BONDED ANCHORS UNDER CYCLING SUSTAINED LOADS

VERBUNDDÜBEL MIT ZYKLISCHER DAUERBELASTUNG

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SUMMARY

The long-term performance of bonded anchors is crucial for structural integrity. Creep behaviour of bonded anchors is evaluated for constant sustained load. Service loads sustained by anchors can vary during service life. This study is an attempt to understand the creep behaviour of bonded anchors subjected to variations in the sustained load. An experimental program executed to meet this end is discussed in this paper. Sustained load tests with different long period load cycling amplitudes were performed. A comparison of displacement-time behaviour of the different cases provides insights into the adverse effects of cycling of loads on the creep behaviour.

ZUSAMMENFASSUNG

Die Dauerhaftigkeit von Verbunddübeln ist entscheidend für die strukturelle Integrität. Das Kriechverhalten von Verbunddübeln wird bei konstanter Dauerlast bewertet. Die von den Dübeln getragenen Lasten können während der Nutzungsdauer variieren. Diese Studie ist ein Ansatz zum Verständnis des Kriechverhaltens von Verbundankern, die unterschiedlichen Dauerlasten ausgesetzt sind. Ein zu diesem Zweck durchgeführtes Versuchsprogramm wird in diesem Beitrag diskutiert. Es wurden Dauerlastversuche mit verschiedenen langperiodischen Lastwechselamplituden durchgeführt. Ein Vergleich des Weg-Zeit-Verhaltens der verschiedenen Fälle gibt Aufschluss über die nachteiligen Auswirkungen der Lastwechsel auf das Kriechverhalten.

1. INTRODUCTION

Bonded anchors are very popular in fastening technology because of the ease and flexibility associated with their installation. The development of high strength and fast curing products have further optimized the overall application of bonded anchors. The creep behaviour of adhesive anchors is known to be problematic in practice. Creep behaviour can lead to sudden and brittle failure of the anchors at lower loads relative to the load capacity. The Boston tunnel accident [1], [2], is a popular example of failure of bonded anchors because of creep. Fastening technology experts have worked towards methods for considering the effects of creep in the design process. Notable studies in this direction have been reported by [3], [4]. The perspectives from these studies have manifested as guidelines for safe consideration of the creep effects of adhesive anchors in EN 1992-4 [5], ACI 318 [6], EAD 330499 [7] and ACI 355.4 [8].

The procedure adopted for evaluation of a safe load level that could be sustained throughout the service life is essentially same in both US [6], [8] and Europe [5], [7]. Independent expressions for level of safe sustained load N_{sust} are proposed in [7] and [8]. Under the prescribed safe sustained load N_{sust}, displacement-time curves are evaluated using specified procedures. An extrapolation of the displacement is done as a power function of the time, to evaluate the projected displacement at the end of service life (typically 50 or 100 years). The assessment criteria for safely sustaining the loads is a condition that the projected displacement should be lesser than the limiting displacement at loss of adhesion evaluated using the reference tests. If the assessment criteria is not satisfied, the level of N_{sust} is reduced by a factor α_{sust} and the test procedure is repeated till a safe load level satisfying the displacement criteria is obtained. It is noted here that the sustained load behaviour is product dependent, and each adhesive anchor product is evaluated independently. A time-to-failure experimentation approach [4], [9] is a rational method to estimate the safe load level N_{sust}.

2. RESEARCH MOTIVATION AND OBJECTIVE

The investigations and evaluation of creep behaviour is conducted for a constant sustained load over the entire service life. However, the service loads are expected to vary during the service life. The creep displacements occurring along the service life tend to typically reduce the load in individual anchors because of loss of tightening torque. During maintenance, the nuts for anchorages are re-tightened as a standard practice. Furthermore, the redistribution of loads can cause increase in the loads on individual anchors. Thus, the load in the anchor could vary over a certain amplitude about the service load level.

This study attempts to generate preliminary insights on the consequence of deviations of anchor loads from the service load level on the long-term creep behaviour of bonded anchors. A test program executed at IWB, University of Stuttgart to meet this end is described in this paper. The behavioural insights based on the test results are discussed. In this process, attention is drawn towards open questions for further investigations. By combining sustained service load tests with deviations in the load level, this research seeks to provide comprehensive behavioural insights on the realistic creep behaviour of bonded anchorages.

3. TEST PROGRAM AND PROCEDURE

The test program conducted in this work is summarized in Table 1. A vinyl based bonded anchor system was considered for investigation in this work. Short term tests (ST) were performed to determine the load-displacement characteristics for the selected bonded anchor system. The service load level was assumed to be roughly 50 % of the ultimate short-term capacity based on engineering judgement and previously generated experience [9]. Based on the short-term tests, a value of 9 kN was assumed as the service load level for performing the long-term sustained load tests. To consider influence of load deviations from the sustained service load, three different long-period cycling amplitudes (15 %, 30 % and 50 % of the service load level) were considered. The case (LT-REF) corresponds to constant sustained load test concurrent with the current state-of-the-art practice. The number of tests performed for each case are indicated.

Table 1: Test program and varying parameters

Sl. No. [-]	ID [-]	No. Tests [nos.]	Type [-]	Service load [kN]	Cycling Amplitude [kN]
1	ST	4	short term	N.A.	N.A.
2	LT-REF	3	long term	9.00	0.00 (0 %)
3	LT-CY-15p	3	long term + load deviation	9.00	1.35 (15 %)
4	LT-CY-30p	2		9.00	2.70 (30 %)
5	LT-CY-50p	2		9.00	4.50 (50 %)

3.1 Test Procedure

Schematic sketches of specimens, and the test set up arrangement for short term and long-term tests used in the present investigation are shown in Fig. 1. The specimen consisted of a steel ring to provide lateral confinement, and a confining plate was used in both tests set up, so that bond pull out is the only possible failure mode. The anchor rods (6 mm) were installed with an anchorage length of 6 D (36 mm) using the manufacturer's prescription. Short term tests were conducted with monotonically increasing displacement on the anchor for obtaining the load-displacement curves using the schematic test set up as shown in Fig. 2. In the sustained load tests, an arrangement of hanging weights as shown was used for introducing the load on the anchor. The hanging weights arrangement facilitated addition and removal of loads corresponding to the cycling amplitude as intended in Table 1.

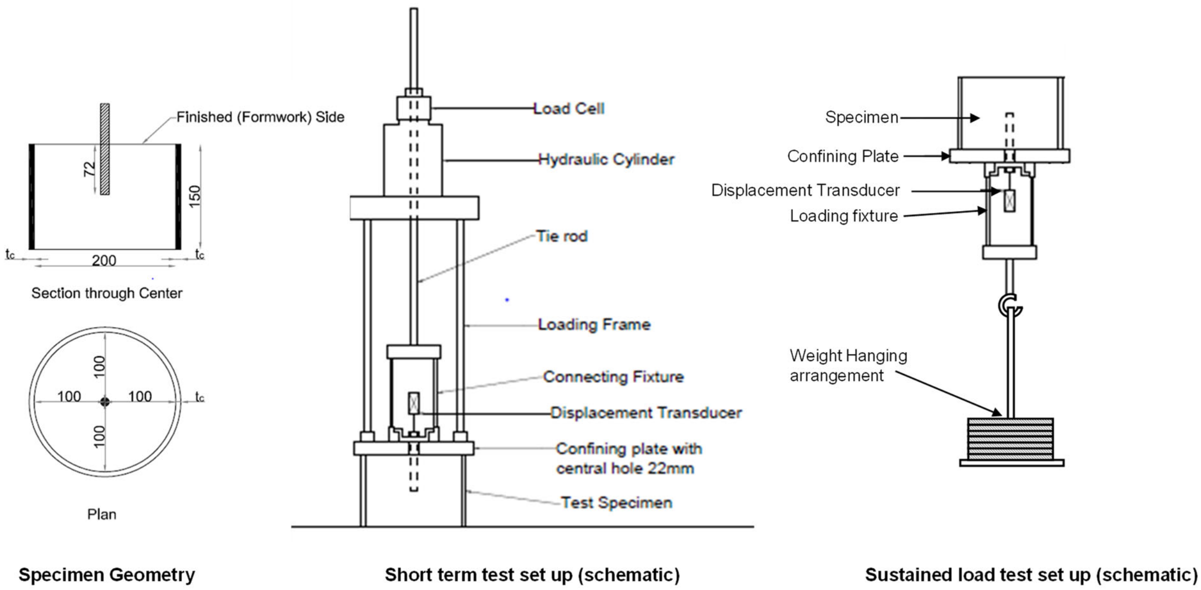

Fig. 2: Specimen geometry and test set up

During the long-term tests (LTT), the load corresponding to the maximum cycling load (service load + cycling amplitude) was introduced on the anchor. The anchor displacement was recorded after the load was applied. After 24 hours, load on the anchor was increased by adding weights to a level corresponding to minimum cycling load (service load - cycling amplitude). Again after 24 hours, the load was changed to maximum cycling load. This process of changing loads every 24 hours was continued for a duration of up to 1000 hrs. Anchor displacement was recorded before and after every change in load and at least at one time point in the 24 hours between the change of loads.

4. TEST RESULTS

The results obtained from different tests are discussed here. Short term tests were performed to determine the ultimate capacity and load-displacement behaviour of the bonded anchor system. The load displacement graphs and the failed specimens from the short-term tests are presented in Fig. 3.

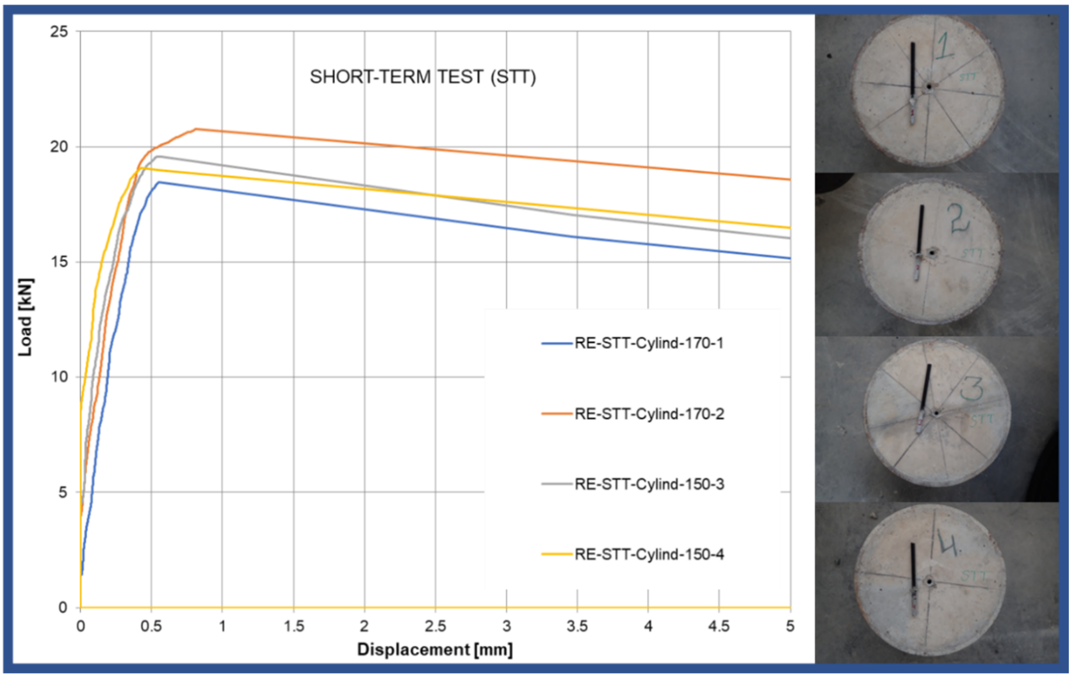

Fig. 3: Results of the short term tests

The mean ultimate capacity in the short term tests was observed to 18 kN. All the specimen clearly exhibited pure bond pull-out failure. The service load for all sustained load tests was fixed at 50 % of the mean short-term capacity, at 9 kN.

4.1 Reference long term tests: L-REF

In the reference long term tests, the load corresponding to the service load (9 kN) was maintained constant for a period of up to 1000 hrs. the anchor displacement was measured using dial gauges at regular intervals (at least once every 24 hrs). A plot of recorded displacement as a function of time is shown in Fig. 4. The displacements sustained after application of the load are observed to be more or less constant over a period of 1000 hrs. The displacements recorded for LT-REF-2 were found to be significantly lower that those recorded in the other two tests. Hence, a band of displacement based on the LT-REF-1 and 3 as shown by the shaded region in Fig. 4 is assumed to be the displacement-time behaviour for constant sustained load of 9 kN corresponding to 50 % of the ultimate capacity.

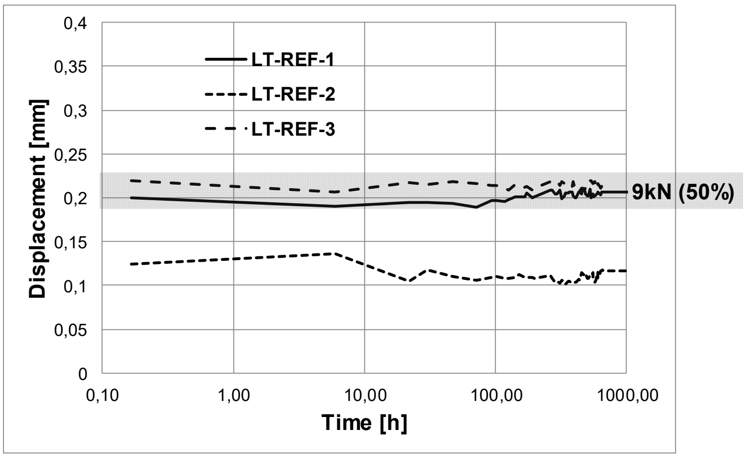

Fig. 4: Displacement time behaviour in long term tests with constant load

In the sustained cycling tests LT-CY-15p, the load was cycled between a maximum of 10.35 kN and minimum of 7.65 kN. These levels respectively correspond to 57.5 % and 42.5 % of the ultimate capacity. The displacements recorded during sustaining the maximum load and minimum load as a function of time are plotted separately in Fig. 5a. Based on the results from the 3 tests, band of displacement corresponding to the maximum load and minimum load are plotted. A mean level of the displacements based on the maximum and the minimum displacement bands is estimated and plotted as a dotted curve in Fig. 5a. For the LT-CY-15p series, the mean level displacement falls within the displacement band corresponding to constant sustained load at the cycling mean level.

In the sustained cycling tests LT-CY-30p, the load was cycled between a maximum of 11.7 kN and minimum of 6.3 kN. These levels respectively correspond to 65 % and 35 % of the ultimate capacity. The displacements recorded during sustaining the maximum load and minimum load as a function of time are plotted separately in Fig. 5b. Based on the results from the 2 tests, band of displacement corresponding to the maximum load and minimum load are plotted. A mean level of the displacements based on the maximum and the minimum displacement bands is estimated and plotted as a dotted curve in Fig. 5b. For the LT-CY-30p series, the mean level displacement is relatively higher than the displacement band corresponding to constant sustained load at the cycling mean level.

In the sustained cycling tests LT-CY-50p, the load was cycled between a maximum of 13.5 kN and minimum of 4.5 kN. These levels respectively correspond to 75 % and 25 % of the ultimate capacity. Out of the two tests, one test failed during application of the load and the other test failed at about 100hrs. Thus, a sustained behaviour could not be observed for this series.

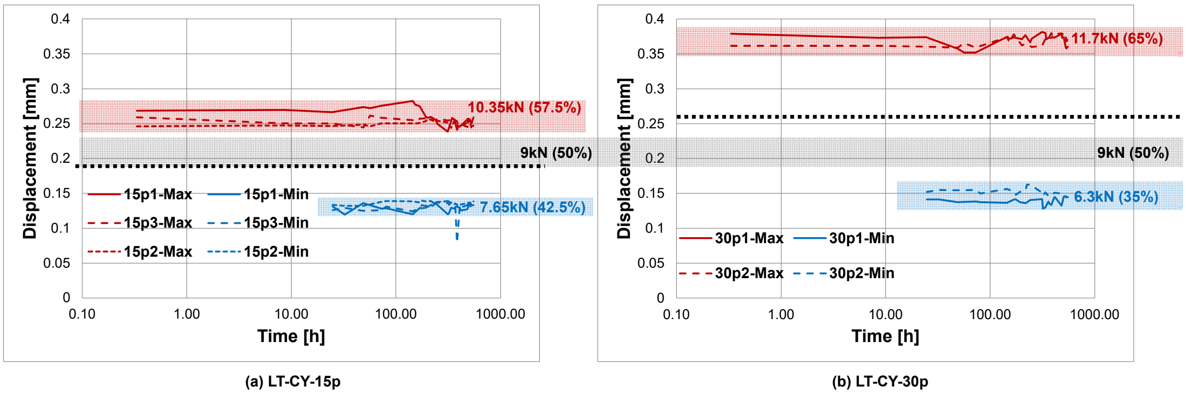

Fig. 5: Results of cycling sustained load tests

5. DISCUSSION

This work is a preliminary investigation of the effect of cycling sustained load on the anchor behaviour. 50 % of the ultimate capacity was assumed as a service load in this work. Constant sustained load tests LT-REF were conducted for load corresponding to 50 % of the ultimate capacity. The displacement band obtained from these tests (see Fig. 4) constitutes a reference for comparing with the cycling sustained load tests in Fig. 5.

In the cycling sustained tests LT-CY-15p, the load on the anchor was cycled between 57.5 % and 42.5 % of ultimate capacity with the mean cycling load of 50 %. For this cycling protocol, the mean displacement was found to be comparable with the displacement observed in the constant sustained load tests at 50 % of the ultimate capacity. In the cycling sustained tests LT-CY-30p, the load on the anchor was cycled between 65 % and 35 % of ultimate capacity with the mean cycling load of 50 %. For this cycling protocol, the mean displacement was found to be larger than the displacement observed in the constant sustained load tests at 50 % of the ultimate capacity. Thus, increase in the cycling amplitude tends to result in increase in the effective mean displacement behaviour.

6. CONCLUDING REMARKS

This paper offers preliminary insights on effect of cycling sustained load on the creep behaviour of bonded anchors. The approach adopted in this work used the displacement corresponding to constant sustained load as a reference for comparing the effect of cycling. For the lower cycling amplitude investigated in this study, the mean cycling displacement was found to be comparable with the displacement corresponding to constant cycling mean load. For the higher cycling amplitude, relatively higher mean cycling loads were observed, thereby indicating the influence of cycling load on the creep behaviour. Such an approach could help to quantify allowable deviation from the service load level for an anchor in real practice. More intensive studies in this direction are necessary for development of related assessment guidelines.

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