STRUCTURAL CHANGES OF STEEL FIBRE CONCRETE IN COMPRESSION

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1. Scope

In the late seventies, increasing use of steel fibre concretes in this country induced the Department of Building Materials, Technical University, Budapest, to make research — in cooperation with the *Civil Engineering Enterprise* — on the

— watertightness under stress
— shrinkage
— creep

of such concretes. Relative structural changes of concretes made with different percentages by volume of steel fibre and of concretes without steel fibre, and effect of these changes on the load capacity of the concretes were examined. This research could be justified on hand of several practical examples, among them that of thin-walled reservoirs will be quoted. Exposure to both compression and bending causes a certain further compaction in the concrete compressed zone, improving e.g. the watertightness, so it is very important to know how the structure of the concrete changes under compression.

Thus, the investigation attempted — besides of tracking the physical process of failure — to conclude from structural changes in the concrete on its condition, on its behaviour with time and under load.

The study recapitulates major research results.

2. Research method

From publications and research results, deformation and failure of concrete are known to be decided directly by the structure of the hardened cement. Properties of hydration products constituting the hardened cement (in the actual case the strength and deformation properties) change, however, in a rather wide range so that the hardened cement structure is not uniform, neither is the stress distribution.

This is why failure of the concrete proceeds gradually from the unloaded condition to the complete disintegration [1]. Several publications [2, 3] have pointed out that in ultimate analysis, development of deformations cannot be related to mean stresses referred to the entire domain under load, because stress peaks are primarily decisive for structural changes caused by loads. Namely these are responsible for local failures (micro-cracks, crystal face slips, slackening) decisively changing the material behaviour, among others its watertightness. Under conditions of free development of the deformation normally to the load direction, at least in one direction, in the first stage of the failure process, expansion and slackening are decisive. In case of compression, of course, transversal strains develop, hence slackening occurs at a given value of transversal elongations. Analysis of this phenomenon is found in many papers [2, 4, 5, 6, 7] which expressed the slackening rate essentially in terms of the volume change

$$\Theta = \varepsilon_x - 2\varepsilon_y$$

or of the volume change increment

$$\Delta\Theta = \Delta\varepsilon_x - 2\Delta\varepsilon_y.$$

Accordingly, the process of structure disintegration may be described by two characteristic stress values:

σ^a_{cr} — beginning disintegration of the structure;

σ^f_{cr} — developed level (inducing the unstable condition) pertaining to the inflexion point or the extreme value in the concrete stress—strain diagram. Therefore the σ^a_{cr} and σ^f_{cr} values are best determined from the difference curve of the stress—strain diagram, by means of the extreme value of the curve and its intersection point with the stress axis, respectively.

Structural changes of the concrete under load are best illustrated by the analysis — beside the examination of the specific strain — of the change of transverse contraction factor $\nu = \frac{\varepsilon_y}{\varepsilon_x}$ or its increment

$$\Delta\nu = \frac{\Delta\varepsilon_y}{\Delta\varepsilon_x}.$$

3. Experimental

Major characteristics of the tested concrete:
Planned concrete quality: B 280/30/4;
cement dosage: 330 kg/m^3 S 54 pc;
w/c ratio: 0.49;

aggregate: sandy gravel;
D_{max}: ∅ 30 mm;
grade: on the verge of classes I and II, according to ME 19—63;
steel fibre percentage in the concrete: 0—2.3—4.6—5.7% by mass.

The axial compression tests were made on 120×120×360 mm prisms, prepared in the laboratory of the *Civil Engineering Enterprise.*

To test slackening of the compressed concrete structure, measurement of surface deformations of the concrete under load was applied. In these tests transversal and axial dimension changes of slowly, continuously loaded prisms were measured by means of inductive strain gauges D 32, connected to analog testers. The load rate was measured by a cylindrical dynamometer indicating the resistance changes. The force and length changes were recorded by a *Honeywell* $x-y-y'$ plotter.

Mean characteristics calculated from test results obtained on 9 to 20 specimens from each type have been compiled in Figs 1 and 2.

Examining the curves in Fig. 1 according to statements in the former chapter, it is seen that during loading of the concrete three stages of its structure can be distinguished:

— stage I until the lower critical load shows no important structure destructions,

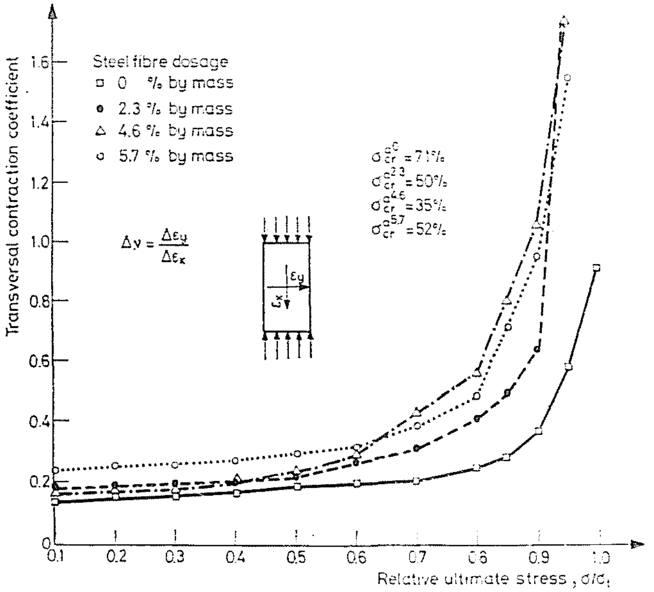

Fig. 1. Variation of transversal contraction factor of concretes grade B 280—30/4 subject to uniaxial compression

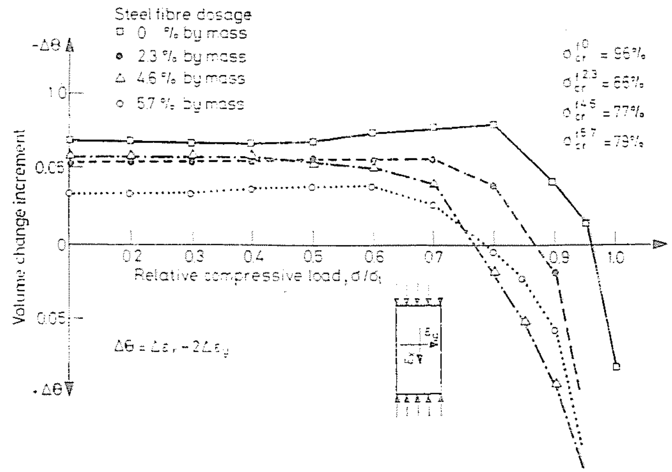

Fig. 2. Stress - strain difference curves of concretes grade B 280 30/4 under axial compression

— stage II where aggregate adhesion gradually ceases, especially on the surface of larger particles,

— stage III where a consistent net of cracks develops on the aggregate surface and in the interior of hardened cement.

In stage I, until a certain value of the relative ultimate load (σ/σ_l), decrease of volume, i.e. compaction occurs, thus, the load effect produces a denser structure than that of the unloaded concrete, extremely favourable e.g. from the aspect of watertightness.

Accepting either the specific volume change index Θ or the volume change increment $\Delta\Theta$ as the parameter of slackening, anyhow, compaction under pure compression is found to last as long as the transversal contraction factor (or its increment)

$$\nu = \frac{\varepsilon_y}{\varepsilon_x} = \text{constant}.$$

Figure 2 shows the increment of the tranverse contraction factor for the tested concretes.

In Fig. 3, σ_{cr}^{a} and σ_{cr}^{f} values calculated according to the above and the loading domain characteristics have been plotted as a function of the steel fibre percentage.

In Fig. 4 average values of prism strength and the initial moduli of elasticity have been plotted vs. steel fibre percentage, accompanied, for the sake of comparison, by creep maxima obtained in earlier tests [8] on prisms compressed by ≈ 200 kN constant load for 150 days. It must be mentioned that the creep value proportions developed already in the initial test period.

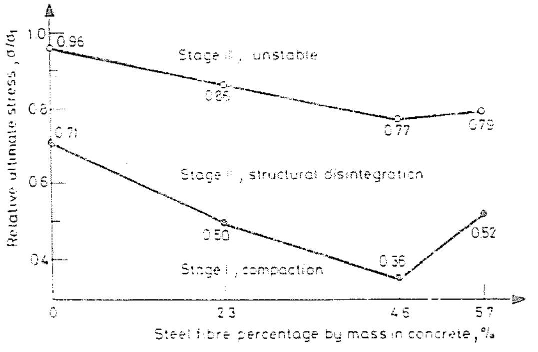

Fig. 3. Development of σ_{cr}^{a} and σ_{cr}^{f} vs. steel percentage in case of axial compression

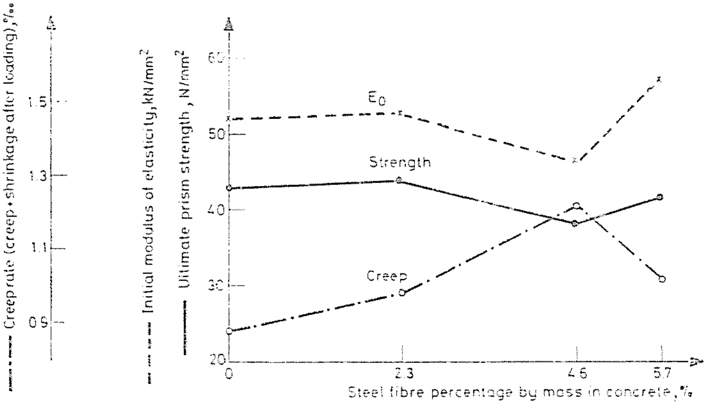

Fig. 4. Effect of fibre addition on compressive strength, modulus of elasticity and creep

In final account, measured and calculated characteristics of axially compressed concrete specimens lead to the following main conclusions:

— steel fibre addition much increases the Poisson's ratio, the increase is the most apparent for concretes made with 4.6% of steel fibres, adverse to watertightness [9];

— steel fibre addition increases the change of volume and reduces the σ_{cr}^{a}; σ_{cr}^{f} values, the prism strength and the initial modulus of elasticity.

This means actually that it reduces the compressive ultimate load. This phenomenon is favourable to some properties, e.g. watertightness.

These research results hint to the importance of structural changes for the behaviour of concretes — especially in higher load ranges — and of the knowledge of structural changes under short-time loading for the correct evaluation of other properties.

Summary

Tests on the change of concrete structure aim at a closer insight into concrete behaviour to various stresses.

Concrete failure depends on strength and deformation characteristics of hardened cement and of its constituent hydration products. Uniaxial compression tests were made on concretes containing different percentages of steel fibres. Longitudinal and transversal deformations were measured on surfaces of prisms under axial compression underlying calculations of the extreme values of structural changes.

Confrontation of these values to ultimate stresses shows the compressive load causing compaction, structure decomposition or instability in concretes, decisive for the concrete load capacity.

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* In Hungarian