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Creep and creep recovery of cement mortar

Das Kriechen und seine Rückbildung beim Zementmörtel

Fluência de uma argamassa de cimento e sua recuperação

Fluage d'un mortier de ciment et sa récupération

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Introduction

Creep tests have been made on cement mortar beams at the Swedish Cement and Concrete Research Institute. The relation between creep and creep recovery has been studied in accordance with the following hypothesis regarding the principle of superposition of time effects in concrete expressed by Douglas McHenry: [1]

> «The strains produced in concrete at any time t by a stress increment applied at any time t_0 are independent of the effects of any stress applied either earlier or later than t_0. The stress increment may be either positive or negative, but stresses which approach the ultimate strength are excluded.»

According to this principle, recovery following removal of load at the time t_2 is obtained by subtracting the creep curve for the loading applied at the time t_2 from the creep curve for the loading applied at the time t_1 (Fig. 1).

Making and Curing Test Specimens

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

Cement content (Standard Portland cement): 640 kg/m^3
Water-cement ratio: 0,35
Maximum size of the aggregate: 4 mm
Fineness modulus of the aggregate: 2,9.

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(1) Douglas McHenry: A New Aspect of Creep in Concrete and Its Application to Design, Proc., A. S. T. M., Vol 43, p. 1069 (1943).

36 beams, $2 \times 5 \times 40$ cm, were cast for the creep tests, 10 beams, $2 \times 5 \times 25$ cm, for determination of modulus of rupture, and 10 beams, $2 \times 5 \times 25$ cm, for determination of modulus of elasticity. The mortar was placed in steel moulds and was vibrated.

The beams were cured in water for 7 days, and were then kept in the room where the tests were performed. The temperature in the room was 20° C, and the relative humidity was 60 percent.

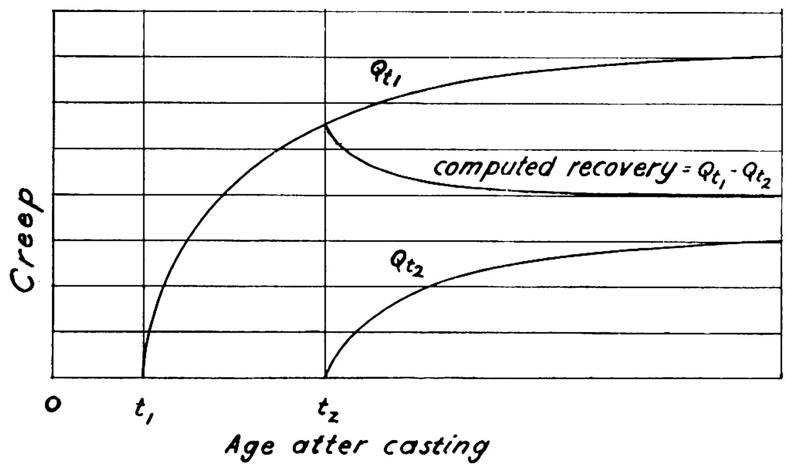

FIG. 1. Computation of creep recovery

Testing

The beams were subjected to a bending moment by means of weights and levers, see Fig. 2. The weights were adjusted so that the stress in each beam was 30-35 percent of the modulus of rupture of the 25-cm beams at the time of the first load application (Table 1).

Immediately after application or removal of load the deflection, W_0, was measured with a 0,01-mm gauge attached to each beam. Readings were taken at certain definite intervals during some months. The deflections caused by non-uniform shrinkage, W_s, were measured on control beams.

The modulus of elasticity at each application of load, E_0, was computed from the flexural frequency of the 25-cm beams (Table 1).

The creep due to unit load was computed from the following formula:

$$Q = \frac{W_t - W_s - W_o}{W_o \cdot E_o} = \frac{W_c}{W_o \cdot E_o}$$

where:

Q = creep due to unit load
W_t = total deflection at the time t after loading
W_c = deflection caused by creep

The creep recovery was computed in an analogous way.

No account was taken of the fact that creep occurs not only after, but also during application of load.

Results

Two tests, S and T, were made. Test S was started in November 1953 and Test T in September 1954. In each test 36 beams were loaded at different ages, see Table 1.

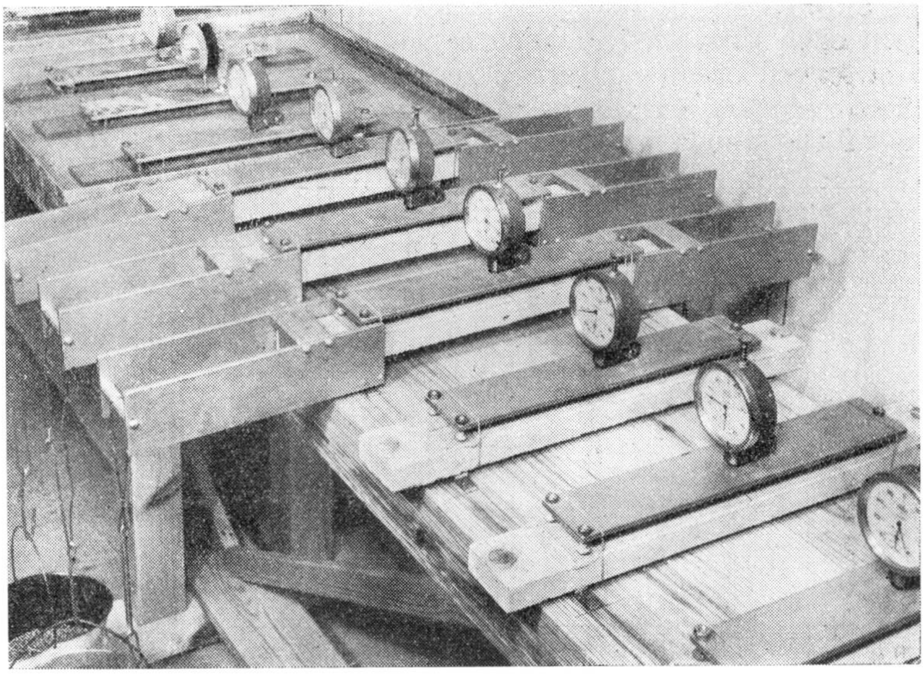

FIG. 2. Equipment used for creep tests

TABLE 1

Age at Loading, Modulus of Elasticity, and Stress.

TEST	S				T			
Series	SA	SB	SC	SD	TA	TB	TC	TD
Number of beams	12	9	6	3	12	9	6	3
Number of days in water ...	7	7	7	7	7	7	7	7
Number of days in air before loading	0	7	21	84	21	42	70	105
E_o,* 1000 kg/cm²	371	362	359	363	303	317	313	302
Modulus of rupture,** kg/cm²	67,6 (7 days in water and none in air)				75,0 (7 days in water and 21 in air)			
Stress, kg/cm²	22,5				22,5			

* E_o = Modulus of elasticity computed from flexural frequency at the 25-cm beams at each application of load. Each value is the average of ten tests.

** Modulus of rupture of the 25-cm beams, determined at the time of load application in the series *A*. Each value is the average of ten tests.

Each application of load was accompanied by removal of load from 3 beams in each previously loaded series.

The observed creep and creep recovery curves are shown in Figs. 3 and 4. The recovery curves were also computed from the creep curves by means of the above principle.

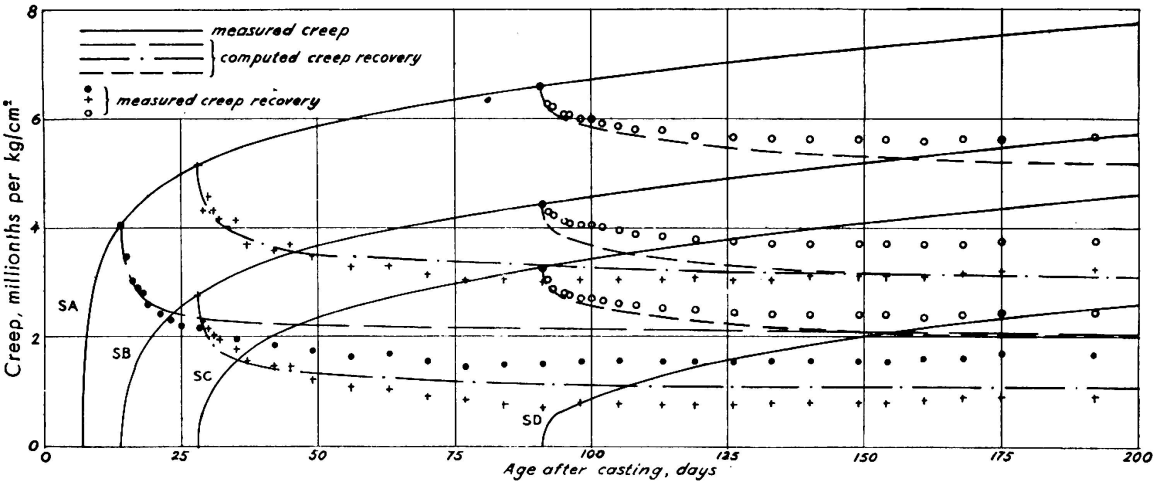

FIG. 3. Creep and creep recovery, series S

The shape of the creep curves in the two tests is not the same, although the mix proportions and the curing conditions were identical (cf. the curves *SC* and *TA*), nor was the consistency of the mortar the same. The reason is probably that both sand and cement stocks were renewed before the casting of the beams of series *T*.

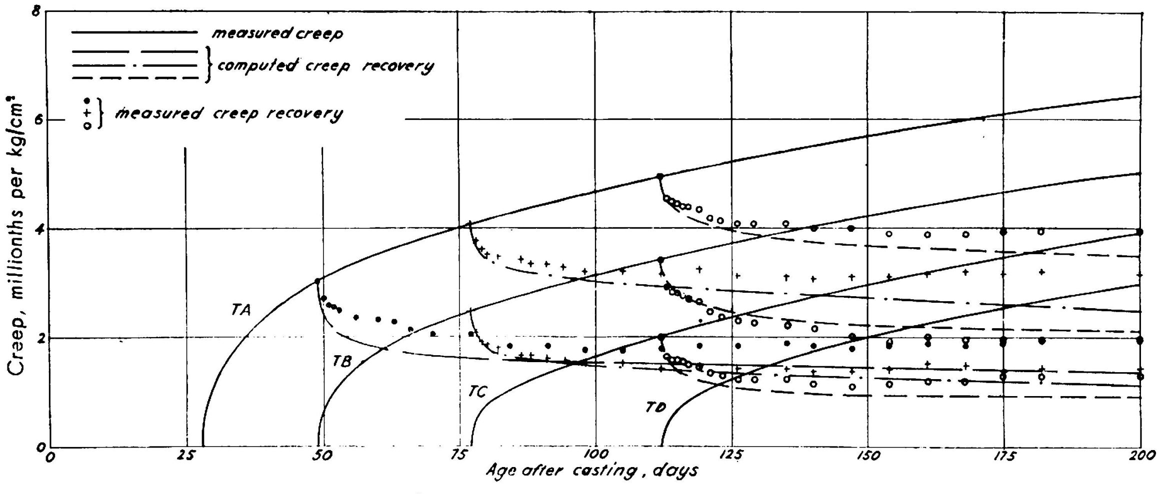

FIG. 4. Creep and creep recovery, series T

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Creep Equation

Creep tests have also been made on cement mortar beams of varying composition. All the creep curves were satisfactorily defined by the following equation, suggested by McHenry.

$$Q = a\,(1-e^{-rt}) + be^{-pk}\,(1-e^{-mt})$$

where:

Q = creep due to unit load,
k = age at time of loading,
t = time after loading,
e = base of natural logarithms, and,
a, b, r, p, m = constants which must be determined from laboratory tests.

In the tests the age at the time of loading was always 28 days, i. e. the expression $b \cdot e^{-pk}$ is replaced by a constant c.

The creep curves S and T, which refer to varying age at the time of loading, were also defined by the above equation:

$$S: \quad Q = 4{,}15\,(1 - e^{-0{,}006t}) + c\,(1 - e^{-0{,}2t})$$
$$T: \quad Q = 6{,}00\,(1 - e^{-0{,}006t}) + 5{,}20 \cdot e^{-0{,}025k}\,(1 - e^{-0{,}2t})$$

where t and k are expressed in days and the unit of Q is one millionth per kg/cm^2.

In the curves S the influence on creep of the age at the time of loading is not defined by $b \cdot e^{-pk}$, but, at the chosen values of the constant c, the accuracy of the equation is good (see Fig. 5).

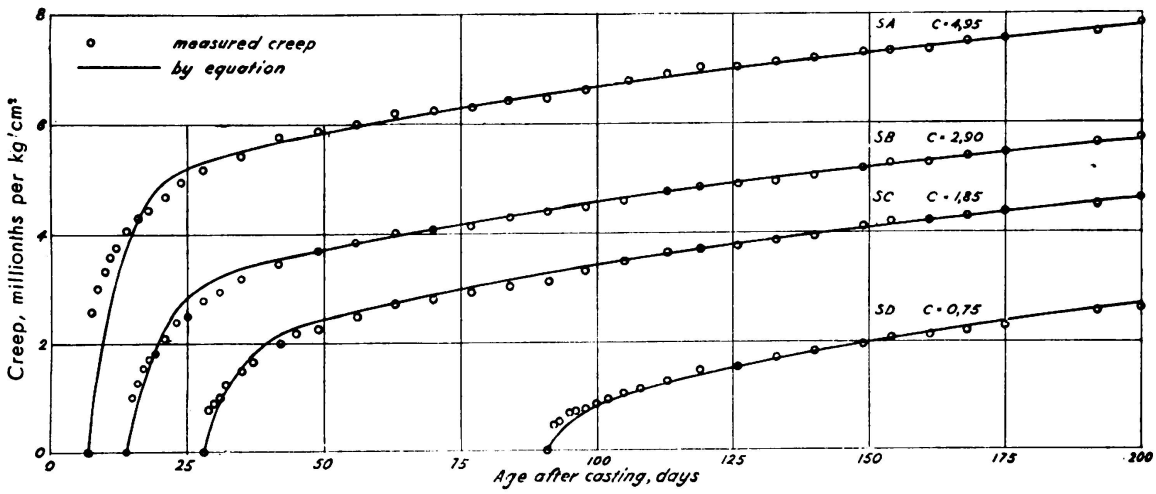

FIG. 5. Creep curves, series S

In the curves TA, TB, and TC the accuracy is good but TD is not satisfactorily defined (see Fig. 6).

Unfortunately the tests were finished too early. If they had been continued till the creep was close to its ultimate value, the accuracy of the chosen constants could have been better estimated.

Conclusions

These tests are to be regarded as preliminary only, but there is no doubt that the principle of superposition is worth studying and that the equation used is well adapted for defining creep curves.

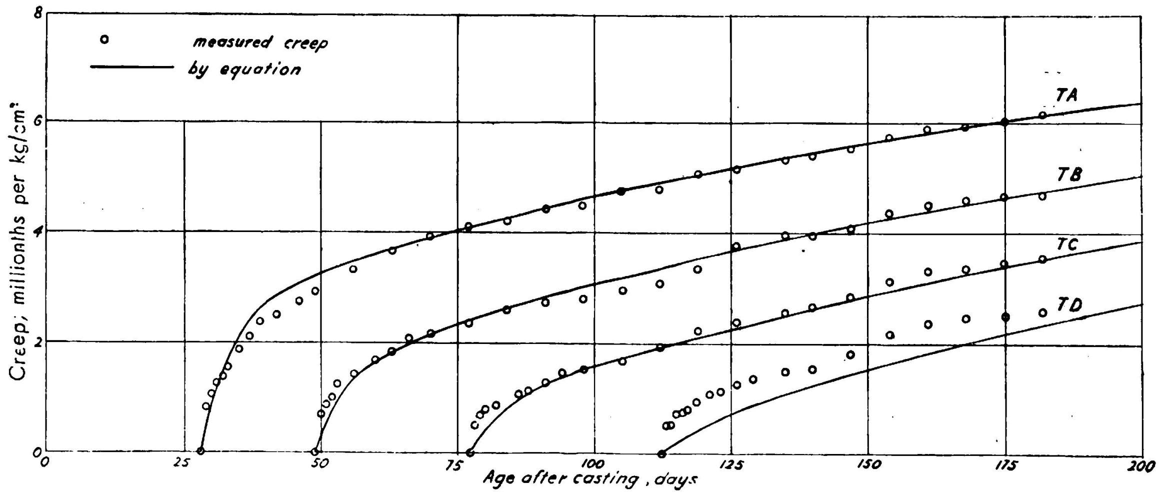

FIG. 6. Creep curves, series T

SUMMARY

Cement mortar beams have been loaded at different ages. Each time load was applied, the loads were removed from some beams in each previously loaded series. Creep and creep recovery were measured. Moreover, creep recovery was computed by means of a principle of superposition stated by Douglas McHenry. The creep curves were defined by an equation suggested by McHenry.

ZUSAMMENFASSUNG

Die Untersuchungen wurden mit gleichzeitig hergestellten Balken aus Zementmörtel durchgeführt. Einerseits erfolgte das Aufbringen der Last auf die einzelnen Balkenserien in verschiedenem Alter, anderseits wurde jeweils in diesen Zeitpunkten ein Teil der früher belasteten Balken bereits wieder entlastet. Die Messungen bezogen sich auf das Kriechen und seine Rückbildung. Daneben wurde die Rückbildung mit Hilfe der Superpositionsmethode nach Douglas McHenry berechnet. Die Kriechkurven liessen sich durch eine von McHenry entwickelte Gleichung darstellen.

RESUMO

Carregaram-se várias vigas de argamassa de betão de idades diferentes. Sempre que a carga era aplicada, retiravam-se as cargas de algumas vigas em cada série anteriormente carregada. Mediram-se a fluência e sua recuperação; esta recuperação foi também calculada pelo princípio de sobreposição definido por Douglas McHenry. As curvas de fluência foram estabelecidas utilizando uma equação sugerida por McHenry.

RÉSUMÉ

On a chargé, à différents âges, un certain nombre de poutres en mortier de béton. Chaque fois que la charge était appliquée on déchargeait quelques poutres dans chacune des séries déjà mises en charge. On a mesuré le retrait et sa récupération; cette récupération a été également calculée par le principe de superposition défini par Douglas McHenry. Les courbes de fluage ont été établies en utilisant une équation suggérée par McHenry.

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