METODE EXPERIMENTALE PENTRU DETERMINAREA VALORILOR NOMINALE ALE DEFORMAȚIEI DIN CONTRACȚIA BETONULUI

EXPERIMENTAL METHOD FOR DETERMINING THE NOMINAL VALUES OF CONCRETE SHRINKAGE STRAINS

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The shrinkage deformations may lead to concrete cracking with adverse effects on structural reliability, durability and aspect of the reinforced concrete elements and structures. For preventing and mitigation of shrinkage effects measures must be taken in structural design in determining the composition and in concreting. The paper presents theoretical, practical and experimental aspects related to shrinkage strains calculation, pointing out the differences between the values computed using the provisions of SR EN 1992-1-1 -„Design of concrete structures" and measured values. Due to these differences we consider that a new approach for computing the shrinkage deformations is needed. This need is emphasized by the large number of cases in our country of cracked structural elements short time after the concrete was cast.

Deformațiile împiedicate din contracția betonului pot provoca fisurarea acestuia, cu efecte negative asupra siguranței structurale, durabilității şi aspectului elementelor şi structurilor din beton armat. Pentru prevenirea şi limitarea efectelor fenomenului de contracție trebuie luate măsuri corespunzătoare la proiectarea, la stabilirea compoziției şi la punerea în operă a betonului. Articolul prezintă aspecte teoretice, practice şi experimentale privind calculul deformațiilor din contracție şi evidențiază diferențele constatate între rezultatele obținute. Datorită acestor diferențe, între valorile obținute experimental şi cele recomandate în SR EN 1992-1-1 „Proiectarea structurilor din beton armat", este necesară o nouă abordare a modului de calcul al deformațiilor din contracție. Acest aspect este în concordanță cu realitatea din țară, unde, în ultima perioadă, au apărut numeroase cazuri de fisurare ale elementelor de construcție după punerea în operă a betonului.

Keywords: *Concrete, Shrinkage, Test methods*

1. Introduction

The concrete shrinkage is a type of deformation characteristic for this material. Known from the beginning of the concrete history it is still a problem with significant implications on reliability and durability of RC buildings.

Shrinkage, after hardening of concrete in open air (RH%<100%), is the decrease with time of concrete volume. In saturated environment (RH%=100%) the converse of shrinkage is produced (swellage) which denotes volumetric increase due to moisture gain in the hardened concrete (Fig.1). Because in most cases concrete is not in saturated environment and shrinkage results in concrete cracking, this is the aspect that matters in structural engineering.

Drying shrinkage is a long term process, fast after the concrete hardening and progressively attenuated with time. Troxell`s experiments quoted by Neville [1] shows that at 28 days the shrinkage strain is about 40% of the strain at 20 years and at 1 year is about 80% of the same strain (Fig.2).

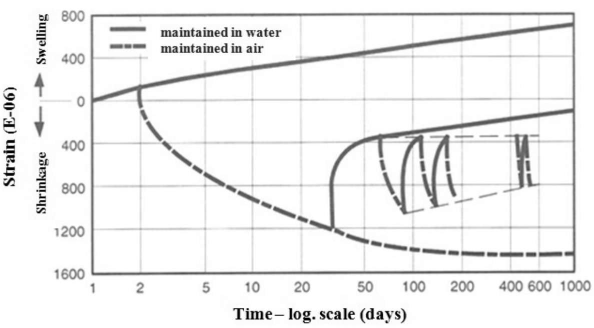

Fig. 1 – *Shrinkage and swelling of concrete [1].*

The main cause of shrinkage is the loss of adsorbed water in the pores which results in reducing the distances between the solid parts. The phenomenon in only partially reversible probably because of hydrated calcium silicate gels hardening (C-S-H).

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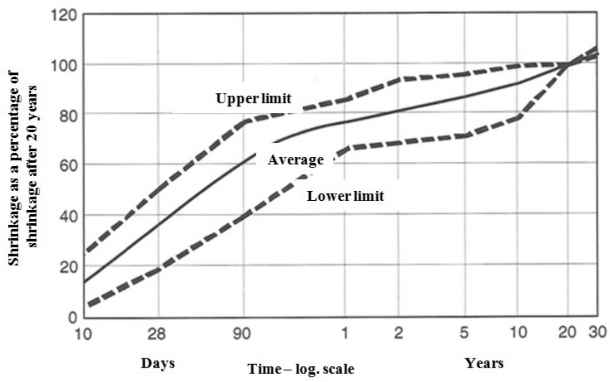

Fig. 2 – *Shrinkage time-history [1]*

2. Factors affecting shrinkage

The shrinkage is produced in hydrated cement paste. The main factors affecting are:

- Cement and water content: the shrinkage increases with the cement content and water-cement ratio. For concrete with the same composition, that with lower workability (smaller water-cement ratio) will have lesser shrinkage strains.
- Type of cement: some studies suggest that the Portland Cement (CEM I) characteristics have a minor influence o shrinkage (a large shrinkage strain of the cement paste doen not mean, in every cases, a large shrinkage strain of the concrete).
- Additions materials and admixtures: the presence of mineral additions materials has the tendency to increase the proportions of fine pores in the hydrated cement paste and the loss of water from the pores is the main cause of shrinkage. Addition materials as fly ash and blast-furnace slag enhances shrinkage: blended in high proportions in the cement paste they may enhance the shrinkage strains with more of 60%. Admixtures as superplasticizers (high-range water-reducing admixtures) may induce an increase of the shrinkage with 10÷20%. Retarding admixtures can produce plastic shrinkage resulting in cracks.
- Environmental humidity: the shrinkage increases with the decrease of humidity because this accelerates the water draining out from pores.
- Element geometry: the speed of drying depends on the length of the path, the water must travel out. The ratio between the sectional area and the element perimeter in contact with the air called “mean radius” is a good indicator in this direction.
- The reinforcement: in accordance with [1] the presence of steel reinforcement reduces the shrinkage strains with more than 30%.
- Aggregates, dimensions and grading: using correctly proportionated blends of aggregates results in obtaining a concrete with less cement and thus with less shrinkage. A smaller shrinkage strain can be obtained, also, by usig gradings with bigger dimensions of the particle. Using aggregates of expanded shale results in shrinkage strains 30% bigger than using normal aggregate.
- Modulus of elaticity of aggregates: more stiff aggregates hamper the concrete deformation. The shrinkage strains will be smaller but the interior stress increases all together with the risk of concrete cracking.

3. Experimental determination of shrinkage deformation

In Romania, unrestrained shrinkage deformations are experimentally determined according with the provisions of Romanian code SR2833:2009 - *Tests on concretes. Determination of the axial shrinkage of hardened concrete* [2]. The tests can highlight the influence of various composition factors on this deformation, inclusively using various type of cement.

In our case for determining the axial shrinkage in laboratory, prisms of 100x100x500 mm were used (Fig.3).

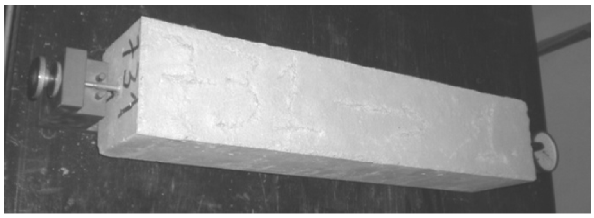

Fig. 3 – *Concrete prism*

The benchmarks position, the methodology and the interpretation of results were in accordance with the provisions of section „ Method using the Graf device” from SR 2883-2009 [2].

Using the same type of cement (CEM II/A 42.5) a large number of prisms were cast (Fig. 4). From the same batch of fresh concrete, cubic specimens were made, in order to determine the compressive strength of concrete.

Fig. 4 – *Concrete prisms for determination of the axial shrinkage.*

4. Calculation of shrinkage strain according to code SR EN 1992-1-1

In SR EN 1992-1-1 [3, 4] the total shrinkage strain is composed of two components, the autogenous shrinkade strain (develops mostly in the early days after casting) and the drying shrinkage which develops slowly in time. Thus, the total shrinkage strain is:

$$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} \tag{1}$$

where:

ε_{cs} - is the total shrinkage strain

ε_{cd} - is the drying shrinkage strain

ε_{ca} - is the autogenous shrinkage strain

The final value of the drying shrinkage strain:

$$\varepsilon_{cd,\infty} = k_h \cdot \varepsilon_{cd,0} \tag{2}$$

$$\varepsilon_{cd,t} = \beta_{ds}(t, t_s) \cdot k_h \cdot \varepsilon_{cd,0} \tag{3}$$

where :

$\varepsilon_{cd,\infty}$ - final value of the drying shrinkage strain

$\varepsilon_{cd,t}$ - value of the drying shrinkage strain at „*t*”, days

k_h - coefficient function of the element dimensions (Table 1), with values function of the mean radius h_0:

$$h_0 = 2A_c / u \tag{4}$$

Where:

A_c - concrete section area

u - perimeter of that part of the cross section which is exposed to drying

Table 1

Values for k_h in Expression (2) and (3)

h_0	k_h
100	1,00
200	0,85
300	0,75
≥500	0,70

$\beta_{ds}(t, t_s)$ - coefficient function of time and of mean radius h_0:

$$\beta_{ds}(t, t_s) = \frac{(t - t_s)}{(t - t_s) + 0.04\sqrt{h_0^3}} \tag{5}$$

where:

t- the age of the concrete at the moment considered

t_s - the age of the concrete in days at the beginning of drying shrinkage

$\varepsilon_{cd,0}$ - basic drying shrinkage strain (Annex B - SR EN 1992-1-1 [3, 4]):

$$\varepsilon_{cd,0} = 0.85 \cdot \left[(220 + 110 \cdot \alpha_{ds1}) \cdot e^{\left(-\alpha_{ds2} \cdot \frac{fcm}{fcmo}\right)} \right] \cdot$$

$$\cdot 10^{-6} \cdot \beta_{RH} \tag{6}$$

where:

α_{ds1} - coefficient which depends on the type of cement:

= 3.00 for cement class S
= 4.00 for cement class N
= 6.00 for cement class R

α_{ds2} - coefficient which depends on the type of cement:

= 0.13 for cement class S
= 0.12 for cement class N
= 0.11 for cement class R

f_{cm} - the mean compressive strength

$f_{cmo} = 10$ Mpa

β_{RH} - coefficient function of relative humidity:

$$\beta_{RH} = 1.55\left[1 - \left(\frac{RH}{RH_0}\right)^3\right] \tag{7}$$

where:

RH - ambient relative humidity (%)

RH_0 - 100%

For concrete with age less than 28 days the compressive strength (f_{cm}) is calculated according to SR EN 1992-1-1 with:

$$f_{cm}(t) = \beta_{cc}(t) \cdot f_{cm} \tag{8}$$

where:

$f_{cm}(t)$ - mean compressive strength at age *t*, (in days)

f_{cm} - mean compressive strength, according to tablei 3.1 in SR EN 1992-1-1 [3, 4]

$\beta_{cc}(t)$ - coefficient function of concrete age at time *t* (days):

$$\beta_{RH} = e^{s \cdot \left[1 - \left(\frac{28}{t}\right)^{0,5}\right]} \tag{9}$$

where:

Table 2

Values for α_{ds1} and $\varepsilon_{cd,0}$

	Experimental		SR EN 1992-1-1		Percentage [%]	
	α_{ds1}	$\varepsilon_{cd,0}$	α_{ds1}	$\varepsilon_{cd,0}$	α_{ds1}	$\varepsilon_{cd,0}$
C40/50	7.92	0.61	4.00	0.38	98.08	58.53
C45/55	7.64	0.51	4.00	0.36	90.96	41.12
Average	7.78	0.56	4.00	0.37	94.52	50.08

t - concrete age, in days, at the consided moment

s - coefficient with values function of the cement type:

= 0.20 for cement class: CEM 42.5 R, CEM 52,5 N and CEM 52,5 R (class R)

= 0.25 for cement class: CEM 32.5 R şi CEM 42,5 N (class N)

= 0.38 for cement class: CEM 32.5 N (class S)

5. Comparison between the experimental results and the results obtained using the SR EN 1992-1-1 provisions

In order to determine the shrinkage deformations of concrete prisms, the same type of cement was used CEM II/A 42.5N class N. Also, the speciment were identical in terms of aggregate (blending, type, dimensions etc.), the only difference being the water-cemet ratio. In that case two values were used: 0.44 and 0.41. The instruments readings were made at 7 days (initial reading δ_0) and at 14, 28, 90 and 180 days (δ_i).

Also, compression tests on cubes were made at the same period of time as shrinkage strains measurement. As expected, concrete with lower water-dement ratio showed bigger resistance.

For the 100x100x500mm prisms, the basic drying shrinkage strain $\varepsilon_{cd,0}$ was determined based on $\varepsilon_{cd,t}$ the measured value of the drying shrinkage strain at „*t*" days, using the methodology of SR EN 1992-1-1 presented before.

In equation (6) there are two coefficients whose value depend on the cement type, S,N or R: α_{ds1} and α_{ds2}. The value of α_{ds2} was taken 0.12 as requires SR EN 1992-1-1 for cement of class N. The values of α_{ds1} were computed knowing the basic drying shrinkage strain $\varepsilon_{cd,0}$ and the compressive strength of the concrete obtained testing the concrete cubes and are presented in the Table 2. The mean value is 7,78.

This value is almost double the value of 4,0 given in SR EN 1992-1-1 Annex B [3, 4] for class N cement.

After the test and interpretation of results resulted two concrete classes function of the water-cement ratio:C40/50- for a water-cement ratio of 0.44 and C45/55- for a water-cement ratio of 0.41

Using the provisions of Annex B of the code SR EN 1992-1-1 [3, 4], the basic drying shrinkage strain $\varepsilon_{cd,0}$ for each concrete class resulted with the values: 0,38‰ for C40/50 class and 0,36‰ for C45/55 class. The experimental values are on average with more than 50% bigger than those calculated using the Annex B provisions: 0,61‰ for C40/50 and 0,51‰ for C45/55 (Table 2).

6. Conclusions

The shrinkage strains can cause the concrete cracking with adverse effects on durability and the aspect of elements and structures of reinforced concrete.

For the same type of cement, a bigger dosage of cement, using inappropiate admixtures and a high water-cement ratio, are the main factors related to composition that favor shrinkage. Regardless of the type of cement, for limiting shrinkage measures must be taken at design, at designing the cement composition and at the concrete casting.

The study presents some theoretical and experimental aspects regarding shrinkage strains calculation, highlighting the differencies between the experimental values and those computed using the SR EN 1992-1-1 [3, 4] provisions. A reassessment of the values for α_{ds1} and α_{ds2} coefficients appears as necessary considering the large number of cases in our country of structural elements cracked short time after the concrete was cast.

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