LABORATORY EVALUATION
OF HIGH STRENGTH CONCRETE

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MATERIALS & RESEARCH DIVISION

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TABLE OF CONTENTS

ABSTRACT

This investigation was undertaken to determine the feasibility of producing high strength concrete from materials currently available in the northwest region of Vermont. Compressive strengths in excess of 6,500 psi, were targeted using the Vermont Agency of Transportation specification for prestressed concrete as a guide.

Twenty concrete batches were produced in the laboratory with two types of cement using quantities ranging from 611 to 800 pounds per cubic yard. All test batches contained a high range water reducing admixture and test specimens were cured using either standard or accelerated methods.

Only one of the test batches failed to yield concrete with a compressive strength in excess of 6,500 psi @ 28 days when cured in a standard moist condition. The durability, as indicated by weight loss due to freezing and thawing, and the compressive strength increased as cement content increased and water cement ratios decreased.

Until a greater population of test results is established, this report recommends that specified design compressive strengths for prestressed concrete be limited to a maximum of 5,500 psi for Vermont Agency of Transportation work.

INTRODUCTION

This investigation examined the feasibility of producing high strength concrete using materials currently available in northwestern Vermont. Aggregates were obtained from local sources and cements chosen represented those available to ready mixed concrete producers in this area.

Three sources of Type II cement were used in the testing program as well as one source of Type III cement. Cement quantities of 611, 660, 752, and 800 pounds per cubic yard were incorporated in the mix designs. A high range water reducing and retarding admixture was added to all batches of concrete.

Vermont Agency of Transportation specifications for prestressed concrete were used as a guide in trying to achieve compressive strengths in excess of 6,500 psi. Cylinders were subjected to standard curing and accelerated curing methods with test ages ranging from 1 day to 90 days. Test specimens were also prepared to examine resistance to freezing and thawing of the various concretes.

Accelerated curing, as used in this investigation, was accomplished by covering the cylinders to prevent loss of moisture, then placing the cylinders in a sealed, insulated (styrofoam) enclosure. Temperature levels reached in this investigation were similar to those recorded at prestressed and precast concrete operations which cure their products with insulating planks or tarps.

MATERIALS

The materials used in this investigation are as follows:

A. Aggregates

1. Coarse Aggregate

3/4 Inch Crushed Stone

Swanton Limestone, Swanton, Vermont

TABLE 1

COARSE AGGREGATE TEST DATA

	3/4 Inch Crushed Stone Date Sampled 1/24/85	VAOT Specification Requirements
Sieve Size	% Passing	% Passing
1"	100	100
3/4"	100	90-100
3/8"	43	20-55
#4	4	0-10
#8	2	0-5
L.A. Abrasion, percent loss "B" Grading	22.8	35 Maximum
Thin & Elongated Pieces, percent	1.4	10 Maximum
Fractured Faces, percent	100	-

2. Fine Aggregate

A. G. Anderson, Highgate, Vermont

TABLE 2

FINE AGGREGATE TEST DATA

	Fine Aggregate Date Sampled 1/28/85	VAOT Specification Requirements
Sieve Size	% Passing	% Passing
3/8"	100	100
#4	99	95-100
#8	87	-
#16	69	60-80
#30	44	25-60
#50	19	10-30
#100	4	2-10
#200	0.8	-
Fineness Modulus	2.78	2.60-3.10
Organic Impurities, color	<1	2 Maximum

B. Cements

1. Type III Cement

Independent Cement Company, Beauport, Quebec

TABLE 3

CEMENT TEST DATA - TYPE III CEMENT

	Independent Type III Date Sampled 2/4/85	AASHTO M85-84I Specification Requirements
Air Content of Mortar, percent by volume	6.4	12 Maximum
Fineness - Specific Surface, Sq. cm. per gram	5440	–
Soundness - Autoclave Expansion, percent	0.22	0.80 Maximum
Normal Consistency - Vicat Needle	27.5	–
Time of Setting - Gillmore Needle		
Initial - Hrs:Min	1:45	1:00 Minimum
Final - Hrs:Min	2:50	10:00 Maximum
Compressive Strength, psi	2:50	
3 days - Cube No. 1	4538	
Cube No. 2	4400	
Cube No. 3	4400	
Average	4450	3500 Minimum
7 days - Cube No. 4	4575	
Cube No. 5	4575	
Cube No. 6	4788	
Average	4650	-

2. Type II Cements

a. Independent Cement Company, Joliette, Quebec

b. Glens Falls Portland Cement Company, Glens Falls, New York

c. Northeast Cement Company, St. Constant, Quebec (Insufficient quantities obtained to conduct physical testing)

TABLE 4

CEMENT TEST DATA - TYPE II CEMENT

	Independent Type II Date Sampled 2/4/85	Glens Falls Type II Date Sampled 2/21/85	AASHTO M85-84I Specification Requirements
Air Content of Mortar, percent by volume	8.6	7.4	12 Maximum
Fineness - Specific Surface, Sq. cm. per gram	3423	3651	2800 Minimum 4000 Maximum
Soundness - Autoclave Expansion, percent	0.02	0.02	0.80 Maximum
Normal Consistency - Vicat Needle	25.0	24.0	-
Time of Setting - Gillmore Needle			
Initial - Hrs:Min	2:05	3:00	1:00 Minimum
Final - Hrs:Min	3:00	4:20	10:00 Maximum
Compressive Strength, psi			
3 days - Cube No. 1	3038	2913	
Cube No. 2	3088	2913	
Cube No. 3	3100	2950	
Average	3080	2930	1500 Minimum
7 days - Cube No. 4	3400	3737	
Cube No. 5	3725	3980	
Cube No. 6	3300	3838	
Average	3330	3850	2500 Minimum

C. Air Entraining Admixture

Daravair

W. R. Grace & Company, Cambridge, Massachusetts

D. High Range Water Reducing and Retarding Admixture

Daracem 100

W. R. Grace & Company, Cambridge, Massachusetts

PROCEDURES

Concrete used in this investigation was prepared in the laboratory in a Sears 3½ cu. ft. mixer. Mixes were designed to provide concretes with four different cement contents - 611, 660, 752, and 800 pounds per cubic yard. Materials were prepared to produce batches yielding 1¼ cubic feet of concrete.

Mix design quantities for the various types, brands and quantities of cement represented in this program are shown in Tables 5, 6, and 7.

TABLE 5

BATCH QUANTITIES PER CUBIC YARD

INDEPENDENT TYPE III CEMENT

	Batch No. 1	Batch No. 2	Batch No. 3	Batch No. 4	Batch No. 5	Batch No. 6	Batch No. 7	Batch No. 8
*3/4" Crushed Stone, lbs.	1605	1605	1605	1605	1605	1605	1605	1605
*Fine Aggregates, lbs.	1598	1598	1511	1511	1380	1380	1330	1330
Cement, lbs.	611	611	660	660	752	752	800	800
Daravair, oz.	6.5	7.5	11.0	13.0	16.0	18.0	21.5	23.5
Daracem 100, oz.	91.7	91.7	99.0	99.0	112.8	112.8	120.0	120.0
Net Water, gal.	32.8	32.3	32.6	31.5	33.5	33.6	33.6	34.2

* Weights converted to saturated surface-dry condition.

TABLE 6

BATCH QUANTITIES PER CUBIC YARD

INDEPENDENT TYPE II CEMENT

	Batch No. 9	Batch No. 10	Batch No. 11	Batch No. 12	Batch No. 13	Batch No. 14	Batch No. 15	Batch No. 16
*3/4" Crushed Stone, lbs.	1605	1605	1605	1605	1605	1605	1605	1605
*Fine Aggregates, lbs.	1598	1598	1511	1511	1380	1380	1330	1330
Cement, lbs.	611	611	660	660	752	752	800	800
Daravair, oz.	4.0	3.0	4.5	4.5	7.5	7.5	9.0	9.0
Daracem 100, oz.	91.7	91.7	99.0	99.0	112.8	112.8	120.0	120.0
Net Water, gal.	26.7	28.2	29.1	28.8	29.5	29.1	30.8	30.6

* Weights converted to saturated surface-dry condition.

TABLE 7

BATCH QUANTITIES PER CUBIC YARD

GLENS FALLS TYPE II CEMENT & NORTHEAST TYPE II CEMENT

	Glens Falls Type II		Northeast Type II	
	Batch No. 17	Batch No. 18	Batch No. 19	Batch No. 20
*3/4" Crushed Stone, lbs.	1605	1605	1605	1605
*Fine Aggregate, lbs.	1598	1330	1598	1330
Cement, lbs.	611	800	611	800
Daravair, oz.	3.0	9.0	3.0	9.0
Daracem 100, oz.	91.7	120.0	91.7	120.0
Net Water, gal.	26.4	27.4	26.2	27.8

* Weights converted to saturated surface-dry condition.

Tests were performed on the fresh concrete to determine Slump (AASHTO T 119-82), Air Content (AASHTO T 152-84I), Unit Weight (AASHTO T 121-82) and temperature.

Compressive strength was determined using 4 inch x 8 inch cylinders. Cylinders were tested at ages ranging from 1 day to 90 days using both standard curing and accelerated curing methods.

Accelerated curing was accomplished by covering cylinders to prevent loss of moisture, then placing the cylinders in a sealed styrofoam box. Cylinders stored in this manner were tested at ages of 1 day and 3 days. Additional cylinders were then removed from the styrofoam box and either air-dried or subjected to moist curing until the desired age of test was attained.

One freeze-thaw specimen, 3" W x 3" D x 16" L, was cast from each batch of concrete. These specimens were moist cured for 14 days, after which they were subjected to freezing and thawing (AASHTO T 161-83I) in a 3% NaCl solution.

RESULTS

Results of tests on the fresh concrete are shown in Tables 8, 9, and 10.

TABLE 8

FRESH CONCRETE TEST RESULTS

INDEPENDENT TYPE III CEMENT

	Batch No. 1	Batch No. 2	Batch No. 3	Batch No. 4	Batch No. 5	Batch No. 6	Batch No. 7	Batch No. 8
Slump, inches	2¼	2	3	2½	2½	3¼	2½	2 3/4
Air Content, percent	3.4	3.8	4.4	4.8	4.3	4.9	4.7	5.3
Unit Weight, lbs./ft.^{3}	148.33	148.71	147.47	146.94	147.23	146.50	146.70	145.50
Temperature, °F	74	74	74	72	72	71	72	71
W/C Ratio	.45	.44	.41	.40	.37	.37	.35	.36

TABLE 9

FRESH CONCRETE TEST RESULTS

INDEPENDENT TYPE II CEMENT

	Batch No. 9	Batch No. 10	Batch No. 11	Batch No. 12	Batch No. 13	Batch No. 14	Batch No. 15	Batch No. 16
Slump, inches	1½	2½	4	3¼	3	2 3/4	3	2 3/4
Air Content, percent	6.0	6.0	6.9	6.1	6.2	6.0	6.5	5.2
Unit Weight, lbs./ $ft.^3$	147.18	147.51	145.64	147.56	146.26	148.14	145.59	147.75
Temperature, °F	74	74	74	72	71	72	71	71
W/C Ratio	.36	.38	.37	.36	.33	.32	.32	.32

TABLE 10

FRESH CONCRETE TEST RESULTS

GLENS FALLS TYPE II CEMENT & NORTHEAST TYPE II CEMENT

	Glens Falls Type II		Northeast Type II	
	Batch No. 17	Batch No. 18	Batch No. 19	Batch No. 20
Slump, inches	2 3/4	3	2½	3½
Air Content, percent	6.5	6.4	5.5	7.6
Unit Weight, lbs./ft.^{3}	146.60	147.56	148.62	144.87
Temperature, °F	68	71	70	70
W/C Ratio	.36	.29	.36	.29

The temperature inside the enclosure used for accelerated curing reached 135-140°F during the initial 24 hours of curing of the specimens. The temperature dropped to 105-110°F after 2 days of curing and to 95-100°F after 3 days of curing. Temperature levels were the same for concrete containing Type II cement as with concrete containing Type III cement.

The results of compressive strength tests are shown in Tables 11, 12, 13, and 14. Strength age plots illustrating average compressive strengths are shown in Figures I through XII in Appendix A.

TABLE 11

COMPRESSIVE STRENGTH TEST RESULTS, PSI

CEMENT CONTENT, 611 POUNDS PER CUBIC YARD

Age Tested, Days	Independent Type III						Independent Type II						Glens Falls Type II		Northeast Type II	
	Batch No. 1			Batch No. 2			Batch No. 9			Batch No. 10			Batch No. 17		Batch No. 19	
	Type of Cure			Type of Cure			Type of Cure			Type of Cure			Type of Cure		Type of Cure	
	Standard	Accelerated		Standard	Accelerated		Standard	Accelerated		Standard	Accelerated		Standard	Accelerated	Standard	Accelerated
1	3979	4436		4158	4615		4496	4417		4655	4496		4198	4456	4118	4536
3	4954	5232		5232	5232		5013	5133		5193	5093		5173	5272	4258	5113
		Air-Dry	Moist		Air-Dry	Moist		Air-Dry	Moist		Air-Dry	Moist		Moist		Moist
7	5491	5749	5411	5769	5909	5471	5849	5849	5252	5809	5690	5173	5093	5411	5531	5332
28	6346	6167	6128	6844	6366	6247	7003	6386	6307	6724	6307	6048	6804	6565	6724	6108
56	7162	6247	6744	7421	6386	7063	7540		6665	7182		6506				
90	7122			8057			8157			7520						

TABLE 12

COMPRESSIVE STRENGTH TEST RESULTS, PSI

CEMENT CONTENT, 660 POUNDS PER CUBIC YARD

Age Tested, Days	Independent Type III						Independent Type II					
	Batch No. 3			Batch No. 4			Batch No. 11			Batch No. 12		
	Type Of Cure			Type Of Cure			Type Of Cure			Type Of Cure		
	Standard	Accelerated		Standard	Accelerated		Standard	Accelerated		Standard	Accelerated	
1	4436	5033		4417	4695		4496	4496		4536	4655	
3	5391	5610		5411	5650		5033	5033		5312	5232	
		Air-Dry	Moist		Air-Dry	Moist		Air-Dry	Moist		Air-Dry	Moist
7	5590	6028	5511	5909	5909	5650	5491	5551	5292	5690	5650	5451
28	6605	6685	6426	7063	6625	6486	6665	6167	6008	6884	6267	6108
56	7580	6705	6923	7441	6526	7043	7202		6406	7878		6724
90	7839			8177			7640			8117		

TABLE 13

COMPRESSIVE STRENGTH TEST RESULTS, PSI

CEMENT CONTENT, 752 POUNDS PER CUBIC YARD

Age Tested, Days	Independent Type III						Independent Type II					
	Batch No. 5			Batch No. 6			Batch No. 13			Batch No. 14		
	Type Of Cure			Type Of Cure			Type Of Cure			Type Of Cure		
	Standard	Accelerated		Standard	Accelerated		Standard	Accelerated		Standard	Accelerated	
1	4795	5173		4715	5113		4974	4934		5033	5117	
3	5650	6028		5531	5749		5710	5531		5929	5710	
		Air-Dry	Moist		Air-Dry	Moist		Air-Dry	Moist		Air-Dry	Moist
7	6346	6287	6008	6008	6386	5849	6327	6128	5650	6207	6267	5730
28	7401	6884	6665	7142	6645	6565	7282	6804	6486	7520	6665	6685
56	7898	6983	7162	7580	6386	7142	7739		7341	8137		7580
90	8157			8376			8256			8416		

TABLE 14

COMPRESSIVE STRENGTH TEST RESULTS, PSI

CEMENT CONTENT, 800 POUNDS PER CUBIC YARD

Age Tested, Days	Independent Type III						Independent Type II						Glens Falls Type II		Northeast Type II	
	Batch No. 7			Batch No. 8			Batch No. 15			Batch No. 16			Batch No. 18		Batch No. 20	
	Type of Cure			Type of Cure			Type of Cure			Type of Cure			Type of Cure		Type of Cure	
	Standard	Accelerated		Standard	Accelerated		Standard	Accelerated		Standard	Accelerated		Standard	Accelerated	Standard	Accelerated
1	5173	5292		4854	5252		4934	4934		5491	4815		4854	5531	4815	5093
3	6028	5968		5710	5829		5411	5392		5988	5968		5670	5630	5332	5451
		Air-Dry	Moist		Air-Dry	Moist		Air-Dry	Moist		Air-Dry	Moist		Moist		Moist
7	6446	6466	6366	6267	6088	5829	5988	6128	5431	6585	6506	5968	6167	6008	5949	5730
28	7361	6824	6705	7083	6665	6426	7142	6724	6565	7481	7003	7341	7083	7600	6923	6764
56	7898	7023	7182	7978	6684	7122	7978		7560	8340		7839				
90	8774			8276			8356			8714						

The results of dynamic testing of freeze-thaw specimens are shown in Tables 15, 16, and 17. The percent weight change resulting from freezing and thawing of specimens is shown in Tables 18, 19, and 20.

TABLE 15

FREEZE-THAW TEST RESULTS - DURABILITY FACTOR

	Independent Type III Cement							
	611 lbs/cy		660 lbs/cy		752 lbs/cy		800 lbs/cy	
	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7	Batch 8
Number Of Cycles	Durability Factor							
50	99.6	101.1	100.4	99.6	101.1	101.1	100.0	100.7
100	99.3	99.6	99.3	98.9	100.0	99.3	98.9	99.3
150	98.2	97.9	97.1	98.2	98.2	97.5	98.2	99.3
200	98.2	97.5	97.5	97.5	97.5	96.4	97.5	98.6
250	97.2	97.2	97.5	97.2	97.5	96.4	97.5	98.6
300	97.2	96.8	96.8	97.5	97.9	96.8	97.9	98.6
350	97.9	97.5	97.1	97.5	98.2	96.8	97.5	98.6
400	97.9	97.5	97.1	97.2	98.2	97.2	98.2	99.3
450	97.5	97.5	97.9	97.5	98.6	97.2	98.2	99.3
500	97.5	97.5	97.9	98.9	98.9	97.9	98.9	99.3

TABLE 16

FREEZE-THAW TEST RESULTS - DURABILITY FACTOR

	Independent Type II Cement							
	611 lbs/cy		660 lbs/cy		752 lbs/cy		800 lbs/cy	
	Batch 9	Batch 10	Batch 11	Batch 12	Batch 13	Batch 14	Batch 15	Batch 16
Number Of Cycles	Durability Factor							
50	98.6	97.2	97.2	99.3	100.0	100.0	100.0	99.3
100	93.7	98.6	95.0	96.5	98.6	99.3	98.6	100.0
150	98.6	98.6	96.4	97.2	97.9	99.3	99.3	100.0
200	98.6	98.6	97.9	97.2	97.9	100.0	99.3	98.6
250	99.3	99.3	97.2	97.2	98.6	100.0	100.0	100.0
300	99.3	97.9	100.7	97.2	99.3	100.0	100.7	99.3
350	100.0	99.3	99.3	97.2	97.9	100.0	100.0	99.3
400	100.7	99.3	98.6	97.9	97.2	99.3	100.0	99.3
450	98.6	97.2	97.2	96.5	97.2	99.3	100.0	97.9
500	99.3	97.2	98.6	97.2	97.2	98.6	98.6	100.7

TABLE 17

FREEZE-THAW TEST RESULTS - DURABILITY FACTOR

Number Of Cycles	Glens Falls Type II Cement 611 lbs/cy Batch 17	Glens Falls Type II Cement 800 lbs/cy Batch 18	Northeast Type II Cement 611 lbs/cy Batch 19	Northeast Type II Cement 800 lbs/cy Batch 20
	Durability Factor			
50	96.5	97.9	98.6	97.9
100	97.2	97.9	97.1	97.9
150	97.2	98.6	97.1	97.9
200	95.8	97.9	97.1	98.6
250	97.2	98.6	98.6	98.6
300	99.3	98.6	99.3	99.3
350	98.6	97.9	100.0	98.6
400	96.5	99.3	99.3	98.6
450	99.3	98.6	99.3	98.6
500	96.5	99.3	99.3	99.3

TABLE 18

FREEZE-THAW TEST RESULTS - PERCENT WEIGHT CHANGE

	Independent Type III Cement							
	611 lbs/cy		660 lbs/cy		752 lbs/cy		800 lbs/cy	
	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7	Batch 8
Number Of Cycles	Percent Weight Change							
50	-5.3	-3.0	-1.5	-2.1	-1.4	-0.6	-0.4	-0.9
100	-7.9	-5.2	-1.8	-2.5	-1.6	-0.3	+0.2	-0.5
150	-10.9	-8.4	-2.7	-3.4	-2.3	-0.4	+0.1	-1.0
200	-14.5	-11.6	-3.9	-4.5	-3.1	-1.0	-0.1	-1.4
250	-16.7	-13.3	-4.5	-5.1	-3.8	-1.3	-0.2	-1.8
300	-19.5	-16.0	-5.4	-6.1	-4.5	-1.8	-0.6	-2.4
350	-22.9	-19.0	-6.2	-6.9	-5.4	-2.1	-0.6	-2.6
400	-24.5	-21.1	-6.9	-7.3	-5.7	-2.4	-0.8	-3.2
450	-26.4	-23.0	-7.3	-7.9	-6.2	-2.7	-1.0	-3.4
500	-28.7	-26.2	-8.6	-9.0	-6.9	-3.2	-1.7	-4.1

TABLE 19

FREEZE-THAW TEST RESULTS - PERCENT WEIGHT CHANGE

	Independent Type II Cement							
	611 lbs/cy		660 lbs/cy		752 lbs/cy		800 lbs/cy	
	Batch 9	Batch 10	Batch 11	Batch 12	Batch 13	Batch 14	Batch 15	Batch 16
Number Of Cycles	Percent Weight Change							
50	-1.7	-2.2	-0.7	-0.3	-0.1	-0.1	+0.1	-0.4
100	-3.2	-3.8	-1.4	-0.5	0	0	+0.1	-0.6
150	-3.9	-5.7	-2.3	-1.0	-0.4	-0.2	0	-0.7
200	-5.1	-6.7	-2.9	-1.5	-0.6	-0.2	-0.1	-1.0
250	-5.9	-7.8	-3.3	-1.9	-0.8	-0.2	-0.2	-1.6
300	-7.4	-9.5	-4.3	-2.5	-1.3	-0.4	-0.6	-1.9
350	-8.9	-11.2	-5.3	-3.5	-2.2	-0.6	-1.0	-2.3
400	-10.2	-12.3	-5.8	-4.1	-2.7	-0.9	-1.4	-2.7
450	-11.2	-13.3	-6.9	-4.9	-2.7	-1.0	-1.6	-2.9
500	-11.8	-14.0	-7.2	-5.3	-3.7	-1.4	-2.2	-3.5

TABLE 20

FREEZE-THAW TEST RESULTS - PERCENT WEIGHT CHANGE

	Glens Falls Type II Cement		Northeast Type II Cement	
	611 lbs/cy Batch 17	800 lbs/cy Batch 18	611 lbs/cy Batch 19	800 lbs/cy Batch 20
Number Of Cycles	Percent Weight Change			
50	-2.2	-0.3	-2.3	-0.1
100	-3.4	-0.4	-4.1	-0.5
150	-4.9	-0.9	-5.3	-0.7
200	-5.6	-1.3	-6.3	-1.1
250	-6.7	-1.7	-7.4	-1.5
300	-7.5	-2.1	-8.8	-1.8
350	-9.3	-2.9	-10.3	-2.5
400	-10.2	-3.2	-11.3	-2.8
450	-10.8	-3.5	-12.1	-3.0
500	-12.0	-4.0	-13.2	-3.8

SUMMARY & CONCLUSIONS

1. Although workability appeared equal and slump tests indicated similar consistency, water cement ratios of concrete mixed with Type II cement averaged 0.06 less than those of concrete mixed with equal quantities of Type III cement.

The higher water quantities needed to impart the same workability were likely due to the high fineness of the Type III cement [1]. The specific surface of the Independent Type III cement was 5,440 sq. cm. per gram compared to 3,423 sq. cm. per gram for the Independent Type II cement, indicating nearly 60 percent more cement surface area per unit weight.

2. With the exception of Batch No. 1 (611 lbs./cy of Type III cement), the 28 day compressive strength of standard cured specimens exceeded the 6,500 psi target strength.

All concrete specimens cured under standard conditions for 56 days and 90 days attained compressive strengths in excess of 7,000 psi and 7,500 psi, respectively.

Based on building code requirements outlined by ACI, when sufficient test results are not available, i.e. less than 15, required average compressive strength should be 1,400 psi greater than f'c (specified compressive strength of concrete, psi) [2].

Results obtained in this evaluation indicate use of design values of 6,500 psi would require more trial batches to establish a greater population of test results as no single break exceeded 7,900 psi @ 28 days. If live loading could be limited prior to 56 days, a design value of 6,000 psi could be permitted based on compressive strengths of standard cured specimens molded from concrete mixed with 752 lbs. of cement per cubic yard which averaged 7,938 psi and 7,739 psi @ 56 days using Type II and Type III cements respectively.

Without further testing the specified 28 day design compressive strengths should be limited to 5,500 psi for prestressed concrete structures requiring greater compressive strengths than the 5,000 psi presently being used in Agency design work. Breaks in excess of 6,900 psi @ 28 days were attained with cement contents of 752 lbs. per cubic yard and 800 lbs. per cubic yard using both Type II and Type III cements.

3. Accelerated curing had a greater effect on the development of early strength of concrete containing Type III cement than on the early strength of concrete containing Type II cement.

Compressive strength following 3 days of accelerated curing averaged 275 psi higher for concrete containing Type III cement compared to concrete mixed with Independent Type II cement.

4. Following completion of accelerated curing at 3 days, the compressive strength of cylinders stored in air increased for a short period of time. Beyond 7 days, strength gain was minimal due to the drying of specimens resulting in no moisture available for continued hydration of cement [3]. The cylinders placed in moist curing after 3 days of accelerated curing, showed a more gradual, but consistent increase in compressive strength.

5. Results of sonic testing on freeze-thaw specimens failed to establish meaningful differences in the various concretes. The results obtained by weight change measurements; however, were more conclusive.

Weight loss decreased as cement contents increased and water cement ratios decreased.

Except for Batches No. 1 and No. 2 with air contents of 3.4% and 3.8% respectively, the durability of concrete mixed with Type II and Type III cements was approximately equal at any given cement content. Batches No. 1 and No. 2 with Type III cement had weight losses of 28.7% and 26.2%, respectively, after 500 cycles of freezing and thawing. The remaining 4 batches with 611 lbs. per cubic yard contained the three brands of Type II cement and had air contents ranging from 5.5% to 6.5% with weight losses between 11.8% and 14.0% after 500 freeze-thaw cycles. Batches of concrete containing 800 lbs. per cubic yard had air contents between 4.7% and 7.6% and weight losses which ranged from 1.7% to 4.1% after 500 cycles of freezing and thawing.

6. As cement contents increased, so did the quantity of air-entraining agent required to maintain an equal percentage of air in the concrete. Air-entrainment admixture dosages increased up to 200% over the full range of cement contents, due primarily to the loss in efficiency of the air-entraining agent as total cement per unit volume of concrete increased [4].

The proportion of air-entraining admixture required to generate equivalent air contents in concrete with Type III cement was 50% to 150% greater than in concrete with equal quantities of Type II cement as a result of the increased fineness of the Type III cement [4, 5].

RECOMMENDATIONS

Until sufficient test data has been gathered to justify greater design strengths, this Report recommends that the Agency limit 28 day design compressive strengths to 5,500 psi for prestressed concrete structures. This design value should be considered where strengths in excess of the 5,000 psi value presently in use are required.

Once a facility has established a field record of 30 or more consecutive breaks with an average compressive strength greater than 6,700 psi and a standard deviation of less than 500 psi using similar materials, the design compressive strength could be increased to 6,000 psi @ 28 days for future structures.

REFERENCES

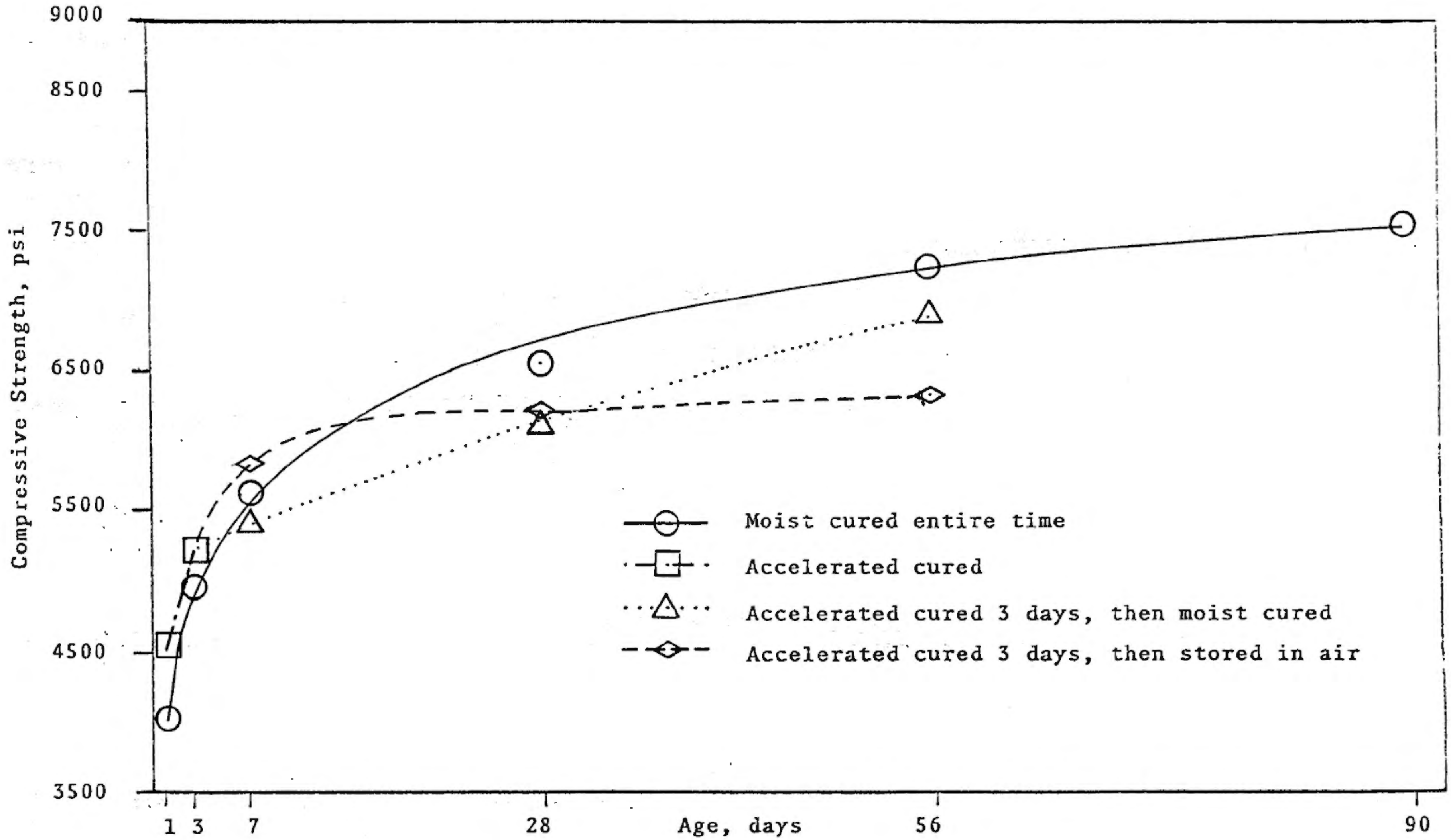
[1] Neville, A.M., Properties Of Concrete, Pitman, London, England, 3rd Edition, 1981, p. 20.

[2] ACI Committee 318, "Building Code Requirements For Reinforced Concrete (ACI 318-83)", American Concrete Institute, 1983, pp. 318. 14-15.

[3] Waddell, Joseph J., Concrete Construction Handbook, McGraw-Hill, 1968, p. 29-1.

[4] Whiting, D. and Stark, D., Transportation Research Board, National Cooperative Highway Research Program Report 258, "Control Of Air Content In Concrete", Washington, D.C., May 1983.

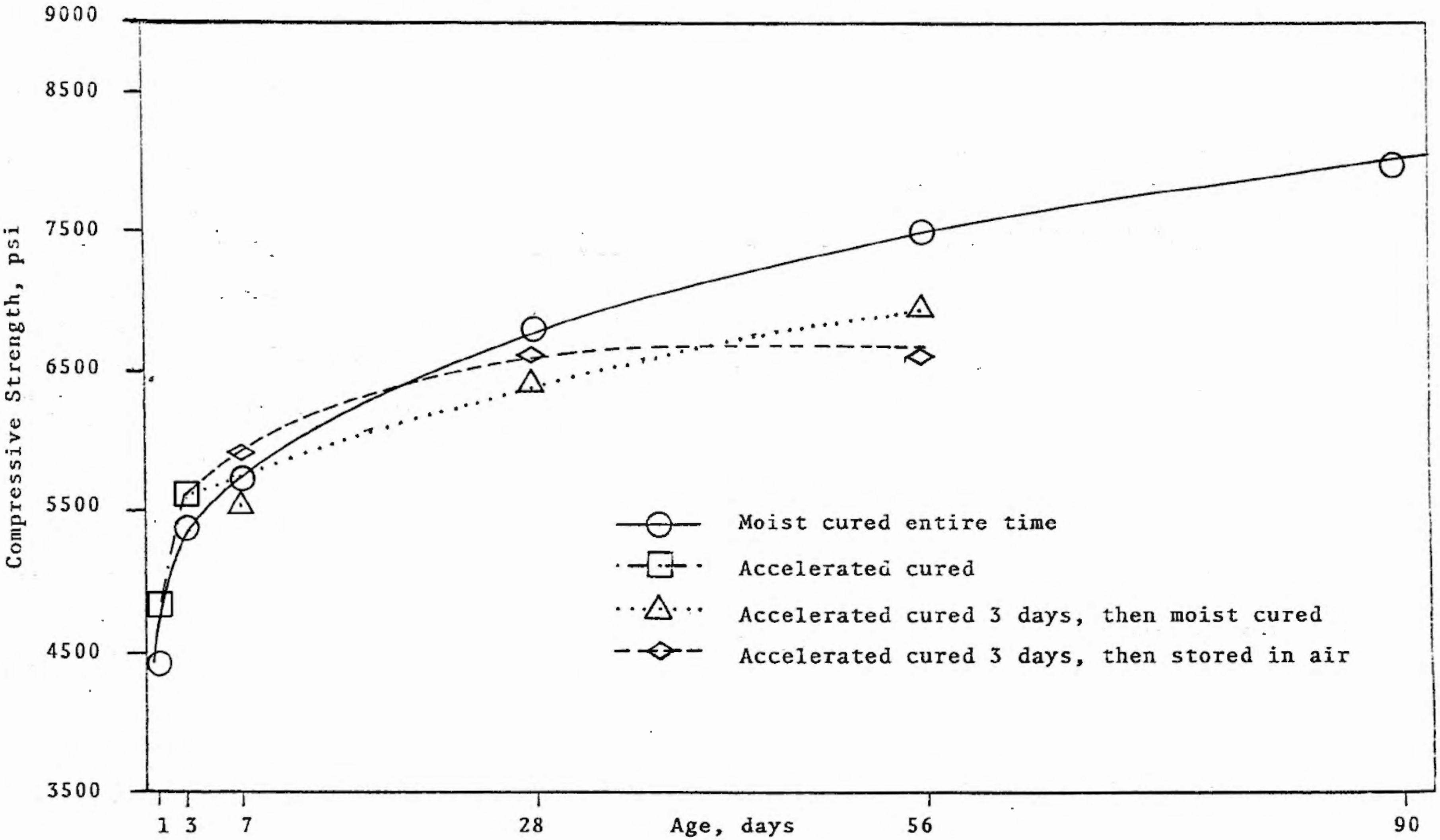
[5] "Design And Control Of Concrete Mixtures", Portland Cement Association, Skokie, Illinois, 1979, p. 45.



AVERAGE COMPRESSIVE STRENGTH VS. AGE

611 lbs/cy INDEPENDENT TYPE III CEMENT

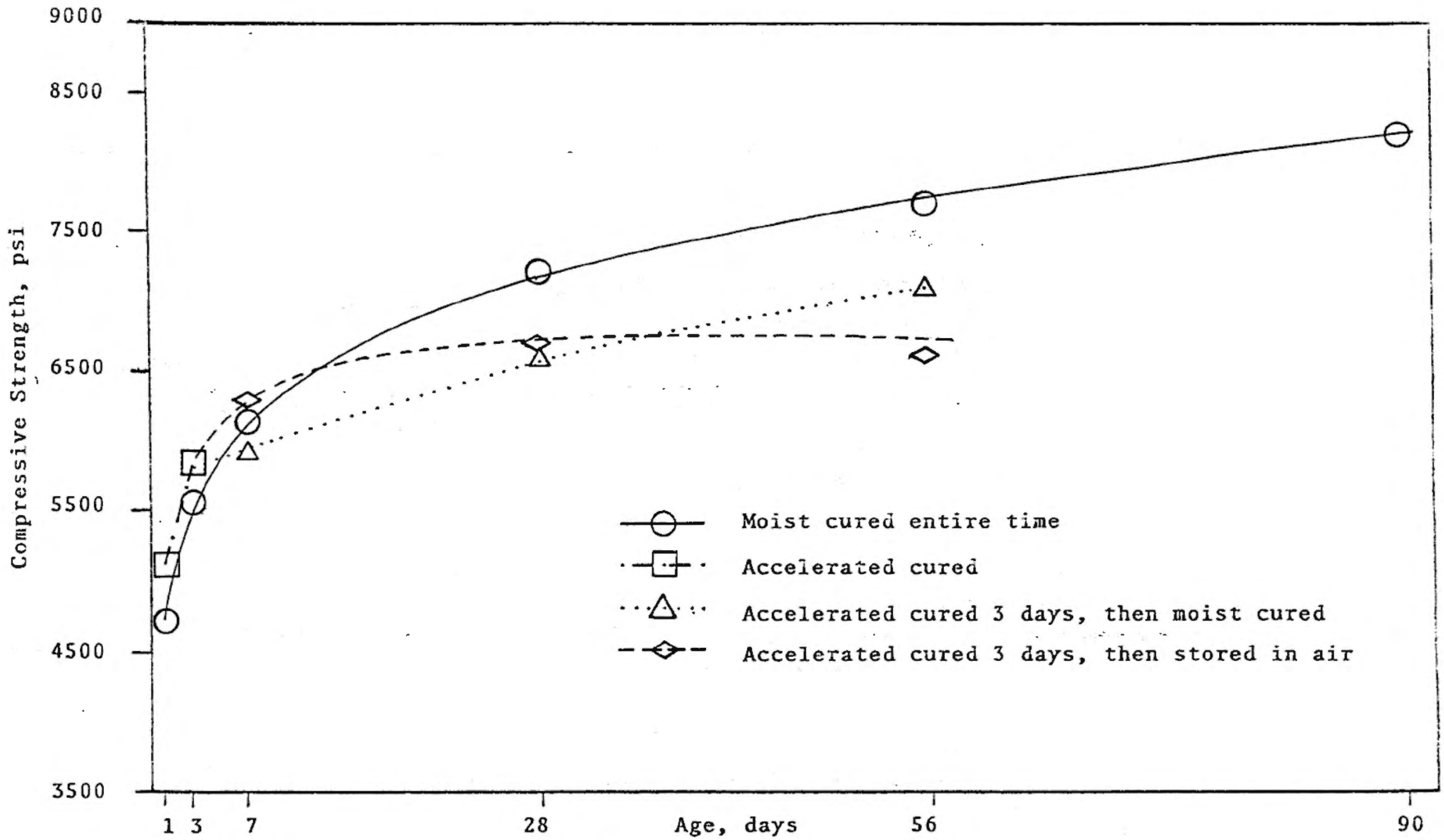
FIGURE I



AVERAGE COMPRESSIVE STRENGTH VS. AGE

660 lbs/cy INDEPENDENT TYPE III CEMENT

FIGURE II

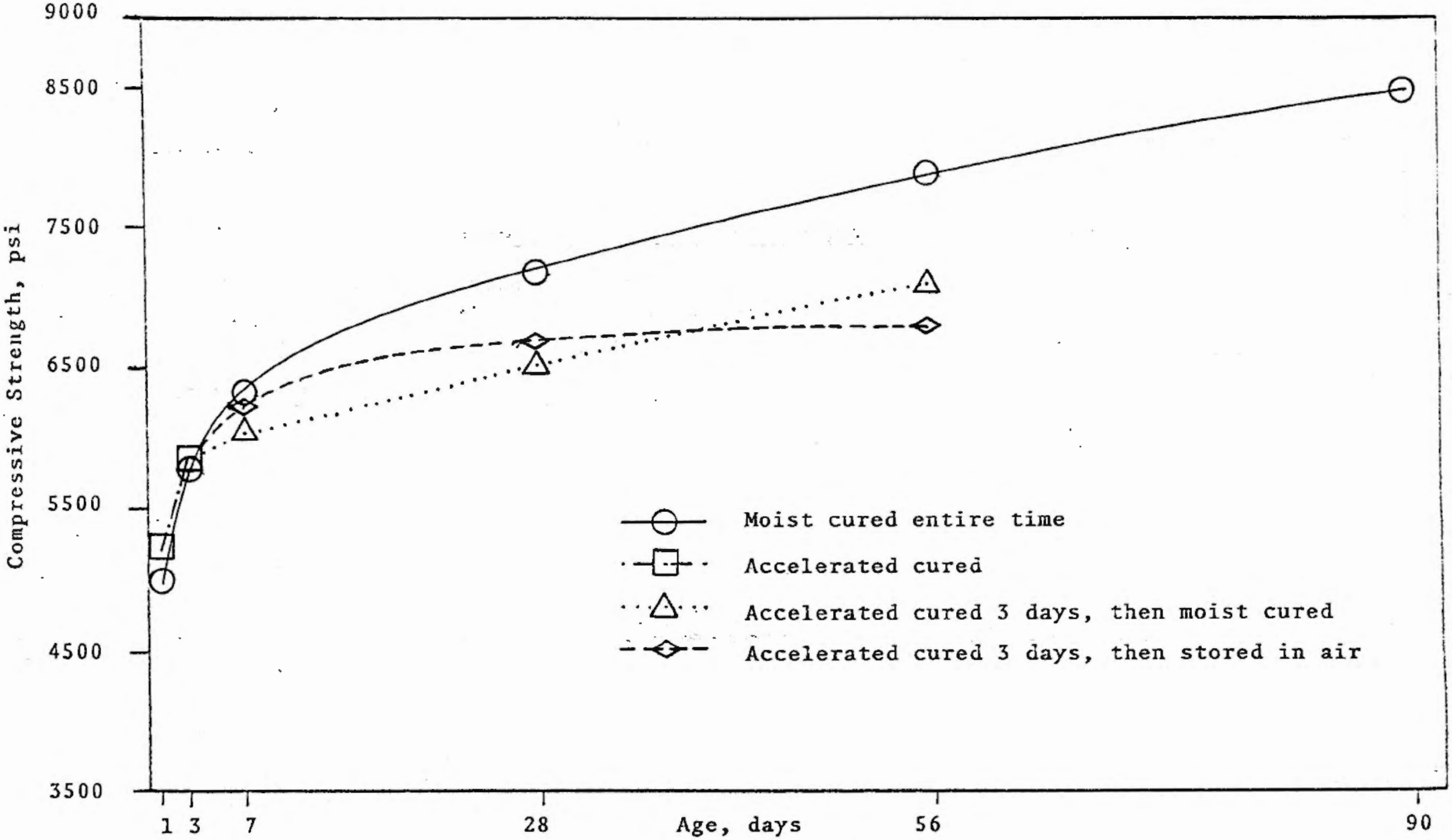


AVERAGE COMPRESSIVE STRENGTH VS. AGE

752 lbs/cy INDEPENDENT TYPE III CEMENT

FIGURE III

Appendix A



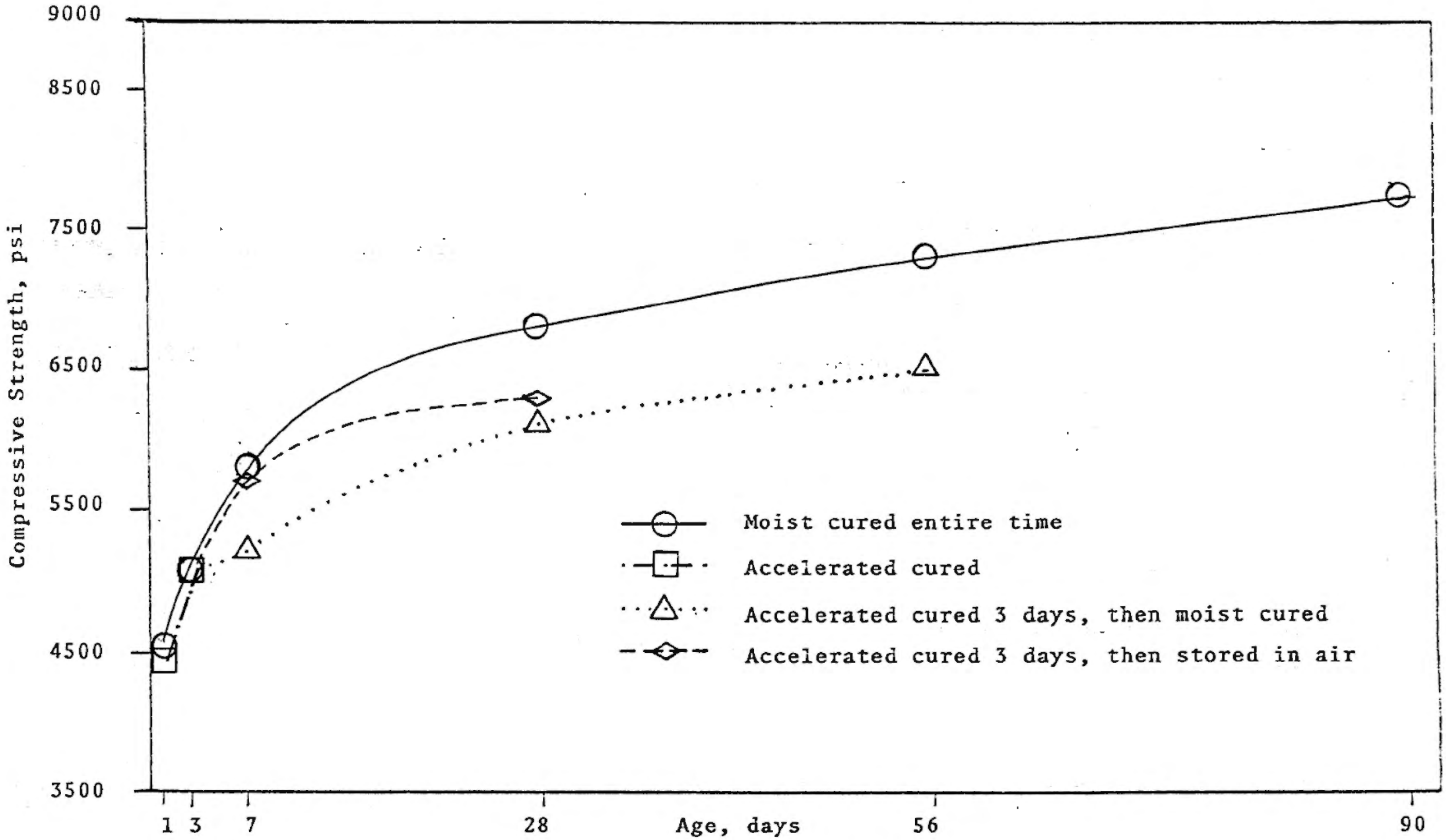
AVERAGE COMPRESSIVE STRENGTH VS. AGE

800 lbs/cy INDEPENDENT TYPE III CEMENT

FIGURE IV

(35)

Appendix A



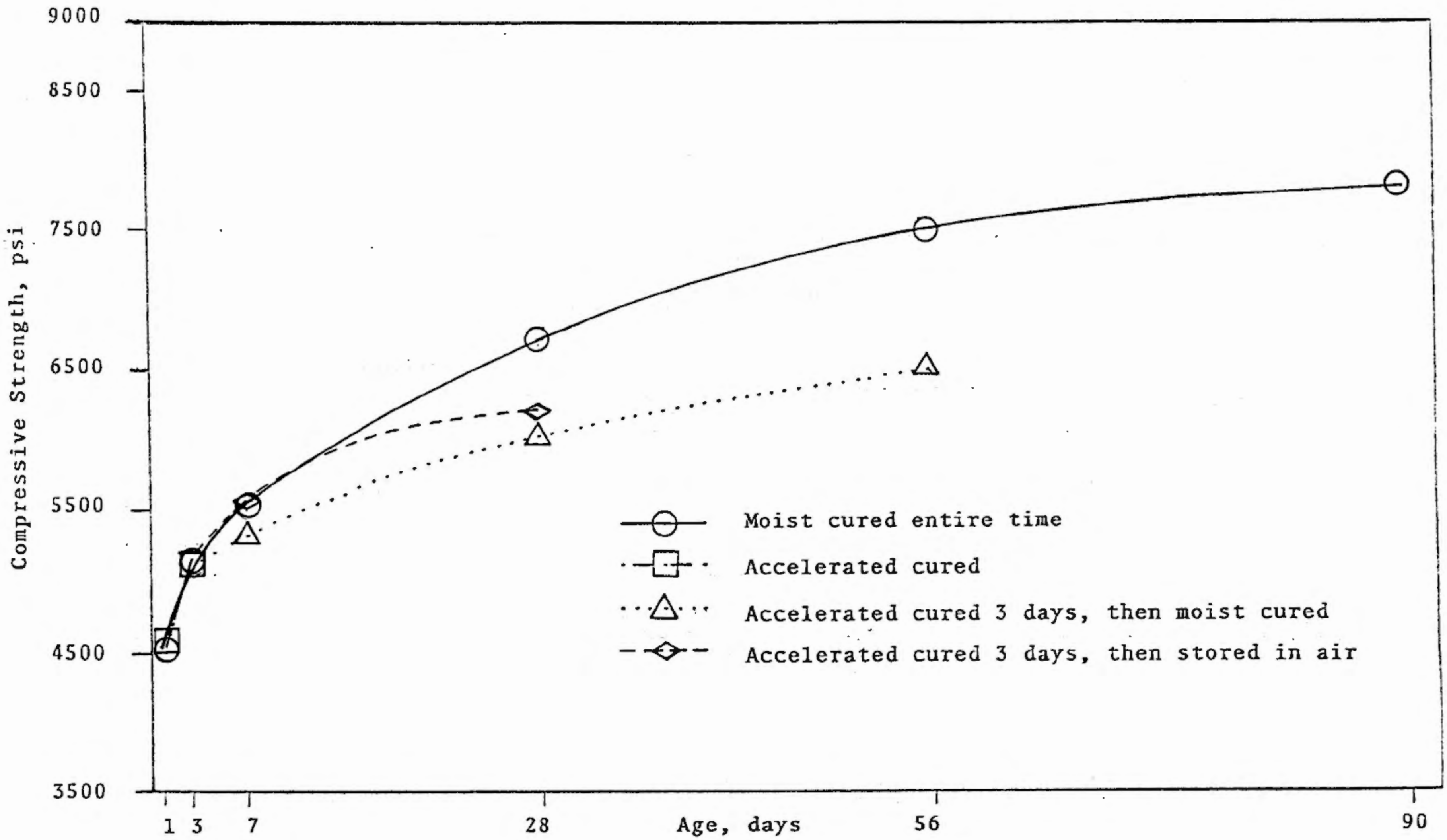
AVERAGE COMPRESSIVE STRENGTH VS. AGE

611 lbs/cy INDEPENDENT TYPE II CEMENT

FIGURE V

(3.6)

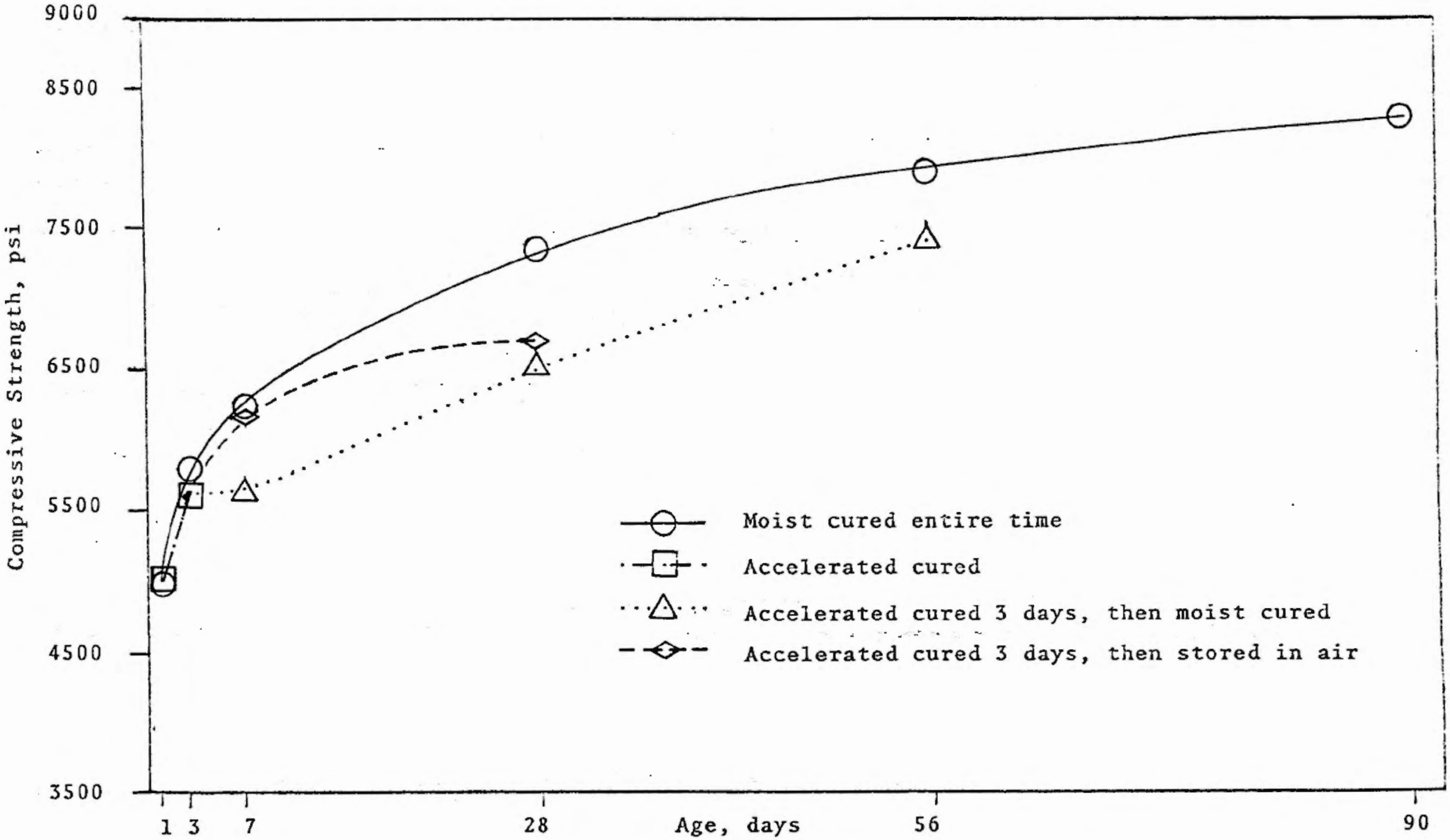
Appendix A



AVERAGE COMPRESSIVE STRENGTH VS. AGE

660 lbs/cy INDEPENDENT TYPE II CEMENT

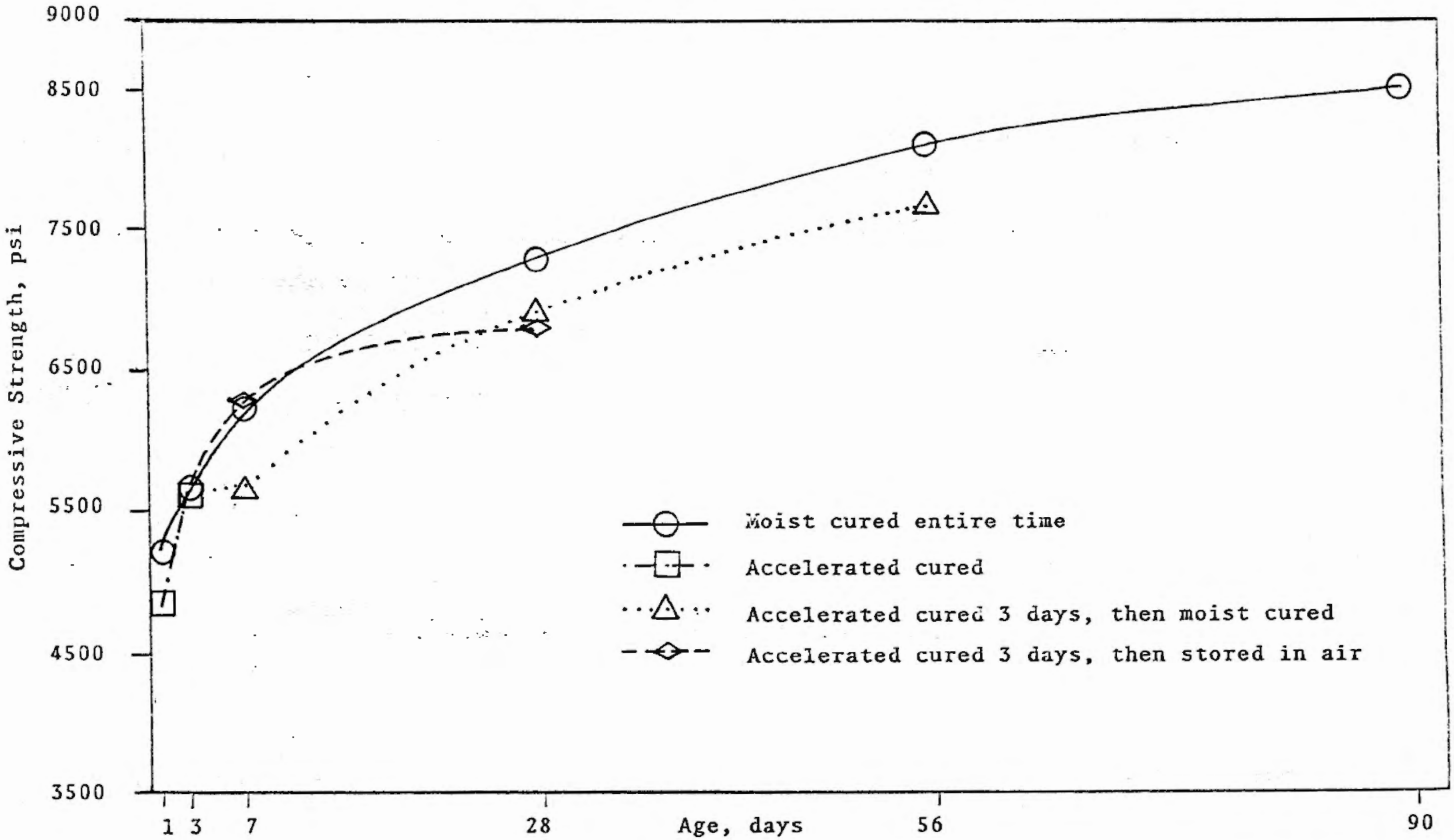
FIGURE VI



AVERAGE COMPRESSIVE STRENGTH VS. AGE

752 lbs/cy INDEPENDENT TYPE II CEMENT

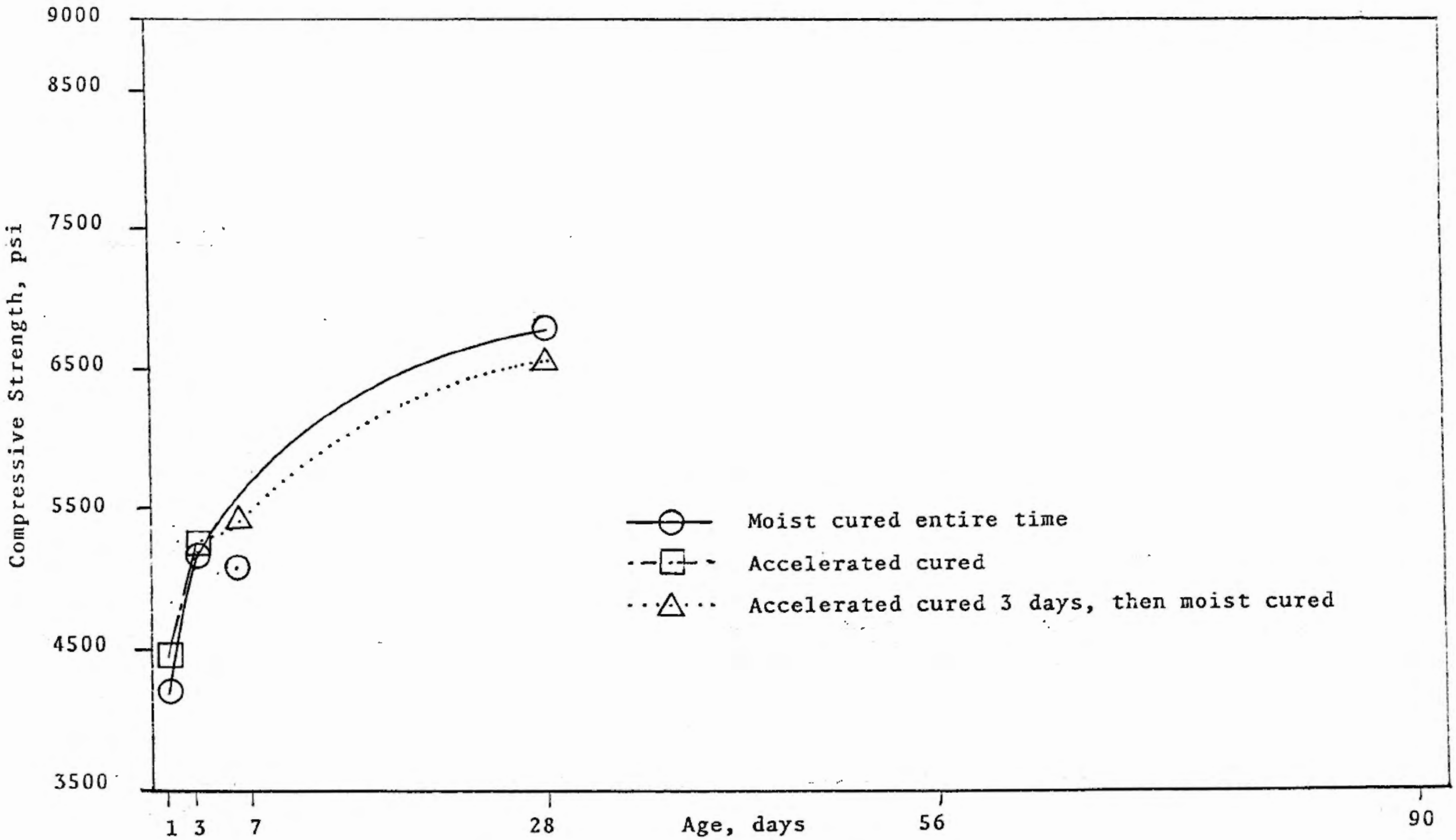
FIGURE VII



AVERAGE COMPRESSIVE STRENGTH VS. AGE

800 lbs/cy INDEPENDENT TYPE II CEMENT

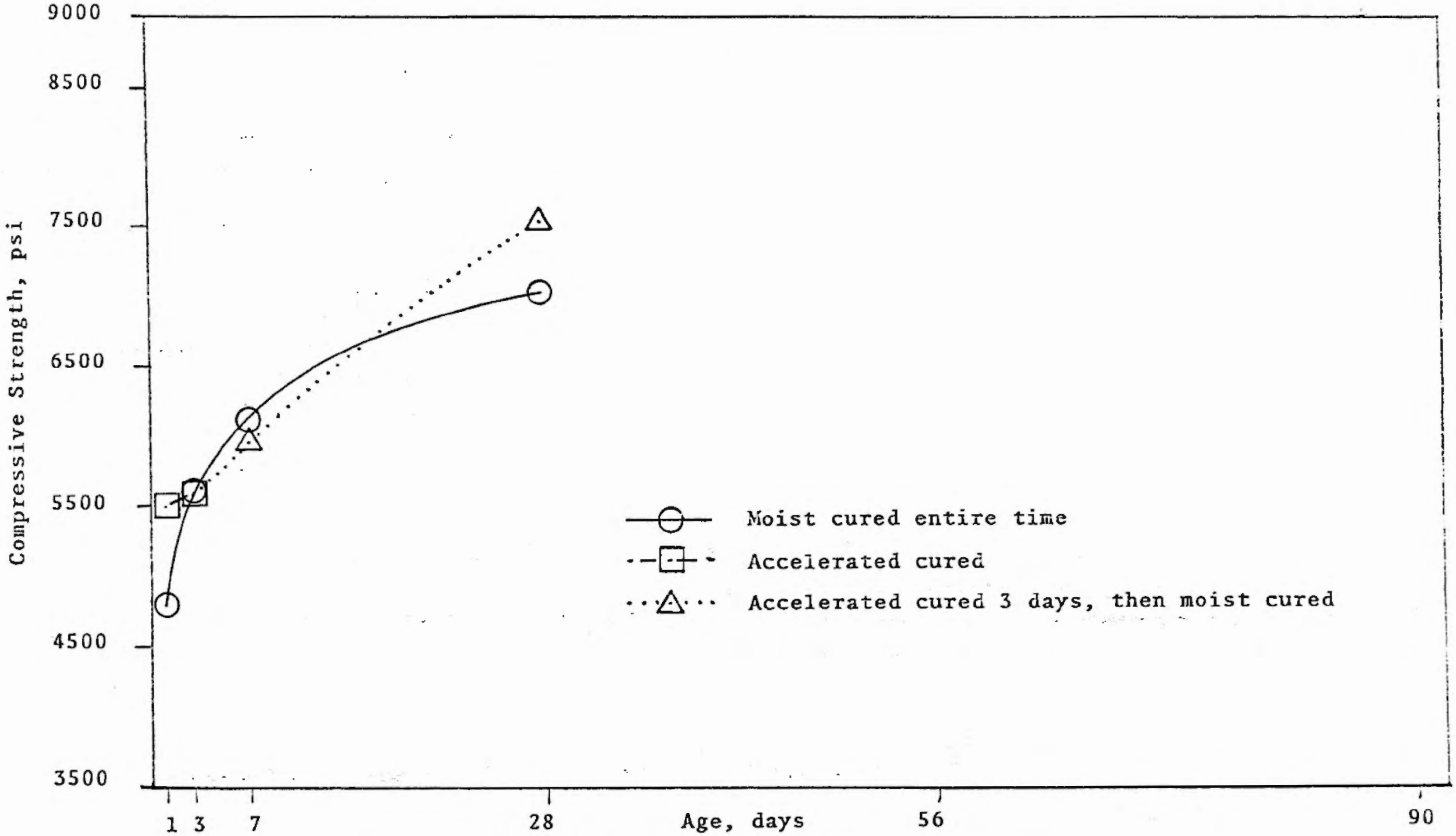
FIGURE VIII



AVERAGE COMPRESSIVE STRENGTH VS. AGE

611 lbs/cy GLENS FALLS TYPE II CEMENT

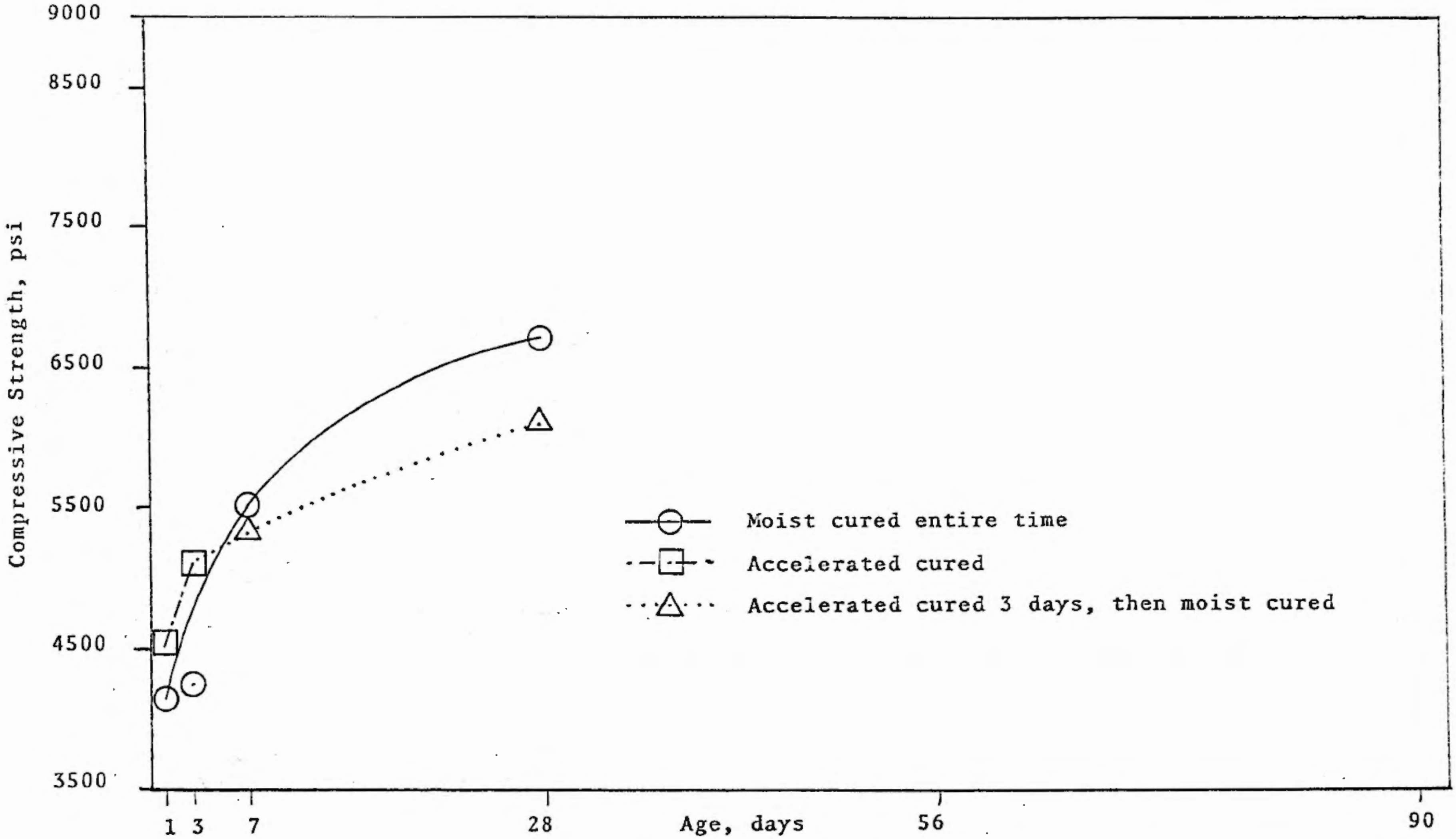
FIGURE IX



AVERAGE COMPRESSIVE STRENGTH VS. AGE

800 lbs/cy GLENS FALLS TYPE II CEMENT

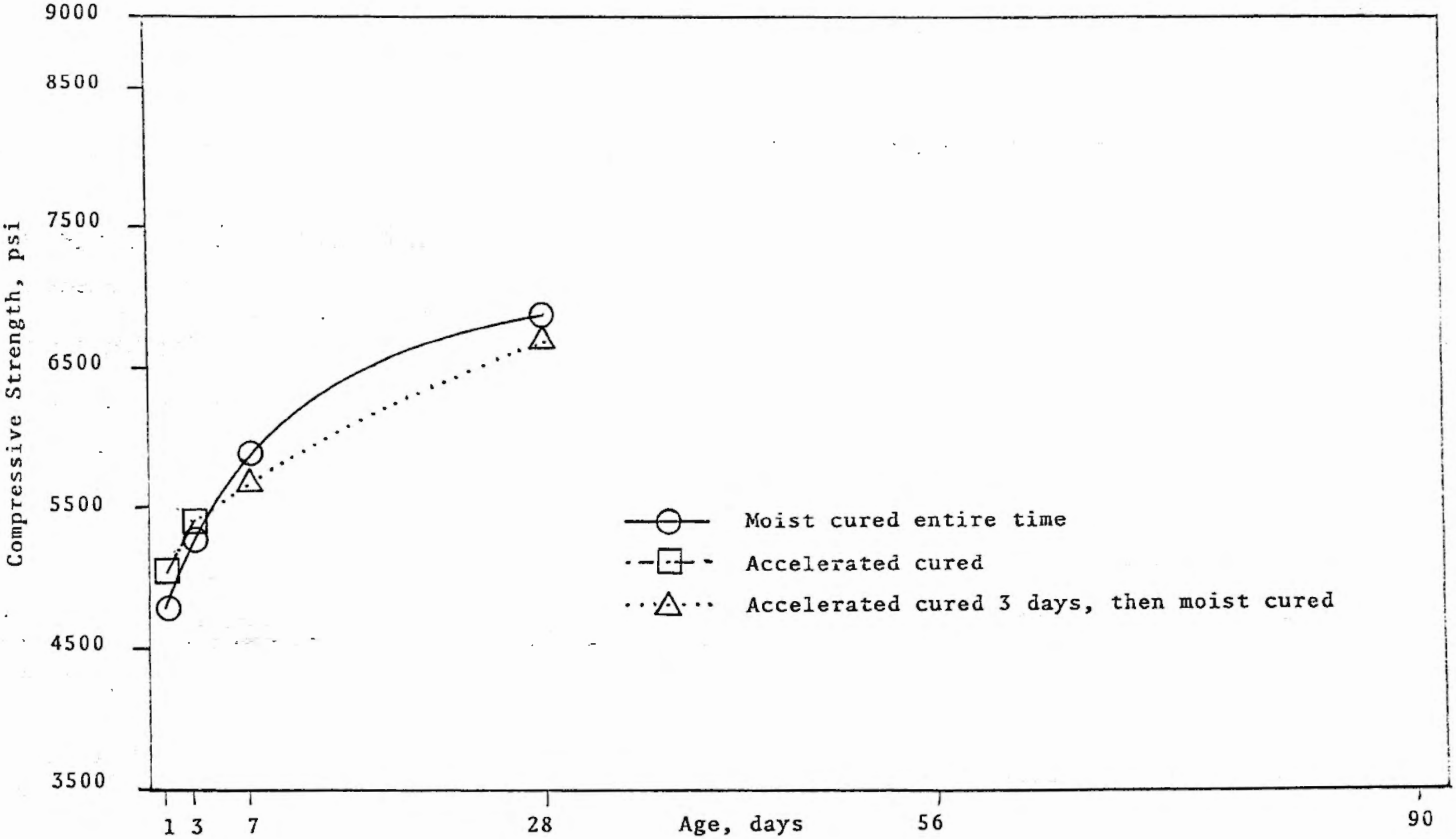
FIGURE X



AVERAGE COMPRESSIVE STRENGTH VS. AGE

611 lbs/cy NORTHEAST TYPE II CEMENT

FIGURE XI



AVERAGE COMPRESSIVE STRENGTH VS. AGE

800 lbs/cy NORTHEAST TYPE II CEMENT

FIGURE XII

Appendix B

TA 565 Rev. 4/79

Prepared By: C. C. Benda
Date: 1-17-85
Sheet 1 of

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH DIVISION

RESEARCH INVESTIGATION

Work Plan No. 85-C-1

Subject An evaluation of High Strength Concrete

Investigation Requested By Structural Concrete Engineer Date 1-17-85

Date Information Required ASAP

Purpose of Investigation The intent of this study is to determine the feasibility of producing high strength, 6500 psi+, concrete from materials currently available in the northwest region of Vermont.

Proposed Tests or Evaluation Procedure Trial batches will be mixed with Type II and Type III cement contents varying from 611#/cy to 800#/cy and aggregate from the Swanton-Highgate area. For each set of proportions selected, two batches will be mixed and tested. Materials meeting Vt. A.O.T. specifications for prestressed concrete members will be incorporated into all mixes.

Fresh concrete tests will include air content, unit weight, and slump. 4"x8" concrete cylinders will be molded for compressive strength testing at 1, 3, 7, and 28 days and one 3"x3"x16" beam will be fabricated from each batch for exposure to freeze-thaw durability testing.

Examination will include standard as well as accelerated curing and inclusion of high range water reducer into the mix to lower water cement ratios.

Proposal Discussed With D. Brown, N. Danforth Projected Manpower Requirements 30 man days

Investigation To Be Conducted By Structural Concrete Subdivision

Proposed Starting Date 1-21-85 Estimated Completion Date 3-22-85 W/O F-T data, 6/22/85 W/F-T data

Approval/Disapproval by Materials & Research Engineer R. F. Nicholson 01-21-85

Comments by Materials & Research Engineer

Materials & Research Division
Agency of Transportation
Date Typed: 1/21/85