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CREEP AND SHRINKAGE OF HIGH PERFORMANCE CONCRETE

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ABSTRACT

The Sustained by experimental data, we conducted a complex analysis to assess the influence on high performance concrete shrinkage and creep of several factors, such as: the age of the concrete at the application of the load, the stress level, the temperature and relative humidity of the environment. The experimental results were compared to several instituted predictions.

Keywords: - compression, concrete, creep, shrinkage, reinforced concrete, deformations.

1. INTRODUCTION

Latest demands regarding reinforced concrete structures, with ever expansion in height and length, require the use of concrete with superior physical and mechanical properties.

The use of high performance concrete for reinforced concrete structures meets the requirements, with several advantages in terms of cost and slenderness. The durability of high strength concrete is also extremely beneficial in a long term analysis.

On the other hand, the concrete rapid increase in strength at an early age leads to a rapid removal from framework and to an early start of service life with important financial benefits. Furthermore, this type of concrete displays small deformations of shrinkage and creep, very good durability, high resistance to abrasion, low loss of tension and so forth.

2. BACKGROUND OF GEO-POLYMERS

2.1 Scope and means:

Information regarding time behavior of high performance concrete is rather limited. Therefore, an experimental program was initiated to determine the long term characteristics of high performance concrete.

The experimental program was conducted in three directions:

- We monitored the shrinkage and the creep for variable curing conditions.
- We monitored the shrinkage and the creep for constant curing conditions
- We estimated the long term behavior of high performance concrete structural members in their service life.

2.2 Concrete composition and testing specimens:

The concrete class studied with Portland Cement and with an addition of silica fume of 10 percent of the cement weight. The concrete composition is detailed in Table 1.

Table 1. Concrete composition

Portland Cement CEM I 52.5 R	480 kg/m^3
Silica fume	48 kg/m^3
Gravel 8-16 mm	706 kg/m^3
Gravel 4-8 mm	530 kg/m^3
Sand 0-4 mm	530 kg/m^3
Water	152 l/m^3
Superplastifiant	13.5 l/m^3

The test specimens were: cubes 150x150x150 mm (for compression resistance); prisms 100x100x550 mm (to determine the shrinkage); cylinders Φ90x300 mm (to determine the creep at centered compression force); prisms 40x700x500 mm (to monitor the creep at centered tensile force in time). The reinforced concrete elements consisted in a series of 4 rectangular beams of 125x250 mm, with a length of 3200 mm, and a clear span of 3000 mm. The longitudinal reinforcing ratio was 2.075%, of the same concrete composition.

3. VARIABLE CURING CONDITIONS

3.1 Shrinkage

The specimens were kept in water for 28 days and after that, in variable conditions of temperature and humidity. The evolution in time of the experimental results of the shrinkage "ε_{cs}" is illustrated in Figure 1, in comparison to the design values presented in IS-456:2000.

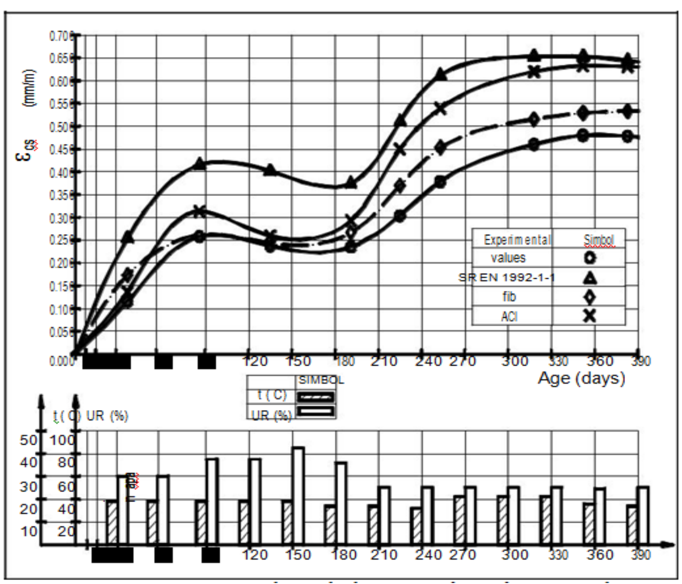

Fig.1: Experimental and design shrinkage values

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Due to the variable curing conditions, the attenuation of the shrinkage phenomenon was observed around the age of 250 days. After approximately one year of monitoring, the value of the shrinkage was 0.480 ‰, as seen in Figure 1. The comparison between the design values εcs,d and the experimental values εcs,e is detailed in Table 2.

Table 2. Ratio variation εcs,d / εcs,e as a function of time, for different standards

Age (days)	$\varepsilon_{cs,d} / \varepsilon_{cs,e}$		
	SR EN 1992-1-1	*fib* –1999	ACI –2005
90	1.608	1.011	1.290
190	1.591	1.311	1.217
250	1.616	1.195	1.410
380	1.345	1.115	1.320

The equations for the evaluation of the shrinkage are:

$\varepsilon_{cd}(t)=\beta_{ds}(t,t_s)\cdot k_h\cdot\varepsilon_{cd,}$ (1)

$\varepsilon_{cds}(t,t_s)=\varepsilon_{cdso}(f_{cm})\cdot\beta_{RH}(RH)\cdot\beta_{ds}(t-t_s)$ (2)

$$(\varepsilon_{sh})_t = \frac{t}{35+t}\bullet(\varepsilon_{sh})_u$$

The design values closest to those obtained in the experimental program seen in Table 2.

3.2 Creep

The cylinder specimens, Φ90x300 mm were subjected to long term compression loading, beginning with the age of 210 days. At this time, compression strength on cube specimens of 150x150x150 mm was of 83 MPa. The long term loading represented 23% of the failure strength. The curing conditions were identical to the specimens used for the shrinkage.

The specimens were monitored for 150 days under the long term loading. The evolution in time of the creep specific deformations, the design and the experimental values, are shown in Figure 2.

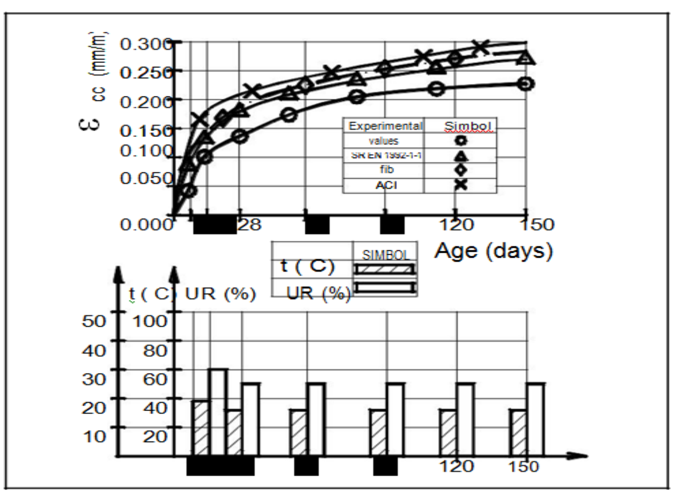

Fig.2: Experimental and design creep values

The start of the attenuation takes place around the age of 90 days from the moment the loading was applied. The design values were obtained using calculation methods of SR EN 1992-1-1 [1], fib – 1999 [2] and ACI – 2005 [3].

$$\varepsilon_{cc}(t, t_0) = \varphi(t, t_0)\cdot\frac{\sigma_c}{E_c} \qquad \varphi(t,t_0)=\varphi_0\cdot\beta_c(t,t_0) \tag{4}$$

$$\varepsilon_{cc}(t, t_0) = \varphi(t, t_0)\cdot\frac{\sigma_c}{E_c} \qquad \varphi(t,t_0)=\varphi_0\cdot\beta_c(t,t_0) \tag{5}$$

$$\varepsilon_{cc}(t, t_0) = \nu(t, t_0)\cdot\frac{\sigma_c}{E_c} \qquad \nu_t = \frac{t^{0,6}}{10 + t^{0,6}}\cdot\nu_u$$

The comparison between the design values $\varepsilon_{cc,d}$ and the experimental values $\varepsilon_{cc,e}$ is detailed in Table 3.

Table 3. Ratio variation $\varepsilon_{cc,d} / \varepsilon_{cc,e}$ as a function of time, for different standards

Age (days)	$\varepsilon_{cc,d} / \varepsilon_{cc,e}$		
	SR EN 1992-1-1	*fib* –1999	ACI –2005
28	1.316	1.382	1.470
90	1.350	1.424	1.436
150	1.230	1.286	1.318

4. CONSTANT CURING CONDITIONS (t = 200 ± 20C; RH = 60% ± 5%)

In general, the influence of relative humidity on the creep of concrete can be distinguished based on the curing conditions prior to the application of loading. Shrinkage were studied in restrained conditions under a constant loading $\sigma / f_{c,t} = 0.4$ during the first week after casting (7 days).

The experimental results are presented in Figure 3. The total tensile creep strain is calculated as the difference between the cumulated restrained deformation and the unrestrained shrinkage according to the formula below:

$$\varepsilon cc = \varepsilon r - \varepsilon cs \tag{7}$$

Where, ε_c = total creep strain;

ε_r = restrained deformation;

ε_{cs} = unrestrained shrinkage.

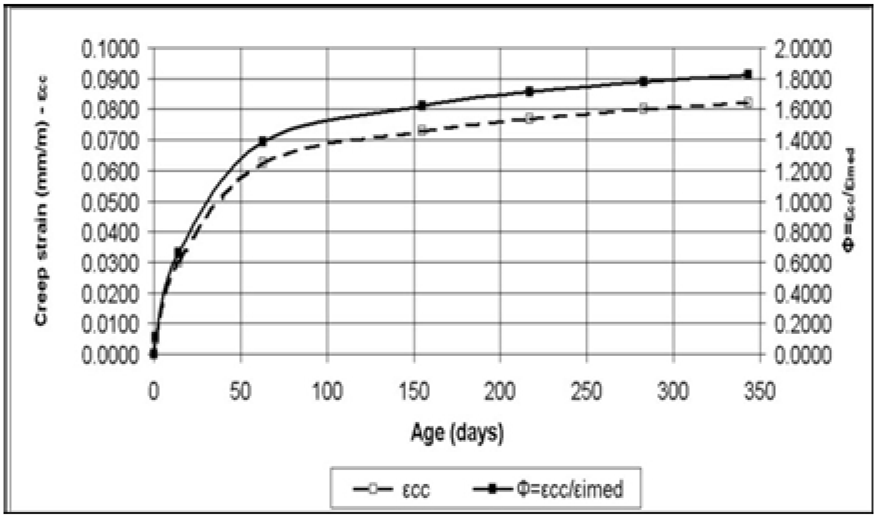

Fig.3: Creep strain vs. time

4.1 Creep deformation at compression

High performance concrete is influenced by the early age at the application of the load (7 days after casting) and by the different stress / strength ratios (σ / fc,cyl): 0.23 and 0.30.

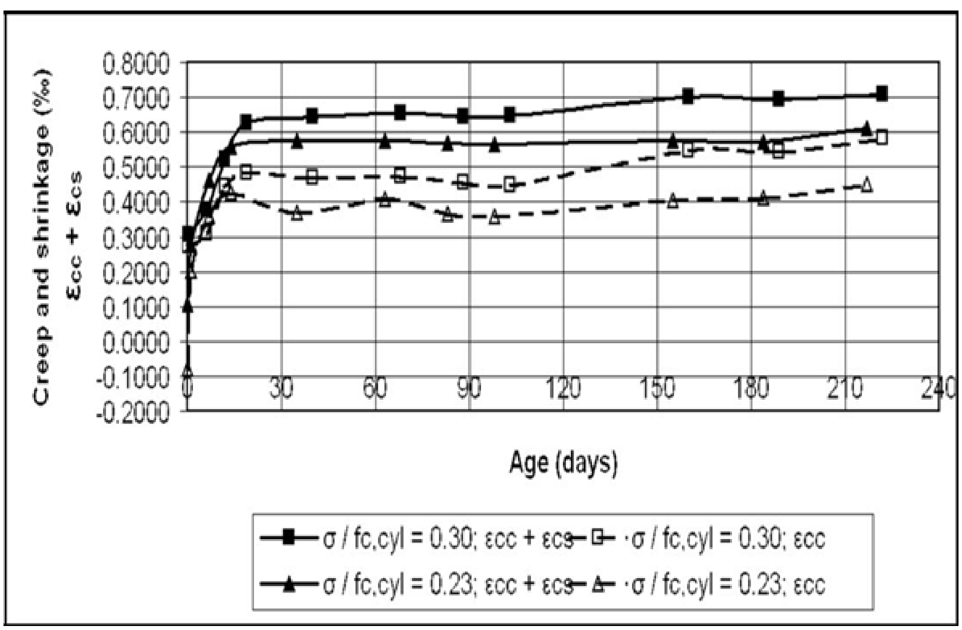

Fig.4 Creep and shrinkage vs. time

The development of the cumulative creep and shrinkage strain is displayed in Figure 4.

5. REINFORCED CONCRETE ELEMENTS

5.1 Test set-up

The experimental program consisted in monitoring a series of 4 rectangular beams of 125x250 mm, with a length of 3200 mm, and a clear span of 3000 mm, as shown in Figure 5.

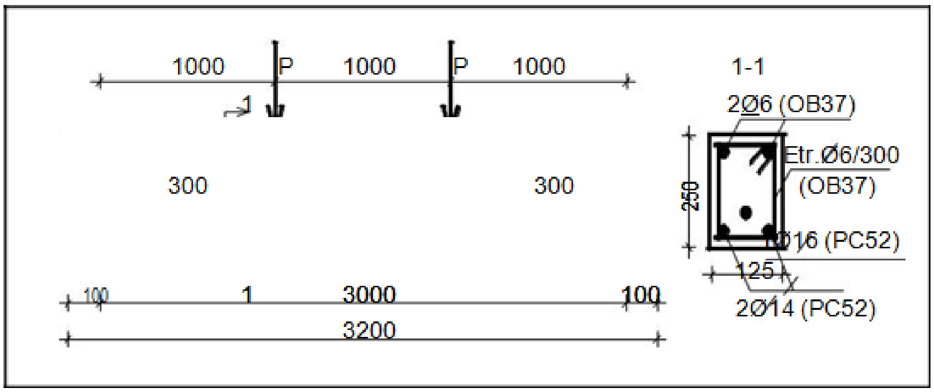

Fig.5: Longitudinal and cross section – reinforcing and loading manner

Longitudinal reinforcing ratio is 2.075%.

The reinforcement used was PC52 with a maximum stress of σ_y = 300 MPa and OB37 with a maximum stress of σ_y = 210 MPa.

Two elements with the same characteristics were subjected to short term loading, resulting the bending moment at failure Mu. The bending moment related to the long term loading, Mlt, represents 40% of the bending moment at failure: Mlt / Mu = 0.40.

The beams subjected to both short term and long term loadings are simply supported and loaded with 2 concentrated loads applied at 1/3 of the clear span length.

The elements subjected to long term loading were monitored to the age of 360 days.

5.2 Experimental results

5.2.1 Deformations

The deflections at loading and the long term deflections, measured in the middle of the clear span are shown in Figure 6.

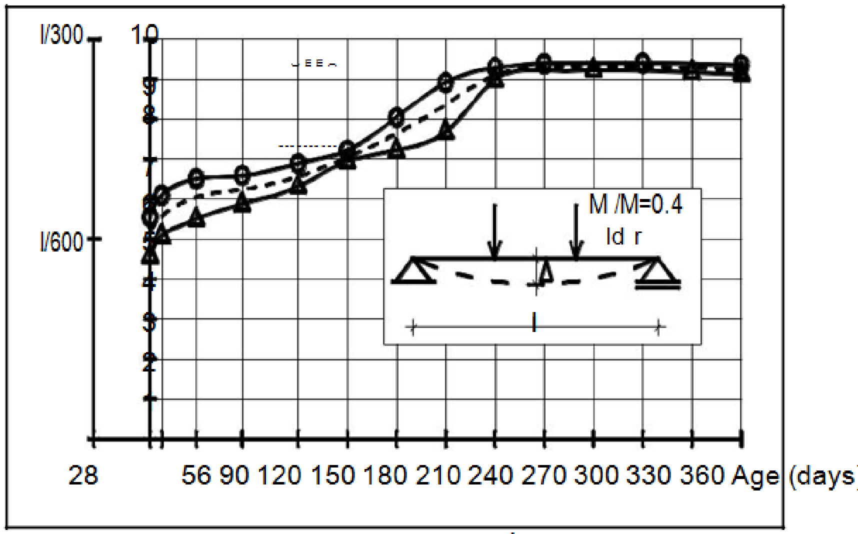

Fig.6: Instantaneous and long term deflections

At the level of loading of Mlt / Mu = 0.40, the instantaneous deflection represents 1/600 of the clear span length. The development of the long term deflections until the age of 1 year, as shown in Figure 6, shows an attenuation of the phenomenon after 200 days from the application of the long term loading. After 1 year, the total deflections represent 1/300 of the clear span length l (instantaneous and long term deflections).

Time development of long term deflections φ = cc+cs / i (long term deflections / instantaneous deflections) are shown in Figure 7.

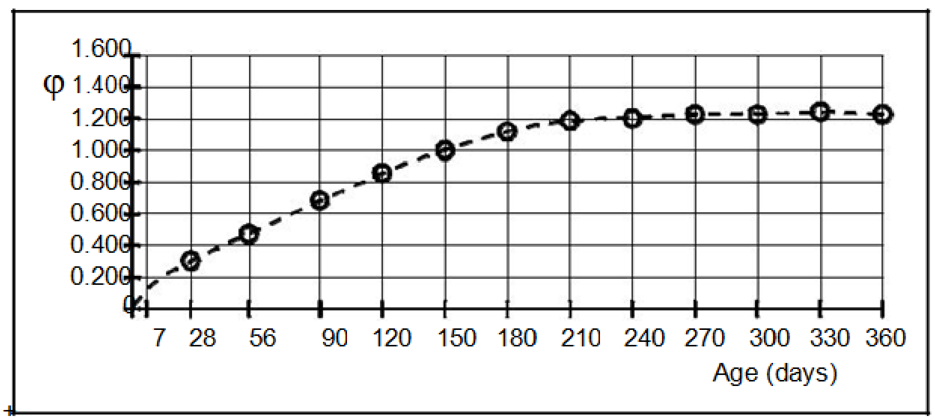

Figure 7: Time development of φ

After approximately 200 days of long term loading,

φ is 1.2÷1.3. Above this age φ remains constant with rheological deformations attenuated.

5.2.2 Cracking

The cracking at the time of loading and its development in time are shown in Figure 8.

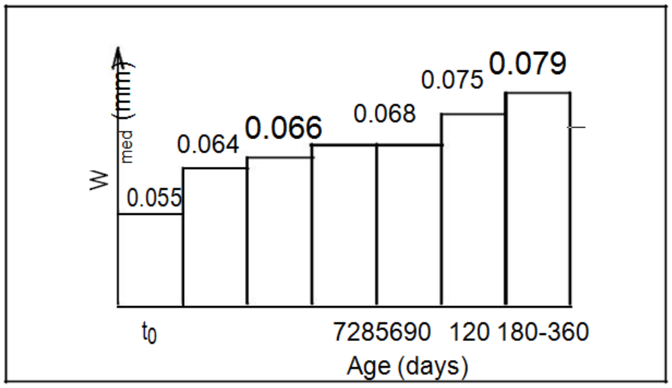

Fig. 8: Time development of the average crack widths

Regarding the average crack opening, measured at the center of gravity of the tensed reinforcement, the following can be assessed:

- At the time of loading with service life loads (after a preload with static service loads), the average crack width was around 0.055mm.
- The average crack width was stabilized around 0.080mm, around the age of 200 days. Above this time, until the age of 360 days, the width of the existing cracks remained constant and no more new cracks were recorded.

6 CONCLUSIONS

The shrinkage measured on specimens subjected to variable curing conditions attenuated after 250 days from casting. The design values closest to those obtained in the experimental program belong to fib-1999.

The attenuation of the creep measured on specimens subjected to variable curing conditions took place around the age of 90 days from the loading point.

In case of the reinforced concrete elements, after 200 days, the long term deflections attenuated and the crack pattern remained unchanged.

Based on the level of observations recorded so far, high performance concrete is suitable for long term loading. However, the research is to be continued with the study of other parameters of influence, such as: the age of the loading, the ratio of loading, the reinforcing ratio and so on.

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