Title

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SHRINKAGE AND CRACKING CHARACTERISTICS OF CONCRETE CONTAINING SUNOL AGGREGATES

As Used in the Construction of the Engineering Building
at San Jose State College

by

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INTRODUCTION

This report presents the results of a study of shrinkage and cracking characteristics of concretes containing materials the same as those used in the construction of the Engineering Building on the San Jose State College campus. These studies were carried out in the Engineering Materials Laboratory of the University of California, Berkeley, California, during the period of April to July 1961.

The purpose of these studies was to determine the relative magnitudes of shrinkage and of cracking tendency of concrete mixes made with Sunol aggregates as compared with the results obtained on concretes made with Fair Oaks aggregates. Altogether eight laboratory-mixed concretes and four job-mixed concretes were evaluated. They had a cement content of either 6 or 6½ scy and a slump ranging from ½ in., to 7½ in. With the exception of two job-mixed concretes which contained 1½-in. maximum-size aggregate, all other concretes were made with 3/4-in. maximum-size aggregate.

CONCRETE MATERIALS AND MIXES

Portland Cement

The portland cement used in this investigation was Calaveras Type II cement, the same brand and type as that used for the concrete of the Engineering Building.

The chemical analysis of this cement is given in Table 1.

<u>Aggregates</u>

Two types of aggregates were used in these tests: (1) Sunol, supplied by the Concrete Services Company of San Jose, which was used in construction of the Engineering Building, and (2) Fair Oaks, supplied by Pacific Cement and Aggregates of San Francisco.

<u>Physical Properties</u>.--The physical properties of the aggregates are given in Table 2.

The fineness modulus of Sunol sand was 3.46, and of Fair Oaks sand 2.86. Their absorption capacity was 2.3 and 1.9 percent respectively. The specific gravity of both sands was 2.64. The 3/4-inch maximum-size Sunol aggregate had a specific gravity of 2.67; the corresponding size of Fair Oaks had a specific gravity of 2.79.

The Sand Equivalent for the Sunol sand was only 57, whereas that for the Fair Oaks sand was 80. State specifications require that the Sand Equivalent value be not less than 75. Both of the coarse aggregates met the minimum required Cleanness Value of 75.

<u>Petrographic Analyses</u>.--The petrographic analyses of the aggregates as reported in Corps of Engineers, U.S.A. Technical Memorandum No. 6-370, "Test Data Concrete Aggregates in Continental United States", are summarized as follows:

The Sunol coarse aggregate consists of two types of sandstone, a bluish-gray, composed of feldspar and quartz, and a tan with flat bedding planes. There are also traces of vein quartz and altered andesite.

The Sunol sand consists of quartz, biotite, magnetite, amphibole, pyroxene, antigorite, and glaucophane.

The Fair Oaks gravel consists of basic igneous rocks (24%), basic metaigneous rocks (42%), andesite (14%), sandstone (11%), quartzite (5%), slate (2%), vein quartz, chert, and schist (2%).

The Fair Oaks sand is composed predominantly of quartz and feldspar, plus minor amounts of all the rock types found in the gravel, and minor amounts of hornblende and biotite.

Concrete Mixes

The mix proportions for the three basic concrete mixes evaluated in this investigation are given in Table 3. Mix proportions of concretes employed in this investigation were similar to those used in the construction of the Engineering Building.

Eight of the concretes were batched and mixed in the laboratory. As shown in Table 4, four of these had a cement content of 6 scy (Mixes 1 to 4) and the other four had a cement content of 6½ scy (Mixes 5 to 8). Of these two groups of concrete mixes, three contained Sunol and one contained Fair Oaks aggregate. The maximum size of aggregate was 3/4 inch, and the sand-to-aggregate ratio was 0.49 by weight.

Four additional concrete mixtures were taken from the truck mixers at the job site (Table 4). One of these had a cement content of 6 scy (Mix 9), and the other three had a cement content of 6½ scy (Mixes 10 to 12). Two of these mixes (Mixes 11 and 12) contained 1½-in. maximum-size aggregate. All job-mixed concretes were made with Sunol aggregates.

Mixes 2 and 6, which had the low slumps of ½ and 2½ in. respectively, had the same water content (50 lb. per sack of cement) as that shown on the records for the job mixes. Since the specifications called for a maximum slump of 4 inches, the water-cement ratio of the other mixes was increased so as to produce a slump of 3 to 4 inches. Since frequently the job mixes had slumps as high as 7 inches, two of the laboratory mixes (Mixes 4 and 8) were designed to simulate such mixes. The actual water contents of job mixes (Mixes 9 to 12) could not be determined, since no record was kept on the job as to the additional water added during retempering.

Specifications for the Engineering Building required that the concrete have a minimum 28-day compressive strength of 3,000 psi.

MANUFACTURE OF SPECIMENS AND MEASUREMENTS

Mixing of Concretes

All laboratory concretes were mixed in a six-cubic-foot, pan-type, Cumflow mixer. The aggregates and cement were placed in the mixer first, and were mixed together for half a minute. Water was added during the next full minute of mixing. The mixing was then continued for another three minutes. The concrete was then discharged into wheelbarrows and used for casting of specimens. Mixing and casting were done at 70°F.

Test Specimens

Shrinkage and crack-resistance specimens for concretes containing 3/4-inch maximum-size aggregates were cast in 3 by 3 by 40-inch molds. In order to produce the restraining effect for the crack-resistance bars, a steel rod of 3/4-inch diameter was secured in the mold longitudinally along the centerline of the mold. As shown in Fig. 1, this steel rod was threaded at each end for a distance of 3 inches to provide anchorage. To prevent bond along the remaining 34-inch length, the bar was covered with a 1/8 inch-thick soft rubber tube.

For the job concretes containing 1½-inch maximum-size aggregate, specimens for shrinkage tests only were manufactured. The size of these specimens was 4 7/8 by 6 by 16 in.

All molds used for casting of shrinkage specimens had ½-inch diameter brass plugs secured in the ends of the mold for embedment in the concrete. These plugs projected ½-inch out of the concrete specimens to permit length measurements. A similar ½-inch projection was provided on the steel bars of the crack-resistance concrete specimens.

Compressive-strength specimens were cast in 6 by 12-inch cardboard molds.

Casting of Specimens

In the laboratory, the molds for shrinkage and crack-resistance bars were filled in two successive 1½-inch layers. A table vibrator was used for consolidation of the concrete. Immediately after casting, specimens were stored in the curing room. They were stripped after 24 hours, and remained in the curing room (70°F and 100 percent relative humidity) until age of test.

In the field, the concrete was placed in the molds and consolidation was accomplished by rodding and spading. Specimens were stored in shade and covered with wet canvas. The canvas was kept wet by continuous sprinkling. At age one day these specimens were brought to the laboratory and stored, after removal of the molds, in the curing room.

Standard procedure was employed for the casting of the 6 by 12-in. compressive-strength specimens.

Measurements

After completion of the moist-curing period (7 or 14 days), initial measurements were taken on both the shrinkage and crack-resistance bars. The bars were then transferred to the drying room (70°F and 50 percent relative humidity), where length measurements were taken every 24 hours until a crack occurred in the crack-resistance bars. Shrinkage measurements were then continued, at weekly intervals, for three months. All measurements were made using a 40-inch horizontal extensometer.

Shrinkage.-- The shrinkage, in millionths of an inch per inch of length, was computed by dividing the total change in length by the effective length (39 inches) of the concrete bar.

Crack Resistance.-- The resistance of concrete to cracking is the tensile stress developed in the concrete due to restrained drying shrinkage (Fig. 1). Crack resistance of a concrete is evaluated on the bases of (1) tensile stress developed prior to formation of crack and (2) the drying period (in days) required to produce a crack. The tensile stress in the concrete was calculated from the observed length change of the steel bar, using the following equation:

$$S_c = \frac{\Delta L}{L} \cdot E_s \cdot \frac{A_s}{A_c}$$

where:

S_c = Average tensile stress in concrete, psi

ΔL = Measured deformation of steel rod, in.

L = Effective length of steel rod = 37 in.

E_s = Modulus of elasticity of steel rod = 30×10^6 psi

A_s = Area of steel rod = 0.442 sq. in.

A_c = Net area of concrete bar = 8.21 sq. in.

Compressive Strength.-- Compressive-strength tests on 6 by 12-in. cylinders were performed in accordance with ASTM Specification C39. Hydrostone was used for capping the ends of the cylinders.

TEST RESULTS

Properties of Concretes

Properties of fresh concretes and compressive strengths at ages of 7 and 28 days are given in Table 4.

Water Requirement.-- The water requirement for concretes containing 3/4-in. maximum-size Sunol aggregates and having low to high slumps ranged from 6.0 to 7.0 gal/sk for the 6-scy mixes and 6.0 to 6.6 gal/sk for the 6½-scy mixes. The 6-scy mix made with 3/4-in. maximum-size Fair Oaks aggregate had a water requirement of 6.6 gal/sk and the 6½-scy mix 6.3 gal/sk.

Water requirement of job mixes was not known since no record was kept of the additional water added to the truck mixers during retempering.

Compressive Strength.-- Compressive strengths of concretes at ages of 7 and 28 days are shown in the last two columns of Table 4. Data given are the average of three cylinders per test condition.

Except for one of the field concretes (Mix 12) all other mixes produced 28-day compressive strengths in excess of the specified 3000-psi minimum. This job mix, containing 1½-in. maximum-size aggregate, had a 28-day strength of 2890 psi.

The strengths of concretes containing Fair Oaks aggregates were somewhat lower than those of corresponding mixes containing Sunol aggregates. The reason for this is that the mix designs, which were based on those for Sunol aggregates, are not appropriate for concretes made with Fair Oaks aggregates. However, to remove the variable of mix proportions, the concretes containing Fair Oaks had the same mix designs as the corresponding Sunol mixes. It is to be expected that if appropriately designed, a mix containing Fair Oaks aggregate would produce higher compressive strengths than would one made with Sunol aggregates.

Shrinkage And Crack-Resistance

Shrinkage and crack-resistance tests were made on concrete specimens moist-cured for either 7 or 14 days prior to drying at 70°F. and 50 percent relative humidity.

Shrinkage.-- Shrinkage data for the 6-scy concretes containing 3/4-in. maximum-size aggregate (Mixes 1 to 4 and 9) are given in Table 5 and Figure 2. Data for the corresponding 6½-scy concretes (Mixes 5 to 8 and 10) are given in Table 6 and Figure 3. The shrinkage data for the job-mixed concretes made with 1½-in. maximum-size Sunol aggregate (Mixes 11 and 12) are given in Table 7 and Fig. 4.

A study of these data reveals that the concretes containing

Sunol aggregates after 21 days of drying had a shrinkage about 70 to 90 percent larger than that of the concretes containing Fair Oaks aggregate. After 90 days of drying, the concretes containing Sunol aggregate had a shrinkage about 50 to 70 percent larger than that of the concretes containing Fair Oaks aggregate. For example, the shrinkage after 21 days of drying for the 6-scy concrete containing Fair Oaks aggregate and moist-cured for 7 days (Mix 1, Table 5 and Fig. 2) was 420 millionths (0.0420 percent) as compared to 710 millionths (0.0710 percent) for the corresponding concrete containing Sunol aggregate (Mix 3).

It will be noted that the curing period (7 or 14 days) had only a small effect on the shrinkage of concretes. The shrinkage of concretes moist-cured for 14 days was generally slightly lower, especially at later drying periods.

The shrinkage of the job-mixed concretes containing Sunol aggregate was higher than the shrinkage of corresponding laboratory-mixed concretes. This difference is probably due to the prolonged mixing periods employed at the job site.

As would be expected, the shrinkage of job-mixed concretes containing 1½-inch maximum-size aggregate (Table 7 and Fig. 4) was lower (about 20 percent) than that of the corresponding mixes containing 3/4-in. maximum-size aggregate.

Crack Resistance.--Tensile stresses developed in the restrained-concrete crack-resistance bars are plotted in the top halves of Figs. 5 to 8. The lower halves of these figures contain plots of shrinkage observed on specimens of corresponding concretes. Data for the 6-scy mixes moist-cured for 7 days are shown in Fig. 5

and for those moist-cured for 14 days in Fig. 6. Corresponding data for the 6½-scy concretes are given in Figs. 7 and 8.

These data are summarized in Table 8 in which are given the periods of drying at which cracks formed and the tensile stress at time of cracking. Also given are the shrinkage values for the drying period at which cracks were formed.

In studying the crack-resistance data it should be realized that several factors influence the tendency for crack formation. They include shrinkage characteristics, tensile strength, and the elastic properties and creep characteristics of the concrete mix. The size of specimen and degree of restraint (size of restraining steel bar) will also influence the cracking tendency of a concrete mix. For this reason, comparisons should only be made on a relative rather than an absolute basis. However, the cracking tendency of a concrete mix as herein evaluated is far more significant than the drying shrinkage alone.

A study of these data (Table 8) reveals that all concretes containing Sunol aggregates cracked within 3 to 10 days of drying. The cracking of concretes containing Fair Oaks aggregate occurred within 33 to 63 days of drying. The tensile stress levels at which the concretes containing Sunol aggregate cracked were considerably lower than those of the corresponding concretes containing Fair Oaks aggregate. For example, for the 6½-scy concrete containing Sunol aggregate (Mix 7) cracking occurred after 7 days of drying at a tensile stress of 283 psi whereas the corresponding concrete containing Fair Oaks aggregate cracked after 35 days at a tensile stress of 345 psi.

Cracking data and corresponding values of tensile stress and shrinkage for the 3 to 4-inch slump laboratory-mixed concretes are shown in the bar diagrams of Fig. 9. This graphical representation clearly demonstrates the large influence of type of aggregate in its cracking and shrinkage characteristics--in all respects the Fair Oaks aggregate exhibited a lower cracking tendency.

DISCUSSION

From the results of this investigation it may be observed that:

1. The major factor influencing the shrinkage and cracking characteristics of concretes is the nature of the aggregates. Concrete containing Sunol aggregates exhibited a much greater shrinkage and tendency towards cracking than did concretes containing Fair Oaks aggregates.

2. The influence of water content of concretes on their shrinkage and cracking characteristics is also significant. The higher the water content the greater the shrinkage and tendency toward cracking.

3. The increase in moist-curing period from 7 to 14 days increased the stress level at which cracking occurred and slightly decreased the drying shrinkage of the concretes.

4. Laboratory data, as herein reported, should only be analyzed on a comparative basis. The relatively small laboratory specimens cannot duplicate the shrinkage and cracking characteristics that will occur in a concrete structure.

ACKNOWLEDGMENTS

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The field observations, collection of data, and supervision of preparation of specimens was directed by Dr. A. El-Erian, a visiting scholar from Egypt. Mr. Yuzo Akatsuka, graduate student in Civil Engineering, was in charge of the shrinkage and crack-resistance studies.

Faculty investigators were Professors Milos Polivka and David Pirtz.

TABLE 1--CHEMICAL ANALYSIS OF CALAVERAS TYPE II CEMENT

Oxide Composition	Per cent
SiO_2	23.3
Al_2O_3	4.2
Fe_2O_3	2.6
CaO	64.4
MgO	2.3
Alkalies as Na_2O	0.5
SO_3	1.8
Ignition loss	0.9
Compound Composition	
C3S	48
C2S	31
C3A	7
C4AF	8

TABLE 2--PHYSICAL PROPERTIES OF AGGREGATES

Sieve Size	Cumulative Per cent Passing			
	Sunol		Fair Oaks	
	Sand	No. 4 to 3/4-in.	Sand	No. 4 to 3/4-in.
1 in.	--	99	--	100
3/4	--	59	--	96
1/2	--	29	--	55
3/8	100	13	100	30
No. 4	91	3	97	1
8	67	0	83	0
16	47	--	71	--
30	29	--	45	--
50	14	--	14	--
100	6	--	4	--
Fineness Modulus	3.46	7.25	2.86	6.73
Specific Gravity	2.64	2.67	2.64	2.79
Absorption Capacity, %	2.3	1.6	1.9	0.9
Sand Equivalent	57	--	80	--
Cleanness Value	--	79	--	97

TABLE 3--CONCRETE MIX PROPORTIONS

Material	Quantities of Materials, lb. per cu. yd.		
	3/4-in. max. size aggregate		1 1/2-in. max. size aggregate
	6 scy	6 1/2 scy	6 1/2 scy
Cement	564	611	611
Water	300	325	325
Sand	1580	1530	1345
Coarse Aggregate	1650	1600	1790

TABLE 4--PROPERTIES OF CONCRETES

Mix No.	Concrete Mixed at	Cement Content, Scy	Aggregate Type	Aggregate Max. Size, in.	S/A Ratio, by wt.	W/c, gal/sk	Slump, in.	Compressive Strength,[c] psi 7 da	Compressive Strength,[c] psi 28 da
1	EML[a]	6	Fair Oaks	3/4	0.49	6.6	3	2000	3740
2			Sunol	3/4	0.49	6.0	1/2	3080	5070
3						6.4	3	2510	4410
4						7.0	7 1/2	1750	3300
5	EML[a]	6 1/2	Fair Oaks	3/4	0.49	6.3	3 1/2	2120	3900
6			Sunol	3/4	0.49	6.0	2 1/4	2570	4260
7						6.2	3 1/2	2130	3960
8						6.6	7	1950	3450
9	Job[b]	6	Sunol	3/4	0.49	(d)	3 1/4	--	3750
10		6 1/2				(d)	3 1/2	--	3720
11		6 1/2		1 1/2	0.43	(d)	3 1/2	2810	4180
12						(d)	7 1/2	1680	2890

a - Engineering Materials Laboratory, University of California, Berkeley, California.

b - Job-mixed concrete at the Engineering Building, San Jose State College, San Jose, California.

c - Average of three 6 by 12-in. cylinders; standard curing.

d - W/C ratio of job mixes not known.

TABLE 5--SHRINKAGE OF 6-SCY CONCRETES
CONTAINING 3/4-IN. MAXIMUM-SIZE AGGREGATE

Period of Moist Curing, days	Period of Drying at 70°F and 50% R.H., days	Shrinkage, Millionths[a]				
		Fair Oaks Aggregate	Sunol Aggregate			
		Slump, inches				
		3	1/2	3	7 1/2	3 1/4
		Mix 1	Mix 2	Mix 3	Mix 4	Mix 9[b]
7	1	70	80	75	90	80
	3	115	170	165	210	200
	7	190	325	315	395	380
	21	420	715	710	815	790
	42	570	925	945	1075	1050
	60	650	1000	1045	1165	1140
	90	670	1020	1085	1175	1155
14	1	75	110	115	115	---
	3	115	165	170	180	---
	7	190	325	325	325	---
	21	390	690	665	720	---
	42	565	950	920	980	---
	60	630	1000	1015	1065	---
	90	650	1020	1045	1095	---

a - Average of two 3 by 3 by 40-in. concrete bars.

b - Mix 9 was a job-mixed concrete. All others were mixed in the laboratory.

TABLE 6--SHRINKAGE OF 6 1/2-SCY CONCRETES CONTAINING 3/4-IN. MAXIMUM-SIZE AGGREGATE

Period of Moist Curing, days	Period of Drying at 70°F and 50% R.H., days	Shrinkage, millionths[a]				
		Fair Oaks Aggregate	Sunol Aggregate			
		Slump, inches				
		3 1/2	2 1/4	3 1/2	7	3 1/2
		Mix 5	Mix 6	Mix 7	Mix 8	Mix 10[b]
7	1	45	120	120	115	110
	3	85	220	210	200	205
	7	155	360	350	375	355
	21	335	685	655	865	740
	42	490	940	915	1110	1020
	60	535	1035	995	1180	1080
	90	565	1080	1040	1210	1095
14	1	80	85	90	135	120
	3	125	185	170	220	205
	7	195	330	310	365	350
	21	395	700	655	805	740
	42	545	960	885	1055	980
	60	600	1040	970	1135	1025
	90	615	1085	1015	1170	1090

a - Average of two 3 by 3 by 40-in. concrete bars.

b - Mix 10 was a job-mixed concrete. All others were mixed in the laboratory.

TABLE 7--SHRINKAGE OF 6 1/2-SCY JOB-MIXED CONCRETES CONTAINING 1 1/2-IN. MAXIMUM-SIZE SUNOL AGGREGATE

Period of Moist Curing, days	Period of Drying at 70°F and 50% R.H., days	Shrinkage, millionths [a]	
		Slump, inches	
		3 1/2	7 1/2
		Mix 11	Mix 12
7	1	85	70
	3	125	100
	7	200	170
	21	410	375
	42	610	610
	60	720	730
	90	845	870
14	1	55	55
	3	95	110
	7	175	165
	21	380	355
	42	565	580
	60	675	710
	90	830	855

a - Average of two 4 7/8 by 6 by 16-in. concrete bars.

TABLE 8--CRACKING CHARACTERISTICS OF CONCRETES

All concretes contained 3/4-in. maximum-size aggregate. Data given are average for two 3 by 3 by 40-in. restrained concrete bars.

Mix No.	Cement Content	Aggregate	Slump, in.	Moist-Cured 7 Days: Crack Formation: Days at 70°F and 50% R.H.	Moist-Cured 7 Days: Crack Formation: Tensile Stress, psi	Moist-Cured 7 Days: Shrinkage, millionths	Moist-Cured 28 Days: Crack Formation: Days at 70°F and 50% R.H.	Moist-Cured 28 Days: Crack Formation: Tensile stress, psi	Shrinkage, millionths
1	6	Fair Oaks	3	63	472	665	33	480	510
2	6	Sunol	1/2	6	207	290	10	396	420
3	6	Sunol	3	8	288	345	9	338	380
4	6	Sunol	7 1/2	4	215	260	6	272	280
9[a]	6	Sunol	3-1/4	5	240	280	--	--	--
5	6-1/2	Fair Oaks	3-1/2	35	345	460	40	415	525
6	6-1/2	Sunol	2-1/4	6	275	335	7	296	330
7	6-1/2	Sunol	3-1/2	7	283	350	10	398	400
8	6-1/2	Sunol	7	7	290	375	8	420	395
10[a]	6-1/2	Sunol	3 1/2	3	236	205	5	206	275

a - Job-mixed concrete. All others were mixed in the laboratory.

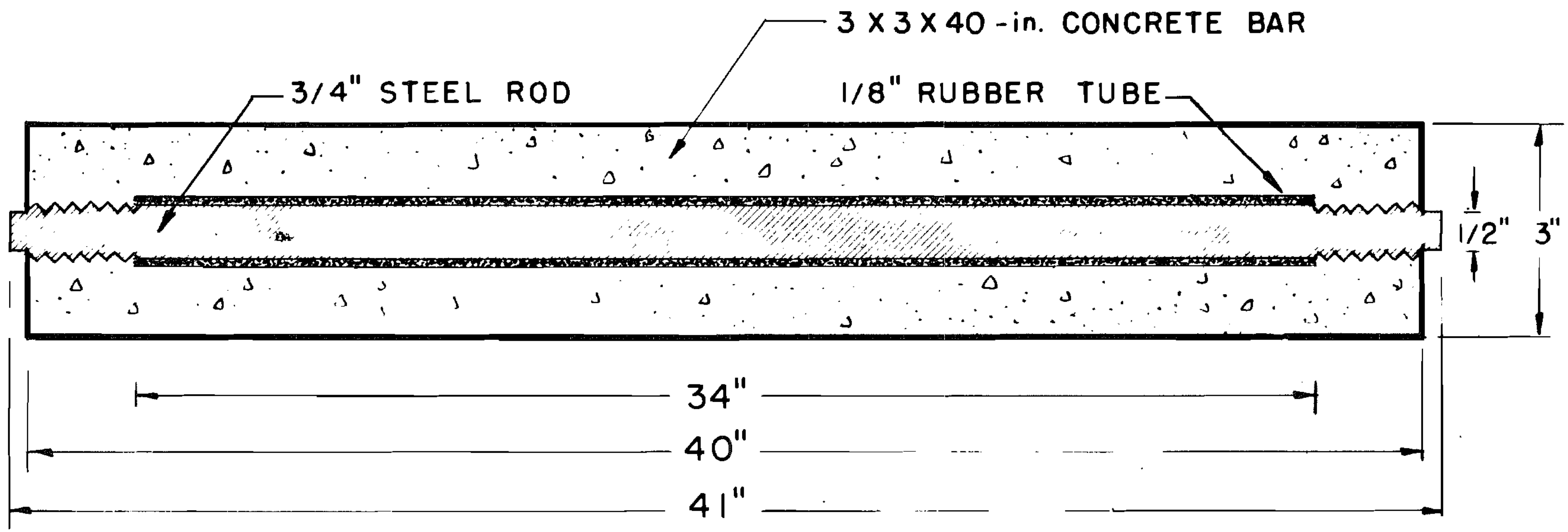

FIG. I — CRACK-RESISTANCE SPECIMEN

Fig. I

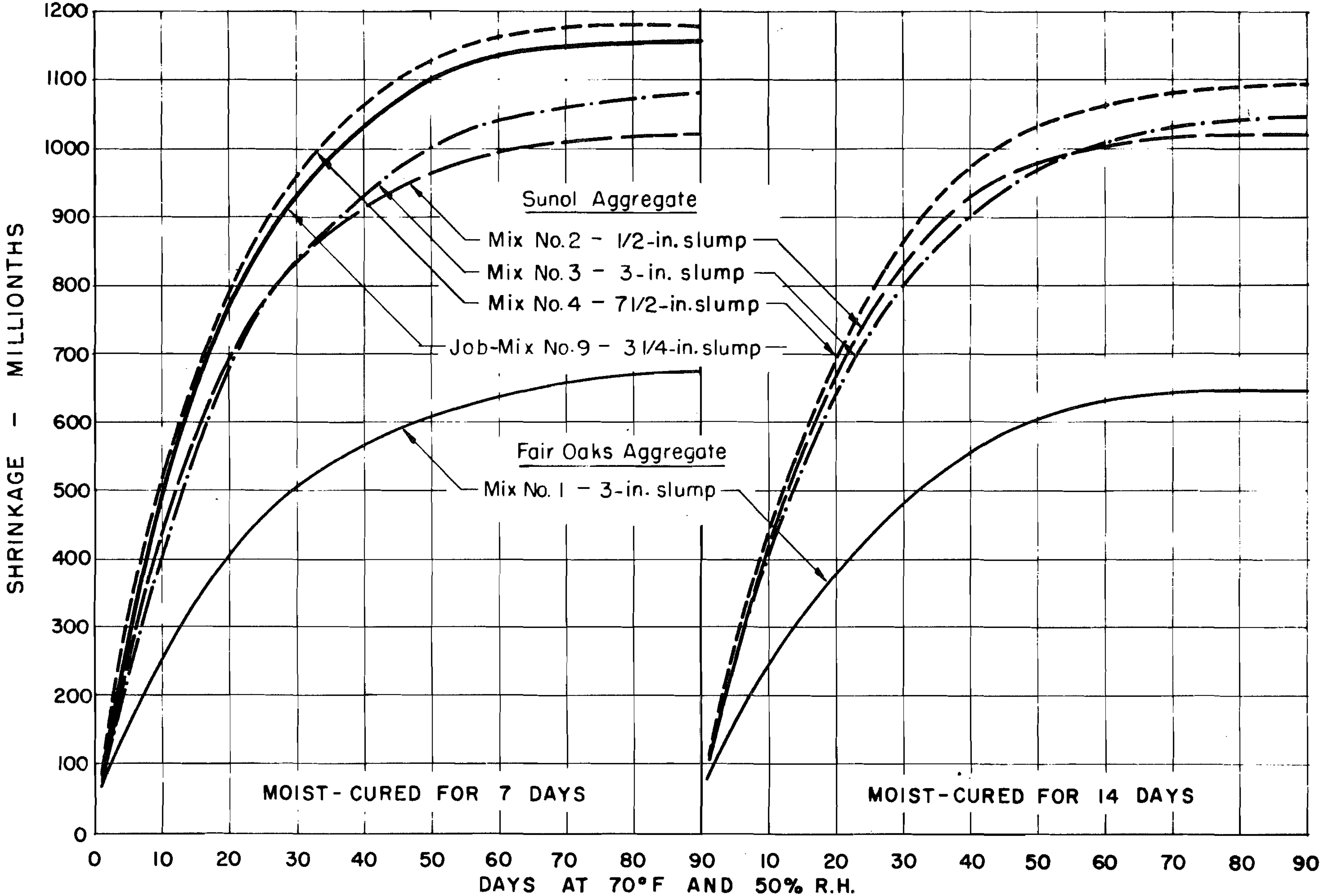

FIG. 2 — SHRINKAGE OF 6-SCY CONCRETES
3/4-in. Maximum-Size Aggregate

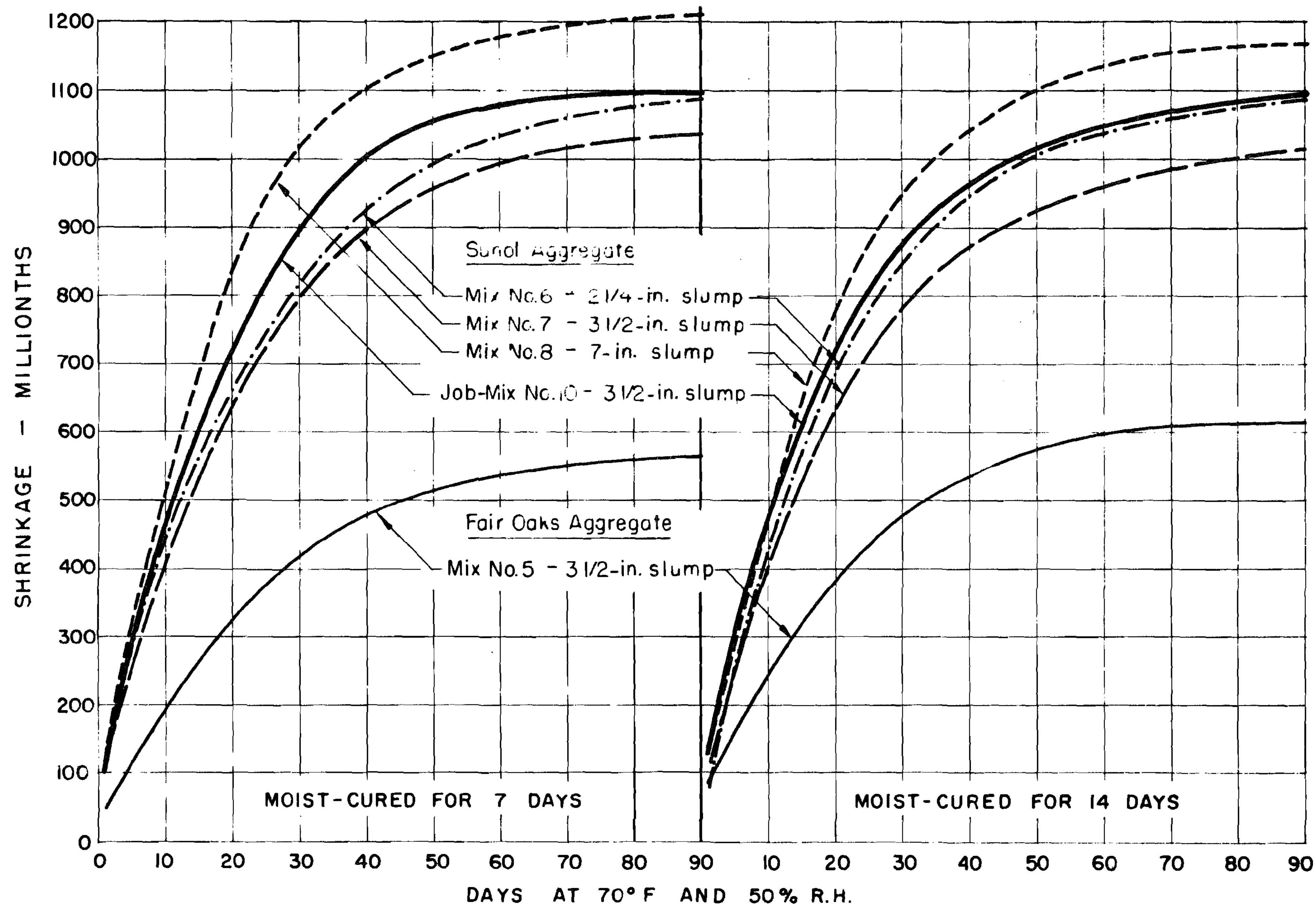

FIG. 3 — SHRINKAGE OF 6 1/2-SCY CONCRETES
3/4-in. Maximum-Size Aggregate

Fig. 3

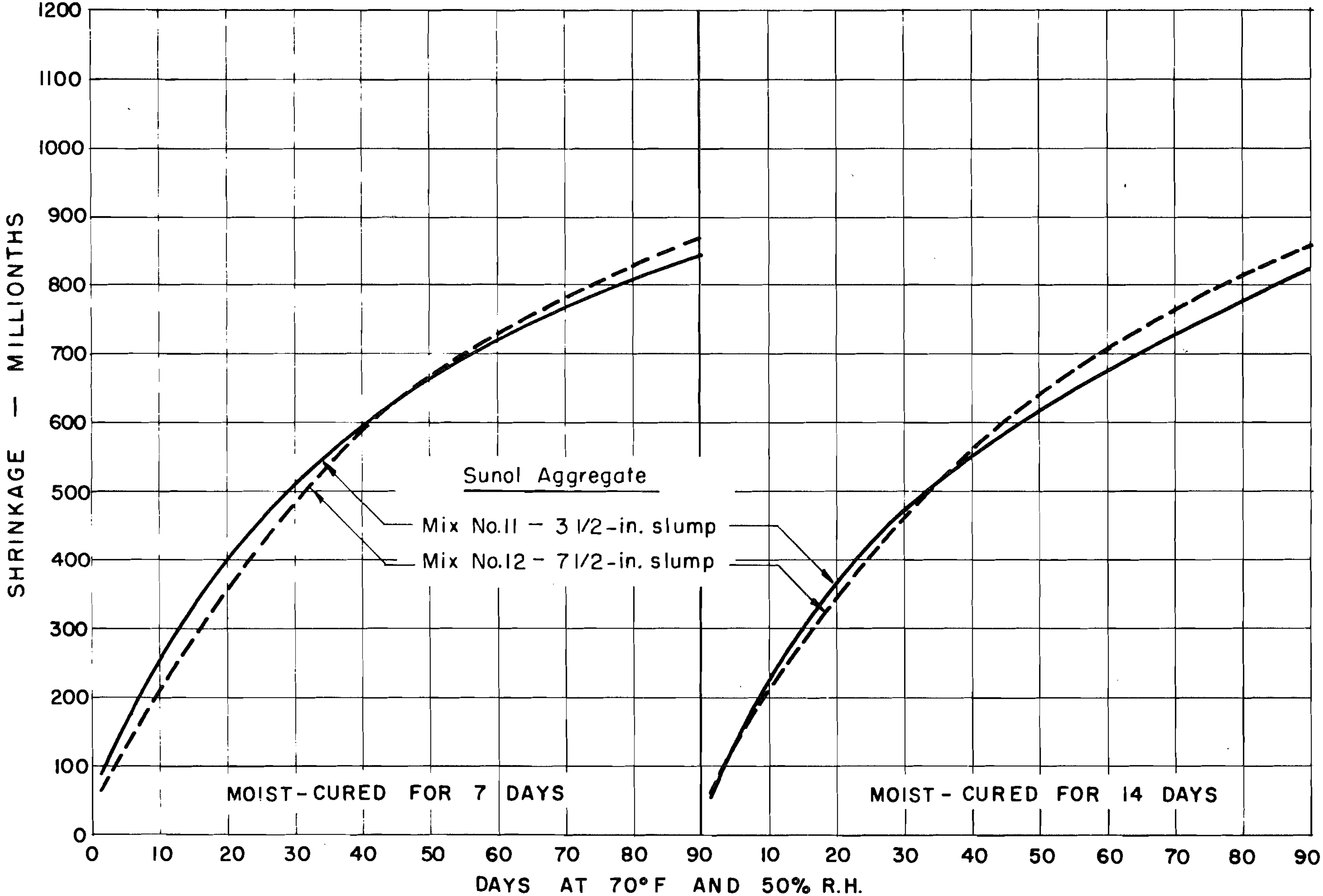

FIG. 4 — SHRINKAGE OF 6 1/2-SCY JOB MIXED CONCRETES

1 1/2-in. Maximum-Size Aggregate

Fig. 4

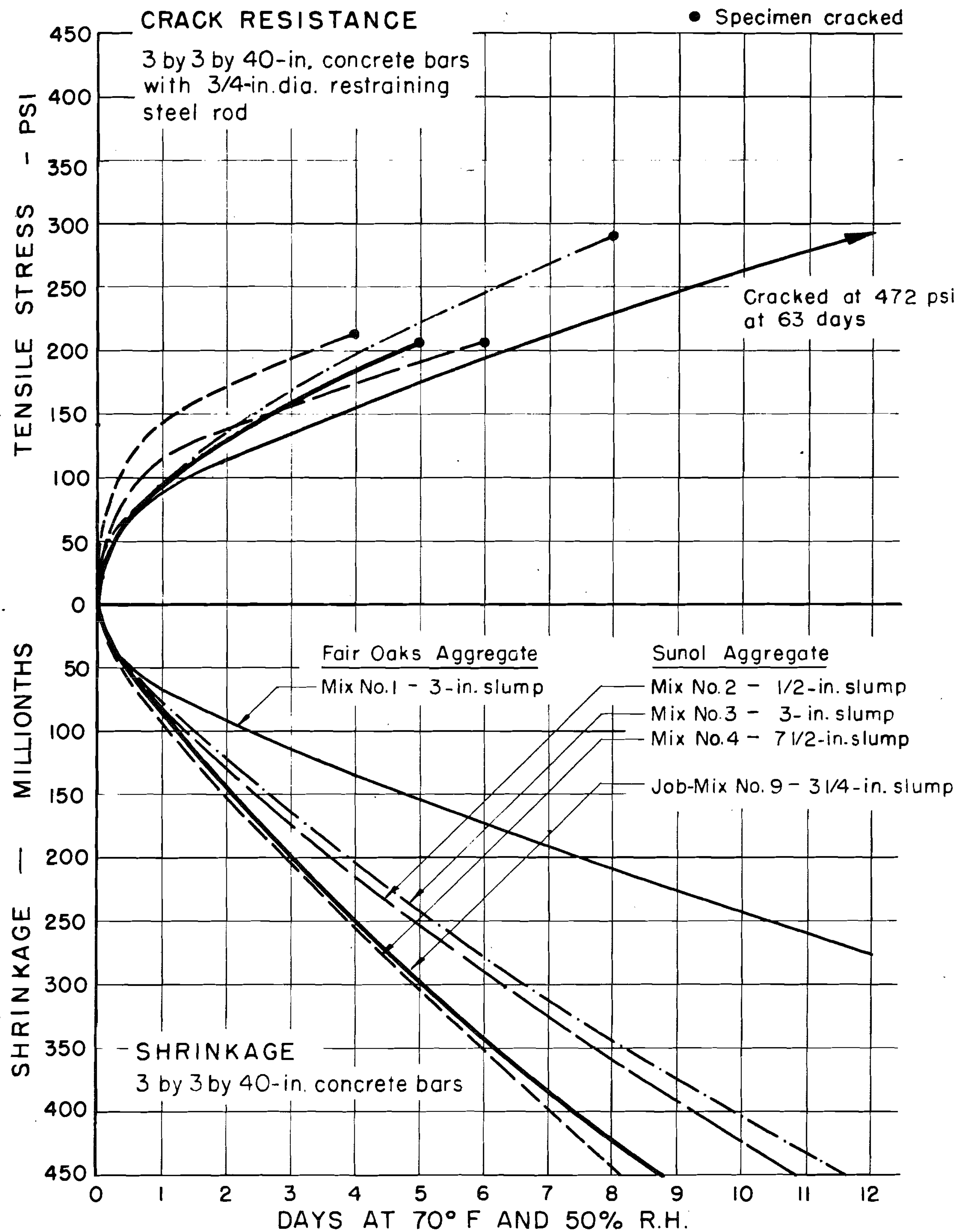

FIG. 5 — SHRINKAGE AND CRACK RESISTANCE OF 6-SCY CONCRETES, MOIST-CURED FOR 7 DAYS

3/4 - in. Maximum-Size Aggregate

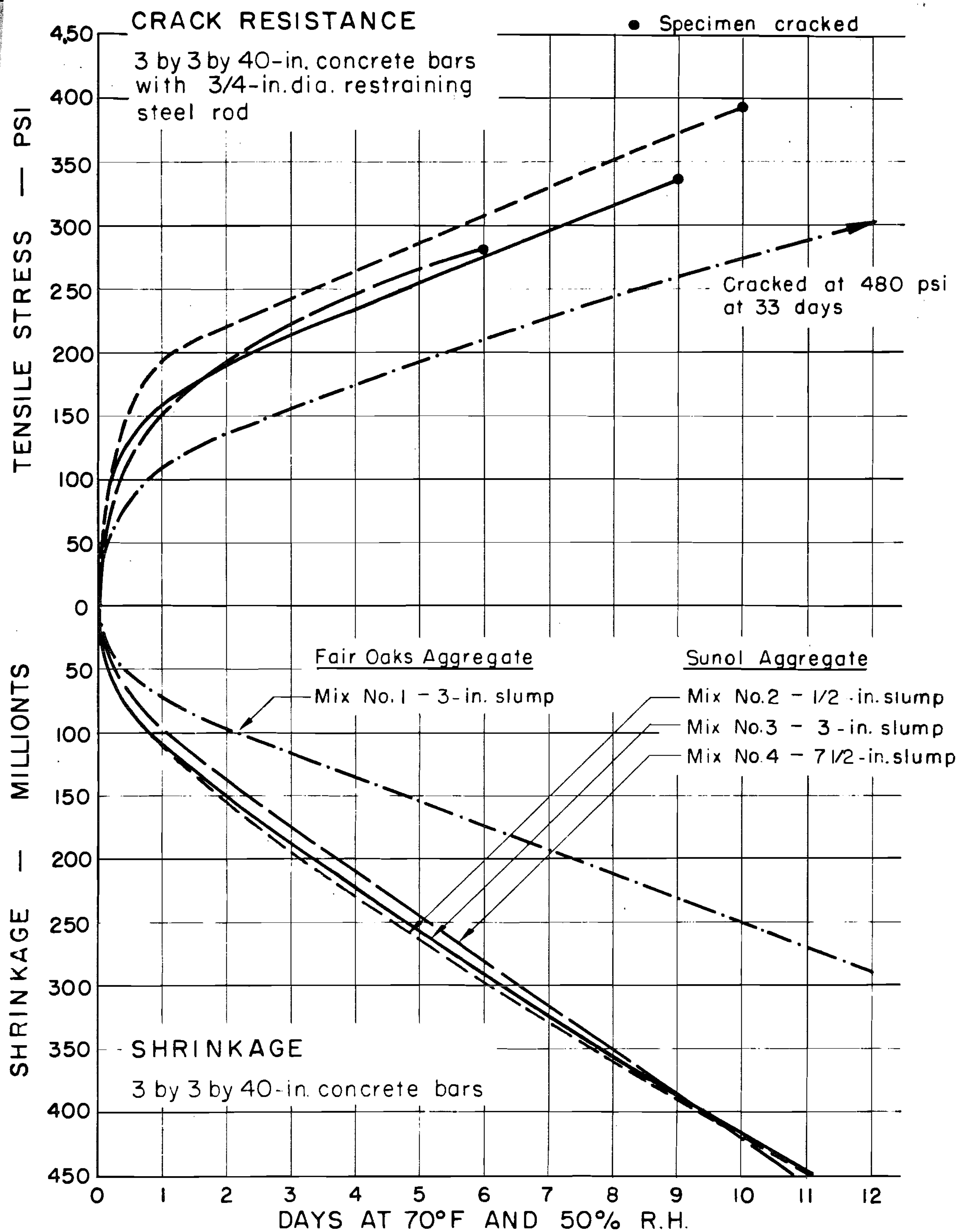

FIG. 6 — SHRINKAGE AND CRACK RESISTANCE OF 6-SCY CONCRETES, MOIST-CURED FOR 14 DAYS

3/4-in. Maximum-Size Aggregate

Fig. 6

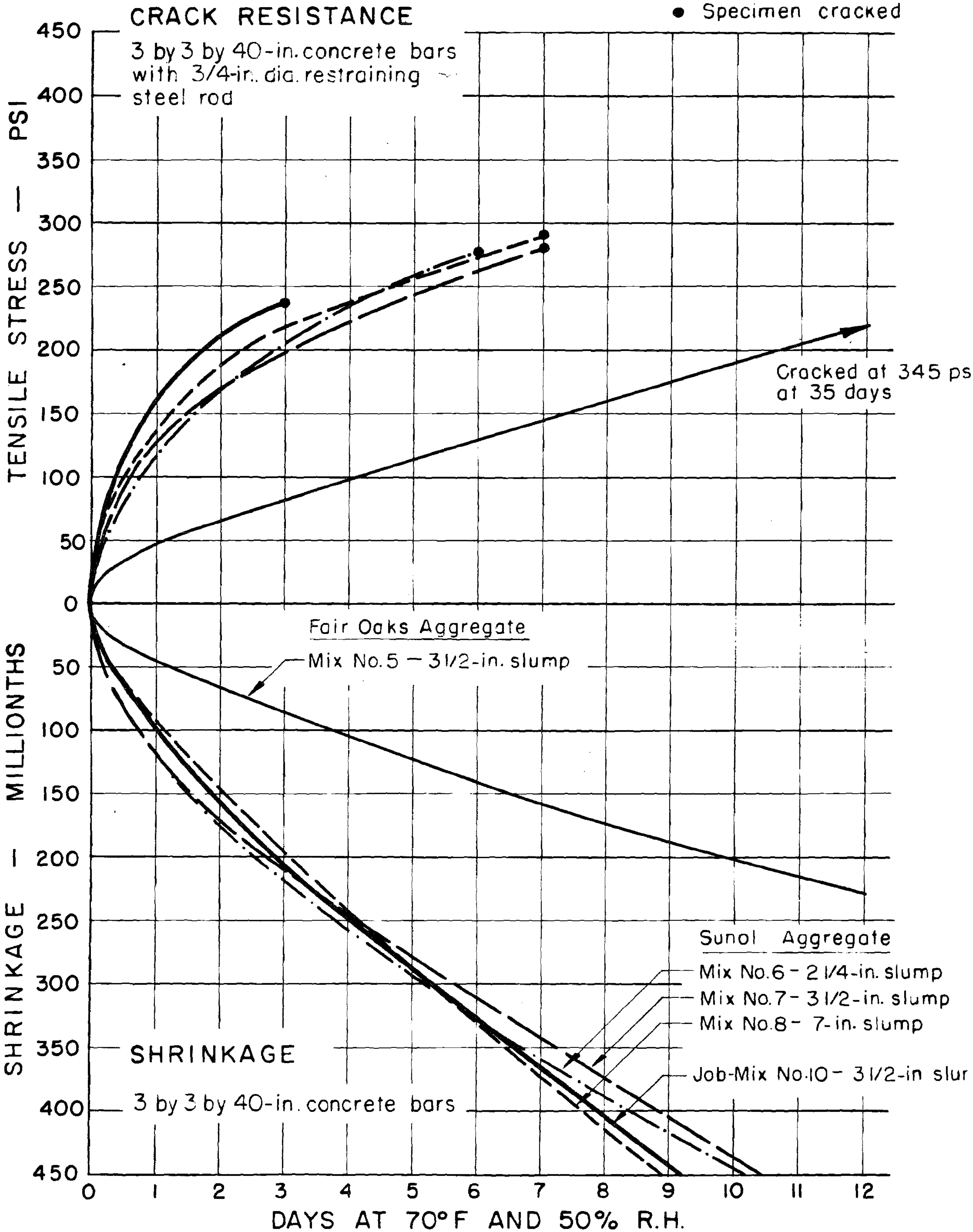

FIG. 7 — SHRINKAGE AND CRACK RESISTANCE OF 6 1/2-SCY CONCRETES, MOIST-CURED FOR 7 DAYS

3/4 - in. Maximum-Size Aggregate

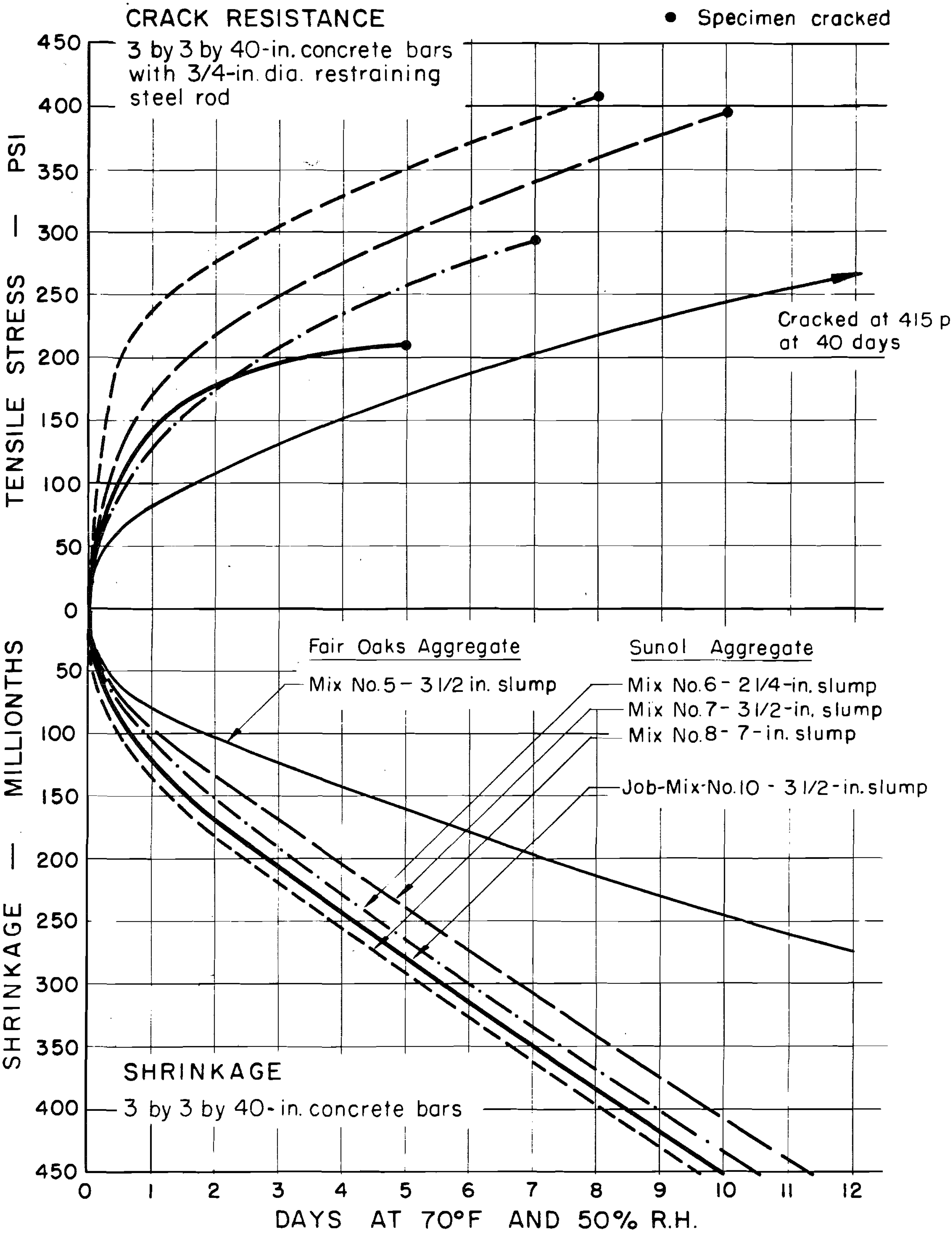

FIG. 8 — SHRINKAGE AND CRACK RESISTANCE OF 6 1/2-SCY CONCRETES, MOIST-CURED FOR 14 DAYS

3/4-in. Maximum-Size Aggregate

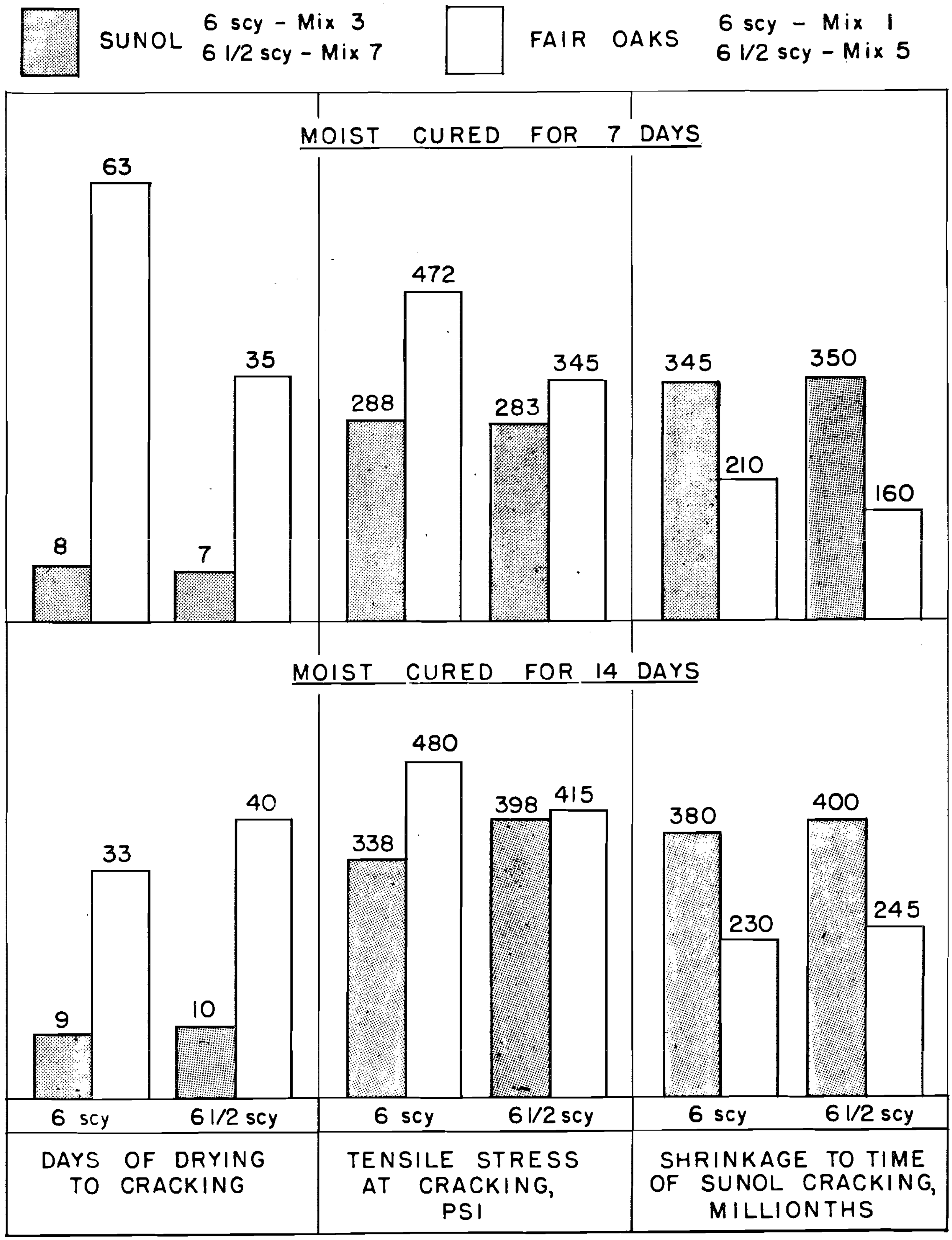

FIG. 9 — CRACKING OF CONCRETES

3/4-in. Maximum - Size Aggregate;
Slump 3 to 4 Inches