MATEC Web of Conferences **196**, 02024 (2018) https://doi.org/10.1051/matecconf/201819602024
XXVII R-S-P Seminar 2018, Theoretical Foundation of Civil Engineering

Creep of Concrete According to Creep Prediction Models and Own Research

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Abstract. The paper presents the currently used procedures for calculating the deformation of concrete and creep coefficients. Laboratory research was conducted on the creep of concrete. Creep coefficients were calculated on the basis of experimentally obtained data and later compared to the ones acquired by using previously demonstrated procedures. In the case of the sample subjected to the influence of compressive stress and not exceeding the limit of linear creep, the models in Eurocode 2 and fib Model Code 2010 did not correspond to the experimentally obtained data.

1 Introduction

The phenomenon of creep involves the increase of deformations which results from a given duration of loading. The increase of deformations resulting from creep may be several times bigger than elastic deformations caused by load and this is why creep is essential in construction projects [1]. The influence of creep is calculated in reinforced and pre-stressed concrete structures with the help of the approximate methods [2] (e.g. effective modulus method) which use the creep coefficient. The norms [3,4] and literature [5] offer a variety of methods for calculating this coefficient, but the obtained values are not always similar. This is why we decided to analyse these methods and compare the results of calculations with the experimentally obtained values. In this article we present tree procedures for calculating creep: according to Eurocode 2 (EC2), according to Model Code 2010 (MC2010) and B3. Then we describe our own creep research and compare our results with the ones obtained based on calculations.

2 Creep Prediction Models

2.1 Method according to PN-EN 1992-1-1:2008 [3]

Concrete creep coefficient $\varphi(t, t_0)$ depends on the value of the basic creep φ_0 and a function describing the development of creep with time $\beta_c(t, t_0)$, which is represented by the following expression

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$$\varphi(t, t_0) = \varphi_0 \cdot \beta_c(t, t_0). \tag{1}$$

The values shown in formula (1) are described in Annex B Eurocode 2 [3].

2.2 Method according to the Pre-norm for fib Model Code concrete structures 2010 [4]

A different approach to the quantitative assessment of concrete creep characteristics is presented in [4]. Concrete creep coefficient $\varphi(t, t_0)$ is determined according to the formula (2) as the sum of the coefficients: the basic creep coefficient $\varphi_{bc}(t, t_0)$ and the drying creep $\varphi_{dc}(t, t_0)$:

$$\varphi(t, t_0) = \varphi_{bc}(t, t_0) + \varphi_{dc}(t, t_0). \tag{2}$$

Details of calculations $\varphi_{bc}(t, t_0)$ and $\varphi_{dc}(t, t_0)$ are given in [4].

2.3 B3 model developed by Z. P. Bažant and S. Baweja [5]

The model presented in [5] was developed based on a very wide range of results of research on creep and shrinkage of concrete. The scope of model B3 application is determined by the limit values of the following parameters:

- $0.35 \leq w/c \leq 0.85$,
- $2.5 \leq a/c \leq 13.5$, where a/c is the weight ratio between the contents of aggregate and cement,
- $17\ MPa \leq \bar{f_c} \leq 70\ MPa$, where $\bar{f_c}$ is the concrete compressive strength determined for cylindrical samples at the age of 28,
- $160 \frac{kg}{m^3} \leq c \leq 720 \frac{kg}{m^3}$, where c is the content of cement,
- $\sigma \leq 0.45\bar{f_c}$,
- the age at the time of loading $t' \geq 1$ day.

The creep coefficient is expressed by the following formula:

$$\varphi(t, t') = E(t')J(t, t') - 1, \tag{3}$$

where $E(t')$ is the module of elasticity at the time of loading t', and $J(t, t')$ is a function of the sum of deflections: elastic (temporary) q_1 and creep – basic $C_0(t, t')$ and drying $C_d(t, t')$ for unit strain, t is the age of concrete at the considered moment in time, and t' is the age at the time of loading. The value of the function of the sum of strains is obtained using the following relation:

$$J(t, t') = q_1 + C_0(t, t') + C_d(t, t'), \tag{4}$$

and the values of the individual component units of the formula above are obtained using the following formulas:

$$q_1 = 0.6 \cdot \frac{10^6}{E_{c,28}} \tag{5}$$

$$C_0(t, t') = q_2 Q(t, t') + q_3 \ln[1 + (t - t')^n] + q_4 \tag{6}$$

$$C_d(t,t') = q_5\{\exp[-8H(t)] - \exp[-8H(t'_0)]\}^{0.5}. \tag{7}$$

The values presented in the above formulas are explained in detail in paper [5].

3 Laboratory creep research

The creep research was carried out on a cylindrical sample of 150 mm in diameter and 300 mm in height.

Fig. 1. Concrete creep testing machine Type HKB-1000 kN.

First, the sample was cured for 14 days, and the sample's bases were ground and steel anchor plates were attached alongside its lateral area, forming three lines, each at a distance of 120^{o} from the next one, and marking three measuring sections. The length of the measuring base was 250 mm. The unloaded sample used for measuring shrinkage deformations was prepared in the same way. All samples were stored in the same room and at the same position throughout the duration of the experiment (the relative humidity was 50% and the temperature was 20^{0} C). The analysis started 14 days after the samples had been prepared. The mean strength of 14-day-old concrete was defined (*fc*=58.83 MPa). The compressive force was assumed to be equal to 280 kN and it caused a compressive stress of 15.84 MPa. The samples for creep analysis were placed vertically and centrally between the loading frames of the creep testing machine HKB-1000 made by Walter Bai AG (Figure 1) (a similar study was described in [6]). Ten minutes elapsed between applying the force and its leveling off. Within that time, indirect readings of temporary deformations for forces of 90kN, 180 kN and 280kN were taken. Measurements of total deformations and shrinkage deformations of the unloaded samples started on the following day. The measurements were taken with the extensometer with the level of resolution at 1/100 mm. The readings were taken every day throughout the first week of the experiment, once a week throughout the next month of the experiment and once every month till the end of the experiment. The readouts of the level of the compressive force were checked at the same time. The creep research lasted in total 378 days. The total strains and shrinkage were calculated as the mean value of the readings from the three measuring sections. The course of total strain is presented in Figure 2.

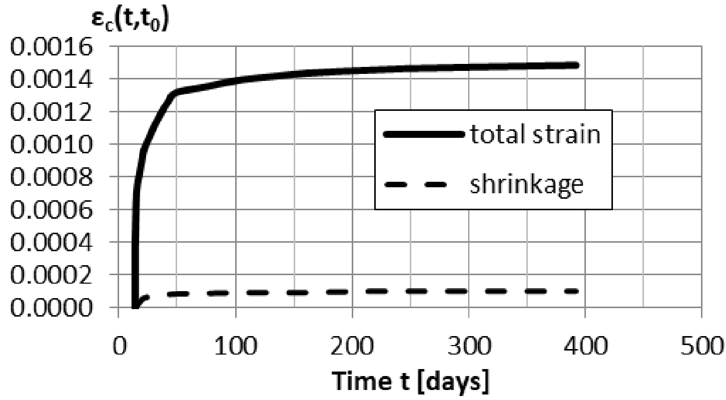

Fig. 2. Concrete creep curve for axial compression (t_0=14d, $f_{c(}$14)=58.83MPa) the stress equals 0.27f_c(14).

4 Values of creep coefficients

Based on the results of our research, creep coefficients in time t were calculated from the following formula:

$$\varphi(t, t_0) = \varepsilon_{cc}(t, t_0)/\varepsilon_e(t_0)\ , \tag{8}$$

where creep strain $\varepsilon_{cc}(t, t_0)$ at the age of t were calculated using the following relation:

$$\varepsilon_{cc}(t, t_0) = \varepsilon_c(t) - \varepsilon_s(t) - \varepsilon_e(t_0), \tag{9}$$

where:

$\varepsilon_c(t)$ – total strain at the age of t,

$\varepsilon_s(t)$ – shrinkage strain at the age of t,

$\varepsilon_e(t_0)$ – elastic strain at the age of t_0.

The values of coefficients were calculated using the methods mentioned in the first part of the paper and compared with the results of the experiment presented in Table 1.

5 Conclusions

Based on the analysis it may be assumed that there is no correspondence between the results of the experiment and the results arrived at using EC2 and MC2010. The coefficient value is more than twice as big for the age of concrete t=49 days in case of both: calculations according to EC2 (228%) and to MC2010 (238%). The ratio of measured values to calculated values on the last day of the experiment is better: EC2 – 163%, MC2010 – 179%, but still unsatisfactory. Models assumed in [2] and [3] do not reflect the actual effects of creep in case of the analyzed concrete. The differences between coefficients obtained in the experiment and calculated with the use of the procedures presented in Eurocode 2 and Model Code 2010 are significant. Amongst the three compared procedures, Model B3 best reflects the actual creep of the analyzed sample. Throughout the whole experiment the predicted values of the creep coefficient were smaller than the actual ones until day 320, when the values obtained based on model B3 and the experiment drew level and then eventually became higher.

Table 1. Comparison of creep coefficients obtained based on the experiment and norm [3] (EC2), pre-norm [4] (MC2010) and model B3 [5].

Age of concrete	**Expe-riment**	**EC2**		**MC2010**		**B3**	
t [days]	$\varphi_1 = \varphi(t, t_0)$	$\varphi_2 = \varphi(t, t_0)$	$\frac{\varphi_1 - \varphi_2}{\varphi_1} \cdot 100\%$	$\varphi_3 = \varphi(t, t_0)$	$\frac{\varphi_1 - \varphi_3}{\varphi_1} \cdot 100\%$	$\varphi_4 = \varphi(t, t_0)$	$\frac{\varphi_1 - \varphi_4}{\varphi_1} \cdot 100\%$
14	0.00	0.00	-	0.00	-	0.00	-
15	0.70	0.34	51.43	0.31	55.71	0.32	54.29
16	0.89	0.41	53.93	0.41	53.93	0.40	55.06
17	0.97	0.47	51.55	0.47	51.55	0.46	52.58
18	1.04	0.51	50.96	0.51	50.96	0.51	50.96
19	1.13	0.54	52.21	0.55	51.33	0.55	51.33
20	1.21	0.57	52.89	0.58	52.07	0.59	51.24
21	1.30	0.60	53.85	0.60	53.85	0.62	52.31
28	1.57	0.74	52.87	0.73	53.50	0.82	47.77
35	1.81	0.82	54.70	0.81	55.25	0.96	46.96
42	2.03	0.89	56.16	0.87	57.14	1.08	46.80
49	2.17	0.95	56.22	0.91	58.06	1.18	45.62
77	2.26	1.11	50.88	1.04	53.98	1.48	34.51
105	2.36	1.21	48.73	1.12	52.54	1.70	27.97
133	2.41	1.28	46.89	1.18	51.04	1.87	22.41
161	2.46	1.34	45.53	1.23	50.00	2.02	17.89
189	2.48	1.38	44.35	1.27	48.79	2.14	13.71
217	2.49	1.42	42.97	1.30	47.79	2.25	9.64
245	2.51	1.46	41.83	1.33	47.01	2.34	6.77
273	2.53	1.48	41.50	1.35	46.64	2.42	4.35
301	2.54	1.51	40.55	1.37	46.06	2.50	1.57
329	2.55	1.53	40.00	1.39	45.49	2.57	-0.78
357	2.56	1.55	39.45	1.41	44.92	2.63	-2.73
392	2.57	1.57	38.91	1.43	44.36	2.69	-4.67

Creep depends on many factors which are little controlled by scientists. The presented, time-consuming study of only one sample confirmed satisfactory compliance with model B3, but it obviously does not invalidate the other two models. In an earlier experiment based on a sample of weaker concrete described in [6], the measured deformations complied to a great extent with the EC2 model.

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