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Creep Characteristics of Mass Concrete for Dworshak Dam

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CREEP CHARACTERISTICS OF MASS CONCRETE FOR DWORSHAK DAM

A Report

by

David Pirtz

Professor of Civil Engineering

To

Walla Walla District

U. S. Engineers Office

Contract DA-35-026-Civ. Eng.-63-301

Structural Engineering Laboratory

UNIVERSITY OF CALIFORNIA

Berkeley, California

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CREEP CHARACTERISTICS OF MASS CONCRETE FOR DWORSHAK DAM

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Part I - INTRODUCTION

Purpose of Tests

The purpose of this test program was to determine some of the effects of maximum size of aggregate, cement content, specimen size, storage temperature, and age at loading on the creep characteristics for concrete to be used in the Dworshak Dam. All concrete mixes were designed to maintain the same W/C ratios, slumps, and air contents. Both the data obtained from this investigation and the information obtained from instrumentation in the dam itself can be used to calculate the stresses in the dam. Also, creep of concrete in tension and autogenous volume-change of concrete can be used to predict if cracks will occur in the concrete mass due to thermal changes.

Scope of Tests

A total of 25 compression creep specimens were fabricated including different specimen sizes and different concrete mixes, and tested at both variously different ages and at different temperatures. Six tensile creep specimens were fabricated, all having the same specimen size and concrete mix, and tested at ages of both 7 and 28 days, all at a temperature of 70°F. Two relaxation specimens were fabricated having the same specimen size and the same concrete mix and tested at age of 28 days and 70°F. Twenty seven companion specimens were fabricated for compressive strength tests to determine the stress to be applied to the creep specimens. Eleven specimens for autogenous volume-change and three specimens for thermal expansion were fabricated so that strains, due only to load, could be calculated. The test program and creep loading schedule are shown in Tables 1 and 8 respectively.

PART II - SPECIMEN FABRICATION AND TESTS

Mixtures

Mix proportioning data for concretes having 6-in., 3-in., 1 1/2 in., and 3/4-in. maximum sized aggregate were furnished by the North Pacific Division Laboratory of the U. S. Army Engineering Division, North Pacific Corps of Engineers as Mix Nos. 12128, 12257, 12258, and 12259 respectively. The data for these mixes, for purposes of record, are appended to this report, as Tables 2, 3, 4, and 5. These mixes were designed to maintain the same W/C ratios, slumps, and air contents for concretes cast at 66°F.

The materials used in all of the concrete mixes, both by the Corps of Engineers and subsequently at the University of California were as follows: fine aggregate, laboratory produced granite-gneiss sand (50/50 blend of No.4-No.16 and of minus No. 16); coarse aggregate, laboratory crushed granite-gneiss; cement, blended Type II cement (25% each - Ideal, Lehigh, Oregon, and Permanente); pozzolan, Idealite (calcined shale) Great Western Aggregate Company, Laramie, Wyoming; air entraining agent, laboratory stock N.V.R. #11356.

Mix proportioning data for concretes cast at the University of California are given in Table 6. Mixes are designated as follows: Mix Nos. I, II, and III for concretes containing maximum size of aggregate of 3-in., 1 1/2-in., and 3/4-in. respectively.

All creep specimens at the University of California were to be cast at 45°F; therefore all aggregates were stored at 35°F and ice water was used for all concrete mixes. Pertinent features of the fresh concrete mixtures were as shown in Table 7.

Manufacture of Specimens

Specimens for determination of creep, autogenous length-change, compressive strength, modulus of elasticity, and thermal expansion were cast as indicated in Table 1.

The aggregates necessary for the manufacture of all specimens were first air dried, then stored in covered metal drums. Before mixing, aggregate, cement, and pozzolan were stored at 35°F for at least three days. Ice was used in amounts required to produce a temperature of about 45°F for fresh concrete. The capacity of the mixer was 3 cubic feet. The wet mixing procedure was as follows: mix 2 min., rest 3 min., mix 1 min., and then cast.

The 6- by 18-in. and 16- by 44-in. specimen molds were 16 gage sheet metal lined inside with 1/8-in. thick, fabric reinforced, seamless butyl rubber sleeves, bonded to a 2-in. thick machined base plate with rubber cement. Butyl rubber sleeves remained on the specimens to provide a moisture seal.

To insure good contact between capping plates and concrete, a thin conical-shaped layer of mortar was formed on the top of each creep specimen after casting. About 5 to 7 hours later, when water-gain had ceased, steel capping plates were lowered onto the specimens and worked in a circular motion until mortar appeared uniformly around the periphery of the specimens. The upper ends of the butyl sleeves were then bonded to these capping plates using rubber cement, and then clamped with a metal band to form a moisture tight seal.

All specimens were then stored in a room maintained at 70°F. The sheet metal molds were removed one day after specimens were cast, and the lower ends of the butyl sleeves were clamped to the lower base plates by means of a metal band.

The 6- by 25-in. specimens for creep tests in tension were fabricated in the same manner except that cages made with 1/4 in. deformed reinforcing bars were placed in the specimens as shown in Figure 1.

Compressive strength test cylinders for concretes both with 3/4-in. and with 1 1/2-in. maximum size aggregate, were cast in 6- by 12-in. metal can molds which, after casting, were sealed until the time of test. Concrete with aggregate of 3-in. maximum size were cast in 9- by 14-in. metal can molds, which were sealed after casting.

Instrumentation

Strain Measurements

Carlson strain meters were utilized to determine strains for both creep and for control specimens. Each 16- by 44-in. specimen contained five strain meters, three mounted axially, and two transversely. Figure 2 shows the meter locations in these specimens. Each 6- by 18-in. and 6- by 25-in. specimen contained a single axial strain meter.

The strain meters were recalibrated for both strain and for changes in resistance due to a change in temperature before casting within the concrete specimens. The strain calibration constant for each meter was obtained by averaging the ratio change at displacement intervals equivalent to strains of 200 millionths over the whole range of linear proportionality. The change in resistance due to a change in temperature of the strain meter coefficient was obtained by averaging values observed between 40°F and 70°F and between 70°F and 100°F. The change in resistance due to a change in temperature coefficient was used to determine the temperature at the meter location.

A special ratio test set consisting of a precision 1000-ohm resistor and a five step dekabox having a least reading of 0.01 ohm was used to measure the ratio change of the strain meter to 0.001 percent. This corresponds to a strain change of approximately 0.3 millionths. A four step Carlson test set was used to measure the total resistance of the meters to 0.01 ohm, which corresponds to a temperature change at the strain meter of approximately 0.1°F. The strain reading for each meter was observed also by the Carlson test set (four step) to check roughly against the five step strain box. Both test sets were checked twice against a standard precision Wheatstone bridge during the time the strain readings were taken. The results showed satisfactory accuracy and stability.

Load Control

The load control system employed was that developed at the University of California for creep studies, and is described in detail in the ASTM Bulletin (1)*. Separate control systems were set up to supply constant pressures at 60 psi, 200 psi, 300 psi, and 800 psi. Calibrated pressure gauges were used to provide continuous check of the pressure in each system. The control units were able to maintain the pressure at within ± 0.5 percent. By use of a hand pump, the required initial pressure on each specimen could be reached within 10 seconds. The valve to the automatic control system was opened immediately after the initial pressure was obtained.

To load biaxial and triaxial 16- by 44-in. creep specimens, a double layered rubber tube vulcanized for a length of 1 inch at both ends, was placed between the outside of the concrete specimen and the inside of a 1/4 inch thick 18-in. diameter steel pipe. A retainer ring was placed at each end of the steel pipe to prevent the rubber tube from expanding in the logitudinal direction. When oil was pumped between the two layers of the rubber tube, pressure would build up between the steel pipe and the concrete specimen resulting in biaxial loading. For triaxial loading, pressure was also applied to the top of the specimen through a piston cup as shown in Figure 2. The photograph of

*Numbers in parentheses refer to the list of references appended to this report.

Figure 3 shows both 16- by 44-in. concrete specimens under triaxial loading and under uniaxial loading.

For creep under tension a dead weight loading system having a 10:1 lever arm ratio was used. At the ends of the short 3/4-in. threaded rods extending from the ends of the creep specimen a short length of metal chain was attached to avoid bending stresses due to loading. To avoid impact stresses in putting on dead load, a hydraulic jack was used to transfer the dead load to the specimen.

Test Procedures

All specimens for tests of creep, autogenous length-change, compressive strength, modulus of elasticity, and thermal expansion were stored after casting in a room maintained at 70°F. At age 6 days, creep and autogenous length-change specimens to be tested at 40°F and 100°F were transferred from 70°F curing to the required temperature environments. The specimens for tests of linear thermal expansion of concrete were moved as follows: from 70°F to 40°F at age 27 days, from 40°F to 100°F at age 28 days, and then back to 70°F at age 30 days.

Creep specimens were loaded as shown in Table 8.

A strain reading was taken on each strain meter both within one hour before, and within 10 seconds after, application of load. Then both strain and temperature observations were made at 1 min., 3 min., 5 min., 30 min., 10 hrs., and 1 day on the loaded specimens. Thereafter, readings were taken at intervals close enough so that a proper curve could be plotted on semi-log paper with time in days along the log scale.

Strain readings were taken at sufficient time intervals on all specimens for autogenous length-change so that corrections could be applied to the strain readings for the loaded specimens. All creep measurements were corrected for autogenous length-change, for temperature expansion of the strain meter, and for linear thermal expansion of the concrete to obtain the actual strain due to loading only.

PART III: RESULTS

Compressive Strength and Elastic Properties

The results of tests for compressive strength and for static modulus of elasticity are listed in Table 9. These results provided a limited description of the hardened concrete that was tested.

Linear Thermal Expansion

The coefficient of linear thermal expansion of the concrete was obtained from measurements at three different constant temperatures (40°F, 70°F, and 100°F) on three 6- by 18-in. sealed specimens containing one Carlson strain meter with concrete having a maximum size of aggregate of 1 1/2-in. The average value for coefficient of linear thermal expansion at age 28 days was 5.1×10^{-6} in./in./°F. This is the value used throughout all subsequent calculations. Although this will not be the correct coefficient for concrete at all other ages, the correction for linear thermal expansion in determination of strains being in itself very small due to small temperature changes, changes in such values at ages other than 28 days will have negligible influence upon the calculated strains.

Autogenous Length-Change

Data for autogenous length-change were obtained on sealed specimens not subjected to load, but stored continuously in the immediate vicinity of the specimens that were under load. Only that portion of the autogenous length-change which occurred after any given loading date was used to correct creep data for specimens loaded on that date. Data for autogenous length-change of concrete having maximum size of aggregate of 1 1/2 in. and stored at 70°F, 40°F, and 100°F are tabulated in Table 10. Corresponding data for concretes having both 3/4-in. or 3-in. maximum size aggregate and stored at 70°F are tabulated in Table 11.

Creep

Data for creep plus elastic strains, and for creep (only), per psi of applied stress in millionths are given in tables as tabulated below.

Table No.	Page No.	Maximum Size of Aggregate, Inches	Mix No.	Age of Loading, Days	Applied Stress, psi Original	Applied Stress, psi Increased to	Storage Temp., °F	Specimen Size, Inches
12	27	3/4	III	28-833	800 Comp.		70	6 x 18
13	28	1 1/2	II	1-86	60 Comp.		70	6 x 18
	29	"	II	86-1000	60 Comp.	800 Comp.	70	
	28	"	II	3-86	200 Comp.		70	6 x 18
	29	"	II	86-1002	200 Comp.	800 Comp.	70	
	30	"	II	7-100	300 Comp.		40	6 x 18
	31	"	II	100-1006	300 Comp.	800 Comp	40	
	30	"	II	7-100	300 Comp.		70	6 x 18
	31	"	II	100-906	300 Comp.	800 Comp.	70	
	32	"	II	7-100	300 Comp.		100	6 x 18
	33	"	II	100-371	300 Comp.	800 Comp.	100	
	34	"	II	28-780	800 Comp.		70	6 x 18
	34	"	II	90-791	800 Comp.		70	6 x 18
14*	35	"	II	28-777	800 Comp.		70	16 x 44
15*	36	3	I	28-714	800 Comp.		70	16 x 44
16	37	1 1/2	I	7-636	50 Ten.		70	6 x 25
	37	"	I	28-636	100 Ten.		70	6 x 25

*Also given are lateral strains and Poisson's ratio.

Creep plus elastic strains and creep only (millionths per psi) are plotted vs. log of time (days) as shown in Figures Nos. 4 through 15 as listed below.

Figure No.	Notes
4	Shows the effect of creep plus elastic strains vs. age for concretes loaded at ages 1, 3, 7, 28, and 90 days. The initial applied stress in all cases was less than 40 percent of the observed compressive strength of concrete. All specimens were 6- by 18-in. in size containing aggregate of maximum size of 1 1/2 in. and stored at 70°F.
5	Same as for Figure 4 except creep only is plotted.
6	Shows creep vs. age with zero creep plotted at 1 day after load was increased to 800 psi. The loading schedule for the concrete specimens was as follows: 800 psi at age 86 days with previous loading of 60 psi from age of 1 to 86 days; 800 psi at age 86 days with previous loading of 200 psi from age 3 to 86 days; and 800 psi at age 100 days with previous loading of 300 psi from age 7 to 100 days. Creep under original loading of specimens noted above is shown in Figure 5. Data were obtained for Figure 6 by assuming that the method of superposition is valid, and computed as shown on page 275 of "Symposium on Mass Concrete," American Concrete Institute, Publication SP-6 (2).
7	Shows the effect of creep plus elastic strains vs. age for concrete specimens of different specimen sizes, and containing concretes with different maximum sizes of aggregate. All concrete specimens were stressed to 800 psi at age 28 days and stored at 70°F.
8	Same as for Figure 7 except that creep only is plotted.
9	Same as for Figure 8 except that zero creep is plotted at age 1 day

Figure No.	
	after loading.
10	Shows the effect of creep plus elastic strains vs. age for concrete variously stored at temperatures of 40°F, 70°F, or 100°F. All specimens were 6- by 18-in. in size containing aggregate of maximum size of 1 1/2-in. and stressed to 800 psi at age of 7 days.
11	Same as for Figure 10 except that creep only is plotted.
12	Same as for Figure 11 except that zero creep is plotted at age 1 day after loading.
13	Shows creep vs. age with zero plotted 1 day after the load was increased from 300 to 800 psi. All specimens were loaded previously at a stress of 300 psi between ages 7 and 100 days. Creep for the original loading of these specimens is shown in Figures 11 and 12. The concrete specimens were stored variously at 40°F, 70°F, or 100°F.
14	Shows creep plus elastic strains vs. age for concretes loaded in tension at ages 7 and 28 days. All concrete specimens were 6- by 25-in. in size containing maximum size of aggregate of 1 1/2-in. and stored at 70°F.
15	Same as for Figure 14 except that creep only is plotted.

In Figure 16 there are shown for two 16- by 44-in. concrete specimens under load, the lateral creep plus elastic strains and the lateral creep only in millionths per psi of applied stress and Poisson's ratios vs. age in days. Maximum size of aggregate was 1 1/2-in. for one specimen and 3-in. for the other specimen. Specimens were stored at 70°F and stressed to 800 psi at age of 28 days.

Discussion and Summary of Results

In general, for all ages of loading, the creep for the first 10 hours after loading was not of semilogarithmic character, although the relation is distinctly semilogarithmic after the first day. Inasmuch as the modulus of elasticity, as determined both from tests of compressive strength specimens and from initial loading of the creep specimens were in fair agreement it appears that the load on the creep specimens was not applied too rapidly. In Figures 6, 9, 12, and 13 zero creep was plotted at age 1 day after the load was applied to eliminate the lack of semilogarithmic effect in order that creep data could be better interpreted.

The effect of age at time of loading, upon creep plus elastic strains and upon creep only, for mix No. II as shown in Figures 4 and 5 respectively does not agree with results for similar tests conducted by the Corps of Engineers at Vicksburg, Mississippi and reported in Miscellaneous Paper No. 6-613 (3). The pressure in the load cell for the specimens loaded at age 90 days was low from about 10 days to 100 days after loading because the valve to the load cell was left closed. This does not seem to affect the results at later ages. The main differences noted between these tests and those conducted by the Corps of Engineers are reflected in the initial elastic strains and the creep for the first 10 hours after loading. These differences may be caused by the initial casting temperature of the concrete.

The effect of previous load history on creep for concrete mix No. II is shown in Figure 6. These data demonstrate that previous loading history, at early ages of concrete, has a definite effect upon creep at later ages. This agrees with previous tests conducted at the University of California, shown in Figure 10 page 275, and Figure 13 page 280 in Paper No. 12 "Studies of Creep of

Mass Concrete" in the "Symposium on Mass Concrete," American Concrete Institute Publication SP-6, 1963 (2).

The effect of specimen size (6- by 18-in. or 16- by 44-in. sealed specimens) upon creep plus elastic strains or upon creep only--for the same mass concrete--is small, as shown in Figures 7, 8, and 9.

The effect of maximum size of aggregate for concrete mixes having the same W/C ratio on creep is best shown in Figure 9, which has zero creep plotted at age 1 day after loading. This figure indicates that creep is proportional to the paste content for Mix Nos. I and III.

The effect of temperature upon creep plus elastic strains is shown in Figure 10 and upon creep only in Figures 11 and 12. All specimens were cast at 45°F with concrete Mix No. II and then stored for the first 6 days at 70°F. At age 6 days, creep and autogenous length-change specimens to be tested at 40°F and 100°F were transferred from 70°F to the required temperature environments. In general, for concrete loaded at ages of 28 days or more, the creep increases with higher storage temperature. Figures 11 and 12 show little difference between the creep for specimens maintained at 70°F and 100°F, in fact, the specimens at 70°F show the higher creep. The autogeneous length-change for Mix No. II, as affected by temperature, shown in Table 10, and used in calculating the creep strains may account for this discrepancy.

Tensile creep plus elastic strain and creep only as shown in Figures 14 and 15 indicates values for time under stress of 100 days of approximately 20 percent less than for corresponding compression creep tests. The shapes of the curves are mainly due to the autogeneous length-change correction used in calculating the creep strains.

In Tables 14 and 15 and in Figure 16 are shown the lateral strains and

Poisson's ratios for concretes maintained under constant stress and at constant temperature. The value of Poisson's ratio decreased approximately 20 percent under a constant stress maintained for two years.

ACKNOWLEDGEMENTS

The investigations reported here were performed at Berkeley under the terms of Contract DA-35-026-Civ. Eng. -63-301 between the Walla Walla District of the U. S. Army Corps of Engineers and the Institute of Engineering Research of the University of California. The Corps of Engineers North Pacific Division Testing Laboratory were responsible for the design of all concrete mixtures under the general supervision of Mr. O. E. Borge, Acting Chief, Concrete Branch. Mr. George Hayler was responsible for determining all of the fresh properties of the concrete at the University of California. Messrs. A. Klein and V. Nicolayeff assisted in the preparation of this report.

REFERENCES

1. C. H. Best, D. Pirtz, and M. Polivka, "A Loading System for Creep Studies of Concrete," ASTM Bulletin No. 224, September 1957, pp. 44-47.

2. M. Polivka, D. Pirtz, and R. F. Adams, "Studies of Creep in Mass Concrete," Paper No. 12, "Symposium of Mass Concrete," American Concrete Institute Publication SP-6, 1963.

3. E. E. McCoy, Jr., H. T. Thornton, and J. K. Allgood, "Concrete Laboratory Studies Dworshak (Bruce's Eddy) Dam, North Fork, Clearwater River near Orofino, Idaho" Report 2 "Creep Tests," Miscellaneous Paper No. 6-613, U. S. Army Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi.

Table 1

TEST PROGRAM

Type of Test	Size of Specimen, Inches	No. of Specimens	Aggregate Maximum Size, Inches	Age at Loading, Days	Storage Temp., °F
Creep, Compression	6 x 18	3	3/4	28	70
Auto. Volume Chg.	6 x 18	3	"	--	"
Comp. Strength	6 x 12	3	"	--	"
Creep, Compression	6 x 18	3	1 1/2	1	70
	"	3	"	3	"
	"	4	"	7	"
	"	2	"	28	"
	"	2	"	90	"
	"	2	"	7	40
	"	2	"	7	100
Auto. Volume-Chg.	6 x 18	3	"	--	70
	"	2	"	--	40
	"	2	"	--	100
Thermal Expansion	6 x 18	3	"	--	
Comp. Strength	6 x 12	21	"	--	70
Creep, Comp. Axial	16 x 44	1	3	28	70
Biaxial	"	1	"	"	"
Triaxial	"	2	"	"	"
Auto. Volume-Chg.	16 x 44	1	"	--	"
Comp. Strength	9 x 14	3	"	--	"
Creep, Tension	6 x 25	3	1 1/2	7	70
	"	3	"	28	"
Relaxation	6 x 16	2	1 1/2	7	70

Table 2

CORPS OF ENGINEERS MIX NO. 12128 - 6-IN. MAXIMUM SIZE AGGREGATE

MIX DATA

MATERIAL	% C.A.	SAMPLE NO.	SOLID VOLUME cu ft	WEIGHTS S.S.D. lb	BULK SP. GR. S.S.D.	% ABSORP
Coarse Agg (A)	30	11778	5.185	886	2.74	0.3
" " (B)	30	"	5.185	893	2.76	0.3
" " (C)	20	"	3.449	590	2.74	0.3
" " (D)	20	"	3.449	585	2.72	0.8
Sand		"	4.426	751	2.72	0.6
Cement		12078	1.088	213.8	3.15	
Pozzolan		12064	0.466	74.1	2.55	
Water			2.742	171.1		
Air (6.0% on-1½)			1.010			
Totals			27.000	4164		

MIX CHARACTERISTICS

WATER-CEMENT RATIO	Gallons per bag, equivalent cement	6.32
	By weight, " "	0.56
	By weight, water / (cement + pozzolan)	0.594
Cement factor, bags/cu yd (Eq. Sol. Vol. as P.C.)		3.25
Pozzolan, % replacement by solid volume		30.0
Slump, inches (2-2½)		2
Air content (Note 1), % (5.8-6.6)		6.2
Unit weight, lbs/cu ft (Theoretical)		154.0
Bleeding (Note 2), %		3.5
Sand/aggregate, % by volume		21.0
Temperature of plastic concrete, °F		67

STRENGTH TEST DATA (Compressive)

Age, days	3	7	28
Strength, psi (average)	840	1050	2270
Age, days	90	180	365
Strength, psi (average)	3640		

NOTES:
1. In that portion of the concrete containing aggregate smaller than the 1½"-inch sieve.
2. Percentage of mix water separating from concrete in bleeding test.

REMARKS **Compressive strengths are average of six cylinders: two from each of three batches.**

SCREEN ANALYSES - % RETAINED

SIEVE SIZE	NOMINAL SIZES (A) 6" to 3"	(B) 3" to 1½"	(C) 1½" to ¾"	(D) ¾" to 4	Sand	COMBINED Coarse Aggregate	Total Aggregate
7"	0					0	0
6"	5					1.6	1.3
5"	24					8.7	6.9
4"	46					22.5	17.9
3"	20					28.5	22.7
2½"	5	33				39.9	31.8
2"		34				50.1	39.9
1½"		28	6			59.7	47.6
1"		5	50			71.2	56.6
¾"			35	4		79.0	62.9
½"			7	38		88.0	70.0
⅜"			2	28		94.0	74.8
4				26		99.2	79.0
8				4	19		83.0
16					25		88.3
30					16		91.4
50					16		95.0
100					14		98.0
PAN					10	100.0	100.0
F. M.					2.89		

PROJECT BRUCES EDDY DAM

DISTRICT Walla Walla (E-278)

FINE AGGREGATE Laboratory produced granite gneiss sand; 50/50 blend of No. 4 - No.16

COARSE AGGREGATE Laboratory crushed granite-gneiss

CEMENT Blended Type II cement, 25% each, Ideal, Lehigh, Oregon and Permanente

POZZOLAN Idealite (calcined shale) Great Western Aggregates Company, Laramie, Wyoming

A.E.A. Lab Stock NVR, (#11356) 426 cc/cu.yd.

OTHER ADMIXTURE None

MIX NO. 12128   W/O NO. 62-CPCh-68

CAST 1/28/63

OCT 15 1963 (Date of Report)   O. E. BORGE Act'g Chief, Concrete Branch

Table 3

CORPS OF ENGINEERS MIX NO. 12257 - 3-IN. MAXIMUM SIZE AGGREGATE

MIX DATA

MATERIAL	% C.A.	SAMPLE NO.	SOLID VOLUME cu ft	WEIGHTS S.S.D. lb	BULK SP. GR. S.S.D.	% ABSORP.
Coarse Agg(A)						
" " (B)	40	11778	5.988	1031	2.76	0.3
" " (C)	30	"	4.506	770	2.74	0.3
" " (D)	30	"	4.506	765	2.72	0.8
Sand		"	5.576	946	2.72	0.6
Cement		12078	1.306	256.7	3.15	
Pozzolan		12064	0.560	89.1	2.55	
Water			3.290	205.3		
Air 6.0 % on-1½)			1.268			
Totals			27.000	4063		

MIX CHARACTERISTICS

WATER-CEMENT RATIO	Gallons per bag, equivalent cement	6.32
	By weight, " "	0.56
	By weight, water / (cement + pozzolan)	0.594
Cement factor, bags/cu yd (Eq. Sol. Vol. as P.C.)		3.90
Pozzolan, % replacement by solid volume		30.0
Slump, inches		2¼
Air content (Note 1), %		6.2
Unit weight, lbs/cu ft		150.2
Bleeding (Note 2), %		-
Sand/aggregate, % by volume		28.0
Temperature of plastic concrete, °F		66

STRENGTH TEST DATA (Flexural)

Age, days	7	35	
Strength, p s i (average)			
Age, days			
Strength, p s i (average)			

NOTES:
1. In that portion of the concrete containing aggregate smaller than the 1½" - inch sieve.
2. Percentage of mix water separating from concrete in bleeding test.

REMARKS

3" Max. version of Mix A-2

SCREEN ANALYSES - % RETAINED

SIEVE SIZE	NOMINAL SIZES (A) 6" to 3"	(B) 3" to 1½"	(C) 1½" to ¾"	(D) ¾" to 4	Sand	COMBINED Coarse Aggregate	Total Aggregate
7"							
6"							
5"							
4"							
3"						0	0
2½"		33				13.2	9.6
2"		34				26.8	19.5
1½"		28	6			39.8	29.0
1"		5	50			56.8	41.4
¾"			35	4		68.5	50.0
½"			7	38		82.0	59.8
⅜"			2	28		91.0	66.3
4				26		98.8	72.0
8				4	19		77.2
16					25		84.1
30					16		88.7
50					16		93.0
100					14		96.8
PAN					10	100.0	100.0
F. M.					2.89		

PROJECT BRUCES EDDY DAM

DISTRICT Walla Walla (E-278)

FINE AGGREGATE Laboratory produced granite-gneiss sand; 50/50 blend of No. 4 - No. 16 and minus No. 16.

COARSE AGGREGATE Laboratory crushed granite-gneiss

CEMENT Blended Type II cement, 25% each, Ideal, Lehigh, Oregon and Permanente

POZZOLAN Idealite (Calcined Shale) Great Western Aggregates Company, Laramie, Wyoming

A.E.A. Lab. Stock NVR (#11356) 550 cc/cu.yd.

OTHER ADMIXTURE None

MIX NO. 12257 W/O NO. 62-CPCh-68

CAST 4/22/63

APR 26 1963 (Date of Report)

O. E. BORGE
Actg. Chief, Concrete Branch

NPD RF APRIL 61 **359**

REPORT OF CONCRETE MIXTURE DESIGN
METHODS CRD-C 3 AND 10
CORPS OF ENGINEERS NORTH PACIFIC DIVISION TESTING LABORATORY

Table 4

CORPS OF ENGINEERS MIX NO. 12258 - 1 1/2-IN. MAXIMUM SIZE AGGREGATE

MIX DATA

MATERIAL	% C.A.	SAMPLE NO.	SOLID VOLUME cu ft	WEIGHTS S.S.D. lb	BULK SP. GR. S.S.D.	% ABSORP.
Coarse Agg(A)						
" " (B)						
" " (C)	50	11778	5.744	982	2.74	0.3
" " (D)	50	"	5.744	975	2.72	0.8
Sand		"	7.283	1236	2.72	0.6
Cement		12078	1.674	329.0	3.15	
Pozzolan		12064	0.717	114.1	2.55	
Water			4.218	263.2		
Air 6.0 % on-1½)			1.620			
Totals			27.000	3899		

MIX CHARACTERISTICS

WATER-CEMENT RATIO	Gallons per bag, equivalent cement	6.32
	By weight, " "	0.56
	By weight, water / cement + pozzolan	0.594
Cement factor, bags/cu yd (Eq. Sol. Vol. as P.C.)		5.0
Pozzolan, % replacement by solid volume		30.0
Slump, inches		2
Air content (Note 1), %		5.8
Unit weight, lbs/cu ft		144.7
Bleeding (Note 2), %		-
Sand/aggregate, % by volume		40.0
Temperature of plastic concrete, °F		66

STRENGTH TEST DATA (Compressive)

Age, days	3	7	28
Strength, p s i (average)	840	1120	2320
Age, days	90	130	365
Strength, p s i (average)	3700		

NOTES:
1. In that portion of the concrete containing aggregate smaller than the 1½"-inch sieve.
2. Percentage of mix water separating from concrete in bleeding test.

REMARKS
1½" Max. version of Mix A-2

SCREEN ANALYSES - % RETAINED

SIEVE SIZE	NOMINAL SIZES (A) 6" to 3"	(B) 3" to 1½"	(C) 1½" to ¾"	(D) ¾" to #4	Sand	COMBINED Coarse Aggregate	Total Aggregate
7"							
6"							
5"							
4"							
3"							
2½"							
2"						0	0
1½"			6			3.0	1.8
1"			50			23.0	14.1
¾"			35	4		47.5	29.1
½"			7	38		70.0	42.9
⅜"			2	28		85.0	52.0
4				26		98.0	60.0
8				4	19		67.5
16					25		77.4
30					16		83.6
50					16		89.9
100					14		95.3
PAN					10	100.0	100.0
F. M.					2.89		

PROJECT
BRUCES EDDY DAM

DISTRICT Walla Walla (E-278)

FINE AGGREGATE Laboratory produced granite-gneiss sand; 50/50 blend of No. 4 - No. 16 and minus No. 16

COARSE AGGREGATE
Laboratory crushed granite-gneiss

CEMENT
Blended Type II cement, 25% each, Ideal, Lehigh, Oregon and Permanente

POZZOLAN
Idealite (Calcined Shale) Great Western Aggregates Company, Laramie, Wyoming

A.E.A. Lab. stock NVR (#11356)
320 cc/cu.yd.

OTHER ADMIXTURE
None

MIX NO. 12258	W/O NO.
CAST 4/28/63	62-CPCh-68
OCT 15 1963 (Date of Report)	C. E. BORGE Actg. Chief, Concrete Branch

Table 5

CORPS OF ENGINEERS MIX NO. 12259 -3/4-IN. MAXIMUM SIZE AGGREGATE

MIX DATA

MATERIAL	% C.A.	SAMPLE NO.	SOLID VOLUME cu ft	WEIGHTS S.S.D. lb	BULK SP. GR. S.S.D.	% ABSORP.
Coarse Agg (A)						
" " (B)						
" " (C)						
" " (D)	100	11778	8.755	1486	2.72	0.8
Sand		"	8.754	1486	2.72	0.6
Cement		12078	1.925	378.4	3.15	
Pozzolan		12064	0.825	131.3	2.55	
Water			4.851	302.7		
Air (7.0% on -1½)			1.890			
Totals			27.000	3784		

MIX CHARACTERISTICS

WATER-CEMENT RATIO	Gallons per bag, equivalent cement	6.32
	By weight, " "	0.56
	By weight, water / (cement + pozzolan)	0.594
Cement factor, bags/cu yd (Eq. Sol. Vol. as P.C.)		5.75
Pozzolan, % replacement by solid volume		30.0
Slump, inches (2¼-2½)		2¼
Air content (Note 1), % (6.5-8.0)		7.1
Unit weight, lbs/cu ft (Theoretical)		140.0
Bleeding (Note 2), %		6.2
Sand/aggregate, % by volume		52.0 ?
Temperature of plastic concrete, °F		66

STRENGTH TEST DATA (Compressive)

Age, days	3	7	28
Strength, p s i (average)	870	1220	2540
Age, days	90	180	365
Strength, p s i (average)	4000		

NOTES:
1. In that portion of the concrete containing aggregate smaller than the 1½"-inch sieve.
2. Percentage of mix water separating from concrete in bleeding test.

REMARKS 3/4" Max. version of Mix A-2

SCREEN ANALYSES-% RETAINED

SIEVE SIZE	NOMINAL SIZES (A) 6" to 3"	(B) 3" to 1½"	(C) 1½" to ¾"	(D) ¾" to 4	Sand	COMBINED Coarse Aggregate	Total Aggregate
7"							
6"							
5"							
4"							
3"							
2½"							
2"							
1½"							
1"							
¾"				4		4	2.0
½"				38		42	21.0
⅜"				28		70	35.0
4				26		96	48.0
8				4	19		58.1
16					25		71.2
30					16		79.4
50					16		87.6
100					14		94.8
PAN					10	100	100.0
F. M.					2.89		

PROJECT BRUCES EDDY DAM

DISTRICT Walla Walla (E-278)

FINE AGGREGATE Laboratory produced granite-gneiss sand; 50/50 blend of No. 4 - No. 16 and minus No. 16

COARSE AGGREGATE Laboratory crushed granite-gneiss

CEMENT Blended Type II cement, 25% each, Ideal, Lehigh, Oregon and Permanente

POZZOLAN Idealite (Calcined Shale) Great Western Aggregates Company, Laramie, Wyoming

A.E.A. Lab Stock NVR (#11356) 250 cc/cu.yd.

OTHER ADMIXTURE None

MIX NO. 12259	W/O NO. 62-CPCh-68
CAST 4/26/63	
OCT 1 [illegible] (Date of Report)	Act'g O. E. BORGE Chief, Concrete Branch

Table 6

MIX DATA - UNIVERSITY OF CALIFORNIA

Mix No.	Material	Solid Volume, cu. ft. per cu. yd.	Weights S.S.D. Basis, lbs./cu.yd.	Bulk Specific Gravity, S.S.D.	Percent Absorption
I (3-in. Maximum Size Aggregate)	Coarse Agg. (B)	5.968	1024	2.75	0.5
	" " (C)	4.441	765	2.76	0.4
	" " (D)	4.379	760	2.78	0.3
	Sand	5.515	940	2.73	0.9
	Cement	1.298	255.2	3.15	--
	Pozzolan	0.556	88.5	2.55	--
	Water	3.266	203.8	1.00	--
	Air	1.577	--	--	--
	Total	27.000	4036	---	---
II (1 1/2-in. Maximum Size Aggregate)	Coarse Agg. (C)	5.746	989	2.76	0.4
	" " (D)	5.663	983	2.78	0.3
	Sand	7.309	1245	2.73	0.9
	Cement	1.687	331.7	3.15	--
	Pozzolan	0.724	115.2	2.55	--
	Water	4.251	265.3	1.00	--
	Air	1.620	--	--	--
	Total	27.000	3929	---	---
III (3/4 in. Maximum Size Aggregate)	Coarse Agg. (D)	8.643	1499	2.78	0.3
	Sand	8.801	1499	2.73	0.9
	Cement	1.941	381.6	3.15	--
	Pozzolan	0.832	132.4	2.55	--
	Water	4.893	305.3	1.00	--
	Air	1.890	--	--	--
	Total	27.000	3817	---	---

Table 7

PROPERTIES OF FRESH CONCRETE

Mix No.	Aggregate Maximum Size Inches	Cement Factor, sks.per cu. yd.	Percent Paste, Volume Basis	Percent Sand, Volume Basis	Temp. °F	Slump, inches	Unit Weight, pcf.	Air Content percent
I	3	3.89	24.8	27.7	44	4	144	7 1/2
II	1 1/2	5.04	30.6	39.0	44	4 3/4	146	6
III	3/4	5.80	35.4	50.5	45	5	143	7

(1) W/C + P was held constant for all mixes at 0.594

(2) Pozzolan replacement by solid volume 30%

(3) Cement factor, bags per cu. yd. (Equal solid volume as portland cement)

(4) Concrete for Mix No. I for air, unit weight, and slump tests was wet-screened on 1 1/2-inch sieve.

Table 8

CREEP LOADING SCHEDULE

Mix No.	Maximum Size of Aggregate, Inches	Age of Loading, Days	Applied Stress, psi		Storage Temp., °F	Specimen Size, Inches
			Original	Increased to		
III	3/4	28-861	800 Comp.		70	6 x 18
II	1 1/2	1-86	60 Comp.		70	6 x 18
	"	86-1000	60 Comp.	800 Comp.	70	
II	1 1/2	3-86	200 Comp.		70	6 x 18
		86-1002	200 Comp.	800 Comp.	70	
II	1 1/2	7-100	300 Comp.		40	6 x 18
		100-1006	300 Comp.	800 Comp.	40	
II	1 1/2	7-100	300 Comp.		70	6 x 18
		100-906	300 Comp.	800 Comp.	70	
II	1 1/2	7-100	300 Comp.		100	6 x 18
		100-371	300 Comp.	800 Comp.	100	
II	1 1/2	28-780	800 Comp.		70	6 x 18
II	1 1/2	90-791	800 Comp.		70	6 x 18
II	1 1/2	28-777	800 Comp.		70	16 x 44
I	3	28-714	800 Comp.		70	16 x 44
I	3	28-*	800 Comp. Axial		70	16 x 44
			400 Comp. Lateral			
I	3	28-*	400 Comp. Axial		70	16 x 44
			400 Comp. Lateral			
I	3	28-*	400 Comp. Lateral		70	16 x 44
II	1 1/2	7-636	50 Tension		70	6 x 25
II	1 1/2	28-636	100 Tension		70	6 x 25

* Rubber tubes to apply the lateral stress failed within 30 minutes.

Table 9

COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES

Mix No.	Maximum Size of Aggregate, Inches	Age at Test, Days	Compressive Strength, psi (a)	Elastic Modulus psi x 10^{-6} (a)	Elastic Modulus psi x 10^{-6} (b)	Elastic Modulus Stress Level, psi	Rate of Loading, lb./min.
III	3/4	28	2400	2.86	2.62*	800	40,000
II	1 1/2	1	280	1.10	1.07*	60	4,000
II	"	3	640	1.38	1.51*	200	10,000
II	"	7	960	1.88	1.90*	300	20,000
II	"	28	2080	2.67	2.75*	800	40,000
II	"	28			2.77**	800	
II	"	90	3180		3.40*	800	
I	3	28	1590		1.99*	800	

(a) Average results of tests on three compressive strength specimens.

(b) Results from initial loading on creep specimens, 10 seconds.

* Specimen size 6- by 18-in.

** Specimen size 16- by 44-in.

Table 10

AUTOGENOUS LENGTH-CHANGE FOR MIX NO II.

Maximum Size of Aggregate: 1 1/2 in.
Specimen size: 6- by 18-in.

Temperature: 70°F		Temperature: 40°F		Temperature: 100°F	
Age, Days	Length-change, Millionths	Age, Days	Length-change, Millionths	Age, Days	Length-change, Millionths
1	0	7	0	7	0
2	-4	8	-1	8	+10
4	-4	10	-1	10	+17
7	-4	14	0	14	+13
8	-4	21	+1	21	-4
10	-4	24	+2	24	-11
14	-5	28	+1	28	-19
21	-8	31	+1	31	-25
24	-12	35	+1	35	-33
28	-16	41	0	41	-41
31	-19	49	-2	49	-52
35	-24	56	-4	56	-61
41	-27	63	-3	63	-66
49	-29	70	-8	70	-71
56	-29	77	-8	77	-77
63	-30	84	-12	84	-80
70	-31	91	-14	91	-85
77	-32	98	-17	98	-88
84	-34	108	-20	108	-93
91	-36	122	-25	122	-99
98	-37	141	-25	141	-107
108	-39	157	-23	157	-113
122	-43	175	-26	175	-115
141	-46	191	-26	191	-124
157	-51	220	-25	220	-128
175	-53	253	-26	253	-138
191	-57	295	-27	295	-141
220	-62	343	-26	343	-144
253	-69	371	-23	371	-147
295	-78	1208	-14	1208	-206
343	-83				
371	-87				
1384	-110				

Table 11

AUTOGENOUS LENGTH-CHANGE FOR MIX NOS. I AND III

Mix No. I
Maximum size of aggregate: 3-in.
Temperature: 70°F
Specimen size: 6- by 18-in.

Age, Days	Length-change, Millionths
1	0
3	-4
7	-5
14	-5
21	-9
28	-14
45	-26
64	-28
80	-31
98	-34
114	-38
143	-43
176	-50
219	-53
260	-57
297	-60
708	-70
714	-68

Mix No. III
Maximum size of aggregate: 3/4-in.
Temperature: 70°F
Specimen size: 6- by 18-in.

Age, Days	Length-change, Millionths
1	0
3	+2
4	+2
7	+5
15	+6
22	+3
29	-4
32	-9
36	-15
43	-19
50	-20
57	-23
64	-20
74	-23
88	-28
107	-34
123	-40
141	-45
157	-50
186	-58
219	-65
262	-70
303	-75
340	-79
761	-93
861	-94

Table 12

CREEP AND ELASTIC STRAINS FOR MIX NO. III

Maximum Size of Aggregate: 3/4-in.
Specimen Size: 6- by 18-in.
Temperature: 70°F
Age at Loading: 28 Days
Applied Stress: 800 psi

Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	-0.382	0
0.021	-0.455	-0.073
0.210	-0.494	-0.112
0.750	-0.523	-0.141
1	-0.530	-0.148
2	-0.550	-0.168
3	-0.570	-0.188
4	-0.584	-0.202
8	-0.621	-0.239
11	-0.642	-0.260
15	-0.659	-0.277
18	-0.669	-0.287
22	-0.681	-0.299
29	-0.698	-0.316
36	-0.712	-0.330
44	-0.732	-0.350
60	-0.752	-0.370
79	-0.766	-0.384
95	-0.779	-0.397
113	-0.791	-0.409
129	-0.798	-0.416
158	-0.810	-0.428
191	-0.823	-0.441
234	-0.834	-0.452
275	-0.840	-0.458
312	-0.848	-0.466
833	-0.906	-0.524

Table 13

CREEP AND ELASTIC STRAINS FOR MIX NO. II

Maximum Size of Aggregate: 1 1/2 in.
Specimen Size: 6- by 18-in.
Temperature: 70°F

Age at loading: 1 Day Applied Stress: 60 psi		
Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	-0.966	0
0.021	-1.323	-0.357
0.125	-1.417	-0.451
1	-1.568	-0.602
2	-1.636	-0.670
3	-1.655	-0.689
6	-1.714	-0.748
9	-1.745	-0.779
13	-1.770	-0.804
16	-1.775	-0.808
20	-1.798	-0.832
23	-1.820	-0.854
26	-1.814	-0.848
30	-1.822	-0.856
34	-1.837	-0.870
41	-1.829	-0.863
48	-1.821	-0.855
55	-1.825	-0.858
62	-1.829	-0.863
69	-1.837	-0.871
76	-1.834	-0.868
83	-1.889	-0.923
85	-1.888	-0.922

Age at Loading: 3 Days Applied Stress: 200 psi		
Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	-0.663	0
0.021	-0.877	-0.213
0.125	-0.943	-0.280
0.416	-0.992	-0.328
1	-1.037	-0.373
4	-1.153	-0.490
7	-1.207	-0.543
11	-1.255	-0.591
14	-1.282	-0.618
18	-1.313	-0.650
21	-1.335	-0.671
24	-1.350	-0.686
28	-1.362	-0.698
32	-1.375	-0.711
39	-1.385	-0.721
46	-1.395	-0.731
53	-1.407	-0.743
60	-1.410	-0.746
67	-1.420	-0.756
74	-1.432	-0.768
81	-1.440	-0.776
83	-1.457	-0.793

Table 13 (Con't)

CREEP AND ELASTIC STRAINS FOR MIX NO. II

Maximum size of Aggregate: 1 1/2 in.
Specimen Size: 6- by 18-in.
Temperature: 70°F

Age at Increased Loading: 86 Days
Orig. Loading: 60 psi from 1-86 Days
Total Applied Stress: 800 psi

Days under Stress, t	Additional Creep Due to Stress of 740 psi, Millionths per psi
0.0001	0
0.021	-0.010
0.250	-0.030
1	-0.044
14	-0.083
64	-0.135
114	-0.156
214	-0.177
314	-0.189
414	-0.197
514	-0.203
614	-0.207
714	-0.210
814	-0.212

Age at Increased Loading: 86 Days
Orig. Loading: 200 psi from 3-86 Days
Total Applied Stress: 800 psi

Days under Stress, t	Additional Creep Due to Stress of 600 psi, Millionths per psi
0.0001	0
0.021	-0.033
0.229	-0.051
1	-0.064
16	-0.130
66	-0.164
116	-0.182
216	-0.197
316	-0.207
416	-0.213
516	-0.217
616	-0.222
716	-0.224
816	-0.226

Table 13 (Con't)

CREEP AND ELASTIC STRAINS FOR MIX NO. II

Maximum Size of Aggregate: 1 1/2 in.
Specimen Size: 6- by 18-in.

Temperature: 40°F
Age at Loading: 7 Days
Applied Stress: 300 psi

Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	-0.532	0
0.021	-0.694	-0.162
0.125	-0.710	-0.179
0.375	-0.728	-0.197
1	-0.750	-0.219
3	-0.778	-0.247
7	-0.815	-0.283
14	-0.852	-0.320
17	-0.863	-0.332
21	-0.880	-0.349
24	-0.888	-0.357
28	-0.902	-0.370
34	-0.917	-0.386
42	-0.935	-0.404
49	-0.944	-0.412
56	-0.995	-0.464
63	-0.994	-0.463
70	-1.005	-0.474
77	-1.009	-0.477
84	-1.045	-0.514
91	-1.044	-0.512
93	-1.044	-0.512

Temperature: 70°F
Age at Loading: 7 Days
Applied Stress: 300 psi

Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	-0.530	0
0.021	-0.660	-0.130
0.125	-0.712	-0.182
0.142	-0.746	-0.216
1	-0.779	-0.249
3	-0.842	-0.312
7	-0.915	-0.385
11	-0.959	-0.429
14	-0.980	-0.450
17	-1.002	-0.472
21	-1.027	-0.497
24	-1.038	-0.508
28	-1.055	-0.525
34	-1.065	-0.535
42	-1.075	-0.545
49	-1.085	-0.555
56	-1.097	-0.567
63	-1.108	-0.578
70	-1.115	-0.585
77	-1.126	-0.596
84	-1.132	-0.602
91	-1.139	-0.609
93	-1.137	-0.607

Table 13 (Con't)

CREEP AND ELASTIC STRAINS FOR MIX NO. II

Maximum Size of Aggregate: 1 1/2-in.
Specimen Size: 6- by 18-in.

Age at Increased Loading: 100 Days Orig. Loading: 300 psi from 7-100 Days Total Applied Stress: 800 psi	
Days under Stress, t	Additional Creep Due to Stress of 500 psi, Millionths per psi
0.0001	0
0.021	-0.061
0.210	-0.101
1	-0.137
6	-0.185
56	-0.318
106	-0.357
206	-0.396
306	-0.422
406	-0.442
506	-0.455
606	-0.468
706	-0.478
806	-0.487
906	-0.496

Age at Increased Loading: 100 Days Original Loading: 300 psi from 7-100 Days Total Applied Stress: 800 psi	
Days under Stress, t	Additional Creep Due to Stress of 500 psi, Millionths per psi
0.0001	0
0.021	-0.027
0.229	-0.042
1	-0.057
6	-0.078
66	-0.134
106	-0.148
206	-0.156
306	-0.164
406	-0.166
506	-0.169
606	-0.173
706	-0.176
806	-0.178

Table 13 (Con't)

CREEP AND ELASTIC STRAINS FOR MIX NO. II

Maximum Size of Aggregate: 1 1/2-in.
Specimen Size: 6- by 18-in.
Temperature: 100°F
Age at Loading: 7 Days
Applied Stress: 300 psi

Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	-0.502	0
0.021	-0.590	-0.088
0.125	-0.626	-0.124
0.333	-0.660	-0.158
1	-0.749	-0.247
3	-0.818	-0.316
7	-0.888	-0.386
14	-0.937	-0.435
17	-0.950	-0.448
21	-0.966	-0.464
24	-0.977	-0.475
28	-0.985	-0.483
34	-1.001	-0.499
42	-1.011	-0.509
49	-1.011	-0.509
56	-1.026	-0.524
63	-1.034	-0.532
70	-1.037	-0.535
77	-1.045	-0.543
84	-1.064	-0.562
91	-1.058	-0.556
93	-1.059	-0.557

Table 13 (Con't)

CREEP AND ELASTIC STRAINS FOR MIX NO. II

Maximum Size of Aggregate: 1 1/2 in.
Specimen Size: 6- by 18-in.
Temperature: 100°F
Age at Increased Loading: 100 Days
Original Loading: 300 psi from 7-100 Days
Total Applied Stress: 800 psi

Days under Stress, t	Additional Creep Due to Stress of 500 psi, Millionths per psi
0.0001	0
0.021	-0.028
0.210	-0.039
1	-0.052
8	-0.077
15	-0.094
29	-0.108
57	-0.124
75	-0.132
91	-0.137
120	-0.146
153	-0.156
243	-0.172
271	-0.177

Table 13 (Con't)

CREEP AND ELASTIC STRAINS FOR MIX NO. II

Maximum Size of Aggregate: 1 1/2-in.
Specimen Size: 6- by 18-in.
Temperature: 70°F

Age at Loading: 28 Days Applied Stress: 800 psi		
Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	-0.364	0
0.021	-0.431	-0.067
0.333	-0.469	-0.105
1	-0.497	-0.133
3	-0.522	-0.157
7	-0.554	-0.190
10	-0.566	-0.202
14	-0.581	-0.216
17	-0.589	-0.225
21	-0.599	-0.235
24	-0.607	-0.242
28	-0.613	-0.248
35	-0.624	-0.260
42	-0.636	-0.271
49	-0.635	-0.270
56	-0.643	-0.279
66	-0.650	-0.286
80	-0.658	-0.293
99	-0.666	-0.301
115	-0.674	-0.310
133	-0.683	-0.318
149	-0.688	-0.323
178	-0.697	-0.333
211	-0.704	-0.339
254	-0.711	-0.347
295	-0.715	-0.350
332	-0.722	-0.358
752	-0.773	-0.408

Age at Loading: 90 Days Applied Stress: 800 psi		
Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	-0.296	0
0.021	-0.343	-0.047
0.250	-0.345	-0.049
0.833	-0.358	-0.062
1	-0.360	-0.064
3	-0.375	-0.079
7	-0.391	-0.095
15	-0.396	-0.100
66	-0.434	-0.138
84	-0.463	-0.167
100	-0.473	-0.177
129	-0.487	-0.191
162	-0.498	-0.202
205	-0.502	-0.206
253	-0.508	-0.212
281	-0.514	-0.218
701	-0.557	-0.261

Table 14

LONGITUDINAL STRAINS, LATERAL STRAINS, AND POISSON'S RATIOS FOR MIX NO. II

Maximum Size of Aggregate: 1 1/2-in.
Specimen Size: 16- by 44-in.
Temperature: 70°F
Age at Loading: 28 Days
Applied Stress: 800 psi

Days under Stress, t	Longitudinal Strain, Millionths			Lateral Strain, Millionths			Poisson's Ratio
	Creep plus Elastic	Creep plus Elastic per psi	Creep per psi	Creep plus Elastic	Creep plus Elastic per psi	Creep per psi	
0.0001	-291	-0.364	0	+60	+0.075	0	0.191
0.021	-345	-0.431	-0.067	+64	+0.080	+0.005	0.186
0.125	-366	-0.457	-0.093	+67	+0.084	+0.009	0.183
0.625	-388	-0.485	-0.121	+68	+0.086	+0.011	0.176
1	-395	-0.493	-0.129	+70	+0.087	+0.012	0.176
3	-418	-0.522	-0.158	+70	+0.087	+0.012	0.167
7	-446	-0.557	-0.193	+73	+0.091	+0.016	0.163
10	-458	-0.573	-0.209	+73	+0.091	+0.016	0.160
14	-471	-0.589	-0.225	+75	+0.093	+0.018	0.159
17	-479	-0.599	-0.235	+75	+0.094	+0.019	0.157
21	-490	-0.613	-0.249	+79	+0.099	+0.024	0.161
24	-496	-0.621	-0.257	+78	+0.098	+0.023	0.158
28	-502	-0.628	-0.264	+79	+0.098	+0.023	0.157
35	-511	-0.639	-0.275	+80	+0.101	+0.026	0.157
42	-519	-0.648	-0.284	+81	+0.101	+0.026	0.156
49	-525	-0.656	-0.292	+82	+0.103	+0.028	0.156
56	-531	-0.663	-0.299	+82	+0.103	+0.028	0.155
66	-538	-0.673	-0.309	+82	+0.103	+0.028	0.153
80	-546	-0.682	-0.318	+83	+0.104	+0.029	0.152
99	-554	-0.693	-0.329	+84	+0.105	+0.030	0.152
115	-559	-0.699	-0.335	+85	+0.107	+0.032	0.153
133	-566	-0.708	-0.344	+86	+0.107	+0.032	0.151
149	-570	-0.712	-0.348	+86	+0.107	+0.032	0.151
178	-578	-0.722	-0.358	+86	+0.107	+0.032	0.148
211	-583	-0.729	-0.365	+87	+0.109	+0.034	0.149
254	-588	-0.735	-0.371	+88	+0.110	+0.035	0.150
295	-592	-0.740	-0.376	+91	+0.113	+0.038	0.153
332	-594	-0.743	-0.379	+93	+0.116	+0.041	0.156
743	-613	-0.766	-0.402	+101	+0.126	+0.051	0.165
749	-613	-0.767	-0.403	+101	+0.126	+0.051	0.165

Table 15

LONGITUDINAL AND LATERAL STRAINS AND POISSON'S RATIOS FOR MIX NO. I

Maximum Size of Aggregate: 3-in.
Specimen Size: 16- by 44-in.
Temperature: 70°F
Age at Loading: 28 Days
Applied Stress: 800 psi

Days under Stress, t	Longitudinal Strain, Millionths			Lateral Strain, Millionths			Poisson's Ratio
	Creep plus Elastic	Creep plus Elastic per psi	Creep per psi	Creep plus Elastic	Creep plus Elastic per psi	Creep per psi	
0.0001	-407	-0.509	0	+78	+0.098	0	0.192
0.021	-487	-0.609	-0.100	+108	+0.135	+0.037	0.222
0.208	-530	-0.663	-0.154	+116	+0.146	+0.048	0.220
1	-565	-0.706	-0.197	+121	+0.151	+0.053	0.214
3	-590	-0.738	-0.228	+123	+0.154	+0.056	0.208
10	-629	-0.786	-0.277	+126	+0.158	+0.060	0.201
17	-648	-0.810	-0.300	+127	+0.159	+0.061	0.196
24	-667	-0.834	-0.325	+126	+0.158	+0.060	0.189
36	-678	-0.848	-0.338	+129	+0.161	+0.063	0.190
52	-692	-0.865	-0.356	+132	+0.165	+0.067	0.190
70	-704	-0.880	-0.370	+133	+0.167	+0.069	0.189
86	-709	-0.887	-0.377	+137	+0.171	+0.073	0.193
115	-721	-0.901	-0.392	+135	+0.169	+0.071	0.188
148	-728	-0.910	-0.400	+137	+0.171	+0.073	0.188
191	-736	-0.920	-0.411	+139	+0.174	+0.076	0.189
232	-743	-0.929	-0.420	+137	+0.171	+0.073	0.184
269	-748	-0.935	-0.426	+133	+0.166	+0.068	0.178
680	-778	-0.973	-0.464	+128	+0.160	+0.062	0.164
686	-780	-0.976	-0.466	+131	+0.164	+0.066	0.168

Table 16

TENSILE CREEP AND ELASTIC STRAINS FOR MIX NO. II

Maximum Size of Aggregate: 1 1/2 in.
Specimen Size: 6- by 25-in.
Temperature: 70°F

Age at Loading: 7 Days
Applied Stress: 50 psi

Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	+0.262	0
0.021	+0.338	+0.076
0.125	+0.353	+0.091
1	+0.411	+0.149
5	+0.527	+0.265
11	+0.587	+0.325
14	+0.614	+0.352
22	+0.699	+0.437
26	+0.734	+0.472
40	+0.781	+0.519
56	+0.810	+0.548
85	+0.798	+0.536
118	+0.821	+0.559
161	+0.893	+0.631
202	+0.923	+0.661
239	+0.970	+0.708
629	+1.149	+0.887

Age at Loading: 28 Days
Applied Stress: 100 psi

Days under Stress, t	Millionths per psi	
	Creep plus Elastic	Creep
0.0001	+0.192	0
0.021	+0.232	+0.040
0.125	+0.245	+0.053
1	+0.264	+0.072
5	+0.297	+0.105
19	+0.361	+0.169
35	+0.402	+0.210
64	+0.406	+0.215
97	+0.429	+0.238
140	+0.497	+0.305
181	+0.534	+0.343
218	+0.539	+0.348
608	+0.605	+0.414

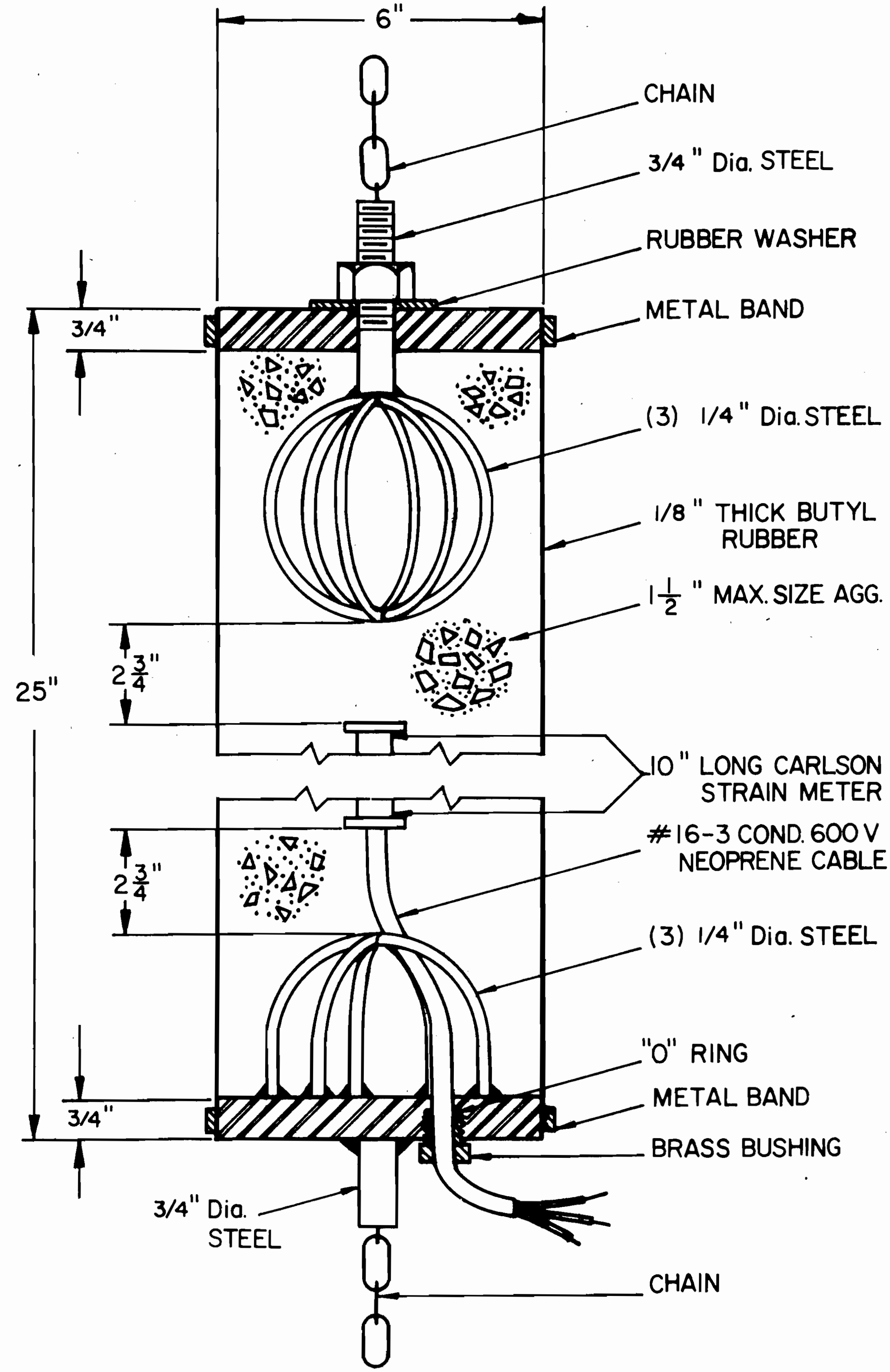

FIG. I TENSILE CREEP SPECIMEN

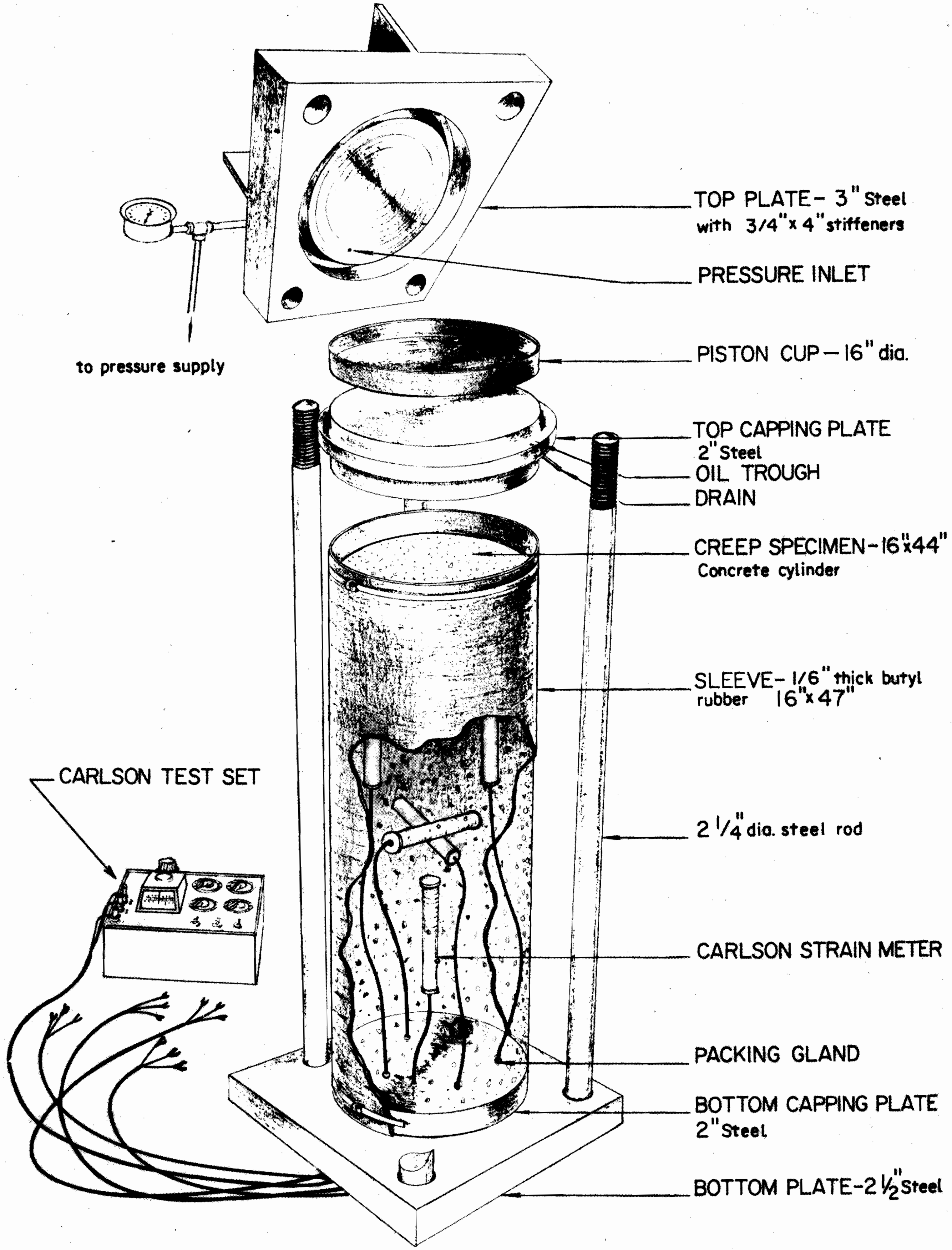

FIG. 2 LOADING FRAME AND 16"x 44" CONCRETE SPECIMEN

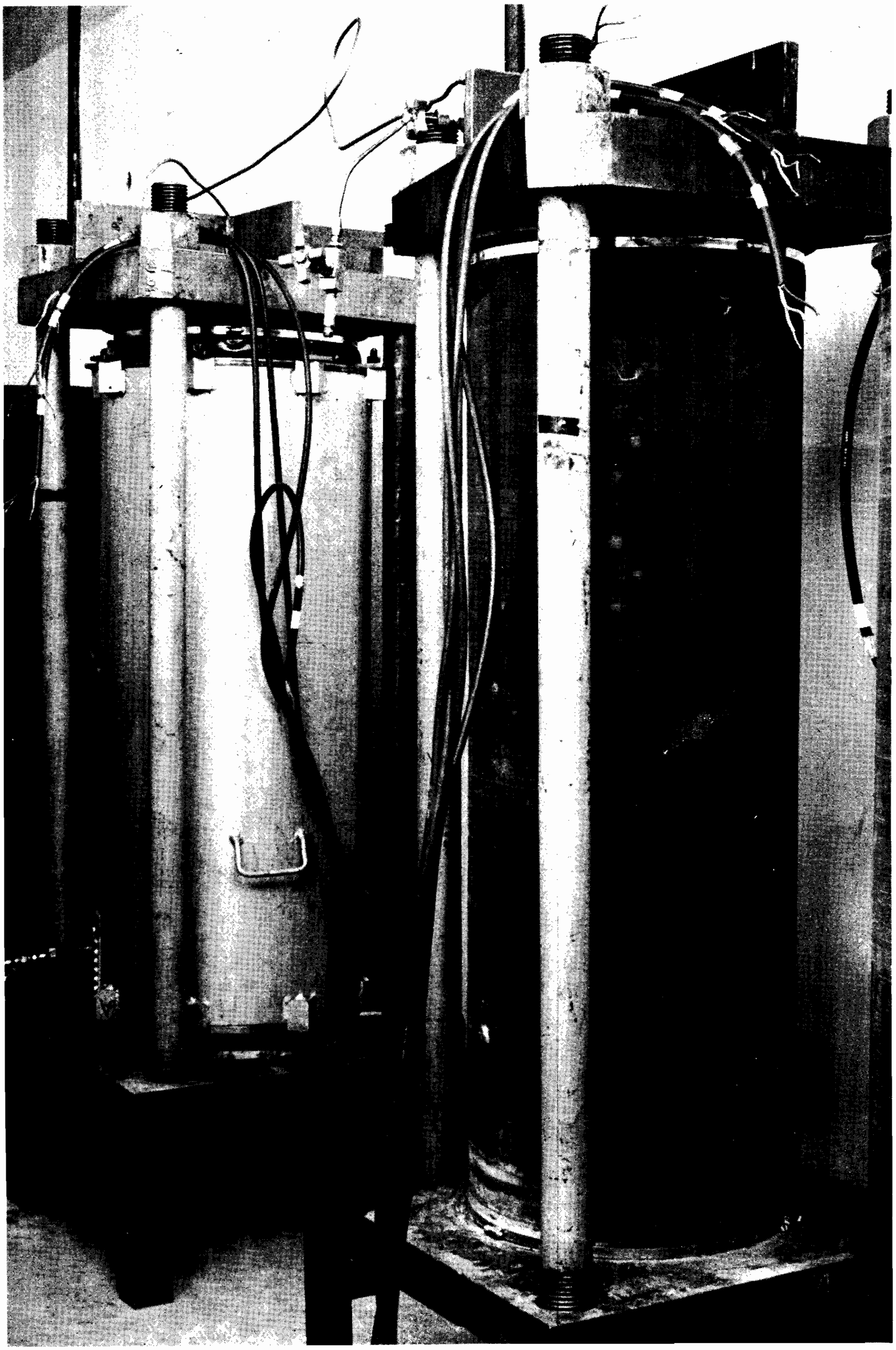

FIG.3 16"x44" CONCRETE SPECIMENS UNDER UNIAXIAL AND UNDER TRIAXIAL LOADING

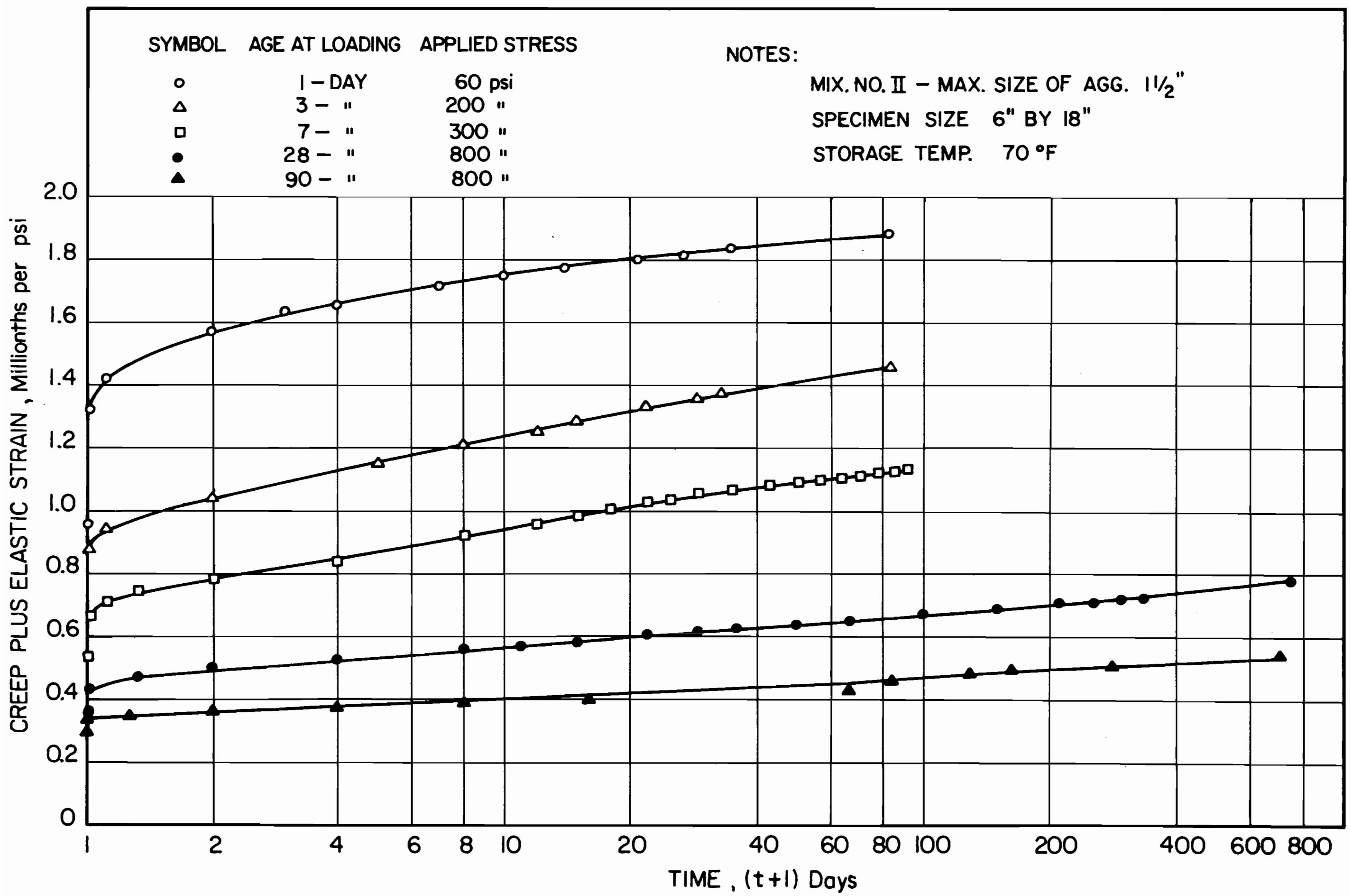

FIG. 4 EFFECT OF AGE AT TIME OF LOADING UPON CREEP PLUS ELASTIC STRAIN FOR MIX. NO. II

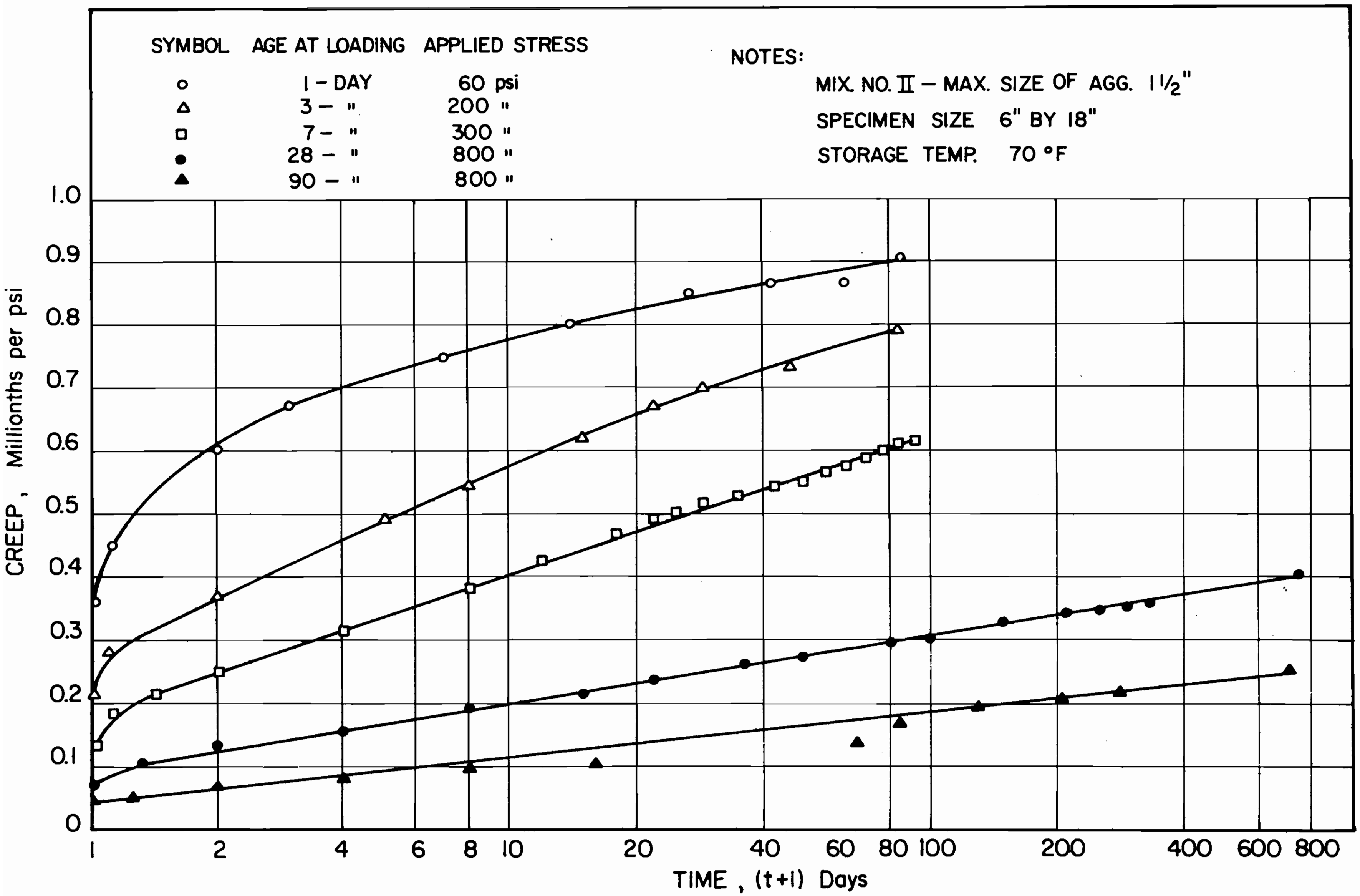

FIG. 5 EFFECT OF AGE AT TIME OF LOADING UPON CREEP FOR MIX. NO. II

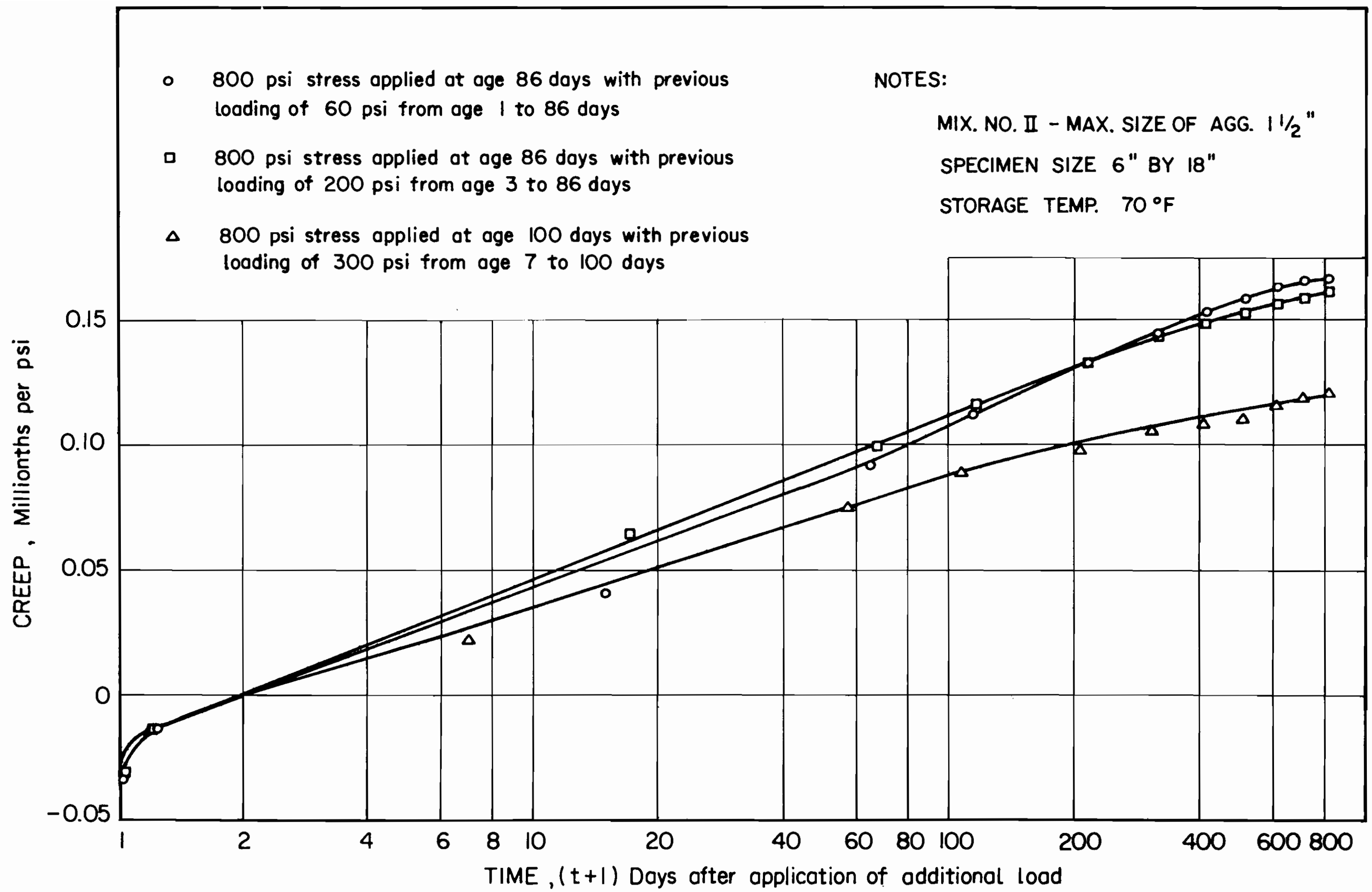

FIG.6 EFFECT OF PREVIOUS LOAD HISTORY UPON CREEP AFTER APPLICATION OF ADDITIONAL STRESS FOR MIX. NO. II WITH ZERO CREEP PLOTTED AT AGE 1 DAY AFTER LOADING

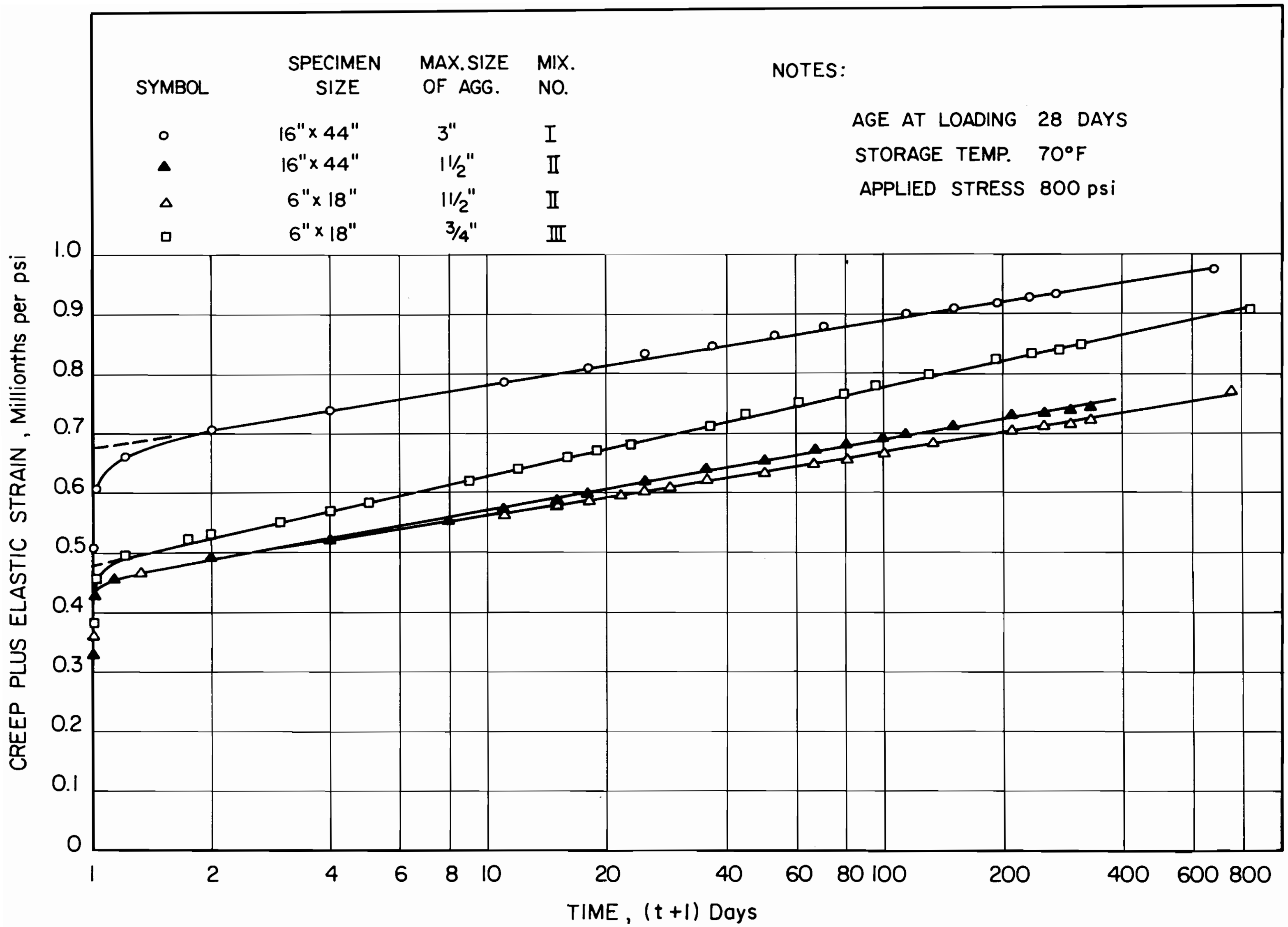

FIG. 7 EFFECT OF SPECIMEN SIZE AND MAXIMUM SIZE OF AGGREGATE UPON CREEP PLUS ELASTIC STRAIN

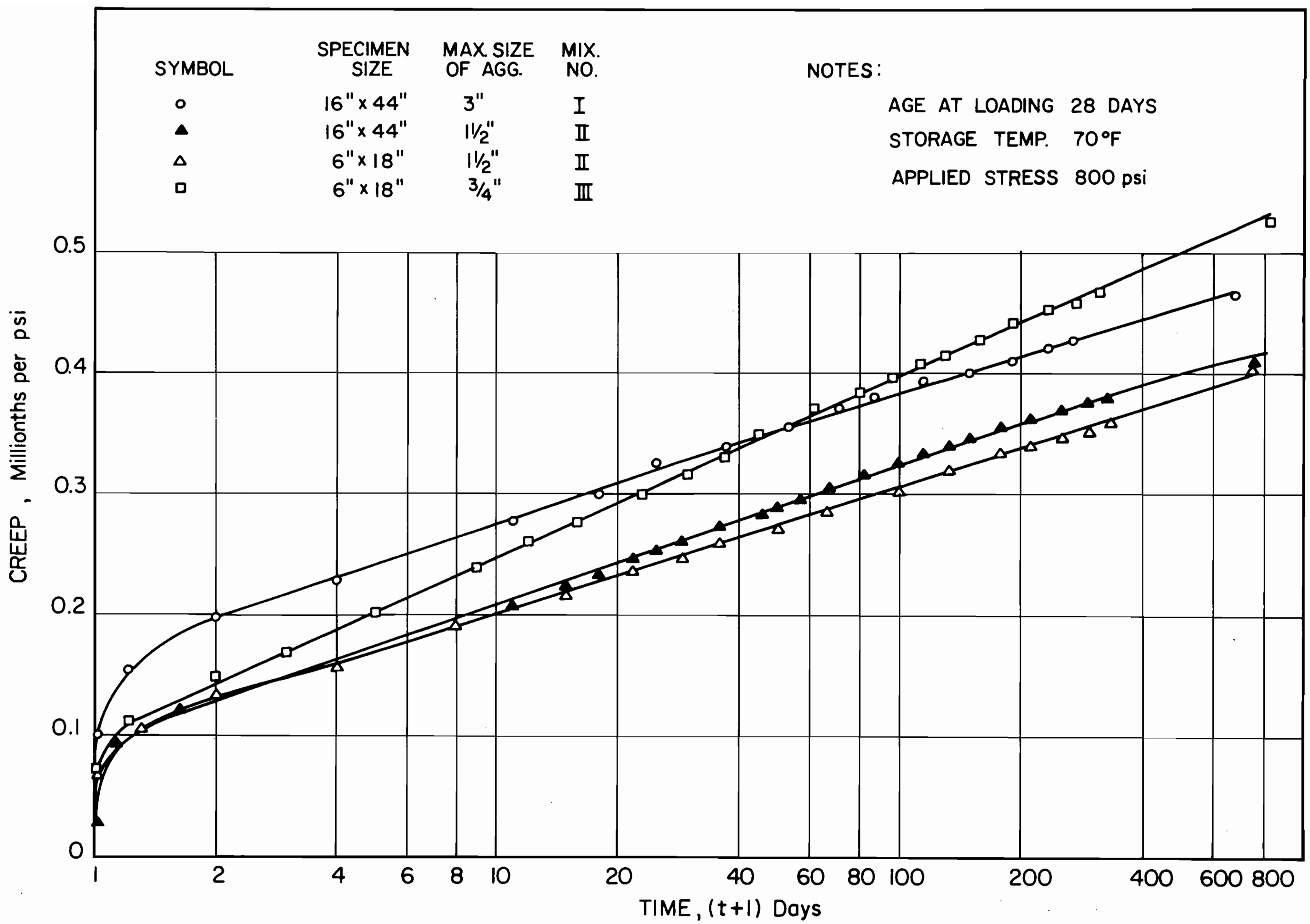

FIG.8 EFFECT OF SPECIMEN SIZE AND MAXIMUM SIZE OF AGGREGATE UPON CREEP

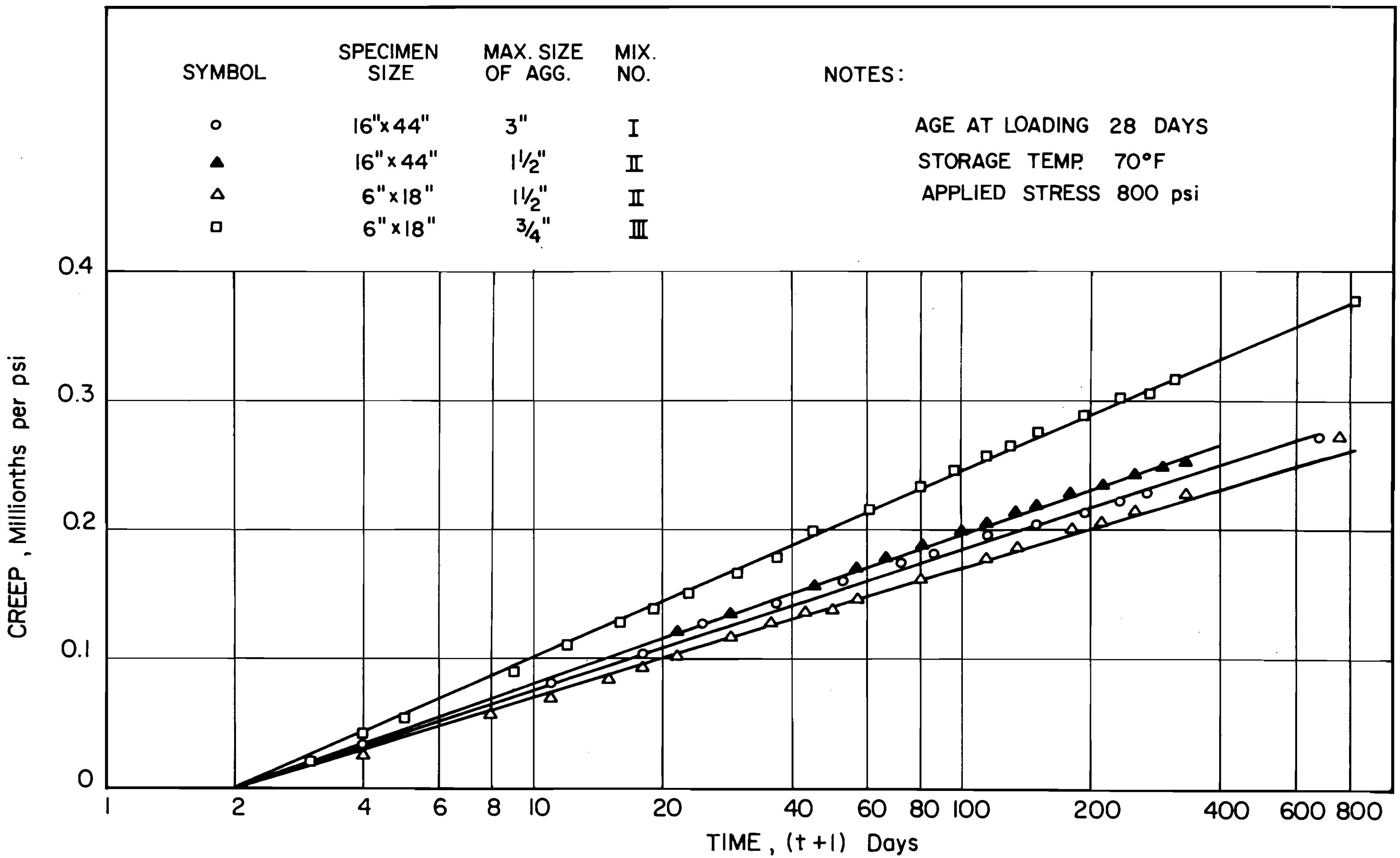

FIG. 9 EFFECT OF SPECIMEN SIZE AND MAXIMUM SIZE OF AGGREGATE UPON CREEP WITH ZERO CREEP PLOTTED AT AGE 1 DAY AFTER LOADING

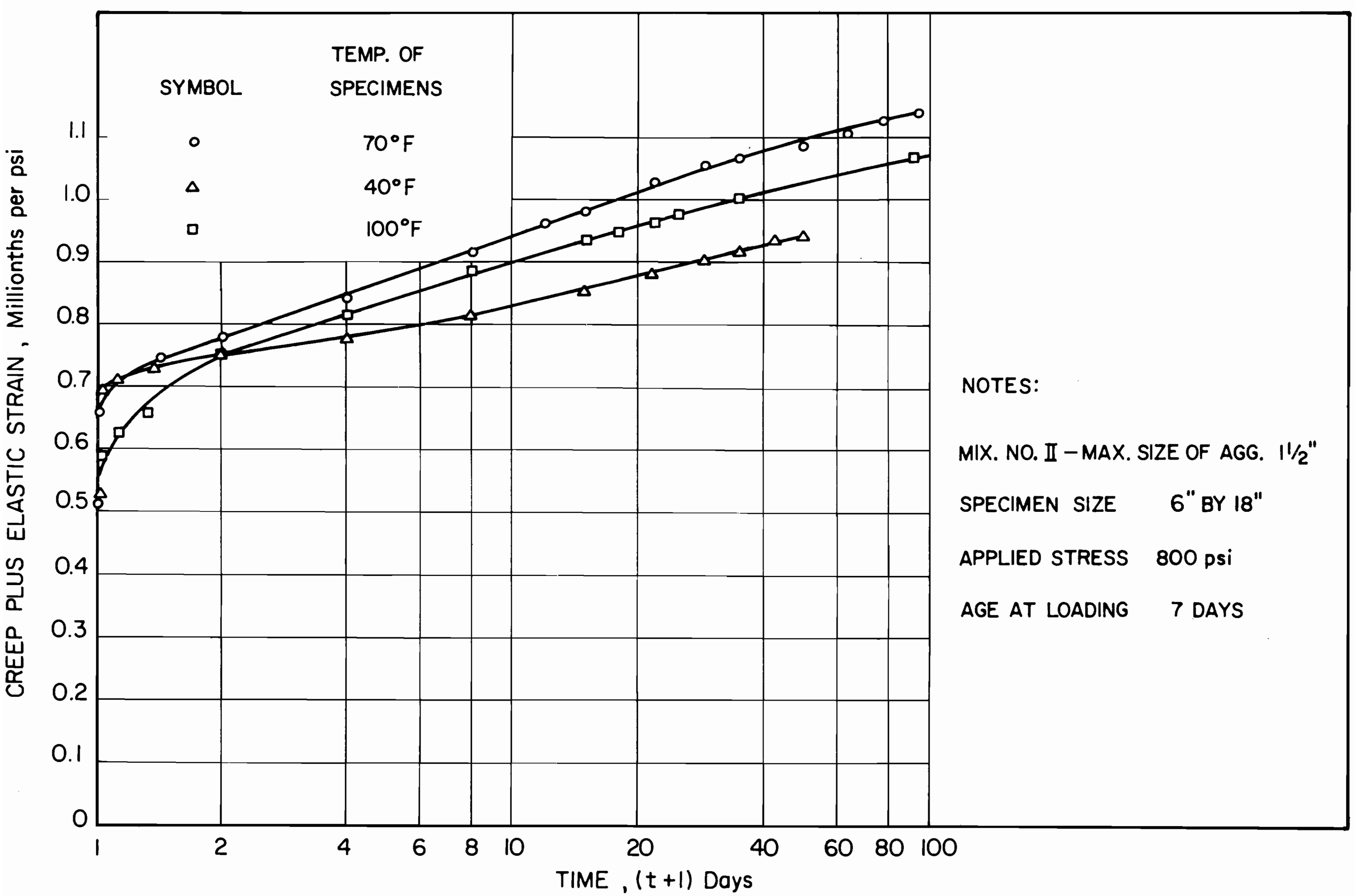

FIG.10 EFFECT OF TEMPERATURE UPON CREEP PLUS ELASTIC STRAIN FOR MIX. NO. II

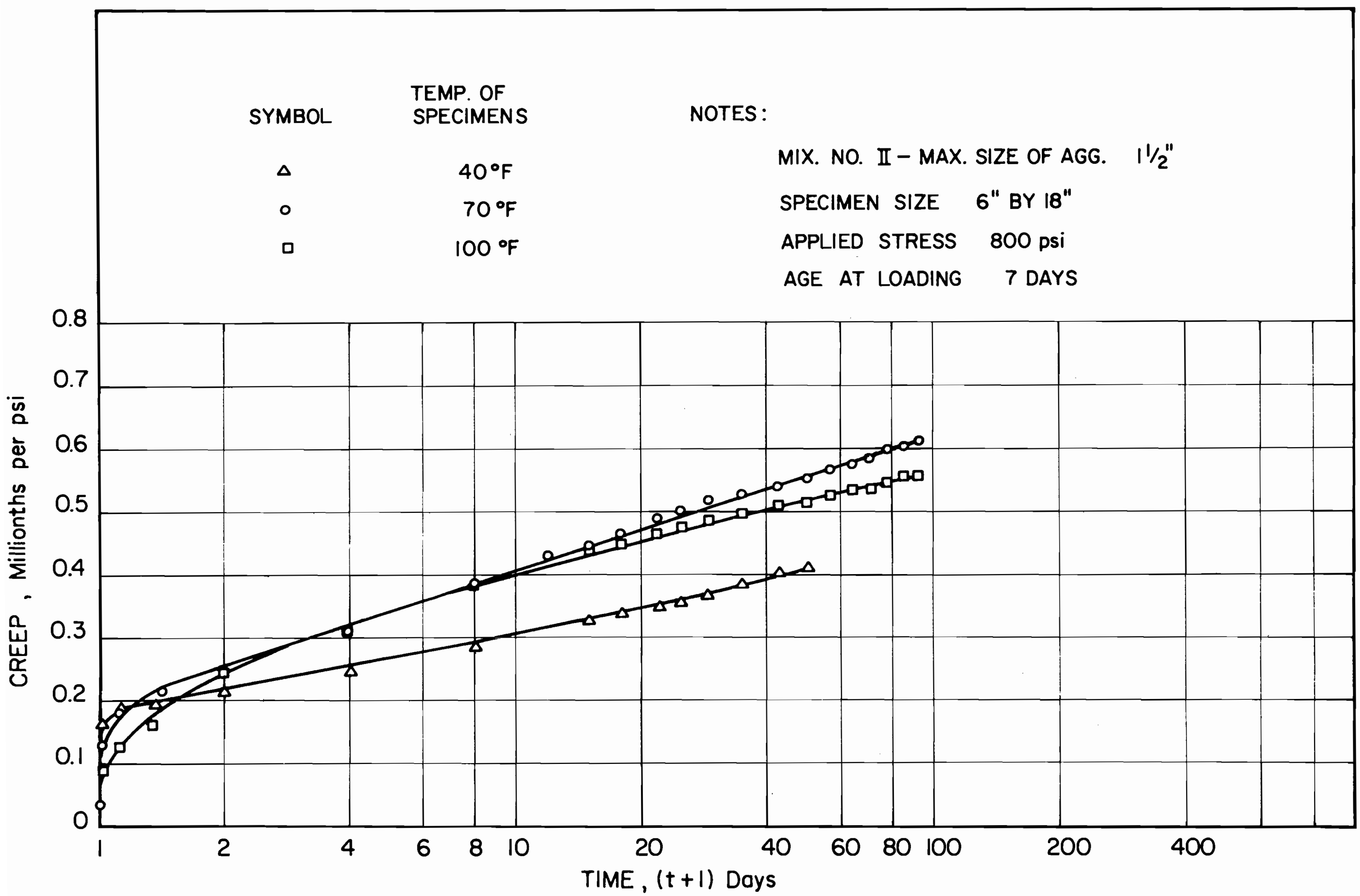

FIG. 11 EFFECT OF TEMPERATURE UPON CREEP FOR MIX. NO. II

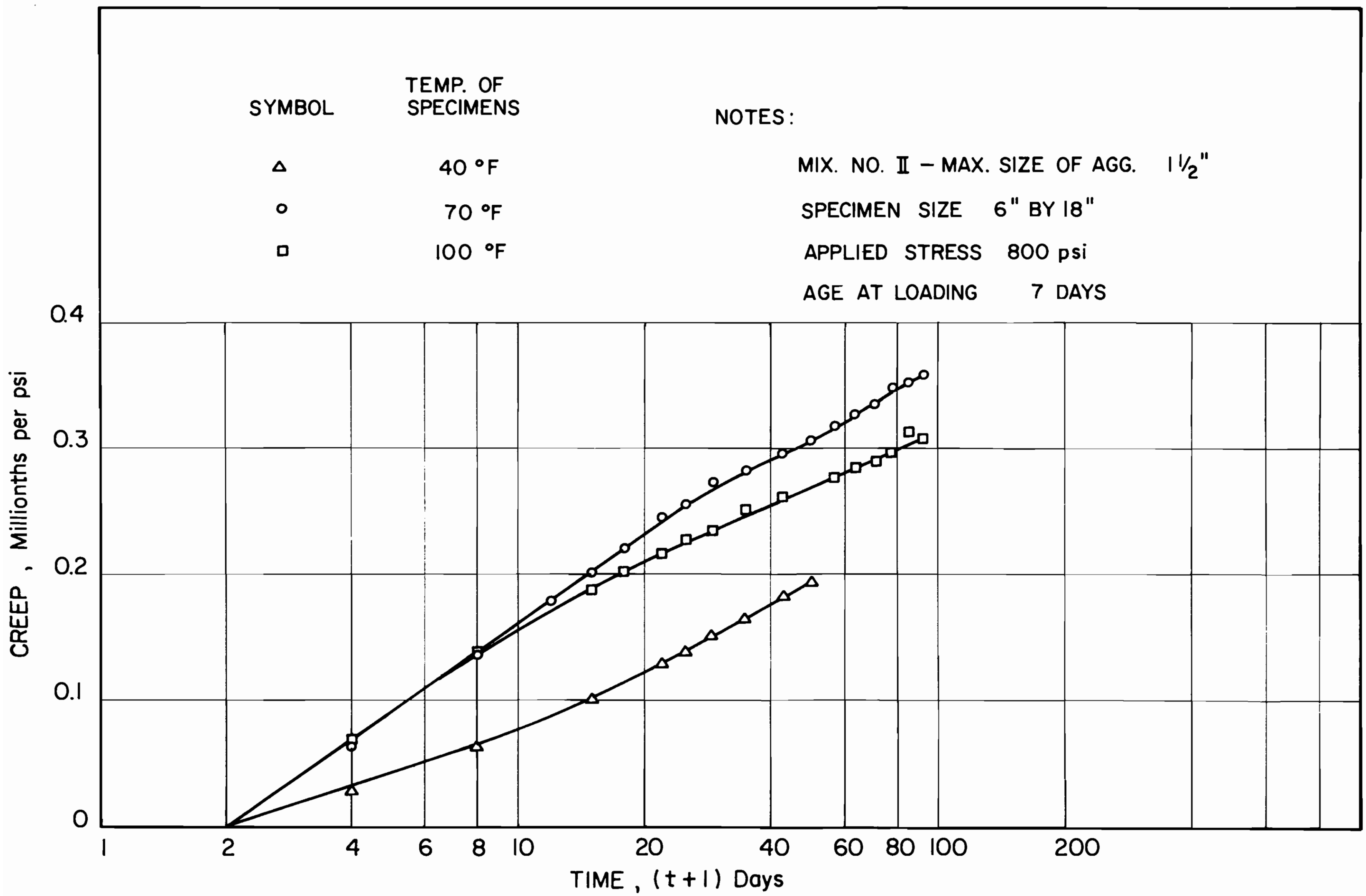

FIG. 12 EFFECT OF TEMPERATURE UPON CREEP WITH ZERO CREEP PLOTTED AT AGE 1 DAY AFTER LOADING FOR MIX. NO. II

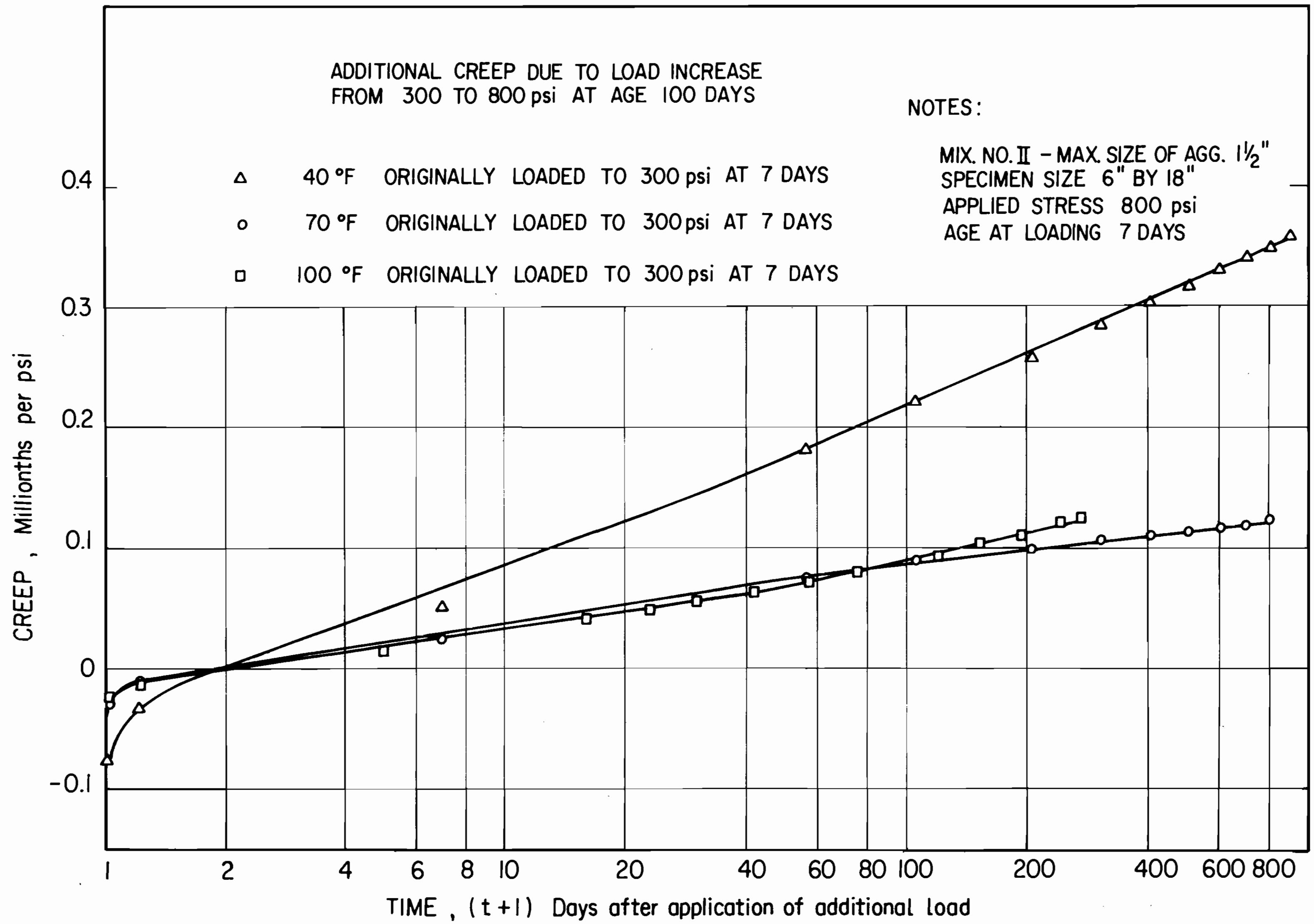

FIG. 13 EFFECT OF PREVIOUS LOAD HISTORY UPON CREEP OF CONCRETE MAINTAINED AT DIFFERENT TEMP. FOR MIX. NO. II WITH ZERO CREEP PLOTTED AT AGE 1 DAY AFTER LOADING

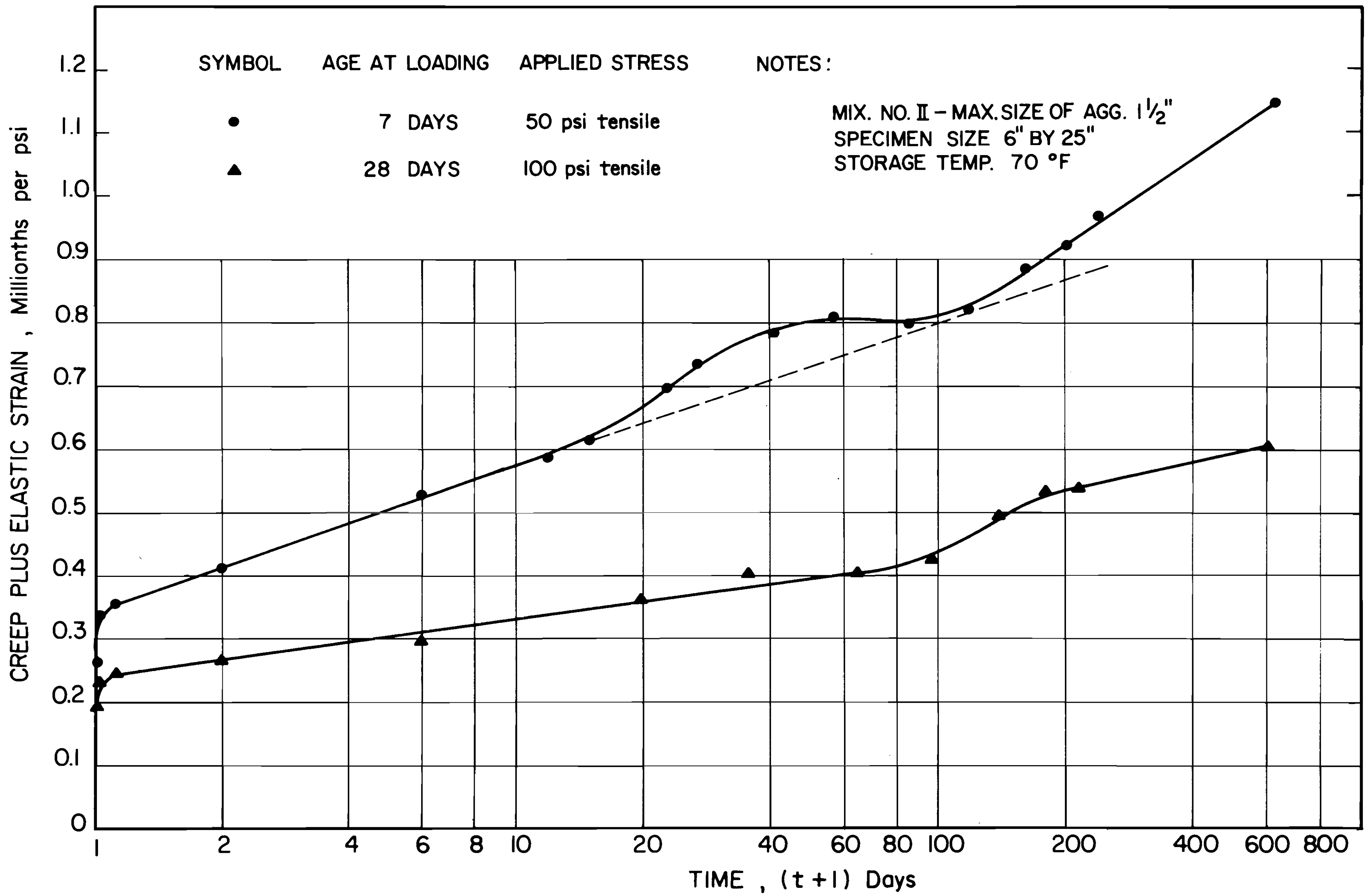

FIG. 14 TENSILE CREEP PLUS ELASTIC STRAIN FOR AGE AT LOADING OF 7 AND 28 DAYS FOR MIX. NO. II

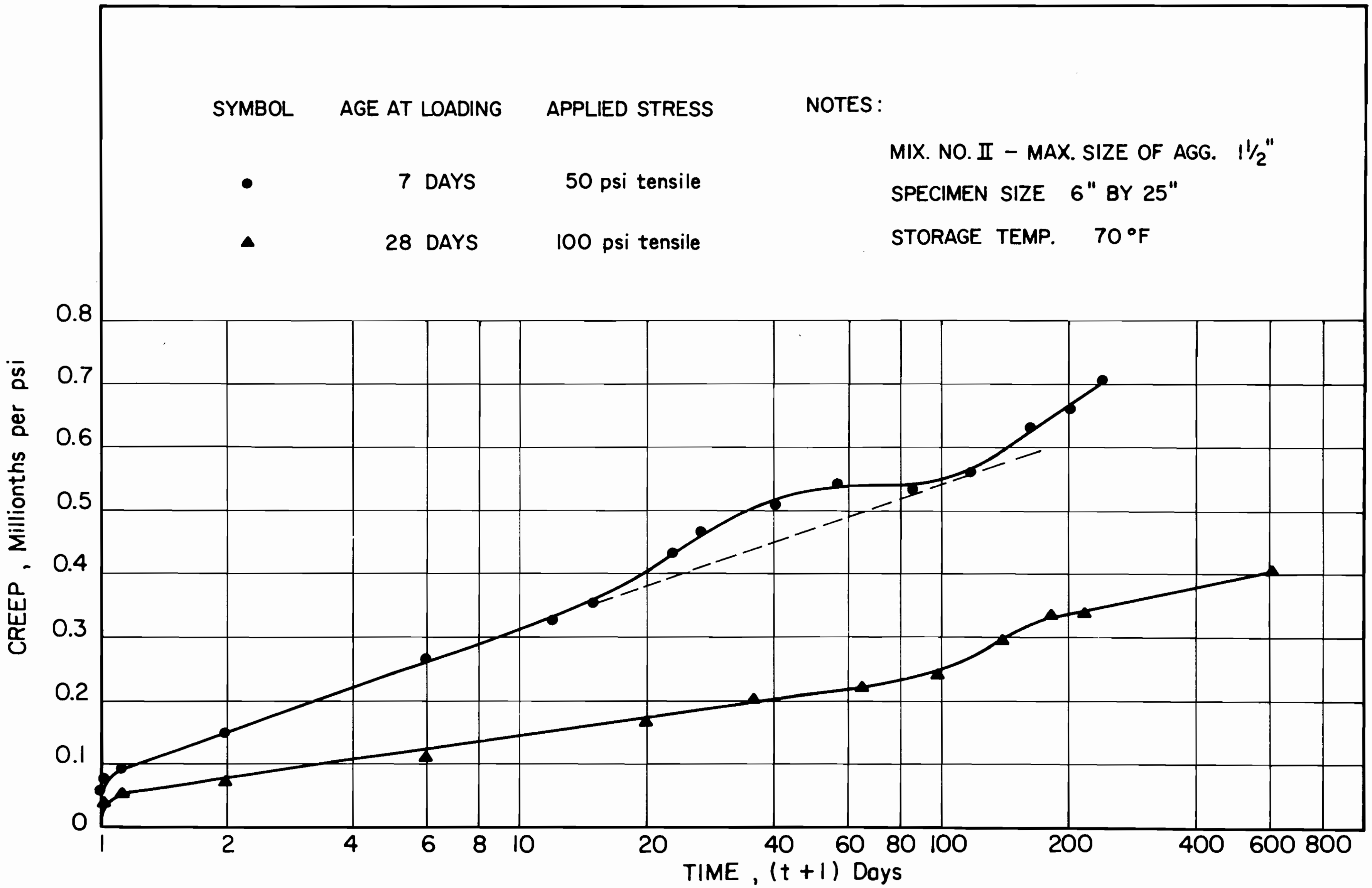

FIG. 15 TENSILE CREEP FOR AGE AT LOADING OF 7 AND 28 DAYS FOR MIX. NO. II

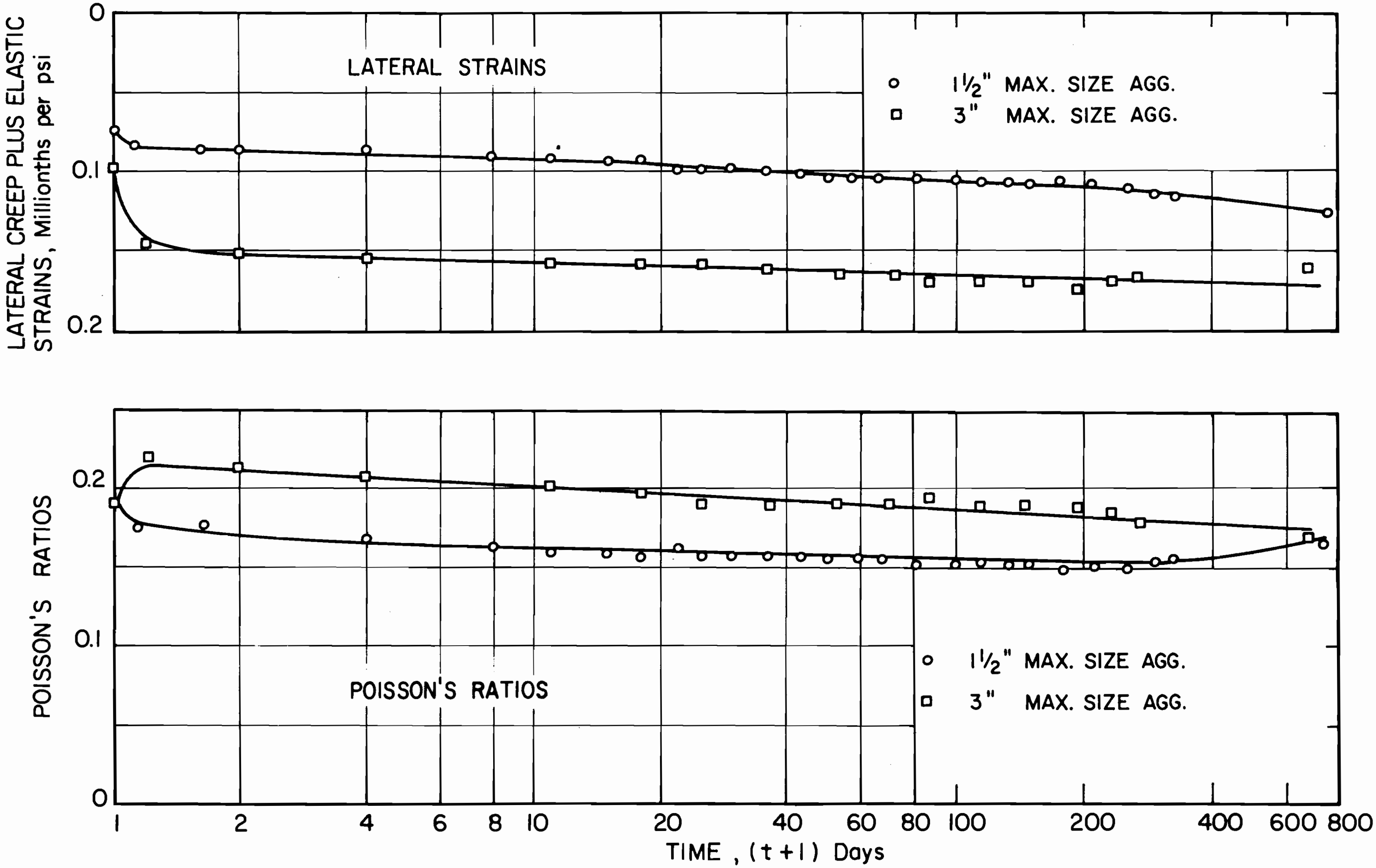

FIG. 16 LATERAL STRAINS AND POISSON'S RATIOS FOR 16" BY 44" CONCRETE SPECIMENS FOR MIX. NOS. I AND II