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Creep of Concrete. The Influence of Variations in the Humidity of the Ambient Atmosphere

Le fluage du béton. Influence des variations de l'humidité de l'air.

Das Kriechen von Beton. Einfluß der Variation der Luftfeuchtigkeit

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Introduction

The humidity of the ambient atmosphere is one of the most important factors which influence long-time deformation of cement mortar and concrete under sustained load.

Creep tests have usually been carried out in airconditioned rooms in laboratories where the temperature and humidity of the atmosphere have been kept more or less constant. Thus much information has been obtained about creep of concrete under such constant conditions. It is known that creep of concrete which is not exposed to any drying or wetting during the period of sustained loading (the so-called basic creep) is much smaller than creep of concrete which dries under load. Moreover, the basic creep is greater when concrete is loaded while it is wet, and decreases with decreasing water content (HANSEN, 1958).

Routine measurements of shrinkage and creep on cement mortar beams at the laboratories of the C. B. I. gave rise to the idea that creep is highly influenced by variations in the humidity of the surroundings. Later on it has been reported (R.I.L.E.M. Colloquium, 1958) that it was difficult to estimate creep of concrete structures on building sites on the basis of laboratory tests, this probably due to an unknown effect on creep of the varying climatic conditions of the surroundings. It was suggested that a change in humidity, whether positive or negative, should tend to increase creep. This is supported by experimental results reported by PICKETT, 1942.

The variations of humidity in the ambient atmosphere seems to be of considerable practical and theoretical interest when considering the influence upon creep. Therefore a more systematical investigation of this problem was made at the C.B.I., as a part of an extensive research program on creep of concrete.

Method of Testing

7 series of cement mortar beams were loaded at the age of 28 days and the creep deflection of the beams was measured during a period of 100 days. All series were cured one day under wet sacks at 100% RH before removal of forms. Then 6 days in water at 20° C and 21 days in an airconditioned room (70% RH, 20° C). Special precautions were taken that no drop in humidity under 70% RH should occur during this period.

After loading, each series followed a special program.

Series 1 was loaded and stored in air of 60 % RH.

Series 2 was loaded and stored in air of 70 % RH.

Series 3 was loaded and stored in air of 50 % RH.

Series 4 was loaded in air of 50 % RH and exposed to a humidity alternating between 50 % RH and 70 % RH in periods of one day.

Series 5 was loaded in air of 50 % RH and exposed to humidity alternating between 50 % RH and 70 % RH in periods of one week.

Series 6 was loaded at the age of 35 days in air of 70 % RH after having been exposed to 50 % RH for one week. For the following 100 days this series was treated in the same way as series 5, that is exposed to humidity alternating between 70 % RH and 50 % RH in periods of one week.

The humidity was controlled within ± 1% RH and the temperature within ± 1° C.

10 beams $2 \times 5 \times 40$ cm, and 6 beams $2 \times 5 \times 25$ cm were cast in each series. 6 long beams were loaded in the creep test and warping was measured on 4 companion specimens without load. Shrinkage was measured on the 6 short beams by means of a special comparator. Finally 10 beams $2 \times 5 \times 25$ cm were cast for determination of modulus of rupture after the 28 days of initial curing.

The cement mortar was mixed for 5 minutes, placed in steel moulds and vibrated for 3 minutes.

The loaded beams were subjected to a constant bending moment by means of weights and levers (see fig. 1). The weights were adjusted so that the stress in the extreme fibers of each beam was 32 kg/cm^2, that is one third of the modulus of rupture of the 25 cm beams at the time of load application.

Immediately after application of load the instantaneous elastic deflection was measured with a 0.01 mm dial gauge attached to each beam and readings

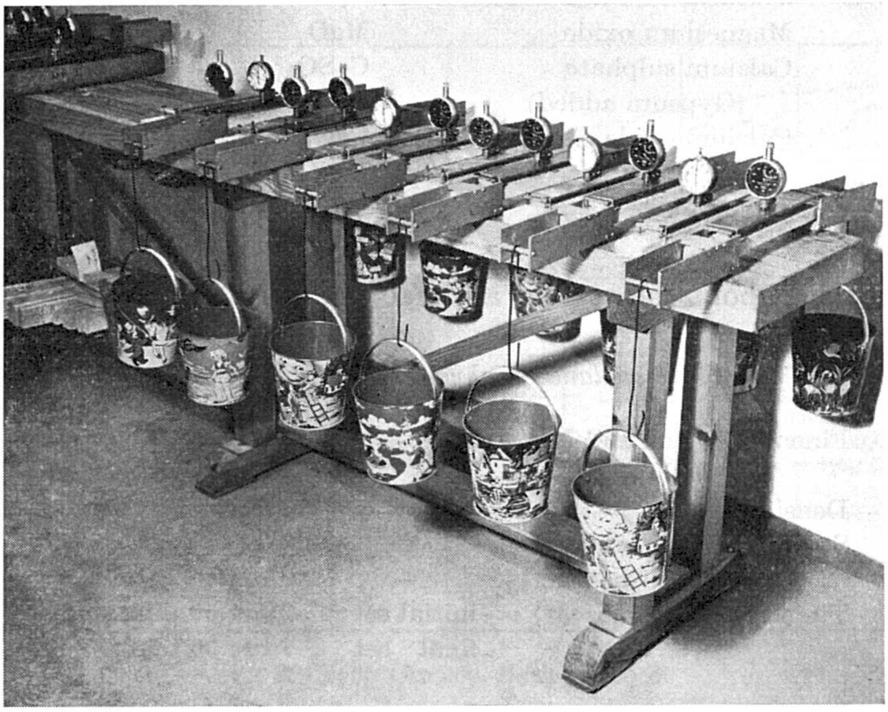

Fig. 1. Equipment Used for Creep Test.

were then taken every day during 100 days. The deflections caused by warping were measured, as earlier mentioned, on 6 companion specimens without load, and the deflection curves shown on fig. 2 are duly corrected as well for warping as for instantaneous elastic deformation.

Materials

The cement mortar used in the investigation had the following composition.

Cement content (Std. portland cement)	850 kg/m^3
Water-cement ratio after weight	0,35
Volume concentration of cement paste	59 %

The slump was determined as an average of 3 measurements on each batch and was always between 8.5 and 9.5 cm.

The phase composition of the cement clinker has been determined, using the formulæ given by Bogue.

Table 1. Calculated phase composition of the cement clinker

Compound		Percentage
Tricalcium silicate	C_3S	44
Dicalcium silicate	C_2S	28
Tricalcium aluminate	C_3A	10
Tetracalcium aluminoferrite	C_4AF	5,7
Magnesium oxide	MgO	5,1
Calcium sulphate (Gypsum added)	$CaSO_4$	5
Calcium oxide	CaO	0,9
Alcali oxides	Na_2O and K_2O	0,8
Remainder		1,0

Further data about the cement are given in table 2.

Table 2. Miscellaneous physical properties of the cement

Fineness	(Lea and Nurse)		3480 sq. cm per gm
	(Blaine)		3530 sq. cm per gm
Density			3.07 gm per c. c.
Soundness	(Autoclave)		3.8 per cent
	(Le Chatelier)		0 mm
Time of setting	(Viscat)	initial set	2 hrs 50 min.
		final set	7 hrs 30 min.

The aggregates are a partly siliceous, partly calcareous material of glacial origin from a local source.

Maximum size of aggregate	4 mm
Fineness modulus of aggregate	2,1

Experimental Results

The creep deflection curves of series 1—6 are presented in fig. 2.

It is interesting to notice that the creep of series 4 and 5, which were exposed to an alternating humidity of the surroundings, is nearly as important as the creep of series 3 which was constantly exposed to the lower humidity of 50 % RH, and condiderably greater than the creep of series 1 which was exposed to the average humidity of 60 % RH. As is seen from fig. 3, the shrinkage is not influenced in the same way by such variations in humidity.

A closer examination of the experimental results reveals that the whole increase in creep is limited to the first period of drying. Moreover, when the cement mortar is loaded during the second period of drying, as in series 6, the total creep is even smaller than the creep of series 2 which was exposed to a lower humidity of 70 % RH.

In the case of series 6 a variation in the humidity of the surroundings thus caused a decrease in creep, while in series 4 and 5 creep was increased because of such variations.

These results are somewhat confusing and an explanation seems to be needed.

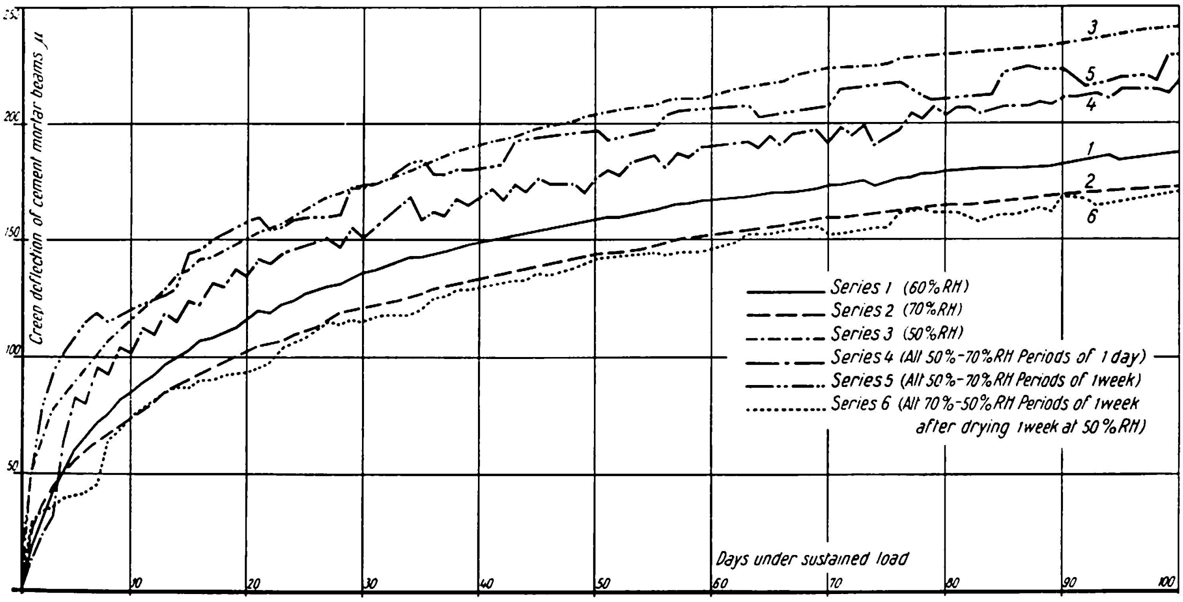

Fig. 2. Creep Curves, Series 1 to 6.

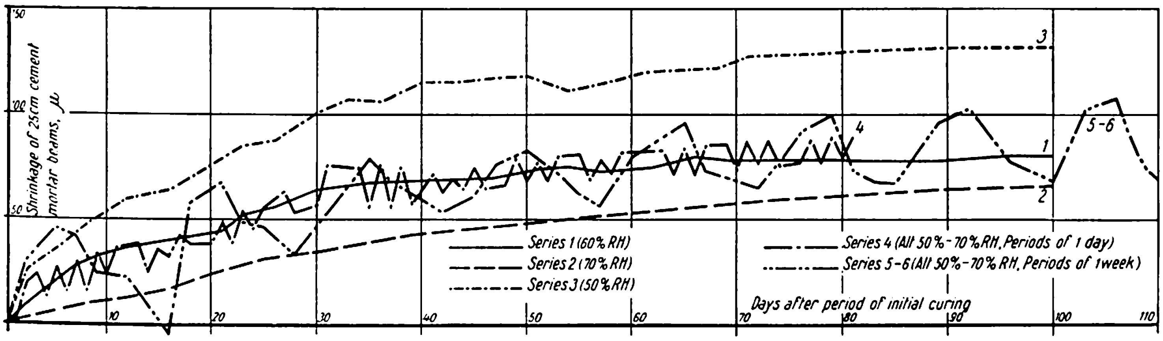

Fig. 3. Shrinkage Curves Series 1—6.

Discussion

According to the experimental results, the first period of drying is of outstanding importance for the deformational behaviour of cement mortar and concrete. If the material is loaded during this period, creep is greatly increased. A similar effect on creep is not apparent on any subsequent drying after an intermediate exposure to a higher relative humidity.

The Author first thought that this effect was a natural consequence of a non-uniform shrinkage and a non-linear stress-creep relationship for concrete. According to PICKETT, 1942, shrinkage is restrained in a concrete prism of finite size, and produces a non-uniform internal stress over a section, which must be added to the stress due to external load. Hence the resultant stress in certain parts of the section will be higher than the plastic limit of concrete, and the section as a whole will undergo a total deformation which exceeds the simple sum of creep and shrinkage.

It has earlier been shown that this influence of shrinkage upon creep is very common when concrete beams are exposed to flexural load while drying (HANSEN, 1958). However, if "Pickett's effect" was the explanation of the increase in creep during the first period of drying in our experiment, the effect should be as important during the second period of drying as during the first, since the amount of shrinkage measured in these two periods does not differ appreciably. Since there was no such increase in creep during the second period of drying it is inferred that "Pickett's effect" has been of secondary importance in the whole experiment.

This was also confirmed when investigating the effect of drying upon the flexural strength of $2 \times 5 \times 25$ cm beams of the same composition as used in the main investigation. It has earlier been explained (HANSEN, 1958) that the internal stresses due to non-uniform shrinkage will also affect the instantaneous deformations and the strength (especially the flexural and tensile strength) of drying concrete specimens. The decrease in flexural strength in a test specimen is therefore a good measure of the internal stresses and the importance of an eventual "Pickett's effect".

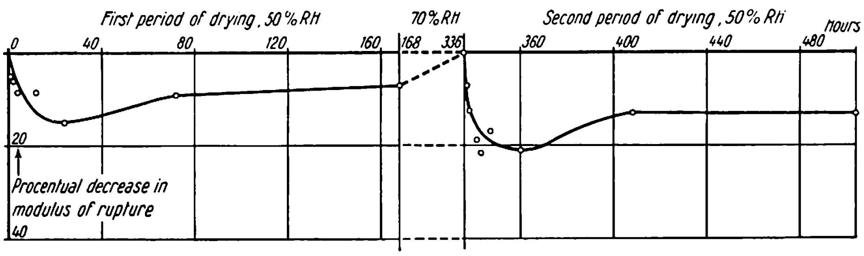

Fig. 4. Procentual Decrease in Flexural Strength of Cement Mortar Beams During First and Second Period of Drying.

Fig. 4 shows that the procentual decrease in strength is of the same magnitude as well in the second as in the first period of drying. Consequently it is safe to conclude that the internal stresses and "Pickett's effect" have been of the same magnitude for series 5 and 6. This effect cannot therefore explain the accelerated creep during the first period of drying.

It is reasonable to believe that an irreversible modification of the cement gel takes place during the first drying. And this effect is not repeated during any subsequent drying. BREWER and BURROWS (1951) found a pattern of very fine haircracks in dried cement paste and mortar. It might be that these cracks develop during the first period of drying, as a consequence of shrinkage of the cement gel, restrained by grains of aggregate and unhydrated cement, and that this fact contributes to the characteristic deformational behaviour of the material during this period. When a small stress is applied, the irreversible cracking distortions, which usually are miscellaneously orientated, might be unidirected, and the resultant deformation could be of considerable magnitude. During any subsequent drying such cracking does not occur, and creep is much smaller.

PICKETT (1956) found a similar effect when dealing with the shrinkage of concrete. In his experiments the shape of the shrinkage curves and the amount of shrinkage were different at the first period of drying from what was observed during any subsequent period of drying after submersion in water. PICKETT suggested that during the first drying some adjacent particles in the cement gel are pushed closer together, while other particles are pulled farther apart. As a result of high contact pressures, the particles develop chemical or surface bonds which tend to prevent future separation. During the first drying, particles and groups of particles reach new and more stable positions of equilibrium. During any subsequent drying such modification of the paste does not take place. This also provides us with a possible theory of the influence of first drying upon creep, if we imagine that these small distortions are unidirected by an external load.

There still remains to be explained why a submersion of dry concrete in water, while loaded, also causes an increase in creep as compared with the creep of wet or dry concrete (DUTRON, 1936). The reason could be that a strong sudden change in humidity (submersion of dry concrete in water) causes the same cracking or other modifications in the gel as during the first period of drying but to a smaller extent. This could explain PICKETT's observation (1942) that a change in moisture condition whether positive or negative (submersion in water or drying out) causes an increase in creep. Our experiments show that this effect cannot generally be expected when the changes in humidity are smaller (alternations between 50 % RH and 70 % RH).

Any conclusive explanation of these effects cannot be given before more is known about the shrinkage mechanism of cement and concrete.

Conclusion

It can be concluded that creep is increased when concrete is exposed to variations in the relative humidity of the surroundings, if concrete is loaded before or during the first period of drying. If these variations are slow it may be expected that the total creep is as important as creep of concrete which has constantly been exposed to the lower relative humidity. With quicker variations in humidity, the total creep will tend towards the value obtained when concrete is constantly exposed to the average humidity during the time of sustained loading.

Quite different effects are to be expected when concrete is loaded after the first period of drying. Under such conditions concrete creeps far less than it does when loaded during the first drying. Our experimental results show that the total creep of concrete loaded during a subsequent period of drying, was of the same magnitude as creep of concrete constantly exposed to the higher relative humidity.

A practical conclusion of this investigation is that creep of concrete structures on building sites can be estimated only with difficulty from ordinary laboratory tests which have been done under constant conditions of humidity. To be on the safe side, the lower rather than the average humidity on the building site should be used as a basis for the estimation. Moreover, due consideration should be paid to the fact that concrete behaves differently during the first period of drying and in any subsequent period.

It is believed that these results will even contribute to a better understanding of the mechanism of creep of concrete under simultaneous drying.

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Summary

Creep of cement mortar beams has been investigated while the beams were exposed to cyclic variations in the relative humidity of the surroundings. It was found that the first period of drying greatly increases the creep over the amount which is observed when specimens are stored constantly under the average humidity. During any subsequent period of drying after intermediate exposure to a higher relative humidity, the amount of creep is smaller than the creep observed when specimens are stored under constant average humidity.

It is a practical conclusion of the investigation that creep of concrete structures on building sites can be estimated from laboratory experiments only with difficulty. To be on the safe side, the lower rather than the average humidity on the building site should be used as a basis for an estimation. Moreover, due consideration should be paid to the fact that concrete behaves differently during the first period of drying and in any subsequent period.

Résumé

L'auteur a étudié le fluage de poutres en mortier de ciment, sous l'influence de variations cycliques de l'humidité relative de l'air.

Il a constaté qu'au cours de la première période de séchage, la valeur du fluage dépasse celle observée pour une humidité moyenne constante de l'air. En revanche, au cours de toutes les périodes de séchage suivantes, précédées d'une période intermédiaire s'écoulant sous une forte humidité de l'air, les phénomènes de fluage se révèlent plus faibles que sous les conditions moyennes constantes.

Ces investigations montrent que les études de laboratoire ne permettent que difficilement d'estimer le fluage qui doit se produire dans le béton, sur le chantier. Pour obtenir des résultats offrant quelque certitude, il est préférable de prendre pour base la teneur inférieure en humidité plutôt que la teneur moyenne. Il y a lieu d'autre part de tenir judicieusement compte du fait qu'au cours d'une première période de séchage, le comportement du béton est différent de celui que l'on constate dans les périodes suivantes.

Zusammenfassung

Es wurde das Kriechen von Balken aus Zementmörtel bei zyklischer Variation der relativen Luftfeuchtigkeit untersucht.

Es hat sich gezeigt, daß in der ersten Trockenperiode das Kriechen über das bei konstanter, durchschnittlicher Luftfeuchtigkeit beobachtete Maß ansteigt. Demgegenüber zeigen die folgenden Trockenperioden, denen jeweils eine Periode mit hoher Luftfeuchtigkeit voranging, daß hier die Kriecherscheinungen geringer sind als diejenigen bei konstanten mittleren Verhältnissen.

Die Untersuchungen zeigen, daß das Kriechen von Beton auf der Baustelle nur mit Schwierigkeiten im Laboratorium geschätzt werden kann. Um die Ergebnisse auf der sichern Seite abzuschätzen, soll eher der niedrigere als der durchschnittliche Feuchtigkeitsgehalt der Luft zugrunde gelegt werden. Zudem sollte der Tatsache, daß sich der Beton während einer ersten Trockenperiode anders verhält als in allen folgenden, gebührend Rechnung getragen werden.

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