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THE PROBLEM OF ADDITIVITY OF CREEP AND SHRINKAGE IN CONCRETE UNDER TENSION

1. Introduction

When analyzing every investigation on the strain of concrete subjected to long-term operation of stresses, there arises the problem of evaluating the participation of shrinkage strains. The frequently used method of separating the creep strains consists of subtracting the shrinkage strains measured in twin experimental elements not subjected to external loads. The basis for this is the assumption of additivity of creep and shrinkage strains, implied by the concept of independence of these phenomena. This assumption is criticized by most of authors. Soviet researches introduced the concept of the so-called "stress shrinkage"(see item 2.1), supposedly caused by faster drying of loaded concrete. In turn, according to the prevailing opinion of researchers in the West, the drying of concrete increases the creep by the quantity called "the creep at drying"(see item 2.2).

With reference to the above there are two questions: whether the interdependence of creep and shrinkage actually takes place, and on what it depends, and also whether the effect of this possible interaction is measurable and significant. In the present paper, on the basis of testing of the experimental elements, the authors attempt to answer only the latter question.

2. State of art report

2.1. Effect of long-term loads on drying and shrinkage of concrete

The dependence of drying and shrinkage of concrete on long-term loads hat not been much investigated. The results obtained from an insufficient

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number of investigations do not warrant extensive explanation of this problem - the more so, as the opinions of the various authors on the subject are different.

ALEKSANDROWSKI [1] explained that long-term load causes the changes of the dimensions of concrete pores, thus changing the conditions of its drying which should affect the shrinkage.

MEIER and NILSON [2] explained the dependence of shrinkage on long--term loads as follows: in the case when a concrete specimen is subjected to the action of external loads, then apart from the immediate strains which are followed by creep strains, the load also causes a change in the water vapour pressure in the concrete. This change results, in turn, in a process aiming at levelling the water vapour pressure inside the concrete to the water vapour pressure of the surrounding environment, as a result of which moisture strains are created. Similar opinions on this subject were offered by ROSS, SEED, DAVIS and HAMILTON acc. to [3].

Interesting investigations on the drying of elements under load (compressed or stretched) and load-free were made by ALEKSANDROWSKI [4, 5]. His results would prove e.g., that tensioned specimens dry up more quickly than the specimens not loaded with this effect being more evident at higher stresses and possibly (acc. to the author of these investigations) at smaller dimensions of the cross-section of the specimen. The results of these tests do not permit a direct comparison of the quantity of shrinkage in loaded and load-free concrete as the quantity of creep is not known. Such comparisons given in investigations [4, 5] are not accurate (comp. item 2.2) since the author assumed that the creep of the drying specimens is equal to the creep of the insulated reference specimens, and on this basis evaluated the creep strain (the same in accuracy is found in the work of MITZEL [6]). In a more recent work ALEKSANDROWSKI has shown that the quantity of shrinkage in loaded concrete may be estimated on the basis of the dependence between the amount of water evaporated from the concrete and the value of this shrinkage. Such a dependence was presented by ALEKSANDROWSKI in papers [1, 7]. As a result, this permitted, in an indirect way, a comparison of the discussed quantities of shrinkage [1]. In this way, the author demonstrated that the shrinkage of an element under load is greater than the shrinkage of an element without load. The difference between these two values was called "the stress shrinkage". According to ALEKSANDROWSKI [1, 4, 5] and MITZEL [6], the existence of this difference shows that shrinkage and creep are not additive values. In their opinion, the calculated value of creep e.g., for tension, as the sum of the strains measured (in a loaded and drying specimen) and of the shrinkage strains (in a drying comparison--specimen without load) is burdened with an error equal to the value of "the stress shrinkage", Fig.1.

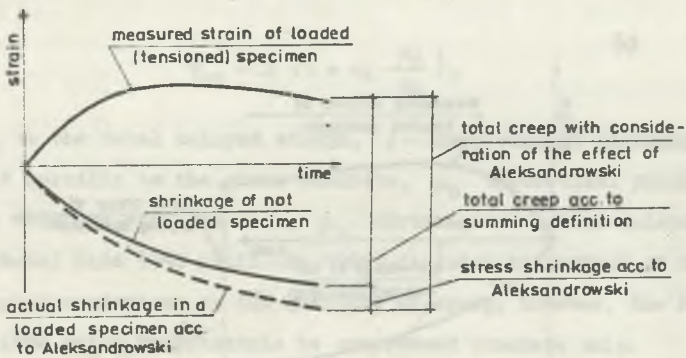

Fig.1

The authors of other studies MAMILLAN, MANEY, NEVILLE acc. to [8], as opposed to ALEKSANDROWSKI [4], did not find any essential difference between the loss of moisture in the specimens subjected to long-term compressive loads and in load-free specimens. HANSEN [8] expressed an opinion that the methods of measuring moisture losses (measurements of weight) in the above-mentioned investigations were not very accurate. CEB-FIB Model Code 1990 (Bull.No 190a) does not contain any relations describing the effect of loads on the drying and shrinkage of concrete.

2.2. Creep at drying

Some researchers, like e.g., VOGT [9], PICKET [10], HANSEN [8], NEVILLE [11], BROOKS [12], ILISTON [13] and others make use of the notion of the so-called "creep at drying". This is the quantity by which the creep resulting from the drying of concrete, is increased, Fig. 2.

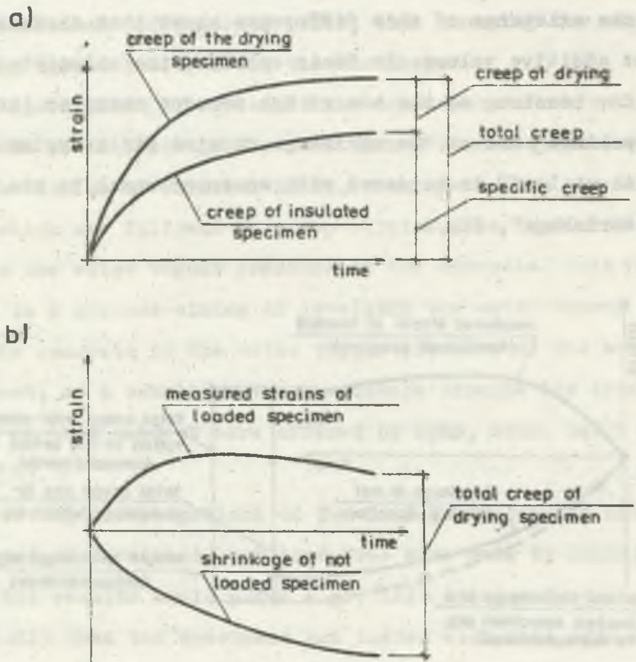

Fig.2

According to these authors, total creep is the sum of the creep of the element protected against the loss of moisture (insulated), and the creep at drying, associated with the loss of moisture, fig.2a. The creep of the insulated element is called the specific creep or basic creep. For the tensioned elements, fig.2b, the sum of the strains measured in a loaded and drying specimen and the shrinkage strains in a drying reference specimen without load represents total creep.

VOGT [9] explained in this theory, that shrinkage influences the creep as a result of internal stresses, which it causes. As a result of the drying of the concrete element, non-uniform fields of moisture and shrinkage strains are created in it. These are the cause of the formation of internal shrinkage stresses of non-uniform distribution in the area of the specimen section. The tensile stresses are created more quickly in the drying, external layers, while the compressive ones - in the deeper layers. These stresses are summed up with the stresses resulting from the external load. As a result, the distribution of stress changed on account of drying is ruling the creep.

PICKET [10] suggested that the causes of the increased creep in the drying specimen in comparison with the specimen protected against loss of moisture are not to be found only in the increase of stresses, but also in the possibility ef exceeding the linearity of creep as a result of the increase of these stresses.

L'HERMITE [14] suggested the linking of shrinkage and creep by equation:

2.1 $$\eta_{op} = \Delta \left(1 + a_{\Delta} \frac{\mu_a}{\mu_o}\right),$$

where: η_{op} is the total delayed strain, Δ - creep without shrinkage, a_{Δ} constant specific to the given concrete, μ_o theoretical shrinkage at relative moisture equal to zero, μ_a shrinkage at actual moisture.

CEB-FIP Model Code 1990 (Bull. No 190a) includes the effect of the concrete drying conditions on the quantity of creep; however, the relationships given refer in principle to compressed concrete only.

3. Formulation of the problem, aim of own investigations

Summing up the review of literature, it may be stated that the opinion of the researchers as to the influence of long-term loads on the drying and shrinkage of concrete, and hence as to the existence of the so-called "stress shrinkage" are not univocal. Thus, it should be believed that the problem has not been solved. An insufficient number of investigations and associated with it, differences of opinions prompted the, conducting of experiments in this field.

However, it may be assumed that there is a uniformity of views on the so-called "creep at drying". According to the authors of the article, the existence of an excess of creep caused by the drying of concrete does not negate the principle of additivity of shrinkage and creep of concrete for a properly conducted test. This is an experiment in which the specimens under load and reference specimens are in the same thermal-moisture conditions. This means, among others, that the insulated loaded specimen cannot be the comparison specimen (useful for the calculation of the shrinkage strains) for the drying specimen under load. The insulated specimen is in different thermal-moisture conditions than the specimen which has not been insulated so this is an additional factor introduced in the experiment. The authors of the article made the following hypothesis: "The creep of tensioned concrete may be presented as an algebraic sum of strains measured on the same specimens, loaded and load free which are in the same thermal-moisture conditions (both environmental and those inside the specimen)".

To verify this hypothesis, the problem of the so-called "stress shrinkage" had to be solved. In other words, it should have been found whether there exists an influence of long-term loads on the drying and shrinkage of concrete. Lack of such an an influence favours the assuming of this hypothesis, while its existence would suggests rejecting it. The authors of the article carried out the investigations described further on and these permitted the sulution of the problem in the case of axially tensioned concrete.

4. Method, plan and description of own investigations

A direct measurement of the shrinkage of concrete elements subjected to the operation of long-term loads is not possible. In view of this, it has been assumed that it is possible to conclude about the quantity and progress of the moisture shrinkage on the basis of the changes of the concrete moisture [1, 7, 11]; and the moisture of the concrete may be assessed by means of its electric conductivity [11, 15, 16]. The high mutual correlation of these phenomena has not been questioned.

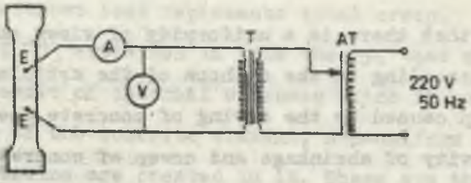

Fig.3. Scheme of the measuring device

The investigations concerned the concrete of the composition: 243 kg of Portland cement "35", 2084 kg sand-gravel mix, 174 kg of water. The shape of the experimental element is presented in Fig.3. On account of the small dimensions of the cross-section (100x100 mm) and a relatively long testing time, it has been assumed that at each point of the measurement area the moisture is the same [17]. The specimens were shaped after one day and next stored and tested at the temperature 20±1°C.

Two series of specimens were planned, each of which was divided into two groups (Table 1) - loaded specimens in creep--testing machines and load-free. The selection of specimens was a random one. In "a" series the stress was maintained for 28 days at the relative level $\sigma(t)/f_{ctm}(t) = 0,6$ and for the next 304 days $\sigma = 0,6\, f_{ctm}^{28} = 0,8$ MPa (at relative air humidity RH = 70±10%). The immediate mean tensile strength $f_{ctm}(t)$ had been determined earlier on other elements of the same shape [18]. In "b" series, a practically constant primary length of the elements was forced inducing in this way the shrinkage stresses $\sigma_{bs}(t)$ until the fracture of the concrete at RH = 85% [18].

Table 1.

series	concrete mix	Number of test elements		
		not loaded	loaded	R_z^{28}
"a"	1	4	4	4
	2	4	4	4
"b"	3	4	4	4
	4	4	4	4

The investigations of the concrete moisture were based on the method of measuring the electric conductivity acc. to the scheme shown in fig.3. Alternating current supply (50 Hz) was used which excludes the possibility of creating the phenomena of electrolysis and polarization. Corrosion--resistant carbon electrodes (E) of stable characteristics were used. The electrodes of cylinder shape (ø7 mm , l = 10 mm) were placed in the longitudinal axis of the element, 150 mm from each other. The power lead was glued (to the opening drilled in the electrode) by means of a special conducting glue.

The measurement consisted in forcig in the circuit of the current intensity of constant value and registering of the voltage drop U between the electrodes. The voltages $U_k(t)$ - for the load-free elements and $U_k^*(t)$ - for the loaded ones, changing in the course of the drying of

concrete, were measured. The ratio of these quantities to the corresponding to them initial voltages $U_k(t)/U_p$, $U^*_k(t)/U^*_p$ was the basis for the comparison of the processes of drying of both groups of elements.
The measurement values from the testing of the groups of specimens loaded and load-free in "a" series were as follows: the mean primary voltage from both groups $\overline{U}_p = 0{,}130$ V at current intensity J = 0,05 mA (with the man values in groups not differing much). The average tensile strength $f^{28}_{ctm} = 1{,}79$ MPa.

To avoid shunting of the electrical installation the system was insulated from the handle of the creep-testing machine in which the tests were made. It was also found that there is no directed relationship between the electric conductivity of the concrete and the value of tensile stresses (an additional series of elements underwent immediate tests).

The strains were measured by means of frames, rods and dial indicators 1 μm, on a base of 400 mm in length. For the measurements of free shrinkage ε_s, elements of the same shape were used which were placed in a rheological chamber of the same height as the elements in the creep-testing machines. A detailed description of the investigations can be found in paper [18].

5. Test results

On elaborating the results obtained, statistical analyses at significance level 0,01 have been assumed. Making use of variance analysis to the value f^{28}_{ct} (accompanying tests), it has been found that the experimental material in each series is a homogenecus set. It has also been checked, by means of Dixon test [19], whether the extreme values of the results are not burdened with gross errors. The graphic interpretation of the results of "a" series is given in fig.4, 5 and 6. The broken lines in these figures connect the mean values obtained from the calculations.

The diagrams from fig.4 present the course of variations (in logarithmic scale) of the quantity U_k/U_p and of the shrinkage strains ε_s, depending on the time for the load-free elements. The value of the ratio U_k/U_p increases with time, with growing intensity in the course of the drying of concrete. In the last period of time, when the increments of

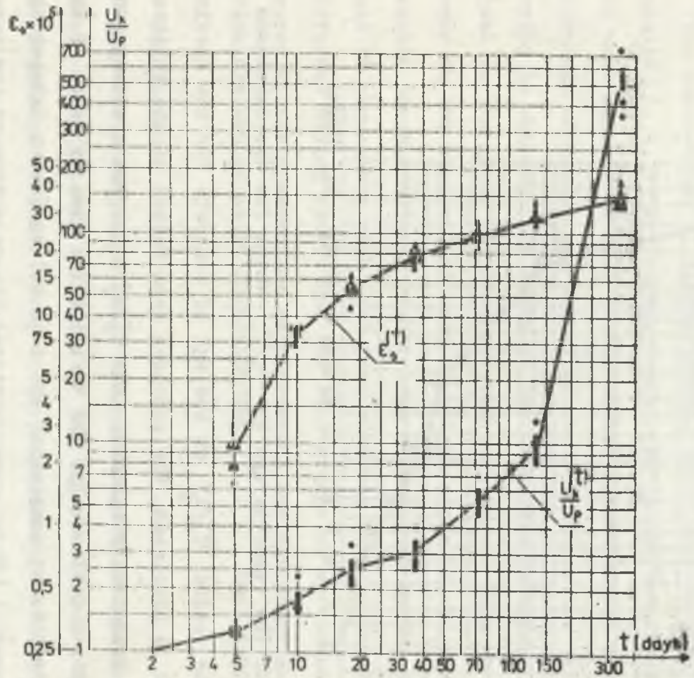

Fig.4. Effect of the concrete age on shrinkage and the value of the U_k/U_p ratio in load-free specimens

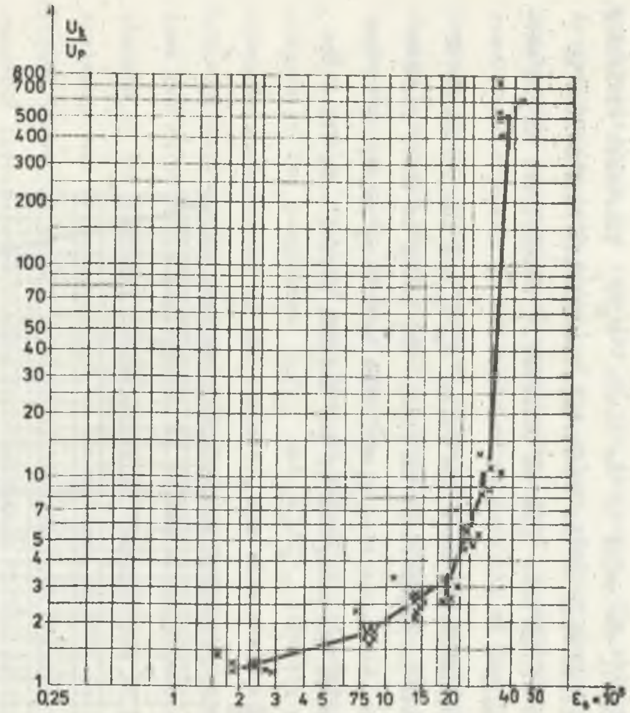

Fig.5. Dependence between the U_k/U_p ratio and shrinkage of concrete

shrinkage are small, the value of the ratio U_k/U_p increases violently. This denotes a rapid drop of the electric conductivity of concrete in this period, and at the same time an increase of sensitivity in the measuring method used.

The direct dependence between the ratio U_k/U_p and the shrinkage of load-free concrete is illustrated in fig.5. The plots in those figures show that, of the two quantities given, more sensitive to drying is the ratio U_k/U_p (with the exception of the initial period). In fig.6 the

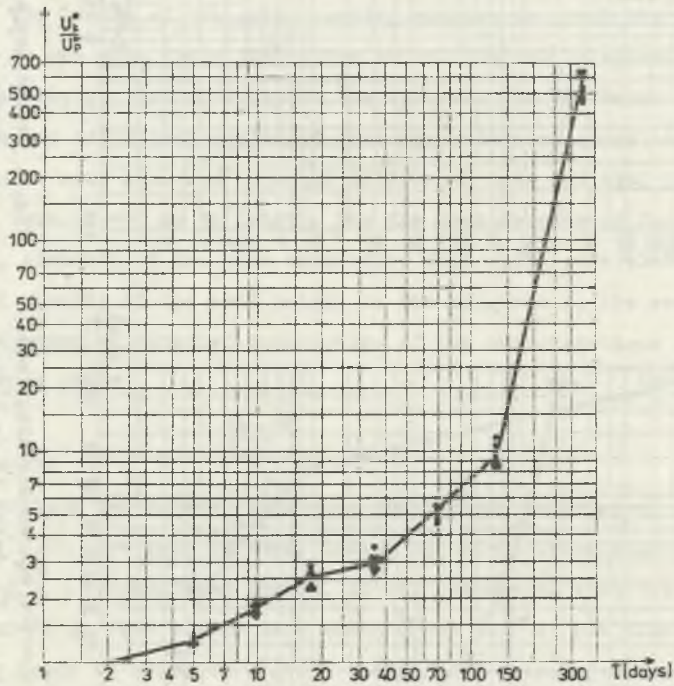

Fig.6. Effect of the concrete age on U_k/U_p value for the specimens cured under load

dependence of the ration U_k^*/U_p^* on the age of concrete for the specimens cured under load is presented. The compared mean values of the ratios: U_k/U_p – for the load-free specimens, and U_k^*/U_p^* – for the specimens under load do not differ significantly. The verification made by means of the test t_{α}, of the hypotheses concerning the mean values (seven independent cases for different t) in no case justified the rejection of the zero hypothesis about the equality of the two means. The observed small mutual deviations (to both sides) of the values studied should be related to the natural dispersion of experimental data. A qualitatively identical result was obtained on the basis of an analysis of the "b" series. Because of the short period of investigating the specimens from this series - about 6 weeks - till the time of cracking, the results of these tests are not given in this article.

The results obtained mean that no effect of long-term tensions on the changes of the quantities U_k/U_p and U_k^{*}/U_p^{*}, directly related to the electric conductivity of the concrete, has been ascertained. On the basis of this it has been assumed that the influence under discussion does not exist or is negligible. As it has already been mentioned, the changes in the electric conductivity of concrete and of its (moisture) shrinkage are closely related to the changes in the humidity of this material; thus, it should be assumed that no such influence exists in the concrete investigated - also with reference to the drying and shrinkage.

The conclusions of ALEKSANDROWSKI which are contrary to the above test results [1, 4, 5] are controversial. As it has been shown in chapter 2.1, the test results of this author do not permit direct comparisons of the shrinkage of loaded and load-free concrete since the value of creep at drying is unknown (the creep of the insulated reference specimens is not equal to the creep of not-insulated specimens). This is the cause of error in the comparisons carried out in paper [4, 5]. In turn, the results demonstrating a higher loss of moisture by the specimens under load in comparison with load-free ones may have depended, perhaps, on the different drying conditions for both groups of specimens (interferences caused by the presence of reinforcement and different shapes of specimens) which are not given by ALEKSANDROWSKI.

6. Conclusion

With the assumptions made, the conducted investigations did not demonstrate a significant influence of the tensile stresses in concrete on its shrinkage strains. Thus, in the experimental conditions described, there is no basis for rejecting the thesis of the additivity of the creep and shrinkage strains.

In technical applications, as well as scientific investigations in which the conditions are not much different from the experimental conditions quoted in the article, the authors suggest the assuming as true, the following theorem:

The creep of concrete at tension may by presented as an algebraic sum of the strains measured on the same specimens, loaded and load-free, stored in the same thermic- moisture conditions.

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ZAGADNIENIE ADDYTYWNOŚCI PEŁZANIA I SKURCZU W BETONIE ROZCIĄGANYM

Streszczenie

Omówiono badania wpływu długotrwałych rozciągań na wysychanie i skurcz betonu. Wilgotność betonu oceniano na podstawie pomiarów wielkości elektrycznych. Nie stwierdzono istotnych różnic między wysychaniem próbek obciążonych i nie obciążonych. W opisanych warunkach nie było podstaw do odrzucenia założenia o addytywności odkształceń pełzania i skurczu.

ПРОБЛЕМА АДДИТИВНОСТИ ПОЛЗУЧЕСТИ И УСАДКИ В РАСТЯГИВАЕМОМ БЕТОНЕ

Резюме

Обсуждается исследование влияния длительного растяжения на высыхание и усадку бетона. Влажность бетона оценивается на основании измерения электрических параметров. Не обнаружено существенных различий между высыханием нагруженных и не нагруженных образцов.

В описанных условиях не было основания отказываться от предпосылок об аддитивности деформаций ползучести и усадки.