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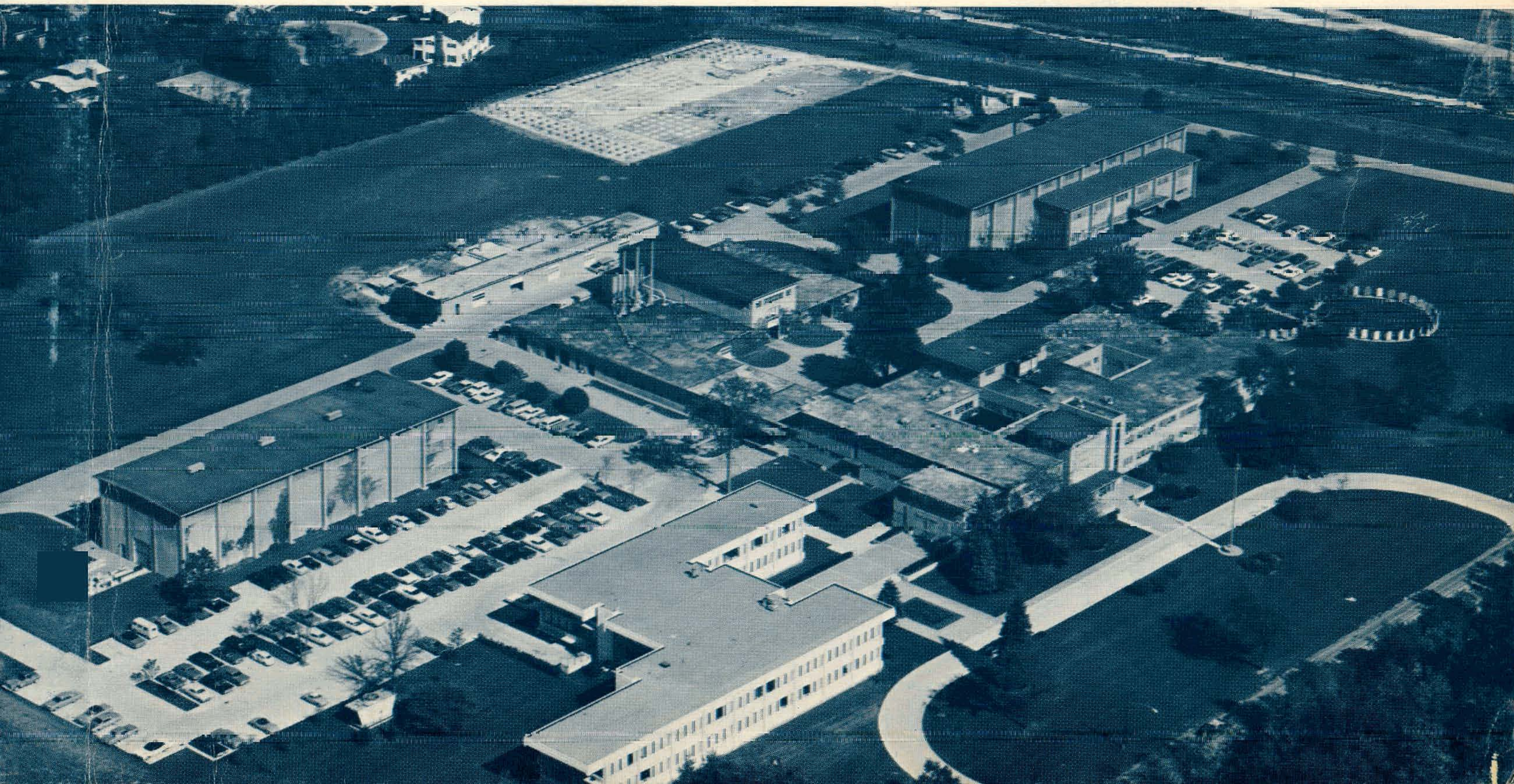

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STRENGTH AND ELASTIC PROPERTIES OF CONCRETES FROM WASTE TANK FARMS

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December 1978

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PREFACE

High-level radioactive waste from the current waste management operation at Hanford is stored in underground reinforced concrete tanks with a steel liner on the sides and bottom. The removal of pumpable liquid results in a moist salt-cake of sodium salts that is relatively immobile compared to its original liquid state. Additional immobilization and isolation techniques are being studied to further improve waste isolation and containment. Retrieval of the waste and permanent disposal will be deferred until a permanent disposal mode and location is selected. The integrity of the storage tanks is of critical importance during this interim period.

Technical studies and laboratory tests have been performed to determine the effect of the stored waste's temperatures and chemistry on the reinforced concrete's strength and elastic properties. This work was performed for Rockwell Hanford Operations under the technical direction of the Pacific Northwest Laboratories at Richland, Washington by the Construction Technology Laboratories, a division of the Portland Cement Association, Skokie, Illinois.

Concrete cores from the domes of waste storage tanks in the 241-A, T, and U tank farms were tested to determine the strength of the concrete after tens of years of waste storage. Full size specimens (6 inch diameter x 12 inch long) could not be provided and sub-size specimens (3 inch diameter x 6 inch long and 3 inch cubes) were cored and cut from the dome cores. Data correlation was established by cutting and coring full sized laboratory cast specimens to determine the effect of specimen size and shape on test results. All of the tank dome specimens exceeded the minimum design strength.

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by

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Submitted by
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SYNOPSIS

Tests were conducted on concretes from Hanford Waste Tank Farms, and on concrete cast by the Portland Cement Association using Hanford mix designs and materials, to determine strength and elastic properties at room and elevated temperatures. Elastic modulus (static method), Poisson's ratio, and compressive and splitting tensile strengths were determined at room temperature, and for specimens maintained at 250F for varying lengths of time. Variables examined in the test program were the effect of (a) temperature, (b) length of exposure to elevated temperature, and (c) geometry of test specimens.

Compressive strength generally decreased after specimens were exposed to heat. Maximum losses were 20 to 33 percent of room temperature strength. Initially stronger concretes lost a proportionately larger percentage of their strength after exposure than did weaker concrete. In some series, concrete appeared to gain strength after exposure. In other series, concrete initially lost strength, then recovered strength after prolonged heating.

Splitting tensile strength of heated specimens followed trends similar to those obtained for compressive strength. Highest strength losses were about 40 percent. However, in most cases, considerably less strength deterioration resulted from exposure to heat.

Modulus of elasticity and Poisson's ratio also decreased after exposure to heat. Greatest losses were about 40 percent of room temperature values, but amounts differed widely among test series.

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TEST PROGRAM

A statement of objectives, a description of materials, and schedules of the test program follow.

Objectives

The objectives of the test program were as follows[1]*:

1. To determine the strength and elastic properties of concretes from Hanford Waste Tank Farm structures, and to evaluate the effects of the service temperature history on these properties.
2. To determine these same properties on concrete fabricated at the Portland Cement Association Construction Technology Laboratories from supplied materials of similar composition to those used in Hanford concrete structures. Some of the in-house concrete specimens were used in this program as companion specimens to those obtained from Waste Tank Farms. Others were used in another ongoing research program to determine elastic and strength properties at room and elevated temperatures[2].
3. To compare results obtained from tests on in-house specimens with those on specimens obtained from Waste Tank Farm structures.

*Superscript numbers in parentheses refer to References on Page 47.

4. To determine the influence of specimen size and shape on strength and elastic properties.

Thus, variables in the test program were the effect of temperature, time of exposure to elevated temperature, and geometry of test specimens.

Test Materials

Cored concrete samples were supplied from Hanford Waste Tank Farms 241-A, 241-T, and 241-U. From these samples, a number of 3-in. diameter cylinders were cored and cut to a 6-in. length. Three-inch cube specimens were cut from Tank Farm core samples not suitable for obtaining cylindrical specimens.

In addition, a number of 6 x 12-in. concrete cylinders, having a 3000 psi minimum design strength, on hand at the Construction Technology Laboratories (CTL), were used as comparison specimens to those obtained from Tank Farm concrete. All but four of these cylinders were tested as 6 x 12-in. specimens. Four cylinders were cored and cut to provide 3-in. cube and 3 x 6-in. cylinder companion specimens for determining the influence of specimen geometry on property determination. Detailed information on fabrication of these specimens may be found in the Appendix.

Dimensions and weights of all specimens used in this test program are listed in Tables 1, 2, and 3. Hereafter, specimens from Waste Tank Farms are designated as members of Series A, T,

TABLE 1 - DIMENSIONS AND WEIGHTS OF 3 x 6-IN. CYLINDERS AT 73F

Specimen No.	Diameter, in.	Length, in.	Weight, lb.
3K9-7-1	2.78	5.66	2.864
3K9-7-2	2.78	5.61	2.836
3K5-15-3	2.78	5.60	2.860
3K5-15-4	2.78	5.63	2.866
3K5-24-5	2.78	5.33	2.752
3K5-24-6	2.78	5.40	2.803
3K9-4-7	2.78	5.63	2.882
3K9-4-8	2.78	5.62	2.774
241AI-1	2.78	5.64	2.908
241AI-2	2.78	5.65	2.864
241AII-3	2.78	5.72	2.932
241AI-4	2.78	5.64	2.840
241A-5	2.78	5.15	2.638
241A-6	2.78	5.21	2.649
241A-7	2.78	5.11	2.592
241A-8	2.78	5.00	2.543
241AII-9	2.78	5.65	2.768
241AII-10	2.78	5.67	2.787
241AI-11	2.78	5.35	2.710
241AI-12	2.78	5.40	2.728
241AI-13	2.78	5.65	2.893
241AI-14	2.78	5.47	2.748
241AII-15	2.78	5.66	2.816
241AII-16	2.78	5.52	2.717
241A-17	2.78	5.61	2.818
241AII-18	2.78	5.64	2.794
241AII-19	2.78	5.60	2.864
241T-1	2.78	5.64	2.848
241T-2	2.78	5.65	2.875
241T-3	2.78	5.69	2.849
241T-4	2.78	5.67	2.904
241T-5	2.78	5.65	2.867
241U-1	2.78	5.62	2.860
241U-2	2.78	5.64	2.783

TABLE 2 - DIMENSIONS AND WEIGHTS OF CTL CAST 6 x 12-IN. CYLINDERS AT 73F

Specimen No.	Diameter, in.	Length, in.	Weight, lb.
3K5-18	6.02	12.00	29.34
3K5-19	5.95	12.00	29.57
3K5-21	5.95	11.98	29.28
3K5-22	5.93	12.00	29.37
3K9-6	5.96	11.97	28.88
3K9-13	5.98	11.98	29.07
3K9-16	6.00	12.01	28.88
3K9-22	6.00	12.00	29.10

TABLE 3 - DIMENSIONS AND WEIGHTS OF 3-IN. CUBES AT 73F

Specimen No.	Height, in.	Width, in.	Depth, in.	Weight, lb.
3K9-18-1	2.92	3.02	2.98	2.385
3K8-7-2	2.96	2.99	2.91	2.187
3K9-18-3	3.04	2.96	2.95	2.394
3K9-18-4	2.91	2.94	2.96	2.181
241T-5	2.96	3.10	2.98	2.419
241T-6	2.98	2.95	2.99	2.412
241T-7	3.10	2.96	3.00	2.355
241T-8	2.93	2.98	2.92	2.183
241T-9	2.95	2.99	3.12	2.513
241T-10	2.99	3.08	3.03	2.485
241T-11	2.89	2.94	3.06	2.224
241T-12	2.97	2.96	2.99	2.368

or U, depending on their source. Specimens fabricated at the Construction Technology Laboratories are referred to as Series K, if used in this test program, and Series M, if used in another ongoing research program.

Test Schedule

Table 4 shows the test schedule for this investigation. Tests were conducted at room temperature, and on specimens heated at 250F for 3, 30, 80, 150, and 270 days. Ideally, tests at all intervals for each tank farm would have been conducted. However, sufficient specimens could not be made from the concrete samples provided.

Specimens used for determining elastic properties were used afterwards for compressive strength tests. No elastic properties tests were conducted on specimens used for determining splitting tensile strength.

Three types of tests were performed on specimens: the splitting tensile strength test, ASTM Designation: C496[3]; elastic constants determination, ASTM Designation: C469[4]; and tests for compressive strength, ASTM Designation: C39[5].

TEST PROCEDURES

Details of specimen preparation and test procedures to determine strength and elastic properties are given below.

Specimen Preparation and Curing

All specimens used in this investigation had load-bearing

TABLE 4 - TEST SCHEDULE

Temperature at Test, F	73	250				
Time in Oven, Days	0	3	30	80	150	270
Test Specimens, Size						
Series A, 3 x 6-in. Cylinders	T*, C/E**	T,C/E	T,C/E	T,C/E	T,C/E	T,C/E
Series K, 3 x 6-in. Cylinders	T,C/E	-	T,C/E	-	-	-
Series T, 3 x 6-in. Cylinders	T	-	T,C/E	-	T	-
Series U, 3 x 6-in. Cylinders	-	-	T,C/E	-	-	-
Series K, 6 x 12-in.Cylinders	T,C/E	-	T,C/E	-	-	-
Series K, 3-in. Cubes	C/E	-	C/E	-	-	-
Series T, 3-in. Cubes	C/E	C/E	C/E	-	C/E	-

*T = Tensile Splitting Strength Tests
**C/E = Compressive Strength and Elastic Properties Tests

surfaces lapped plane by hand. Specimens were then stored in a room maintained at a 73F, and 50 percent relative humidity.

Specimens designated for heating were removed from their controlled environment, weighed, measured, and placed in an oven initially at room temperature. The temperature of the oven was gradually increased at a rate of 75F per day until 250F was reached. At this point, specimens were transferred in an insulated container to a second oven maintained at 250F 5F, for storage until tested. The oven was monitored three times daily to insure that the proper temperature was being maintained.

Immediately prior to testing, specimens were removed from the oven and weighed again, then transported in an insulated container to the test location.

Modulus of Elasticity and Poisson's Ratio

Elastic constants of 6 x 12-in. test cylinders were determined using equipment and procedures described in ASTM Designation: C469[4].

The compressometer was fitted with differential transformers to measure longitudinal and lateral strains. A third differential transformer in the testing machine was used to measure load. Figure 1 shows a cylinder fitted with the compressometer in the test machine.

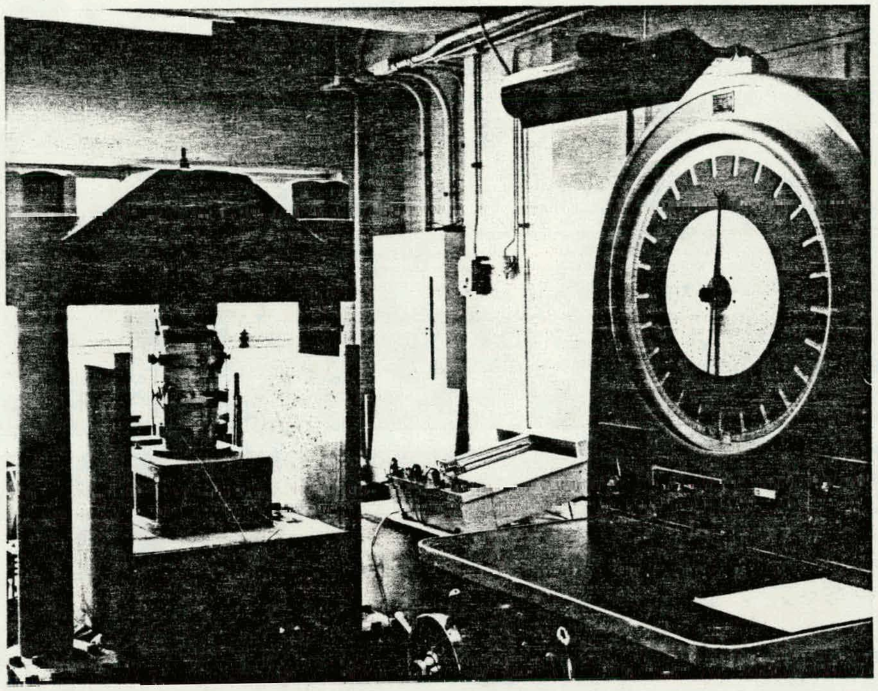

Fig. 1 - Test Apparatus

Outputs from the differential transformers were recorded on an X-Y-Y plotter. Specimens were loaded four times to approximately 50 percent of their ultimate strength. The first loading was to insure proper seating of the specimen in the test apparatus. No data were recorded. The final three loadings were recorded. Elastic constants were calculated from slopes of each of the three sets of curves and averaged. A typical plot is shown in Fig. 2.

Elastic constants for 3 x 6-in. cylinders were determined using a smaller version of the compressometer described in ASTM Designation: C469. Test procedures were idential to those followed in testing 6 x 12-in. cylinders.

Originally it was planned to determine elastic constants for 3-in. cubes using electrical resistance-type strain gages bonded to the specimens. Longitudinal and lateral strains were to be measured by these gages. However, the strain gages did not perform well at elevated temperatures. A compressometer, fabricated to fit the cubical specimen geometry, performed satisfactorily.

Test procedures for cube specimens were similar in all respects to those followed in testing cylinders. All modulus of elasticity and Poisson's Ratio data reported were determined using the cube compressometer.

After tests for determining the elastic constants at 250F were completed, specimens were returned to the oven for a period of one hour. They were then tested to determine compressive strength.

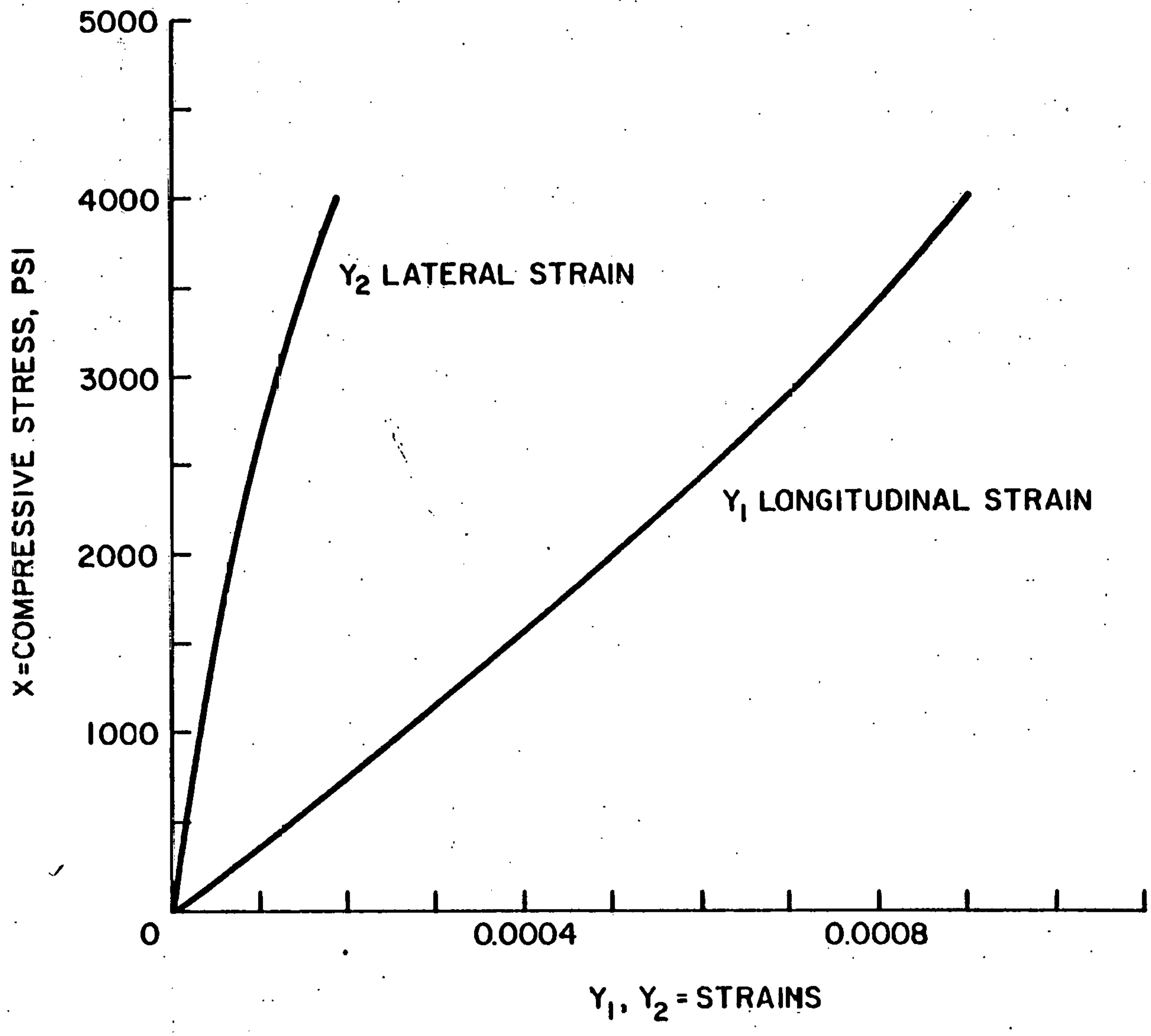

FIG. 2 – STRESS-STRAIN CURVES USING X-Y-Y PLOTTER FOR STATIC TEST

Compressive Strength

Compressive strength of 6 x 12-in. test cylinders was determined using methods described in ASTM Designation: C39[5]. Similar procedures were used in testing 3 x 6-in. cylinders and 3-in. cubes. Heated specimens were transported to the testing machine in an insulated box. Testing was completed within 5 min. after removal from the oven.

Splitting Tensile Strength

Splitting tensile strength of all cylindrical specimens was obtained using general guidelines of ASTM Designation: C496[3]. Elevated temperature specimens were transported to the testing machine in an insulated box. Testing was completed within 5 min. after removal from the oven.

TEST RESULTS

In the following paragraphs, results of tests to determine strength and elastic properties are given. Also the effects of specimen geometry on test results are discussed. Finally, a comparison of results obtained from tests on Waste Tank Farm specimens are compared with those obtained from specimens cast or prepared at CTL.

Modulus of Elasticity

Modulus of elasticity values determined for room temperature and heated specimens are shown in tabular form in Tables 5, 6, and 7, and plotted as a function of time at 250F in Figs. 3 and 4.

TABLE 5 - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES OF 3 x 6-IN. CYLINDERS AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test Mo.-Day-Yr.	Time in Oven Days	Temp. at Test, F	Weight at Test, lb	Compressive Strength, Psi	Modulus of Elasticity Psi, millions	Poisson's Ratio
3K9-7-2	5-25-77	0	73	2.836	5190	3.78	0.19
3K5-15-4	5-25-77	0	73	2.866	5025	4.07	0.19
241AII-9	5-25-77	0	73	2.786	7700	4.83	0.22
241AI-11	5-25-77	0	73	2.710	8240	5.32	0.19
241AI-13	7-28-77	3	250	2.864	6820	4.52	0.16
241AII-15	7-28-77	3	250	2.787	7910	3.78	0.18
3K5-24-5	8-24-77	30	250	2.752	5245	2.96	0.14
3K9-4-8	8-24-77	30	250	2.774	3870	2.59	0.12
241T-5	8-24-77	30	250	2.867	3160*	-	-
241U-1	8-24-77	30	250	2.860	4185	2.88	0.22
241A-6	8-12-77	80	250	2.601	5690	3.19	0.18
241A-7	8-12-77	80	250	2.548	5490	3.04	0.18
241AI-4	9-9-77	150	250	2.797	7875	3.11	0.18
241AII-18	9-9-77	150	250	2.756	7940	2.95	0.12
241AII-3	4-21-78	270	250	2.894	7070	2.98	0.18

*Surface cracks visible on specimen prior to testing.

TABLE 6 - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES OF 3 IN. CUBES AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test Mo.-Day-Yr.	Time in Oven Days	Temp. at Test, F	Weight at Test, lb	Compressive Strength, Psi	Modulus of Elasticity Psi, millions	Poisson's Ratio
3K9-18-1	4-13-78	0	73	2.385	6970	4.16	-
3K8-7-2	4-13-78	0	73	2.187	5230	3.70	0.16
241T-5	4-13-78	0	73	2.419	3690	2.69	0.23
241T-6	4-13-78	0	73	2.412	4120	3.03	-
241T-7	4-13-78	3	250	2.309	4260	2.78	-
241T-8	4-13-78	3	250	2.151	3430	2.55	0.18
3K9-18-3	4-13-78	30	250	2.307	7190	4.61	-
3K9-18-4	4-13-78	30	250	2.114	6740	3.89	0.17
241T-9	4-13-78	30	250	2.466	10600	4.76	0.12
241T-10	4-13-78	30	250	2.439	8000	4.61	0.13
241T-11	4-13-78	150	250	2.186	3440	2.26	0.12
241T-12	4-13-78	150	250	2.243	2530*	1.92	0.30

*Surface spalling prior to test.

TABLE 7 - COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES OF 6 x 12-IN. CYLINDERS AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test Mo.-Day-Yr.	Time in Oven Days	Temp. at Test, F	Weight at Test, lb	Compressive Strength, Psi	Modulus of Elasticity Psi, millions	Poisson's Ratio
3K5-21	8-9-77	0	73	29.28	5600	4.66	0.16
3K9-6	8-9-77	0	73	28.88	6000	4.44	0.17
3K5-19	9-7-77	30	250	28.28	5490	3.35	0.13
3K9-22	9-7-77	30	250	27.85	5260	3.21	0.13

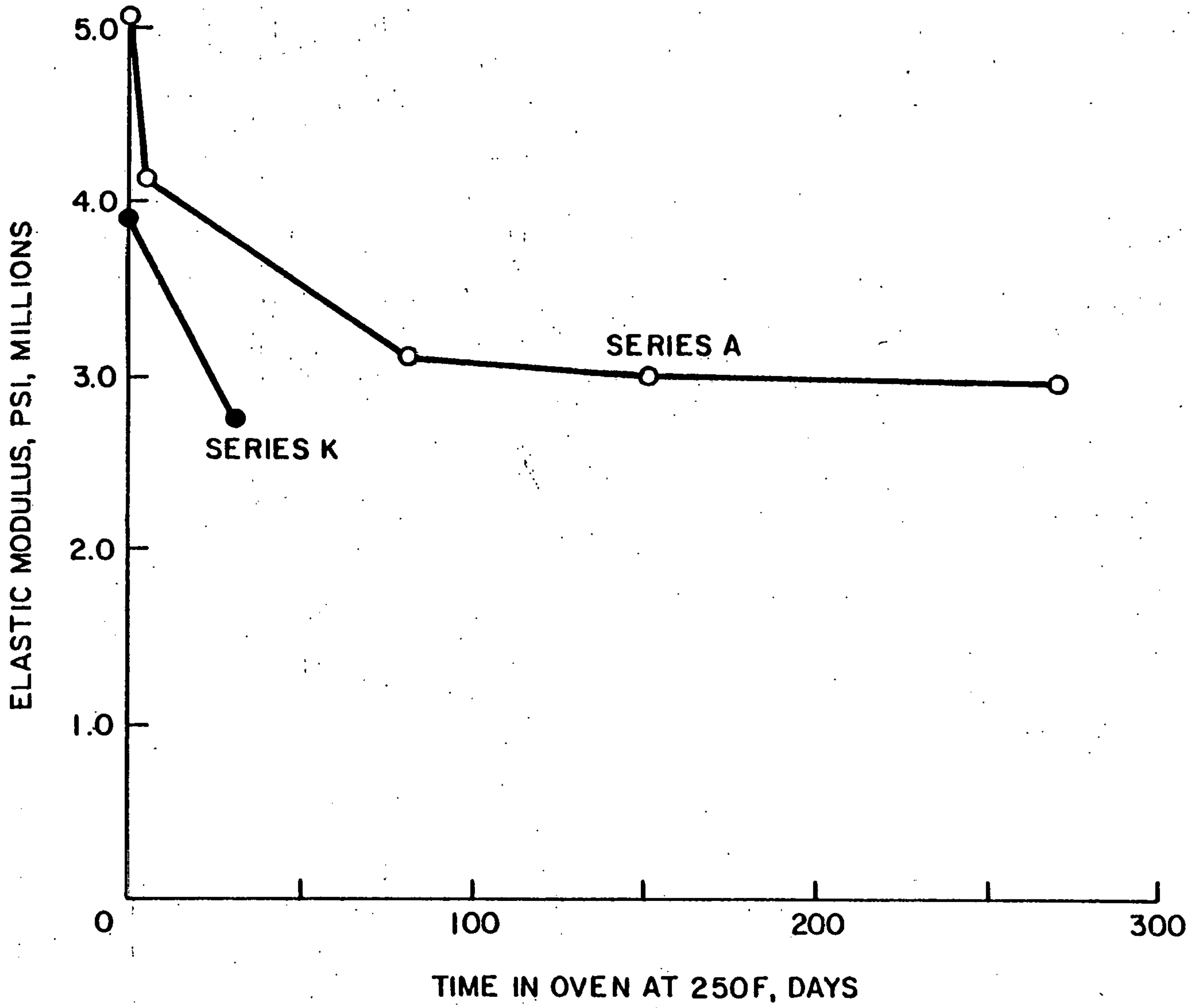

FIG. 3- ELASTIC MODULUS OF 3x6-IN. CYLINDERS EXPOSED TO ELEVATED TEMPERATURE

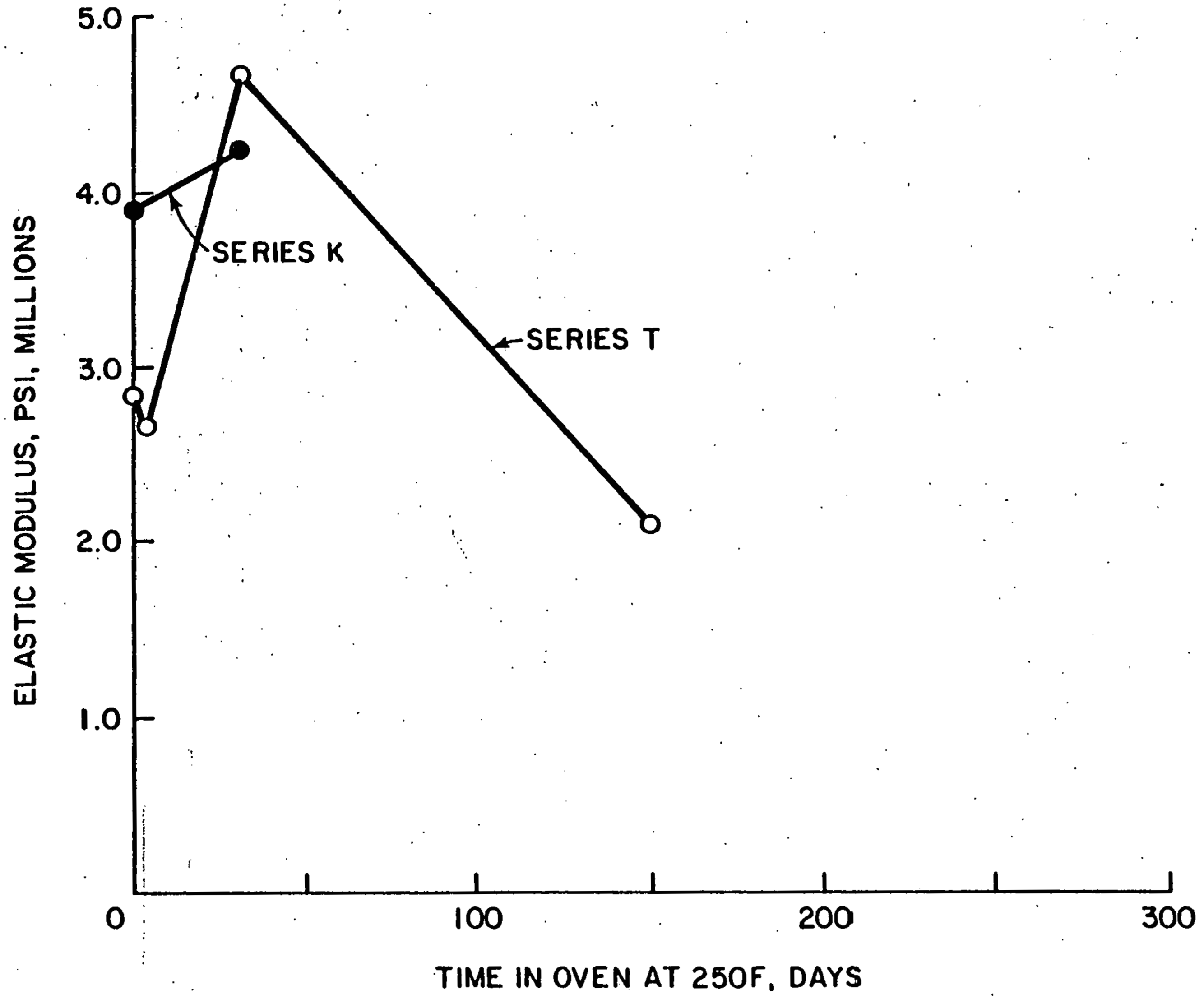

FIG. 4 - ELASTIC MODULUS OF 3-IN. CUBES EXPOSED TO ELEVATED TEMPERATURE

Figure 3 illustrates the effect of prolonged heating on the elastic modulus of 3 x 6-in. cylinders from Tank Farm Series A, and from Series K. Room temperature elastic modulus for Series A exceeded 5 million psi. After 80 days of heating it was about 3 million psi. Specimens from Series K were tested only at room temperature and after 30 days of heating. However, their modulus losses appear to parallel those of Series A during this time interval.

From Table 7 it can be seen that modulus losses of Series K 6 x 12-in. cylinders heated for 30 days were about equal to those observed for the 3 x 6-in. cylinders of the same series, Table 5. Modulus of elasticity values for both cylinder sizes decreased approximately 1.2 million psi during this interval of heating.

Modulus of elasticity values for 3-in. cubes displayed a more complex behavior, as shown in Table 6 and Figure 4. Modulus values for cubes from Series T and K after 30 days of heating at 250F showed an increase over the room temperature values. This increase was 1.8 million psi for the Series T specimens. A large strength increase for the same specimens paralleled this increase in modulus of elasticity. However, the elastic modulus values of Series T cubes decreased approximately 2.5 million psi upon heating between 30 and 150 days.

The two 3-in. cubes from Series T tested after 30 days of heating were cut from the same piece of core sample material. No other specimens of Series T were obtained from this particular concrete sample. The large measured values for these test specimens are probably not a thermally-induced phenomenon, but the result of intrinsic differences in concrete as originally received from Tank Farm T.

With the above exception, the general trend for modulus of elasticity of specimens subjected to prolonged heating was a rapid decrease during the first 30 days of heat exposure. Further heating produced a very gradual additional decline in the modulus of elasticity. Cumulative losses at the end of 150 to 270 days of heating were from 25 to 40 percent of the initial room temperature values.

Poission's Ratio

Poisson's ratio values determined for room temperature and heated specimens are shown in Tables 5, 6, and 7, and in Figs. 5 and 6. Figure 5 shows the affect of prolonged heating on Poisson's ratio for 3 x 6-in. cylinders from Series A, K, and U. As with the elastic modulus for these same specimens, Poisson's ratio decreased rapidly during early stages of heating. The decrease was not as rapid in Series A.

Values of Poisson's ratio for Series K showed a larger spread between room temperature and 30 day results than did values for Series A. The difference between room temperature

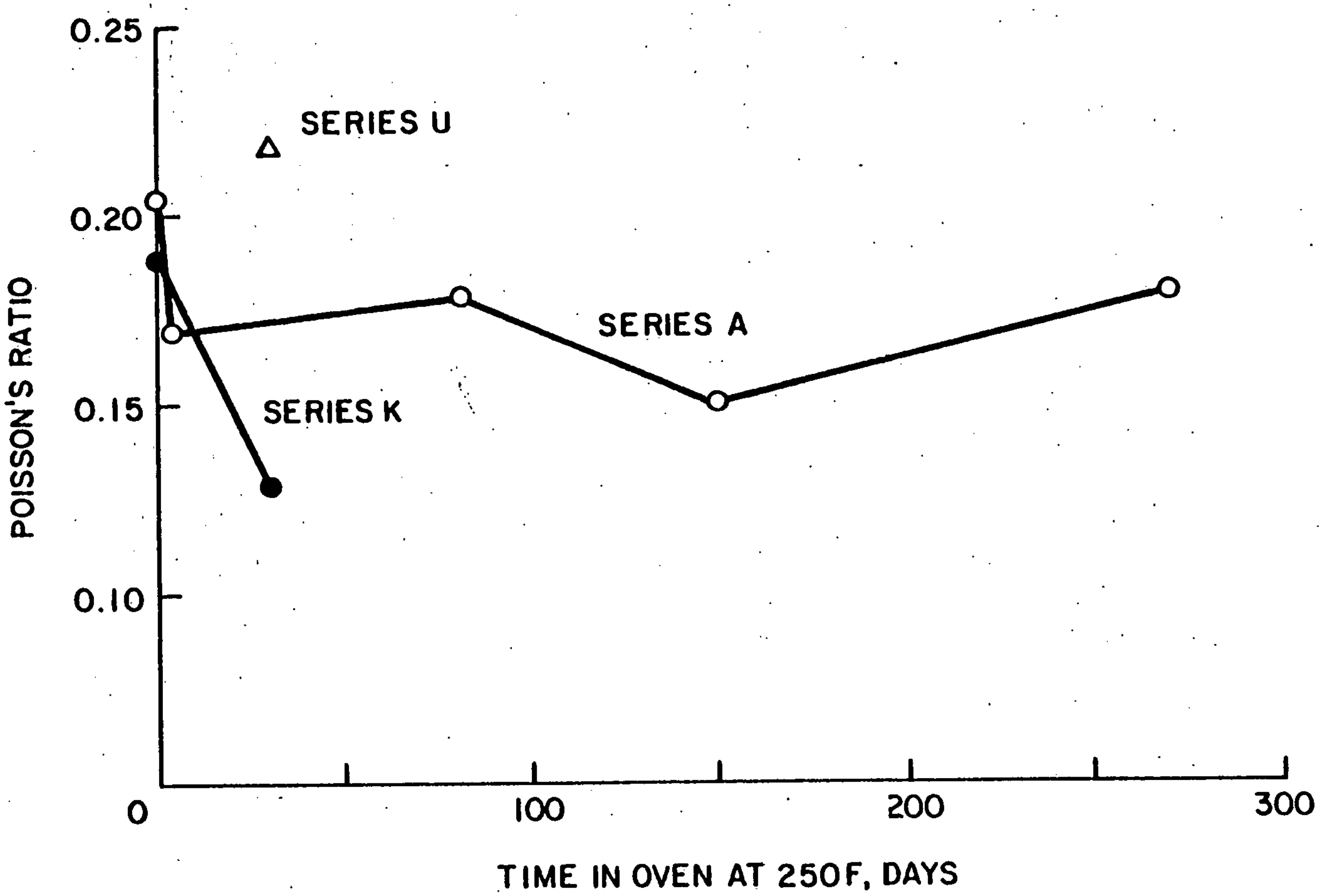

FIG. 5-POISSON'S RATIO OF 3x6-IN. CYLINDERS EXPOSED TO ELEVATED TEMPERATURE

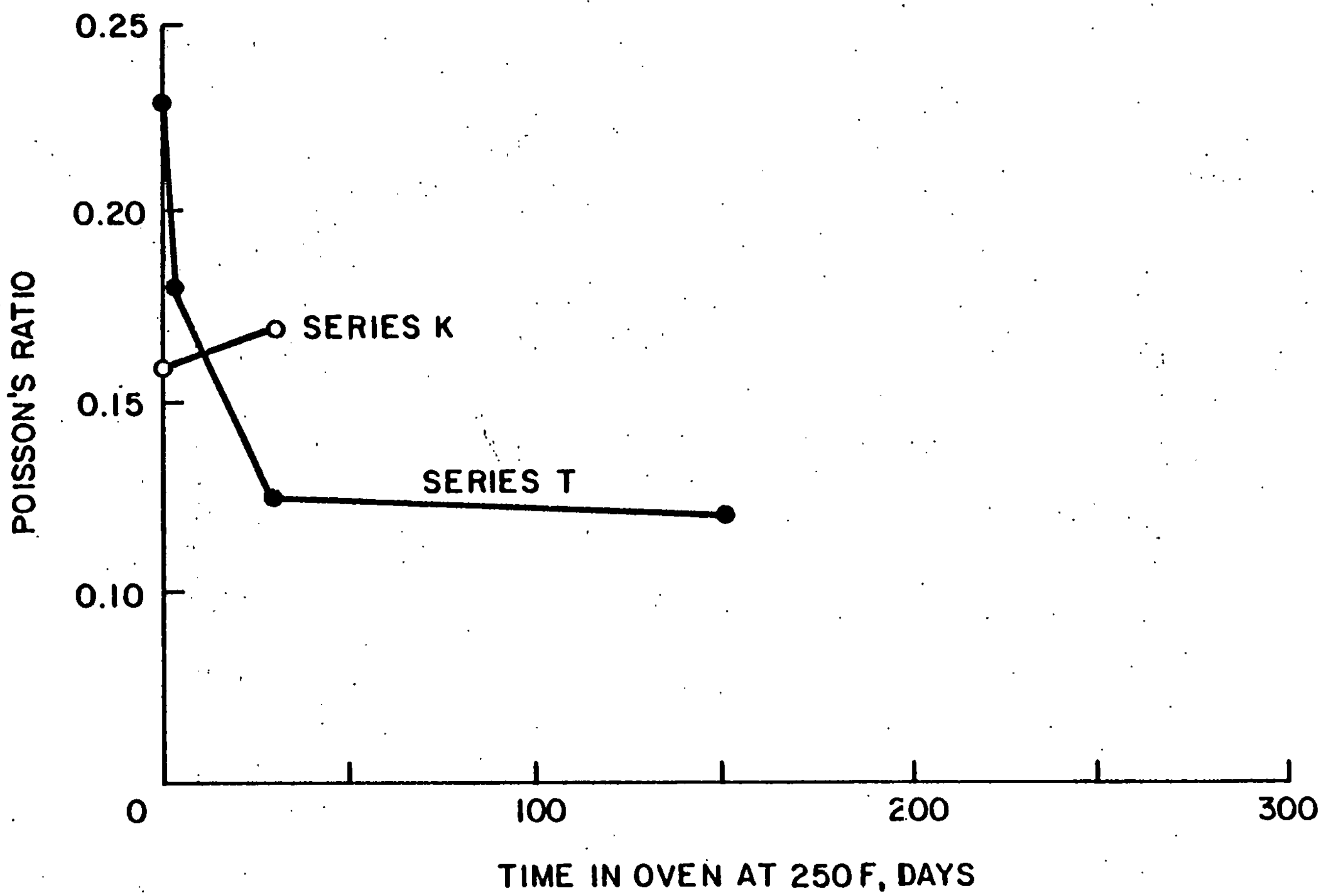

FIG. 6 – POISSON'S RATIO OF 3-IN. CUBES EXPOSED TO ELEVATED TEMPERATURE

and 270 days of heating values of Poisson's ratio for Series A amounted to 12 percent.

The decrease in Poisson's ratio for Series K, 6 x 12-in. cylinders after 30 days of heating at 250F was approximately 0.03. This loss was about one half of that observed with the Series K, 3 x 6-in. cylinders over the same period of heating.

Poisson's ratio values for the cube specimens differed from data generated from tests on cylindrical specimens. Series K cubes heated for 30 days at 250F showed an increase in Poisson's ratio from room temperature values. For Series T, the losses over the initial 30 days of heating period were almost 50 percent of the room temperature Poisson's ratio value.

Measurements of Poisson's ratio for some cube specimens were probably influenced by the presence of internal voids and cracks. These in-place flaws were discovered during subsequent compressive strength tests. Such flaws were also observed in several Tank Farm, 3 x 6-in. cylinders.

Some heated cube specimens also exhibited surface spalling of aggregates when loaded. This disruption of the specimen surface made it impossible to obtain lateral-strain data necessary for calculating Poisson's ratio.

Compressive Strength

Compressive strength values determined for room temperature and elevated temperature specimens are shown in tabular form in Tables 5, 6, and 7. These data are plotted as a function of length of exposure at 250F in Figs. 7 and 8.

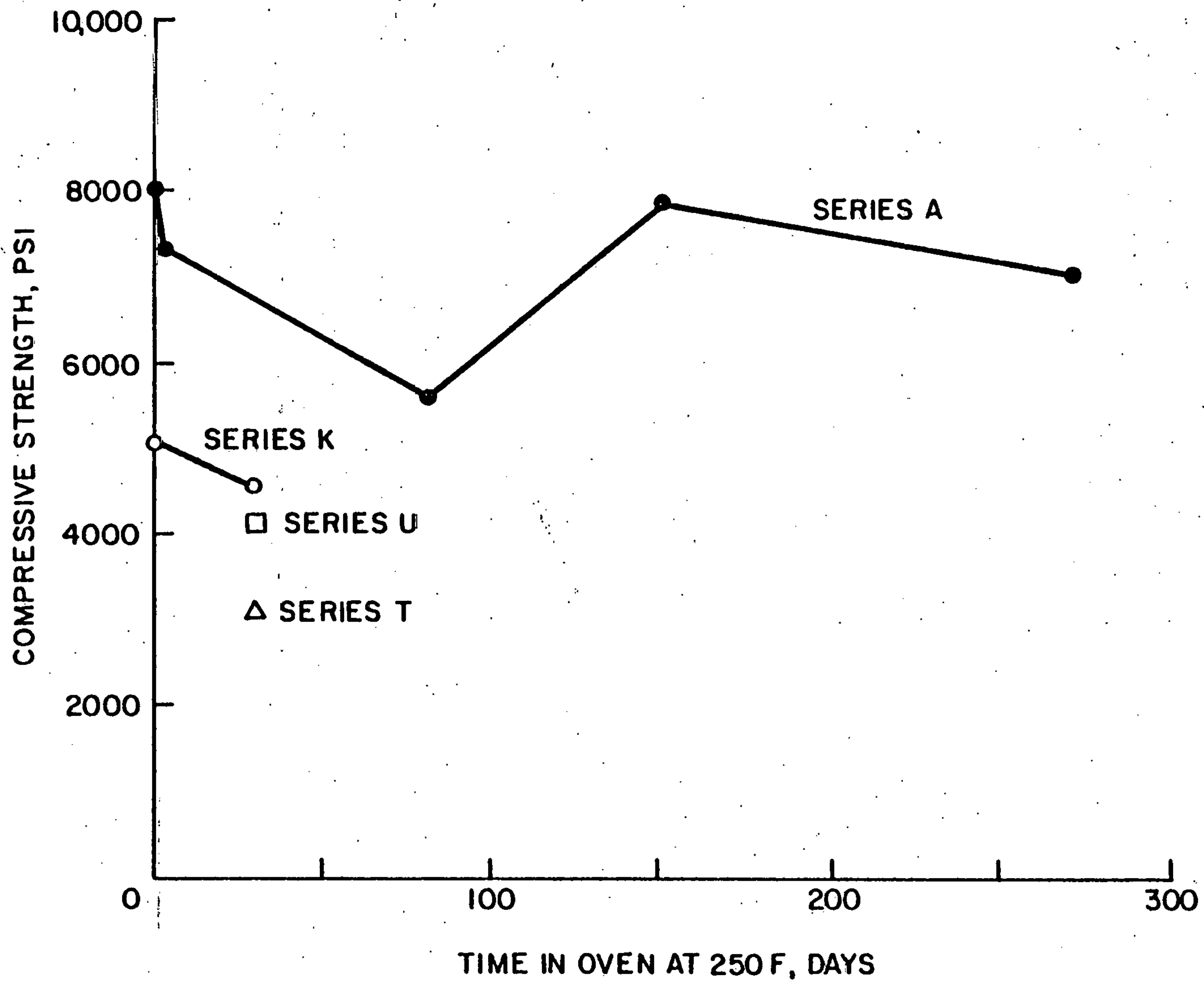

FIG. 7 — COMPRESSIVE STRENGTH OF 3x6 IN. CYLINDERS EXPOSED TO ELEVATED TEMPERATURE

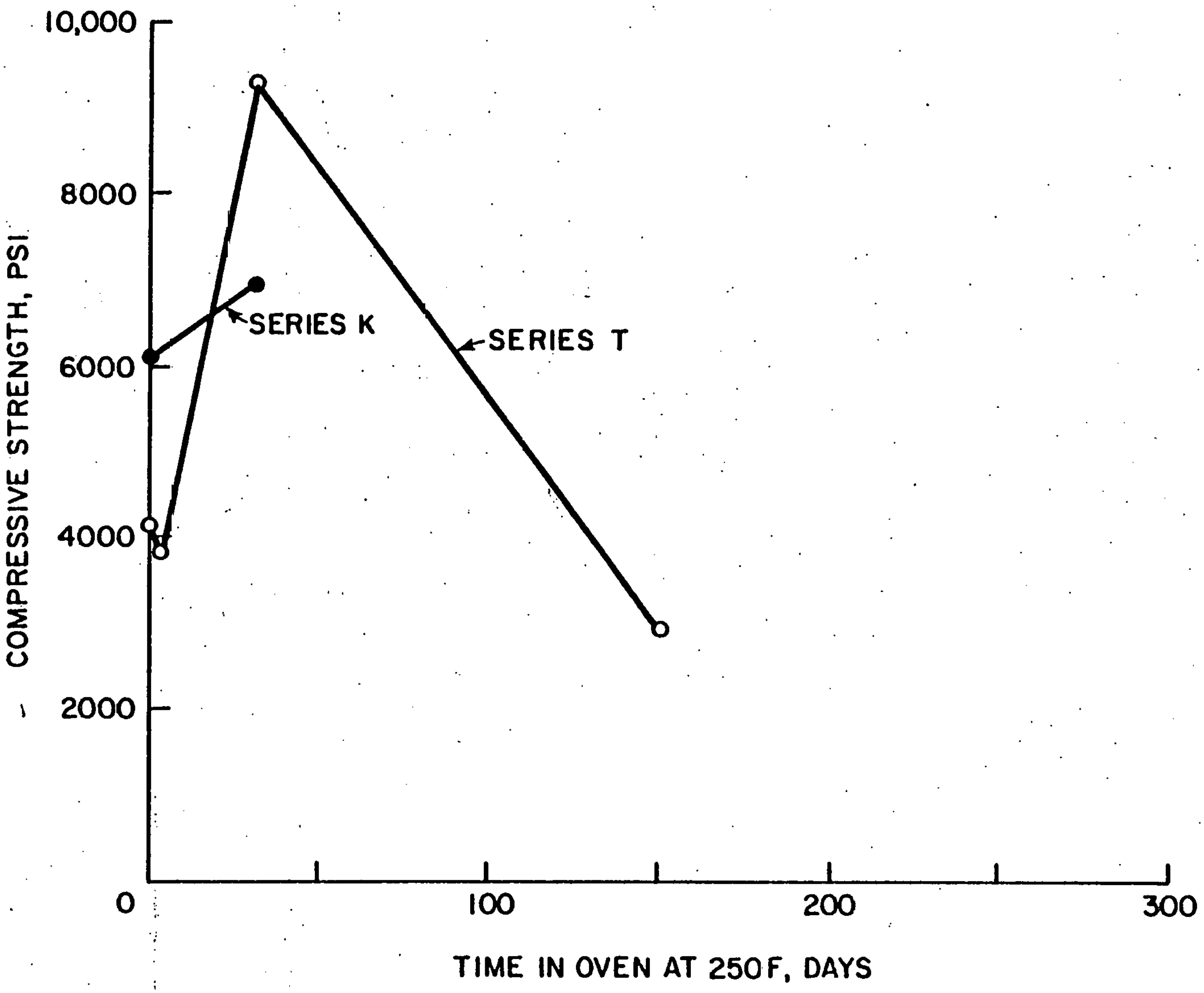

FIG. 8 — COMPRESSIVE STRENGTH OF 3-IN. CUBES EXPOSED TO ELEVATED TEMPERATURE

Compressive strengths of selected 3 x 6-in. test cylinders are plotted as a function of time at 250F in Fig. 7. As can be seen in this graph, the room temperature strength of Series A Tank Farm concrete was approximately 8000 psi. The strength of cylinders from this series decreased to about 5800 psi after heating for 80 days. Then, strength increased to almost the initial room temperature strength after being heated at 250F for 150 days. Finally, a compressive strength of approximately 7100 psi was obtained at the end of 270 days at elevated temperature.

Strength losses of Series K cylinders paralleled those obtained for Series A specimens over the initial 30 day heating period. However, Series K cylinders had overall strengths 2500 to 3000 psi lower than those of Series A. Compressive strength tests were performed on specimens from Series T and U after 30 days of heating. Their elevated temperature strengths were lower than those of either Series A or K during this heating interval.

Strength measured for the Series T, 3 x 6-in. specimen at 30 days may not be representative since there were some surface cracks visible on the specimen prior to loading. Lack of sufficient core sample material made it impossible to substitute another specimen in place of this one.

Compressive strengths of Series K, 6 x 12-in. cylinders at room temperature and 250F were about 600 to 800 psi higher than the companion 3 x 6-in. cylinders. Strength losses after heating for 30 days were about 400 to 500 psi for both size cylinders.

The compressive strength of cube specimens increased during the early stages of heating at 250F, as shown in Fig. 9. The strength of Series T cubes heated for 30 days averaged more than 5000 psi over values measured at room temperature. Such a dramatic increase is almost certainly not due to the effect of exposure to elevated temperature. Also, specimens at the end of 150 days of heating at 250F showed an approximate compressive strength of 3000 psi, a 6300 psi loss from room-temperature strength.

The most probable explanation for these large strength excursions is a variation in the strength of concrete in the Waste Tank Farm structures. Such a large variation may or may not be of concern in itself, but it does present difficulties in determining effects of long-term exposure to elevated temperatures on the concrete compressive strength.

Excluding the data obtained at 30 days, it would appear that exposure to 250F over a prolonged period of time generally resulted in a strength loss of about 25 percent during the first 30 to 80 days of heating. Thereafter, strength recovery was observed for some specimens, while for others a further gradually strength decline occurred.

Splitting Tensile Strength

Splitting tensile strengths determined for test specimens at room and elevated temperatures are listed in Tables 8 and 9, and shown graphically in Fig. 9. From Tables 8 and 9, it can be seen that the splitting tensile strengths of cylindrical test specimens at room temperature varied widely, from a high of 1140 psi to a low of approximately 520 psi.

As seen in Fig. 9, highest strengths were observed for Series A, 3 x 6-in. cylinders. On prolonged heating, however, the strength losses within this series were about 40 percent of initial strength.

At the other extreme, the Series T specimens displayed very little change in splitting tensile strength on heating from 3 to 150 days.

Strength losses of Series K, 3 x 6-in. cylinders after heating were not as large as for Series A. These losses amounted only to about a 25 percent reduction in strength after 30 days of heating at 250F.

It can be seen from Table 8 that strength losses of Series K, 6 x 12-in. cylinders amounted to only 10 percent of the strength loss observed for Series K, 3 x 6-in. cylinders after 30 days of heating.

One cylinder from Series U was tested after 30 days of heating. Its tensile splitting strength, about 630 psi, was almost identical to strengths of Series K cylinders heated for the same period of time.

TABLE 8. - TENSILE SPLITTING STRENGTH OF 6 x 12-IN. CYLINDERS AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test Mo.-Day-Yr.	Time in Oven Days	Temp. at Test, F	Weight at Test, lb	Tensile Split. Strength, Psi
3K5-22	8-9-77	0	73	29.37	522
3K9-16	8-9-77	0	73	28.88	516
3K5-18	9-7-77	30	250	28.08	492
3K9-13	9-7-77	30	250	27.83	496

TABLE 9 - TENSILE SPLITTING STRENGTH OF 3 x 6-IN. CYLINDERS AT ROOM AND ELEVATED TEMPERATURES

Specimen Number	Date of Test Mo.-Day-Yr.	Time in Oven Days	Temp. at Test, F	Weight at Test, lb	Tensile Split. Strength, Psi
3K9-7-1	5-25-77	0	73	2.864	850
3K5-15-3	5-25-77	0	73	2.860	769
241AII-10	5-25-77	0	73	2.787	1018
241AI-12	5-25-77	0	73	2.728	1255
241AI-14	7-28-77	3	250	2.721	971
241AII-16	7-28-77	3	250	2.684	996
241T-2	7-28-77	3	250	2.816	527
241T-3	7-28-77	3	250	2.790	571
3K5-24-6	8-24-77	30	250	2.743	721
3K9-4-7	8-24-77	30	250	2.825	538
241AII-19	8-24-77	30	250	2.827	859
241T-4	8-24-77	30	250	2.838	582
241U-2	8-24-77	30	250	2.713	633
241A-5	8-12-77	80	250	2.597	845
241A-8	8-12-77	80	250	2.504	834
241AI-1	9-9-77	150	250	2.869	1064
241AI-2	9-9-77	150	250	2.819	920
241T-1	9-9-77	150	250	2.797	556
241A-17	4-21-78	270	250	2.764	674

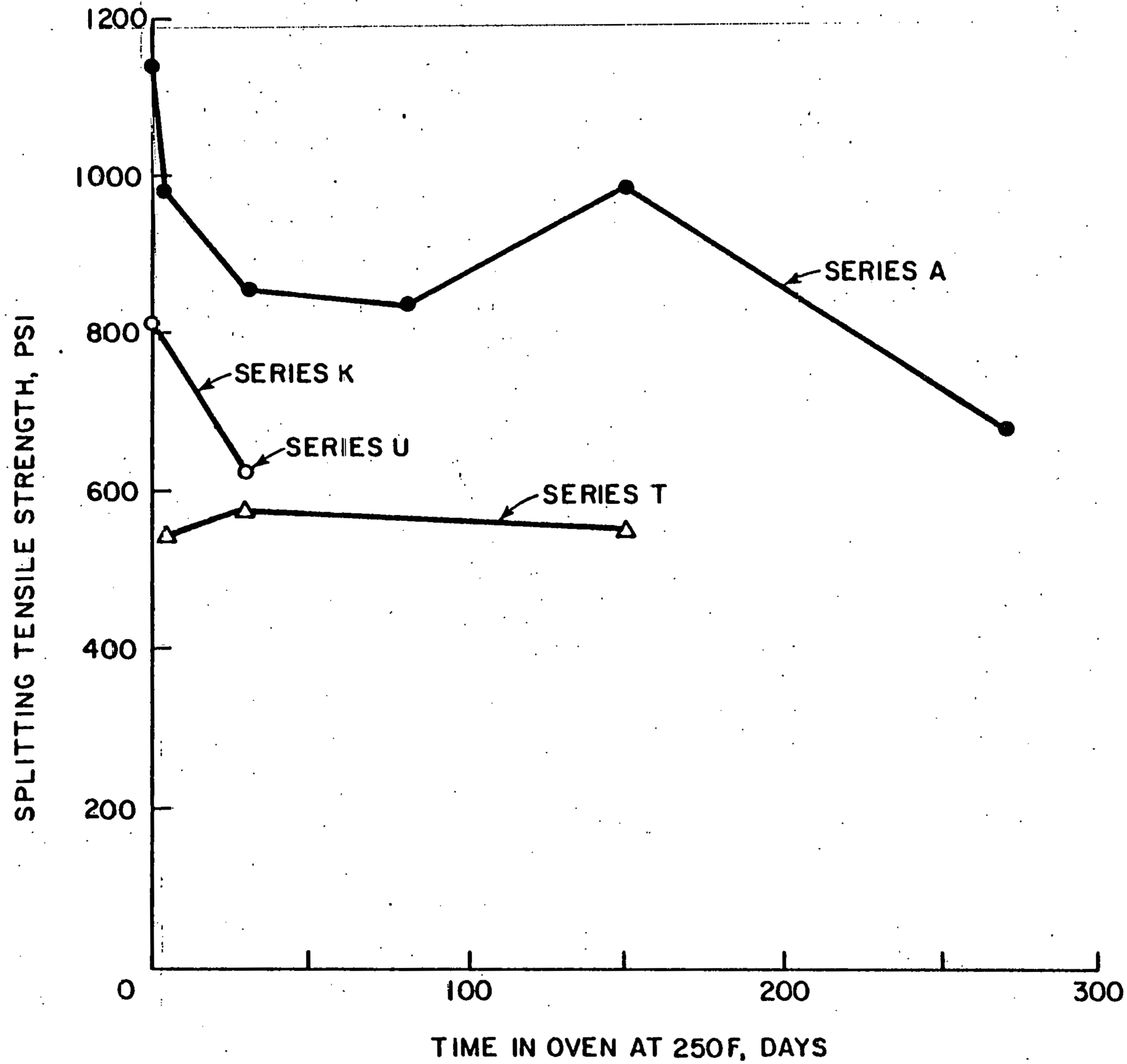

FIG. 9 – SPLITTING TENSILE STRENGTH OF 3x6 IN. CYLINDERS EXPOSED TO ELEVATED TEMPERATURE

Comparison of Tank Farm and CTL Cylinders

Waste Tank Farm concrete specimens differed greatly in their properties. Consequently, it is difficult to summarize test results about their collective performance in comparison to concrete cast at CTL. To make useful comparisons, it is necessary to discuss the elastic and strength properties series by series.

Series A, T, and U

Of the Waste Tank Farm specimens, Series A had the highest values for elastic modulus, compressive, and splitting tensile strengths at room temperature. Series A also had the largest losses in these properties on heating.

Waste Tank Farm Series T generally had the lowest property values. However, a few Series T specimens showed strengths considerably higher than most of those tested in this investigation. The values for compressive strength of Series T, 3-in. cubes tested after 30 days of heating at 250F, averaged over 9000 psi. Such variations make it difficult to draw conclusions about the influence of service temperature on the properties of that concrete sample from the 241-T Tank farm.

Only two specimens were tested from Tank Farm Series U. Their results fall near those of Series T for both strength and elastic properties.

CTL Series K

Results of tests for Series K specimens fabricated at the

Portland Cement Association tended to fall between the extremes for the Waste Tank Farm specimens of Series A and T (Figs. 7 and 9). This comparison is limited by the fact that Series K specimens were tested only up to 30 days of heating, while Waste Tank Farms specimens were tested out to 270 days of heating. Overall, the early heating effects on Series K specimen properties tended to parallel those of Tank Farm Series A.

CTL Series M

Some in-house concrete specimens, designated Series M, were used in a separate ongoing research program to determine strength and elastic properties at room and elevated temperatures[2]. One objective of the present investigation was to compare test results of this separate research program to results of tests on Tank Farm concrete.

Results of this related program for specimens at 250F are shown as Series M in Figs. 10, 11, 12, and 13. Comparison of elastic modulus values of Series M, 6 x 12-in. cylinders to Series A, 3 x 6-in. Tank Farm concrete cylinders is shown in Fig. 10. Initial values of Series A modulus of elasticity were somewhat higher than for Series M concrete. Modulus values of both series were almost identical after heating from 80 to 270 days.

Poisson's Ratio values of Series M and Series A cylinders are shown as a function of time at 250F in Fig. 11. Series A

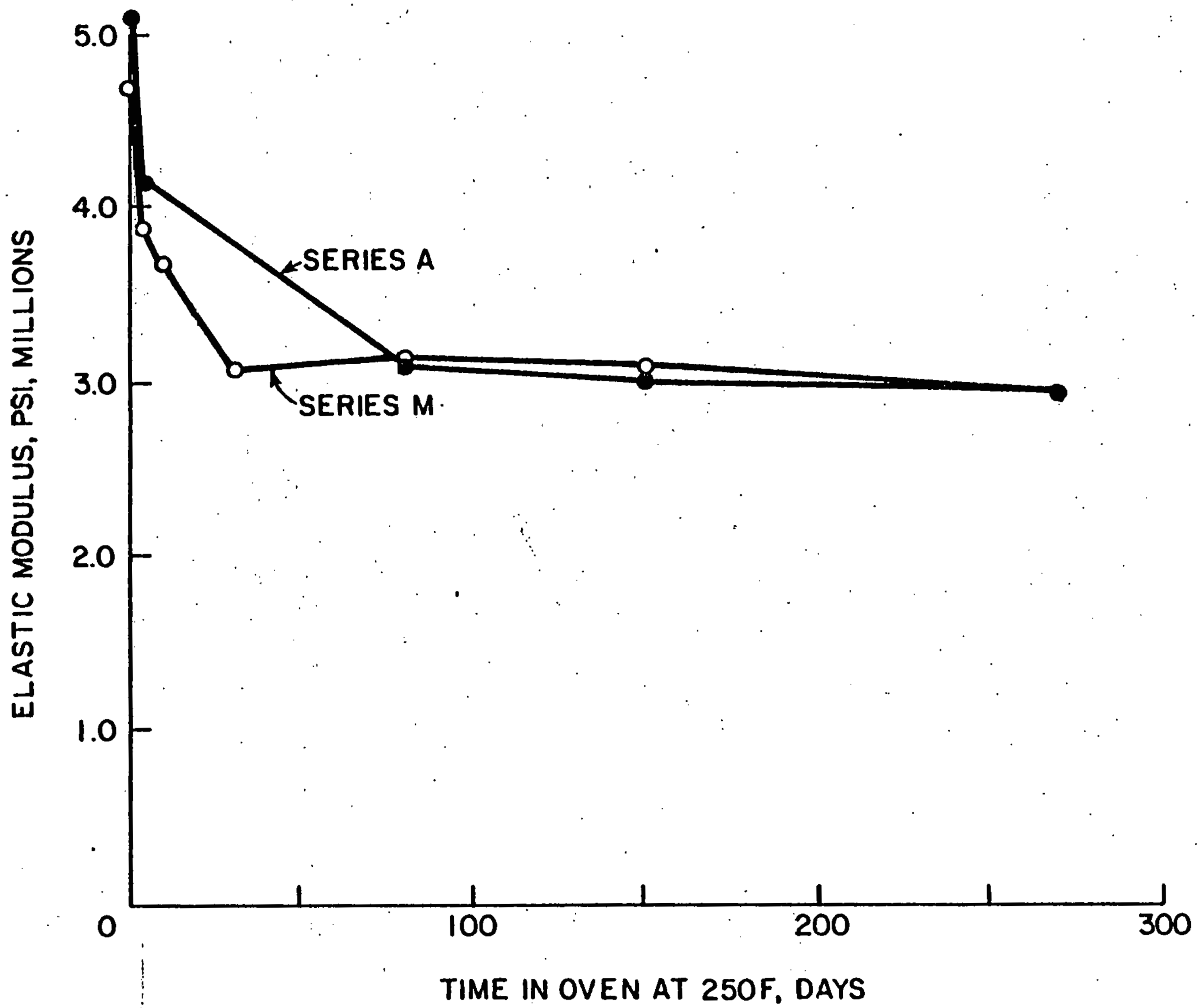

FIG. 10– ELASTIC MODULUS OF TANK FARM AND SERIES M CONCRETE EXPOSED TO ELEVATED TEMPERATURE

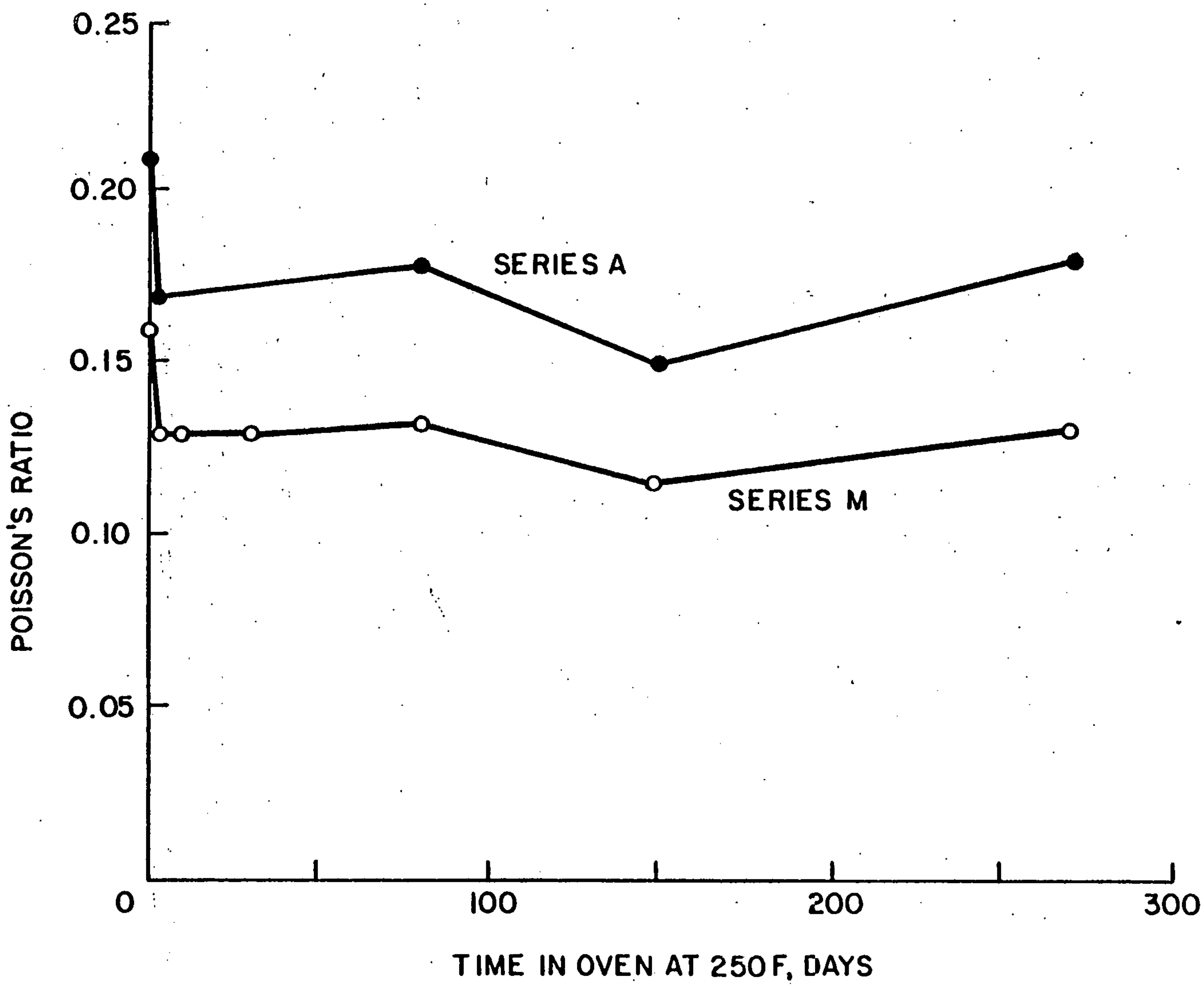

FIG. 11 – POISSON'S RATIO OF TANK FARM AND SERIES M CONCRETE EXPOSED TO ELEVATED TEMPERATURE

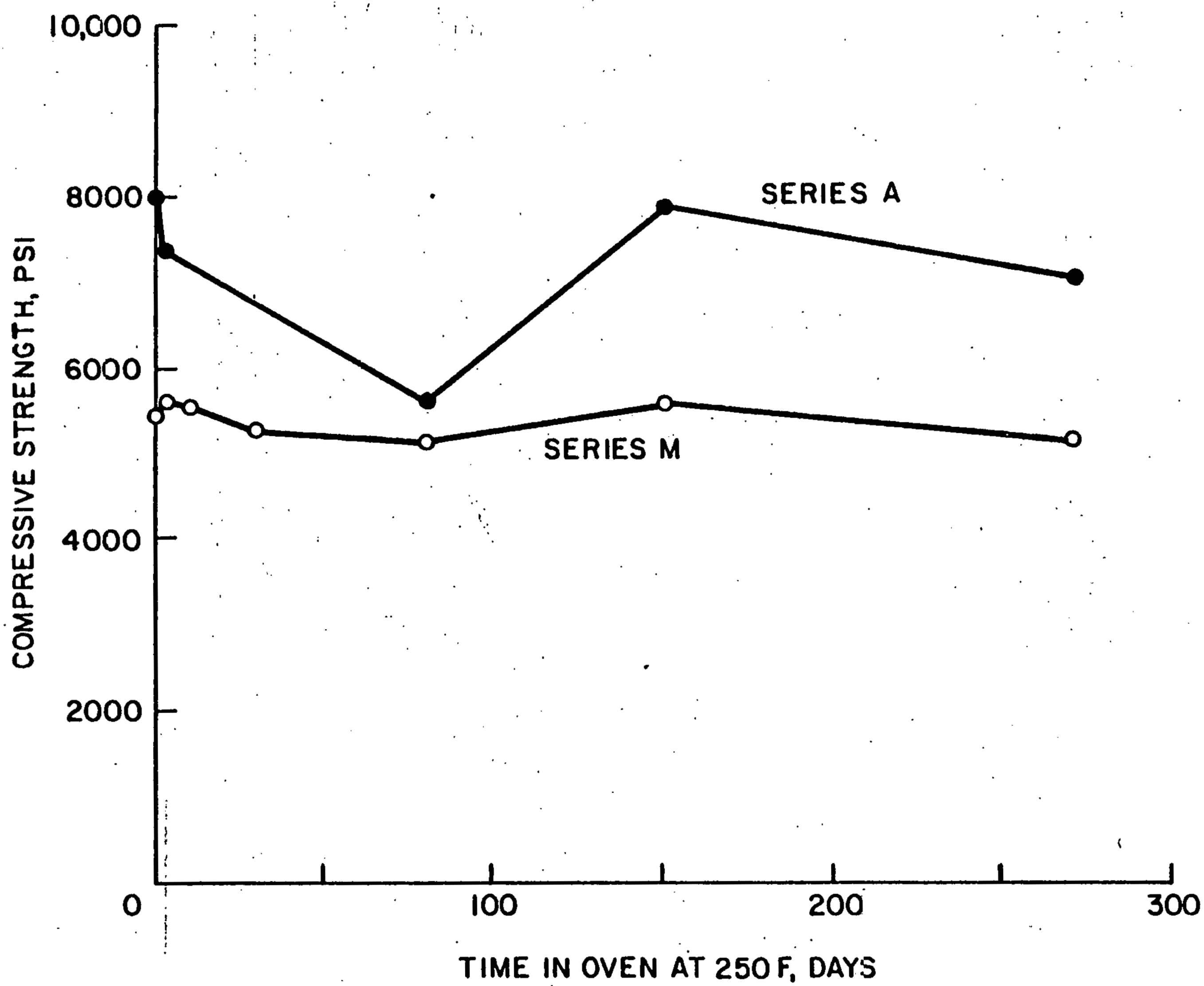

FIG. 12 – COMPRESSIVE STRENGTH OF TANK FARM AND SERIES M CONCRETE EXPOSED TO ELEVATED TEMPERATURE

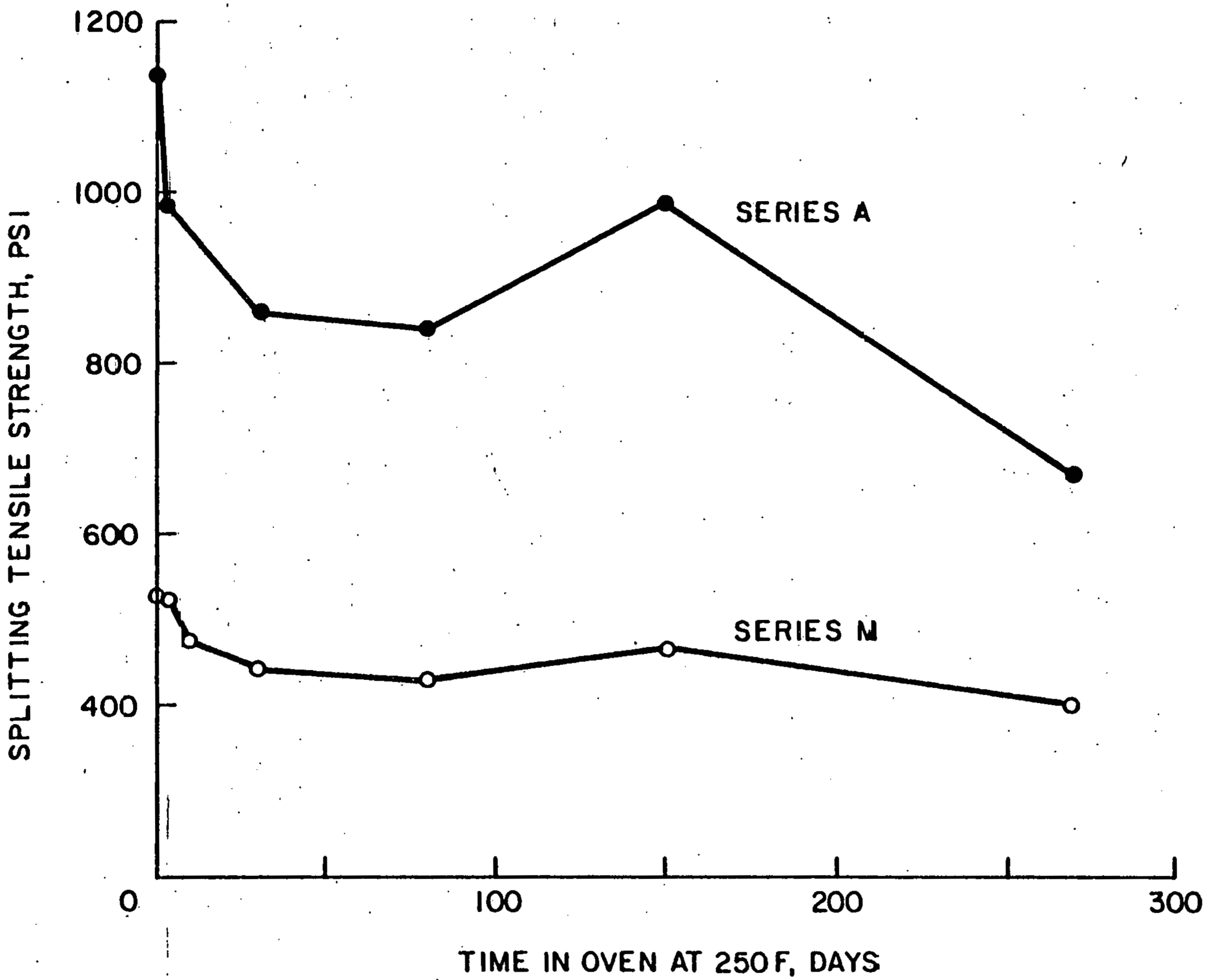

FIG. 13— SPLITTING TENSILE STRENGTH OF TANK FARM AND SERIES M CONCRETE EXPOSED TO ELEVATED TEMPERATURE

concrete had Poisson's Ratio values approximately 0.05 larger than Series M specimens at most test dates. However, the decrease in Poisson's Ratio for both series was similar throughout the 270 day testing period.

Compressive strengths of Series A and M specimens are shown in Fig. 12. Variations of original strength of Series A specimens make comparisons with Series M difficult. After 270 days of heating there was only a small decrease in compressive strength from the room temperature strength for each series.

In Fig. 13 splitting tensile strengths of Series A and M specimens as a function of heating time are compared. Strength losses after heating at 250F for 270 days were twice as large for Series A than for Series M.

As seen in Figs. 12 and 13, compressive and splitting tensile strengths appeared to increase for Series A cylinders when heated from 80 to 150 days. These large variations in strengths for Series A cylinders may be partially due to large room temperature strength differences rather than the effect of prolonged exposure to elevated temperature.

<u>Influence of Specimen Geometry</u>

A comparison of strength and elastic properties using different specimen geometries shows varying degrees of agreement. The room temperature modulus of elasticity of about 4.0 million psi was obtained for the 3 x 6-in. cylinders and 3-in. cubes of Series K. After 30 days of heating at 250F, modulus of elasticity values for the 3 x 6-in. cylinders dropped to under 2.8 million psi, while the 3-in. cubes values increased to over 4.2 million psi. A similar trend was observed for Poisson's ratio for these same specimens.

The effect of specimen geometry on measurement of compressive strength is illustrated in Fig. 14. Strengths of Series K specimens of three different geometries are compared at room temperature and after 30 days at 250F.

Neville has shown that for cast specimens at room temperature, smaller specimen geometries yield higher measured strengths[6]. This was only partially true for cored specimens at 73 and 250F in this study.

Strengths of 3-in. cube specimens were larger than those of 6 x 12-in. cylinders at room and elevated temperatures. However, 3 x 6-in. cylinders had strengths lower than cubes and larger cylinders at both test temperatures.

Cylindrical specimens suffered a loss in strength on heating. However, cube specimens showed an increase in strength on heating from 73 to 250F, however.

Overall, the cube specimens indicated trends in strength and elastic properties contrary to both sets of cylindrical specimens. Also, within a given series, there appeared to be larger property variations measured between cube specimens than between cylinders. No simple explanation for these differing results is apparent.

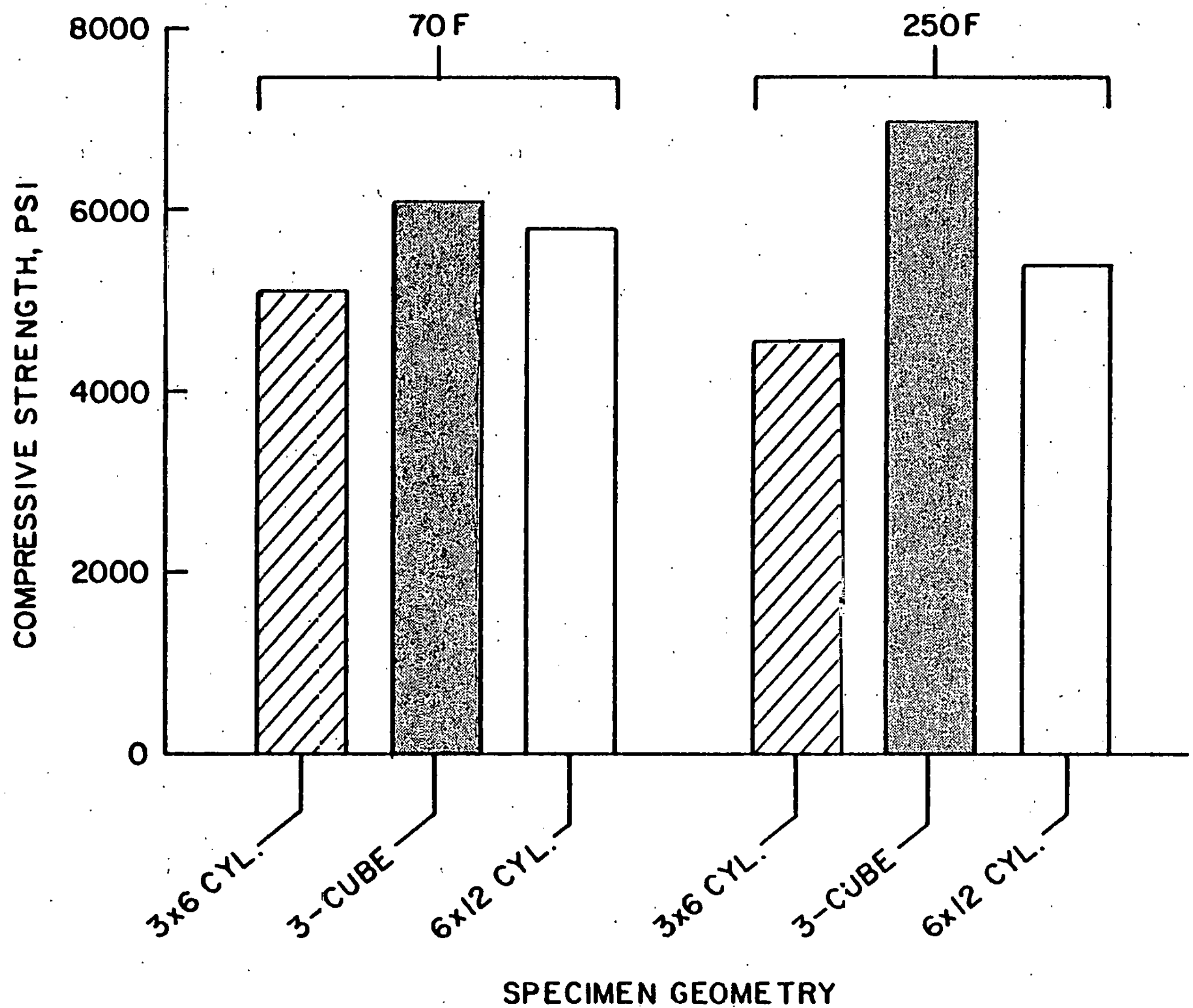

FIG. 14 — COMPARISON OF COMPRESSIVE STRENGTH VERSUS SPECIMEN GEOMETRY. SERIES K CONCRETE AT ROOM TEMPERATURE AND AFTER 30 DAYS AT 250 F

SUMMARY

Test specimens were fabricated from concrete samples cored from Hanford Waste Tank Farm structures, and from concrete cylinders cast at the Portland Cement Association Construction Technology Laboratories using Hanford mix designs and materials.

The following observations are based on the results of strength and elastic properties tests conducted on 3-in. cubes, 3 x 6-in. cylinders, and 6 x 12-in. cylinders at room temperature and 250F. The modulus of elasticity, Poisson's ratio, and compressive and splitting tensile strengths were determined in accordance with static compression methods described in ASTM Designations: C39, C469, and C496.

1. The elastic modulus of Hanford Waste Tank Farms concrete at room temperature ranged from a high of 5.32 million psi for the 241-A Tank Farm, to a low of 2.69 million psi for the 241-T Tank Farm.
2. The average value of modulus of elasticity for CTL cast specimens, Series K, at room temperature was 4.14 million psi.
3. The modulus of elasticity of Tank Farm specimens generally decreased with increased exposure time to a temperature of 250F. The modulus of elasticity for heated specimens dropped to an average of 2.09 million psi for the 241-T Tank Farm after 150 days of heating. The average modulus for the 241-A Tank Farm specimens after 270 days of heating was 2.98 million psi.

4. The modulus of elasticity of the 241-T Tank Farm cube specimens increased after 30 days of heating by about 1.8 million psi, then dropped by more than 2.5 million psi after 150 days of heating. These large changes probably were not related to exposure to elevated temperatures, but resulted from intrinsic strength differences of the in-place concrete in the tanks.
5. The average value for the modulus of elasticity for Portland Cement Association cast specimens, Series K, heated for 30 days at 250F was 3.44 million psi.
6. Poisson's ratio for Waste Tank Farm specimens at room temperature averaged approximately 0.22.
7. Poisson's ratio for Series K specimens, cast at PCA, at room temperature averaged 0.17.
8. Poisson's ratio for Waste Tank Farm specimens decreased after heating at 250F. The largest losses of 0.11 were for the 241-T Tank Farm specimens. The smallest losses of 0.01 were for the 241-A Tank Farm specimens, after 270 days of heating.
9. The average value of Poisson's ratio for Series K specimens after 30 days of heating at 250F was 0.14.
10. The compressive strength of Waste Tank Farm specimens at room temperature varied widely. The highest recorded strength, 8240 psi, was for a specimen from the 241-A Tank Farm. The lowest recorded room temperature strength, 3690 psi, was for a specimen from the 241-T Tank Farm.

11. The average compressive strength for Series K specimens was 5670 psi. The highest strengths for these specimens were obtained for 3-in. cubes, while the lowest strengths were for 3 x 6-in. cylinders. Results of 6 x 12-in. cylinders agreed closely with those of the 3-in. cubes.

12. Compressive strength of Waste Tank Farm specimens behaved in a complex manner on heating. Specimens from the 241-A Tank Farm lost strength on being heated for the first 80 days. Between 80 and 150 days of heating at 250F, the 241-A specimens showed an increase in strength to almost their initial room temperature strength. By the end of 270 days of heating, specimens from this series showed a decline in strength to approximately 7100 psi.

13. The compressive strength of specimens from the 241-T Tank Farm increased in strength by almost 5000 psi during the first 30 days of heating. Then these specimens showed a decline of more than 6000 psi between 30 and 150 days of heating. As stated earlier, these changes are probably due to differences in strength of concrete in-place and not the result of exposure to elevated temperatures.

14. The average compressive strength of Series K specimens after 30 days of heating at 250F was 5630 psi. This

represents practically no net change in these specimens on heating. However, there were measurable changes in the strength, after heating, of specimens of different geometries. The 3 x 6-in. cylinders decreased in strength, while the 3-in. cube specimens increased in strength. The strength changes were of equal and opposite character, and cancelled out in the average.

15. The splitting tensile strength of Waste Tank Farm specimens at room temperature varied widely. Highest strengths were for the 241-A Tank Farm, which averaged approximately 1140 psi.

16. The splitting tensile strengths for Series K specimens at room temperature averaged 664 psi. The splitting strengths for 3 x 6-in. cylinders were larger than for 6 x 12-in. cylinders. The opposite case was true for compressive strength.

17. A difference in behavior was observed in the splitting tensile strength of 241-A and 241-T specimens heated for varying lengths of time at 250F. In the case of the 241-A Tank Farm concrete, the strength dropped from 1140 psi at 73F to approximately 680 psi at the end of 270 days of heating. The 241-T Tank Farm specimens had almost no change in strength from 3 to 150 days of heating. The splitting strength of the

specimen from the 241-U Tank Farm, after 30 days of heating, was only slightly higher than specimens from the 241-T Tank Farm.

18. The splitting tensile strengths of Series K specimens averaged 562 psi at the end of 30 days of heating at 250F. This represents about a 100 psi decrease from the room temperature strengths.

19. A comparison of the strength and elastic properties of Waste Tank Farm and Series K specimens at room and elevated temperatures indicated similar performances. The strengths and elastic constants for CTL cast specimens remained approximately mid-way between the highest and lowest strengths for the Hanford Tank Farm concretes under all test and temperature conditions.

20. In this study the relationship of specimen size to test results often differed from trends observed by other investigators[6]. Larger specimens usually have lower measured strengths than smaller specimens of similar composition. However, in tests for this study on concrete cast at CTL, the strength of 6 x 12 in. cylinders was larger than that of 3 x 6 in. cylinders.

21. The strength and elastic property values of the cube specimens tended to run contrary to the performance of the cylindrical concrete specimens. Properties of

cylindrical specimens had lower values after heating to 250F than cube specimens. Values of strength and elastic properties of 3-in. cube specimens were usually larger at 250F than at 73F.

22. The results of tests on concrete cast at CTL, Series K and M, generally followed similar trends for comparable test conditions at room temperature and at 250F.

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2. M. S. Abrams, Proposals for Research, "Strength and Elastic Properties at High Temperatures," submitted to Battelle Northwest Laboratories, Richland, Washington by Portland Cement Association Construction Technology Laboratories, September, 1975, and March, 1976.

3. ASTM Designation: C469, "Standard Method of Test for Splitting Tensile Strength of Cylindrical Concrete Specimens," American Society for Testing and Materials, Philadelphia, Pa.

4. ASTM Designation: C469, "Standard Method of Test for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," American Society for Testing and Materials, Philadelphia, Pa.

5. ASTM Designation: C39, "Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens," American Society for Testing and Materials; Philadelphia, Pa.

6. A. M. Neville, Properties of Concrete, pp. 490-2, J. Wiley and Sons, 1973.

APPENDIX

CTL Specimens - Concrete Mix Information

Portland Cement Association
Construction Technology Laboratories

Project CR-1480 - Concrete Test Cylinder Fabrication
Battelle Pacific Northwest Laboratories

TABLE 19 - CONCRETE MIX INFORMATION

Mix No.	Water Cement Ratio	Portland Cement	Water	Air	Sand	Aggregate	Darex
3K Concrete Mixture							
3K3	0.55	498	277	3.8	1217	2102	0.20
3K4	0.50	490	247	4.9	1198	2068	0.29
3K5	0.51	494	255	4.5	1202	2083	0.34
3K6	0.53	489	260	5.0	1179	2071	0.39
3K7	0.53	484	261	6.3	1169	2047	0.38
3K8	0.54	491	267	4.9	1183	2072	0.34
3K9	0.53	489	263	5.0	1179	2068	0.36
Ave.	0.53	491	261	4.9	1190	2073	0.33
Target	0.54	498	271	5.0	1213	2096	0.20
4.5K Concrete Mixture							
4.5K3	0.42	652	278	5.0	1215	1864	0.59
4.5K4	0.44	652	289	4.6	1209	1860	0.63
4.5K5	0.47	651	309	4.5	1192	1855	0.63
4.5K6	0.43	640	280	5.4	1190	1830	0.67
4.5K7	0.45	643	294	5.7	1186	1832	0.67
4.5K8	0.45	652	294	4.6	1207	1856	0.68
4.5K9	0.36	650	239	5.2	1240	1862	0.68
Ave.	0.43	649	283	5.0	1206	1851	0.65
Target	0.43	658	286	5.0	1240	1880	0.30

Portland Cement Association
Construction Technology Laboratories

Project CR-1480 - Concrete Test Cylinder Fabrication
Battelle Pacific Northwest Laboratories

TABLE 20 - MATERIAL CONSUMPTION

Mix No.	Lone Star Cement	S Aggregate	R Aggregate	6x12 in. Spec	Cast Order
		3K Concrete Mixtures			
1	64.6	164.94	271.70	15	1
2	64.6	164.94	271.70	17	2
3	110.6	270.04	472.0	27	5
4	110.6	271.50	462.7	30	6
5	110.6	271.00	467.3	30	7
6	110.6	271.00	467.3	30	8
7	110.6	271.00	467.3	29	15
8	110.6	271.00	467.3	30	16
9	110.6	271.00	467.3	29	17
SUB TOTAL TO DATE	903.4	2497.42	3814.6	237	-
		4.5K Concrete Mixures			
1	85.30	168.61	243.70	16	3
2	85.30	168.61	243.70	16	4
3	146.2	275.6	417.8	28	9
4	146.2	275.6	417.8	30	10
5	146.2	275.6	417.8	28	11
6	146.2	275.6	417.8	30	12
7	146.2	275.6	417.8	29	13
8	146.2	275.6	417.8	30	14
9	146.2	275.6	417.8	29	18
SUB TOTAL TO DATE	1194.0	2266.42	3412.00	236	-
TOTAL TO DATE	2097.4	4763.84	7226.60	473	18

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PROJ. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 7 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 3K 5 DATE 22 MAY 75 TIME 1100

MATERIALS

CEMENT	LONE STAR P C CO TYPE II	
FINE AGGREGATE . .	1-S	
	2-NONE	
COARSE AGGREGATE .	1-R	
	2-NONE	
ADMIXTURE.	1-DAREX AEA	
	2-NONE	

BATCH INGREDIENTS

CEMENT	LBS/CU YD	494.	BGS/CU YD	5.26
FINE AGGREGATE . . 1 . .		1202.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		2083.		
2 . .		0.00		
ADMIXTURE. . . . . 1 . .		0.34		
2 . .		0.00		
WATER.		255.	GALS/CU YD	30.72
TOTAL WEIGHT	LBS/CU YD	4037.08		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE

SLUMP IN INCHES . . .	3.0
AIR CONTENT,PERCENT . .	4.5
UNIT WEIGHT,LBS/CU FT .	149.5

BATCH ANALYSIS

WATER CEMENT RATIO	0.51	BY WT	5.84	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.5	BY WT	36.9	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.09	PRESS	2.12	UNIT WT

ADDITIONAL DATA

SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 30 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE 10 - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO SK 8 DATE 23 MAY 75 TIME 0910

MATERIALS
CEMENT . . . . LONE STAR P C CO TYPE II
FINE AGGREGATE . . 1-S
2-NONE
COARSE AGGREGATE . 1-R
2-NONE
ADMIXTURE. . . . . 1-DAREX AEA
2-NONE

BATCH INGREDIENTS

CEMENT	LBS/CU YD	491.	BGS/CU YD	5.22
FINE AGGREGATE . . 1 . .		1183.		
2 . .		0.		
COARSE AGGREGATE . 1 . .		2072.		
2 . .		0.00		
ADMIXTURE. . . . . 1 . .		0.34		
2 . .		0.00		
WATER.		267.	GALS/CU YD	32.13
TOTAL WEIGHT	LBS/CU YD	4015.08		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE
SLUMP IN INCHES . . . 3.25
AIR CONTENT, PERCENT . . 4.9
UNIT WEIGHT, LBS/CU FT . 148.7

BATCH ANALYSIS

WATER CEMENT RATIO	0.54	BY WT	6.14	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.3	BY WT	36.6	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.21	PRESS	2.22	UNIT WT

ADDITIONAL DATA
SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 30 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

ACCT. NO. CR1480 AWI

---- THE PORTLAND CEMENT ASSOCIATION ----
OLD ORCHARD ROAD - SKOKIE, ILLINOIS

TABLE II - BATCH INGREDIENTS AND PHYSICAL PROPERTIES OF CONCRETE

MIX NO 3K 9 DATE 23 MAY 75 TIME 0930

MATERIALS
CEMENT . . . . LONE STAR P C CO TYPE II
FINE AGGREGATE . . 1-S
2-NONE
COARSE AGGREGATE . 1-R
2-NONE
ADMIXTURE. . . . . 1-DAREX AEA
2-NONE

BATCH INGREDIENTS

CEMENT		LBS/CU YD	489.	BGS/CU YD	5.21
FINE AGGREGATE . .	1 . .		1179.		
	2 . .		0.		
COARSE AGGREGATE .	1 . .		2068.		
	2 . .		0.00		
ADMIXTURE.	1 . .		0.36		
	2 . .		0.00		
WATER.			263.	GALS/CU YD	31.65
TOTAL WEIGHT		LBS/CU YD	4001.33		

PHYSICAL PROPERTIES OF PLASTIC CONCRETE
SLUMP IN INCHES . . . 3.00
AIR CONTENT,PERCENT . . 5.0
UNIT WEIGHT,LBS/CU FT . 148.1

BATCH ANALYSIS

WATER CEMENT RATIO	0.53	BY WT	6.07	GALS/BG
PERCENT OF FINE TO TOTAL AGGREGATE	36.3	BY WT	36.6	ABS VOL
VOIDS CEMENT RATIO, BY ABS VOL	2.20	PRESS	2.24	UNIT WT

ADDITIONAL DATA
SPECIMEN SIZE 6X12 INCH CYLINDERS CAST 29 IN SUMM
CURE MOIST CURE 73F 100RH 90 DAYS
MIXER-6 CUBIC FOOT TILTING DRUM
MIX CYCLE-5 MINUTES ALL IN

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