CREEP OF CONCRETE AT DIFFERENT TEMPERATURES

By

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1. Introduction

Deformation due to creep is an important characteristic of concrete in reinforced concrete structures under permanent load. In prestressed concrete structures it has to be taken into consideration as one of the causes of prestress loss, in hyperstatic reinforced concrete structures it is partly responsible for the redistribution of stresses and in mass concrete and reinforced concrete structures with interior stresses it influences the development of harmful cracks.

The rate of concrete creep depends on many factors. The effects of these parameters are more or less known. Among them temperature also has a great importance, however, its effect on creep is not yet sufficiently clarified experimentally or theoretically.

2. Composition of the test concrete

The quality of the tested concrete was B 400—10/7, the cement used C 500 PC (brand DCW), cement dosage of the concrete 396/kg/m^3 and w/c ratio 0.59. Aggregate: Ia Danube sandy gravel $d_{\max} = 10$ mm and $m = 4.29$. Density of the green mix $= 2345$ kg/m^2.

The hand mixed specimens were cast in steel forms and compacted on a vibrating table. They were kept 7 days in a humid ambient and subsequently under water until the test.

3. Experimental

For testing creep of concrete specimens, special apparatuses actuated by springs were developed earlier. The frame size of these apparatuses is $400 \times 400 \times 1590$ mm, see Fig. 1.

Loading of specimens in the spring apparatuses was carried out by a portable hydraulic equipment, see Fig. 2.

This equipment has been developed at our department.

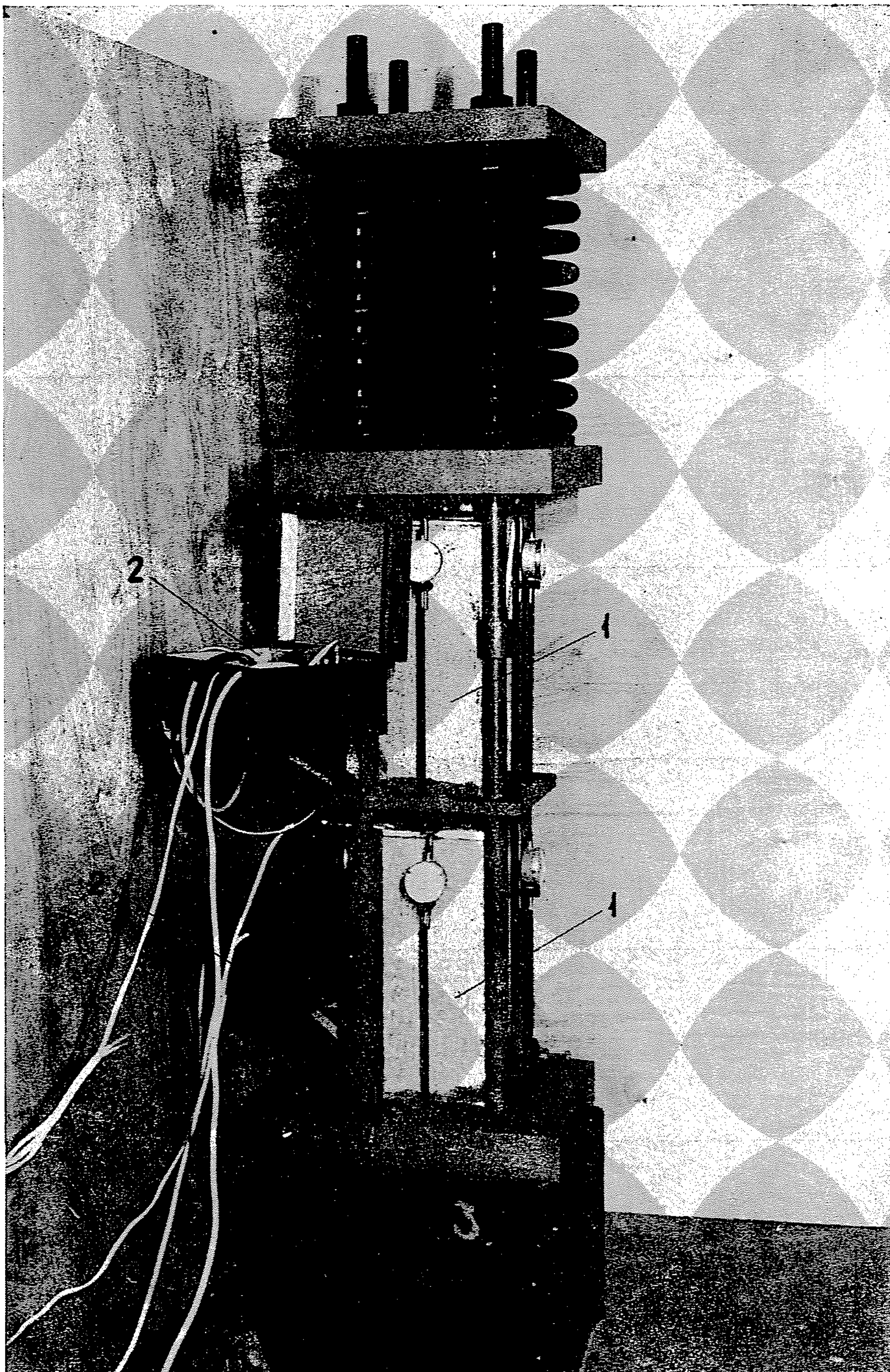

Fig. 1. One of the special spring sets. 1 — tank with specimen; 2 — thermostat

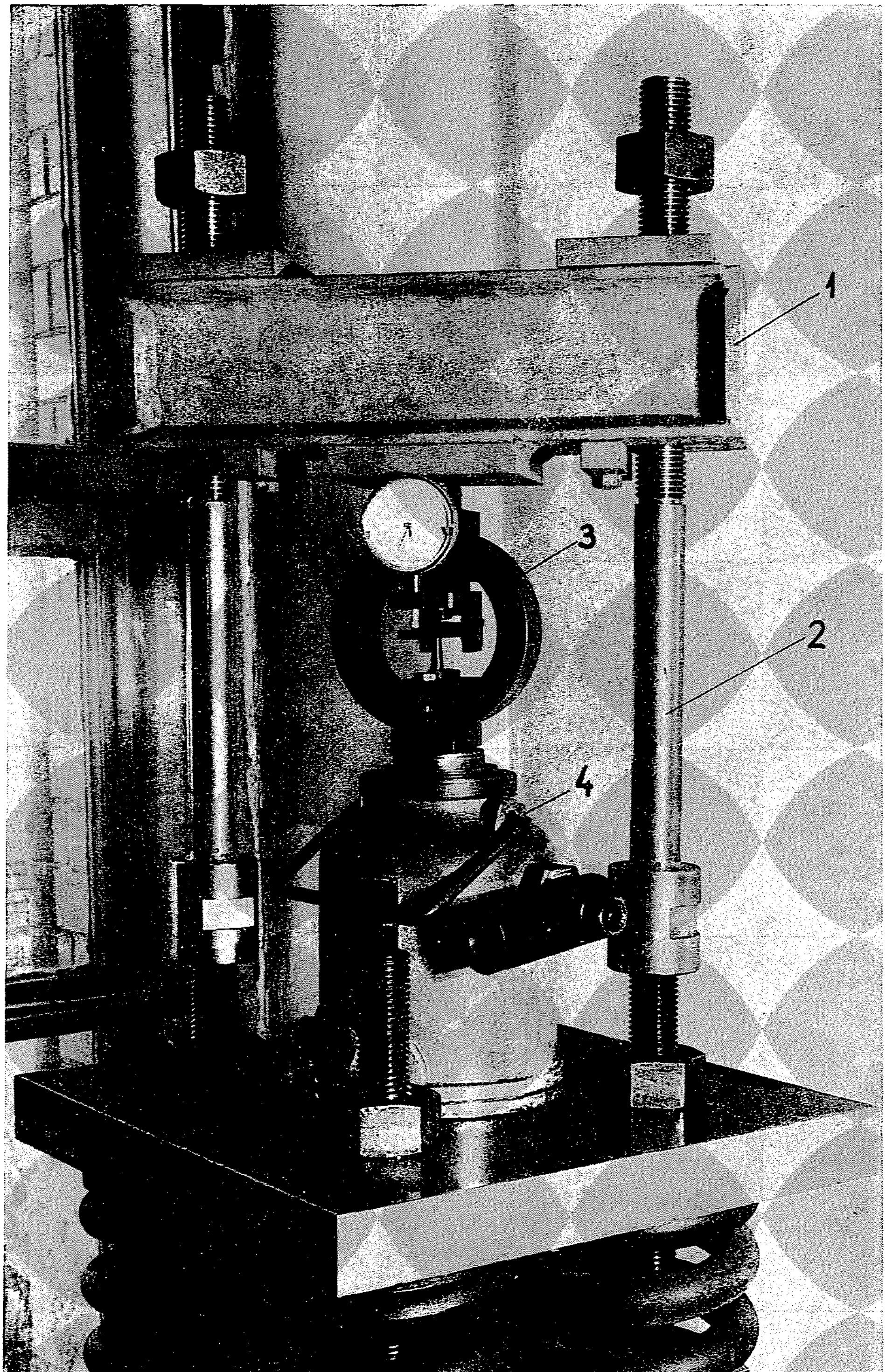

Fig. 2. Portable hydraulic device used for loading the specimens. 1 — support; 2 — tension bar; 3 — dynamometer; 4 — hydraulic lever

For better bearing, 8×120×120 mm steel plates were placed at the end faces of the specimens.

The compressive load was applied through steel plates size 20×120×120 mm, by means of steel balls in the geometric centre of the plates (specimens).

The diameter of the springs was 150 mm, their height 450 mm, each spring thread had a diameter of 30 mm. The load bearing capacity of the springs was 4.5 Mp. Each set had four springs. There were four sets and two specimens were tested simultaneously in each.

The specimens were kept in water-filled tanks during the test. The temperature of the water and of the specimens was kept during the entire test time on a determined constant value by means of a special, electric, submerged boiler and electronic thermostat (Fig. 3).

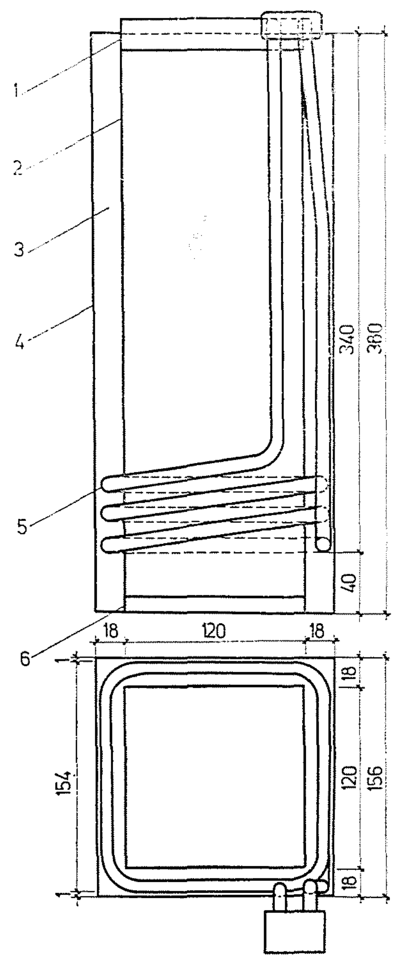

Fig. 3. The tank and the immersion heater; 1 — top steel plate; 2 — specimen; 3 — water space; 4 — tank of zinc plate; 5 — immersion heater; 6 — bottom steel plate

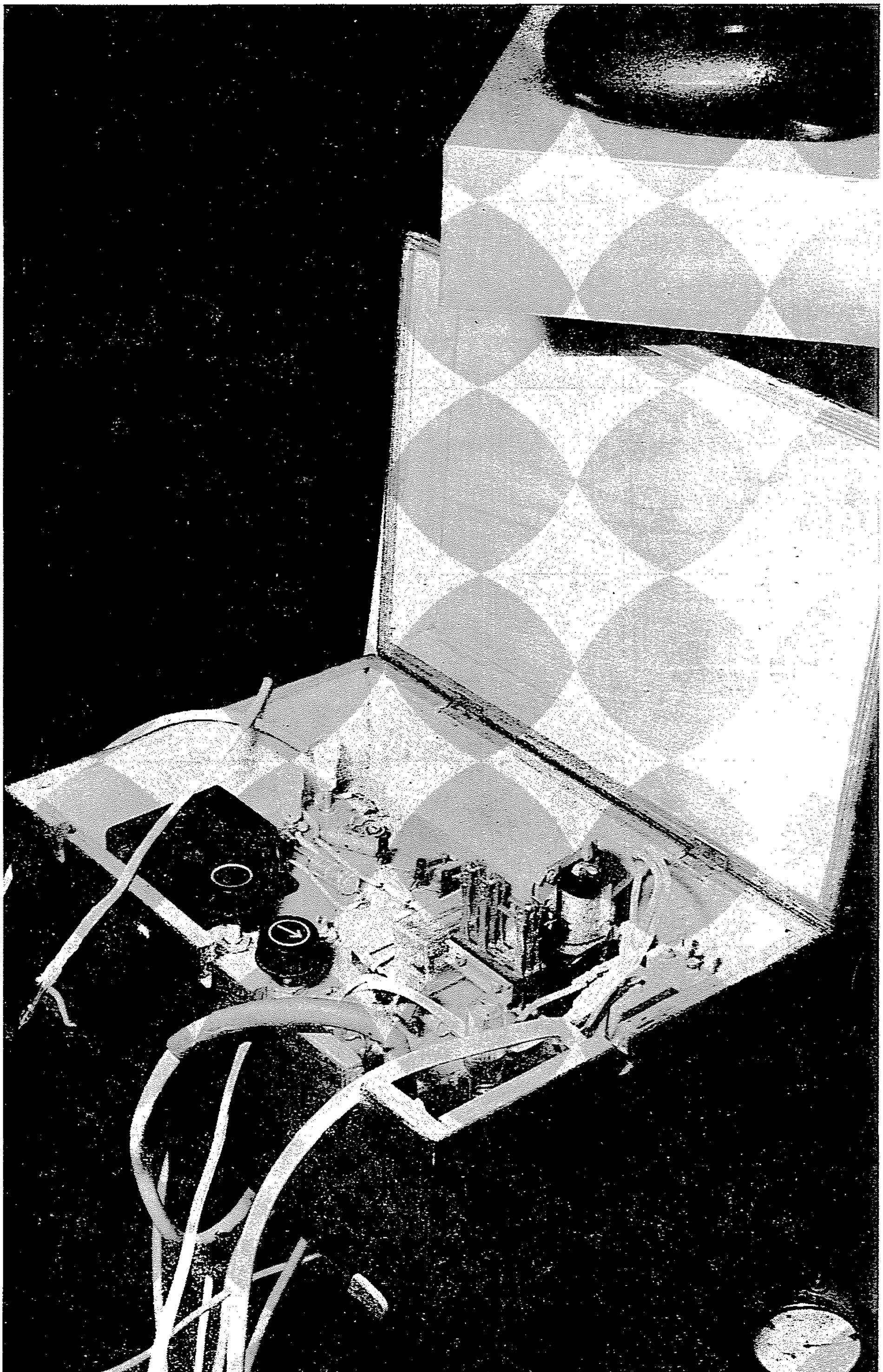

Fig. 4. Picture of the thermostat and its elements

The thermostat of a sensitivity of ± 1°C controlled by a thermistor kept constant the temperature of water in the tank by switching on and off an immersion heater. The elements and the scheme of the control device are shown in Figs 4 and 5.

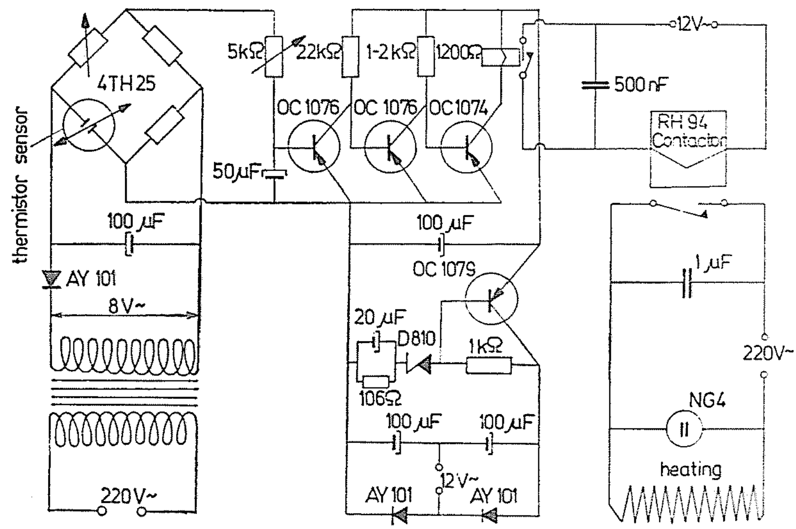

Fig. 5. Circuit diagram of the thermostat

Indicating dials were mounted on protruding supports all four sides of each specimen with a basis length of 36 cm (the complete height of the specimen). Sensitivity of the indicators is 0.01 mm. This arrangement allows a longitudinal deformation accuracy of $2.78 \cdot 10^{-5}$. The measuring equipment is shown in Fig. 6.

To study concrete creep, the experiments were carried out at constant stresses and different temperatures, viz: 26, 40, 60 and 80°C, on specimens of $12 \times 12 \times 36$ cm size, two for each temperature.

The temperature values were chosen as about room temperature of 26°C; 80°C under the boiling point of water (about steam curing) and two intermediate values, 40 and 60°C.

All specimens were loaded in the spring sets at 10 months of age, the hydration rate of concrete has practically steadied thus the physical and mechanical properties of concrete did not change with time.

Static loading was applied by gradually increasing the compressive force and at each force increment the instantaneous longitudinal deformation values were read. So at each temperature the initial E-modulus, the elastic deformation of the water saturated concrete have been determined.

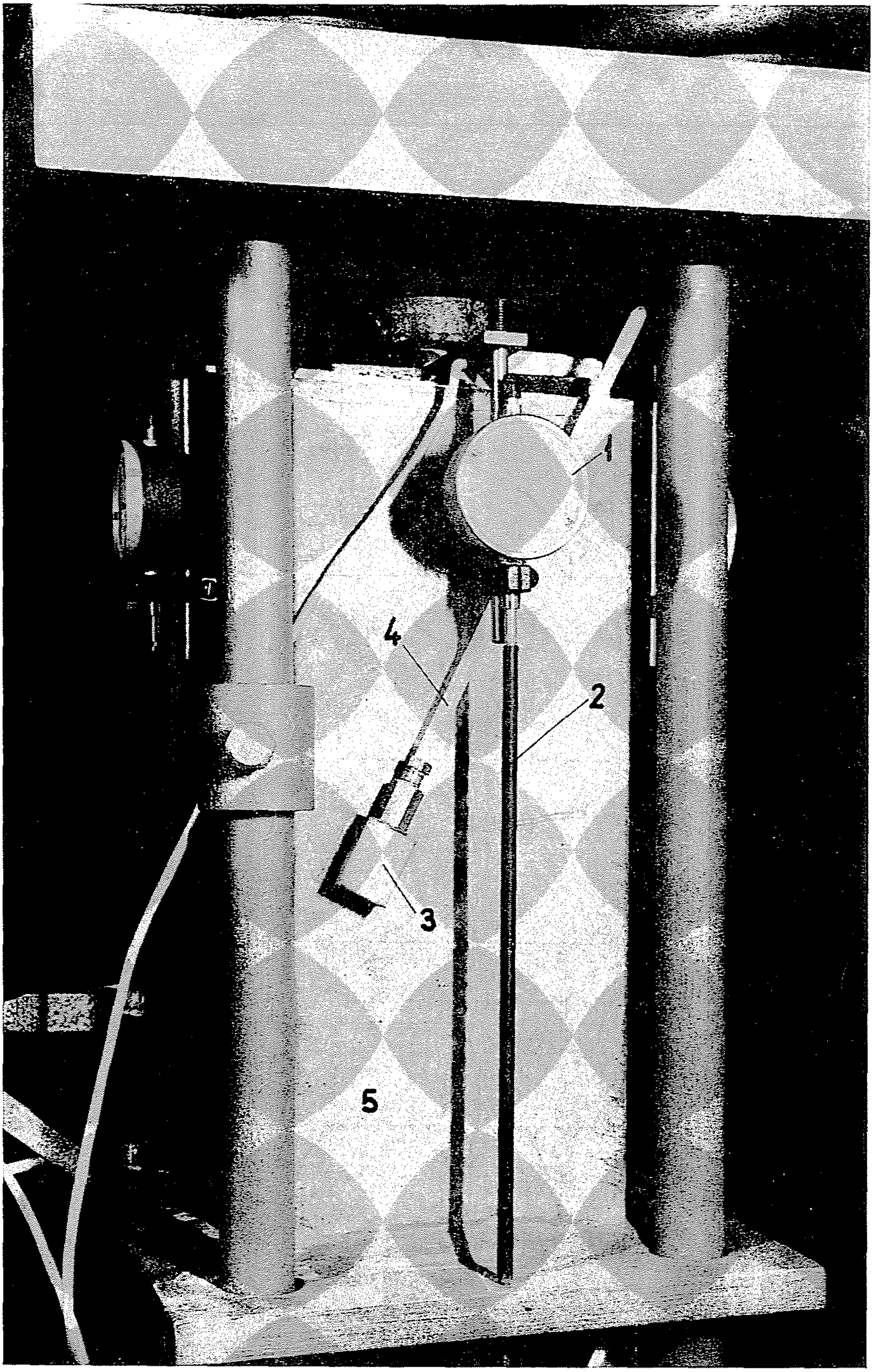

Fig. 6. Specimen and its fittings during the test. 1 — dials on protruding supports: 2 — steel rod for gauging; 3 — connection of the control thermometer: 4 — thermometer; 5 — tank with specimen and water

Table 1

Overall specific deformation $\varepsilon(T, t-\tau)10^{-4}$ of the specimens

Temperature °C	σ kp/cm²	$\frac{\sigma}{\sigma_p}$	Specimen No.	Observation		
				0	2	5
26	15.3	0.053	1	1.27	1.48	1.58
			2	1.41	1.75	1.84
40	31.2	0.111	1	3.24	3.97	4.21
			2	3.45	4.24	4.52
60	45.8	0.168	1	5.11	6.35	6.67
			2	5.74	6.63	6.98
80	62.8	0.236	1	7.02	8.65	9.23
			2	7.30	9.04	9.48

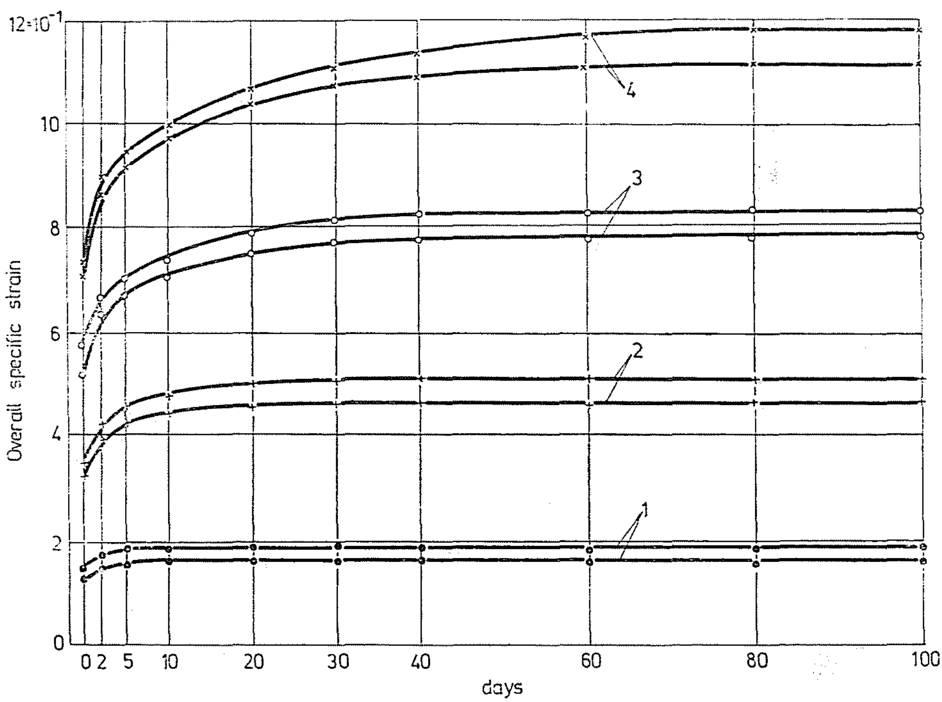

Fig. 7. Overall specific deformation of concrete specimens under constant stresses and at different temperatures $\varepsilon(T, t-\tau)10^{-4}$. 1 σ; 15.3 kp/cm²; $T = 26$°C; 2 σ; 31.2 kp/cm²; $T = 40$°C; 3 σ; 45.8 kp/cm²; $T = 60$°C; 4 σ; 62.5 kp/cm²; $T = 80$°C

under constant stresses and at different temperatures

time in days						
10	20	30	40	60	80	100
1.65	1.65	1.65	1.65	1.65	1.65	1.65
1.88	1.90	1 90	1.90	1.90	1.90	1.90
4.42	4.60	4.65	4.65	4.65	4 .65	4.65
4.74	4.98	5.11	5.11	5.11	5.11	5.11
7.06	7.53	7.74	7.80	7.82	7.83	7.83
7.38	7.89	8.19	8.33	8.35	8.37	8.37
9.69	10.37	10.79	10.99	11.10	11.12	11.12
9.96	10.64	11.11	11.45	11.75	11.80	11.84

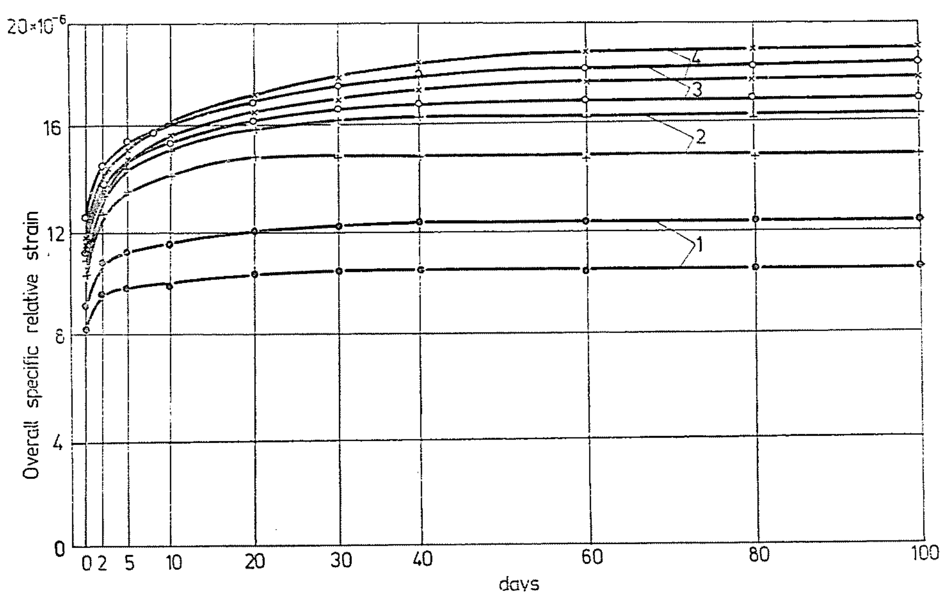

Fig. 8. The overall specific relative deformation of concrete specimens under constant stresses and at different temperatures $\delta(T, t - \tau) \cdot 10^{-6}$ $(\text{kp/cm}^2)^{-1}$; 1 — 26°C; 2 — 40°C; 3 — 60°C; 4 — 80°C

4. Test results

The experimental system provided for measuring and computation of the overall deformation and the specific creep of concrete.

Complete specific deformations obtained in the concrete tests have been compiled in Table 1 and plotted in diagrams of Fig. 7. In Fig. 8 the curves of

Table 2

Overall specific relative deformations $\delta(T, t-\tau)10^{-6}(\text{kp/cm}^2)^{-1}$ of specimens at different temperatures

Temperature, °C	Specimen No	Observation time in days									
		0	2	5	10	20	30	40	60	80	100
26	1	8.30	9.33	9.81	10.12	10.47	10.57	10.57	10.57	10.57	10.57
	2	9.22	10.64	11.16	11.57	12.09	12.39	12.39	12.39	12.39	12.39
40	1	10.38	12.56	13.38	14.00	14.60	14.82	14.82	14.82	14.82	14.82
	2	11.05	13.47	14.41	15.18	15.98	16.32	16.38	16.38	16.38	16.38
60	1	11.12	13.80	14.62	15.40	16.21	16.67	16.88	17.00	17.06	17.06
	2	12.51	14.48	15.34	16.10	16.92	17.50	17.91	18.20	18.26	18.26
80	1	11.22	13.60	14.62	15.56	16.47	17.08	17.40	17.70	17.85	17.85
	2	11.68	14.28	15.24	16.07	17.16	17.88	13.38	18.88	18.97	18.97

Table 3

Specific relative creep $C(T, t-\tau) \cdot 10^{-6}$ $(\text{kp/cm}^2)^{-1}$ at different temperatures

Temperature °C	Specimen No	Observation time in days									
		0	2	5	10	20	30	40	60	80	100
	1	0	1.03	1.51	1.82	2.17	2.27	2.27	2.27	2.27	2.27
26	2	0	1.42	1.94	2.35	2.87	3.17	3.17	3.17	3.17	3.17
	average	0	1.225	1.625	1.085	2.520	2.720	2.720	2.720	2.720	2.720
	1	0	2.18	3.00	3.62	4.22	4.44	4.40	4.44	4.44	4.44
40	2	0	2.42	3.36	4.13	4.93	5.27	5.33	5.33	5.33	5.33
	average	0	2.300	3.180	3.875	4.575	4.855	4.855	4.855	4.855	4.855
	1	0	2.68	3.50	4.28	5.09	5.55	5.76	5.88	5.94	5.94
60	2	0	1.97	2.83	3.59	4.41	4.99	5.40	5.69	5.75	5.75
	average	0	2.235	3.165	3.935	4.750	5.270	5.580	5.785	5.845	5.845
	1	0	2.38	3.40	4.34	5.25	5.86	6.18	6.48	6.63	6.63
80	2	0	2.60	3.56	4.39	5.48	6.20	6.70	7.20	7.29	7.29
	average	0	2.490	3.480	4.365	5.365	6.030	6.440	6.840	6.960	6.960

the overall specific relative deformations referred to unit stresses in the specimens are seen. The corresponding numerical data are given in Table 2.

Knowing the specific elastic deformations, the specific relative creep is given by:

$$\delta(T, t-\tau) = \frac{1}{E(T)} + C(T, t-\tau) . \tag{1}$$

Table 4

Limit values $\varphi(T) \cdot 10^{-6}$ (kp/cm^2)$^{-1}$ of concrete creep rate, at different temperatures

Limit value of creep	Specimen No	Temperature T°C			
		26	40	60	80
$\varphi(T) \cdot 10^{-6}$ (kp/cm^2)$^{-1}$	1	2.27	4.44	5.75	6.63
	2	3.17	5.33	5.94	7.29
	average	2.72	4.88	5.84	6.96

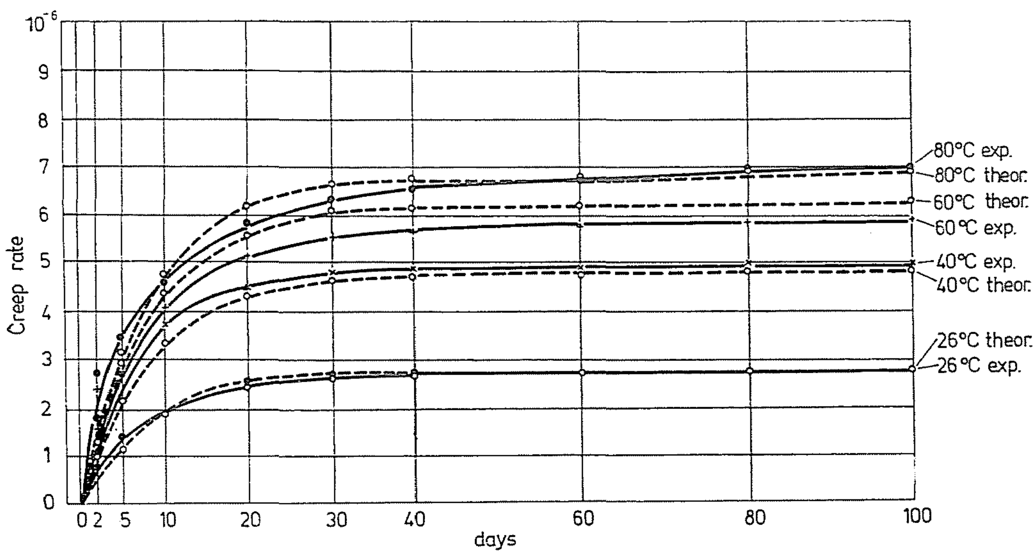

Fig. 9. The specific relative creep of concrete specimens (rate of creep) under constant stresses and at different temperatures; $C(T, t - \tau) \cdot 10^{-6}$ (kp/cm^2)$^{-1}$
——— experimental.
- - - - - theoretical

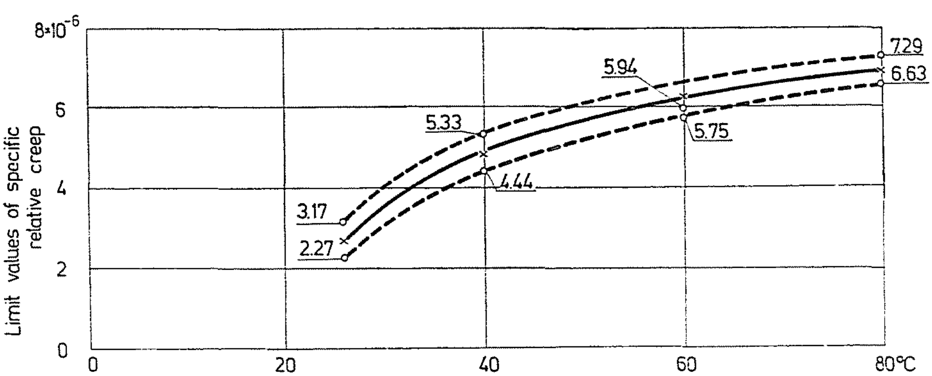

Fig. 10. Limit values of specific relative concrete creep $\varphi(T)$ vs. temperature T:
- - - - - experimental;
——— theoretical

The obtained deformations, namely the creep data expressed by the formula $C(T, T - \tau)$ are given in Table 3.

$C(T, t - \tau)$ curves of average deformations from two specimens each have been plotted in Fig. 9.

Limit values of creep rate $\varphi(T)$ from Table 3 have been compiled in Table 4 and plotted in diagrams of Fig. 10.

In Fig. 10 the test values for $\varphi(T)$ are indicated by circles and numbers, the variance range by dotted line.

Fig. 10 shows limit values of concrete creep rate $\varphi(T)$ to markedly increase with increasing temperature. Thus, upon increasing concrete temperature by 54°C (from 26°C to 80°C), mean limit values of creep $\varphi(T)$ increased to 2.5 times and reached the value $6.83 \cdot 10^{-6}(\text{kp/cm}^2)^{-1}$, in relation to $2.72 \cdot 10^{-6}(\text{kp/cm}^2)^{-1}$ at the basic temperature.

5. Theoretical processing of experimental data

The theoretical processing is based on the possibility to express creep $C(T, t - \tau)$ of concretes at different temperatures by mathematical relationships. A hypothesis has been adopted for the particular affinity of the $C(T, t - \tau)$ curves compared to the experimental temperature T. According to this assumption for $C(T, t - \tau)$ the following formula was accepted:

$$C(T, t - \tau) = f(T)\ C(26, t - \tau) \tag{2}$$

where $f(T)$ = a given function of temperature, determining the affine similarity character of $C(T, t - \tau)$ curves and specific relative creep $C(26, t - \tau)$ at the basic concrete temperature 26°C.

A formula suitable for describing the $C\ (26, t - \tau)$ curve:

$$C(26, t - \tau) = \varphi(26)[1 - e^{-\gamma(t-\tau)}] \tag{3}$$

where $\varphi(26)$ is the limit value for creep $C(26, t - \tau)$.

The condition of best approximation of the experimental curves (Fig. 9) yielded the following parameter values:

$$\varphi(26) = 2.72 \cdot 10^{-6}\ (\text{kp/cm}^2)^{-1} \tag{4}$$

$$\gamma = 0.12\ (\text{day})^{-1}. \tag{5}$$

According to experimental data, function $f(T)$ was chosen in the form

$$f(T) = (1 + g) - g \cdot e^{-\beta(T-26)}$$

where g and β are experimental values.

Taking earlier statements for the rate of creep $C(T, t - \tau)$ and for limit value $\varphi(T)$ into account:

$$C(T, t - \tau) = \varphi(T)\ C(t - \tau) \tag{6}$$

where

$$C(t - \tau) = 1 - e^{-\gamma(t-\tau)} \tag{7}$$

and

$$\varphi(T) = \varphi(26)[(1 + g) - ge^{-\beta(T-26)}]. \tag{8}$$

where $\varphi(26)$ — the limit value of creep of the specimen at basic temperature 26°C,

T — concrete temperature in °C.

g and β — constants as in (5).

Values g and β from the condition of best approximation of experimental mean values for $\varphi(T)$:

$$\begin{aligned} \varphi(26) &= 2.72 \cdot 10^{-6}\ (\mathrm{kp/cm^2})^{-1} \\ g &= 1.65 \\ \beta &= 0.045(°\mathrm{C})^{-1}\,. \end{aligned} \tag{9}$$

Approximate results plotted in a continuous line (Fig. 10) are in a good agreement with the mean curve of experimental $\varphi(T)$ values.

In final account formulae (6), (7), (8) and the test data yield:

$$C(T, t - \tau) = \varphi(26)\left\{1 + g[1 - e^{-\beta(t-26)}]\right\}[1 - e^{-\gamma(t-\tau)}]\,. \tag{10}$$

Values computed by Eq. (10) plotted in Fig. 9 show the closeness of approximation to be acceptable.

Summary

Analysis of the experimental results showed unambiguously that creep of water saturated concrete markedly increases with rising temperature. When raising the temperature of the given concrete from 26 to 80°C, end value of creep has grown to the 2.5 fold.

Theoretically obtained concrete creep curves showed an affinity between ambient and different higher temperatures, a formula being suggested for expressing, and another for approximating experimental creep curves.

Research results for the tested B 400—10/7-grade concrete gave parameter values likely of use for determining similar values experimentally for other quality concretes.

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