Sustained tensile strength of concrete

Sustained Tensile Strength of Concrete

Résistance à la traction du béton sous charge de longue durée

Betonzugfestigkeit unter Dauerlast

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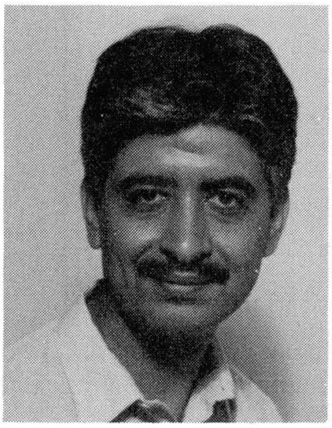

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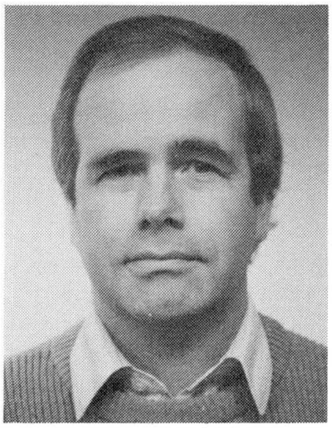

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SUMMARY

Tests have been carried out in order to study the behaviour of concrete under concentric and eccentric sustained tensile loading. Variables were the eccentricity of the load, the shape of the concrete cross-section and the loading rate. Realistic values for the sustained tensile strength were determined, depending on the load level and the loading rate.

RÉSUMÉ

Des expériences ont été menées afin d'étudier le comportement du béton sous charge de traction centrée et excentrée. Les variables étudiées ont été l'excentricité de la charge, la forme de la section en béton et le temps de chargement; ceci aboutit à la détermination de la résistance à la traction, qui dépend du niveau de sollicitation et du temps de mise en charge.

ZUSAMMENFASSUNG

Es wurden Versuche zur Beschreibung des Verhaltens von Beton unter zentrischer und exzentrischer Dauerzugbeanspruchung durchgeführt. Dabei wurden unterschiedliche Exzentrizitäten sowie unterschiedliche Betonquerschnitte untersucht. Eine realistische Grösse der Zugfestigkeit des Betons unter Dauerbeanspruchung wurde in Abhängigkeit von Belastungsniveau und Belastungsgeschwindigkeit ermittelt.

1. INTRODUCTION

Nowadays the significant role of the tensile strength in the design of concrete structures begins to be reckognized. In the introductory lectures by Hillerborg and Duda/König many factors, influencing the concrete tensile strength and the post-cracking ductility, were discussed. However, hardly any attention has been devoted to the role of the so-called sustained loading effect. Nevertheless, if results of various authors may be believed, the sustained tensile strength is considerably lower than the tensile strength, obtained in a short term test. The ratio sustained to short term tensile strength is reported to be about 70%, see Fig. 1.

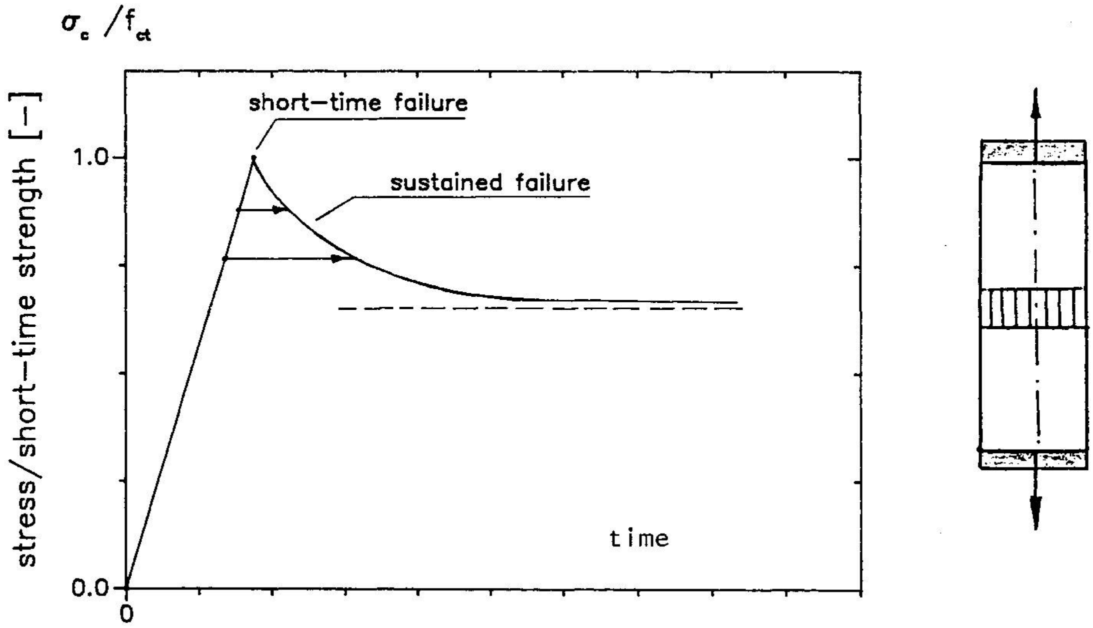

Fig. 1 Principle of sustained tensile test

An important observation is that this sustained strength-limit is reached after a relatively short period. A few days of sustained loading are sufficient to reach the 70% limit. This phenomenon may have important consequences, both in a favourable and in an unfavourable way. With regard to strength considerations, such as the shear capacity of members not reinforced in shear, a reduction of the capacity seems mandatory. On the other hand, a reduction of the tensile strength by sustained loading would have a positive effect in cases where minimum reinforcement is required due to the effect of imposed deformations. In this case the reduction of the tensile strength leads to a proportional reduction of the required amount of minimum reinforcement.

This shows that it is worthwhile to consider the influence of the strain rate more in detail. A number of questions can be raised, f.i.

- To what extend does the sustained strength-limit depend on the definition of the short term tensile strength? If the loading rate of the short-term test is not the same in all the tests, the sustained strength-limits $f_{ct,\infty}/f_{ct,o}$ as reported by various authors in the literature, are not comparable.
- Up to now only concentric sustained tensile tests have been reported. Many structural actions, however, lead to stress gradients. It is questionable if the results of concentric tensile tests can be applied to eccentric load application, or to flexure.
- Furthermore it may be wondered if the classical sustained loading test is representative for any loading case. If imposed deformations are concerned, the tensile stresses develop slowly in time and reach the cracking level within a period which may vary between hours and days.

In order to generate answers on these questions a number of tests has been carried out.

2. EXPERIMENTS

2.1 Sustained concentric tensile loading tests

The classical concept of a sustained loading test is as follows. The short term tensile strength (rapid test) is determined with a certain loading rate: subsequently, concrete with the same properties and storage conditions are loaded to a certain fractile of the previously determined short-term tensile strength. At this loading level the stress is kept constant. For high levels ($\frac{\sigma_c}{f_{ct}} > 0,7$), the concrete is observed to fail after a certain period.
This principle of testing was adopted for the first series of tests. The tests were carried out on cylindrical (ϕ 150 x 300 mm) and rectangular (150 x 150 x 300 mm) specimens, casted vertically in steel moulds. In order to prevent the development of internal stresses by shrinkage, the specimens were sealed before and during testing with plastic sheets. The average cube strength was 32 N/mm^2.

The short-term tensile strength was determined by testing specimens with such a loading rate that failure occured after about 10 seconds. In the sustained loading tests, the sustained load level was reached within one minute. Then the load was kept constant until failure occurred. The results of these tests are shown in Fig. 2.

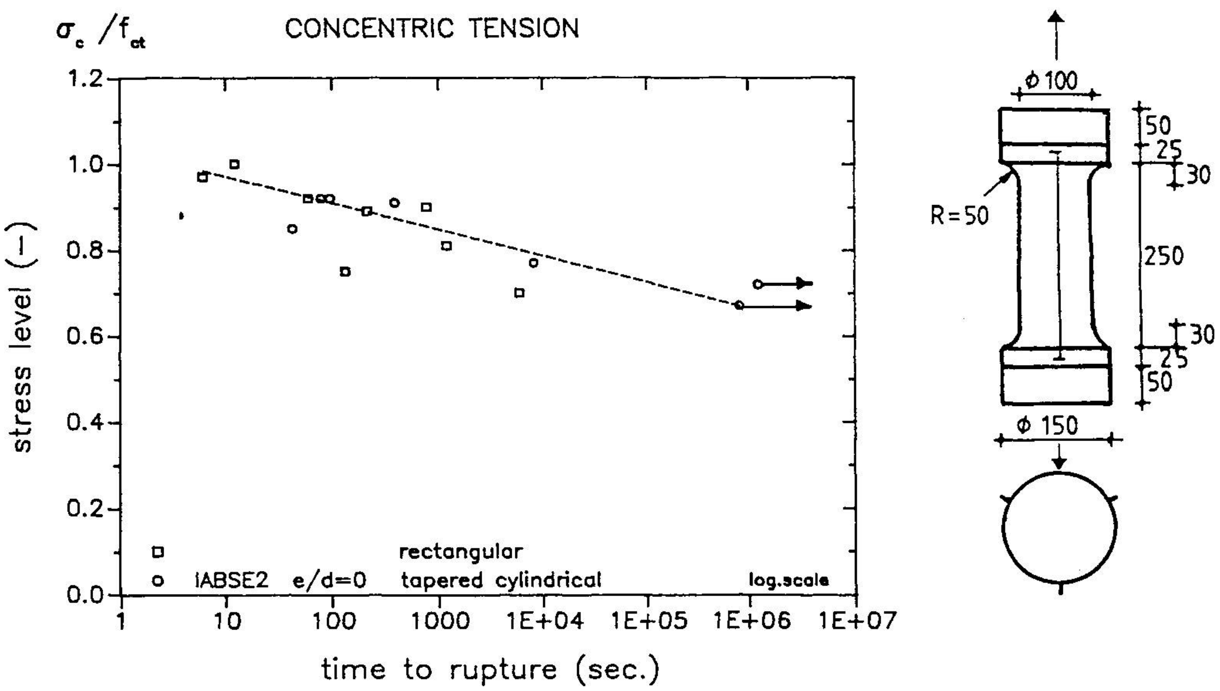

Fig. 2 Relationship between relative sustained stress level and time to failure for the concentric tensile tests

It can be seen that time to rupture increases with decreasing stress level σ_c/f_{ct}. It was found that, if a specimen did not fail within the first three hours, no failure at all occurred (the maximum loading time was two weeks). The lower limit of σ_c/f_{ct}, as observed, was 0.7. The specimens which did not fail after a period of sustained loading were subsequently loaded to failure in a rapid tests. Surprisingly, the strength obtained after this procedure was significantly higher than the strength obtained in a short term test on virgin specimens! This cannot be explained by the effect of continuing hydration, since an increase in strength was also observed after a sustained load of only a few hours. This might be explained by relaxation of the cement matrix during sustained loading, which could lead to a relaxation of stresses at the tip of the micro-cracks.

2.2 Sustained eccentric tensile loading tests

After the concentric tensile loading tests, a series of experiments was carried out on specimens, subjected to an eccentric tensile load. The relative load-eccentricities adopted in the tests were e/d = 0.167 and 0.5.

Figs. 3a and b show, that the decrease of the strength by sustained loading, is smaller, the larger is the eccentricity of the load. For e/d = 0.167 no failure was observed to values of σ_c/f_{ct} smaller than 0.75. For e/d = 0.50 the lower limit was even about 0.9.

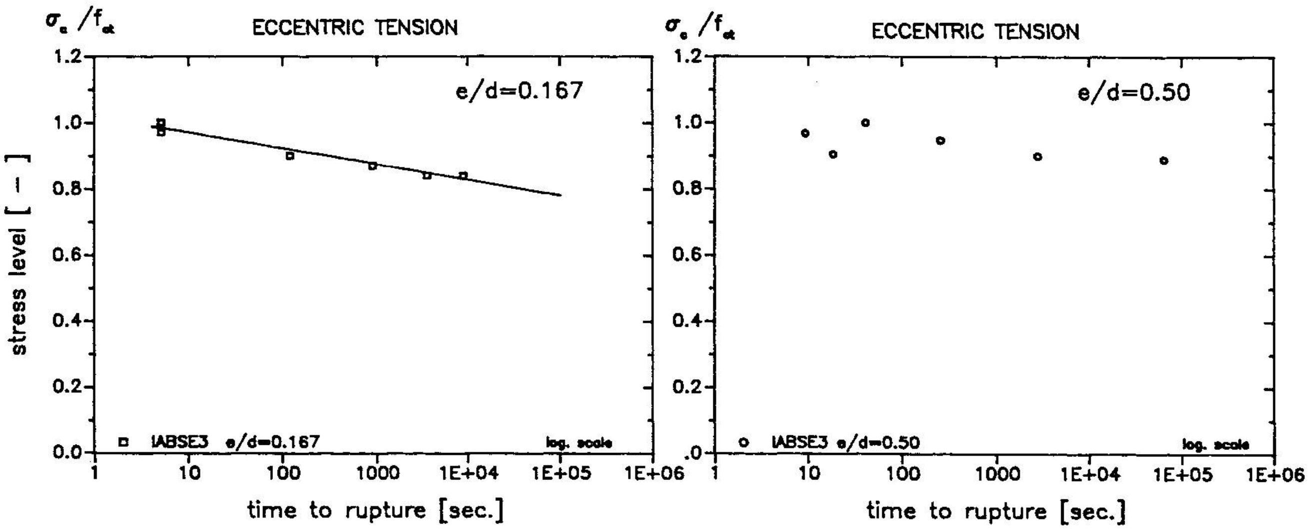

Fig. 3 Relation between relative stress level and time to rupture by eccentric tensile loading, with e/d = 0.167 and e/d = 0.50.

Also here the specimens which did not fail during sustained loading where loaded to failure in a short term test, and also here an increase of the strength was observed.

Obviously the sustained loading effect consists of two mechanisms, a damaging one and a hardening one. If the damaging mechanism is not strong enough to cause failure, the hardening mechanism starts to dominate, which results in a higher strength than the original one.

2.3 Eccentric tensile tests with different loading rates

If the previous conclusions, concerning damaging and hardening, were true, this would mean that, in case of a constant loading rate, a reduction of this loading rate could possibly lead to an increase of the strength. In order to examine this phenomenon, cylindrical specimens were loaded up to failure with different loading rates. The failure occurred after about 6 seconds, 2 minutes, 20 minutes, 1 hour and 2,5 hours. Fig. 4 shows the relationship between the failure load after the loading rate.

In Fig. 4 the loading rate is represented along the horizontal axis. The highest loading rate was such, that failure occurred in about 6 seconds (righthand side of the diagram). If the loading rate is decreased (passing from right to left), the strength decreases too. However, further lowering the loading rate leads to an increase of the strength.

This is remarkable because in such a situation, which reflects f.i. the case of stresses by imposed deformations (such as solar radiation), the lowest strength is obtained for a loading rate, which is generally considered as belonging to a short term test. Tensile splitting tests, carried out on control specimens, as usual in practice, do generally not require more than 2 minutes, so that application of a strength reduction factor to consider a sustained loading effect in practical situations seems to be unjustified.

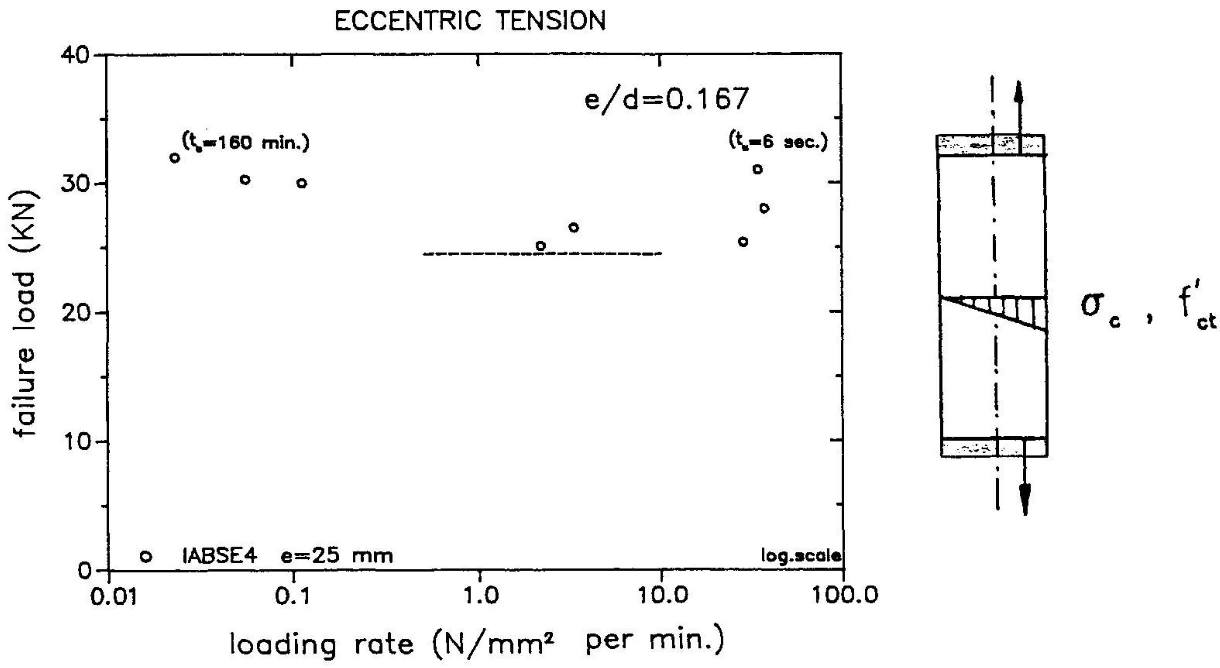

Fig. 4 Relationship between failure tensile load and loading rate for an eccentricity of e/d = 0.167

3. CONCLUSIONS

- In concentric tensile tests the strength under sustained loading is smaller than under short-term loading. In order to determine the sustained strength limit, a clear definition of the short-term strength is necessary. If the short-term strength is determined within a failure time of 10 seconds, the sustained tensile strength is about 70% of the short-term strength, whereas in the case of 100 seconds failure time, the sustained tensile strength is about 85% of the short-term strength.
- The sustained tensile strength increases with increasing eccentricity: i.e. if a stress gradient is available over a cross-section, and the short term strength is defined as that strength, which is obtained in 100 seconds, the sustained loading effect can be neglected.
- In addition to the damaging effect there is also a hardening effect, which can probably be explained by the reduction of the peak stresses by relaxation. This is most effective if the loading rate is relatively small.

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