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Strength of Freeze-Thaw Deteriorated Concrete

Résistance du béton détérioré par des cycles gel-dégel

Festigkeit von durch Frost und Auftauen beanspruchtem Beton

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SUMMARY

Tests have been performed in which drilled-out concrete cores were first subjected to an environmental load in the form of freezing-thawing and then to a functional load in the form of a fatigue or static failure load. The aim was to study the combined influence of the deterioration factors on the strength of concrete. Measured results show that a concrete without entrained air which freezes in pure water shows no appreciable loss of strength. In contrast, if salt is present in freezing medium, strength degradation of up to 50 per cent can occur very quickly.

RÉSUMÉ

Des carottes de béton prélevées par forage ont été soumises à des contraintes dues au gel et dégel, puis à des contraintes physiques, sous forme d'essais de fatigue ou statiques, l'objet étant d'étudier l'influence combinée de ces facteurs de décomposition sur la résistance du matériau. Ces essais on montré qu'un béton sans adjonction d'air, qui gèle dans de l'eau pure, ne perd que très peu de sa résistance. Par contre, si le liquide contient du sel, on note une dégradation rapide de la résistance.

ZUSAMMENFASSUNG

Es wurden Versuche an Betonbohrkernen durchgeführt, welche nach einer umweltmässigen Beanspruchung in Form von Einfrieren/Auftauen einer funktionsbedingten Beanpruchung (Ermüdungs- oder Bruchbeanspruchung) ausgesetzt wurden. Ziel war, die kombinierte Einwirkung dieser Zerstörungsfaktoren auf die Festigkeit des Betons zu untersuchen. Die Ergebnisse zeigen, dass die Festigkeit von in sauberem Wasser eingefrorenem Beton ohne Luftzusatz kaum nennenswert nachlässt. In einem Medium mit Salz hingegen kann sich die Festigkeit sehr schnell um bis zu 50% verschlechtern.

1. BACKGROUND

In the survey by Ingvarsson & Westerberg [1], it emerged that the interaction between environmentally and functionally caused deterioration was a subject on which research was considered a matter of importance. In the first instance, this concerned the problem area of fatiguing of salt- and frost-damaged concrete and fatiguing of concrete with embedded, corroded reinforcement steel. As a continuation, tests on the strength and fatigue properties of freeze-thaw deteriorated concrete have been carried out on behalf of the Swedish National Road Administration and the Swedish Transport Research Board. These tests are reported below.

2. TESTS

2.1 Test specimens

The purpose of the tests was to reflect the combined effect of environmentally caused and functionally caused degradation factors and how this effect varies with different concrete mixes. To this end, tests were carried out according to Fig. 1 in three subseries. These were:

I	W/C = 0.60, without air entrainment
II	W/C = 0.50, without air entrainment
III	W/C = 0.50, with approx. 8 % entrained air

In all cases, use was made of pure standard Portland cement and an aggregate with a maximum size of 16 mm. The weight ratio cement:gravel:stone was 1:3.5:1.4 in series I, 1:2.3:1.7 in series II and 1:2.1:1.6 in series III.

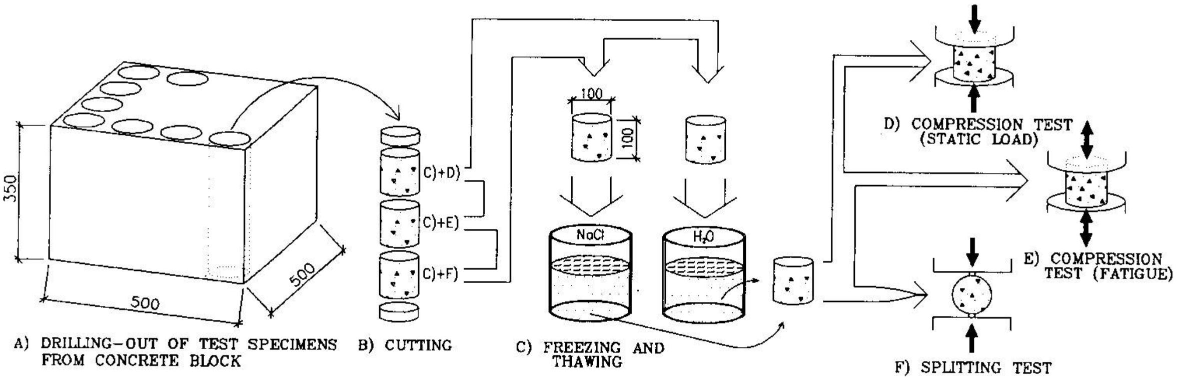

Fig. 1: Test procedure

Cores with a diameter of 100 mm were drilled out of specially cast concrete blocks. The cores were cut into three cylinders with lengths of 100 mm, see Fig. 1:A and 1:B. Each subseries comprised 54 concrete cylinders.

2.2 Environmental load

Half the number of cylinders were frozen in water and half the number in a 3 per cent sodium chloride (NaCl) solution. The 54 cylinders were divided into 9 groups exposed to 0, 7, 14, 28 or 56 freeze-thaw cycles, with or without NaCl in the freezing medium, see Fig. 1:C. After being cast the cylinders were kept continuously moist, until freeze-loading.

2.3 Functional load

After being subjected to freezing and thawing, the strengths and fatigue properties of the concrete cylinders were tested by means of a static load test until failure in compression (Fig. 1:D), a fatigue test (Fig. 1:E) and a splitting test (Fig. 1:F).

3. TEST RESULTS

3.1 Static load tests

3.1.1 Compressive strength

The static load tests to compression failure were conducted with a constant velocity of 5 μm/sec. The results from these tests formed the basis for the load levels used in the fatigue tests, see Section 3.2 below. The ultimate stresses measured in the static load tests are shown in Fig. 2.

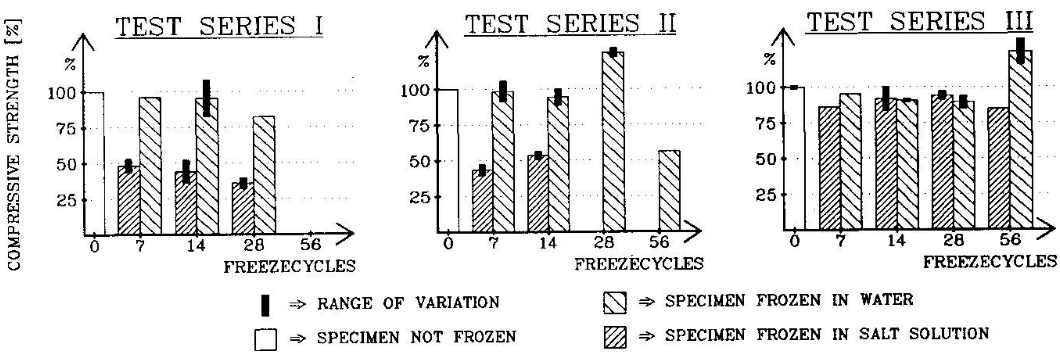

Fig. 2: Results of static compressive strength tests

The measured ultimate compressive strengths of the cylinders are shown in Fig. 2 for the different subseries I, II and III. The results are presented as mean values for each group. The columns are grouped two by two according to the number of freeze cycles. The left-hand columns show the values for the NaCl-frozen cylinders and the right-hand columns those of the water-frozen cylinders. The thick line at the top shows the range of variation for the compressive strength of all cylinders in the group. In some freeze groups one or both columns are missing, the reason being that the specimens did not withstand the freeze-thaw cycles. Cylinders which had passed the fatigue test without rupturing and then were loaded statically to failure are not included in the results shown in Fig. 2.

It is evident from the results that the ultimate compressive strength rapidly decreases on freezing in NaCl solution, if the concrete does not contain an air-entraining admixture. From series I and II it can be concluded that the ultimate strength has fallen to approx. 50 per cent of the original value. On the other hand, the ultimate strength is very good in series III where entrained air was added to the concrete. Measured strengths and deformations also indicated that the moduli of elasticity decreased upon freezing in both water and salt solution. This was valid for all subseries I, II and III.

An interesting observation that can be made is that those strength values which have decreased at only seven freeze cycles tend to become stabilized at this level, or occasionally even to increase slightly again. See Fig. 2.

3.1.2 Splitting strength

It is evident from the results of splitting tests, as presented in Fig. 3, that the tensile strength of the concrete, as well as its compressive strength, is considerable decreased when the concrete freezes in the presence of NaCl. This applies, according to Fig. 3, in the first instance to subseries I and II where the concrete did not contain entrained air. The results from subseries III instead indicates an increasing splitting strength, probably due to deviations in the concrete itself. Also in series III the strengths of the NaCl-frozen cylinders are slightly inferior.

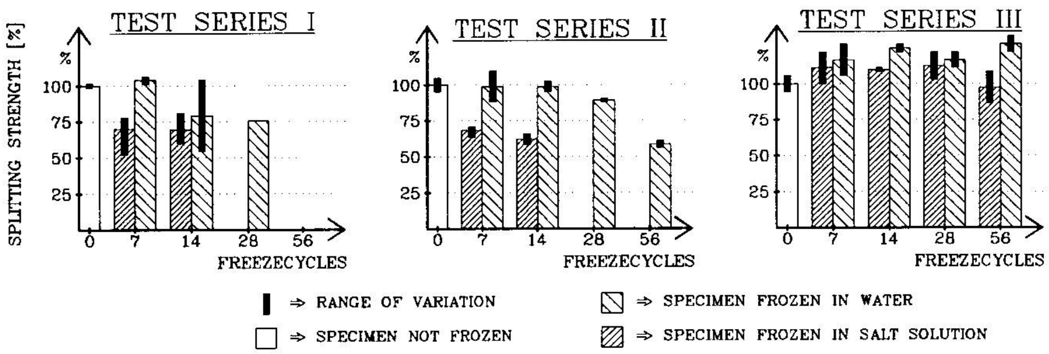

Fig. 3: Results of splitting tests. Designation as per Fig. 2

3.2 Fatigue test

The fatigue tests were performed with a compressive load frequency of 7 Hz at night and 15 Hz during the day. The fatigue test results observed are presented in Fig. 4.

In Fig. 4, σ is used for the maximum stress to which the cylinder was exposed in each load cycle, while f_u designate the ultimate compressive stress measured at the static load tests, see section 3.1.1 above. In each load cycle, the load was varied between 0 and σ. In the diagrams of Fig. 4, the Wöhler curve according to Bennet & Muir [2] is shown in order to make a comparison possible. From this it can be concluded that the fatigue properties of the concrete are affected by freezing and thawing irrespective of whether the freezing medium was provided with NaCl or not. This conclusion is valid for concrete without air entrainment only. With respect to fatigue, concrete cylinders with air entrainment, series III, were not affected at all. These results are somewhat confusing, as they do not correspond to those obtained by Antrim & Mc Laughlin [3]. In this reference concrete cylinders both with and without entrained air are subjected to fatigue. No significant differences in fatigue resistance were detected.

For the cylinders which had not ruptured at $2 \cdot 10^6$ load cycles, the tests were discontinued. Insted these cylinders, which are not included in Fig. 4, were loaded to either static compressive or splitting failure. These cylinders normally showed a higher compressive and lower splitting strength than those not fatigue tested. This tendency however, was not discernible throughout. An explanation may be that these cylinders did not rupture by fatigue due to their high compressive strength. On the contrary, internal cracking due to the fatigue load caused a decrease in splitting strength, i.e. tensile strength.

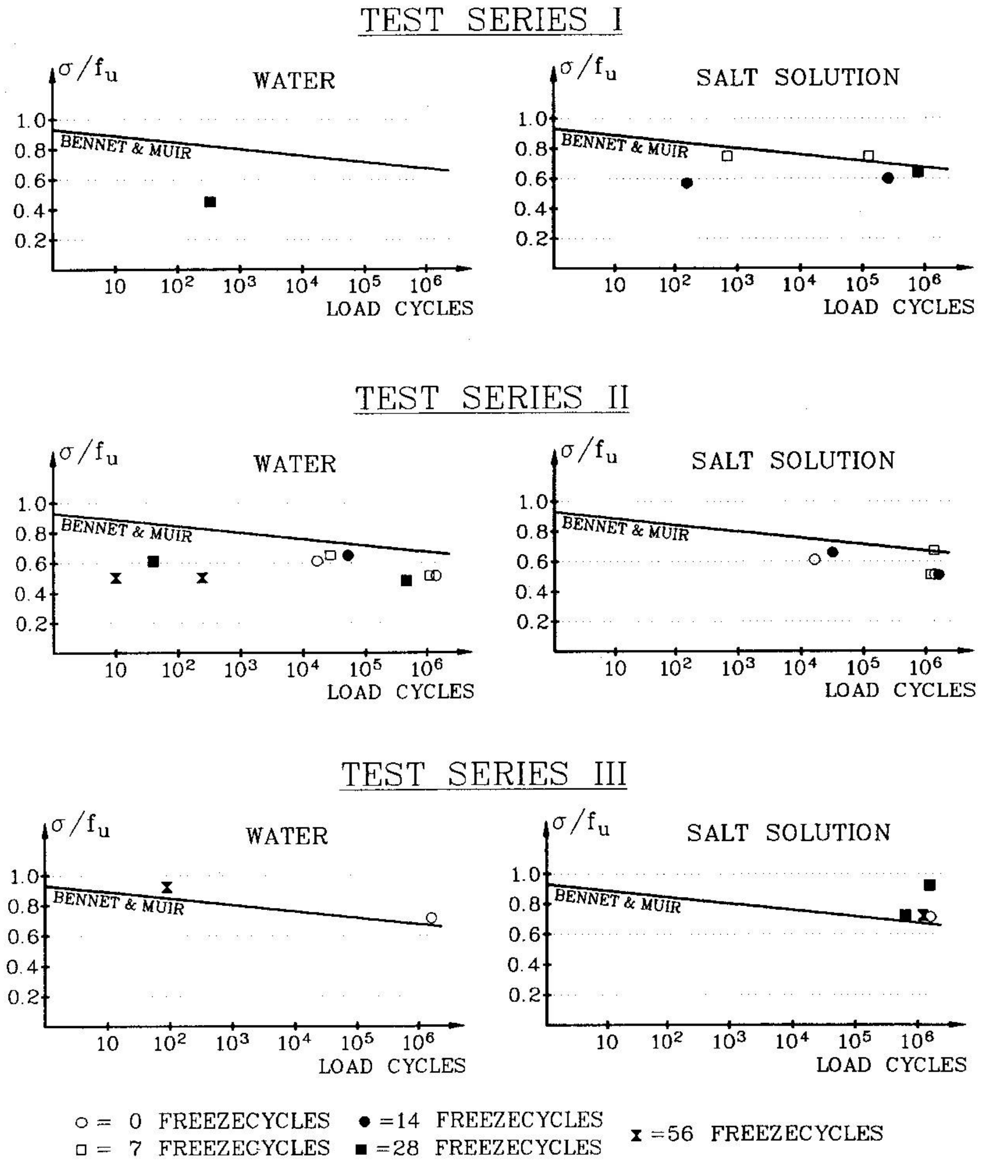

Fig. 4: Results of fatigue tests, series I, II and III

4. CONCLUSIONS

The conclusions from the tests can be summarized as follows:

1. Concrete which freezes in pure water retains its strength properties well.
2. Concrete which freezes in the presence of NaCl very quickly loses its strength properties, unless air is entrained. The strength properties which decrease directly upon freezing in salt solution tend to become stabilized after a small number of freeze cycles.
3. Concrete which freezes in pure water or in salt solution loses some of its fatigue resistance. However, if air is entrained the resistance retains.

Older concrete structures which have regularly been exposed to de-icing salts or seawater may now have deteriorated, resulting in a considerably inferior concrete strength and decreased fatigue resistance. In determining the load-carrying capacity of older structures it is therefore essential to drill cores and to examine the strength and fatigue properties of these. It is thus a doubtful procedure to recalculate older structures in accordance with new codes on the basis of the strength which the concrete had when the structure was built, taking for granted that this strength is retained.

5. FUTURE WORK

In addition to the test series described above, the interaction between functionally and environmentally caused load impacts will be studied. The planned work will embrace both mild (non-tensioned) reinforced concrete beams and prestressed concrete beams. The beams will be exposed either to freeze-thaw cycles or to corrosion of the reinforcement. This will be accomplished by giving the reinforcement a positive electric potential in relation to the concrete. By this means, chlorides will be led in towards the reinforcement and the reinforcement will corrode. When the beams have been exposed to this environmental load, they will be subjected to a functional load in the form of a static load test to failure or a fatigue test.

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