CEB
27 th PLENARY SESSION
PARIS SEPTEMBER 1990

COMITÉ EURO-INTERNATIONAL DU BÉTON
CONTRIBUTION OF THE POLISH NATIONAL GROUP

Wiesław ZAMOROWSKI [1)]

# IMMEDIATE STRAINS OF CONCRETE UNDER AXIAL TENSION

## 1. Introduction

The deformability of concrete under tension as well as its strength, thermal characteristics and humidity, condition its resistance to cracking. Among the features of deformability, of special importance is the ultimate elongation of the concrete subject to its age at the moment of testing. Literature [1,2,3] and CEB-FIP Model Code 1990 does not provide full and explicit information concerning the properties of deformability of concrete (under tension) within the process of curing. This fact has induced the author of the present paper to take up investigations of his own. These investigations constitute a part of the test programme dealing with the resistance of concrete to shrinkage cracking [2)].

## 2. The aims and range of the author's own investigations

The aim of these investigations was to determine the influence of the age of concrete on its elongation at various levels of stresses. Another aim - non included in the subject matter this paper - was to find the mutual relations between shrinkage strains and the elongation of concrete under tension. These relations condition the possibility of the occurrence of shrinkage craks in concrete samples without freedom of deformation [4].

The investigations comprised: the tensile strength $f_{ct}(t)$, the ultimate elongation $\varepsilon_z(t)$, the relation $\sigma$-$\varepsilon$ in the course of tension, $\sigma(\varepsilon, t)$ for concrete 1,3,7,14,28,60 and 120 days old.

---

1) Doctor Eng. Silesian Technical University
ul.Pstrowskiego 5, 44-100 Gliwice, Poland

2) Zamorowski W., The shrinkage crack resistance of concrete elements maturing without freedom of deformation., Doctoral disertation, Gliwice 1983

As the number of samples was rather large (12 samples for each age), they were made of six batches and then, distributed stochastically (at random), viz. 2 samples for each term of testing. Additionally from each batch, five cubes were made for the purpose of determining their compressive strength after 28 days, $f_{cu}$.

The composition of the concrete mix was as follows: 243 kg Portland cement 35, 2084 kg aggregate (sand-gravel mix and river sand), 174 l water. The samples were taken out of their moulds 24 hours after they had been cast, and then they were stored and tested at an ambient temperature of $20 \pm 1°C$ and a relative humidity of air amounting to $85 \pm 2\%$.

The deformations of concrete in this paper do not concern its respective components (binder or aggregate), but express its average deformations, mesured along a measuring basis of some definite length. Similarly, the stresses do not concern the components of concrete but are determined as the mean stresses over the cross-section of the sample. Thus, concrete is considerad to be a quasi-homogenous material. These assumptions do not result from an underestimation of the heterogeneity of the concrete structure and the stochastic character of the fields of deformation, or the microstructural phenomena, but were due to the necessity of applying availabe techniques of investigation.

## 3. Description of the tests

The direct tensile strength and deformability of concrete were tested on samples provided with heads shaped as shown in Fig.1. Along the length of the sample there may be distinguished 3 zones, viz. the head zone, in with the load is transferred from the chucks, the transitory zone, where the stresses are equalized, and the measuring zone, in which the sample failed. The fundamental dimensions of the sample correspond to the general RILEM recomendations [5, 6, 7].

Deformations were measured by means of frames, rods and two 1 μm-dial gauges on a 400 mm basis. The length of the measuring section corresponded to the sixteen-fold diameter of the largest aggregate grains and thus comprised the components of concrete. (Simultaneously certain associated rheological tests were carried out, not described in this paper, which

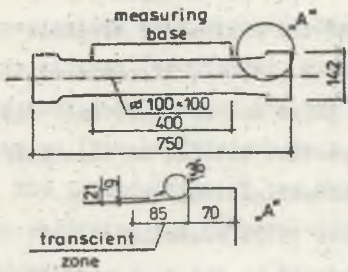


Fig.1. Shape and dimensions of a sample

excluded the possibility of applying electric resistance wire strain gauges). The read-off deformations were recorded for stresses stepwise reduced by 0,063 MPa (i.e. 20 graduations on the dynamometer gauge).

Deformations observed at the moment when the highest stress values - $f_{ct}$ were reached in the concrete, were considered to be the boundary elongation (ultimate elongation).

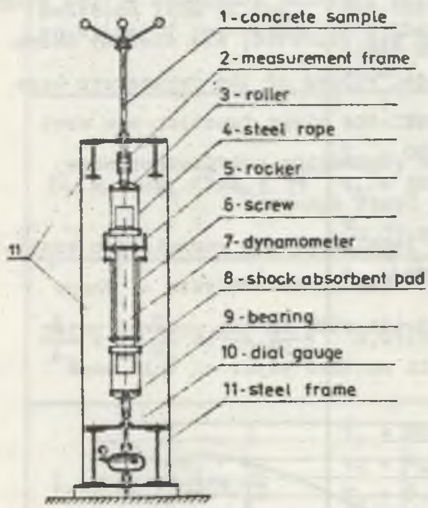


Fig.2. Tensile testing machine

The investigations were carried out with short-termed loads by means of a mechanical tensile testing machine, as represented in Fig.2. The force was generated by means of a fine-coiled screw and measured in series by means of an installed bow-shaped dynamometer, at a constant rate of increment of stresses. The applied roller--rope holders, connected with rocking levers, not only excluded the possibility of the generation of restraint moments in the sample but also facilitated the automatic regulation of the axiality of the load.

4. Test results

Before the results were processed, statistical analysis were carried out on the significance level 0,01 , and it was checked whether the experimental material was a homogeneous set. By means of Dixon's test [8] extreme values displaying blunders were discarded. The homogeneity of the set of test samples was checked making use of the analyse of variance with $f_{cu}$. The obtained value of statistics $F = 1,06$, if compared with $F_{0,001;\ 5;\ 24} = 3,90$, indicates that there was no additional factor between the sets of samples made of the respective batches of concrete.

In accordance with the purpose of these investigations as much information concerning the sought relation was to be accumulated as possible. Mathematically this problem was reduced to the search for a function of statistically trustworthy answers. The analysis of variance and regression was applied, which has made it possible to estimate the degree of scattering and matching of the data, the contribution of the respective components of the function and also to neglect insignificant components. The process of evaluating the function consisted of two stages First an adequate shape of the function was selected, and then by means of the correlation analysis the numerical values of the parameters were determined, at which the approximation of the given function was most favourable. The numerical values of the regression coefficient were determined making use of the method of least squares.

Table 1 contains the more important results of the correlation analysis of selected functions. Detailed results of the analysis of these functions, as well as of functions not dealt with in the present paper but deserving attention, may be found in another paper of this same author.[2)]

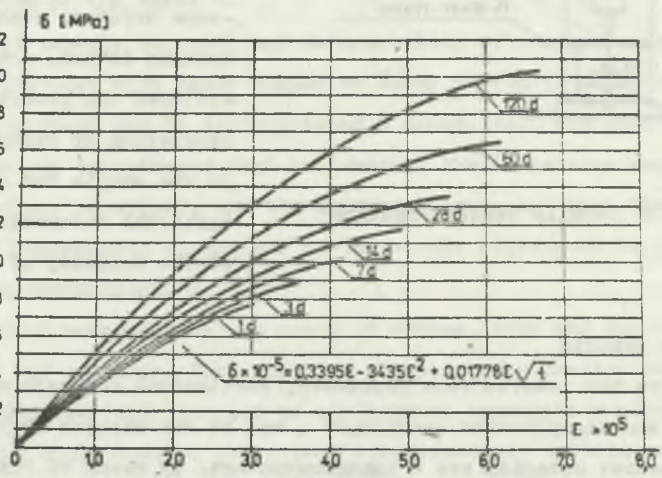


Fig. 3. The relation 6-ε for concrete of varying age

---

2) Cf. footnote 1

Fig.3 represents the relation $\sigma$-$\varepsilon$ for concrete of various ages. Experimental data have not been plotted in the diagram as there are too many of them (about 900). Diagrams of the analysed functions display a distinct influence of the age of concrete on its deformability under tension (the coefficient by t is significant, cf. Table 1).

The introduction of two variables $\varepsilon / \varepsilon_z$ and $\sigma / f_{ct}$ provides a basis for rendering the "stress-strain" relation independent of the age of concrete.

Among the various analysed shapes of the functions meeting the imposed boundary conditions, special attention is to be paid to the relation

TABLE 1

**Results of the correlation analysis**

| Selected form of the equation of regression | The test value $t_s$ for the coefficient of regression | Coefficient of correlation R<br>Test value F |
|---|---|---|
| $\sigma = a_1 \varepsilon + a_2 \varepsilon^2 + a_8 \varepsilon \sqrt{t}$ | $t_1 = 78,56$<br>$t_2 = 32,18$<br>$t_8 = 38,04$<br>$t_{0,01;863} = 2,58$ | $R = 0,98$<br>$F = 6132,4$<br>$F_{0,01;3;863} = 3,80$ |
| $\frac{\varepsilon}{\varepsilon_z} = a_1 \frac{\sigma}{R_z} + (1-a_1)(\frac{\sigma}{R_z})^3$ | $t_1 = 107,90$<br>$t_{0,01;865} = 2,58$ | $R = 0,89$<br>$F = 3240$<br>$F_{0,01;1;865} = 6,67$ |
| $\varepsilon_z = a_o + \frac{a_1}{t} + \frac{a_2}{t^2}$ | $t_o = 32,10$<br>$t_1 = 4,76$<br>$t_2 = 3,12$<br>$t_{0,01;52} = 2,68$ | $R = 0,71$<br>$F = 27,2$<br>$F_{0,01;2;52} = 5,04$ |
| $\varepsilon_z = a_1 R_z + a_3 \sqrt[3]{R_z}$ | $t_1 = 3,77$<br>$t_3 = 8,11$<br>$t_{0,01;53} = 2,67$ | $R = 0,82$<br>$F = 52,8$<br>$F_{0,01;2;53} = 5,03$ |
| $\frac{\varepsilon_z}{R_z} = a_o + \frac{a_1}{t} + \frac{a_2}{t^2}$ | $t_o = 23,67$<br>$t_1 = 6,05$<br>$t_2 = 4,79$<br>$t_{0,01;52} = 2,67$ | $R = 0,71$<br>$F = 26,4$<br>$F_{0,01;2;52} = 5,04$ |

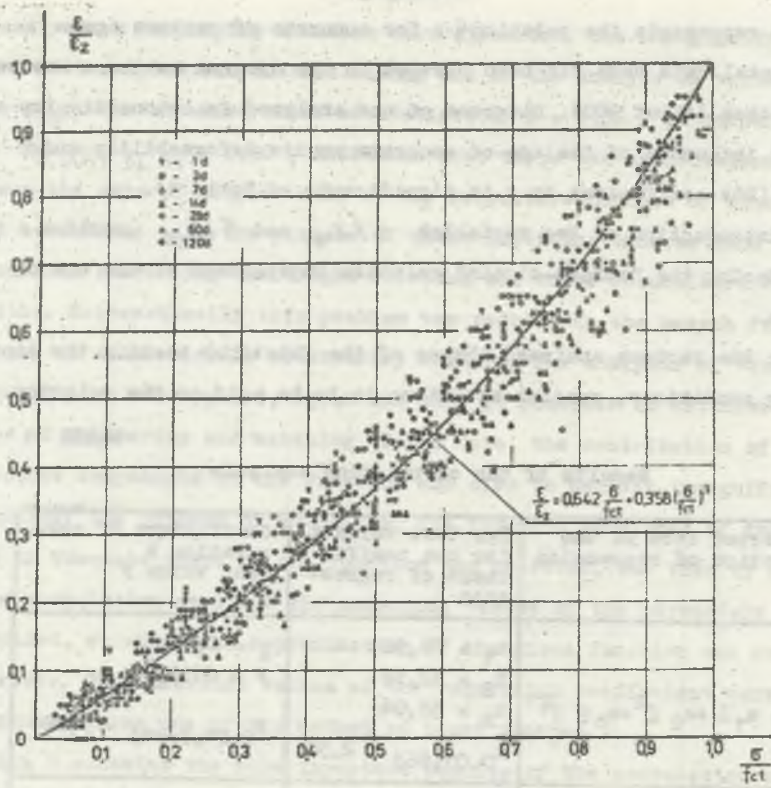


Fig.4

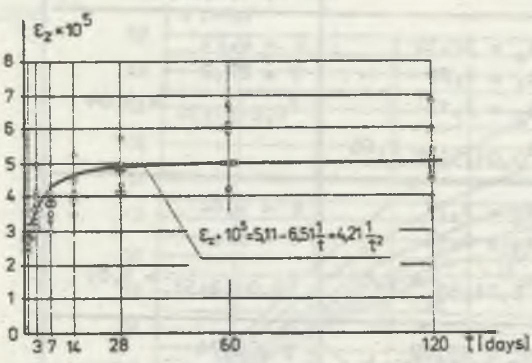


Fig.5. The influence of the age of concrete on its ultimate elongation

shown in Fig.4. In the author's quoted paper[3)] it was proved that the removal of the variable t in such a relation does not greatly affect the general regression due to the high correlation between the variables $\sigma/f_{ct}$ and t [8].

---

3) Cf. footnote 1

Fig.5 illustrates the inluence of that age of concrete on its ultimate elongation. A rapid growth of the ultimate elongation may be observed in the initial period of curing. Basing on the represented curve of regression it may be concluded that after seven days the tested concrete displayed already about 83% of the boundary elongation of mature concrete, and after fourteen days even 91%. As investigations have shown, the development of the tensile strength is distributed over a much longer period of time.

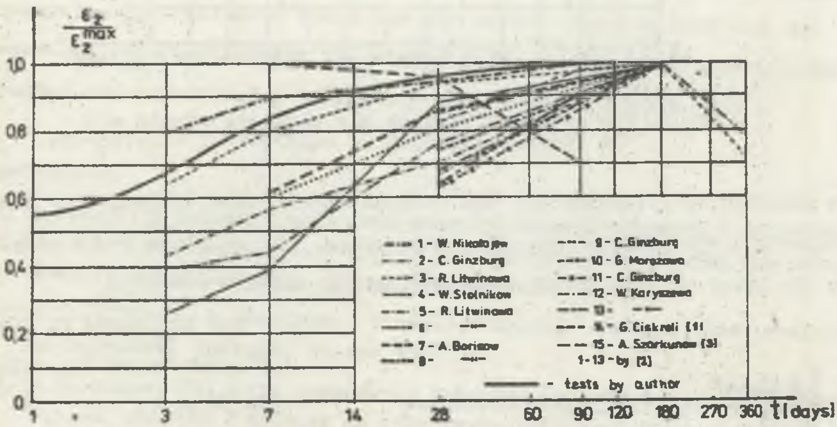


Fig.6. A comparison of test results of several authors

Fig.6 shows the obtained curve of changes in elongation against the background of the results obtained by other researchers. These results have been gathered in various laboratories and concern various kinds of concrete and shapes of the samples. Thus they are not adequate to be used for the purpose of quantitative comparison. It is, however, to be observed that the obtained curve confirms those experimental results in which an increased elongation of the concrete within a period of up to 180 days occurred.

The relation between the ultimate elongation and tensile strength is to be seen in Fig.7. A similar relation, taking also into account the age of the concrete, has been considered by the author in his paper quoted above [4]. Such a relation, as well as the dependence given in Fig.4 make

4) Cf. footnote 1

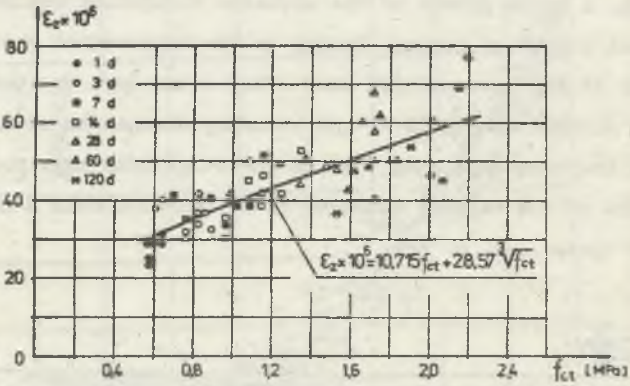


Fig.7. The relation between the ultimate strain and the tensile strength of concrete of varying age

it possible to determine all the deformational characteristics of the concrete under tension (boundary elongation, the relation $\sigma - \varepsilon$) merely on the basis of test results concerning its tensile strength.

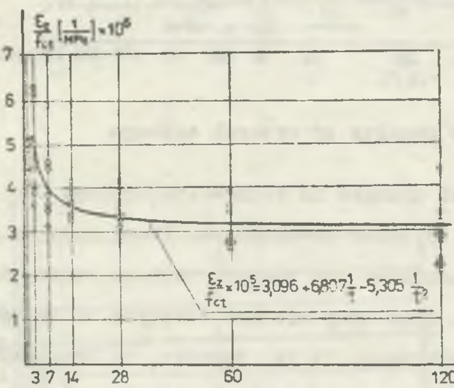


Fig.8. The influence of the age of concrete on the value of $\varepsilon_z/f_{ct}$

The influence of the age of concrete on the value of the ratio $\varepsilon_z/f_{ct}$ is expressed by the curve shown in Fig.8. This ratio is the reciprocal of the coefficient of deformability of concrete under tension calculated as the tangent of the angle of inclination of the secant passing through the points $\sigma = 0$ and $\sigma = f_{ct}$. As may be gathered from the diagram, the value of $\varepsilon_z/f_{ct}$ soon stabilizes approaching some constant value characteristic for mature concrete, while the value of t is groving. The distinctly non--linear shape of this ratio in the initial period of time confirms the different development of both these quantities during the first days of curing.

## 5. Conclusions

In the course of investigations a distinct influence of the age of concrete on its deformations under tension has been observed. A particulary rapid increase of the ultimate elongation was found during the first week of curing. Due to the introduction of the variables $\varepsilon / \varepsilon_z$ and $\sigma / f_{ct}$ , the relation "stress-strain" became independent of the age of concrete. The relations found for the tested concrete have made it possible to determine all the strain characteristics of this material (under axial tension) , basing on its tensile strength only.

## References


1. G.Ciskreli, Soprotivlenie rastjaženiju nearmirovannych i armirovannych betonov (The tensile strength of reinforced concrete and concrete without reinforcement). Giłsa, Moscow 1954
2. V.Stol'nikov, R.Litvinova, Treščinostojkost' betona (Crack resistance of concrete), Energia, Moscov 1972
3. S.Šarkunov, Vlijanie nekotorych faktorov na predel'nuju rastjažimost' betona, Sbornik dokladov po gidrotechnike (The influence of certain factors upon the boundary elongation of concrete. A collection of reports on hydraulic engineering), Fasc.10, Energia 1969, 129-140
4. W.Zamorowski, Rysoodporność skurczowa elementów betonowych dojrzewających bez swobody odkształceń (Shrinkage crack resistance of concrete samples curing without freedom of deformation) . 32 nd Scientific Conference KILiW PAN and KN PZITB, Vol.2, Krynica 1986, 59-64
5. W.Zamorowski, O metodyce badań wytrzymałości i odkształcalności betonu osiowo rozciąganego (Methods of investigating the strength and deformability of concrete under axial tension). Inżynieria i Budownictwo, nr 6,1987, 187-191
6. Concrete test Methods, Tentative Recomendations, Materials and Structures, 35, 1973
7. Wytyczne badania cech mechanicznych betonu na próbkach wykonanych w formach (Guidelines concerning the testing of the mechanical characteristics of concrete on sample cast in moduls). ITB, Instruction No. 194, Warsaw 1976
8. W.Volk, Statystyka stosowana dla inżynierów, Applied statistics for engineers . Wydawnictwa Naukowo-Techniczne, Warszawa 1973

## ODKSZTAŁCENIA DORAŹNE BETONU ROZCIĄGANEGO OSIOWO

### Streszczenie

Badano wpływ wieku betonu na jego wydłużenia przy różnych poziomach naprężeń. Przedstawiono wyniki badań zależności "naprężenia-odkształcenia" w różnym wieku betonu. Pokazano zmiany wydłużalności granicznej w czasie dojrzewania betonu. Otrzymaną funkcję regresji porównano z wynikami badań obcych.

## МГНОВЕННЫЕ ДЕФОРМАЦИИ БЕТОНА ПРИ ОСЕВОМ РАСТЯЖЕНИИ

### Резюме

Исследовалось влияние возраста бетона на его деформацию при осевом растяжении. Представлена диаграмма $\sigma - \varepsilon$ и предельная растяжимость для различного возраста бетона. Определенные статистические зависимости сравнивались с результатами других авторов.