# PROGRAMME LOADING FATIGUE TESTS ON CAST-IN HEADED STUDS

# ERMÜDUNGSVERHALTEN VON EINBETONIERTEN KOPFBOLZEN BEI MEHRSTUFENBELASTUNGEN

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## SUMMARY

If fasteners are subjected to fatigue relevant cyclic loads, their fatigue resistance must be verified according to the provisions of EN1992-4 or according to fib Bulletin 58. In practice, the operational stresses/loads vary in their sequence, amplitude and frequency. Although it is a generally accepted concept to verify the fatigue life of fasteners using the Miner´s Rule in case of block loading scenario, no programme loading tests are available in the literature for fasteners. In this experimental study, constant amplitude and non-constant amplitude fatigue tests were executed on cast-in steel headed studs. The constant amplitude tests were carried out using different relative maximum loads. The programme loading tests were performed using three different block loading scenarios, namely with stepwise increasing, stepwise decreasing and increasing-decreasing-increasing successive loading blocks. Based on the available experimental data from the constant amplitude tests, the Wöhler-curve (S-N curve) was derived as a result of linear regression, and the secondary cyclic creep - log N curve was also evaluated. To verify the assumption of the linear damage accumulation in the different programme loading scenarios, the Miner´s sums were evaluated based on the S-N curves as well as based on the secondary creep rates. The evaluation of the experimental data shows the general safety of the use of the Miner´s Rule in case of concrete cone failure of fasteners. This agrees well with the findings in the literature for fatigue loaded plain concrete.

## ZUSAMMENFASSUNG

Wird eine Befestigung nicht ruhender Beanspruchung ausgesetzt, so müssen die erforderlichen Ermüdungsnachweise nach EN1992-4 oder nach fib Bulletin

58 geführt werden. In der Praxis variieren die Betriebslasten hinsichtlich ihrer Reihenfolge, Amplitude und Frequenz. Bei bekanntem Lastkollektiv wird die Ermüdungslebensdauer von Befestigungen mit Hilfe der Miner-Regel nachgewiesen. Jedoch liegen keine Ergebnisse von Mehrstufenbeanspruchungsversuchen von Befestigungen in der Literatur vor. In dieser experimentellen Arbeit wurden Ermüdungsversuche mit konstanter Amplitude und nicht konstanter Amplitude an einbetonierten Kopfbolzen durchgeführt. Die Ermüdungsversuche mit konstanter Amplitude wurden mit unterschiedlichen relativen Maximallasten durchgeführt. Die Zugschwellversuche mit verschiedenen Laststufen wurden mit drei verschiedenen Belastungsszenarien durchgeführt, nämlich mit schrittweise erhöhteten Lasten, mit schrittweise reduzierten Lasten und mit schrittweise erhöhten und reduzierten Lasten. Basierend auf den vorliegenden experimentellen Daten aus den konstanten Amplitudentests wurde die Wöhler-Kurve (S-N-Kurve) abgeleitet und die sekundäre zyklische Kriechrate - log N - Kurve wurde ebenfalls ausgewertet. Um die Annahme über die lineare Schadensakkumulation in den verschiedenen Belastungsszenarien nachzuweisen, wurden die Miner-Summen sowohl auf Basis der S-N-Kurven, als auch auf Basis der sekundären Kriechraten ausgewertet. Die Auswertung der vorliegenden Ergebnisse zeigt, dass die Miner-Regel bei Betonausbruch von Befestigungen mit ausreichender Sicherheit angewendet werden kann. Diese Erkenntnis stimmt mit den Literaturergebnissen für ermüdungsbeanspruchten Normalbeton überein.

KEYWORDS: Fatigue, programme loading, headed stud, concrete cone failure, linear damage accumulation

## 1. INTRODUCTION

The fatigue behaviour of fasteners under constant loading scenarios was investigated in several experimental studies [1-8]. Under realistic loading conditions, the concrete is rather subjected to a cyclic load of different load amplitudes. To account for the effect of operational stresses (varying amplitudes) on the fatigue behaviour, the number of load cycles and amplitudes are usually counted using, for example, the Rainflow- or Reservoir Methods, and the cumulative damage is accounted for using simplified methods, such as the Miner´s Rule. The most commonly used hypothesis to verify the damage accumulation was introduced by Palmgren (1924) and was later popularised by Miner (1945) [9]. The approach assumes a linear damage accumulation. Each individual cycle with its amplitude contributes to the total damage. This hypothesis is expressed using Eq. 1. According to this approach, the fatigue failure occurs if the total damage, which is a sum of damage caused during the successive loading block, reaches M = 1. In the case of materials with endurance limit (infinite life fatigue strength), the stresses below the endurance limit do not contribute to the total damage. The main drawback of the Miner`s rule is that it does not account for the sequence of the applied successive loading blocks.

$$M = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \cdots + \frac{n_j}{N_j} = \sum_{i=1}^{j} \frac{n_i}{N_i} = \int \frac{dn_i}{N} \leq 1 \tag{1}$$

Therefore, the investigations available in the literature are basically made to validate the Palmgren-Miner linear damage accumulation and to determine whether the total damage is equal to or differ from one. Since this recent experimental study focuses on the concrete governed failure mode of fasteners (concrete cone failure under centric tension loading), the literature findings from plain concrete are summarized in the following. Hilsdorf & Kesler (1966) investigated the influence of stepwise increased and stepwise decreased load amplitude on the fatigue life in two test series [10]. The results showed that Miner´s sum is M < 1 for the stepwise increasing loading regime, whereas the total sum is M > 1 in case of stepwise decreasing load amplitude. The results show that the sequence of the different load amplitudes has an influence on the total damage. However, the sequence of the different load amplitudes is not captured by the Palmgren-Miner damage summation method. Tepfers et al. (1977) also carried out fatigue tests on d/h = 25 / 50 mm concrete cylinders using a sequence of increasing and decreasing load amplitudes [11]. The results showed considerably great scatter, and the calculated total damage was once below, once beyond 1. Therefore, no clear conclusion regarding the total permissible cumulative damage for concrete could be drawn. Holmen (1979) recorded the strain continuously during the fatigue tests [12]. It was concluded by Holmen that such loading scenarios, where the smaller amplitude follows a higher applied stress amplitude, are significantly more unfavourable. The results reported by Oh (1991) include fatigue tests on 4-point bending specimens [13]. The results show that the total cumulative damage is greater than M > 1 in the case of stepwise increasing load amplitudes. The cumulative damage M < 1 was reported for loading cases, where the higher amplitudes were followed by lower amplitudes. Based on these results, the linear damage accumulation could not be confirmed. Zhao et al. (1996) carried out fatigue tests on concrete prisms, and he also reports higher total cumulative damage than 1 if the load amplitude is increased throughout the loading history, and smaller than 1 if a higher amplitude is being reduced during the test [14]. Cornelissen et al. (1984) also carried out programme loading tests in pulsating tension [15]. In the programme loading tests, the different loading scenarios include stepwise increased, stepwise decreased and decresed-increased successive loading blocks. The evaluation of the test data was performed using the S-N relation as well as based on the secondary creep rates in the corresponding loading blocks. Although the Miner´s Rule does not account for the sequence of the applied different loading blocks, the results show that the Miner´s Rule M = 1 is basically a safe approach. Furthermore, it was shown that the Miner sums are much closer to 1 when the evaluation is based on the secondary creep rates. It is explained by the fact that the secondary creep gives a better response to the damage caused by the predecessor-loading block. The presented results show that the sequence of the different load levels/amplitudes plays an important role. Some research data reports about the general safety of the Miner´s Rule (M = 1); however, some not. The total sum of the damage (Miner's sum) shall be higher than M > 1 at fatigue failure if the loading protocol begins with a lower amplitude, which is being increased. To the contrary, the total damage at the fatigue failure may be less than 1, if the loading regime begins with a higher amplitude that is being reduced.

## 2. SCOPE OF STUDY

This experimental study aimed to verify the Miner´s Rule in case of concrete cone failure of fasteners. For a reasonable evaluation of the Miner´s sums, the Wöhler-curve as well as the secondary cyclic creep-log N curve were determined based on newly executed constant amplitude fatigue tests.

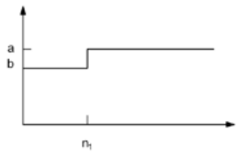
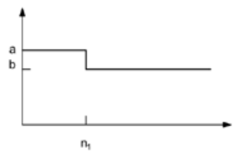
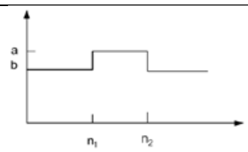
## 3. TEST PROGRAM

The test program presented in Table 1 contains 19 constant-amplitude fatigue tests under pulsating tension. The detailed description of the tests is contained in Tóth (2019) [16]. The test program presented in Table 2 was assembled to capture the influence of non-constant load amplitude on the fatigue life of cast-in headed studs in case of concrete cone failure. Four different programme loading scenarios were tested: decreasing maximum-load, increasing maximum load, increasing and decreasing maximum load. According to the Miner´s Rule, it was checked finally, whether the sum of the total damage exceeds or falls beyond 1. The fatigue tests were carried out using different maximum loads, whereas the minimum-load was 10% of the static concrete cone capacity ($N_{u,m}$). The test frequency during all tests was in the range of 5-8 Hz. The programme loading fatigue tests were carried out in the Testing Laboratory of the Institute of Construction Materials of the University of Stuttgart.

*Table 1: Test program – constant amplitude fatigue tests (reference test series)*

| Concrete | Embedment depth $h_{ef}$ [mm] | Test type | $F_{max}$ / $N_{u,m}$ [%] | $F_{min}$ / $N_{u,m}$ [%] | Number of tests |
|---|---|---|---|---|---|
| C20/25 | 50 | static | - | - | 6 |
| | | dynamic | 85 | 10 | 5 |
| | | dynamic | 80 | 10 | 5 |
| | | dynamic | 75 | 10 | 5 |
| | | dynamic | 70 | 10 | 4 |

*Table 2: Test program – non-constant amplitude fatigue tests*

| Concrete | Embedment depth $h_{ef}$ [mm] | Test type | Test schema | $F_{max}$ / $N_{u,m}$ [%] | $F_{min}$ / $N_{u,m}$ [%] | Number of tests |
|---|---|---|---|---|---|---|
| C20/25 | 50 | static | - | - | - | 9 |
| C20/25 | 50 | dynamic |  | a = 80<br>b = 75 | 10 | 4 |
| C20/25 | 50 | dynamic |  | a = 80<br>b = 75 | 10 | 7 |
| C20/25 | 50 | dynamic |  | a = 80<br>b = 75 | 10 | 8 |

# 4. TEST METHODS & MATERIALS

## 4.1 TESTED MATERIALS

In the engineering practice commonly used S235 J2 +C450 EN ISO 13918 headed studs with a nominal diameter of 25,40 mm (1”) were used. The headed studs were manufactured by NELSON. Normally, the headed studs are welded to anchor plates. In this case, the tension load was introduced into the bolts via M27 threads, which were cold-rolled into the upper 4 cm of the headed studs. The anchor diameter was selected such to avoid the fatigue of the bolts during the tests.

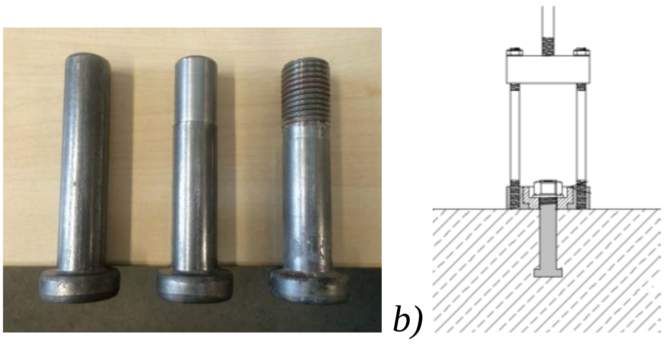
The concrete members for the pulsating tension tests were designed as concrete slabs without steel reinforcement. The distance between the neighbouring headed studs was selected such that the formation of the concrete cone did not influence the adjacent headed stud according to ETAG001 Annex A. The concrete mixture was designed according to DIN EN 206, and the composition of the different charges is given in Table 3. The concrete compressive strength measured on a = 150 mm concrete cubes was between 30 – 35 N/mm$^2$.

*Table 3: Concrete mixture*

| Charge | Concrete str. class | Cem. type | Cem. | Aggregate | | | Water | w/c |
|---|---|---|---|---|---|---|---|---|
| | | | | 0-2 | 2-8 | 8-16 | | |
| [-] | [-] | [-] | [kg/m$^3$] | [kg/m$^3$] | [kg/m$^3$] | [kg/m$^3$] | [kg/m$^3$] | [-] |
| 1 | C20/25 | CEM I, 32,5R | 265 | 708 | 465 | 689 | 185 | 0,69 |

## 4.2 TEST SETUP

The pulsating tension fatigue tests were carried out using servo-hydraulic loading devices and unconfined test setup. The number of cycles, as well as the anchor displacement, were continuously measured during the tests. The schematics of the loading fixture is shown in Fig. 1.



*a)* *b)*

*Fig. 1: a) Tested headed studs b) Schematics of the test arrangement used in the fatigue tests*

# 5. TEST RESULTS

## 5.1 RESULTS OF CONSTANT AMPLITUDE TESTS

The results of the pulsating tension constant amplitude fatigue tests are shown in Fig. 2. All failure points presented in Fig. 2 are associated with full-size undisturbed concrete cone failure, except the aborted tests marked with empty symbols. Linear regression lines were generated for all tested scenarios (excluding the aborted tests). The regression lines were generated to express y = ($F_{max}/N_u$) as a function of x = (log N). The derived equations were solved, and log N for the different tests scenarios can be expressed by Eq. 2. Based on the results, the maximum applied load at N = 2*$10^6$ is ca. 70% of $N_u$.

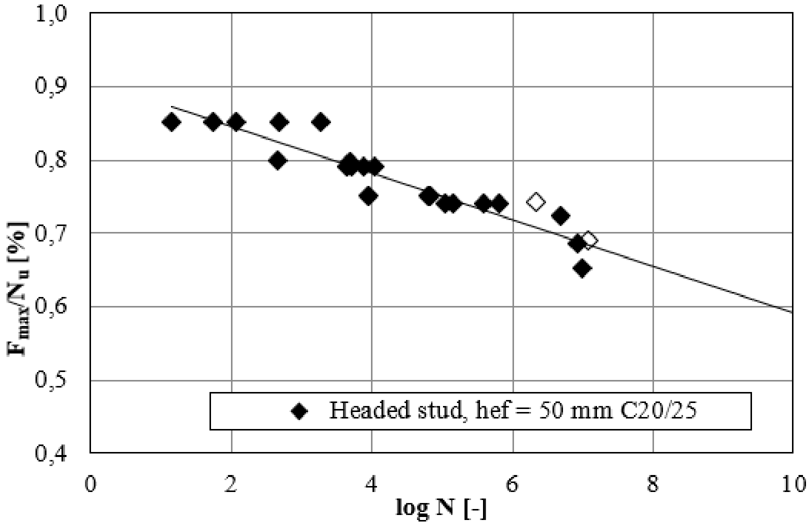



*Fig. 2: S-N curve, headed studs in C20/25 concrete, pulsating tension, concrete cone failure*

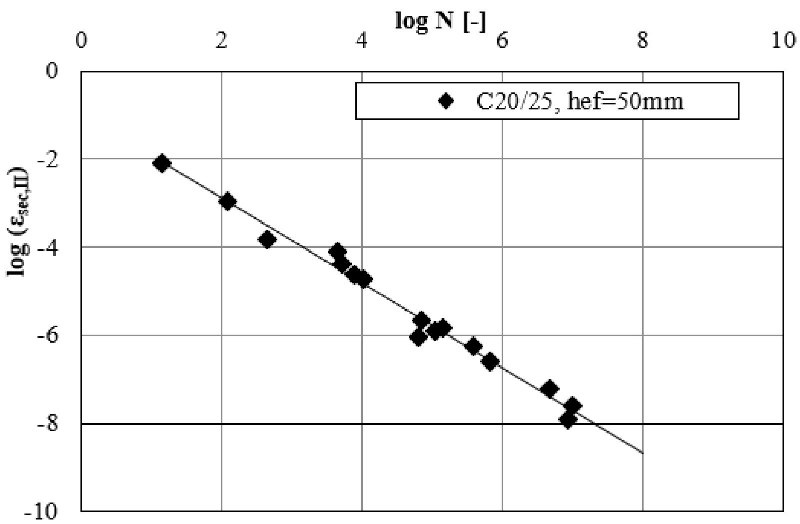



*Fig. 3: Cyclic creep rate as a function of log N, headed studs in C20/25 concrete, pulsating tension, concrete cone failure*

$$log_{10}N = 28{,}2 - 30{,}77 \cdot \frac{F_{max}}{N_u} \quad \text{Pulsating tension C20/25, } h_{ef} = 50 \text{ mm, r=0.95} \quad (2)$$

The secondary cyclic creep rate ($\varepsilon_{sec,II}$) is proportional to the number of cycles at failure (Sparks (1973), Holmen (1979), Cornelissen (1984)). The secondary creep rates in Fig. 3 were calculated at ca. 50% of $N_{failure}$ in each case and it is nearly constant between 0,2 to 0,8 of $N/N_{failure}$ [16]. The smaller the secondary cyclic creep rate is, the higher number of cycles at failure is expected. The log N can be expressed as a function of log $\varepsilon_{sec,II}$ using Eq. 3.

$$\log N = -0{,}815 - 1{,}017 \log \varepsilon_{sec} \quad \text{Puls. tension C20/25, } h_{ef} = 50 \text{ mm, r =0,996} \quad (3)$$

## 5.2 RESULTS OF NON-CONSTANT AMPLITUDE TESTS

The non-constant amplitude fatigue tests were carried out according to Table 2 using different block loading scenarios. The non-constant amplitude fatigue tests were carried out under the same conditions as the constant amplitude fatigue tests (concrete C20/25, Ø25 headed stud, embedment depth $h_{ef}$ = 50 mm). To check the linear damage accumulation using the Miner´s Rule, the determined Wöhler-curve (see Fig. 2) and the log $\varepsilon_{sec,II}$-log N curves (Fig. 3) were used for the evaluation. Altogether 19 programme loading tests were carried out.

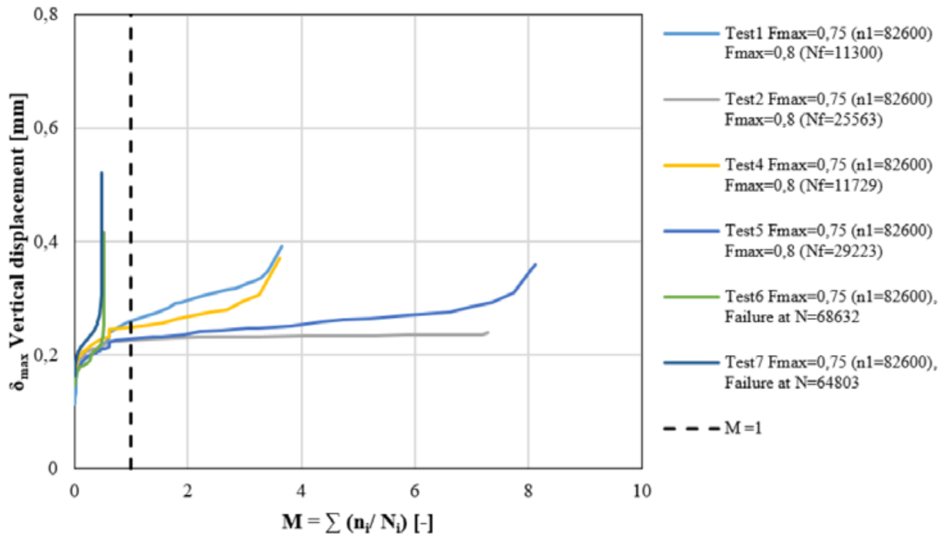



*Fig. 4: Displacement (δ) as a function of n / N (non-constant amplitude fatigue tests in C20/25, headed stud $h_{ef}$ = 50 mm), Loading block 1: 75%, Loading block 2: 80% until failure*

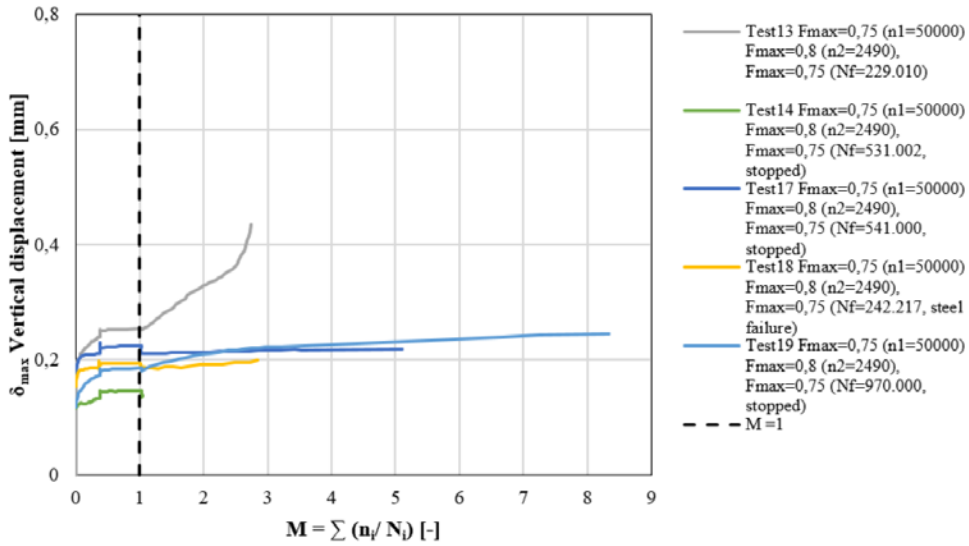



*Fig. 5: Displacement (δ) as a function of n / N (non-constant amplitude fatigue tests in C20/25, headed stud $h_{ef}$ = 50 mm), Loading block 1: 75%, Loading block 2: 80%, Loading block 3: 75% until failure*

# 6. EVALUATION AND DISCUSSION OF TEST RESULTS

## 6.1 EVALUATION OF MINER´S SUMS BASED ON S-N RELATION

The results of the executed non-constant amplitude fatigue tests and the calculated Miner´s sums are summarised in Table 4, where the evaluation of the damage sum is made based on the S-N relation described by Eq. 2 for constant-amplitude pulsating tension.

*Table 4: Miner´s sums based on S-N relation*

| | Appl. loading block 1 | | | Appl. loading block 2 | | | Appl. loading block 3 | | | $N_{failure}$ | Miner´s sum | Mean value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ID** | **$F_{max}/N_u$** | **$N_1$** | **applied $n_1$** | **$F_{max}/N_u$** | **$N_2$** | **applied $n_2$** | **$F_{max}/N_u$** | **log $N_1$** | **log $n_1$** | | $M=\sum_1^i \frac{n_i}{N_1}$ | $\bar{M}$ |
| | [-] | [-] | [-] | [-] | [-] | [-] | [-] | [-] | [-] | [-] | [-] | |
| 1 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 11.300 | 3,57 | |
| 2 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 25.563 | 7,29 | |
| 3 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 9.128[1)] | (0,07) | |
| 4 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 11.729 | 3,68 | 5,69 |
| 5 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 29.223 | 8,24 | |
| 6 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 68.632[1)] | (0,52) | |
| 7 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 64.803[1)] | (0,49) | |
| 8 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 452[1)] | (0,12) | |
| 9 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 3789 | 0,84 | |
| 10 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 505.006[2)] | 4,62 | 3,35 |
| 11 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 483.000 | 4,45 | |
| 12 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 357.015 | 3,50 | |
| 13 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | - | 229.010 | 2,75 | |
| 14 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 531.002[2)] | 5,03 | |
| 15 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 19.056 | 1,17 | |
| 16 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 216.732[3)] | 2,66 | 3,99 |
| 17 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 541.000[2)] | 5,11 | |
| 18 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 242.217[3)] | 2,85 | |
| 19 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 970.000[2)] | 8,34 | |

[1)] Failure during the first loading block
[2)] Stopped
[3)] Steel failure

Premature fatigue failure was observed during the first loading block in tests 3, 6, 7, 8. However, such high maximum loads (75%, 80% of $N_u$) are unlikely to be applied on anchors, with which the programme loading tests were executed.The main reason for testing at such high load levels was to avoid extremely long testing times. It can generally be said that the fatigue tests are carried at relatively high load levels – which are usually higher than the later operation loads - to get the response of the fatigue behaviour in the experimentally possible cyclic range. Obviously, by testing at such high load levels, the premature failure may occur, which, if that is the case, may not be representative in the evaluation. Therefore, it was decided to neglect the results of tests 3, 6, 7, 8 in the evaluation of the Miner´s sums. The executed programme loading tests show that in general, the sum of the total damage exceeds 1. In the increasing loading scenario, the mean sum of total damage is $\overline{M}$ = 5,69 (Test 1-7, Table 4). However, in the decreasing loading scenario, the sum of total damage is $\overline{M}$ = 3,35. Note that in this case, the minimum M was 0,84 (see Test 10). The observed trend agrees well with the findings reported in most of the literature data for concrete.

## 6.2 EVALUATION OF MINER´S SUMS BASED ON SECONDARY CYCLIC CREEP RATE

It can be seen in Table 5 that the Miner´s sums exceed M = 1 if the evaluation is performed based on the secondary creep (Table 5).

*Table 5: Miner`s sums based on secondary cyclic creep rate*

| | **Appl. loading block 1** | | | **Appl. loading block 2** | | | **Appl. loading block 3** | | | **$N_{failure}$** | **Miner´s sum** | **Mean value** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ID** | **$F_{max}/N_u$** | **$N_1$** | **applied $n_1$** | **$F_{max}/N_u$** | **$N_2$** | **applied $n_2$** | **$F_{max}/N_u$** | **log $N_1$** | **log $n_1$** | | **$M=\sum_1^i \frac{n_i}{N_1}$** | **$\bar{M}$** |
| | **[-]** | **[-]** | **[-]** | **[-]** | **[-]** | **[-]** | **[-]** | **[-]** | **[-]** | **[-]** | **[-]** | |
| 1 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 11.300 | 1,04 | |
| 2 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 25.563 | 1,09 | |
| 3 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 9.128[1)] | -[4)] | |
| 4 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 11.729 | 1,20 | 1,14 |
| 5 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 29.223 | 1,23 | |
| 6 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 68.632[1)] | -[4)] | |
| 7 | 0,75 | 132.586 | 82.600 | 0,8 | 3.837 | - | - | - | - | 64.803[1)] | -[4)] | |
| 8 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 452[1)] | -[4)] | |
| 9 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 3789 | -[4)] | |
| 10 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 505.006[2)] | -[4)] | - |
| 11 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 483.000 | -[4)] | |
| 12 | 0,8 | 3837 | 3.110 | 0,75 | 132.586 | - | - | - | - | 357.015 | -[4)] | |
| 13 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | - | 229.010 | 1,17 | |
| 14 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 531.002[2)] | 1,20 | |
| 15 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 19.056 | -[4)] | |
| 16 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 216.732[3)] | -[4)] | 1,17 (0,90) |
| 17 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 541.000[2)] | 0,28 | |
| 18 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 242.217[3)] | 0,70 | |
| 19 | 0,75 | 132.586 | 50.000 | 0,80 | 3.837 | 2.490 | 0,75 | 132.586 | | 970.000[2)] | 1,16 | |

[1)]Failure during the first loading block
[2)]Stopped
[3)]Steel failure
[4)]Measurement data not available

The Miner´s sums are remarkably closer to 1 when the secondary creep rates are used in the evaluation, which is in a good agreement with the conclusions drawn for plain concrete by Cornelissen (1984). This is explained by the fact that the effect of the damage caused by the predecessor loading block is well-captured by the actual displacements. Note that the Miner´s sums of the tests 17 and 18 may not be representative in the evaluation because those tests – among others –were aborted prior to failure.

## 7. SUMMARY AND OUTLOOK

In this experimental study, contant amplitude and variable amplitude fatigue tests were carried out on cast-in headed studs in pulsating tension. The Miner´s sums of the programme loading tests were evaluated once based on the S-N relation as well as based on the secondary creep rates. The results proved the approach of using M = 1 to be generally safe.

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