

PROBLEMS OF CREEP AND SHRINKAGE TESTING IN HARDENED CONCRETE

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Summary: *This paper provides some new views of the familiar problems of measurement and testing of creep and shrinkage of concrete rheological time deformation. Concrete creep is not a theoretical, but a structural problem and solutions must be sought exclusively by experimental tests and measurements. On the basis of such measurements, monitoring and observing the structural changes, it is possible to make theoretical assumptions. What is well known is that the creep directly depends on the condition and magnitude of the stresses to which the concrete cross section is exposed. Those sections of concrete that are only partially used, in terms of stress, are not as sensitive to creep as sections that are loaded to the point of proportionality. A particular problem and the enormous increase in the creep of concrete would occur if sections were loaded above the points of proportionality and elasticity. The creep of concrete over time on real structures in use, in most cases, both in old and new structures, increases unpredictably in the first years. One can ask a question and doubt the magnitude of the actual stress states to which the concrete structures are exposed. Our measurements for determining an ultimate strength of concrete on cubes, prisms and cylinders indicate such doubt. During the conducted tests of creep and shrinkage of concrete, which were done in doctoral studies in 2020 at the Faculty of Civil Engineering in Subotica, which are still ongoing, we present only one segment related to the topic of stress to which sections in concrete structures are exposed.*

Keywords: Concrete, deformation, rheology, shrinkage, creep

1. INTRODUCTION

The time deformation of the reduction of concrete volume without the impact of forces, represents the shrinkage of concrete, which depends on temperature and humidity, the dimensions of elements, the type and amount of cement, water-cement ratio, granulometric

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and mineral composition of aggregates, concrete strength, methods of installing and care, as well as the age of the concrete at the time of interruption of care and more.

The total shrinkage deformation consists (according to [3]):

- Shrinkage due to contraction of hydration products - *hydration shrinkage*,
- Shrinkage due to water evaporation during the cement setting period - *plastic shrinkage*, and
- Shrinkage after completion of the cement setting process - *hydraulic shrinkage*.

While according to [8] the shrinkage is divided into:

- autogenous shrinkage,
- plastic shrinkage,
- shrinkage of hardened concrete due to drying,
- shrinkage due to carbonation.

The physical explanation of the plastic shrinkage of concrete is given in [1], as shown in Figure 1, where water is lost from the surface part of the material, concrete, and as a physical consequence of that fact, the material tends to shrink. In the layer below the surface layer of the material, there was no major loss of water and this layer does not shrink, while preventing the surface layer from shrinking. Thus, tensile stresses occur in that surface layer which the material releases in such a way that a surface crack appears. In order for this not to happen, it is necessary to provide adequate care for the surface of freshly concreted concrete, until the concrete reaches a strength that can overcome the tensile stresses that occur due to the shrinkage of the concrete.

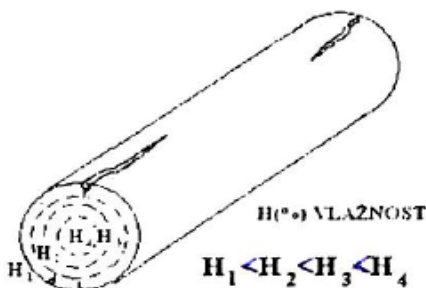


Figure 1. Physical explanation of the rheological phenomenon of material shrinkage and accompanying manifestations that occur, namely cracks and possible volume anomalies in the form of bending and twisting [1]

The rheological features of hardened concrete depend mostly on the rheological features of cement stone and the contact zone between aggregate and cement stone, especially their adhesion, therefore it can be concluded that cement stone should be high quality and optimal, which implies structure II described in [1]. Creep represents the increase in deformations over time where the load can be constant. Creep occurs only when the concrete is loaded and the size of the creep depends on the load. If the stress on the concrete is $\sigma > \sigma_e$, the creep will be very high over time and may cause the structure to break. With large spans, it is important to expose the concrete to the load as late as possible, because

young concrete is more susceptible to creep and the higher the creep values the earlier it is exposed to the load.

The magnitude of the creep is expressed by the creep coefficient $\varphi(t_1, t_0)$ which represents the ratio of the creep deformation $\varepsilon_{te}(t_1, t_0)$ and the current elastic deformation at the moment of applying the load $\varepsilon_{el}(t_0)$.

$$\varphi(t_1, t_0) = \frac{\varepsilon_{te}(t_1, t_0)}{\varepsilon_{el}(t_0)} \quad (1)$$

The creep of concrete increases in the first period, and after a while the creep stabilizes. Stabilization occurs after a few months when it is in conditions where it is not directly exposed to atmospheric and chemically aggressive effects, however, when this is not the case, the process of creep stabilization can take much longer [1]. According to Burgers' rheological model, the state of deformation of a material without stabilization in the creep process over time $\rightarrow \infty$ is described.

$$\varepsilon(t) = \frac{\sigma}{E_1} + \frac{\sigma}{\eta_1} \cdot t + \frac{\sigma}{E_2} \left[1 - e^{-\frac{E_2}{\eta_2} t} \right] \quad (2)$$

The creep of concrete would correspond to Burgers' model that the compactness of concrete is weaker and if the porosity increases over time, which is possible by the action of soft water or some acids.

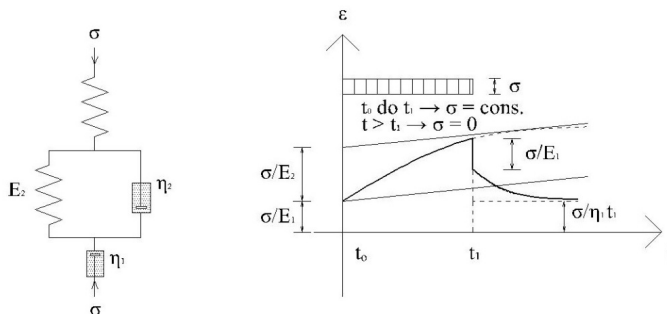


Figure 2. Rheological model of concrete – Burger's model (on the left), deformation of concrete according to Burger's model (on the right)

Rheological model of concrete - Kelvin's model describes the temporal stabilization of the creep process, and after unloading the total deformation tends to zero, in the stress range that is less than the stress of proportionality σ_p .

The Kelvin model describes the state of deformations with creep stabilization during time t , and this value is retained even when $\rightarrow \infty$.

$$\varepsilon(t) = \frac{\sigma_0}{E} \cdot \left[1 + \frac{E_1}{E_2} \left[1 - e^{-\frac{E_2}{\eta_2} t} \right] \right] \quad (3)$$

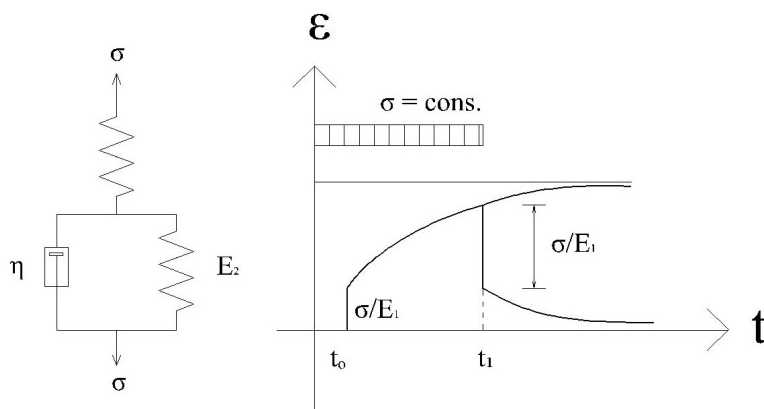


Figure 3. Rheological model of concrete - Kelvin model (left), deformation of concrete according to Kelvin model (right)

Thus, it can be concluded that if for any reason the contact zone between the cement stone and the aggregate is disturbed, the creep stabilization process will be disrupted, which means that the creep will tend to grow further, as described by the Burger's model [1].

2. EXPERIMENTAL PART OF LABORATORY RESEARCH ON REAL EXACT CONCRETE SAMPLES

Concreting of the samples was performed as previously defined by the concrete mixture. A three-fraction river aggregate was used - fractions 0/4, 4/8, 8/16 mm, concrete grade MB40 and concrete class C 32/40 were required.

It is required that the concrete be pumpable, three-fraction with cement CEM II / S-L 42.5 R Lafarge - Holcim, Beočin.

Projected masses of components per volume of 1 m³ of concrete:

Cement	= 350 kg,
Water	= 175 kg,
I fraction 0/4	= 679 kg – river,
II fraction 4/8	= 459 kg – river,
III fraction 8/16	= 698 kg – river.

Test plan:

1. Absorbency testing
2. Determination of compressive hardness on a cylinder
3. Determination of compressive hardness on a prism

4. Determination of compressive hardness on cubes
5. Determination of the modulus of elasticity on the cylinder
6. Cube shrinkage testing
7. Creep test on the prism 10x10x40 cm
8. Creep test on 2 prisms 10x10x20 cm (prisms are placed on top of each other without gluing)
9. Creep test on 2 individual prisms 10x10x20 cm (prisms are placed on top of each other without gluing)

Volume mass of fresh concrete:

$$\gamma_{b,sv} = \frac{m_{b,sv}}{V_{b,sv}} \quad (4)$$

Where in:

$m_{b,sv} = 119,35 \text{ kg}$ - mass of concrete in fresh condition expressed in kg;

$V_{b,sv} = 0,05 \text{ m}^3$ - volume of concrete in fresh condition.

Volume mass of fresh concrete is: $\gamma_{b,sv} = 2387 \frac{\text{kg}}{\text{m}^3}$.



Figure 4. Concrete mixing and preparation of the mold

During the process of making concrete samples, immediately before installation in the molds, the consistency of the mixture was checked. The diameter measured in two perpendicular directions is $R = 45 \text{ cm}$ which corresponds to a plastic consistency.



Figure 5. Concrete consistency tested by spreading method



Figure 6. Samples of fresh concrete built into the molds, cubes 15x15x15 cm, prisms 10x10x40cm and a cylinder with a diameter of 15 cm and a height of 30 cm



Figure 7. Special attention must be paid to leveling the surface of the prism and cylinder specimens so that the results of the concrete strength test are accurate and authoritative

By testing the prism, the following results were obtained:

- for a prism whose contact surface (prism base) is honed:

$$A_p = a^2 = 0,1^2 = 0,01 \text{ m}^2$$

$$P_p = 352 \text{ kN} \rightarrow f_{bp} = \frac{200}{0,01} = 20,00 \text{ MPa}$$

- for a prism whose contact surface (prism base) is honed and treated with epoxy:

$$A_p = a^2 = 0,1^2 = 0,01 \text{ m}^2$$

$$P_p = 352 \text{ kN} \rightarrow f_{bp} = \frac{352}{0,01} = 35,20 \text{ MPa}$$

By testing the cylinder, the following results were obtained:

- for a cylinder whose contact surface (cylinder base) is honed, which means that there may be irregularities and this has been confirmed by the reduced hardness result:

$$A_c = r^2 \pi = 0,075^2 \pi = 0,0177 \text{ m}^2$$

$$P_p = 280 \text{ kN} \rightarrow f_{bp} = \frac{280}{0,0177} = 15,85 \text{ MPa}$$

- for a cylinder whose contact surface (prism base) was ground and treated with epoxy, which automatically affected the higher result:

$$A_c = r^2 \pi = 0,075^2 \pi = 0,0177 \text{ m}^2$$

$$P_c = 412 \text{ kN} \rightarrow f_{bc} = \frac{412}{0,0177} = 23,28 \text{ MPa}$$

By testing the cube, the following results were obtained:

$$A_k = a^2 = 0,15^2 = 0,0225 \text{ m}^2$$

Hardness $f_{bk} = 51,38 \text{ MPa}$ - cube hardness 15x15x15 cm

Hardness $f_{bk} = 51,38 \times 0,95 = 48,11 \text{ MPa}$ - cube hardness 20x20x20 cm

The difference in hardness between a cylinder with a diameter of 15 cm and a height of 30 cm and a cube measuring 20 x 20 x 20 cm must not exceed 25%, which is not the case with our test where we notice that the difference is:

$$\Delta = \left(1 - \frac{23,38}{48,11}\right) \times 100 = 51,4 \% \quad (5)$$

We notice that the difference is 51.4% which is 100% larger than the maximum which can be up to 25%.

3. CONCLUSION

Conducted preliminary tests of the hardness of experimental concrete bodies, cubes and cylinders, in order to reach the stage of testing the modulus of elasticity, shrinkage and flow of hardened concrete, indicate that there is a large difference in strength of the cube and cylinder, which is much higher than the prescribed 25% and amounts, according to these measurements 51.4%. This is a worrying result and points to three possibilities:

1. This is an error in measuring the strength of concrete on a cylinder with a diameter of 15 cm and a height of 30 cm, which is 23.38 MPa.
2. That the strength of the cylinder is good but that the cylinder as a geometric body is not responsible for assessing the quality of concrete because they get much less strength than they really are.
3. That the strength on a standard concrete cube 20x20x20 cm is not relevant for the assessment of the quality of concrete because the strengths obtained are much higher than the actual strength of concrete as a material.

If the third statement were correct, then the cross-sections of concrete structures would be overloaded and would usually be in the area above the point of proportionality and elasticity in terms of stress states in the structure.

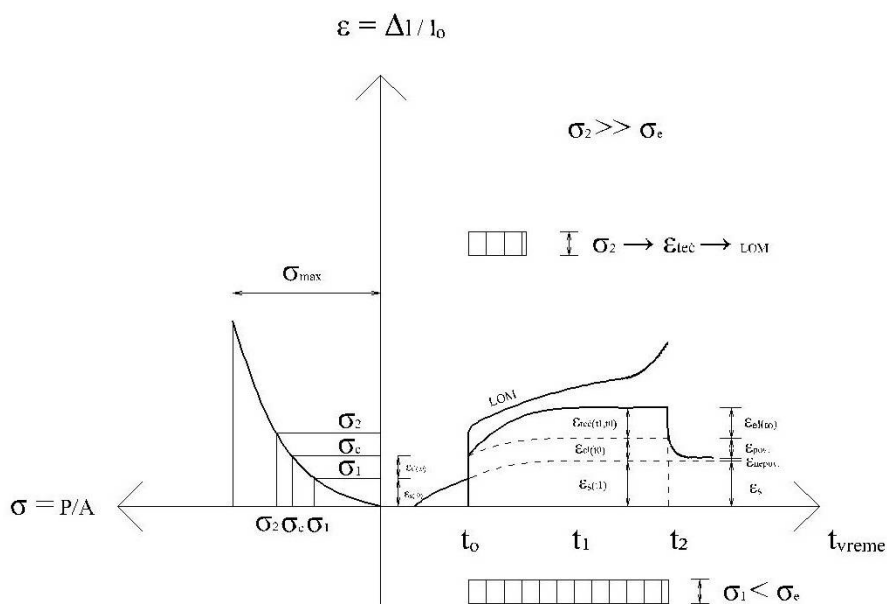


Figure 8. Time deformations of concrete - shrinkage and flow [1]

This would mean, according to Figure 8. [1], that the stresses in the cross section would be equal to or greater than the stress σ_2 , which suggests that the flow will not be stabilized over time, which actually happens with many large, especially bridge concrete structures.

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ПРОБЛЕМАТИКА ИСПИТИВАЊА ТЕЧЕЊА И СКУПЉАЊА КОД ОЧВРСЛОГ БЕТОНА

Резиме: Овај рад даје неке нове погледе већ познате проблематике мерења и испитивања течења и скупљања бетона као реолошке временске деформације. Течење бетона није теоријски, већ структурални проблем и решења се морају тражити искључиво експерименталним испитивањима и мерењима. На основу таквих мерења, праћења и сагледавањима структуралних промена, могуће је урадити теоријске поставке. Оно што јесте добро познато, да течење директно зависи од стања и величини напона којима је изложен пресек бетона. Они пресеци бетона који су само делимично искориштени, у напонском смислу, нису толико осетљиви на течење, као пресеци који су оптерећени до тачке пропорционалности. Посебан проблем и енормни пораст течења бетона би наступио ако би пресеци били оптерећени изнад тачака пропорционалности и еластичности. Течење бетона у току времена на реалним конструкцијама у експлоатацији, у већини

случајева, и код старих и код нових конструкција, непредвиђено расте већ у првим годинама. Може се поставити питање и сумња у величину стварних стања напона којима су изложене бетонске конструкције. Наша мерења одређивања граничне чврстоће бетона на коцкама, призмама и цилиндрима, упућују на такву сумњу. У току спроведених испитивања течења и скупљања бетона, која су урађена на докторским студијама 2020. године на Грађевинском факултету у Суботици, која још увек трају, приказујемо само један сегмент који се односи на тему величине напона којима су изложени пресеци у бетонским конструкцијама.

Кључне речи: Бетон, деформације, реологија, скупљање, течење