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Experimental Execution and Results of Fatigue Test with Prestressing Steel

Exécution et résultats d'essai de fatigue sur des aciers de précontrainte

Ausführung und Ergebnisse von Ermüdungsversuchen an Spannstahl

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SUMMARY
The demand for quality tests of prestressing steels in fatigue with specimen as long as possible, create special requirements for the testing technique. These aspects are presented and, based on test results, individual influences of the fatigue test on prestressing wires and strands are discussed.

RÉSUMÉ
La nécessité de réaliser des essais de fatigue sur des éprouvettes d'une longueur aussi grande que possible, pour les aciers de précontrainte, n'est pas sans conséquence pour la technique d'essai. Ces aspects sont présentés et les divers facteurs d'influence des essais de fatigue sur des fils et des torons de précontrainte sont discutés sur la base de résultats d'essai obtenus.

ZUSAMMENFASSUNG
Die Forderung nach einer Qualitätsprüfung von Spannstählen unter Ermüdungsbeanspruchung mit möglichst langen Proben hat Folgen für die Prüftechnik. Diese Aspekte werden dargestellt, und anhand von Versuchsergebnissen werden einzelne Einflußgrößen der Ermüdungsprüfung von Vorspanndrähten und Spannlitzen diskutiert.

1. FATIGUE TESTING OF PRESTRESSING STEELS

1.1 Test frame

In fatigue tests of prestressing steels it is, according to Castillo [1] strongly recommended to use the longest possible elements, because this has the following advantages

- a better extrapolation to the real length of the element
- closer sample values to the zero-percentile curve
- shorter life and therefore lower costs
- more information at the same time
- the threshold value associated with the asymptotic independence assumption is more likely to be overcome.

Normally, the length of the "longest possible element" is given by the available fatigue testing machine. Commercially available fatigue testing equipment with a 250 kN-load capacity – this load range is well suitable for the quality test of single prestressing wires and strands – is frequently unsuitable in the sense of testing long elements in the meaning mentioned above. Therefore, the best way to deal with large values of length – say 1 meter or more – is to build a test frame which optimizes the conditions for the fatigue testing of elements made of prestressing steel. Such a frame was erected at the Swiss Federal Testing Laboratory (EMPA) and is shown in figure 1. The load limit of this frame is 400 kN. All parts of this test frame belong to a construction kit which serves the needs for a variety of fatigue test tasks. The frame is built up in sections of 2 m length and can easily be dismantled and reassembled in steps for a desired free clamping length of the tested specimen of about 2, 4, 6, 8 or 10 m. On both ends of these sections, identical base plates are attached. The base plate at the "fixed end" of the specimen holds the load measuring device with the clamping system in serie whereas the one at the "movable end" of the specimen holds the servo-hydraulic actuator with the displacement measuring device and with the other clamping system in serie.

The frame with the specimen is placed on the floor in a horizontal position which allows free access to the tested element for inspection during the test.

Wire specimen sometimes show multiple failures, that means that the first failure immediately causes a second failure at the next weak spot and then parts of the specimen are often released from the test frame. To prevent this, segments of plastic tubes should cover the specimen under test.

The specimen is tested symmetrically with regard to the central axis of the frame. For this reason, the load cell and the hydraulic actuator were especially developed with a passing hole in the center of 40 respectively 60 mm diameter, figure 2.

1.2 Measuring devices

Since fatigue tests on prestressing steel are characterized by high upper loads and relatively small load ranges – whereby the load range is primarily responsible for the fatigue of the element – the accuracy and stability of the load cell are of predominant importance for the consistency of the test results. The capacity of the used load cell should suit the highest loads needed and the overall error related to the nominal load should be less than ± 0.05 %.

The deformation of the specimen during the load-controlled test is measured with a separate LVDT-displacement sensor which is attached to the hydraulic actuator. This signal also serves for monitoring the test and for shutting down the whole arrangement after failure of the prestressing wire or after failure of the first wire in strands. In some cases a shock sensor was used parallel to cut off the test in a reliable manner.

1.3 Loading equipment

The loading of the specimen is done by a servo-hydraulic actuator under load control with sinusoidal wave form. This control facilitates the adjustment of the test frequency and the wave form in one–step–tests (constant amplitude). Nevertheless, it should be noted that long specimen and high load ranges cause large amplitudes of deformation and in this case, the use of one or more servovalves with high flow rates is mandatory in order to obtain a reasonable value of the test frequency.

The stroke of the actuator is not only given by the deformation of the specimen under load, but also by the slipping of the specimen in the grips during set-up of the test. For the test of 10 m long specimen a stroke of 200 mm is adequate.

The hollow drilled piston of the actuator also allows to load the specimen without any restraint against torsional movement. Such a rotation around the axis of the specimen would occur in strands. There is no rotation in service and therefore, rotation is prevented during the test by a longitudinal guidance.

1.4 Clamping devices

To perform fatigue tests in an economical way, it is important to use a reliable and easy-to-use clamping system. One should be aware that independent of the mode of clamping, the probability of failure in the clamping region increases with shorter length of the specimen, and this is one more point to test the longest possible specimen. Also the best clamping system cannot prevent that once in a while the weakest point of a specimen is situated in the clamp and thus causes a failure in the clamping region.

The clamping system used for wires shown in figure 3, and the clamps used for strands shown in figure 4, permitted in the past to hold down the rate of failures in the clamp under 1/40.

For clamping the wire, three under 120° displaced wedges of 80 mm length with an adapted stiffness are used, together with a 0.5 mm aluminium sheet formed as a tube to protect the surface of the wire like a sheath. An additional action to prevent failures in the clamping region is to roll the surface of the wire in this range as to increase the hardness of the surface and to put the surface layers under compression. All these methods are advantageous to prevent fretting fatigue as a main cause for failures in the clamps. At the ends of the wire-specimen a punched head with a washer anchors the wire on the wedges.

The strands are clamped by two wedges of 200 mm length, shown in figure 4. Inside the wedges are wooden inserts surrounding the whole specimen and forming a quasi hydrostatic pressure state under load; this causes the wood to yield around the six outer wires of the strand and to guarantee a continuous transfer of the loads into the specimen. To anchor the strand on the two wedges – which is especially important at the beginning of the test – a commercially available anchor head is used.

2. RESULTS OF FATIGUE TESTS ON PRESTRESSING STEELS

2.1 Influence on test position

In this test program only specimen with a 10 m length were fatigued in horizontal position; all other, shorter specimen were tested in vertical position. To check a possible influence of the test position on the initiation site of the crack, the location of the crack initiation was noted with respect to four 90°–sectors named 1 to 4 starting at the upright position and going clockwise around the section. For 27 wire specimen tested with a length of 10 m, the following assignment was observed

number of failures	5	7	8	7
in sector	1	2	3	4

A preferred position for the initiation with regard to a differentiation up/down with 12 failures in sectors 1/2 (up) and 15 failures in sectors 3/4 (down) is not clearly visible.

2.2 Periodicity of flaws

If a periodicity of flaws over the length stemming from fabrication is supposed, it should be noticed in a compilation of the succeeding distances of failures. For the 27 tested wire-specimen with a free clamping length of 10'410 mm, the frequency of occurrence of the distances between failures are given in tab. 1.

The intervals of the fracture distances not listed in table 1, did not show any fracture.

Tab 1: Frequency of occurrence for the distances between the fatigue failures in wire specimen of 10'410 mm free clamping length

fracture distance in m	1–2	4–5	6–7	7–8	8–9	9–10	10–11	11–12	13–14	14–15	15–16
frequency absolute	1	1	2	3	6	3	4	1	2	2	3
frequency relative in %	3.6	3.6	7.1	10.7	21.4	10.7	14.3	3.6	7.1	7.1	10.7

Two of these 27 wire-specimen failed simultaneously at two locations. A statistical treatment of the failure distances with respect to a supposed periodicity – also for the shorter specimen – should be done in future.

The percentage of the fracture surface developed under fatigue was for all tested wire-specimen about 25 to 30 %., more or less independent from the stress ranges (400 to 800 N/mm^2).

2.3 Strands: type of fracture

The fatigue failures in the single wires of the tested 0.6 inch-strands are predominantly caused by fretting corrosion. A designation of these failures according to tab. 2 and an allocation of the fracture types for the various tested proof length is given in tab 3.

Tab. 2: Strands; designation of fracture types

Type No.	Crack started in	Crack started from interface
1	outer wire	outside
2	outer wire	outer / outer wire
3	outer wire	outer / center wire
4	control wire	outer / center wire
5	combination of type 2 and 4	

Tab 3: Strands; number of failures according to type number (see tab. 2)

	Type				
Proof length in m	1	2	3	4	5
0.5	3	7	1	3	-
1	6	5	1	1	-
2	2	8	2	1	3
10	1	11	-	1	4
Sum	**12**	**31**	**4**	**6**	**7**

Tab. 3 shows that in these tests the fatigue crack started mostly at the interface between the outer wires. It is striking that with a test length of 1 m the majority of cracks begun at the outer surface of the outer wires. Obviously, the surface of these strands was damaged during fabrication or transport.

2.4 Strands: influence of pretorsion

To show whether there is an influence of a pretorsion given on the specimen in a clamped condition, strands of test length 1040 mm were tested at a stress range of 350 N/mm^2.

The first group was screwed up and the second group screwed down by an angle of 180° before starting the test. The results are given in tab. 4.

Tab 4: Strand 0.6 inch diameter; effect of pretorsion.
Free length 1040 mm; upper stress $\sigma_u = 1239$ N/mm^2
Stress range $\Delta\sigma = 350$ N/mm^2; test frequency 3.5 Hz

Specimen No.	Handling	Number of cycles until fracture of first wire	Remarks
19	screw down	154'000	* fracture type 1
18	screw down	264'000	fracture type 1
20	screw down	2'000'000	runout
22	screw up	333'000	fracture type 1
21	screw up	495'000	fracture type 1

* fracture type according to tab. 2

Screwing up or down the strand specimen in a clamped condition before starting the test has no clear influence as can be seen in tab 4. The occurrence of fracture type 1 (outer wire / from outside) shows that the outer surface of the single wire became critical and not – as supposed – that the interfaces of the outer wires and hereby the fretting corrosion were predominantly influenced by the pretorsion.

2.5 Wires: influence of test frequency

An influence of the test frequency on the results of fatigue tests is mainly to be expected at relatively high stress ranges. The plastic strain range depends on the rate of loading and, therefore, also on the test frequency. This means that at a lower test frequency higher plastic strain ranges appear which lead to a shorter life. This effect should vanish the closer the stress range reaches the fatigue limit.

For verification of this influence, wires of 150 mm length were fatigued at relatively high stress ranges of 600 and 800 N/mm^2 and a test frequency of 3.5 Hz and 105 Hz. The results are shown in figure 5. On both, the higher and lower level of the stress range, the influence of the test frequency is clearly visible, in the sense of shorter lifes at a lower test frequency.

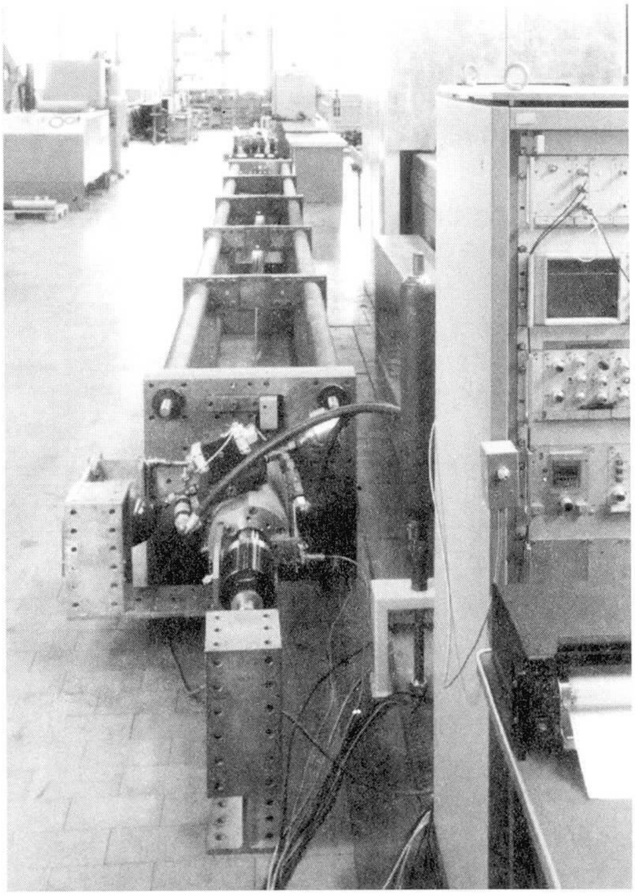

Figure 1: Test frame for fatigue tests of elements up to 10 m proof length

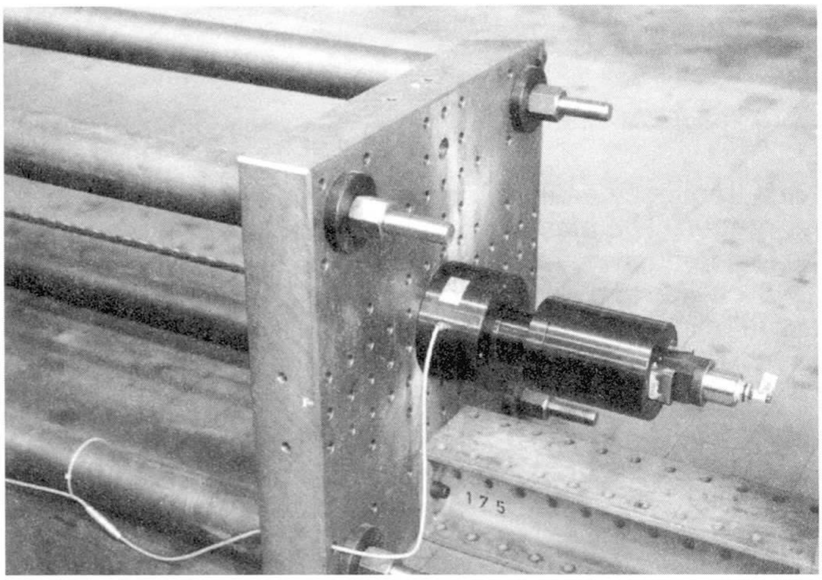

Figure 2: Arrangement of load cell and clamping system mounted on the base plate at the firm end of a fatigue test with a strand

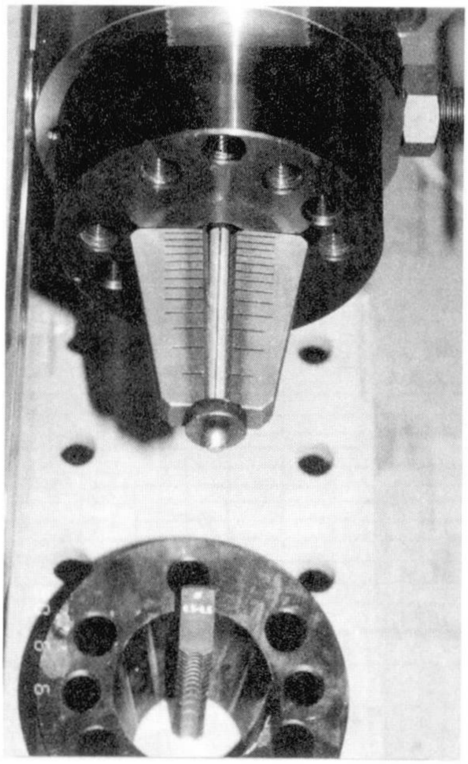

Figure 3: Clamping system for the 7 mm prestressing wire

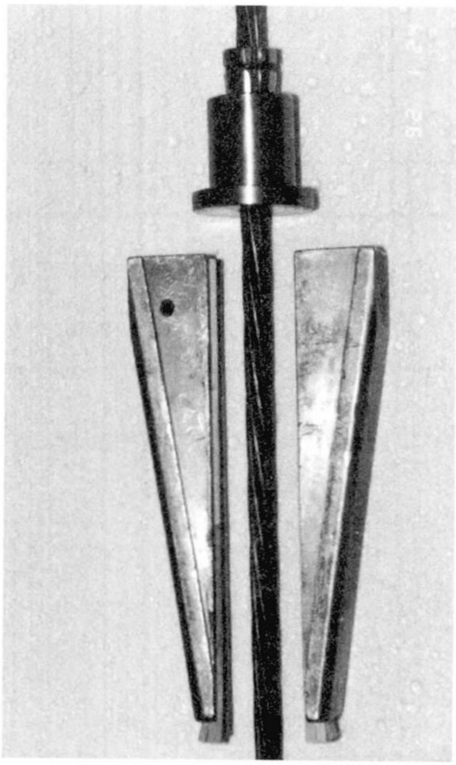

Figure 4: Clamping system for the 0.6 inch strand

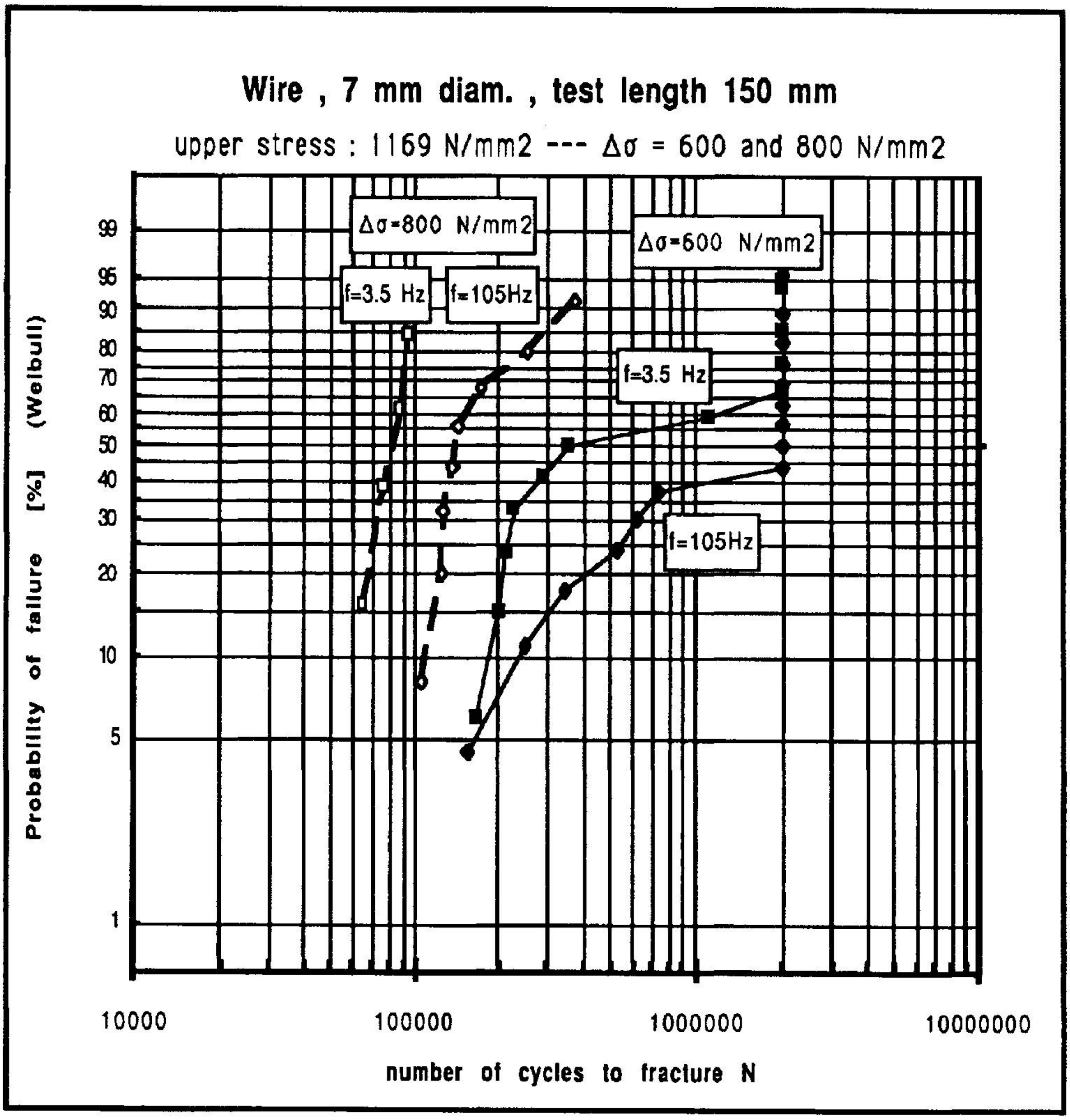

Figure 5: Influence of test frequency on results of fatigue tests on prestressing wire, 7 mm diameter

REFERENCES

[1] Castillo, E. and A. Fernández-Canteli;
Statistical Models for Fatigue Analysis of long Elements;
IABSE Workshop Madrid, September 1992,
Length Effect on Fatigue of Wires and Strands.