REPORT NO.
UC SESM 72-10

STRUCTURES AND MATERIALS RESEARCH
DEPARTMENT OF CIVIL ENGINEERING

MASS CONCRETE INVESTIGATIONS FOR ROSS HIGH DAM

by

JEROME M. RAPHAEL
DAVID PIRTZ
MILOS POLIVKA

REPORT TO
INTERNATIONAL ENGINEERING COMPANY, INC.
SAN FRANCISCO, CALIFORNIA

JULY 1972

STRUCTURAL ENGINEERING LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY CALIFORNIA

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INTRODUCTION

This report gives results of the studies of concrete properties for Ross High Dam carried out at the Structural Engineering Materials Laboratory, University of California, Berkeley.

Properties of aggregates have been determined and an aggregate gradation selected. The mix proportions for a 4.0 and 4.5 sacks per cubic yard (scy) mix containing 6-in. maximum size aggregate (MSA) and a 25% pozzolan replacement were established by trial mixes.

A total of thirty-six 6 by 12 in. and twenty-four 18 by 36 in. cylinders was cast and the compressive strength and elastic properties of the concrete determined at various ages up to the age of one year.

Adiabatic temperature rise, thermal diffusivity and coefficient of thermal expansion have been determined for the 4.0 and 4.5 scy mass concrete mixes.

CONCRETE MIX

The cementing material used in the concrete mixes consisted of three parts of cement to one part of pozzolan by weight (25 percent replacement). The cement used was Lone Star Type II portland cement and the pozzolan was "Sun" brand, a volcanic cinder. In this report the cement factor is expressed in 94 lb. sacks of cement plus pozzolan per cubic yard of concrete. The properties of the cement, as determined by the producer, are shown in Table 1.

The mixing water used was regular laboratory tap water.

The aggregate was received in six sizes as follows: coarse sand (FM = 3.67), blending sand (FM = 1.45), 3/16 to 3/4 in., 3/4 to 1 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 source of the aggregate is the Crane Bar located on the north bank of the Skagit River, 2 miles below Newhalem, Washington. As shown in Table 2, the natural sand is too coarse for a workable concrete. The addition of one-third manufactured blending sand from the same source produced a workable non-bleeding mix. The proportions of the fine and coarse aggregate were obtained by computation to fall within the grading limits recommended by the ACI.*

The water-reducing and retarding admixture used was Pozzolith 300-R, conforming to the Corps of Engineers Specification No. CRD-C-87 Type D. The air-entraining admixture was MB-VR Standard, conforming to Corps of Engineers Specification No. CRD-C-13. Both of these admixtures were manufactured by Master Builders of Cleveland, Ohio.

Once the proportions of the constituents of the concrete mix had been determined, eight trial mixes were made, varying the amounts of water and admixtures, to produce 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. The complete record of the eleven trial batches is shown on Table 3.

The mix proportions selected for the 4.0 and the 4.5 scy mixes are given in Table 4. The sand content of the 4.0 scy mix is 28 percent and that of the 4.5 scy mix is 26 percent by weight of total aggregate.

All batching was done by weight except for the admixtures which were measured by volume. All materials were cooled to 40°F before mixing

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*ACI Committee 207, "Mass Concrete for Dams and Other Structures," Jl. ACI, April 1970.

of the concrete.

Concrete was mixed in a one-fifth cubic yard Essick Model 93 drum-type mixer. Fourteen concrete batches were required for each casting, which included twelve 18 by 36 in. specimens, eighteen 6 by 12 in. 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 temperature of the concrete immediately after mixing was 46^{o}F.

The properties of the fresh concrete are summarized in Table 5. The slump and air content were determined on concrete wet-screened to pass a 1 1/2 in. sieve. Concrete of both the 4.0 and 4.5 scy mixes had a slump of 1 3/4 $\pm$ 1/4 in. and an air content of 5 $\pm$ 0.2 percent. The nominal unit weight of the wet-screened concrete was 149 pounds per cubic foot (pcf) and of the concrete containing 6 in. MSA was 159 pcf. The water-cementing material (w/(c+p)) ratios were 0.41 and 0.38 by weight for the 4.0 and the 4.5 scy mixes, respectively. The w/(c+p) ratio is based on the weight of the water (without the admixtures) divided by the combined weight of cement and pozzolan.

Both the 4.0 and the 4.5 scy mixes proved to be highly workable under vibration. The 4.5 scy mix appeared to be slightly oversanded.

MANUFACTURE OF SPECIMENS

Casting of 6 by 12 in. cylinders was done in three groups of six cylinders for each mix, using concrete wet-screened on a 1 1/2 in. sieve. Specimens were cast in metal cans in two layers; each layer was vibrated by two insertions of a laboratory size, 3/8 HP vibrator, having a 1 1/8 in. diameter spud. After completion of casting the cylinders were fitted with lids and stored at 73^{o}F in fog. Specimens were stripped at age one day and fog cured at 73°F until age of test.

Casting of 18 by 36-in. cylinders was done in three groups of four cylinders for each mix using mass concrete containing 6 in. MSA. The braced galvanized steel cylinder molds were filled in four layers; the first and the third layers were vibrated lightly with one insertion of a flexible-hose 2 3/4 HP vibrator, having a 1 3/4 in. diameter spud. The second and fourth layers were thoroughly vibrated with three insertions (18 to 20 in. deep) of the vibrator. After completion of casting the cylinders were covered with a sheet of polyethylene to prevent loss of moisture. No significant volume of bleeding water appeared on the concrete surfaces of either of the two mixes.

At age one day the concrete surface of the 18 by 36 in. specimens was covered with a 1/4 in. layer of water. At age seven days, the curing water was removed and replaced with a 1/2 in. layer of moist sand, and the top of the specimen was resealed with the polyethylene sheet. The specimens were kept in their mold until age of test. This non-standard curing was selected to simulate field conditions closely. Temperature at the center of the 18 by 36 in. specimens, as measured with copper-constantan thermocouples, varied with age as shown in Fig. 1. The dashed line shows the average temperature expected in the concrete during the construction of the dam, based upon representative adiabatic temperature rise curves, with hydration starting immediately after placement. For both mixes the water-reducing and retarding admixture completely inhibited hydration for about seven hours after mixing and the temperature of the specimens did not catch up with the guide curve until the age of 24 hours. After 24 hours, the temperature of the specimens closely followed the guide curve.

COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES

The 6 by 12 in. cylinders containing 1 1/2 in. MSA wet-screened concrete were tested for compressive strength at ages of 7, 14, 28, 90, 180, and 365 days. Prior to testing each specimen was capped with sulfur and wrapped with sheet plastic (Saran) to prevent moisture loss during handling and testing. The compression test was made using 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. For about six months the strength increased nearly linearly with time on a semi-log scale, with the richer 4.5 scy mix producing on the average about 500 psi more strength than the leaner 4.0 scy mix. There was relatively little strength increase after six months of curing.

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 28, 90, 180, and 365 days. Prior to testing, each specimen was stripped, capped with Hydrostone, and wrapped with Saran to prevent moisture loss during handling and testing. The tests were made in 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 uniformly to the age of six months, and then increased at a much lower rate for the next six months. The one-year strengths were 6850 psi for the 4.0 scy mix and 7210 psi for the 4.5 scy mix. The strengths measured by the mass concrete cylinders increased with age from 79 to 92 percent of the strength for the 6 x 12-in. wet-screened control cylinders, with an average of 87 percent.

As can be seen from Table 6, age and cement content had only a minor effect on the modulus of elasticity of the mass concrete, since this property primarily depends on the elastic modulus of the aggregate, once the cement paste matrix has attained a fair amount of hydration. Thus the modulus of elasticity of the 4.0 scy mix increased from 4.7 to 4.9 million psi, and that of the 4.5 scy mix increased form 4.7 to 5.1 million psi as age increased from 28 to 365 days. No trend can be seen for Poisson's ratio,whose average value for all tests was 0.19.

Tests on 23-year-old cores from the Ross Dam yielded values of 7200 psi for compressive strength, 4.7×10^6 psi for elastic modulus and 0.18 for Poisson's ratio in the mass concrete of the dam. These elastic properties compare favorably with those obtained in the test mixes reported here.

ADIABATIC TEMPERATURE RISE

Adiabatic temperature rise has been determined on two 27 by 30 in. cylindrical specimens for each of the 4.0 and the 4.5 scy mixes containing 6-in. MSA. Concrete used for the adiabatic temperature rise specimens 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 (Note, Table 6).

As the name of the test indicates, the sealed 27 by 30-in. specimens were 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 was an improved version of that developed at this laboratory for the Oroville Dam concrete studies*. It 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 from 2° to 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 2 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

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*David Pirtz, "Improved Adiabatic Calorimeter for Concrete," Materials Research and Standards, Vol. 2, No. 1, January 1962.

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. It is believed that the accuracy of the calorimeter used in this investigation is superior to that of any other calorimeters used in previous mass concrete studies.

The early temperature history of the four specimens is plotted on Fig. 3, showing temperatures to age three days. In casting the first specimen, an unplanned delay of over a half-hour developed, during which the unconsolidated wet concrete was exposed to warm air, and was warmed by simple heat transfer. This extra temperature rise, which amounted to about 2°F, affected the temperature history for about 36 hours, as can be seen easily on the top graph of Fig. 3. The next three specimens followed parallel tracks for a day and a quarter. In showing the long-time adiabatic temperature rise of the two mixes, the first 4.0 scy history was omitted. Thus Fig. 4 shows the average temperature rise of two 4.5 scy mixes, and only that of the second 4.0 scy mix.

The 28-day temperature rise for the 4.0 and the 4.5 scy mixes was 60.8°F and 66.2°F respectively. At ten days, the corresponding temperature rises were 54.3 and 61.8°F. Thus, more than 90 percent of the temeprature 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

Thermal diffusivity has been determined for the 4.0 and the 4.5 scy mixes on one specimen for each mix. The 9 1/2 by 19-in. cylindrical specimens were cast at the same time as the adiabatic temperature rise specimens utilizing the same concrete except that cobbles greater than 4 1/2 in. were removed by hand from the wet concrete and replaced with an equal volume of 3 to 4 1/2 in. aggregate. The sealed specimens were cured adiabatically to age 26 days, then stored at 100°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 thin gage metal mold. Thermal diffusivity was .039 square feet per hour for both the 4.0 and 4.5 scy mixes at an average temperature of 70°F.

THERMAL EXPANSION

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 strain meter 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 strain meter. Only the 4.0 scy mix was used in this test, since the coefficient of thermal expansion is primarily a function of the aggregate properties.

The specimens were cast at 44°F, stored at 60°F to the age of ten days, and then stored at 73°F to the age of 28 days. Two complete cycles of temperature were then run, each cycle consisting of storage at temperatures of 73-110-73-40-73°F. Each storage period lasted about five days, long enough for the internal temperatures to reach equilibrium, as measured on the strain meter.

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 7.

Average coefficient of thermal expansion of the mass concrete was 5.62×10^{-6} per °F.

CONCLUSIONS

1. Using Lone Star Type II cement and Crane Bar aggregate, 6 in. MSA concrete can be produced with one-year strengths of 6850 psi for the 4.0 scy mix and 7210 psi for the 4.5 scy mix, both mixes having a 25% pozzolan replacement.

2. No trouble should be experienced in producing mass concrete with the design strength of 6000 psi assumed for the design of the high dam.

3. Modulus of elasticity at age one year is 4.9 million psi for the 4.0 scy mix, and 5.1 million psi for the 4.5 scy mix.

4. Poisson's ratio in mass concrete is 0.19.

5. The 28-day adiabatic temperature rise is 60.8°F for the 4.0 scy mix, and 66.2°F for the 4.5 scy mix.

6. Thermal diffusivity is 0.039 sq. ft. per hr. for both mixes.

7. Coefficient of thermal expansion averages 5.62 millionths per °F.

APPENDIX A

TABLES

TABLE 1. PROPERTIES OF CEMENT

BRAND Long Star Cement TYPE OF CEMENT II L.A. PLANT Seattle, Wash.

SILO NO. 4 QUANTITY REPRESENTED 9000 BBLS DATE FILLED Feb., 1971

CHEMICAL		PHYSICAL		
DATES		DATES		
SiO_2	22.14	Blaine Fineness		3730
Al_2O_3	4.65	Normal Consistency		23.4
Fe_2O_3	2.73	Autoclave Expansion		
CaO	65.31	Time of Setting		
MgO	1.52	Initial	2:10	
SO_3	2.20	Final	4:00	
Loss	1.23	Vicat	100	
Na_2O	0.25	Tensile Strength, psi		
K_2O	0.23	1 Day	165	
Total	99.78	3 Day	290	
Alkalies as Na_2O	0.40	7 Day	390	
Insoluble Residue		28 Day	---	
Al_2O_3/Fe_2O_3		Water for Cubes		48.4
Compound Composition - Potential		Flow		
C_3S	56.13	Entrained Air		8.0
C_2S	21.17	False Set		93.5
C_3A	7.71	Compressive Strength - 2" Cubes, psi		
C_4AF	8.30	1 Day	1250	
		3 Day	2490	
Date of Report 3/11/71		7 Day	3512	
		28 Day	Pending	

/S/

Lloyd Fuller - Plant Chief Chemist

TABLE 2. PROPERTIES OF AGGREGATE

Sieve Size	Cumulative Percent Retained					
	Coarse Aggregate				Sand	
	3"to 6"	1 1/2" to 3"	3/4"to 1 1/2"	3/16"to 3/4"	Coarse	Blend
6 in.	0					
3 in.	96	33				
1 1/2 in.	100	98	1			
3/4 in.	100	100	99	13		
3/8 in.	100	100	100	73		
No. 4	100	100	100	99	6	0
No. 8	100	100	100	100	28	0
No. 16	100	100	100	100	56	2
No. 30	100	100	100	100	83	14
No. 50	100	100	100	100	95	48
No. 100	100	100	100	100	99	81
Fineness Modulus	-	-	-	-	3.67	1.45
Material Passing No. 200 Sieve		-	-	-	0.2	5.4
Sand Equivalent Value		-	-	-	100	87
Bulk Specific Gravity (SSD)	2.70	2.71	2.71	2.71	2.68	2.68
Absorption Capacity, %	1.0	0.9	0.9	1.1	1.4	1.3
Moisture Content as Stocked, %	0.1	0.1	0.1	0.2	1.0	0

Notes:
1. Specific gravity of cement is 3.15.
2. Specific gravity of pozzolan is 2.49.
3. Combined FM of sands is 2.96 based on 66.9% coarse and 33.1% blending sand by wieght of total sand.

TABLE 3. TRIAL MIXES

Mix	4.0 scy				4.5 scy			
Mix Number	2	3	4	10	6	7	8	11
Batch Size - cf.	3.0	3.0	3.0	5.4	3.0	3.0	3.0	5.4
Batch Weights (SSD), lb.								
Cement	31.3	31.3	30.7	55.2	35.3	35.0	35.0	62.8
Pozzolan	10.4	10.4	10.2	18.4	11.7	11.6	11.6	20.9
Water	18.4	18.1	17.6	30.5	17.0	17.3	17.9	31.7
Coarse Sand	76.0	76.0	76.0	136.6	69.3	69.3	69.3	124.8
Blending Sand	37.5	37.5	37.5	67.5	34.3	34.3	34.3	61.7
3/16" to 3/4"	67.9	67.9	67.9	122.0	68.8	68.8	68.8	123.8
3/4" to 1 1/2"	73.9	73.9	73.9	132.9	74.4	74.4	74.4	134.1
1 1/2" to 3"	76.9	76.9	76.9	138.4	77.4	77.4	77.4	139.5
3" to 6"	76.1	76.1	76.1	136.9	77.3	77.3	77.3	139.0
Pozzolith 300 R - ml.	52.6	52.6	52.6	94.6	59.1	59.1	59.1	106.3
MB-VR Standard - ml.	13.2	19.7	21.0	35.5	23.7	26.6	29.6	48.0
Properties of Fresh Concrete								
Concrete Temp. °F @ 19 min	51	51	51	49	50	50	50	48
W/(C+P) - by weight	0.44	0.44	0.43	0.42	0.36	0.37	0.38	0.38
Slump - inches	1 3/4	3	2 1/4	2 3/4	1	3/4	2	1 3/4
Air Content - %	3.6	5.5	5.3	5.7	2.9	3.7	4.3	3.9
Unit Weight, 1 1/2" MSA - pcf	147.0	146.8	148.5	147.0	153.5	151.5	150.8	152.0
Unit Weight, 6" Msa - pcf	159.5	159.5	158.5	158.5	161.0	160.5	159.0	159.0
Cementing Material - scy	4.08	4.08	3.99	4.00	4.77	4.72	4.58	4.56
Water Content - pcy	170	167	161	156	162	164	165	162
Compressive Strength, psi (6 by 12 in. cyl.)								
28-Day	5950	5210	5560	-	7590	7260	6810	6310
90-Day	7290	6450	6670	-	8380	8530	8330	7860

TABLE 4. PROPORTIONS OF MASS CONCRETE MIXES

Material	One Cubic Yard Batch (SSD)			
	4.0 scy mix		4.5 scy mix	
	Wt., lb.	% by Wt.	Wt., lb.	% by Wt.
Cementing Material:				
Cement	282.6	75.0	318.9	75.0
Pozzolan	94.2	25.0	106.1	25.0
Water	155.6	-	160.5	-
Sand: Coarse	699.4	66.9	639.3	66.9
Blending	345.6	33.1	316.3	33.1
Coarse Aggregate:				
3/16" to 3/4"	624.6	23.0	634.7	23.1
3/4" to 1 1/2"	680.4	25.1	687.5	25.0
1 1/2" to 3"	708.6	26.1	715.2	26.0
3" to 6"	700.9	25.8	712.7	25.9
Admixtures:				
Pozzolith 300 R	1.1	16 fl. oz.	1.2	18 fl. oz.
MB-VR Standard	0.5	7.8 fl. oz.	0.6	9.5 fl. oz.
Total	4,293.5	-	4,293.0	-

Notes: 1. The sand/coarse aggregate for the 4.0 scy mix is 38.5% by wt.

2. The sand/coarse aggregate for the 4.5 scy mix is 34.7% by wt.

TABLE 5. PROPERTIES OF FRESH CONCRETE

Property	4.0 scy Mix	4.5 scy Mix
W/C, by weight	0.55	0.50
W/(C+P), by weight	0.41	0.38
Slump, inches (1 1/2 in. MSA)	1 1/2	1 3/4
Air Content, % (1 1/2 in. MSA)	4.9	5.0
Unit Weight, pcf:		
1 1/2 in. MSA	149	149
6 in. MSA	159	159
Temp. of Conc., ^{o}F		
End of mixing	46	45
End of casting	47	46

Notes: 1. Values based on average of 14 batches for each mix.

2. MSA, Maximum Size Aggregate.

TABLE 6. COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES

Size	1 1/2 in. MSA Mix 6 by 12 in. Cyl.		6 in. MSA Mass Concrete Mix 18 by 36 in. Cylinders					
Mix	4.0 scy	4.5 scy	4.0 scy			4.5 scy		
Age (days)	Strength (psi)	Strength (psi)	Strength (psi)	Elas. Mod. ($\times 10^6$ psi)	Poisson's Ratio	Strength (psi)	Elas. Mod. ($\times 10^6$ psi)	Poisson's Ratio
7	3910	4550						
	3860	4530						
	3990	4360						
Average	3920	4480						
14	4750	5380						
	4640	5220						
	4870	5200						
Average	4750	5270						
28	5600	6210	4730	4.75	0.21	4770	4.70	0.21
	5580	6090	4790	4.70	0.21	4820	4.90	0.22
	5650	6040	4510	4.65	0.20	2910	4.90	0.20
Average	5610	6110	4680	4.70	0.21	4830	4.85	0.21
90	7010	7160	5570	5.05	0.18	6460	4.70	0.19
	7290	7190	4910*	4.60	0.18	6460	4.75	0.17
	6940	7500	6120	4.60	0.18	6610	4.95	0.20
Average	7080	7280	5840*	4.75	0.18	6510	4.80	0.19
180	7260	8220	7450	5.0	0.16	7010	5.1	0.17
	7510	8070	6010	4.6	0.17	6760	5.15	0.19
	7390	7850	6670	4.7	0.18	7390	5.15	0.18
Average	7390	8050	6710	4.8	0.17	7050	5.1	0.18
365	8050	8150	6540	4.96	0.20	7330	5.06	0.19
	7470	7600	7300	-	-	7430	5.08	0.18
	7220	7680	6700	4.90	0.20	6860	5.05	0.20
Average	7580	7810	6850	4.93	0.20	7210	5.06	0.19

Note: Avg. compressive strength of 6 by 12 in. cylinders cast from adiabatic temp. rise mixes.

Age \ Mix	4.0 scy	4.5 scy
2 days	1810	2370
7	3870	4690
28	5440	6140
60	6360	7050

*4910 psi specimen is not included in average. 5840 psi is average of 2 specimens. Average of 3 specimens is 5530 psi.

TABLE 7. COEFFICIENT OF THERMAL EXPANSION

Temperature, °F	Coefficient of Expansion Millionths per °F
70	
	5.37
100	
	5.97
70	
	5.36
40	
	5.77
70	
Average	5.62

APPENDIX B

ILLUSTRATIONS

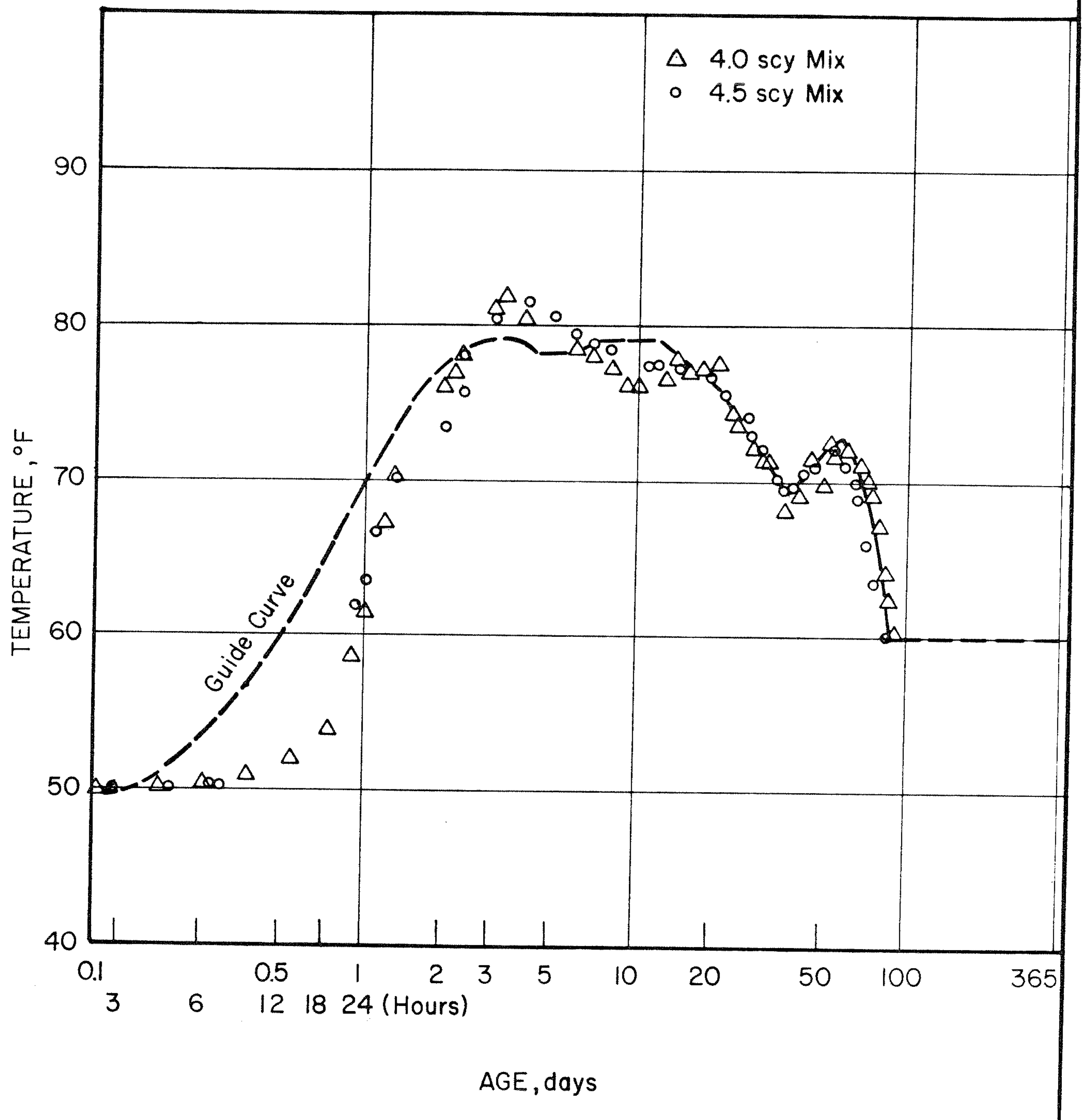

FIG. 1 - CURING SCHEDULE FOR MASS CONCRETE CYLINDERS

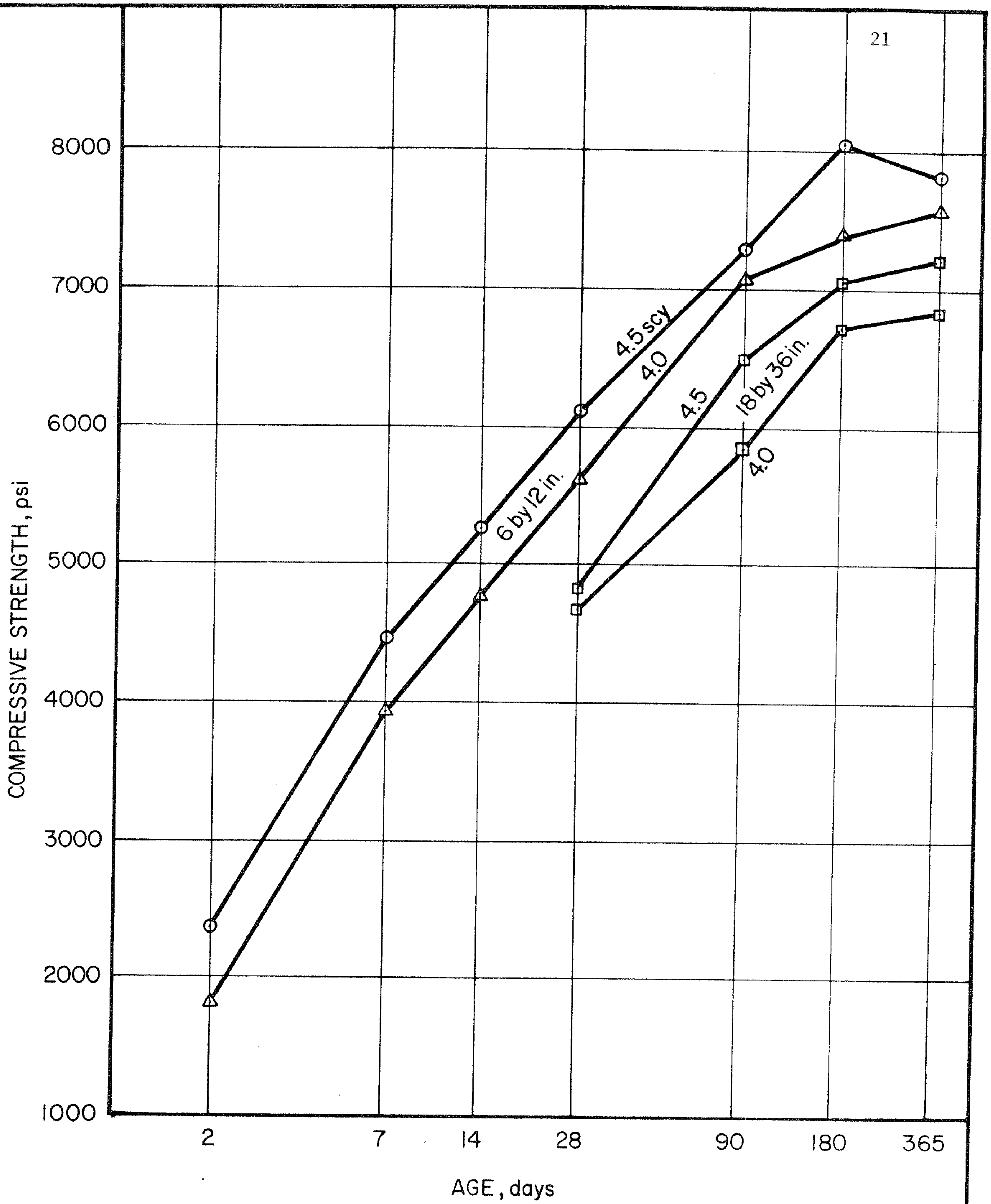

FIG. 2 - COMPRESSIVE STRENGTH

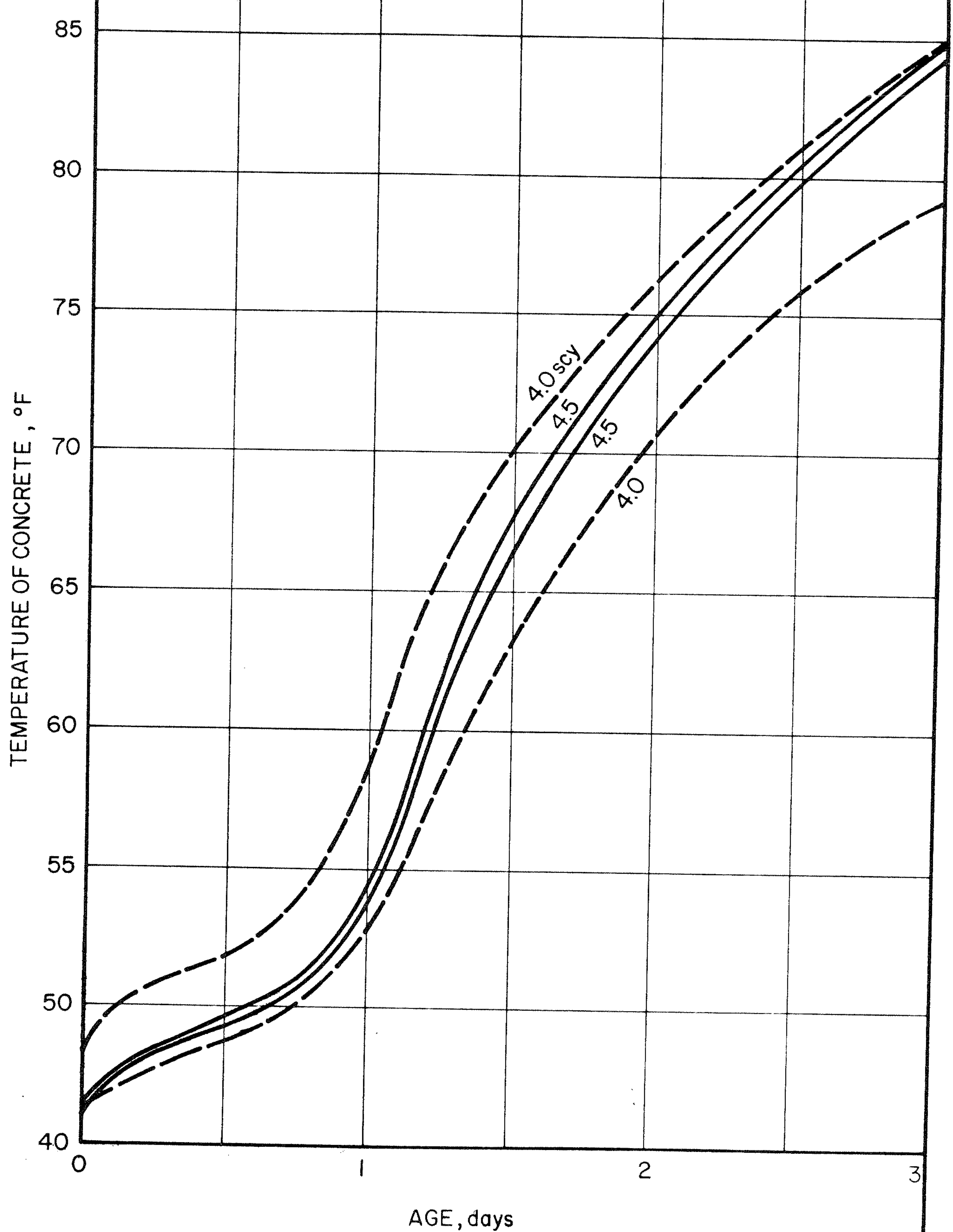

FIG. 3 - EARLY TEMPERATURE HISTORY

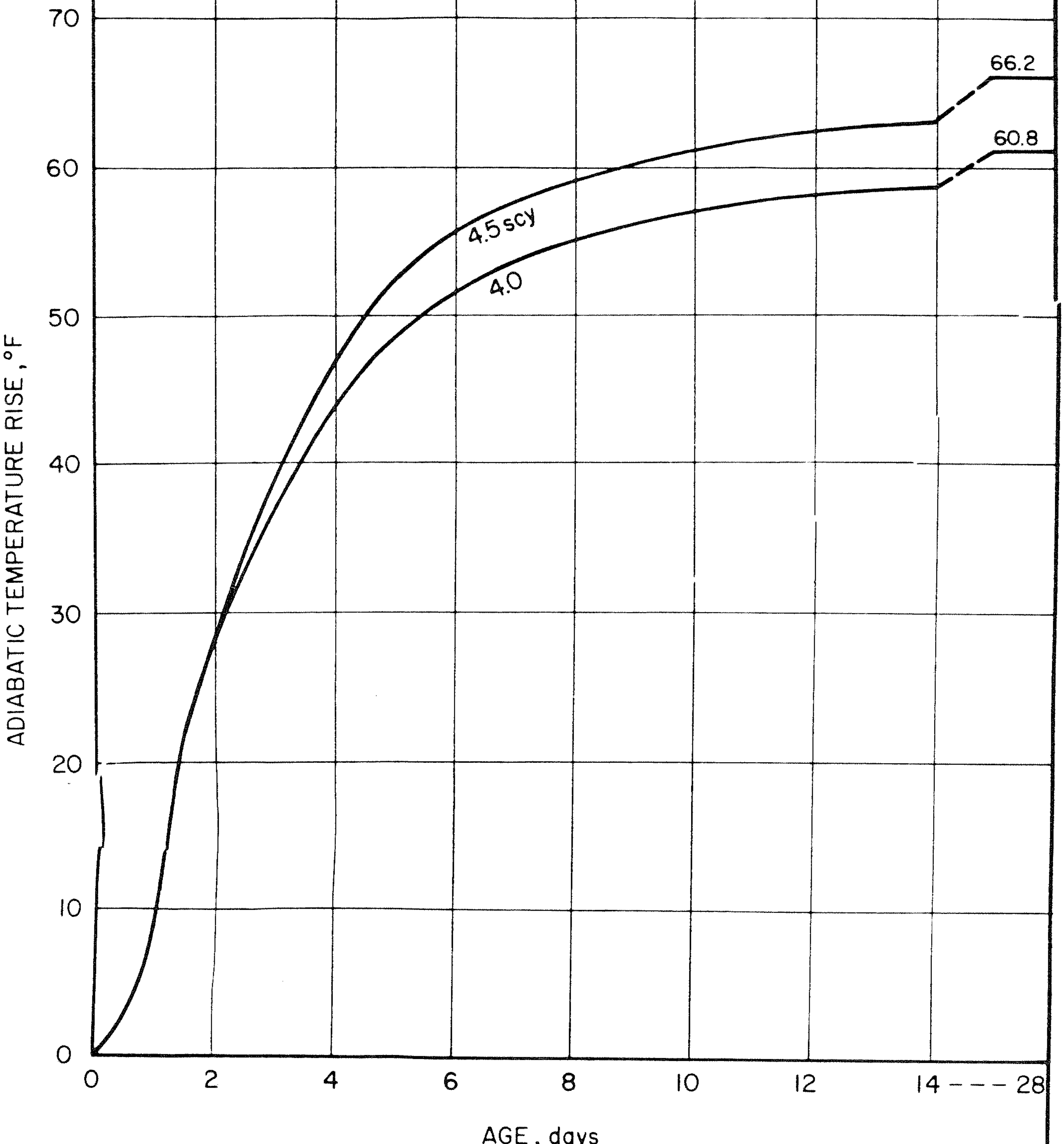

FIG. 4 - ADIABATIC TEMPERATURE RISE