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by
MILOS POLIVKA

Report to
Department of Water Resources
State of California

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State of California

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on

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INTRODUCTION

This report gives the results of a study on the early-age creep characteristics of a lean mass concrete mix containing only two sacks of cementing material per cubic yard of concrete. The creep tests were carried out at 70° F up to an age of 90 days. Based on these results, creep data are predicted up to 999 days after loading. One each of three 16 by 44-in. mass-concrete creep specimens were loaded at ages of 3, 7, and 28 days. An unloaded fourth specimen was used as a control. Figure 1 shows these four specimens during the creep test.

Preliminary concrete studies including material selection and mix proportions were accomplished at the Concrete Laboratory of the Department of Water Resources in Sacramento. The creep studies themselves were conducted at the Engineering Materials Laboratory of the University of California, Berkeley.

CONCRETE MIX

The mass-concrete mix employed in the creep study contained 2 sacks of cementing material per cubic yard and gravel aggregate of maximum size 4 1/2 in. Compressive strengths were determined on a mix of the same proportions as the mass mix but from which the plus 3-in. gravel fraction was omitted. The cementing material (2 scy) contained 63 per cent of Calaveras Type II portland cement (1 1/4 scy) and 37 per cent of Basalt pozzolan (3/4 scy). Both an air-entraining and a water-reducing admixture were employed to improve the workability and to reduce the water content of the mix. The ratio of sand to total aggregate was 0.22 by weight and the water-cement ratio, 0.80 by weight. Nominal slump was 1 3/4 in. and the air content of concrete wet-screened through a 1 1/2-in. sieve was 4.3 per cent. The unit weight of the mass mix was 157.5 pcf and of the wet-screened mix, 150.6 pcf.

All concrete materials were supplied by the Sacramento Laboratory of the Department of Water Resources. The quantities of materials (on a saturated surface-dry basis) per cubic yard of mass concrete are given in the following tabulation.

Ingredient	Dept. of Water Resources Laboratory Designation	Quantity per cubic yard, lb.
Water	- - -	150
Cement--Calaveras Type II	60 C 265	118
Pozzolan--Basalt	60 C 290	70
Sand--Dry Creek	60 C 147	885
Coarse Aggregate--Oroville Dredger Trailings	57 C 291-4	3161
TOTAL		4384
Air Entraining Agent--Durair	58 C 126	50 ml
Water-Reducer--Orzan KRL-40	60 C 250	0.75 lb.

The gradation of sand and of coarse aggregate are given in the following tabulation.

SAND	Sieve Size:	Pan	No. 100	No. 50	No. 30	No. 16	No. 8
	Per cent Retained:	3	11	29	26	16	15

Fineness Modulus = 2.86.

COARSE AGGREGATE	Sieve Size:	No. 4	3/8 in.	3/4 in.	1 1/2 in.	3 in.
	Per cent Retained:	5	17	25	26	27

All material would pass a 4 1/2 in. sieve.

MANUFACTURE OF SPECIMENS

The aggregates necessary for the manufacture of creep specimens and compressive-strength specimens were batched at the Sacramento Laboratory of the Department of Water Resources and shipped in sealed drums to Berkeley. Cement and pozzolan were batched in Berkeley. Each batch was to produce 5.2 cu. ft. of concrete. All batches were stored at 70° F prior to mixing.

Four 16 by 44-in. cylindrical creep specimens and twelve 9 1/2 by 14-in. compressive-strength specimens were cast on September 13, 1960. Casting was started at 10 a.m. and completed at 2 p.m. Concrete temperature during casting was 70° F. Concrete for creep specimens was placed in 16-gage metal molds lined with fabric-reinforced seamless butyl rubber sleeves 1/8 in. thick. These sleeves remained on the specimens throughout the creep study to provide a moisture seal. To facilitate instrumentation and proper concrete placement, the 16 by 44-in. sheet-metal molds were made in two sections. All compressive-strength specimens were cast in tin cans provided with lids which were sealed by soldering immediately after casting. Internal vibration was employed during the casting of all specimens to insure proper compaction. To insure good contact between capping plate and the concrete of creep specimens, a thin conical-shaped layer of mortar was formed on the top of each specimen after casting was completed. About two hours later, when water-gain had ceased, steel capping plates were lowered onto the specimens and worked back and forth until mortar appeared uniformly around the circumference. The upper ends of the butyl-rubber sleeves were then bonded and banded to these capping plates to complete the moisture seal (Figure 2).

Sheet-metal molds were stripped from the creep specimens at the age of one day, and the specimens were left stored at 70° F. All compressive-strength specimens remained in the sealed cans and were stored in fog room at 70° F until age of test.

INSTRUMENTATION

Strain Measurement

Carlson strain meters (10-in. gage length) were employed to measure both axial and lateral deformations during creep. Each 16 by 44-in. specimen contained three meters, two mounted axially and one transversely. The meter locations in the specimens are shown in Figure 2.

Load Control

The load-control system employed was that developed at the University of California for creep studies of mass concrete. A pressure supply and control system was used to load one 16 by 44-in. creep specimen with a stress of 150 psi from the age of 3 days to the age of 90 days. Second system was used to load the second creep specimen with a stress of 230 psi from the age of 7 days to the age of 90 days, and a third system provided the third creep specimen with a stress of 650 psi from the age of 28 days to the age of 90 days. The applied stresses for all creep specimens were about 40 per cent of their compressive strengths at their respective ages of loading.

Details of the loading frames are shown in Figure 2. An over-all view of the specimens used in this creep study is shown in the photograph of Figure 1.

RESULTS

Compressive Strength and Elastic Properties

Compressive strengths were determined on 9 1/2 by 14-in. specimens made with a concrete mix from which the plus 3-in. gravel fraction was omitted. Three specimens were tested at each age, and the average values are given in Table 1. Also shown in this table are the instantaneous strains and the computed moduli of elasticity as determined on the 16 by 44-in. creep specimens during the application of the load.

TABLE 1--COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES

Age, days	Compressive Strength, psi	Instantaneous Strain, 1/E, millionths per psi	Modulus of Elasticity, E, psi
3	385	1.00	1.0×10^6
7	595	0.62	1.6×10^6
28	1630	0.40	2.5×10^6
90	2680	--	---

Strains up to Age 90 Days

Total axial and lateral strains (1/E plus creep) measured up to age 90 days are shown in Figure 3. Values of strain at selected ages, along with the computed Poisson's ratios, are given in Table 2

TABLE 2--STRAINS AND POISSON'S RATIOS AT SELECTED AGES

Age of Concrete After Loading, days	$\frac{1}{E}$ + Creep, millionths per psi								
	Age at Loading -- Sustained Stress								
	3 da--150 psi			7 da--230 psi			28 da--650 psi		
	Axial	Lateral	Poisson's Ratio*	Axial	Lateral	Poisson's Ratio*	Axial	Lateral	Poisson's Ratio*
Instant.	1.00	1.10	0.10*	0.62	0.13	0.21*	0.40	0.06	0.15*
1	1.05	0.10	0.10	0.66	0.13	0.20	0.42	0.06	0.14
3	1.11	0.12	0.10	0.71	0.14	0.20	0.44	0.06	0.14
7	1.16	0.12	0.10	0.75	0.15	0.20	0.46	0.07	0.15
14	1.21	0.13	0.10	0.78	0.15	0.19	0.48	0.07	0.15
21	1.24	0.13	0.11	0.81	0.15	0.19	0.49	0.07	0.14
28	1.26	0.13	0.10	0.82	0.16	0.19	0.51	0.07	0.14
42	1.30	0.14	0.11	0.85	0.16	0.19	0.52	0.07	0.13
56	1.31	0.14	0.11	0.86	0.17	0.20	0.52	0.07	0.13
70	1.33	0.14	0.11	0.88	0.17	0.20			
84	1.35	0.14	0.11	0.89	0.17	0.19			
89	1.35	0.14	0.11						

* Poisson's Ratio

The Poisson's ratios for the creep specimen initially loaded at 7 days were higher than those observed on the specimens initially loaded at 3 or 28 days. For each of the three ages of loading, however, they remained practically constant throughout the creep test.

Creep Coefficient

The creep coefficient, F (K), for each of the three ages of loading was determined from the slope of its creep curve shown in Figure 4. The slopes of these creep curves were adjusted to best fit the expression

$$e = 1/E + F\ (K)\ \ln\ (t+1) \quad \ldots\ldots\ldots\ldots \quad (1)$$

where:

- e is the total strain in millionths per psi,
- 1/E is the instantaneous strain in millionths per psi,
- F (K) is the creep coefficient, and
- t is the time in days after application of the load.

The creep coefficients for the three ages of loading were as follows:

Age of Loading, days	Creep Coefficient F (K)
3	0.077
7	0.062
28	0.030

The numerical expressions for the three sets of creep curves are given in Figures 3 and 4.

Strains at Later Ages

Creep characteristics at later ages were predicted up to 999 days after load application. The strain at 999 days after loading (t+1=1000 days) was computed from the above equation (1). This computation was accomplished by substituting the corresponding values of 1/E and F (K) and using for the value of t the expression (T-K) in which T is the age of the concrete, and K is the age of the concrete at time of loading, t is 999 days. In Figure 5, the computed strains are plotted at (t+1) = 1000 days after load application for various ages of loading up to 28 days. The values of e_{999} for specimens loaded at 3, 7, and 28 days were 1.53, 1.05, and 0.61 millionths per psi respectively. Also plotted in Figure 5 are the values of 1/E and F (K) up to age of loading of 28 days.

In Figure 6, total strain values are plotted up to age (t+1) = 1000 days after age of loading for concretes initially loaded at various ages between 3 and 28 days. These strain curves were plotted by taking the corresponding values 1/E and e_{999} from the curves of Figure 5. For example, at K = 3 days, 1/E = 1.0 and e_{999} = 1.53. The value of 1/E = 1.0 was plotted in Figure 6 at 0 days after loading and the value of e_{999} = 1.53 at 999 days after loading.

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FIG. 1 — CONCRETE SPECIMENS DURING CREEP STUDY

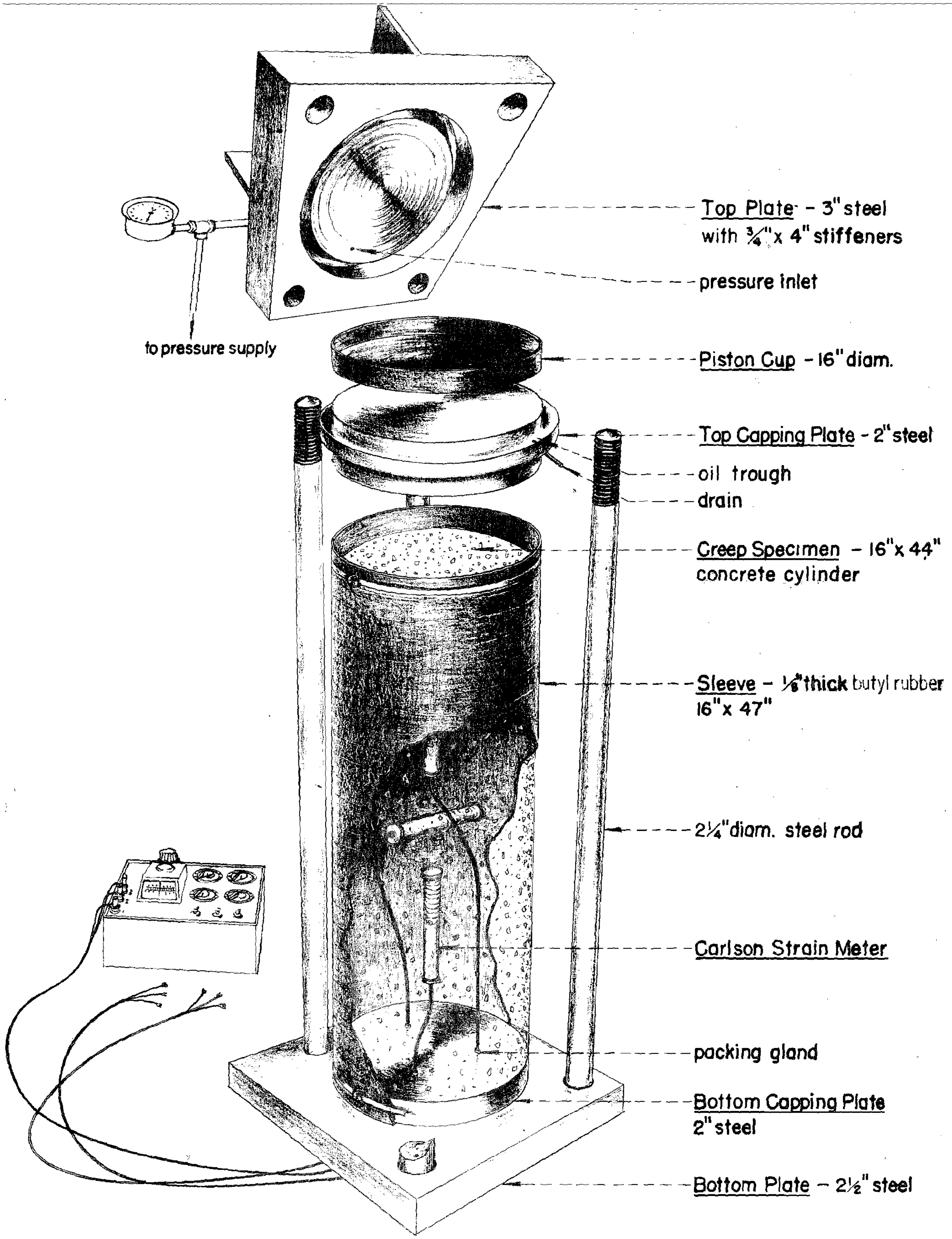

Fig. 2 - Loading Frame for 16"x 44" Concrete Specimen

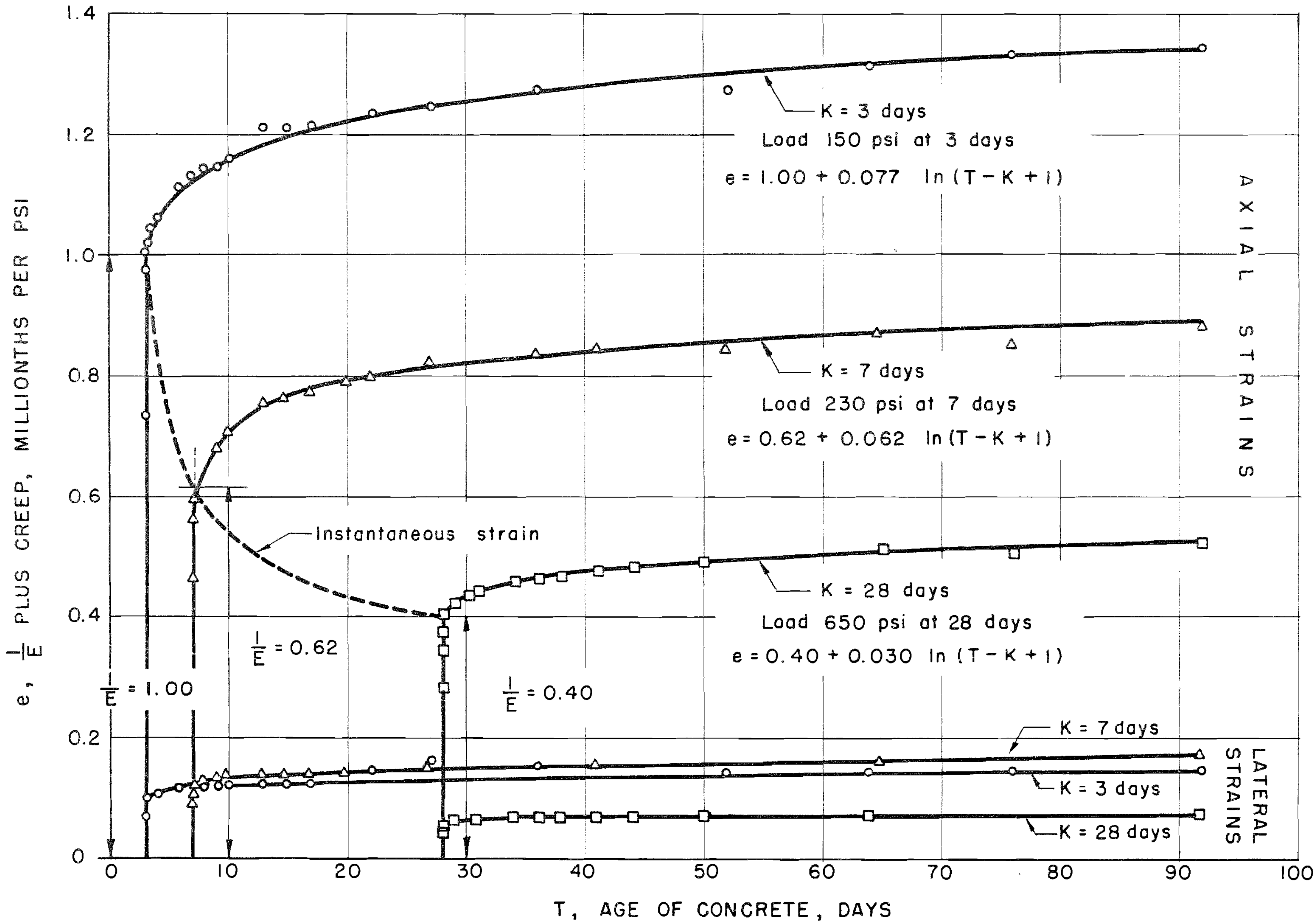

FIG. 3 — MEASURED AXIAL AND LATERAL STRAINS — $\frac{1}{E}$ PLUS CREEP

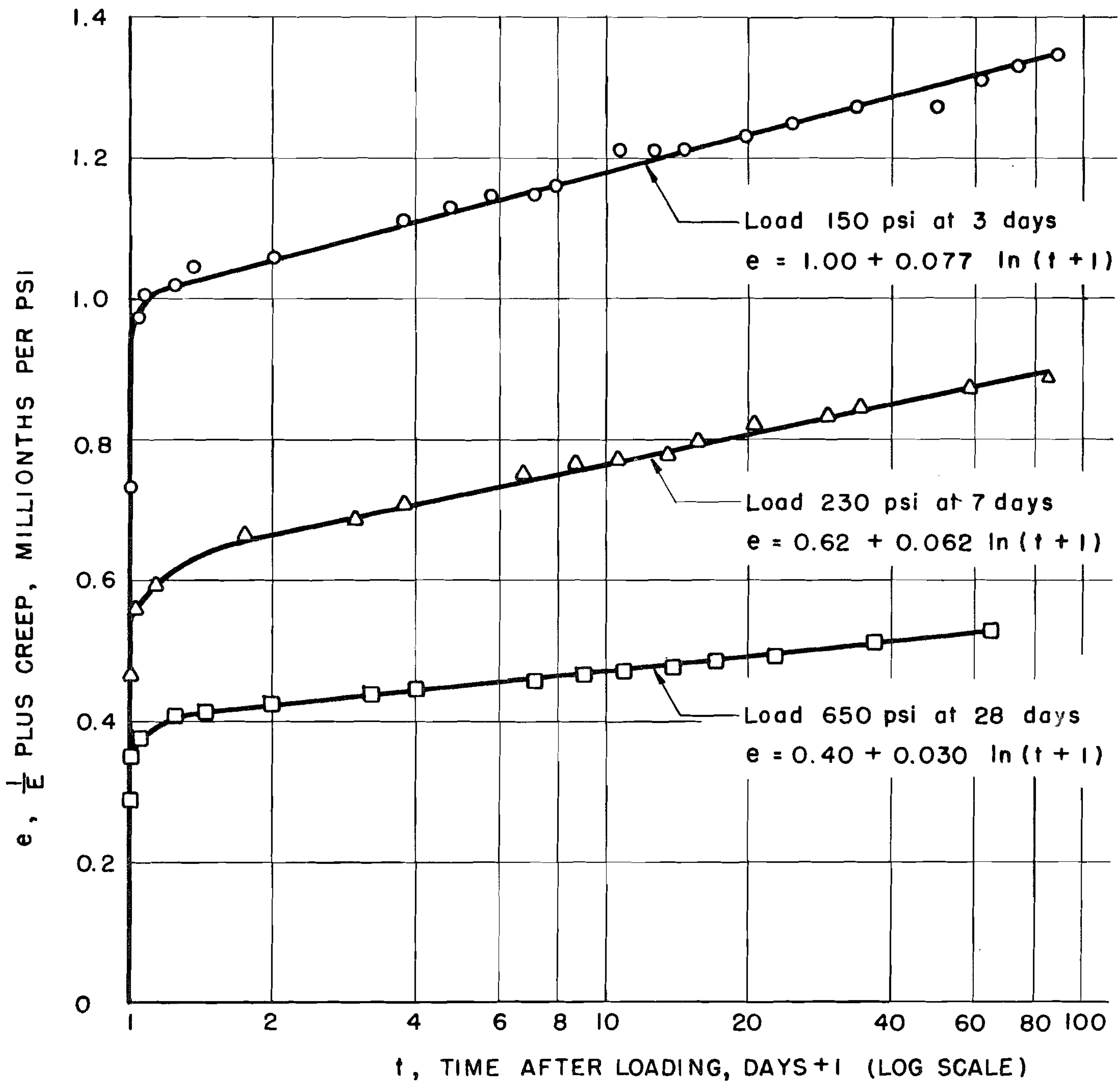

FIG. 4 — TOTAL AXIAL STRAINS — CURVES FITTING $e = \frac{1}{E} + F(K) \ln(t+1)$

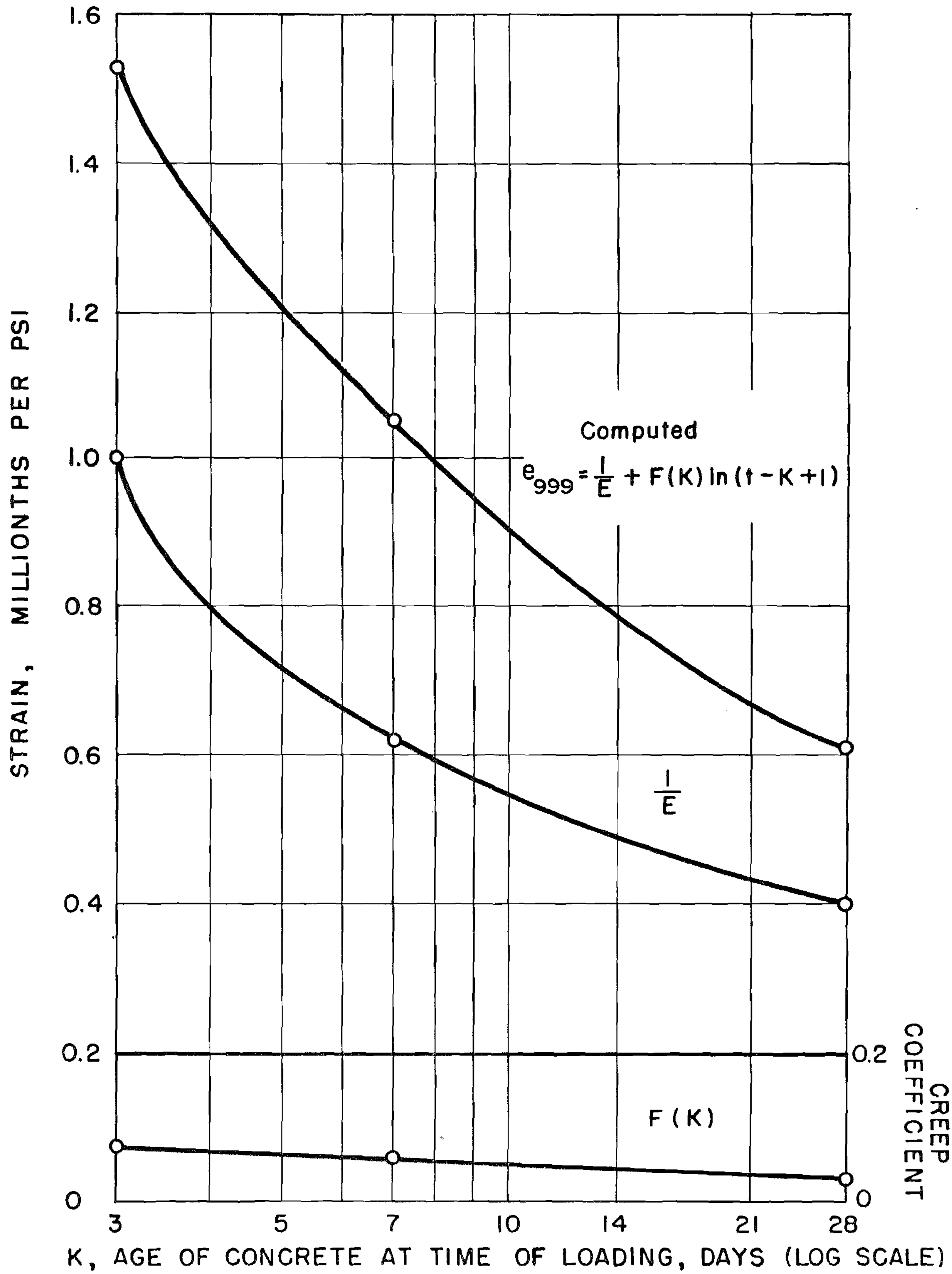

FIG. 5 — CREEP COEFFICIENT F(K) AND INSTANTANEOUS STRAINS $\frac{1}{E}$ UP TO THE AGE OF 28 DAYS — ALSO COMPUTED STRAINS e_{999} AT 999 DAYS AFTER LOAD APPLICATION

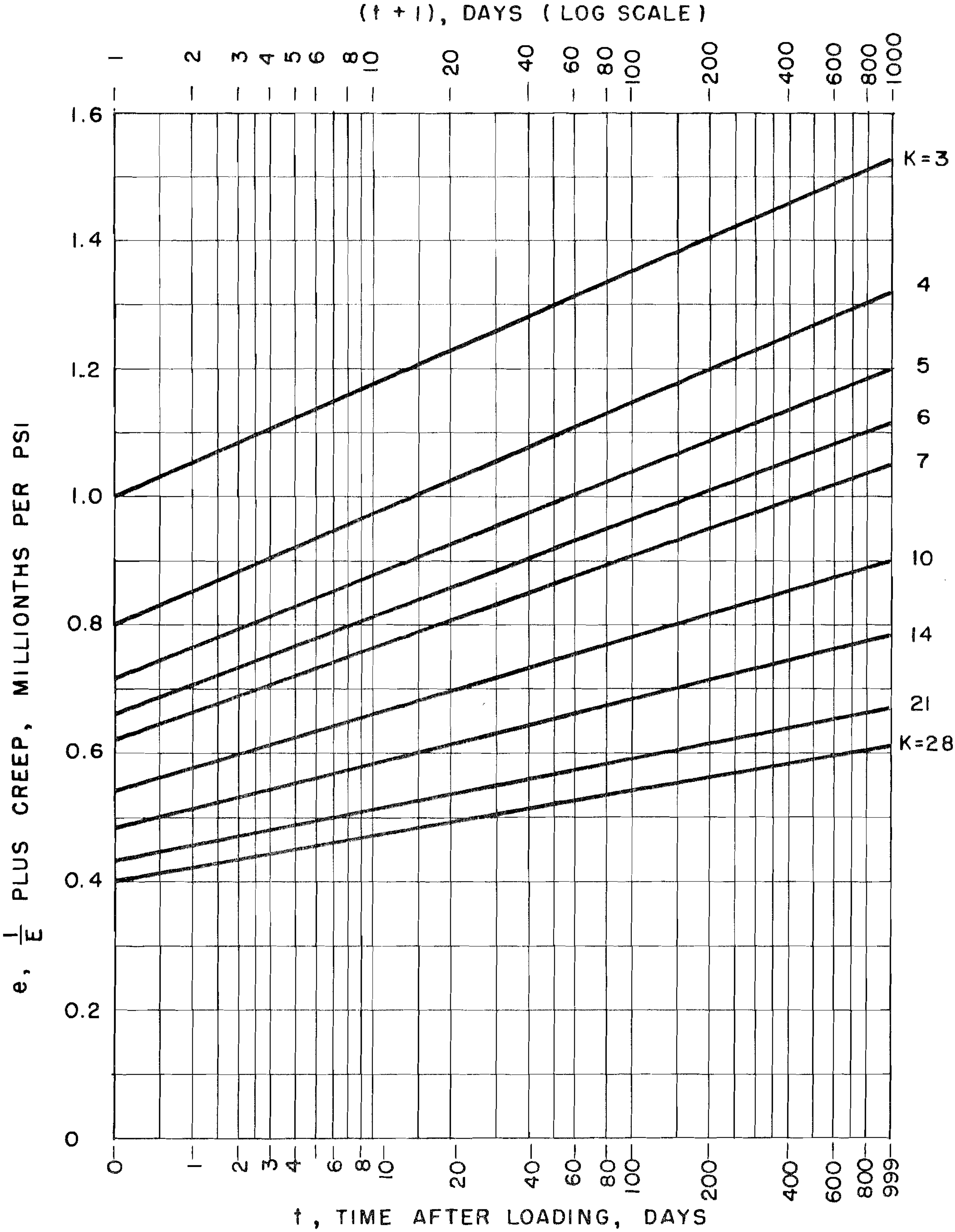

FIG. 6 — PREDICTED STRAINS UP TO 999 DAYS AFTER AGE OF LOADING