PERIODICA POLYTECHNICA SER. CIVIL ENG. VOL. 37, NO. 4, PP. 313–320 (1993)

EFFECT OF INHOMOGENEITY ON STRENGTH AND DEFORMATION CHARACTERISTICS OF CONCRETE

György BALÁZS *, József BORJÁN*, Albert HORVÁTH** and Ferenc SCHWERTECZKY***

* Department of Building Materials
Technical University of Budapest
H-1521 Budapest, Hungary
** Hungarian Consumer Protection Superintendence
Szende Pál u. 3.
H-1051 Budapest, Hungary
*** Design Enterprise Residential and Public Buildings Ltd.
Madách tér 4.
H-1571 Budapest, Hungary

Abstract

The article discusses the experimental results of how the inhomogeneity of concrete influences the next factors:

- preparation of road concrete
- moulding the concrete prism in a lying position and testing in standing position
- the effect of gauge length
- the effect of the type, shape and size of the aggregate used.

Introduction

Material characteristics (strength, deformation) are understood as mean values depending on shape, size, test method, material composition and homogeneity. Among the factors, the effect of homogeneity will only be pointed out on hand of some examples.

Inhomogeneity of Concrete of Highway Construction

Strength of a specimen under central compression and tension load is understood as quotient of the ultimate force and the surface area. It can easily be demonstrated, however, by ultrasonic concrete tests how the ultrasonic velocity varies along the specimen height. Core specimens were drilled out from the highway concrete at corners and midpoints of a square with 1 m sides (*Fig. 1*).

Cores No. 2, 5 and 8 were tested for strength as well as for ultrasonic velocity along the specimen height during compression and tension. Among several test results only one example will be demonstrated.

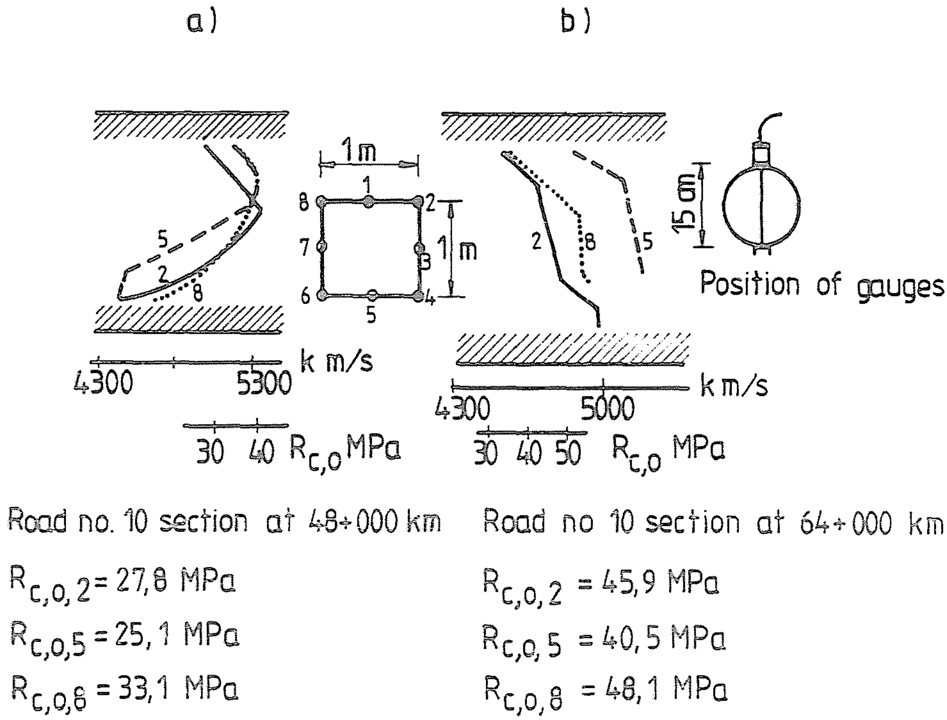

Fig. 1. Ultrasonic testing of highway concrete inhomogeneity

According to *Fig.* 1a, ultrasonic velocity varies considerably along the specimen height. Both the mean velocity and the respective strength are the lowest for specimen No. 5. Velocities along specimen height are more uniform in *Fig. 1b* than in *Fig. 1a.*

It is, however, a contradiction that according to velocities the strength of specimen No. 5 is expected to be the highest, while according to the mechanical compressive test, it resulted the lowest values. Also these examples point to the fact that, on one hand, cores drilled out of a 1 sq.m area of pavement concrete do not show the same strength (concrete is also inhomogeneous in the plane), on the other hand, strength is an intricate outcome of inhomogeneity along the specimen height, moreover, although the ultrasonic propagation velocity points out concrete inhomogeneity, it is insufficient to measure it along a single diagonal.

Casting Horizontally, Testing Vertically

Inhomogeneity may also arise from the specimen being cast horizontally, and loaded vertically during testing. Checking was made by means of 20 mm long strain gauges stuck on the surface of the rectangular specimens made with aggregates of 20 mm maximum size according to *Fig. 2a*. Along a specified length, the cross section of the specimen was constant: 12×12 sq.cm.

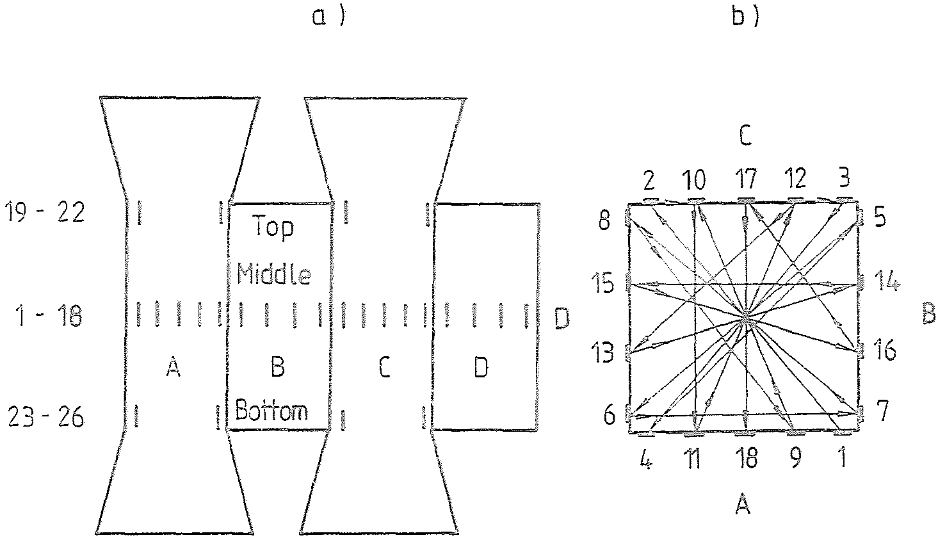

Fig. 2. Spread shell of a tensile specimen with the strain gauges (a), and the sequence of strain gauge readings (b)

For the sake of checking, in each load step, deformations were plotted in the order of measurements (*Fig. 3*).

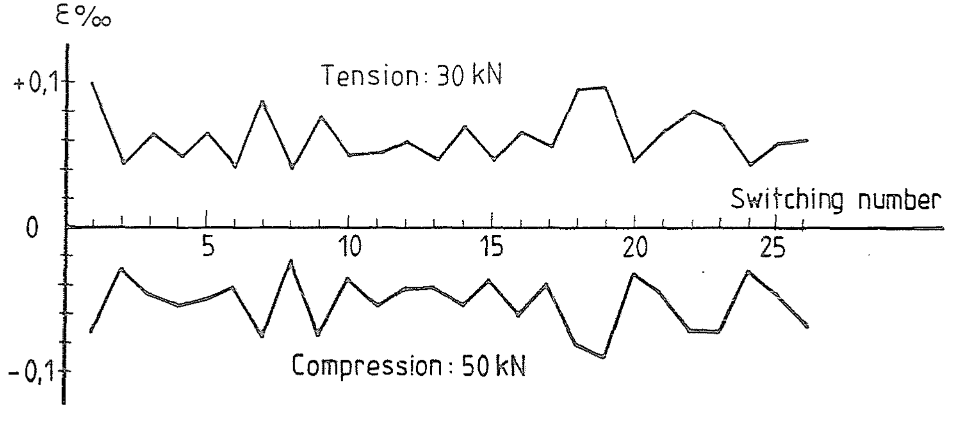

Fig. 3. Deformations in the sequence of measurements according to *Fig. 2b*

It seems that in the order of measurements, there were only random fluctuations. Locally differing deformations could be well observed with the strain gauge measurements. The order of extensometries appears in *Fig. 2*.

Thereafter, specimens were first exposed to compression load, then, after unloading, were put into a tensile testing machine with a special head, and tested for tension. The results were registered in the sequence according to *Fig. 2b*. Deformations are seen in *Fig. 4*. Maximum deformations appeared at the A-B edge, attributable neither to the mentioned error possibilities, nor to the excentric load (the specimen had a geometrically central position both during tensile and compressive loading), but to the deviation between material and geometrical centroidal axes.

Effect of the Gauge Length on Deviations of the $\delta - \varepsilon$ Diagram

Extension measurements under load are applied to conclude on deformational properties of concrete (modulus of elasticity, $\delta - \varepsilon$ diagram). Strain gauge length is of extreme importance, strain gauge is applied for measuring the mean elongation over the gauge length. Elongation of the mentioned rectangular specimen has been tested by means of 180 mm and 40 mm induction strain transmitters and amplifiers. Loaded up to 1.4 MPa tensile stress, after three repetitions (following each repetition, the instrument was removed and then mounted back again), the elongation resulted as 0.043 to 0.044 ‰. While over a gauge length of 40 mm it varied from 0.038 to 0.053 ‰, averaging again 0.044 ‰ (*Fig. 5*).

Thus, a short-gauge length measurement indicates rather the local elongations, while a long-gauge shows the mean elongation typical of the given material. Local deformations depend on shape and size of the specimen, on maximum size aggregate, on richness in mortar of concrete, on load application and rate, on concrete moisture, concrete inhomogeneity, as well as on the kind of extensometer and gauge length.

Effect of Aggregate on Inhomogeneity

Deformation characteristics are different between coarse aggregate and cement mortar and indicate an essential inhomogeneity. Inhomogeneity is mainly affected also by the shape and size of the aggregate. Theoretical and experimental models were applied to test the effects of grain shape (circle, ellipse), grain size (in case of a circle, 10 to 80 mm), aggregate material (steel and glass) and of mortar-matrix quality on the failure pattern. (The mortar quality was described by its modulus of elasticity: $E_h = 20$

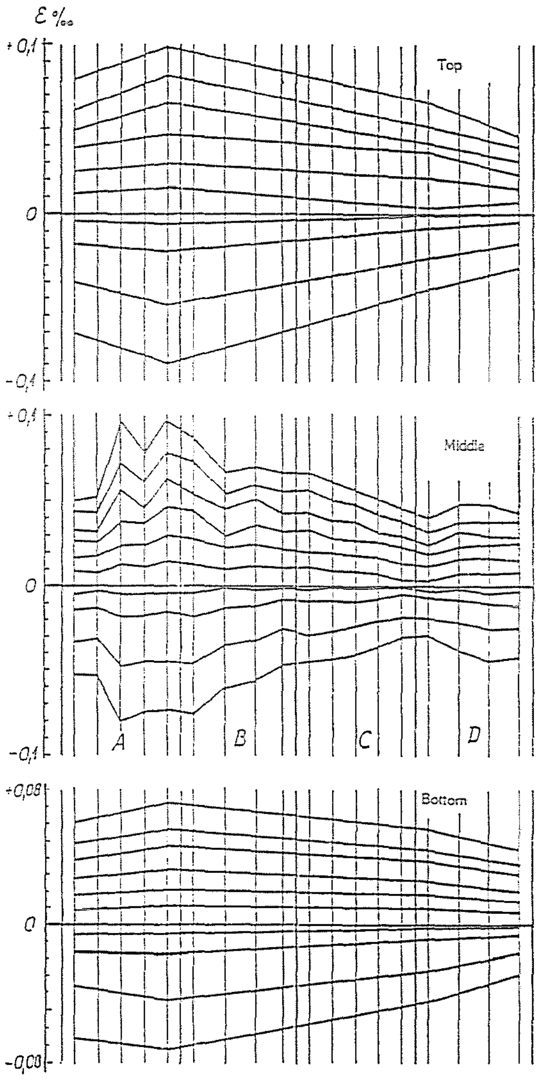

Fig. 4. Deformations on the surface of the rectangular specimen

30 or 40 GPa.) Centroids of the aggregate mortar disc and ones of the disc coincided.

Research results have been recapitulated in *Fig. 6.*

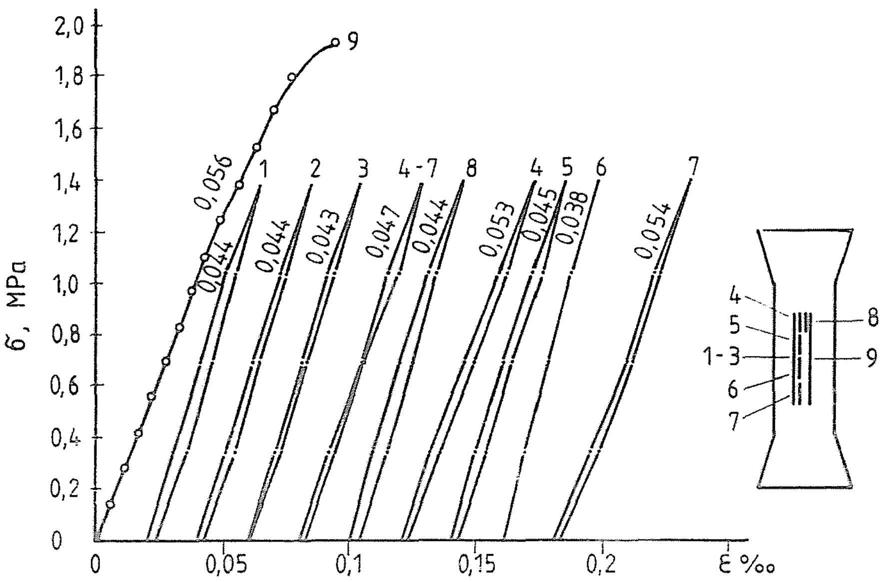

Fig. 5. Tensile $\delta - \varepsilon$ diagrams over 40 and 180 mm strain gauge lengths

Conclusions

a) Stress peaks and failures occurred at four points of the aggregate grain indicated in *Fig. 6a*. Tensile cracks appeared at somewhat lower forces than did compression cracks. The force causing tensile crack was more dependent on diameter and modulus of elasticity of the grain than that causing compression crack.

b) In case of a poor mortar, the ultimate force much depended on grain size and kind. For medium or good quality material ($E_h = 40$ GPa) the dependence was negligible (*Fig. 6* and *Fig. 6b*).

c) For compression the two end points of the smaller axis of the ellipse were critical with respect to the bond between aggregate and mortar. It was always the bond – rather than the mortar – that failed first. The ultimate force was little affected by the ratio of greater to smaller axis of the ellipse (n), but it was significantly affected by the mortar quality (*Fig. 6c*).

d) In case of a tension force parallel to the greater axis of the ellipse, circular aggregate grains ($n = 1$) behaved in the best way. By increasing the value of 'n', the ultimate force decreased for $n = 1$, failure

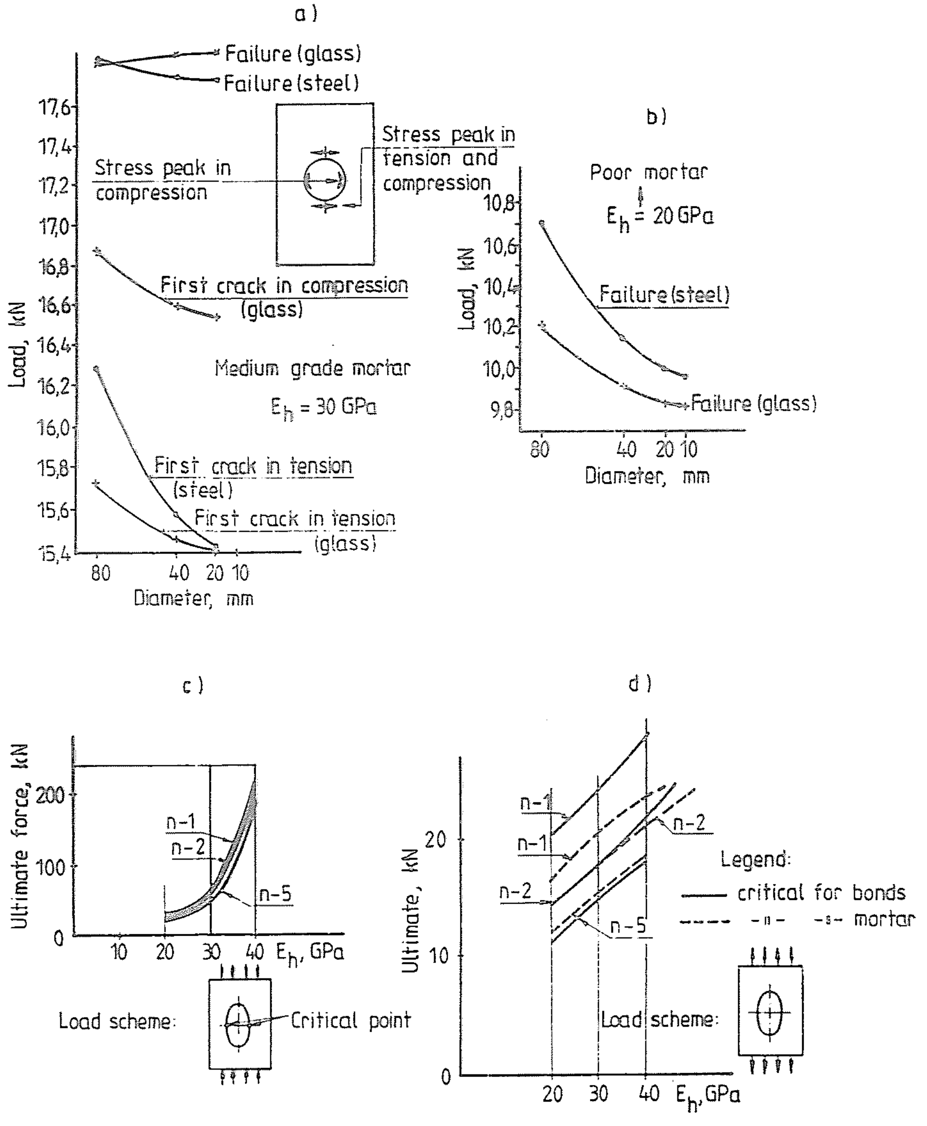

Fig. 6. Effect of grain shape, size, aggregate type, mortar grade on load type on the bond between aggregate and mortar
a.) Effect of grain size and aggregate kind on the stress causing cracking or failure of the bond between aggregate and cement mortar
b.) Effect of grain diameter and aggregate type on stress causing failure of the bond between aggregate and cement mortar
c.) Effect of form factor and mortar type on the ultimate force
d.) Effect of form factor and mortar type on the ultimate force

started at the bond, while for $n = 5$, in the mortar. Failure depended less on mortar quality than on compression (*Fig. 6d*).

Summary

The effect of concrete inhomogeneity on its strength and deformation characteristics was illustrated by examples in the following fields:

- inhomogeneity of highway concrete structures;
- effect of the mode of production;
- effect of the gauge length;
- effect of the grain size, shape and material, as well as of the embedding mortar (matrix) quality.