HIGH STRENGTH CONCRETE UNDER SUSTAINED TENSILE LOADING

HOCHFESTER BETON UNTER DAUERZUGLAST

BETON DE HAUTE RESISTANCE SOUS TENSION SOUTENU

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SUMMARY

A research programme is described which aims at the investigation of the short term and long term tensile strength of high-strength concrete. The loading arrangement is illustrated and first test results are given.

ZUSAMMENFASSUNG

Im folgenden wird ein Forschungsprogramm zur Untersuchung der Kurzzeit- und Langzeitzugfestigkeit von hochfestem Beton beschrieben. Die Versuchseinrichtung sowie erste Ergebnisse werden vorgestellt.

RESUME

On décrit un programme de recherche qui vise la recherche sur le court terme et la résistance à la traction à long terme du béton de haute résistance. L'agencement de chargement est illustré et les premiers résultats d'essai sont donnés.

KEYWORDS: Tensile loading, creep, high strength concrete

1. MOTIVE AND SCOPE

Usual design formulas for structural concrete neglect tensile strength of concrete as a relevant quantity for the bearing capacity of a structure. Some codes state at least a relation between minimum reinforcement and tensile strength in order to prevent collapse of those members which do not need much reinforcement to carry dead and life load, but which may be subject to imposed deformation due to shrinkage and/or temperature. However, every structure relies on tensile strength to a certain extent. If concrete is uncracked tensile strength governs shear and torsional capacity and it is mainly responsible for bond of steel in concrete and thus for anchorage length and cover to reinforcement. Unreinforced structures such as pavements rely directly on tensile strength since traffic load, temperature and shrinkage induce tensile stresses. The serviceability state is often related to crack formation and cracks appear when the tensile strength of concrete is reached. If loads are permanent tensile stresses and they should be compared to tensile strength as determined under sustained loading.

There was some literature attainable on the tensile strength of normal-strength concrete under sustained loading [1, 2, 3, 4]. The experimental results indicate that sustained loading reduces tensile strength by about 40% depending on age at loading and environment. These are two effects which are opposite to each other: tensile stress causes formation and extension of micro-cracks which lead finally to unstable crack propagation on one hand, but there is also continuous hydration which increases strength and may even heal micro-cracks if water is available.

Which mechanism is prevailing and whether the effect of both mechanisms is the same for normal-strength and high-strength concrete is not known. One may argue that micro-cracking is retarded in high-strength concrete because the properties of matrix, aggregate and interfacial zone are closer together. On the other hand, once a crack starts to propagate crack arrest may be less probable and continuous hydration is less pronounced in high-strength concrete than in normal-strength concrete. Thus, there are reasons to believe that sustained loading influences strength not in the same way. Since no test results could be found in the literature on this question it was decided to start a series of tests which will be presented and discussed as far as they have been performed already.

2. RESEARCH PROGRAMME

The programme contains mainly two variables: the concrete strength and the loading level. The strength classes are C55/67, C70/85, C90/105 according to prEN 206. Specimens are loaded at a sustained level of 75, 80, 90 and 95% of the mean short term uniaxial strength. Four specimens will be used per variable combination. Sustained loading is also realised as axial loading in a climate controlled room. Shrinkage will be measured on companion specimens without mechanical loading. Testing proceeds either to failure of the specimen or to two years at the longest.

3. TEST SET-UP

3.1 Loading arrangement and specimen geometry

Many years ago [5, 6] creep and relaxation tests have been performed in the Otto-Graf-Institute on concrete in compression. The loading arrangement has been changed to tensile load for steel testing after some years. It is now adjusted to concrete tensile loading by changing the clamping devices and the hinges on top and bottom of the specimen. Fig. 1 shows the schematic of the loading arrangement.

A water container with about 1 m^3 volume is filled up and serves as load which acts, via a lever and an almost frictionless hinge, on the specimen. The multiplication factor can be varied between 3 and 19. The specimen is tensioned by a rod which is connected to a load cell and a ball hinge. There is another hinge on the bottom between specimen and support. When the specimen is being loaded water can be filled stepwise into the container until the specified level is reached or, when the dead weight of the container is large enough, the container is gradually released from its fixation.

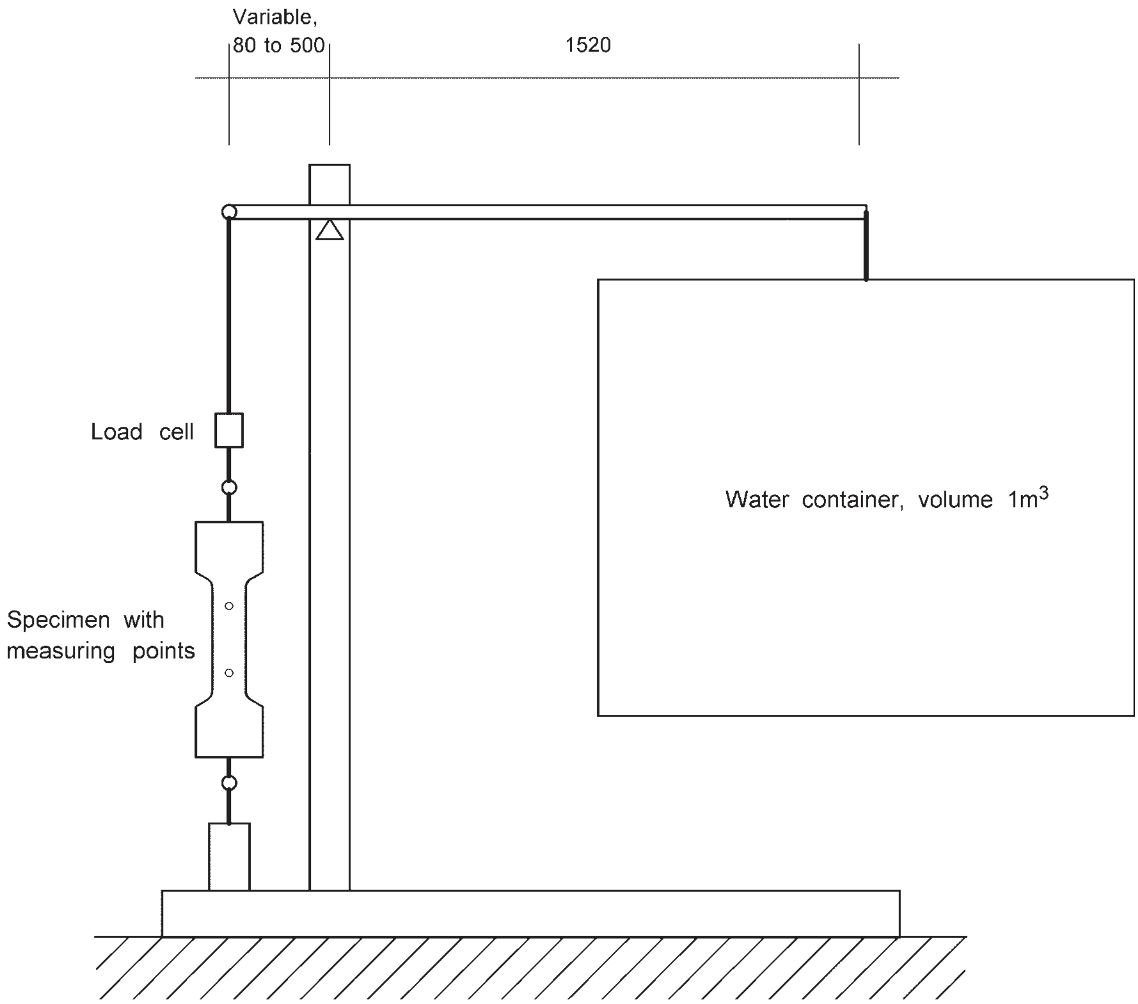

Fig. 1: *Loading arrangement, dimensions in mm*

To load a concrete specimen in uniaxial tension is always a delicate question. In the past, several methods have been used: mechanical grips on a dogbone shaped specimen [7], metal loading plates glued to the ends [8], inserts in the specimen [9], a threaded layer [10]. All of them try to introduce the force centrically and such that the fixing device does not lead to premature failure. In the present investigation, lifting anchors are concreted in the specimen as shown in fig. 2. The anchors have an inner thread M 24 and a cross-bar which ensures reliable anchorage. They are cheap and readily available.

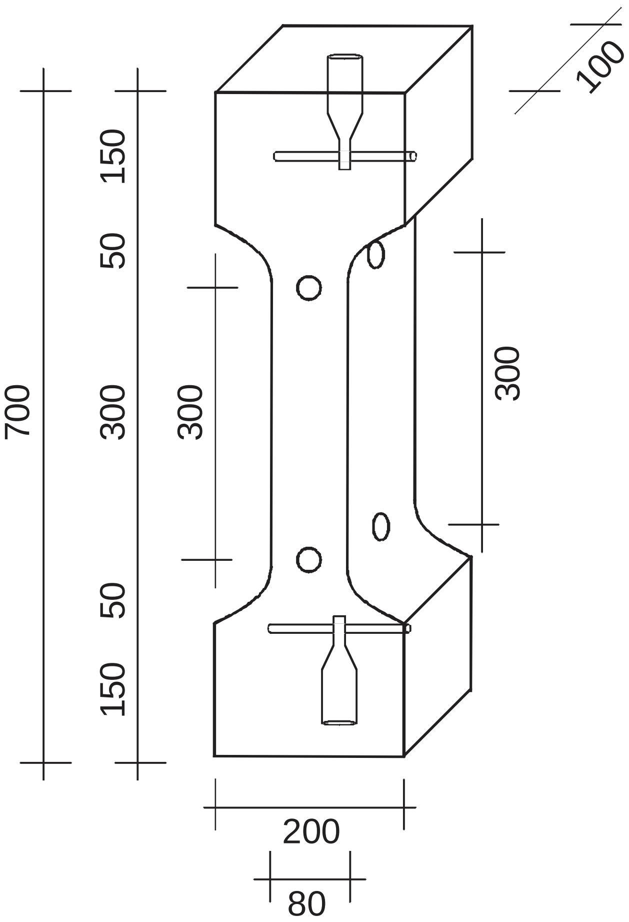

Fig. 2: *Specimen geometry and anchorage, dimensions in mm*

The length changes of the loaded specimens and the length changes of the shrinkage specimens are recorded by LVDTs. All data, i. e. half-bridge arrangement of LVDTs and temperature and humidity from the Almemo unit are logged directly into a dedicated computer terminal and stored in a PC 486/33 with 8 MB RAM.

The specimens have a prismatic section with a cross-section of 80 mm x 100 mm and a length of 300 mm. The distance of the measuring points is 300 mm. LVDTs are fixed to these points.

3.2 Specimen preparation

The specimens are cast in a horizontal position. After concreting, they remain in the steel mould for one day. After demoulding, they are stored in a fog room (20°C) for six days and then, sealed with plastic foils, in a conditioned room (20°C, 65% RH) until beginning of testing at an age of 28 days.

Besides the tapered tension specimens there were 100 mm and 200 mm cubes fabricated and stored according to DIN 1048, i. e. 7 days wet and 21 days at 20°C/65% RH.

4. CONCRETE COMPOSITION

There are four concrete grades the composition of which are given in Table 1. The cement is a rapid hardening portland cement class CEM I 42.5 R according to DIN 1164 (ENV 197). Silica fume is added as a slurry. The water content in Table 1 is given as the sum of added water and water from silica slurry, superplasticizer and retarder.

The properties of fresh concrete and the dry density after 28 days are given in Table 2. Since the projected strength partially was not achieved or was substantially exceeded, for the further tests modified mixtures are used. Also the slumps were too low, which requires the use of much more superplasticizer. The experience showed that then an addition of retarder becomes unnecessary.

Table 1: *Concrete composition in kg/m3*

Component	Concrete			
	Mix1	Mix 2	Mix 3	Mix 4
Cement CEM I 42.5 R	400	450	450	453
Water [1)]	168	128	140	125
Aggregate				
0-2 mm	634	602	453	584
2-4 mm	320	208	324	206
4-8 mm	343	359	309 (Liapor)	374
4-8 mm	464	607	474	636 (Basalt)
Silica fume [2)]	25	40	46	45
Superplasticizer	11.0	20.0	13.8	18.0
Retarder	2.9	1.8	4.1	5.4
Water-cement ratio	0.42	0.28	0.33	0.28
Water-binder ratio	0.40	0.26	0.30	0.25

[1)] Total water, i. e. water of silica slurry, superplasticizer and retarder included

[2)] Dry mass of slurry

Table 2: *Properties of fresh concrete*

Property	Concrete			
	Mix1	Mix 2	Mix 3	Mix 4
Spread table flow, cm	34	56	35	32
Air content, %	2.8	0.6	2.7	2.7
Density of fresh concrete, kg/m³	2260	2480	2200	2440

5. FIRST TEST RESULTS

The connection between loading device and specimen is realized via a hollow anchor bolt (lifting anchor) and a bolt. After 28 days, the specimens with the geometry as shown in fig. 2 are tested by a monotonically increasing load. During the loading the expansions are measured with two or four LVDTs (fig. 3). The specimens normally fail due to cracking in the prismatic section as shown in fig. 4.

Fig. 3: *Test set-up with 2 LVDTs*

The measured Young's moduli (E) and tensile strengths in the tapered specimens with respect to the reduced cross-section are given in table 3. These values agree well with the formulas of Heilmann [11]:

$$f_t = a \cdot f_c^{2/3} \tag{1}$$

and Remmel [14]:

$$f_t = b \cdot \ln\left(1 + \frac{f_c}{10}\right) \tag{2}$$

with f_t = tensile strength, f_c = compressive strength, and the constants a resp. b. The German guideline for high-strength concrete suggests $0.18 < a < 0.21$ [12].

Fig. 4: *Specimens after failure in short-term and long-term tensile test*

Table 3: *Mechanical properties of concrete at 28 days*

Property	Concrete			
	Mix1	Mix 2	Mix 3	Mix 4
E (GPa)	41.5	45.5	38.3	50.4
f_{cc} (MPa)	81.3	94.3	88.8	97.8
f_t (MPa)	4.98	5.20	5.28	5.53
$a = f_t/f_c^{2/3}$	0.27	0.25	0.27	0.27
$b = f_t/\ln(1+f_c/10)$	2.3	2.2	2.3	2.3

Some specimens were loaded with 80, 90 and 95% of their short term tensile strength and the strains were measured. The times until failure are listed in table 4. Specimens loaded with 80% of their short term tensile strength did not fail within 90 days. The measured creep behavior of one test specimen (ratio 0.90) is exemplary shown in fig. 5.

Table 4: *Service lives under sustained tensile loading (single test results)*

Ratio	Concrete		
	Mix1	Mix 2	Mix 3
0.90	1 h	35 d	23 d
0.95	0 h	5 d	9 d

6. CONCLUSION AND OUTLOOK

The testing programme has yet started which makes that only short-term results and a few long-term test results are available. The short-term results are within the range which has been predicted by empirical formulae. The sustained loading results will be evaluated according to [13] who has based the theoretical prediction on the Griffith criterion for brittle materials. The available test results show already that high-strength concrete creeps little due to its brittleness and is able to bear comparatively higher sustained loadings than normal concrete.

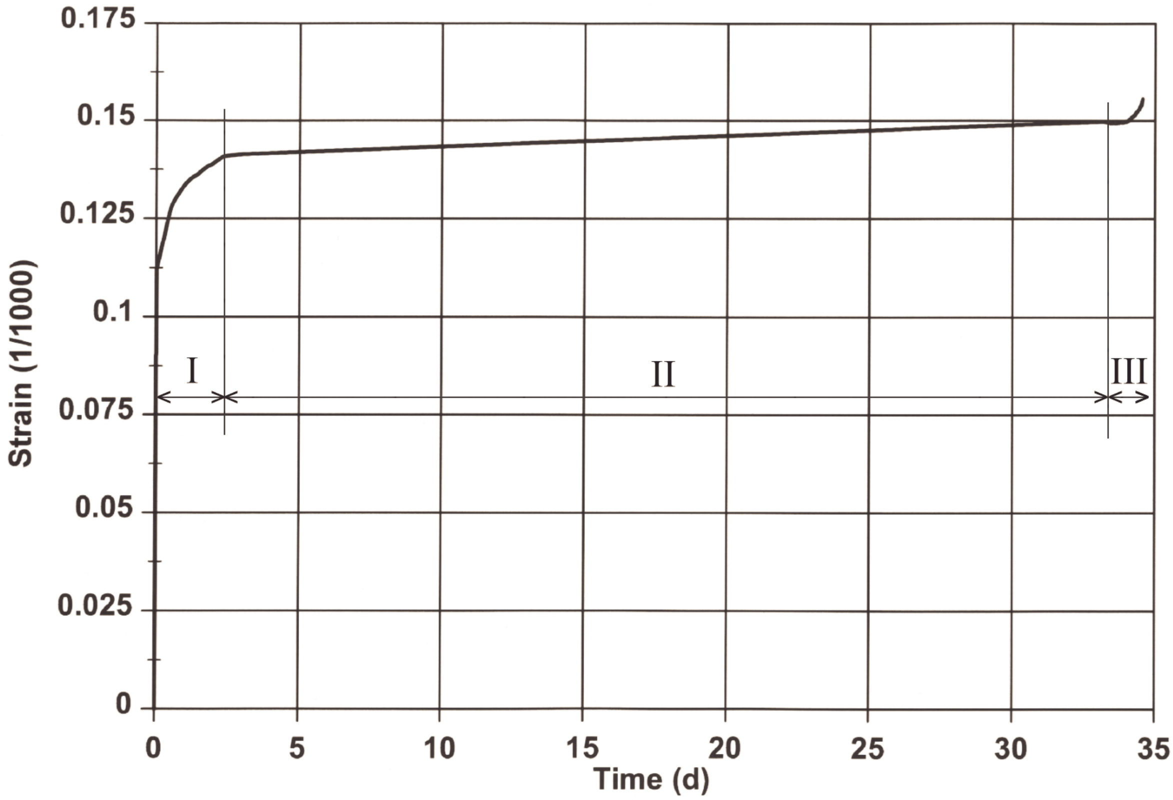

Fig. 5: *Tensile creep of high strength concrete (Mix 2, ratio = 0.90) with I, II, III primary, secondary, and tertiary stage*

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