has an influence on the test result. A clear regulation and definition of the performance of the test is essential and should be clearly specified. In this way, an individual design of the crack control can be avoided.

ZUSAMMENFASSUNG

Im Bauwesen ist aufgrund der langen Bauzeiten die Planung oft terminlich nachläufig. Aus diesem Grund sind nachträgliche Befestigungen an Bauwerken der Regelfall. Zug- und Druckzonen sind in Stahlbetonbauteilen oft nicht exakt zu bestimmen und somit auch auftretende Risse nicht vorhersehbar oder planbar. Da die Belastung und die daraus folgende Rissbreite im Laufe der Lebensdauer

von Stahlbetonbauteilen variieren, werden Versuche mit Rissbreitenänderung unter einer statischen Dauerlast durchgeführt. Da die Eignungsversuche jedoch nicht immer eindeutig geregelt, bzw. die Randbedingungen nicht klar definiert sind, ist bei der Versuchsdurchführung ein gewisser Spielraum möglich.

In diesem Beitrag wird ein Eignungsversuch vorgestellt, bei welcher eine Befestigung unter einer statischen Last und unter zyklischer Rissöffnungen im Beton beansprucht wird

Es wird zur üblichen Versuchsdurchführung eine Alternative Versuchs-steuerungen beschrieb, die im Rahmen der Randbedingungen möglich ist. Es zeigt sich, dass bei unterschiedlicher Auslegung der Versuchsdurchführung des Eignungsversuches nach ETAG 001, Tabelle 5.1/Zeile 5, durchaus einen Einfluss auf die Versuchsergebnisse hat. Eine klare Regelung und Definition der Versuchsdurchführung ist hierbei von großer Bedeutung und sollte dabei klar festgelegt werden. Dadurch kann eine individuelle Auslegung der Risssteuerung vermieden werden.

1. INTRODUCTION

In the suitability tests according to ETAG 001 different influences are examined. One of the factors examined is the properties of the anchoring substrate, which may deviate from the ideal conditions in the laboratory. In this paper the tests with crack width changes (Functioning in crack movements) are dealt with. The aim of these tests is to ensure the long-term use of anchors in cracked concrete. It has to be ensured that fasteners function permanently under a static load, also if they are in cracks.

The performance of the test according to ETAG 001 Annex A is not explicit regulated and some scope in the performance of the test is possible.

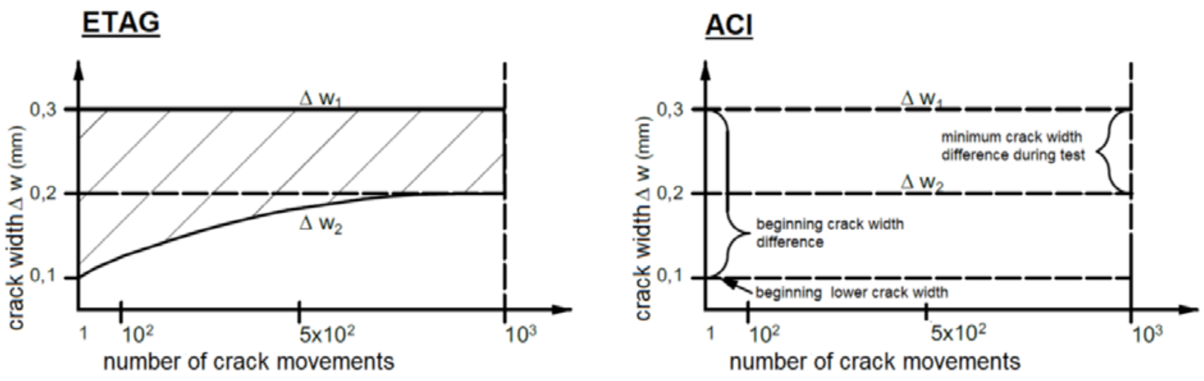


Fig. 1: Different representation of the allowable crack opening variations during the crack movement test (Functioning in crack movement) according to [1, 2]

In this test, a linear hairline crack is produced in a special reinforced concrete test member and then the anchor is installed in the closed hairline crack in accordance to manufactures printed installation instruction. The crack is then opened to 0.3 mm, a centric permanent load is applied to the anchor and the crack is opened and closed 1000 times. The usual test procedure is shown in Fig. 1 on the right. In the course of the test, the upper crack width Δw_1 is kept approximately constant at 0.3 mm, while the lower crack Δw_2 is allowed to run freely from 0.1 mm to a max. of 0.2 mm. If the lower crack width of Δw_2can no longer be closed at ≤ 0.2 mm, the upper crack width Δw_1must be opened further so that a difference Δw_1-$\Delta w_2 \geq 0.1$ is guaranteed. The crack opening procedure is load controlled and no attempt is made to close the crack by external pressure, e.g. with a hydraulic cylinder, if the crack is opened too wide.

In ETAG 001 Annex A a curve is shown (Fig. 1 left), where a precise course of the lower crack width development is shown. This curve runs from 0.1 mm to 0.2 mm via the crack changes. As an alternative to the usual test procedure, the crack width could be run with displacement control. Here the lower crack width is driven along the Δw_2-curve. Exceeding the upper and lower crack width can be controlled by changing the load on the reinforcement of the crack from outside. This is possible by reducing the tensile load on the test specimen and in extreme cases by pressing, for example with a hydraulic cylinder. Compression of the test specimen is expected especially at the beginning of the test, since the lower crack width Δw_2 must close the furthest in the first few crack cycles.

The aim of this paper is to investigate the behaviour of an anchor, especially its behaviour under load, when crack propagation is imposed.

2. TEST DESCRIPTION

2.1 TEST SETUP OF THE MEASURING SYSTEM

The experimental setup can be divided into two components: In the tensile load application to the anchor and in the tool for crack opening of the test member. Fig. 2 shows a schematic representation of the loading set-up for illustration purposes.

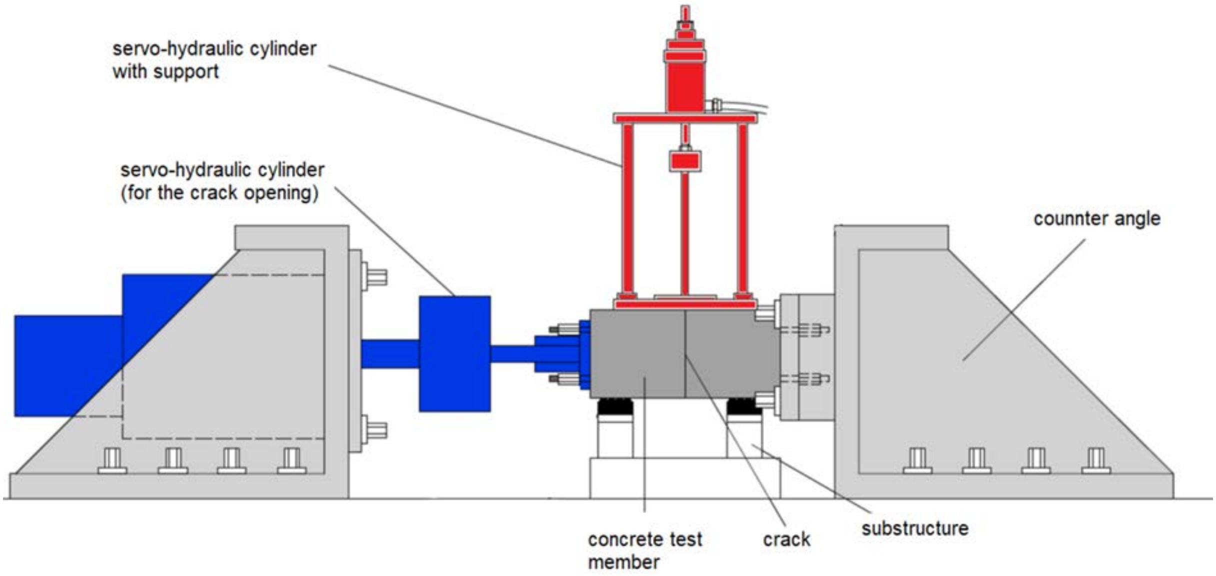


Fig. 2: Schematic representation of the loading setup for fasteners under static load with repeated crack opening

The crack initiation apparatus is made of a servo-hydraulic cylinder and an angle fixture. The test member is secured against displacement by the reinforcement at the angle fixture and is additionally fixed to the servo-hydraulic cylinder (Fig. 2). By attaching the cylinder to the reinforcement, a tensile force can be applied to the longitudinal reinforcement of the test member and thus cause a crack. The cylinder has an integrated load cell with which the applied force is measured. The cylinder is controlled via the measuring cabinet.

The device for applying the tensile load to the anchor requires a second hydraulic cylinder with load cell to measure the applied forces. This is placed over the anchor to be loaded with a support (Fig. 2). A threaded rod connects it in a loading plate so that the load is transferred to the anchor by extending the cylinder (Fig. 3). In the course of the test, the force generated and the vertical displacement of the anchor are continuously recorded.

The vertical displacement of the anchor is recorded with a displacement sensor via direct measurement. The displacement transducer is fixed in a frame, which is placed directly above the anchor and fixed to the concrete test member.

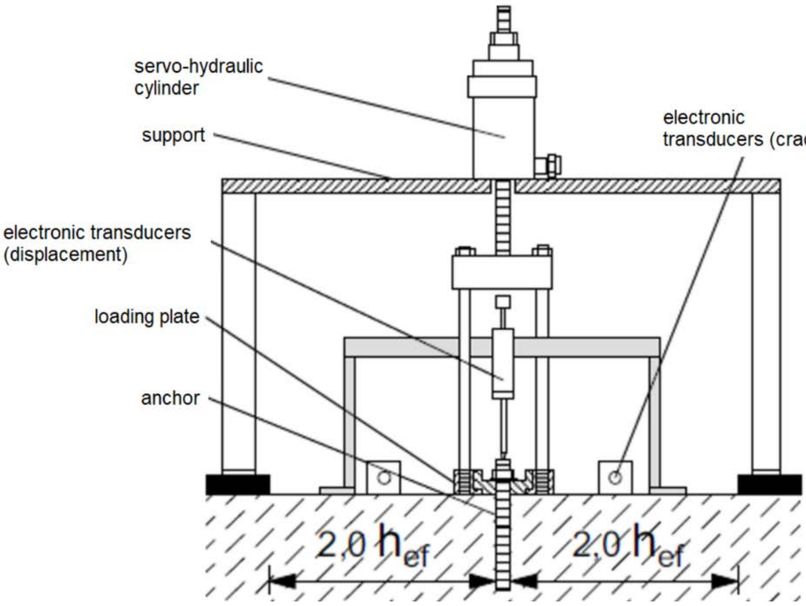


Fig. 3: Loading setup for tensile tests away from edges in cracked concrete according to [3]

The crack width is measured with two displacement transducers. These are glued to the crack left and right of the anchor above the crack, on the surface of the concrete. The displacement of an angle which is glued on the opposite side of the crack is measured (Fig. 4) [3].

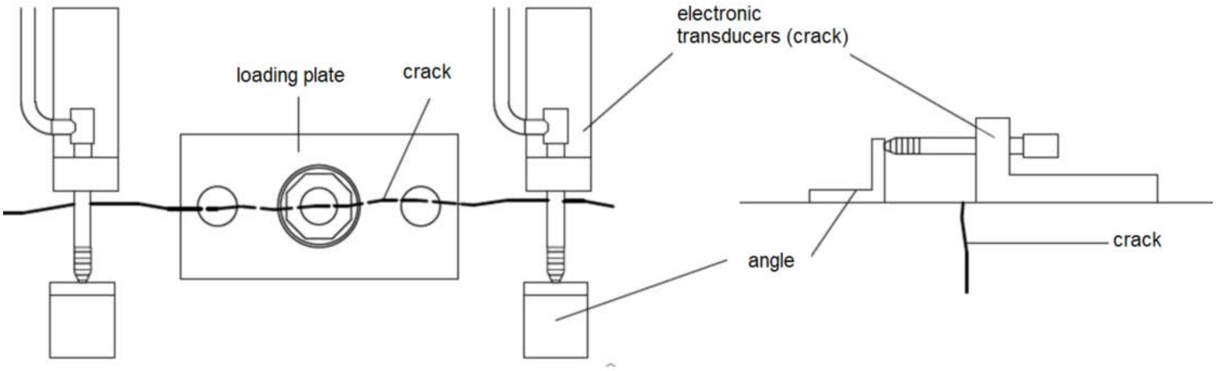


Fig. 4: Arrangement of the crack sensors for measuring the crack displacement

For the tests, concrete screws with a European Technical Approval for cracked concrete were used. The test specimens used as anchor base had a strength class of C20/25 and had constructive measures to cause a targeted crack in the axis of the concrete screw.

2.2 DISPLACEMENT-CONTROLLED CRACK OPENING AS AN ALTERNATIVE

In principle, the displacement-controlled test procedure uses the same test set-up as the load-controlled test procedure. The only difference here is the crack width recording. For the load-controlled test, two displacement transducers are used, which are connected to the measuring cabinet and only serve for data recording. In the case of the displacement-controlled test execution, two special crack sensors are used which are connected to the control cabinet. The entire test is completely controlled by a program. The crack sensors communicate continuously with the control cabinet and determine the tensile and compressive load required to achieve the set crack width.

In this test procedure, no test cycles for crack stabilisation are carried out and the first ten crack movements also do not have to be run manually. These steps are omitted because the load is controlled depending on the recorded crack width.

The crack is opened to 0.3 mm, then the permanent load is applied to the anchor and the anchor goes through the 1000 crack changes. In the displacement-controlled crack opening, the upper and lower load on the test specimen is continuously changed in order to keep the set crack widths.

The program controls the lower and upper crack by changing the amplitude and the average value. This procedure is shown below for illustration in Fig. 5.

The Δw_2-curve is reached stepwise via the crack width increase depending on the cycles. In the first step, the mean value of the crack width is set to 0.2 mm with a crack width amplitude of 0.1 mm. In this way the crack oscillates between 0.1-0.3 mm. After 41 crack cycles the average value is increased to 0.205 mm and the amplitude is decreased to 0.095 mm. Thus the crack width Δw_1 remains at 0.3 mm and the crack width Δw_2 increases to 0.11 mm. This process is repeated with a fixed number of oscillations at different mean values and amplitudes until the 1000 crack cycles are completed. The number of average values and amplitudes passed through are shown in Table 1.

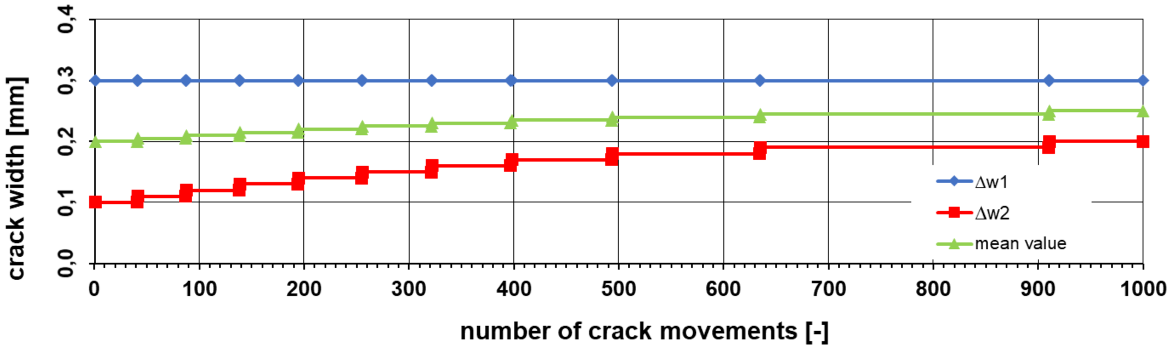


Fig. 5: Illustration of crack opening with displacement-controlled crack

Table 1: Mean values and amplitude values for determining the crack width

Crack cycles [-]	**Mean value** [mm]	**Amplitude** [mm]	**Crack width Δw_1** [mm]	**Crack width Δw_2** [mm]
1-41	0.200	0.100	0.3	0.100
42-87	0.205	0.095	0.3	0.110
88-138	0.210	0.090	0.3	0.120
139-194	0.215	0.085	0.3	0.130
195-255	0.220	0.080	0.3	0.140
256-321	0.225	0.075	0.3	0.150
322-397	0.230	0.070	0.3	0.160
398-493	0.235	0.065	0.3	0.170
494-635	0.240	0.060	0.3	0.180
635-909	0.245	0.055	0.3	0.190
910-1000	0.250	0.050	0.3	0.200

3. RESULTS AND DISCUSSION

3.1 ANCHOR DISPLACEMENT AFTER 1000 CRACK CHANGES (CONCRETE SCREW)

For displacement controlled crack opening, the set limits were kept. This leads to a crack width difference of 0.2 mm at the beginning which decreases to 0.1 mm at the end (Fig. 6).

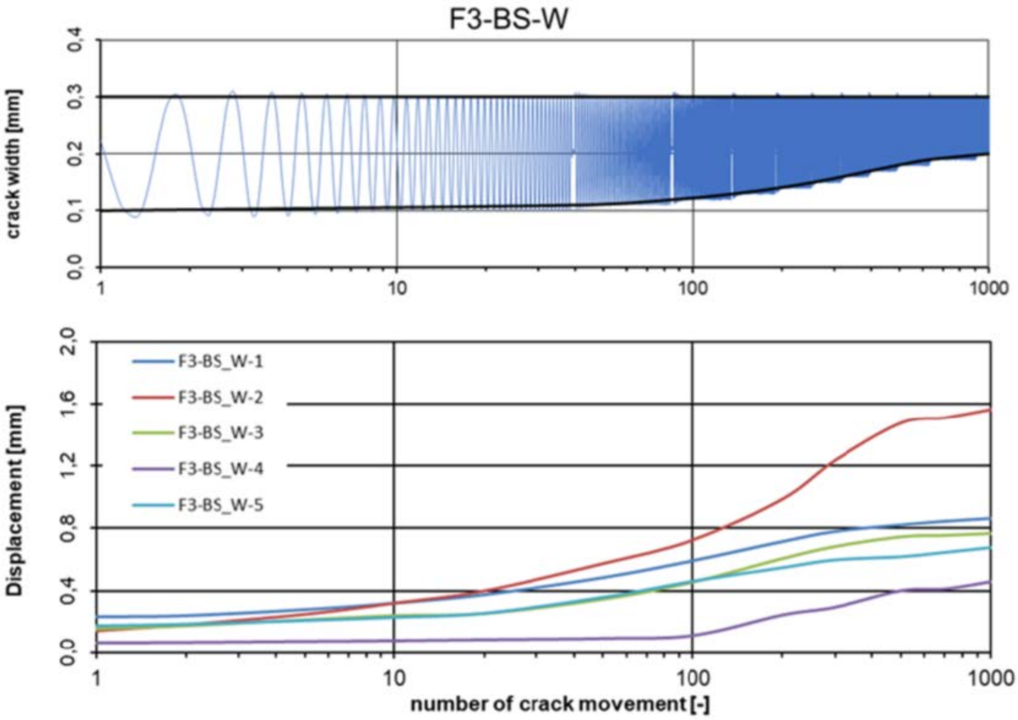


Fig. 6: Crack widths and fasteners displacements of the tests with concrete screws under displacement-controlled crack opening

With load-controlling, the lower crack width Δw_2 usually increased faster in the first 200 crack changes than in the tests with displacement-controlling. After about 200 crack changes the lower crack width mostly stabilized and remained almost constant at a value of $\Delta w_2 \leq 0.2$ mm. For the upper crack width $\Delta w_1$1the upper load had to be reduced in some tests to keep the upper crack width constant at Δw_1= 0.3 mm. A short-term exceeding of the upper crack width could not be avoided (see Fig. 7).

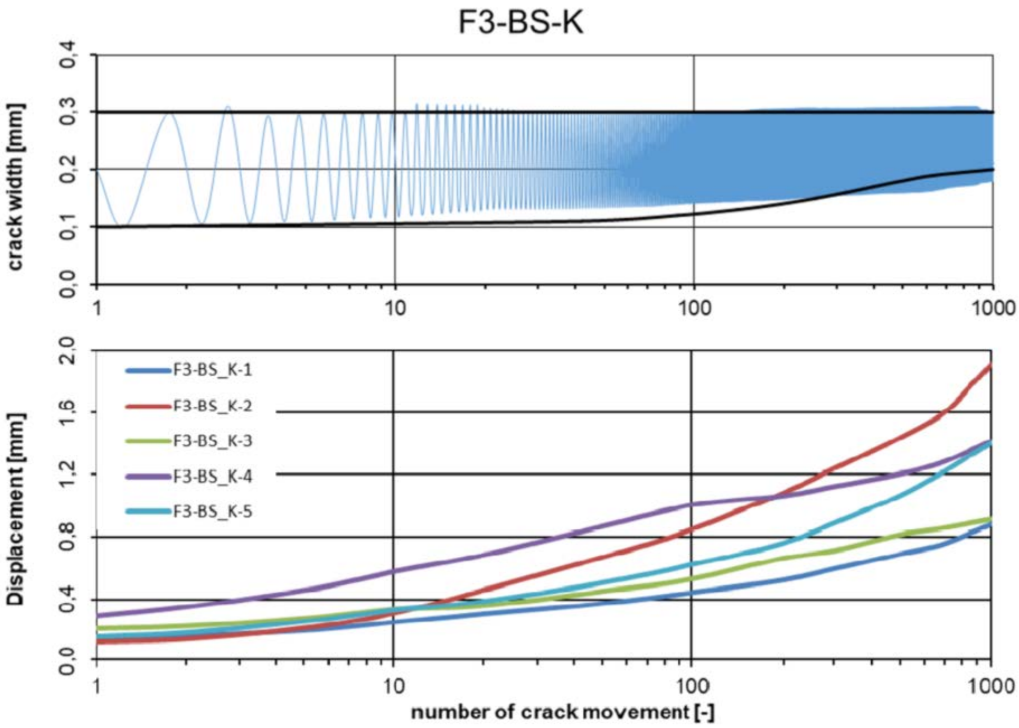


Fig. 7: Crack widths and fasteners displacements of the tests with concrete screws under load-controlled crack opening

The concrete screws were loaded with a permanent load of N_p = 4.0 kN. With this tensile force on the anchor the requirements for crack development could be kept. The permitted displacements of the concrete screw could also be kept in all tests.

A stabilization of the displacement of the fastener could not always be guaranteed with load controlled and displacement controlled crack opening. According to ETAG 001 Annex A this is achieved if the increase in displacement during cycles 750 to 1000 is smaller than that during cycles 500 to 750.

The displacement under load-controlled crack opening showed an average of 15 % higher displacement, which could not stabilize significantly in almost all tests (Fig. 7). In the case of displacement controlled crack opening, a stabilization of the anchor movement can be seen (Fig. 6).

3.2 ULTIMATE LOAD CAPACITY/ FAILURE LOAD (CONCRETE SCREW)

The results of the ultimate load capacity of the concrete screws are summarized in the following Table 2. In addition, the results of the different series of concrete screws are shown as load-displacement diagram in Fig. 8.

The load displacement curves of the different series do not show any significant differences in the development. What is clearly visible is that the load-displacement curves of the F3-BS-W series (BS = concrete screw; W = displacement-controlled crack opening) show a very similar development, while the F3-BS-K series (BS = concrete screw; K = load-controlled crack opening) show significant variation.

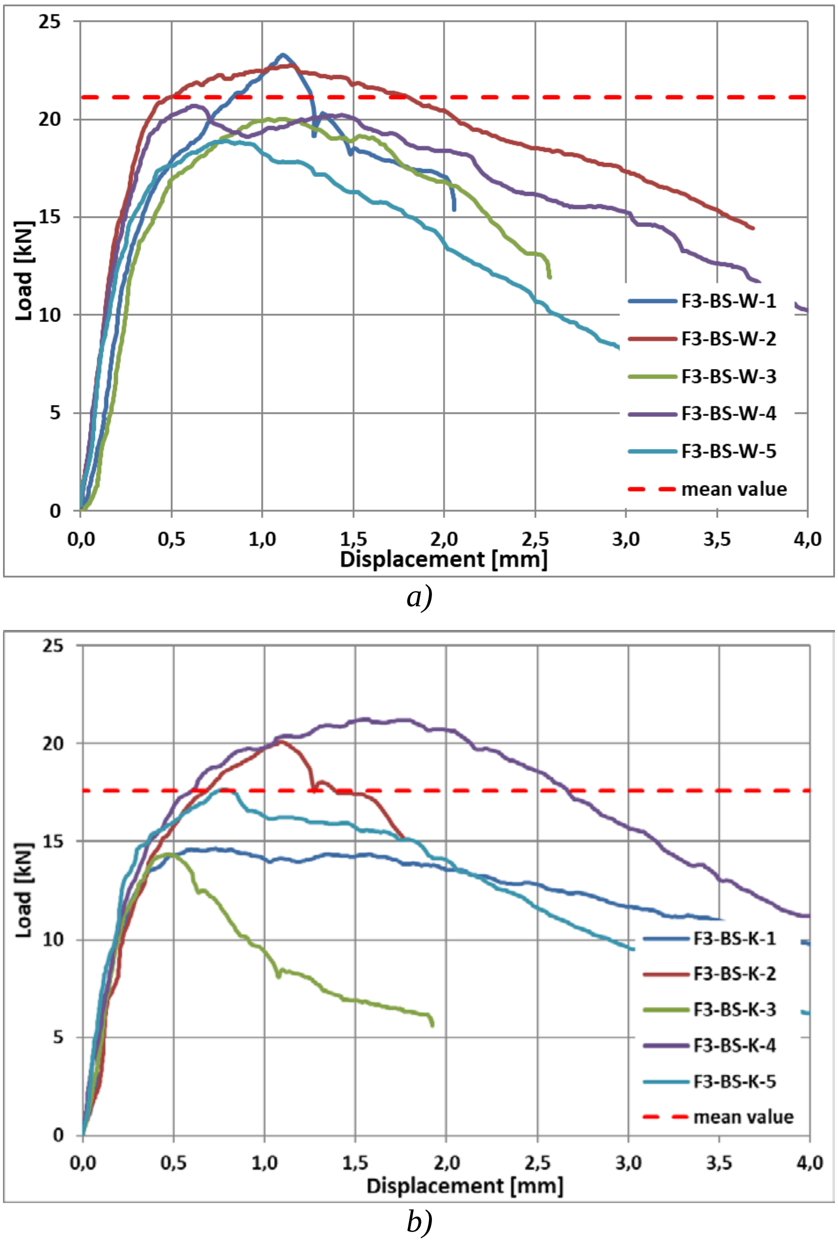


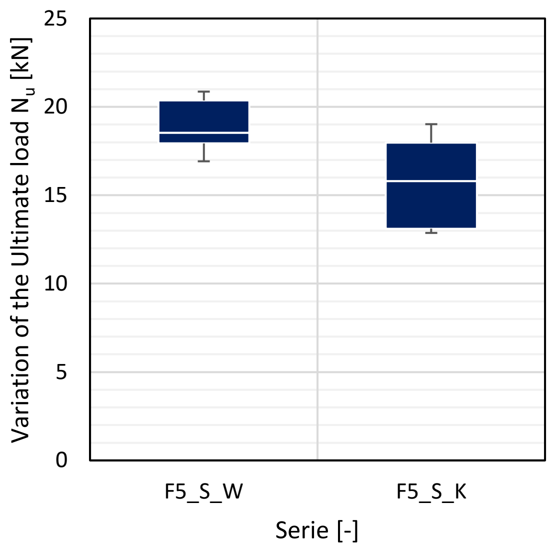
Fig. 8: Load-displacement curves of the residual capacity of the series F3-BS-W a) and F3-BS-K b)

A comparison of the two series clearly shows that the maximum loads of the F3-BS-W series have a 20% higher value on the normalized average than the F3-BS-K series (Fig. 9). At the same time, the maximum loads of the F3-BS-K series have 80% higher variability compared to the F3-BS-W series.

In Table 2 and Fig. 9, the mean values of the ultimate loads (normalized to concrete compressive strength of 25 N/mm²) and the variation coefficient are listed and shown above.

Table 2: Test results of the ultimate load Nu of series F3-BS-W and F3-BS-K

Fastener	**Series**	**Mean value normalized** $N_{u,n,m}$ **[kN]**	**Coefficient of variation** s **[-]**
Concrete screw (BS)	F3-BS-W	18.92	1.85
	F3-BS-K	15.75	2.78



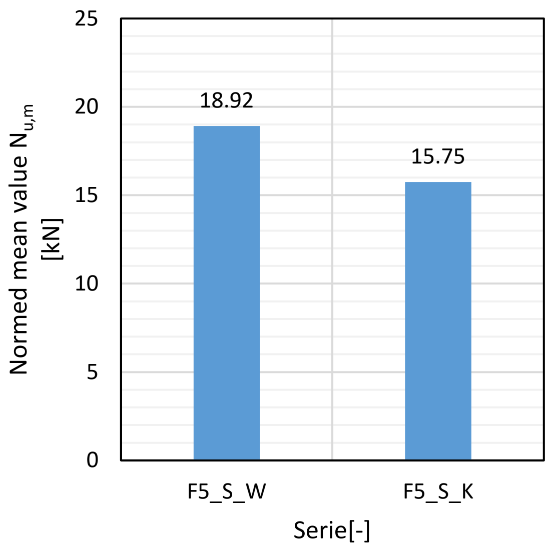


Fig. 9: Normalized ultimate loads with variation a) and mean value b) in tests with concrete screws

3.3 CONCLUSION

ETAG 001 part 1, gives suitability tests for anchors for use in cracked and non-cracked concrete. Table 5.1 / line 5 gives a test to check the functionality in case of crack opening (so-called crack movement test).

In this test, an anchor in cracked concrete is loaded with a constant tensile load N_P. Under this tensile load, a cyclic opening procedure of the ground is performed.

When performing the test according to ETAG 001 Annex A or according to TR 048, it is shown that a different interpretation of the test execution is possible. The results of the test can be influenced by defining different parameters such as the crack movement control in the performance of the test.

The tests show that a displacement controlled crack opening is possible, since all boundary conditions were kept. The strict application of crack course by displacement-controlled crack opening did not show a negative influence on the ultimate load capacity in any test series compared to the conventional performance of the test. Similar results could be observed in the two different control methods.

With regard to economy and time saving, the displacement-controlled performance of the test is a good alternative. With this method, due to automatic control, no test cycles are performed to stabilize the crack and the first ten cycles do not have to be run manually. This leads to a significantly faster performance of the test.

According to ACI the performance with displacement-controlled crack movement is not allowed. ACI 355.4-11 clearly states that the crack movement depends on the fastener itself and therefore must not be controlled from the outside.

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