Mass Concrete Investigations for Reza Shah Kabir Dam

Raphael, Jerome
Pirtz, David
Polivka, Milos

1974-10-01

REPORT NO.
UC SESM 74-11

STRUCTURES AND MATERIALS RESEARCH
DEPARTMENT OF CIVIL ENGINEERING

MASS CONCRETE INVESTIGATIONS FOR REZA SHAH KABIR DAM

by

JEROME M. RAPHAEL
DAVID PIRTZ
MILOS POLIVKA

REPORT TO
HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

OCTOBER 1974

STRUCTURAL ENGINEERING LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY CALIFORNIA

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

This report gives results of the investigation of concrete properties for Reza Shah Kabir dam carried out at the Structural Engineering Materials Laboratory, University of California, Berkeley.

Properties of aggregates were determined and are included in this report. The mix proportions for a 3.8 sacks per cubic yard (scy) mix containing 6-in. maximum size aggregate (MSA) were established by Harza Engineering Company.

Thirty-six 6 by 12-in. and five 16 by 44-in. cylinders were cast from which the compressive strength, elastic and creep properties of the concrete were determined at various ages up to the age of one year. Two 18 by 24-in. and six 6 by 12-in. cylinders were tested for tensile strength.

Adiabatic temperature rise, thermal diffusivity, specific heat and coefficient of thermal expansion were determined for the mass concrete mixes, using eleven specimens of various sizes.

Nine 2 by 4-in. cylinders cored from large specimens of aggregate were tested for compressive strength, tensile strength, modulus of elasticity and Poisson's ratio.

The effect of amount of retarder on time of set of the concrete was determined. And finally the absorption characteristics of the different sizes of aggregate were studied to explain the one-to-one relationship of the compressive strength of the full mass mix 18 by 24-in. cylinders and of the wet-screened concrete 6 by 12-in. cylinders.

CONCRETE MIX

The cement used in the concrete mixes was Doroud Type V portland cement. The properties of the cement, as determined by the producer, are shown in Table 1. It has a C_3A content of only 1.9 percent and a 7-day heat of hydration of only 53 cal perg. Its composition and characteristics make it very suitable for use in mass concrete.

The mixing water used was regular laboratory tap water.

The aggregate was received in six sizes as follows: No. 1 coarse sand (FM = 3.46), No. 2 fine sand (FM = 2.15), 3/16 to 3/4 in., 3/4 to 1/2 in., 1 1/2 to 3 in., and 3 to 6 in. The gradation and physical properties of the aggregate are given in Table 2. The coarse aggregate was a crushed dolomitic limestone from a quarry adjacent to Reza Shah Kabir Dam in Iran. As shown in Table 2, the manufactured No. 1 sand is too coarse for a workable concrete. The addition of roughly two-thirds manufactured blending sand from the same source produced a workable non-bleeding mix. The actual proportions of the coarse and fine aggregate were 35 and 65 percent as specified by Harza.

The water-reducing and retarding admixture used was PDA - 25, a dual purpose water reducing admixture manufactured by Protex Industries, Denver, Colorado. The air-entraining admixture was Sika AEA, produced by Sika Chemical Corporation of Lyndhurst, New Jersey.

The proportions of the constituents of the mass concrete mix determined by Harza are shown in Table 3. The sand content is 26 percent by weight of total aggregate. Two trial mixes were made to ensure that these proportions produced workable mixes with an air content of about five percent, and a slump of about two inches, as measured on the 1 1/2 inch MSA wet-screened concrete.

All batching was done by weight except for the admixtures which were measured by volume. With the exception of the water, which was cooled to 40°F prior to its use in the concrete, all other materials were at a room temperature of 73°F. Thus initial temperature after mixing averaged 68°F.

Concrete was mixed in a one-fifth cubic yard Essick Model 93 drum-type mixer. Altogether, forty concrete batches were mixed, which included primer batches, trial batches, batches for casting specimens and additional concrete for measuring slump and unit weight. The mixing time was 4 1/2 minutes. The 3 to 6 in. cobbles were added to the concrete after three minutes of mixing.

The properties of the fresh concrete are summarized in Table 4. The slump and air content were determined on concrete wet-screened to pass a 1 1/2 in. sieve. The concrete had a slump of 1 1/2 ± 1/4 in. and an air content of 5 ± 0.5 percent. The nominal unit weight of the wet-screened concrete was 148 pounds per cubic foot (pcf) and that of the concrete containing 6 in. MSA was 154 pcf. The water-cement ratio was 0.45 by weight.

MANUFACTURE OF SPECIMENS

Casting of 6 by 12 in. compression cylinders was done in three groups of four cylinders and two groups of three cylinders using concrete wet-screened on a 1 1/2 in. sieve. Specimens were cast in metal cans in three equal layers; each layer was vibrated with a 3/8 HP flexible vibrator. After completion of casting, the cylinders were fitted with lids and stored at 73°F in fog. Specimens were stripped at age one day and fog cured at 73°F until age of test.

Casting of the 18 by 36 in. compression cylinders was done in five groups of three cylinders using mass concrete containing 6 in. MSA. The braced galvanized steel cylinder molds were filled in three layers; all three layers were vibrated thoroughly with three insertions of a flexible-hose 2 3/4 HP vibrator, having a 1 3/4 in. diameter spud. After completion of casting, the cylinders were transferred to a 73°F room, capped with a 3/8 in. steel plate and sealed.

The 27 by 30-in. adiabatic temperature rise specimen was cast from two standard batches of concrete in four layers, vibrated thoroughly with the 2 3/4 HP flexible vibrator.

The 16 by 44-in. creep specimens were cast in butyl rubber-lined steel molds in four layers each using five batches of concrete, spreading each batch over the five cylinders, and using both the 2 3/4 HP and the 3/8 HP flexible vibrators as needed to vibrate around the embedded strainmeters.

The splitting tensile test specimens were cast in two groups each comprising one 18 by 24-in. mass concrete cylinder and three 6 by 12-in. wet-screened concrete cylinders, each group using one batch of concrete, and vibrated and cured similarly to compressive specimens.

The thermal property specimens were cast in three groups, each composed of one specimen each for specific heat, diffusivity, and coefficient of thermal expansion. Specific heat and diffusivity specimens were cast and sealed in copper molds, and the coefficient of expansion specimens were cast and sealed in sheet metal molds.

EFFECT OF ADMIXTURES ON TIME OF SET

The setting of concrete is a way of describing the gradual stiffening of the cement paste as it hydrates, and the gain in strength of the concrete as it changes from a lumpy fluid to a solid mass. Thus the time when "set" is said to occur will be a relative term, depending on an arbitrary selected measure of strength. ASTM C-403 defines set in terms of resistance to penetration of a Proctor needle, in a mortar wet-screened from the concrete on a No. 4 seive, defining initial set as the time after mixing when the mortar reaches a penetration resistance of 500 psi, and final set when the penetration resistance is 4000 psi.

When questions arose whether the additives were actually retarding set, three concrete mixes were made to check their time of set: one representing the normal mix with an air-entraining agent and a water-reducing retarder, one with only the air-entraining agent, and one with no admixture. The proportions and properties of these three mixes are shown on Table 5. From each mix, four specimens of mortar were produced, approximately 8-in. in diameter and 6-in. high. The increase in penetration resistance with time is shown on Fig. 1.

It can be seen that the air-entraining agent had practically no effect on time of set, and that the water-reducing retarder postponed initial and final set by just under three hours.

COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES OF CONCRETE

The 6 by 12-in. cylinders containing 1 1/2 in. MSA concrete wet-screened from the 6 in. MSA mass concrete mix were tested for compressive strength at ages 2, 7, 28, 90, 180, and 365 days. All specimens were moist-cured up to age of test. Prior to testing, each specimen was capped with sulfur. The compression test was made in a 400,000 lb. testing machine using a loading rate of 35 psi per second.

The compressive strength and elastic properties of the individual concrete specimens are shown on Table 6.

Averaged compressive strengths of each group of three 6 by 12 in. specimens containing 1 1/2 in. MSA mix, wet-screened from the 6 in. MSA mass concrete mix, are plotted on Fig. 2.

The 18 by 36-in. cylinders containing 6-in. MSA mass concrete were tested for modulus of elasticity, Poisson's ratio and for compressive strength at ages 7, 28, 90, 180 and 365 days. Prior to testing each specimen was stripped, capped with Hydrostone, and wrapped with a plastic sheet (Saran) to prevent moisture loss during handling and testing. The tests were made on a 4,000,000 lb. testing machine using a loading rate of 35 psi per second. Deformations under load were measured with linearly variable differential transformers and plotted with an XYY' recorder. The complete test record for each cylinder is summarized in Table 6 and the average strengths are plotted against age in Figure 2. On this semi-log plot, strength of the 6-in. MSA concrete mix increased at the same rate as that of the 1 1/2-in. MSA mix to the age of 28 days, and then increased at a lower rate for the remaining period up to one year. The one year strength was 5950 psi.

The values of elastic modulus at different ages are listed on Table 6, and plotted on Figure 3. Comparing the gain in elastic modulus (Fig. 3) with the gain in strength (Fig. 2) it can be seen that the modulus begins at a relatively high value at early age, and increases with age at a much slower rate than strength, with only a slight gain after 28 days age. This suggests that the elastic modulus of mass concrete is primarily dependent on the elastic properties of the rock in the large particles, and only secondarily dependent on the gain in strength of the mortar matrix. The properties of the limestone aggregate were investigated and the results are presented in a subsequent section of this report.

Comparing the strengths shown by the 6 by 12-in. specimens and the 18 by 36 in. specimens on Fig. 1, a very unusual condition is seen: the strengths are about equal for the first three months. Normally strengths for 18 x 36-in. cylinders, which represent the actual strength of the mass concrete, is somewhat less than the strength of wet-screened 6 x 12-in. cylinders, in the range of 70 to 85 percent. The reason for the difference is that in the full mass mix, the effect of bleeding is to introduce zones of water or laitance beneath each large particle, thus weakening the mass. Here the correspondence is 100 percent. Some other factor must be working here. After eliminating a number of possibilities, the absorption characteristics of the aggregate was suspected and tested.

EFFECT OF ABSORPTION OF AGGREGATE ON COMPRESSIVE STRENGTH OF CONCRETE

Normal concrete laboratory practice is to measure and mix the concrete aggregates in the saturated-surface-dry (SSD) condition. To prepare concrete aggregates to be used in this condition, they are soaked in water for twentyfour hours, then thoroughly washed, blended, brought to SSD condition and stored in sealed containers until ready for use. The question was raised, was twentyfour hours of soaking sufficient to saturate the aggregate?

Samples of the four aggregate fractions were tested in the following way. After selecting representative samples of 6-in., 3-in., 1 1/2-in., and 3/4-in. aggregates, they were thoroughly washed to remove any dirt or loose pieces, and then oven dried at 110°C to constant weight. The samples were then submerged in water five seconds, removed, shaken vigorously to remove loose water, allowed to drain in air for one minute, and weighed. This was deemed to be the zero point at which the rock has not absorbed any significant amount of water, yet it is surrounded with a layer of surface water. The sample was then submerged for increasing increments of time and weighed periodically, following the same procedure, until constant weight was reached, with the exception of the very largest particles, which were wiped to SSD after each submergence. Time to reach complete saturation varied with particle size, as follows:

Size of Particle, in.	Time to Saturation
3/16 - 3/4	20 minutes
3/4 - 1 1/2	1.5 hours
1 1/2 - 3	2.5 days
3 - 6	5.0 days

This absorption behavior of the aggregate almost completely explains the relatively high strength of the full mass mix concrete. All the aggregate larger than the 1 1/2 in. size is only partially saturated by twentyfour hours of immersion in water. The concrete mix contained enough water for desired workability. Once mixed, the large aggregate continued to absorb water, thus increasing the strength in two ways. It reduced the water-cement ratio of the mortar, increasing its strength, and it absorbed the water that ordinarily collects under the larger particles, thus eliminating these zones of weakness. If the actual concrete in the field was made of aggregates not soaked for twentyfour hours, it would be expected that the strength gain in the structure would be even greater than that predicted by testing 6 by 12-in. wet-screened cylinders.

TENSILE STRENGTH OF CONCRETE

The tensile strength of the concrete at age 28 days was determined by testing two 12 by 24-in. cylinders made of the full mass mix, and six 6 by 12-in. cylinders of concrete wet-screened to 1 1/2 in. MSA, using the splitting tensile test method ASTM C 496. In this test, the cylinder is laid along its length in the testing machine and loaded in compression on two diametrically opposite elements. While the stress in the immediate vicinity of the loaded area is compressive, for about 90 percent of the diametrical load plane it is tensile and nearly uniform. Tensile strength is related to the load causing failure by the elastic equation:

$$f'_t = \frac{2\,P}{\pi DL} \tag{1}$$

where f'_t = Splitting tensile strength, psi
P = Load at failure, lb.
D = Diameter of cylinder, in.
L = Length of cylinder, in.

Specimens were cast, vibrated, and cured the same as for the compressive cylinders. The 12 by 24-in. specimens were loaded at a rate of 100,000 lb. per minute in a 4,000,000 lb. testing machine, and the 6 by 12-in. specimens were loaded at 15,000 lb. per minute in a 120,000 lb.

testing machine.

Results are shown in Tables 7 and 8. Average 28-day tensile strength of the full mass mix was 387 psi, or 8.2 percent of the compressive strength of the concrete at this age. For the wet-screened cylinders, average 28-day tensile strength was 516 psi, or 11 percent of the compressive strength of comparable concrete. It was noted that the line of failure actually split 75 to 80 percent of the aggregate particles.

The 8 percent factor found for the full mass mix is slightly less than the 10 percent nominal value usually used for design purposes, but the tensile strength obtained (387 psi) is much greater than the value of 200 psi assumed in the design of the Kabir dam. However, in an attempt to see if there were anything unusual in the strength of the aggregate itself, a further evaluation was made of the strength and elastic properties of the aggregate.

STRENGTH AND ELASTICITY OF AGGREGATE

Nine 2 by 4-in. cylinders were cored from large aggregate particles, and tested in sets of three for compressive strength, elastic modulus and Poisson's ratio, and for tensile strength. The cores were sawed to length, capped with sulfur, and loaded in compression at a rate of 6000 lb. per minute in a 120,000 lb. testing machine. Table 9A shows results of the compression tests of the first three cores.

SR-4 strain gages were applied to three more cylinders for measuring elastic modulus and Poisson's ratio, capped and loaded as above. Table 9B shows the individual test results. The elastic modulus was 6.6 x 10^6 psi, Poisson's ratio averaged 0.22, and the average compressive strength of six cores was 16,900 psi.

A final group of three cores was loaded in the splitting tensile test at a rate of 1800 lb. per minute in a 60,000 lb. testing machine. The average tensile strength of the results shown in Table 9C was 1560 psi, which was about four times the 28-day tensile strength of the mass concrete.

The average compressive strength of the cores of 16,850 psi which is almost three times the strength of the mass concrete at age of one year, while elastic modulus is only 20 percent greater than that for the mass concrete at one year. While Poisson's ratio for the mass concrete varies considerably for the five ages tested, its average is identical with the value for the limestone cores. From all this we might draw some tentative conclusions to judge the behavior of mass concrete: Strength properties reflect the strength of the paste, and elastic properties reflect the behavior of the aggregate.

CREEP OF CONCRETE

Like most materials, concrete deforms when loaded, and the relationship of load and deformation at the low load range is termed the elastic modulus. In addition, if load is maintained on concrete, it continues to deform, at a varying rate depending on its age when initially loaded, and on the duration of the load. This continued deformation is termed creep.

Five 16 by 44-in. cylindrical specimens using 4 1/2-in. MSA concrete were cast in neoprene rubber sleeves and sheet metal molds for the determination of creep. Each specimen was fitted with two 20-in. Carlson strainmeters parallel to and three inches from the longitudinal axis and one 10-in. strainmeter perpendicular to the axis at the midheight of each cylinder. To completely seal these specimens, one-inch thick steel end plates were fitted to each end of the cylinder, and butyl rubber sleeves were bonded and strapped to these end plates with stainless steel straps. Each cylinder was initially loaded at 2, 7, 28, 90 or 365 days after casting, and the load was maintained for one year. The 2-day specimen was loaded to 500 psi, and all others were loaded to 1000 psi. Plots of the observed strains less the autogenous volume change of an unloaded control specimen are shown in Fig. 4.

These curves can be expressed in the form

$$\varepsilon = \frac{1}{E} + f(K) \ln (t + 1)$$

where

ε = total strain, millionths per psi
E = instantaneous elastic modulus, psi x 10^6
$f(K)$ = creep rate for a particular age of loading K
ln = natural logarithm
t = age after loading, days

Values of the terms of the equation taken from the curves of Fig. 4 are shown in Table 10.

Table 10 also shows the instantaneous moduli of elasticity obtained from the creep specimens, compared with the moduli of elasticity determined by compressometer on the 18 by 36-in. mass concrete test cylinders. It can be seen that the moduli determined from the creep specimens are consistently higher than those measured on the elasticity specimens, by an average of 37 percent. This is too large a factor to be ignored, and a separate test was run to check out this behavior.

Since the 28-day, the 90-day, and the 365-day creep cylinders were still under load, they were fitted with extensometer points, and then unloaded. At the time of unloading, the cylinders were at an age of 1.6 years. At this age, the modulus of elasticity indicated by the 20-in. embedded strainmeters averaged 9.0 x 10^6 psi. The strains measured by the strainmeters were 1.43 times as large as those measured by the external extensometers.

From an examination of strainmeters similar to those used in the creep cylinders after being embedded it is believed that a design change has resulted in the strainmeters bonding to the concrete at some point along their length, and that the effective gage length of the strainmeters is 14-in., rather than their rated 20-in. This has the effect of increasing the observed strains by a factor 1.43. When the initial elastic moduli observed when the creep specimens are first loaded are divided by this factor, they correspond almost exactly to the moduli measured on the 18 by 36-in. strength specimens, as shown on Fig. 3. It is considered that the proof is irrefutable, and we have accordingly changed the creep equations as follows:

$$\varepsilon_2 = 0.309 + 0.0377 \ln (t + 1)$$

$$\varepsilon_7 = 0.275 + 0.0369 \ln (t + 1)$$

$$\varepsilon_{28} = 0.201 + 0.0286 \ln (t + 1)$$

$$\varepsilon_{90} = 0.190 + 0.0231 \ln (t + 1)$$

$$\varepsilon_{365} = 0.174 + 0.0154 \ln (t + 1)$$

ADIABATIC TEMPERATURE RISE

Adiabatic temperature rise in concrete is the quantitive measurement of the rate of heat generation of the hydrating cement in a particular concrete mixture. Adiabatic temperature rise was determined on a 27 by 30-in. cylindrical specimen for the mass concrete mix containing 6-in. MSA. Concrete used for the adiabatic temperature rise specimen was the same as that used for the 18 by 36-in. compression specimens. High quality control was observed in the batching and the casting procedures, as verified by the properties of fresh concrete and the compressive strengths of companion cylinders.

As the name of the test indicates, the sealed 27 by 30-in. specimen was cured under adiabatic conditions, namely no heat loss or gain from outside source. The external curing temperature was maintained at the same level as the rising internal temperature of the concrete specimen, and was controlled to ± 0.02°F.

The calorimeter for the adiabatic temperature rise test consists essentially of a small chamber inside a large chamber. The small chamber contains the specimen, thermometers, heaters, and fans for air circulation. The heaters automatically control the inner chamber temperature to within 0.02°F. The outer chamber is controlled automatically to ± 1°F and is maintained about 5°F below the inner chamber so that any excessive heat in the inner chamber flows to the outer chamber.

Temperature of the concrete was measured with five resistance thermometers readable to the nearest 0.01°F, located along a diameter at the mid-height of the specimen. A quartz thermometer readable to the nearest 0.001°F was also embedded near the center of the specimen. The specimen was insulated with two inches of expanded vermiculite. Two thermometers were located on the outside of the specimen between the insulation and the specimen and two additional thermometers were located outside the insulation. Temperature of the inner chamber was measured with a fast-acting resistance thermometer and with a second quartz thermometer. Thermometer leads were threaded through the chamber walls to allow temperature readings from the outside of the chambers. Prior to testing, all thermometers were calibrated against a platinum thermometer, previously calibrated by the U. S. Bureau of Standards. During the test the platinum thermometer was located on the top of the specimen under the insulation. The criterion used for ensuring adiabatic conditions was that there should be no temperature gradient from center to outside of the hydrating concrete specimen.

The early temperature history is plotted on Fig. 5, showing temperatures to age two days.

The 28-day temperature rise for the concrete was 54.5°F, as shown on Fig. 6. At ten days, the corresponding temperature rise was 49.5°F. Thus, more than 90 percent of the temperature rise occurred in the first ten days of hydration. This early high temperature rise partly explains the high strength developed in the mass concrete, because it is an indication of a high degree of hydration leading to the development of the high strength potential of the cement.

THERMAL DIFFUSIVITY

Diffusivity is an index of the facility with which a material will undergo temperature change. Thermal diffusivity was determined on two 9 1/2 by 19-in. cylindrical specimens which were cast in thin sheet metal molds at the same time as the adiabatic temperature rise specimens, and utilizing the same concrete except that cobbles greater than 4 1/2 in. were replaced with an equal volume of 3 to 4 1/2 inch aggregate. The sealed specimens were cast and cured at 73°F and tested at age 28 days.

The test procedure consisted of transferring the 100°F specimen into a room maintained at 40°F, immersing it into 40°F water, and reading the temperature at the center of the specimen at regular time intervals. The specimen was tested without removing the metal mold.

Thermal diffusivity for the two specimens was 0.0342 and 0.0361, averaging 0.035 sq. ft. per hr. at an average temperature of 70°F.

SPECIFIC HEAT

The specific heat of concrete is the amount of heat required to raise the temperature of a unit mass of concrete one degree Fahrenheit, usually expressed in units of Btu/lb/°F. The test specimen was a hollow cylinder, 16-in. long, 1 1/2-in. inside diameter, 8-in. outside diameter, made of 3-in. MSA concrete cast in a thin sheet copper mold with a brass inner tube, and all sealed by silicon sealer. Two specimens were cast and cured at 73°F for 28 days after which the tests for specific heat were initiated.

A carefully weighed quantity of water is circulated through and around the test specimen in an insulated chamber in which air is circulated. The amount of electricity needed to energize a heater-stirrer in the central chamber of the specimen is measured on a watt-hour meter. Adiabatic conditions are maintained by increasing the heat input to the air in the outer chamber so that air and water temperature are matched. Temperatures are carefully monitored to 0.1°F by means of thermopiles consisting of four thermocouples. The test is normally run for 2 1/2 hours of heater time plus 45 minutes of stirring with the heater shut off to bring specimen and water to the same temperatures. Allowance must be made for heat losses in the insulation.

The values of specific heat found in the two specimens were 0.237 and 0.241, giving an average value of 0.239 Btu/lb/°F.

THERMAL EXPANSION

Coefficient of thermal expansion is the unit length change of an unconfined concrete specimen due to a unit temperature change, usually expressed as microstrains per °F.

Three 12 by 36-in. cylindrical specimens were cast in 24-gage galvanized steel molds for determining the coefficient of thermal expansion. Each specimen was instrumented with a single 20-in. Carlson strainmeter on its major axis, and sealed after casting. Similarly to the diffusivity test specimens, cobbles larger than 4 1/2-in. were replaced with an equal volume of 3 to 4 1/2-in. aggregate. The use of this smaller size aggregate eliminated difficulties in placing concrete around the strainmeter.

The specimens were cast and stored at 73°F to the age of 28 days. Two complete cycles of temperature were then run, each cycle consisting of storage at temperature of 73-108-73-42-73°F. Each storage period lasted about five days, long enough for the internal temperatures to reach equilibrium, as measured on the strainmeter.

The length changes of the concrete under this temperature cycling showed a sort of hysteresis loop, as shown by the coefficient of expansion for each leg of the cycle in Table 11.

The average coefficient of thermal expansion of the mass concrete was 5.04×10^{-6} per °F.

ACKNOWLEDGMENTS

The authors of this report wish to acknowledge with thanks the contributions of four student research assistants. Charles Mercer and Capt. Ted Trauner manufactured the concrete specimens and performed the strength and expansion tests. Anton Pirtz was in charge of the creep, adiabatic temperature rise, and thermal properties tests. Robert Kohne performed a number of auxiliary tests such as tensile strength of concrete, strength and elasticity and absorption of aggregate, and effects of admixture on setting of mortars, which gave valued insights into the behavior of this concrete.

APPENDIX A

TABLES

TABLE 1. PROPERTIES OF CEMENT(a)

BRAND DOROUD TYPE OF CEMENT V PLANT DOROUD, IRAN

SILO NO. 4 BATCH NO. 25 DATES: GRINDING 25 May, 1972
SAMPLING 25 May, 1972

CHEMICAL	
SiO_2	22.20
Al_2O_3	3.82
Fe_2O_3	4.88
CaO	62.72
MgO	2.56
SO_3	2.20
Na_2O	0.20
K_2O	0.28
Loss	1.14
Total	100.00
Insoluble Residue	0.30
Free CaO	0.88
Compound Composition	
C3S	47.63
C2S	27.99
C3A	1.87
C4AF	14.83
$CaSO_4$	3.74
MgO	2.56
C4AF & 2C3A	18.57
Total Alkali Content	0.38

PHYSICAL	
Blaine Fineness, cm^2/g	3100(b)
Autoclave Expansion, %	0.05
Setting Time (Vicat Needle)	
Initial, hr:min	2:12
Final, hr:min	4:10
Compressive Strength, psi	
3 days	1400
7 days	2280
Heat of Hydration, Cal/g	
2 days	41.6
7 days	53.1
Entrained Air, %	8
False Set, %	85

a - Data taken from Doroud Cement Plant test report.

b- Blaine fineness determined at the University of California = 2950 cm^2/g and specific gravity = 3.20.

TABLE 2. PROPERTIES OF AGGREGATES

Sieve Size	Cumulative Percent Retained					
	Coarse Aggregate Sizes, in.				Sand	
	3-6	1 1/2-3	3/4-1 1/2	3/16-3/4	No.1 Coarse	No.2 Fine
6 in.	0					
3 in.	99	3				
1 1/2 in.	100	88	2			
3/4 in.	100	100	93	7		
3/8 in.	100	100	100	58	0	0
No. 4	100	100	100	98	0.6	0
No. 8	100	100	100	100	26.9	1.5
No. 16	100	100	100	100	57.1	13.7
No. 30	100	100	100	100	77.1	40.9
No. 50	100	100	100	100	89.2	70.4
No. 100	100	100	100	100	95.4	88.9
Fineness Modulus	-	-	-	-	3.46	2.15
Material Passing No. 200 Sieve		-	-	-	2.5	5.7
Sand Equivalent Value	-	-	-	-	96	90
Bulk Specific Gravity (SSD)	2.63	2.63	2.64	2.64	2.61	2.60
Absorption Capacity,%	1.80	2.0	2.0	2.4	2.8	3.1
Moisture Content,%	.7	1.4	.1	2.5	2.8	3.1

Notes:

1. Combined FM of sands is 2.61 based on 35% No. 1 and 65% No. 2 by weight of total sand.

TABLE 3. PROPORTIONS OF MASS CONCRETE MIX

Material	One Cubic Yard Batch (SSD)	
	Wt., lb.	% by wt.
Cement	357.3	
Water	161.8	
Sand: Coarse	325.8	35.4
Bending	595.5	64.6
Coarse Aggregate:		
3/16" to 3/4"	573.0	21.5
3/4" to 1 1/2"	674.2	25.3
1 1/2 to 3"	691.0	26.0
3" to 6"	724.7	27.2
Admixtures:		
AEA (SIKA)	0.2	85 gms.
WRA (PDA - 25)	0.6	296 gms.
TOTAL	4104.1	

TABLE 4. PROPERTIES OF MASS CONCRETE MIX

W/C, by weight	0.45
Temperature of Concrete	
End of Mixing	66°F
End of Casting	68°F
Slump, inches (1 1/2" MSA)	1 1/2
Air Content, % (1 1/2" MSA)	4.7
Unit Weight, pcf	
6" MSA	154.2
1 1/2" MSA	147.5

Notes:

1. Values based on average of 14 batches
2. MSA, Maximum Size Aggregate

TABLE 5. PROPORTIONS AND PROPERTIES OF CONCRETE OF SET TESTS

Batch No.	38	39	40
Description	WRA & AEA	AEA	no admix
Batch Size (cu. ft.)	5.4	3.0	3.0
Date	2/22/73	2/22/73	2/22/73
Mix Proportions			
Cement (lbs.)	71.5	39.7	39.7
Water (lbs.)	32.26	17.92	17.92
Coarse Sand (lbs.)	65.4	36.3	36.3
Fine Sand (lbs.)	119.9	66.6	66.6
Aggr. 3/16-3/4" (lbs.)	114.6	63.7	63.7
Aggr. 3/4- 1 1/2 (lbs.)	134.5	74.7	74.7
Aggr. 1 1/2-3" (lbs.)	137.5	76.4	76.4
Aggr. 3-6" (lbs.)	144.9	80.5	80.5
WEA Sika (ml)	220.0	122.2	-
WRA, PDA-25 (ml)	592.0	-	-
Properties			
Conc. Temp after mix (°F)	67.0	68.5	67.5
Slump (in.)	1 1/2	1	NM
Air Content (%) 1 1/2" MSA	4.8	3.5	-
Unit Weight, 1 1/2" MSA (pcf)	147.1	148.7	NM
W/C by weight, W/O admix	0.454	0.454	0.454
Initial Set, Hrs.	7.7	5.3	5.0
Final Set, Hrs.	10.3	7.7	7.5

Note: NM stands for "not measured".

TABLE 6. COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES

Size	1 1/2 in. MSA mix 6 by 12 in. Cyl.	6 in. MSA Concrete Mix 18 by 36 in. Cylinders		
Age (days)	Strength)psi)	Strength (psi)	Elas. Mod ($x10^6$ psi)	Poisson's Ratio
2	2000			
	2050			
	1980			
Average	2010			
7	3740	3320	3.95	0.23
	3300	3930	4.55	0.27
	3510	3620	4.29	0.25
Average	3520	3620	4.26	0.25
28	4950	4860	4.96	0.22
	4570	4610	4.41	0.23
	4610	4080*	4.39*	0.20*
Average	4710	4740	4.69	0.23
90	5460	5380	5.14	0.17
	5500	5640	5.52	0.15
	5370	5080	5.55	0.14
Average	4710	4740	4.69	0.23
180	5870	5950	5.51	0.20
	6010	5350	5.25	0.19
	5520	5340	5.15	0.18
Average	5800	5540	5.30	0.19
365	6520	5650**	5.20**	0.25**
	6210	6300	5.97	0.26
	6.20	5910	5.51	0.25
Average	6280	5950	5.56	0.25

* Test discard because rigid heat of testing machine head caused eccentric load in specimen and therefore a low ultimate strength.

** Cylinder was tested after a number of loadings to a stress of 2 ksi due to problems with electronic recording equipment.

TABLE 7. TENSILE STRENGTH OF 18 BY 24 INCH CYLINDERS

Sample No.	Batch No.	Age (day)	D (in)	L (in)	P (lb)	f'_t (psi)	% Aggregate Split
1	32	28	18.0	23.9	273000	403	75
2	32	28	18.0	24.5	258000	372	75

Average splitting tensile strength, 387 psi at 28 days.

TABLE 8. TENSILE STRENGTH OF 6 BY 12 INCH CYLINDERS

Sample No.	Batch No.	Age (day)	D (in)	L (in)	P (lb)	f'_t (psi)	% Aggregate Split
52	32	7	5.97	12.10	49400	435	75
53	32	28	5.97	12.12	57300	505	80
54	32	90	5.96	12.01	70000	623	85
55	34	7	5.96	12.10	44800	397	75
56	34	28	5.97	12.09	59900	538	80
57	34	90	5.98	11.99	73800	656	85

Average splitting tensile strength, 516 psi at 28 days.

TABLE 9. PROPERTIES OF LIMESTONE CORES

A. COMPRESSIVE STRENGTH

Specimen No.	Diam. (in.)	Area (in.)	Ult. Load (lbs.)	Comp. Strength (psi)
6	2.02	3.20	55000	17190
7	2.02	3.20	58000	18120
8	2.02	3.20	47000	14690
			Average:	16670

B. ELASTIC MODULUS, POISSON'S RATIO, AND COMPRESSIVE STRENGTH

Specimen No.	Elas. Mod. ($x10^6$psi)	Poisson's Ratio	Comp. Str. (psi)
1	5.25	0.153	16680
2	4.76	0.216	15750
3	9.72	0.275	18700
Average:	6.58	0.215	17040

C. TENSILE STRENGTH TEST

Specimen No.	Diam. (in.)	Length (in.)	Tensile Strength (psi)
4	2.02	3.95	1260
9	2.02	3.95	1880
12	2.02	4.01	1560
		Average:	1564

* Average

TABLE 10 CREEP OF CONCRETE

Age of load	Observed		Instantaneous E		Ecr/	Corrected	
(days)	$\frac{1}{E}$	f(K)	Creep	Strength	Estr	$\frac{1}{E}$	f(K)
2	.216	.0264	4.6	-	-	.309	.0377
7	.193	.0258	5.2	4.26	1.21	.275	.0369
28	.141	.0200	7.1	4.69	1.51	.201	.0286
90	.133	.0162	7.5	5.24	1.43	.190	.0231
365	.122	.0108	8.2	5.56	1.48	.174	.0154

TABLE 11

COEFFICIENT OF THERMAL EXPANSION

Temperature °F	Coefficient of Expansion per °F
73	
	5.02
108	
	5.12
73	
	4.90
42	
	5.14
73	
Average	5.04

APPENDIX B

ILLUSTRATIONS

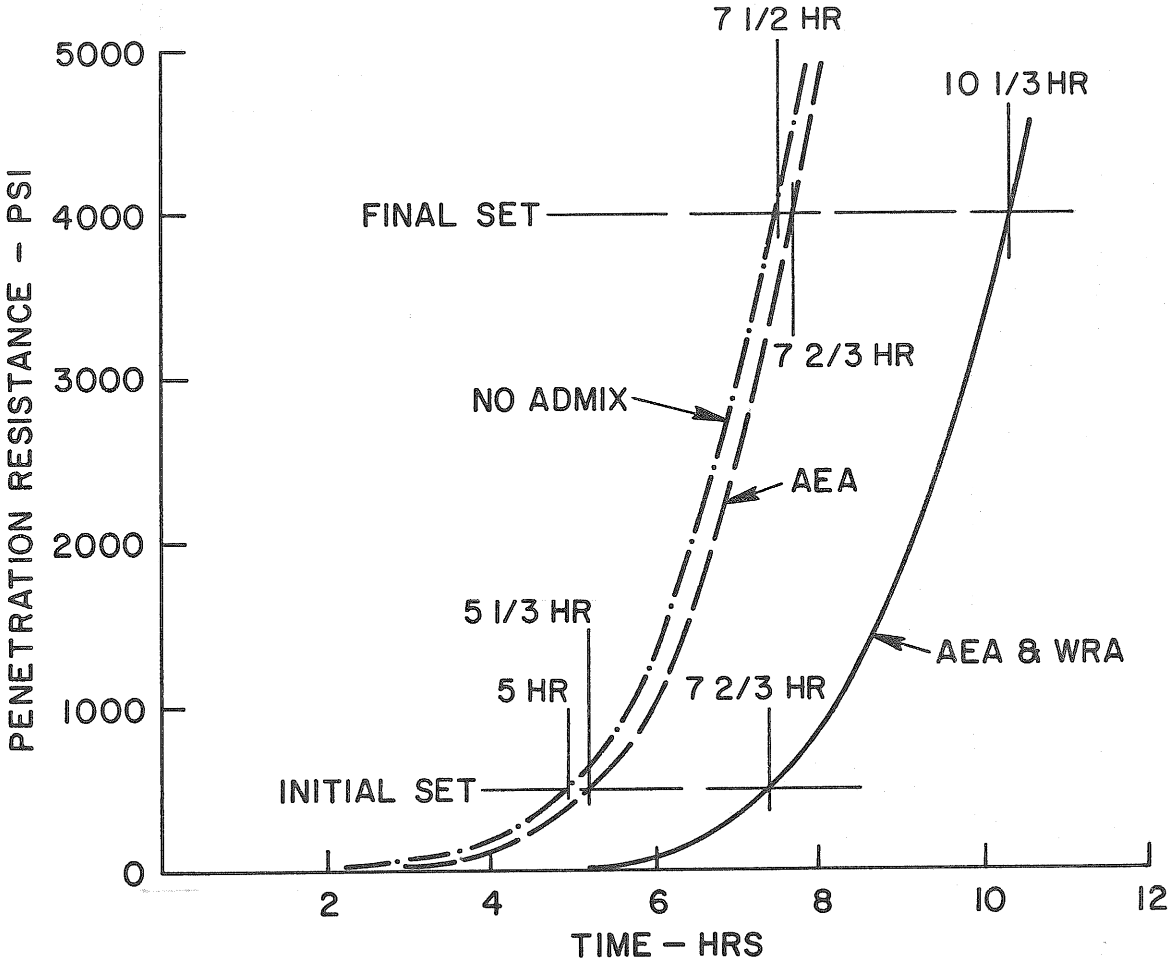

FIG. 1 EFFECT OF ADMIXTURE ON SET

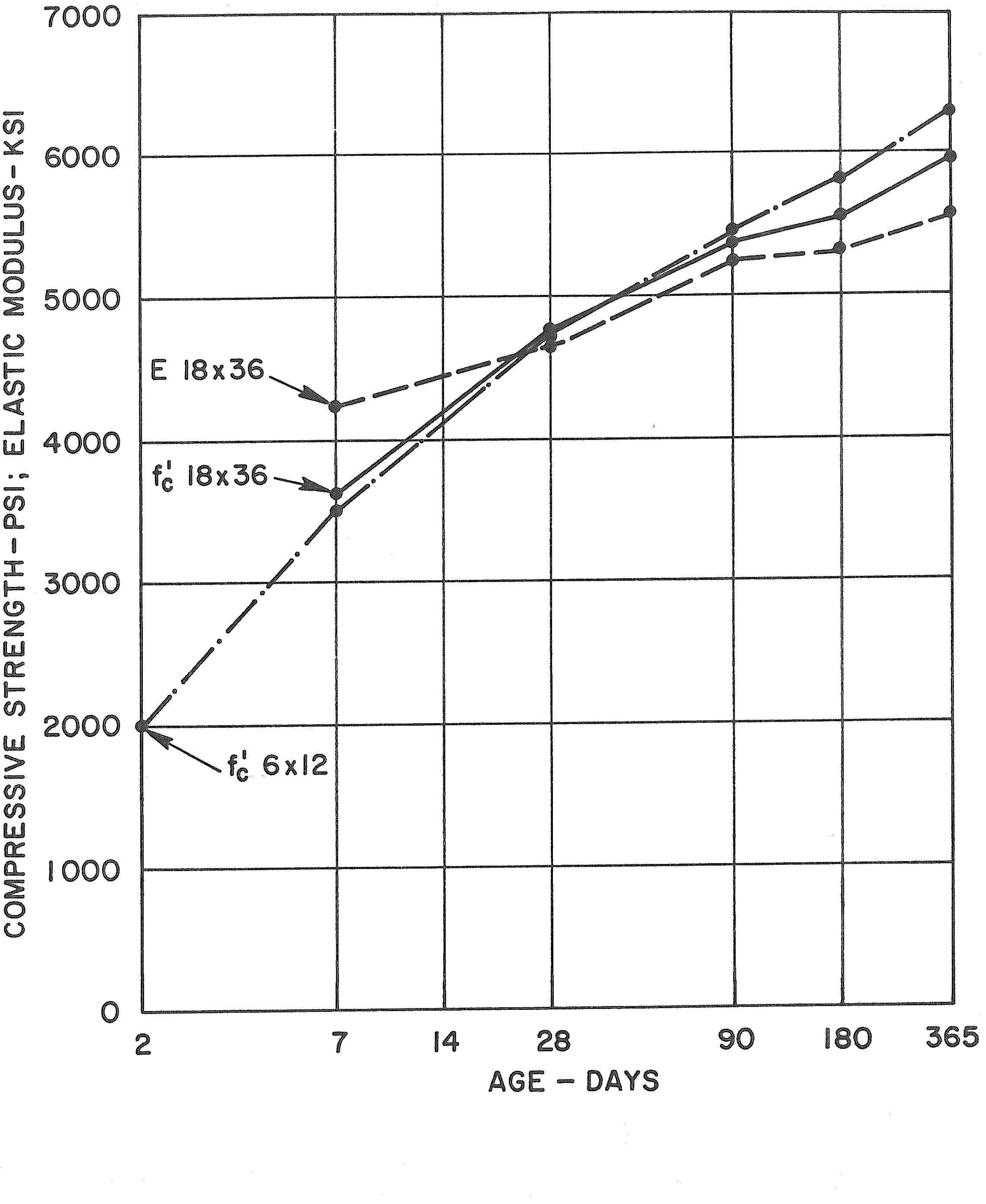

FIG. 2 COMPRESSIVE STRENGTH AND ELASTIC MODULUS

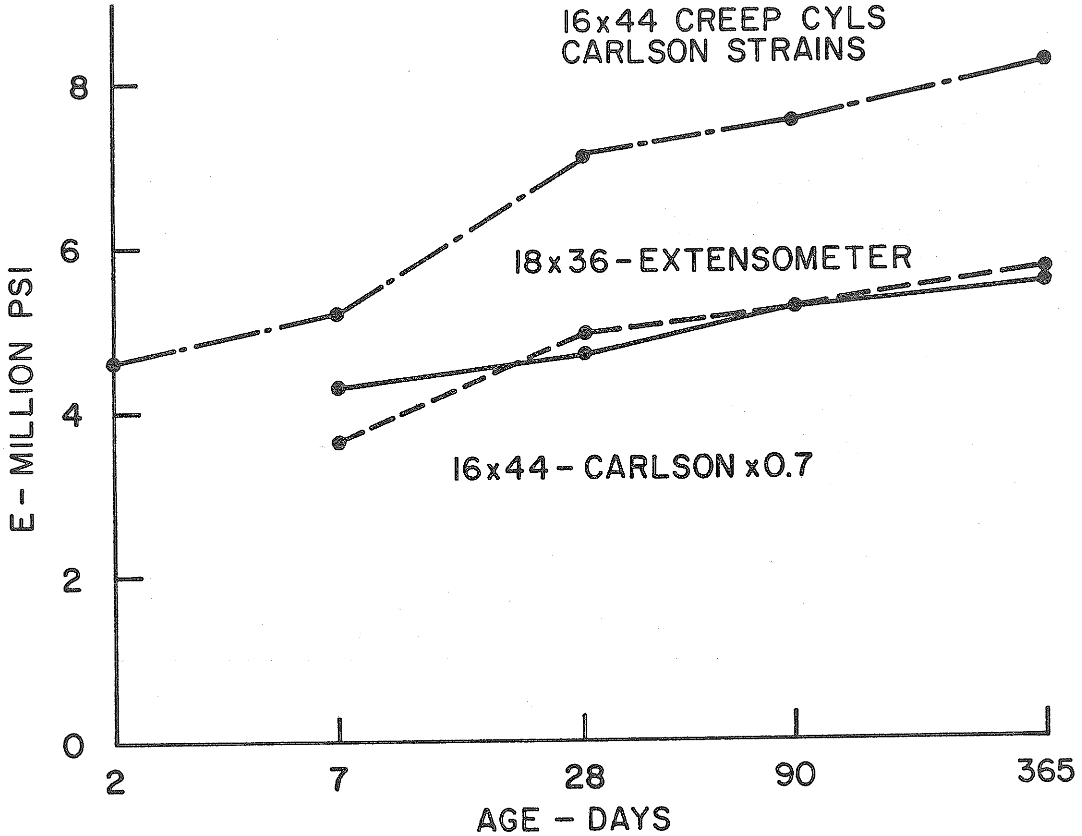

FIG. 3 STRAINMETER CORRELATION FACTOR

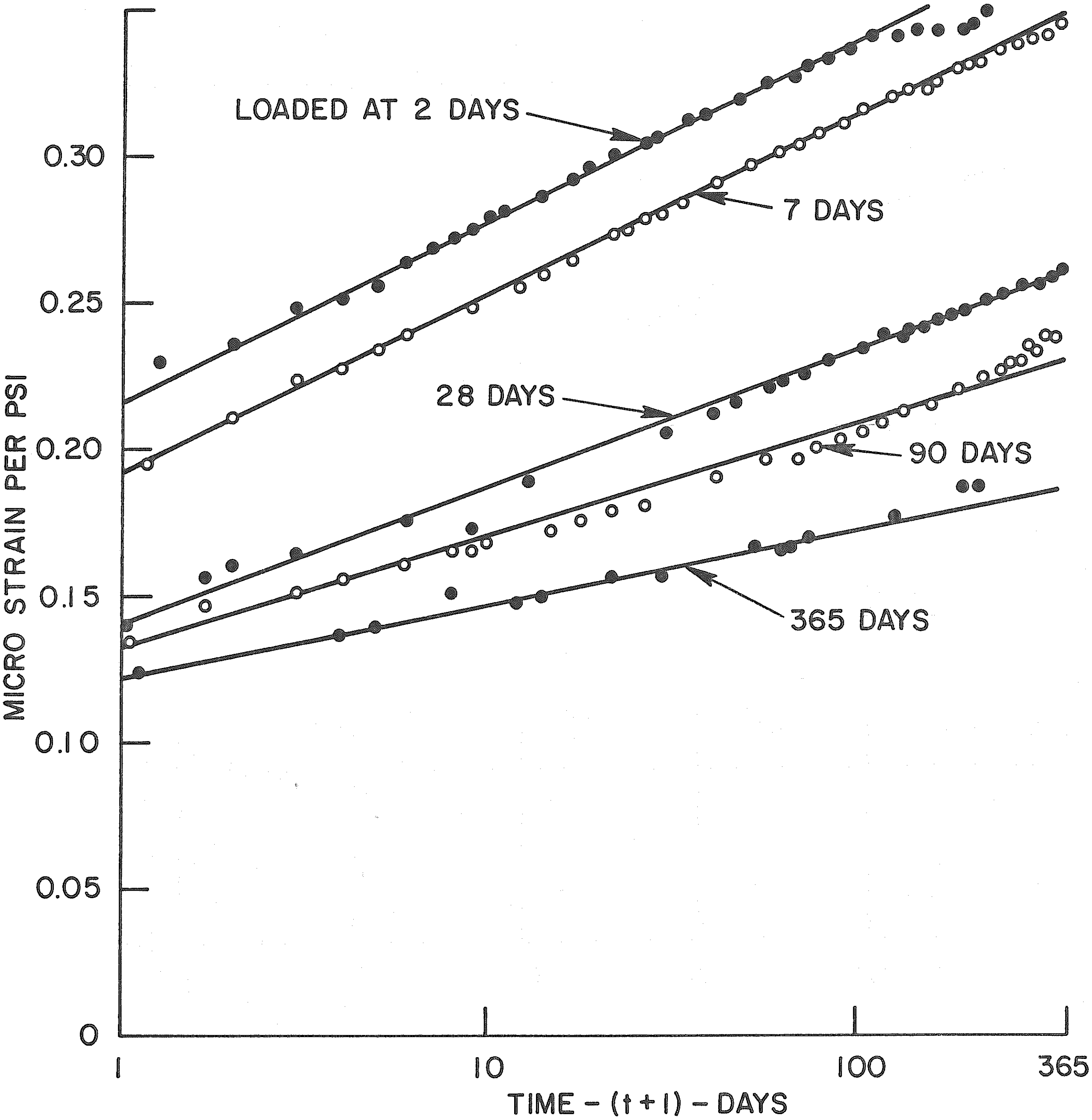

FIG. 4 OBSERVED CREEP CURVES

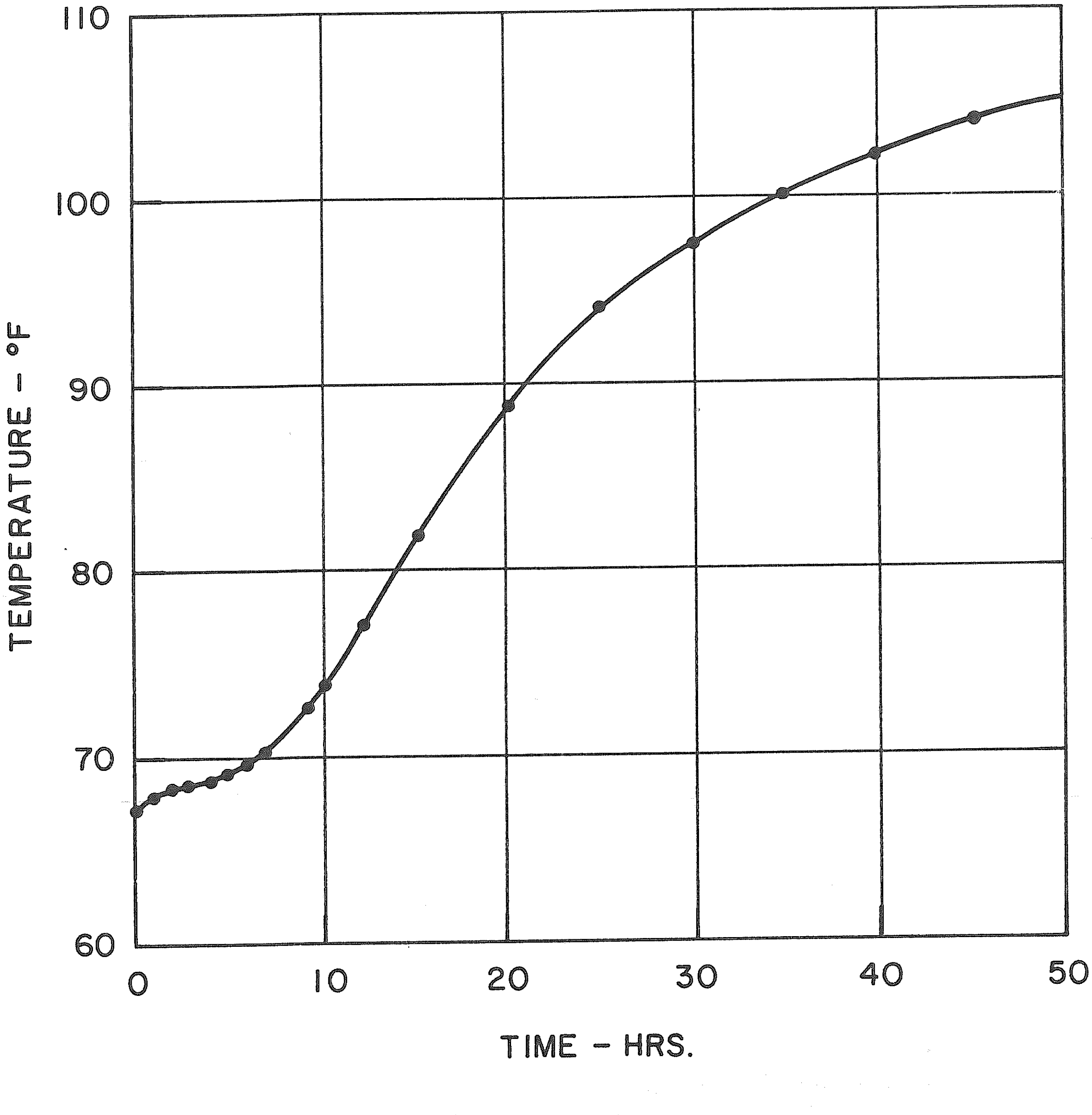

FIG. 5 INITIAL ADIABATIC TEMPERATURE RISE

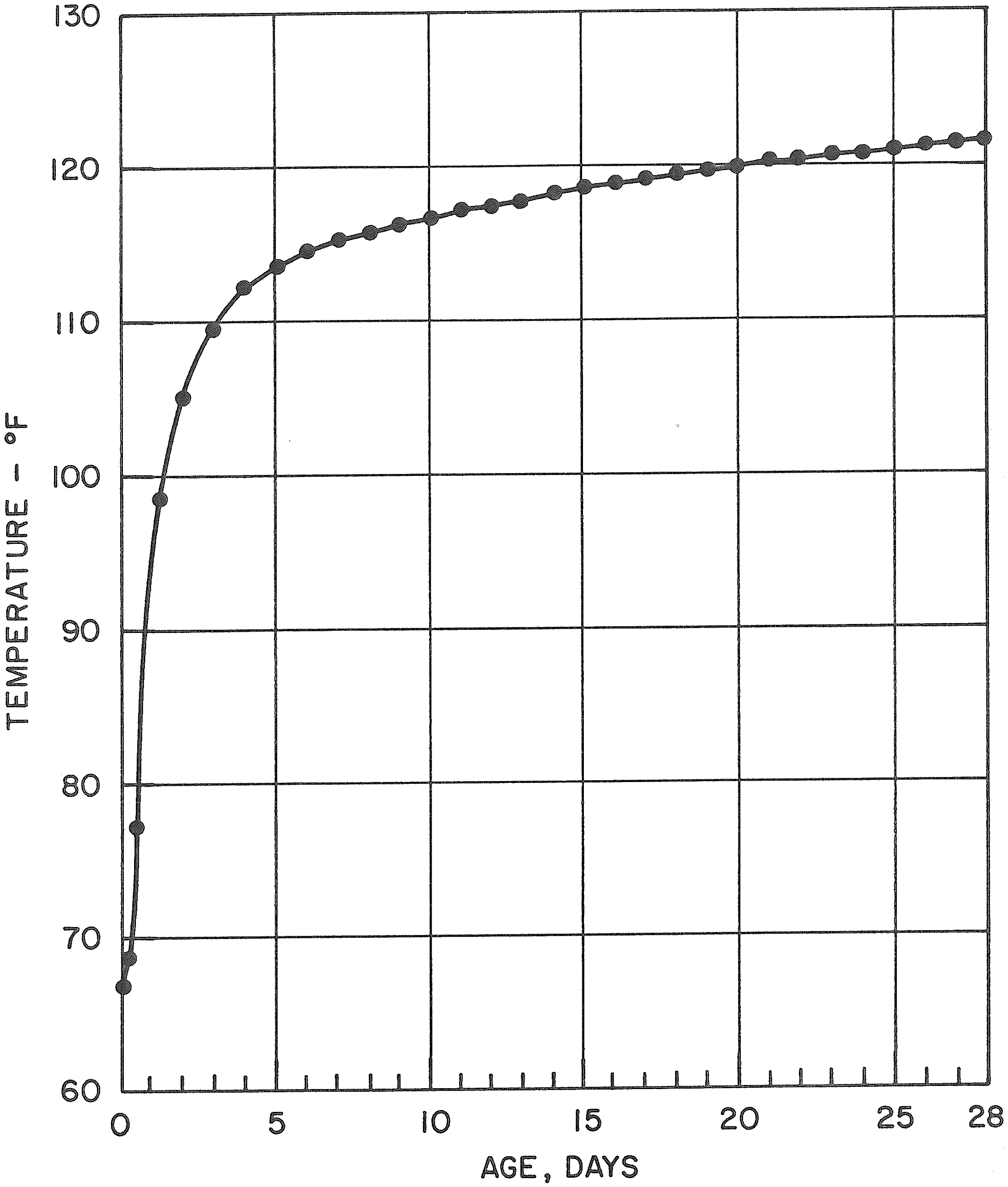

FIG. 6 28-DAY ADIABATIC TEMPERATURE RISE

MASS CONCRETE INVESTIGATIONS
FOR
REZA SHAH KABIR DAM

Report No. UC SESM 74-11

to

HARZA ENGINEERING COMPANY
Chicago, Illinois

by

JEROME M. RAPHAEL

DAVID PIRTZ

MILOS POLIVKA

Professors of Civil Engineering

STRUCTURAL ENGINEERING LABORATORY
UNIVERSITY OF CALIFORNIA

October, 1974