Evaluation of Fly Ash
in
Lean Portland Cement Concrete Base

"Econocrete"

Project No. MLR-85-3
& MLR-86-1

Highway Division
August 1986

Iowa Department
of Transportation

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Abstract

Fly ash was used in this evaluation study to replace 30, 50 and 70 percent of the 400 lbs. of cement currently used in each cu. yd. of portland cement econocrete base paving mix.

Two Class "C" ashes and one Class "F" ash from Iowa approved sources were examined in each mix. When Class "C" ashes were used, they were substituted on the basis of 1.0 pound for each pound of cement removed. When Class "F" ash was used, it was substituted on the basis of 1.25 pounds of ash for each pound of cement removed.

Compressive strengths with and without fly ash were determined at 7, 28 and 56 days of age. In most cases, strengths were adequate.

The freeze/thaw durability of the econocrete mixes studied was not adversely affected by the presence of fly ash.

The tests along with erodibility and absorption tests have demonstrated the feasibility of producing econocrete with satisfactory mechanical properties even when relatively low quality and/or locally available aggregate is being used at no sacrifice to strength and/or durability.

Introduction

Econocrete is portland cement concrete designed for specific strength levels and for specific application and environment. Econocrete is made from locally available, commercially produced aggregates not necessarily meeting conventional quality standards for aggregates used in pavements.

Objective

Sufficient data does not presently exist which establishes the effects of Iowa's fly ashes on the physical properties of portland cement concrete base mixes. Additional study is needed to establish this relationship, particularly when such concrete contains fly ash and/or lower cement contents with water reducing admixtures.

The main objective of the econocrete study is to develop a more economical pavement structure thru judicious use of materials designed for specific applications and environments. A compelling reason for this study is two fold.

1. In these days of spiraling costs, every effort must be made to hold down costs. The use of fly ash as a substitute for a portion of the portland cement and the use of locally, low quality available aggregates in a major portion of the pavement structure can effect real savings. Every effort should be made to use new ideas and innovations in design, materials and construction techniques to hold down prices and maintain quality.

2. Many existing sources of good quality coarse aggregates are becoming depleted or becoming unavailable because of economic reasons such as hauling, restrictive zoning, pollution control and rising land values. Large quantities of aggregates have been discarded or rejected for use in the present or in the past due to restrictive specification requirements or other reasons. Much of this material can and should be used. When these aggregates are restricted to lower depth in the composite structure, their former defects become acceptable.

In summary, the purpose of using econocrete in subbases is to provide a uniform, stable and permanent support for concrete pavement. Other functions of econocrete in subbases are to reduce or eliminate joint faulting, increase the subgrade support (K), prevent pumping of fine grained soils and provide a working platform for construction equipment.

Scope

This study examines the effect on compressive strength, durability, erodibility and absorption from the substitution of fly ash for cement or reducing the cement contents in the econocrete class mix.

The econocrete mix has a cement factor of 400 pounds per cubic yard and was studied in combination with three fly ashes currently used in Iowa.

The fly ashes studied conformed to ASTM C-618 "Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete".

One fly ash was a Class "F" and the other two were Class "C". Of the two Class "C" fly ashes used, one was considered to be reactive ash in terms of setting time and heat of hydration when the pure ash is mixed with water. The other Class "C" fly ash would be considered less reactive in this regard.

The water reducing admixture used in this study is WRDA with HyCol, which is an aqueous solution of complex organic compounds.

Laboratory Procedures

A. Materials

The following materials were used in this study:

1. Portland Cement: Type I, the standard laboratory blend of the mine portland cements sources commonly available in Iowa, was used to prepare the concrete specimens, Lab. No. R-11-Z-85

2. Water: City of Ames.

3. Air Entraining Agent: Neutralized vinsol resin Carter-Waters single strength, Lab. No. ACA5-7

4. Water Reducing Admixtures: WRDA with HyCol, W. R. Grace and Co. Dosage rate 3 fl. oz./100 lbs. of cement, Lab. No. ACI6-28

5. Coarse Aggregate (Strength testing): Glory Quarry, Black Hawk County, Lab. No. AAR5-0040

Coarse Aggregate (Durability & strength testing): Earlham Quarry, Madison County, Lab. No. AAR6-5

6. Fine Aggregate (Strength testing): Waterloo sand, Black Hawk County, Lab. No. AAS5-0005

   Fine Aggregate (Durability & strength testing): Des Moines River sand, Polk County, Lab. No. AAS6-0003

7. Fly Ash: Three fly ash sources were sampled for inclusion in the evaluation study:

   Lansing Ash, Lansing, Iowa, Reactive Class "C" ash (self cementing) Lab. No. ACF5-4

   Ottumwa Ash, Ottumwa, Iowa, mildly reactive Class "C" ash (self cementing) Lab. No. ACF5-2, ACF6-3

   Clinton Ash, Clinton, Iowa, Class "F" ash (noncementing) Lab. No. ACF4-101

B. Mixes

Econocrete mixes for project MLR-85-3 were prepared for strength only as follows:

Mix No.	Description
1	Econocrete (400 lb. cement) with water reducer
2	Econocrete (250 lb. cement) with 150 lb. ash - Lansing & W.R.
3	Econocrete (250 lb. cement) with 150 lb. ash - Ottumwa & W.R.
4	Econocrete (250 lb. cement) with 150 lb. ash - Clinton & W.R.
5	Econocrete (300 lb. cement) with water reducer
6	Econocrete (200 lb. cement) with 100 lb. ash - Lansing & W.R.
7	Econocrete (200 lb. cement) with 100 lb. ash - Ottumwa & W.R.
8	Econocrete (200 lb. cement) with 100 lb. ash - Clinton & W.R.
9	Econocrete (300 lb. cement) with water reducer
10	Econocrete (150 lb. cement) with 150 lb. ash - Lansing & W.R.
11	Econocrete (150 lb. cement) with 150 lb. ash - Ottumwa & W.R.
12	Econocrete (150 lb. cement) with 150 lb. ash - Clinton & W.R.

Econocrete mixes for project MLR-86-1 were prepared for strength, durability, erodibility and absorption as follows:

Mix No.	% Fly Ash	Description
1	0	Econocrete (400 lb. cement) with water reducer, Glory Quarry stone, Waterloo-Cedar River sand & W.R.
2	30	Econocrete 280 lb. cement with 120 lb. Ottumwa ash, Glory Quarry stone, Waterloo-Cedar River sand & W.R.
3	50	Econocrete 200 lb. cement with 200 lb. Ottumwa ash, Glory Quarry stone, Waterloo-Cedar River sand & W.R.
4	70	Econocrete 120 lb. cement with 280 lb. Ottumwa ash, Glory Quarry stone, Waterloo-Cedar River sand & W.R.
5	0	Mix No. 1 with Earlham Quarry stone, Des Moines River sand & W.R.
6	30	Mix No. 2 with Earlham Quarry stone, Des Moines River sand & W.R.
7	50	Mix No. 3 with Earlham Quarry stone, Des Moines River sand & W.R.
8	70	Mix No. 4 with Earlham Quarry stone, Des Moines River sand & W.R.
9	0	Econocrete (300 lb. cement) with water reducer, Glory Quarry stone, Waterloo-Cedar River Sand & W.R.
10	30	Econocrete 210 lb. cement with 90 lb. Ottumwa ash, Glory Quarry stone, Waterloo-Cedar River sand & W.R.
11	50	Econocrete 150 lb. cement with 150 lb. Ottumwa ash, Glory Quarry stone, Waterloo-Cedar River sand & W.R.
12	70	Econocrete 90 lb. cement with 210 lb. Ottumwa ash, Glory Quarry stone, Waterloo-Cedar River sand & W.R.
13	0	Mix No. 9 with Earlham Quarry stone, Des Moines River sand & W.R.
14	30	Mix No. 10 with Earlham Quarry stone, Des Moines River sand & W.R.
15	50	Mix No. 11 with Earlham Quarry stone, Des Moines River sand & W.R.
16	70	Mix No. 12 with Earlham Quarry stone, Des Moines River sand & W.R.

C. Fly Ash Substitution Rates:

Fly ash was substituted for 30, 50 and 70%, by weight of the portland cement in all cases. The substitution of Class "C" fly ash was on a pound-for-pound basis. When Class "F" fly ash was substituted, it was on the basis of adding 1.25 pounds of fly ash for each pound of cement removed. The change in absolute volumes due to the fly ash substitution, was applied to each aggregate in its proper ratio. For the econocrete mix, in this evaluation study, the volumes are 60% coarse aggregate and 40% fine aggregate.

D. Aggregate Gradation:

The combined aggregate gradation was:

Sieve No.	% Passing
3/4"	100
1/2"	90
3/8"	77
No. 4	58
No. 8	48
No. 16	38
No. 30	27
No. 50	11
No. 100	5.7
No. 200	5.0

E. Econocrete Controls:

Econocrete mixes were controlled to a slump of 2.0" ± 1/2" and air content of 6.5% ± 0.5%.

F. Testing:

The investigation of the effects of aggregate and fly ash sources on econocrete strength and durability was accomplished by preparing test specimens in the laboratory. These specimens were made from an econocrete mixes with a cement content of 400 and 300 lb./yd.^{3}. The variables in the mixes were aggregate source, fly ash source, the substitution ratios (pounds of fly ash added for each pound of portland cement removed).

The actual procedure, as to preparation and mixing of the ingredients, was as outlined in ASTM C-192 1/ "Making and Curing Concrete Test Specimens in the Laboratory".

The testing of the compressive test specimens was done in accordance with Iowa Test Method 403 2/ "Method of Test for Compressive Strength of Molded Concrete Cylinders" (see Appendix A). This is a test similar to AASHTO test Procedure T-22 3/. Total of nine 4½"x9" horizontal cylinders were cast from each batch of econocrete. Three cylinders were tested in compression at each age of 7, 28 and 56 days. All specimens received standard moist room curing.

The determination of the durability factor of the econocrete containing the various ashes was done in accordance with Iowa Test Method 408A 2/ "Method of Test for Determining the Resistance of Concrete to Rapid Freezing and Thawing" (see Appendix B). This test is a modification of ASTM C-666 Procedure B 1/ in that the

4"x4" concrete beams are 18" in length rather than 11" to 16" and 90-day moist room cure is substituted for the 14-day lime water cure.

A total of three 4"x4"x18" beams were cast from each batch prepared for the durability testing. The beams were cured for 90 days in the moisture room.

Upon completion of the appropriate curing period, the beams were subjected to cyclic freezing and thawing. Periodic sonic modulus and change in length readings taken twice a week. This was continued until the beams had undergone 300 cycles of freezing and thawing or until the specimens' relative dynamic modulus of elasticity reached 60% of the initial modulus, whichever occurs first.

The coarse aggregates used in the econocrete currently are approved as Class A crushed stone, which is that specified for use in econocrete.

The erodibility testing of the econocrete was determined by the water pressure method. The specimens were subjected to 1500 psi water pressure from a spray nozzle situated 12 inches perpendicular from the face of a 4"x4"x18" beam. The stream of water pressure was spread on each beam for a period of 30 minutes, with a periodic measurements of the depth of erosion taken at 15 and 30 minute intervals.

The absorption test was accomplished by placing the test specimens in an oven to a constant weight and then they were placed in water at room temperature and soaked three days to full saturation.

Test Results and Interpretation

Compressive Strength & Durability

Table No. 1 shows the physical characteristics of the aggregate quality testing, while Table No. 2 & 3 show the econocrete mix characteristics and compressive strength test results. The strength values for various combinations of materials are graphically presented in Figure 1-7. Each strength value indicated is the average of three cylinders. In most cases, with few exceptions, the econocrete containing fly ash exhibited equivalent compressive strengths with the corresponding control econocrete mixes without the fly ash. The exceptions where the compressive strengths were somewhat lower were the 7, 28 and 56 days of the mixes containing the Class "F" ash from Clinton. In summary, acceptable and adequate econocrete strengths can be produced using either Class "C" or "F" ash provided the proper substitution ratio and percent replacement is used.

Table No. 4 itemized the freeze/thaw durability characteristics for the econocrete studied. Earlham, coarse aggregate and Des Moines River sand were used in the durability study. They were used with 400 lb. and 300 lb. cement per cubic yard. There was no significant dif-

ference in the frost resistance with exception to two cases of any of the econocrete studied. The results of the durability factors and the expansion in combination with the different percentages of ash along with the water reducing admixture used in this evaluation study are shown in Figures 15-16.

Table No. 5 shows the rate of absorption for various combination of the materials studied. In all cases with no exception, the econocrete containing higher percentages of fly ash exhibited lower absorption rate than the corresponding mixes.

Table No. 6, itemizes the erodibility characteristics for the econocrete mixes studied. Data obtained revealed that the erodibility of econocrete is related to the strength characteristics and basically to its cement content. Erodibility comparisons are also depicted graphically in Figures 17-20 to show the relative differences between the mixes.

Setting Time of Fly Ash Econocrete

Since Class "F" and "C" ashes have markedly different cementitious properties, and since the early strength gain of the econocrete is not as rapid as conventional concrete mixtures, the resultant effect on setting time has been a concern. Therefore, the strength level desired should be noted, adequate curing time should be specified and careful handling of test specimens is extremely important.

Table No. 1
Fly Ash in PCC Base Mixes
MLR-85-3 & MLR-86-1
Physical Characteristics

Aggregate Source	County	Aggregate Class	Freeze/Thaw Method A Loss %	Freeze/Thaw Method C Loss %	L.A. Abrasion Loss %	Absorption %	Specific Gravity
Earlham	Madison	A	21	8	30	3.2	2.587
Glory Quarry	Black Hawk	A	24	2	28	3.0	2.654

Table No. 2
Fly Ash in Portland Cement Concrete Base
MLR-85-3
Compressive Strength

Mix No.	Cement/Fly Ash Content lbs/yd³	Fly Ash Source	Fly Ash Class	Aggregate Source	Water Reducing Admixture	Slump (inches)	Air Content %	W/C Ratio		Compressive Strength PSI		
								Cement Only	Cement & Fly Ash	7-day	28-day	56-day
1	400 lb. cement	Control	---	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	7.0	0.759	---	2910	3520	3750
2	250 lb. cement 150 lb. fly ash	Lansing	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	6.9	1.157	0.722	2390	3580	4020
3	250 lb. cement 150 lb. fly ash	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	6.8	1.230	0.767	2200	3340	3580
4	250 lb. cement 188 lb. fly ash	Clinton	F	Glory Stone Cedar River Sand	WRDA/HyCol	2.5	7.0	1.075	0.671	1420	2280	2830
5	300 lb cement	Control	---	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	6.8	1.081	-----	1470	1840	1920
6	200 lb. cement 100 lb. fly ash	Lansing	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	7.0	1.622	1.081	1140	1630	1910
7	200 lb. cement 100 lb. fly ash	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	6.9	1.473	0.982	1190	1820	2080
8	200 lb. cement 125 lb. fly ash	Clinton	F	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	7.0	1.486	0.991	800	1330	1630
9	300 lb. cement	Control	---	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	7.0	1.050	----	1520	1880	2070
10	150 lb. cement 150 lb. fly ash	Lansing	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	6.9	1.982	0.991	900	1550	1810
11	150 lb. cement 150 lb. fly ash	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.25	7.2	1.803	0.902	920	1580	1940
12	150 lb. cement 188 lb. fly ash	Clinton	F	Glory Stone Cedar River Sand	WRDA/HyCol	2.0	6.9	1.982	0.992	420	860	1110

Table No. 3
Fly Ash in Portland Cement Concrete Base
MLR-86-1
Compressive Strength

Mix No.	Cement/Fly Ash Content lbs/yd³	Fly Ash Source	Fly Ash Class & Percent	Aggregate Source	Water Reducing Admixture	Slump (inches)	Air Content %	W/C Ratio		Compressive Strength PSI		
								Cement Only	Cement & Fly Ash	7-day	28-day	56-day
1	400 lb. cement	---	--- 0 %	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.6	0.835	---	2640	3200	3350
2	280 lb. cement 120 lb. fly ash	Ottumwa	C 30%	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.0	1.120	0.785	2240	3190	3780
3	200 lb. cement 200 lb. fly ash	Ottumwa	C 50%	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.0	1.487	0.744	1810	2940	3460
4	120 lb. cement 280 lb. fly ash	Ottumwa	C 70%	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.0	2.394	0.717	910	1410	1940
5	400 lb cement	---	--- 0%	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.1	0.890	-----	2090	2570	2870
6	280 lb. cement 120 lb. fly ash	Ottumwa	C 30%	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.0	1.199	0.840	1830	2510	3010
7	200 lb. cement 200 lb. fly ash	Ottumwa	C 50%	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	1.588	0.794	1370	2160	2440
8	120 lb. cement 280 lb. fly ash	Ottumwa	C 70%	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.25	6.3	2.620	0.785	720	1060	1220
9	300 lb. cement	---	--- 0%	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.7	1.101	----	1430	1810	2010
10	210 lb. cement 90 lb. fly ash	Ottumwa	C 30%	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.6	1.524	1.068	1070	1750	2070
11	150 lb. cement 150 lb. fly ash	Ottumwa	C 50%	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.5	2.000	1.000	820	1710	1900
12	90 lb. cement 210 lb. fly ash	Ottumwa	C 70%	Glory Stone Cedar River Sand	WRDA/HyCol	2.25	6.5	3.264	0.977	450	740	1030
13	300 lb. cement	---	--- 0%	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.2	1.258	----	1080	1380	1410
14	210 lb. cement 90 lb. fly ash	Ottumwa	C 30%	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	1.702	1.192	880	1270	1370
15	150 lb. cement 150 lb. fly ash	Ottumwa	C 50%	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	2.191	1.096	670	1010	1160
16	90 lb. cement 210 lb. fly ash	Ottumwa	C 70%	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.25	6.8	3.585	1.073	320	480	570

Table No. 4
Fly Ash in Portland Cement Concrete Base
MLR-86-1
Durability & Expansion

Mix No.	Cement/Fly Ash Content lbs/yd^3	Fly Ash %	Fly Ash Source	Fly Ash Class	Aggregate Source	Water Reducing Admixture	Slump (inches)	Air Content %	W/C Ratio Cement Only	W/C Ratio Cement & Fly Ash	Durability Factor	Expansion %
5	400 lb cement	0	---	---	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.1	0.890	-----	62	0.099
6	280 lb. cement 120 lb. fly ash	30	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.0	1.199	0.840	58	0.090
7	200 lb. cement 200 lb. fly ash	50	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	1.588	0.794	62	0.121
8	120 lb. cement 280 lb. fly ash	70	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.25	6.3	2.620	0.785	92	0.017
13	300 lb. cement	0	---	---	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.2	1.258	----	80	0.043
14	210 lb. cement 90 lb. fly ash	30	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	1.702	1.192	67	0.083
15	150 lb. cement 150 lb. fly ash	50	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	2.191	1.096	77	0.053
16	90 lb. cement 210 lb. fly ash	70	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.25	6.8	3.585	1.073	89	0.013

Table No. 5
Fly Ash in Portland Cement Concrete Base
MLR-86-1
Absorption

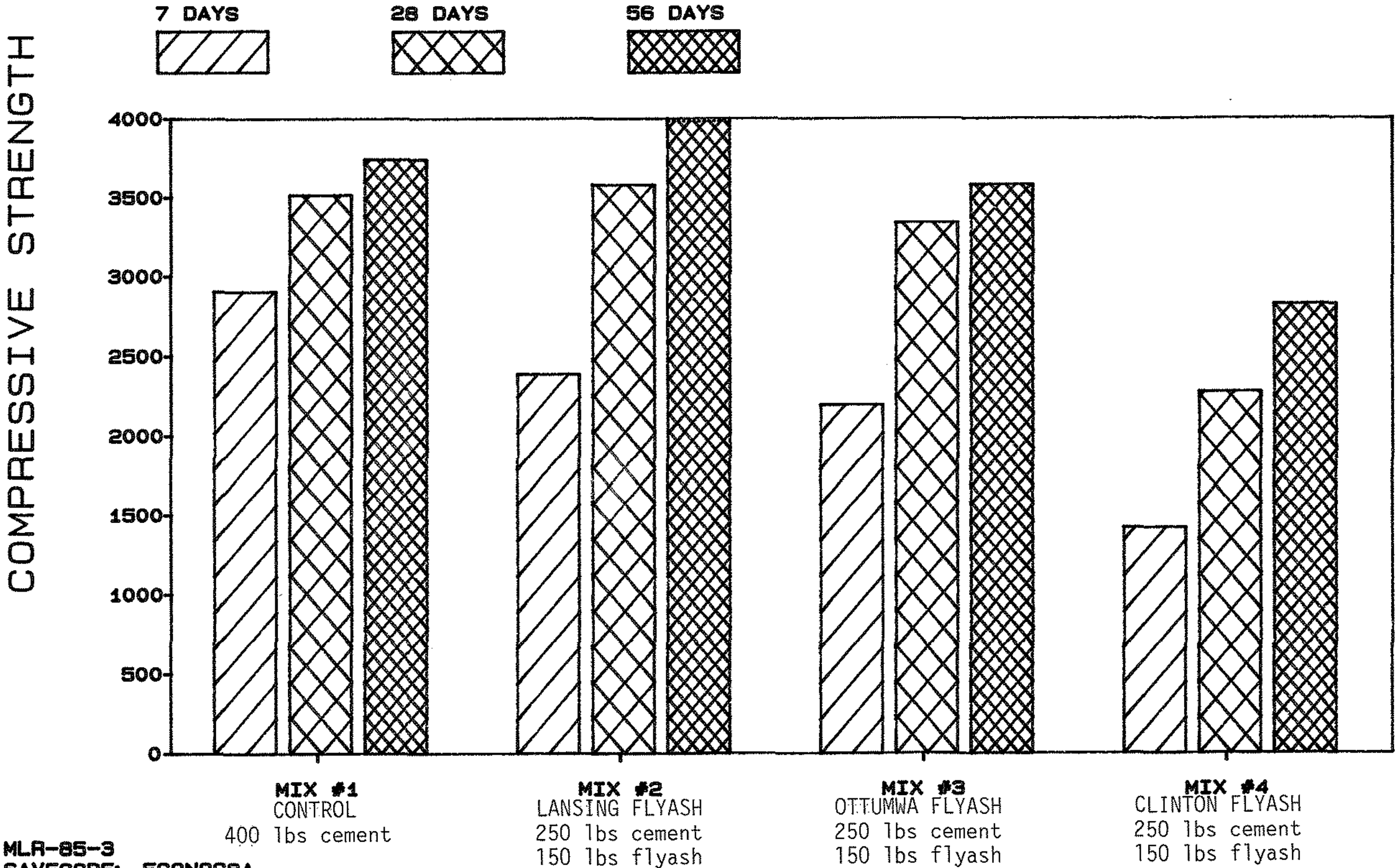
Mix No.	Cement/Fly Ash Content lbs/yd³	Fly Ash %	Fly Ash Source	Fly Ash Class	Aggregate Source	Water Reducing Admixture	Slump (inches)	Air Content %	W/C Ratio		Absorption % (Average)
									Cement Only	Cement & Fly Ash	
1	400 lb. cement	0	---	---	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.6	0.835	---	7.60
2	280 lb. cement 120 lb. fly ash	30	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.6	1.120	0.785	7.30
3	200 lb. cement 200 lb. fly ash	50	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.0	1.487	0.744	7.10
4	120 lb. cement 280 lb. fly ash	70	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.0	2.394	0.717	6.90
5	400 lb cement	0	---	---	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.1	0.890	-----	9.00
6	280 lb. cement 120 lb. fly ash	30	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.0	1.199	0.840	8.80
7	200 lb. cement 200 lb. fly ash	50	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	1.588	0.794	8.50
8	120 lb. cement 280 lb. fly ash	70	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.25	6.3	2.620	0.785	8.20
9	300 lb. cement	0	---	---	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.7	1.101	----	7.80
10	210 lb. cement 90 lb. fly ash	30	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.6	1.524	1.068	7.60
11	150 lb. cement 150 lb. fly ash	50	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.5	2.000	1.000	7.70
12	90 lb. cement 210 lb. fly ash	70	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.25	6.5	3.264	0.977	6.90
13	300 lb. cement	0	---	---	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.2	1.258	----	9.30
14	210 lb. cement 90 lb. fly ash	30	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	1.702	1.192	9.00
15	150 lb. cement 150 lb. fly ash	50	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	2.191	1.096	8.60
16	90 lb. cement 210 lb. fly ash	70	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.25	6.8	3.585	1.073	8.10

Table No. 6
Fly Ash in Portland Cement Concrete Base Mixes
MLR-86-1
Erodibility

Mix No.	Cement/Fly Ash Content lbs/yd^3	Fly Ash %	Fly Ash Source	Fly Ash Class	Aggregate Source	Water Reducing Admixture	Slump (inches)	Air Content %	W/C Ratio: Cement Only	W/C Ratio: Cement & Fly Ash	Erodibility (inches): Depth @ 15 Min.	Erodibility (inches): Depth @ 30 Min.
1	400 lb. cement	0	---	---	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.6	0.835	---	0.250	0.375
2	280 lb. cement 120 lb. fly ash	30	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.6	1.120	0.785	0.325	0.328
3	200 lb. cement 200 lb. fly ash	50	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.0	1.487	0.744	0.250	0.312
4	120 lb. cement 280 lb. fly ash	70	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.0	2.394	0.717	0.692	0.750
5	400 lb cement	0	---	---	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.1	0.890	-----	0.328	0.438
6	280 lb. cement 120 lb. fly ash	30	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.0	1.199	0.840	0.234	0.297
7	200 lb. cement 200 lb. fly ash	50	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	1.588	0.794	0.359	0.406
8	120 lb. cement 280 lb. fly ash	70	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.25	6.3	2.620	0.785	0.594	0.812
9	300 lb. cement	0	---	---	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.7	1.101	----	0.344	0.438
10	210 lb. cement 90 lb. fly ash	30	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.6	1.524	1.068	0.391	0.406
11	150 lb. cement 150 lb. fly ash	50	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.00	6.5	2.000	1.000	0.750	0.766
12	90 lb. cement 210 lb. fly ash	70	Ottumwa	C	Glory Stone Cedar River Sand	WRDA/HyCol	2.25	6.5	3.264	0.977	0.312	1.328
13	300 lb. cement	0	---	---	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.2	1.258	----	0.219	0.562
14	210 lb. cement 90 lb. fly ash	30	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	1.702	1.192	0.453	0.578
15	150 lb. cement 150 lb. fly ash	50	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.00	6.5	2.191	1.096	0.453	0.484
16	90 lb. cement 210 lb. fly ash	70	Ottumwa	C	Earlham Stone Des Moines River Sand	WRDA/HyCol	2.25	6.8	3.585	1.073	1.094	1.172

FIGURE #1

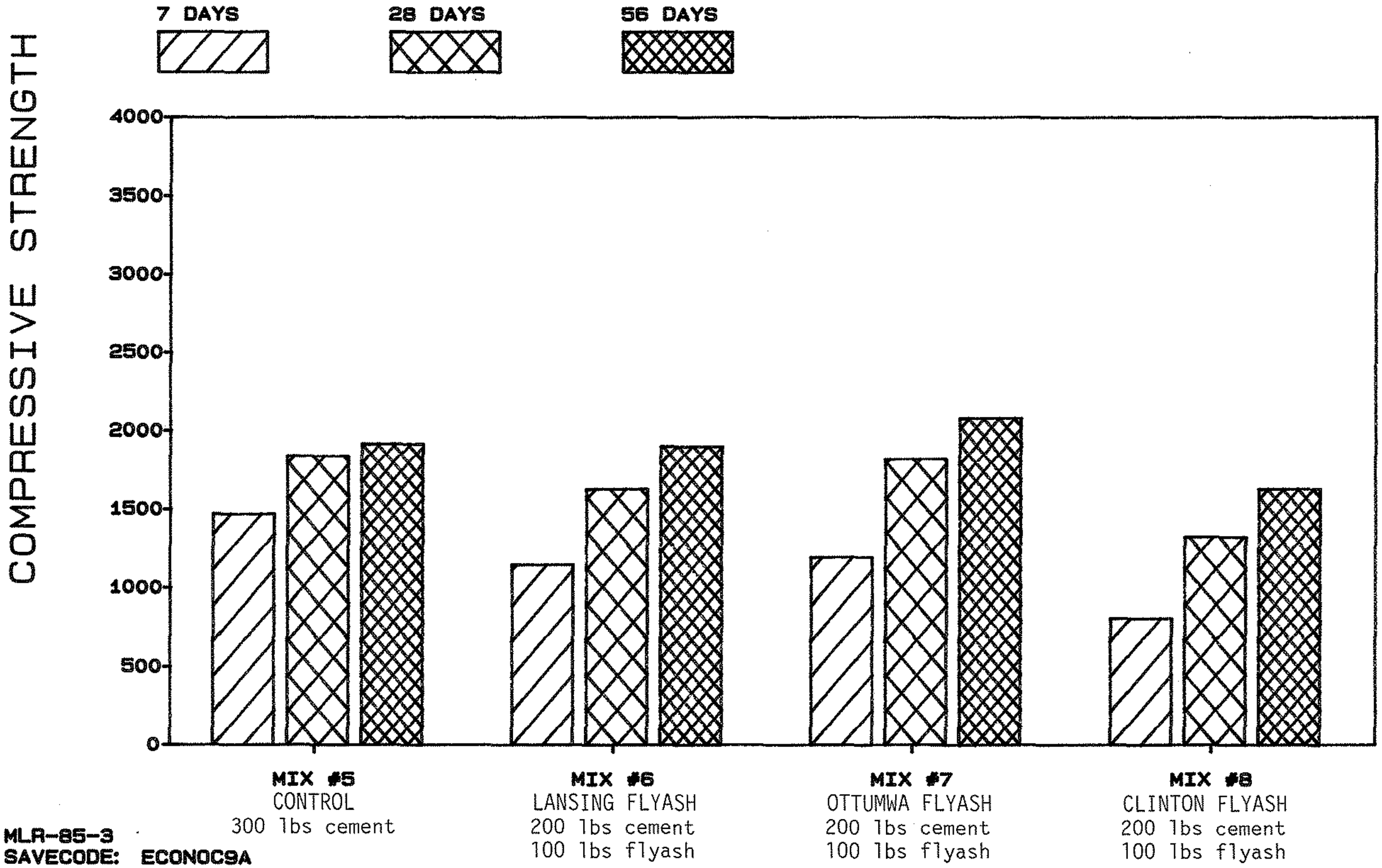
ECONOCRETE COMPRESSIVE STRENGTH COMPARISION
400 LB CEMENTITIOUS MATERIAL PER CUBIC YARD MIX



MLR-85-3
SAVECODE: ECONOC8A

FIGURE #2

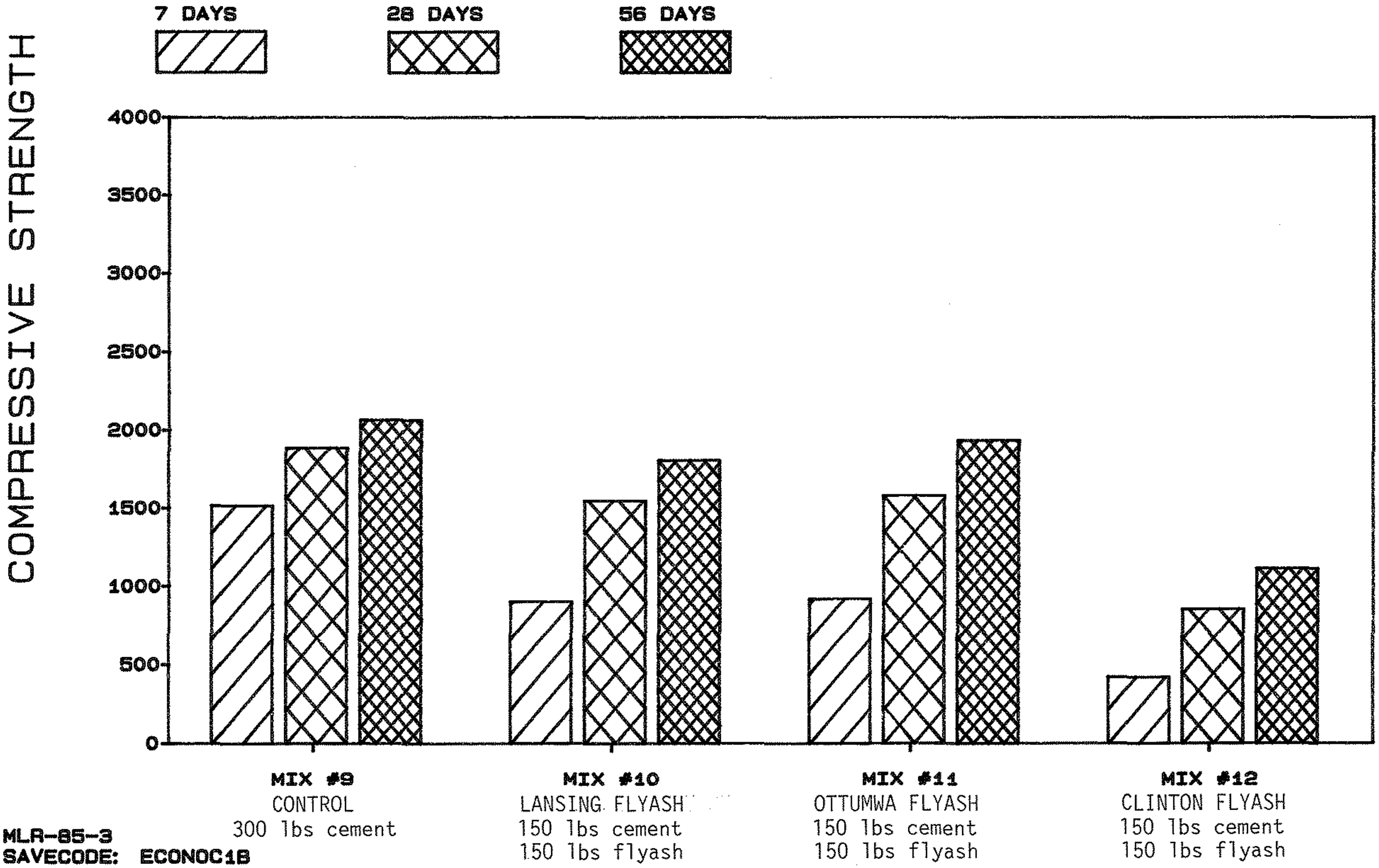
ECONOCRETE COMPRESSIVE STRENGTH COMPARISION
300 LB CEMENTITIOUS MATERIAL PER CUBIC YARD MIX



MLR-85-3
SAVECODE: ECONOC9A

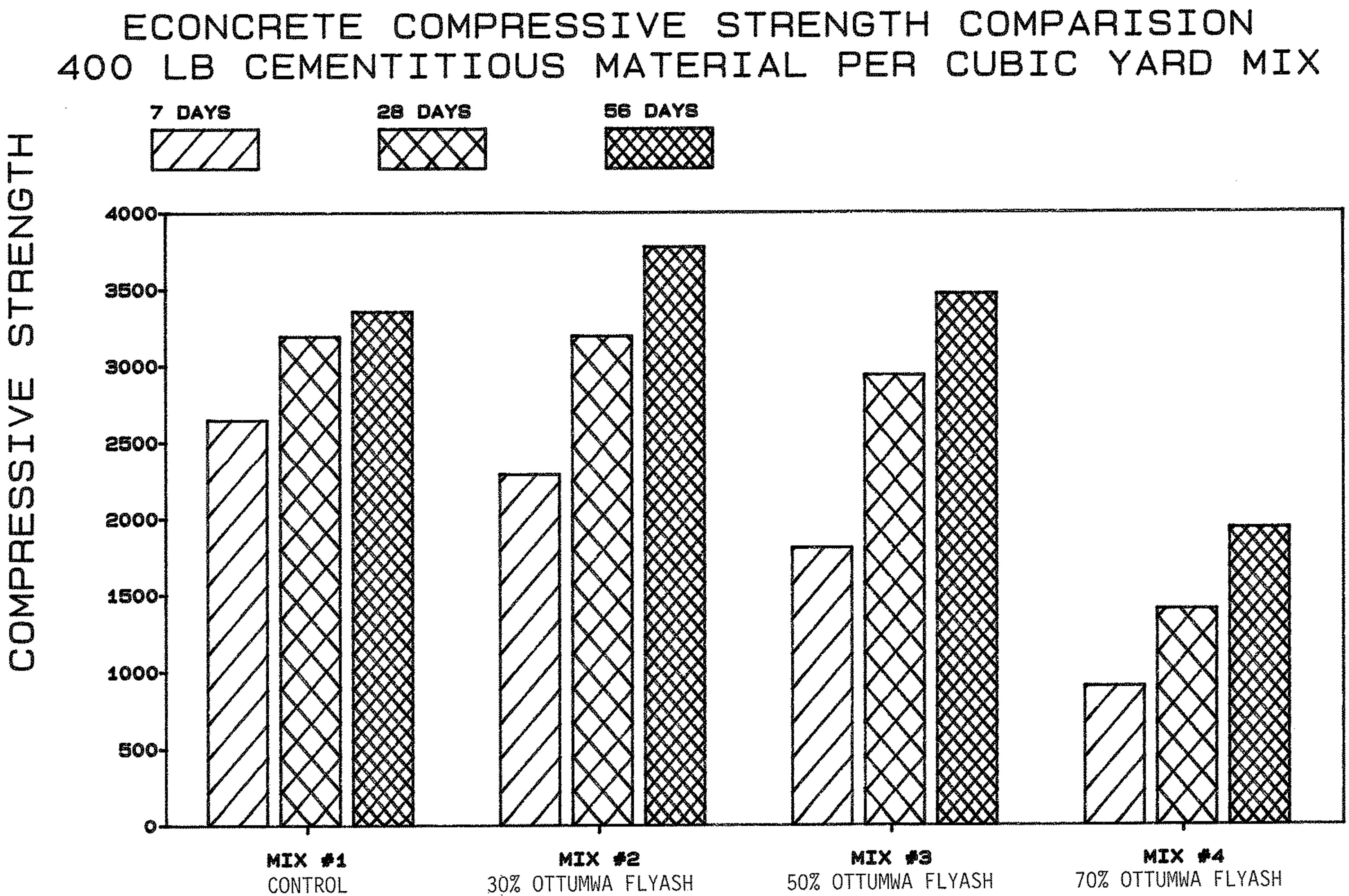
FIGURE #3

ECONCRETE COMPRESSIVE STRENGTH COMPARISION
300 LB CEMENTITIOUS MATERIAL PER CUBIC YARD MIX



MLR-85-3
SAVECODE: ECONOC1B

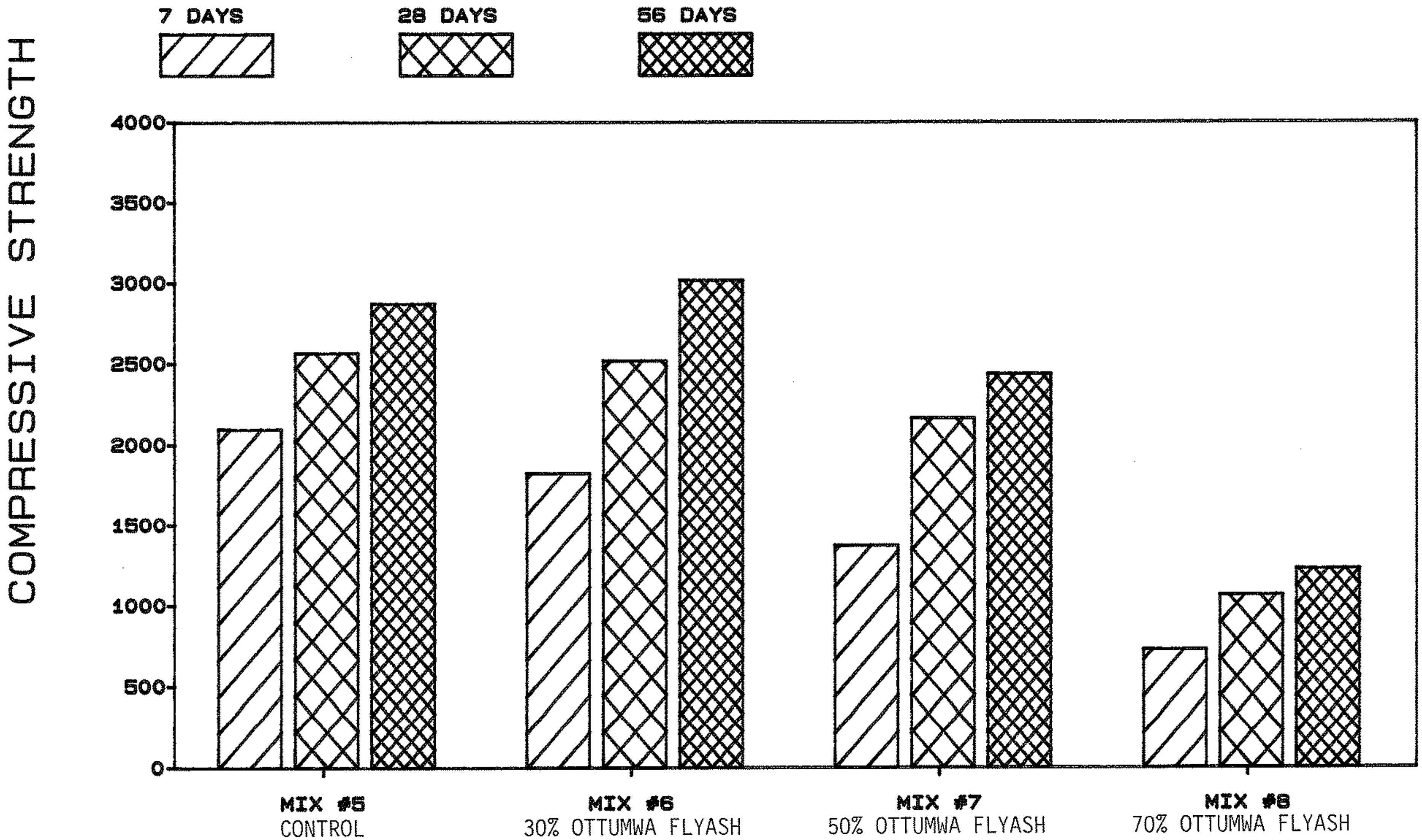
FIGURE #4



MLR-86-1
SAVECODE: ECONOC5B

FIGURE #5

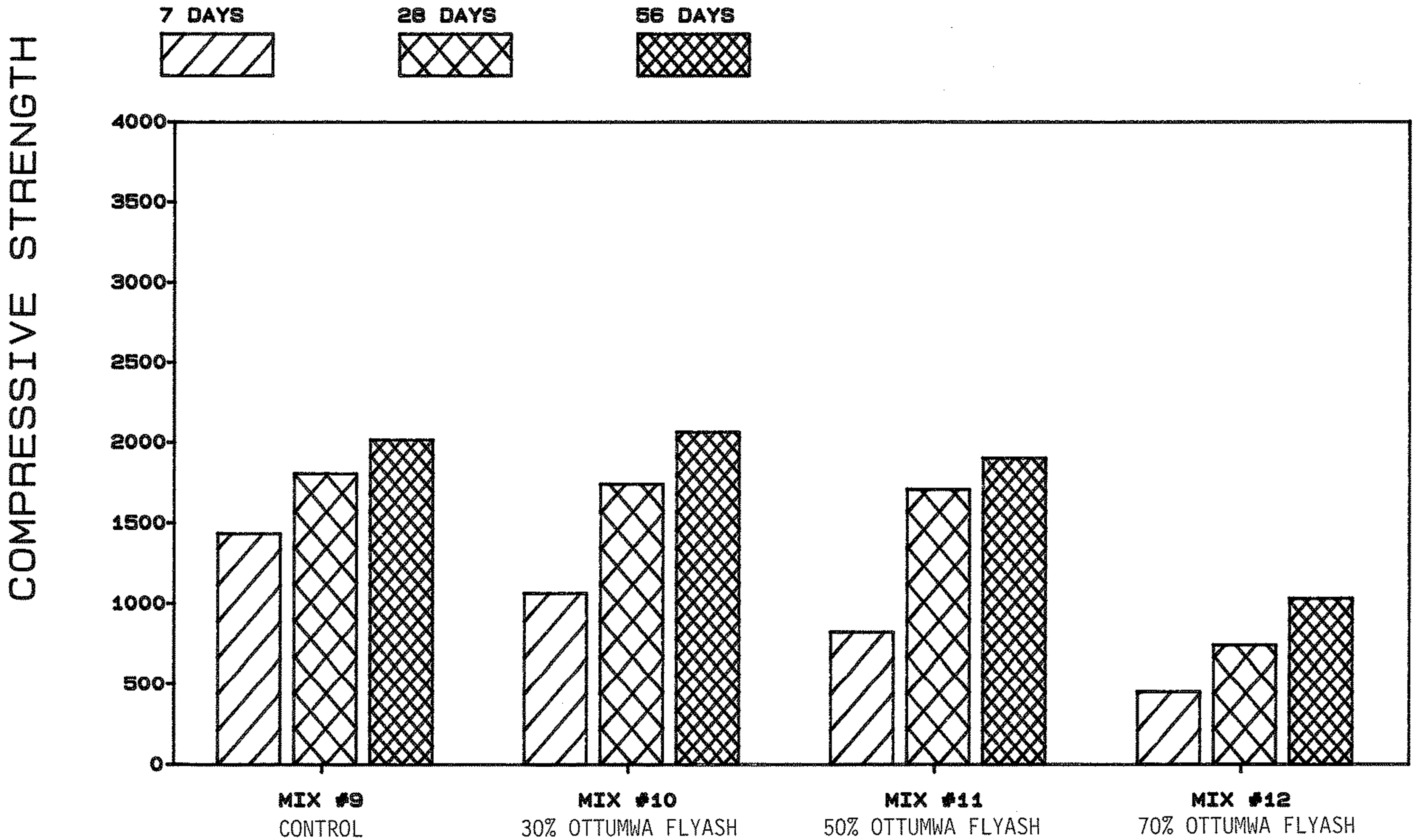
ECONOCRETE COMPRESSIVE STRENGTH COMPARISION
400 LB CEMENTITIOUS MATERIAL PER CUBIC YARD MIX



MLR-86-1
SAVECODE: ECONOC2B

FIGURE #6

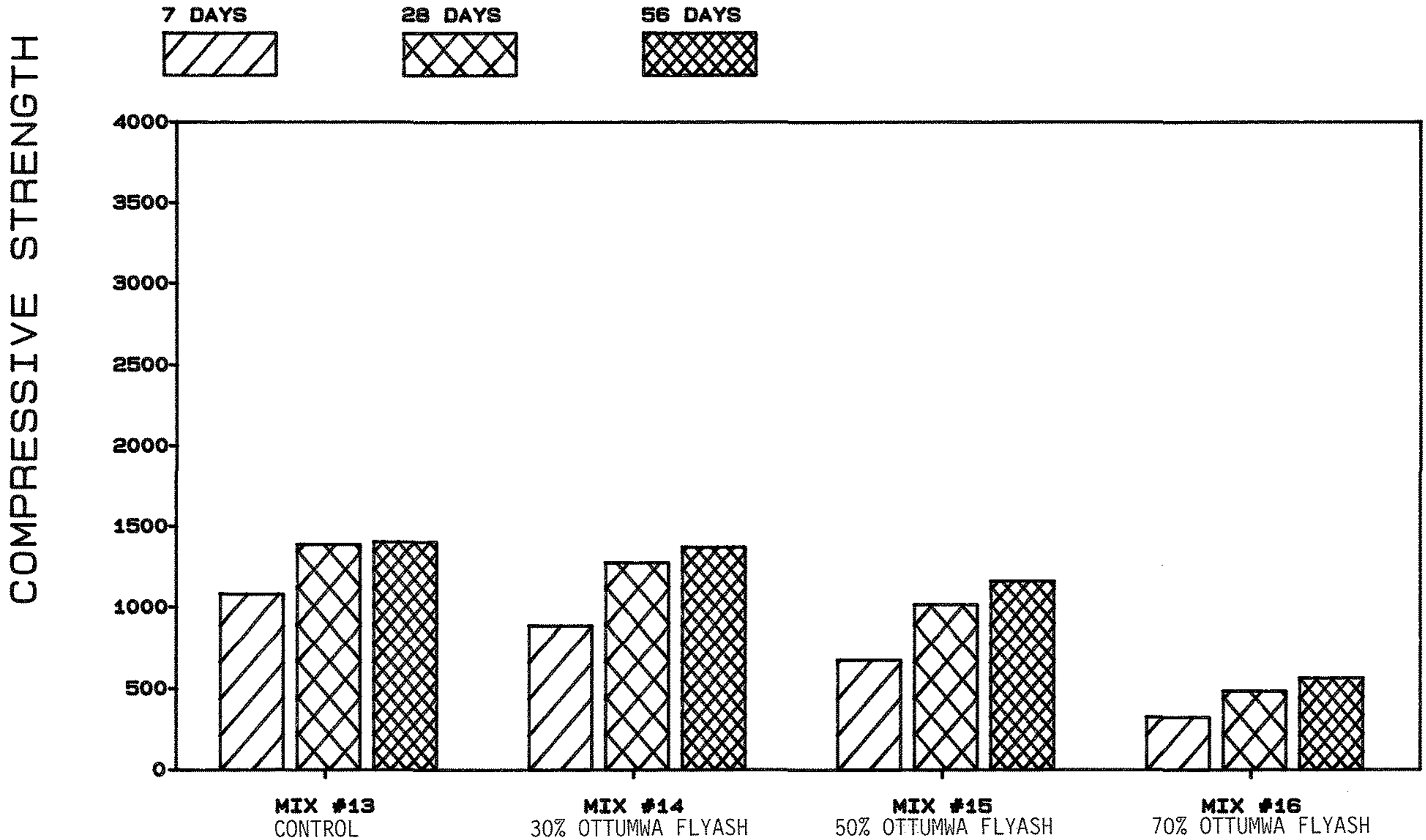
ECONOCRETE COMPRESSIVE STRENGTH COMPARISION
300 LB CEMENTITIOUS MATERIAL PER CUBIC YARD MIX



MLR-86-1
SAVECODE: ECONOC3B

FIGURE #7

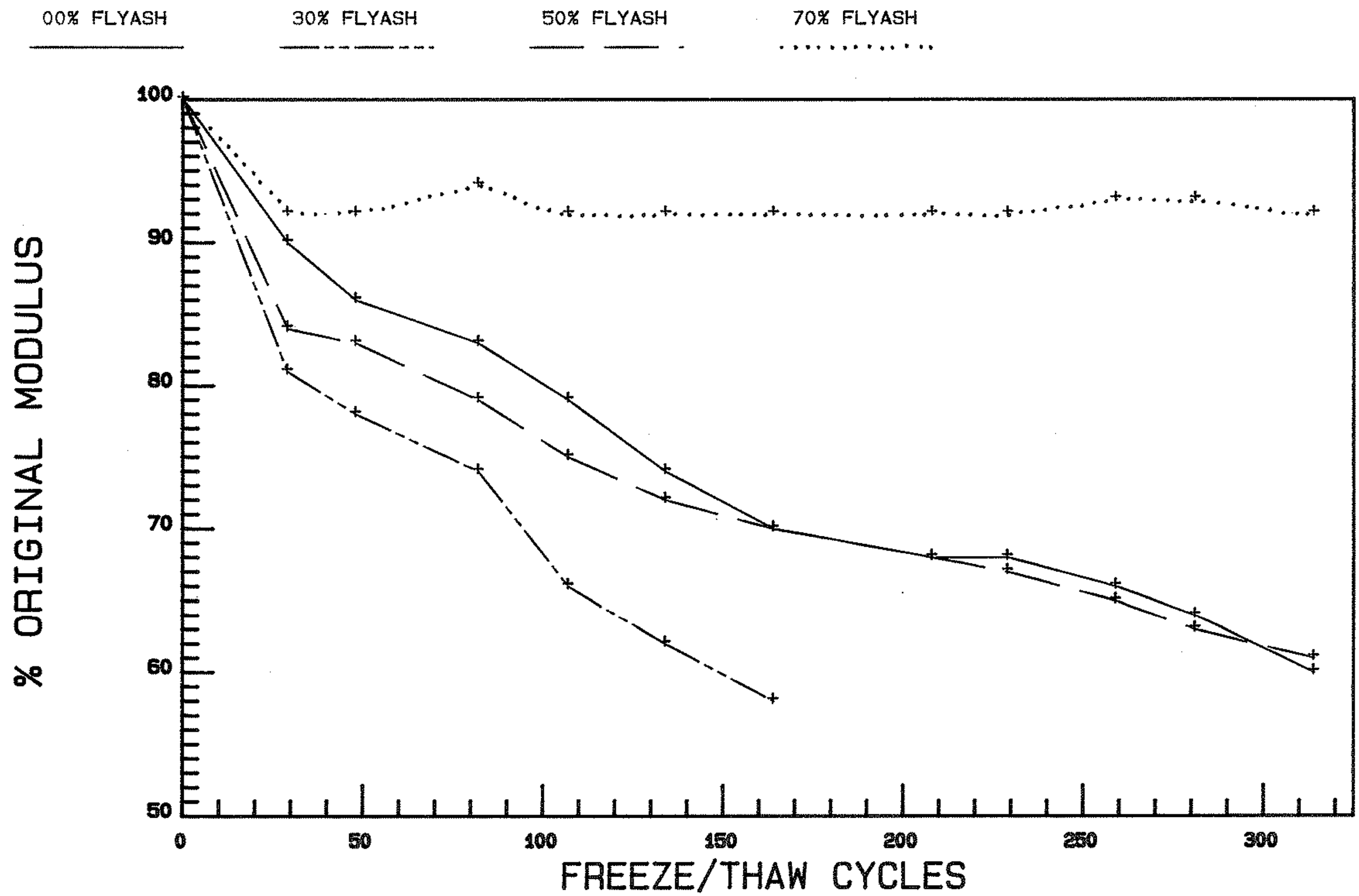
ECONOCRETE COMPRESSIVE STRENGTH COMPARISION
300 LB CEMENTITIOUS MATERIAL PER CUBIC YARD MIX



MLR-86-1
SAVECODE: ECONOC4B

Figure #8

ECONOCRETE DURABILITY COMPARISON
400 LB CEMENTITIOUS MATERIAL PER CUBIC YARD MIX
EARLHAM QR COARSE AGGREGATE & OTTUMWA FLYASH



SAVECODE ECONOC2
IOWA DOT JUNE 11, 1986

Figure #9

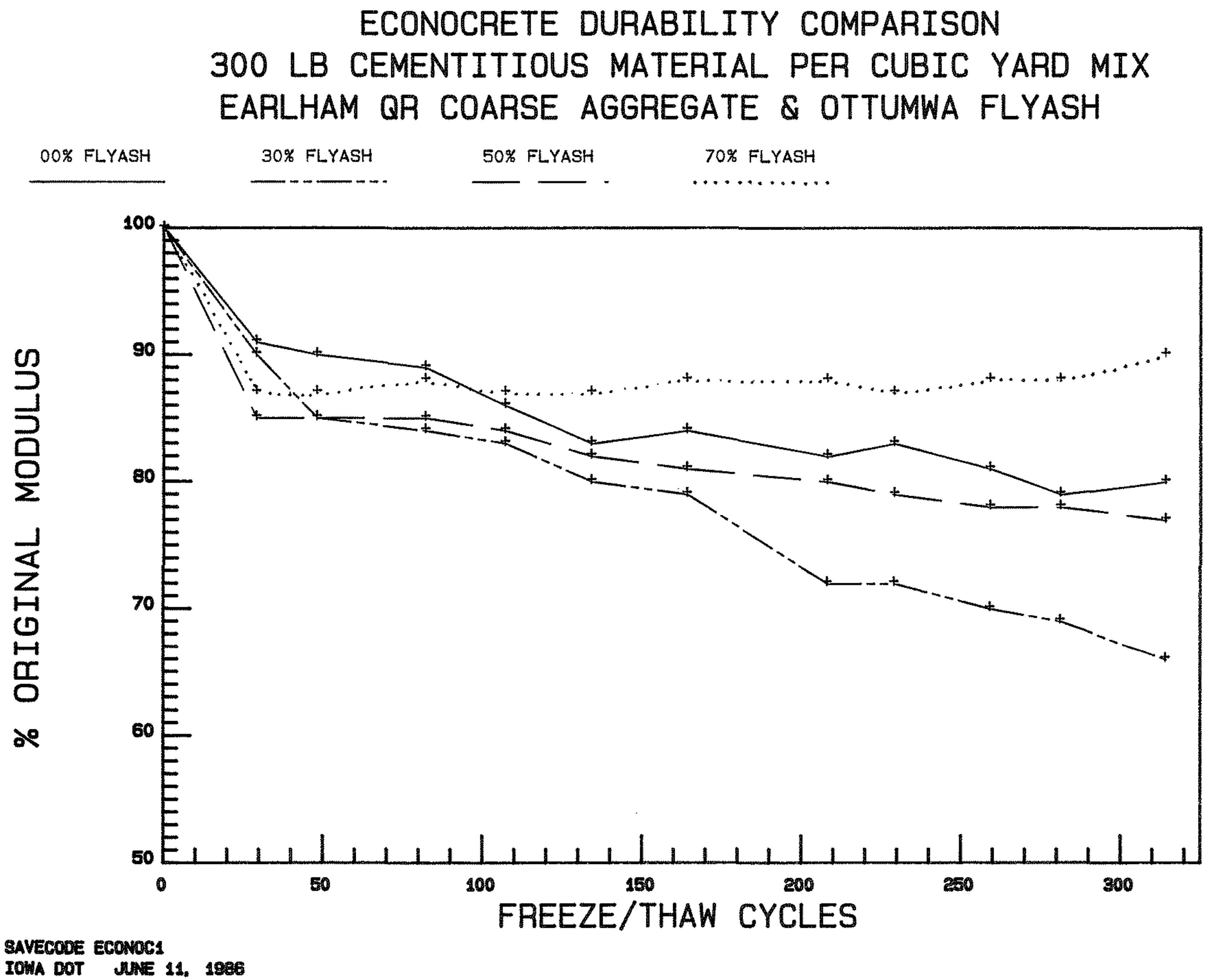
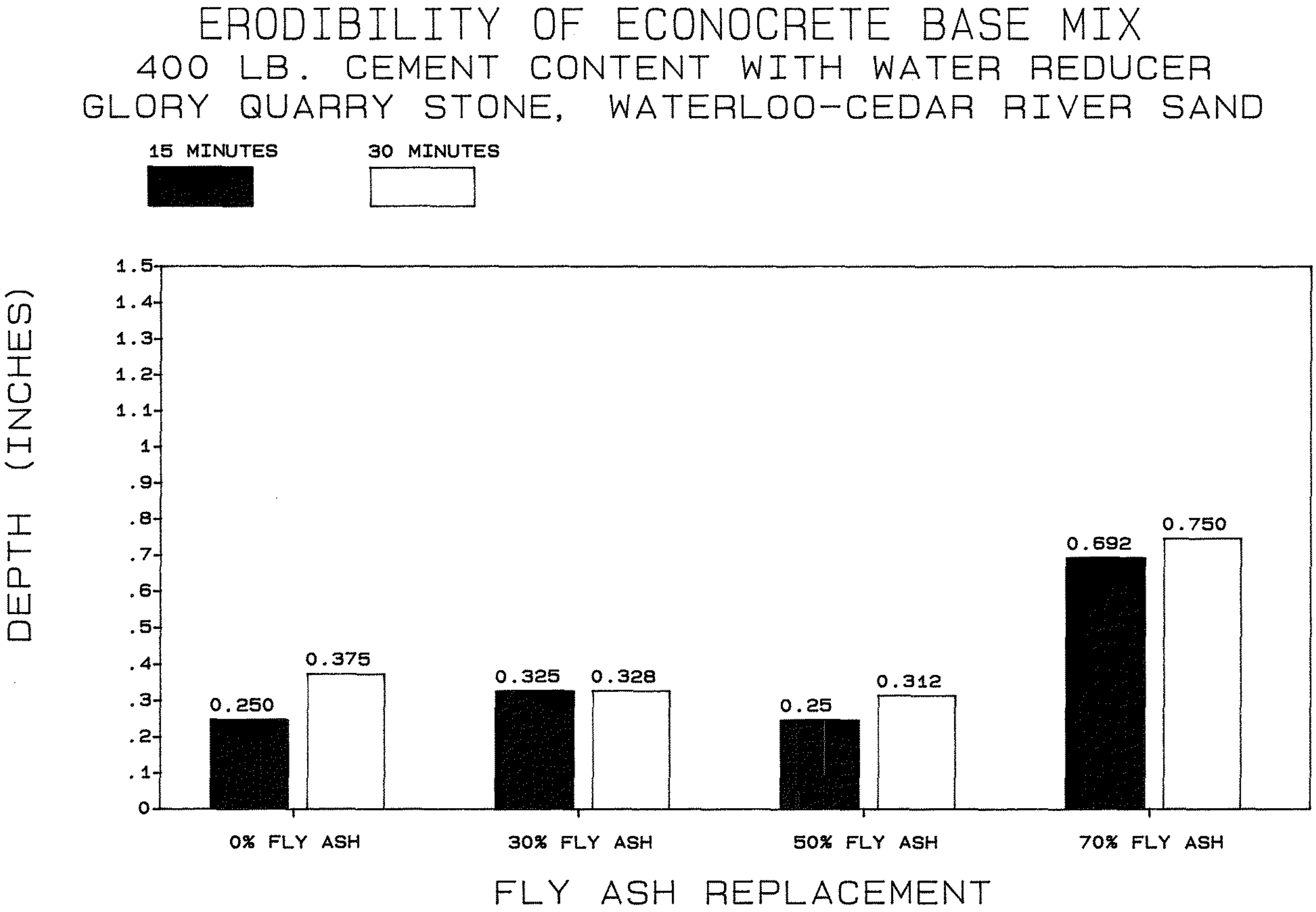

ECONOCRETE DURABILITY COMPARISON
300 LB CEMENTITIOUS MATERIAL PER CUBIC YARD MIX
EARLHAM QR COARSE AGGREGATE & OTTUMWA FLYASH
00% FLYASH
30% FLYASH
50% FLYASH
70% FLYASH
100
90
80
70
60
50
% ORIGINAL MODULUS
0
50
100
150
200
250
300
FREEZE/THAW CYCLES
SAVECODE ECONOC1
IOWA DOT JUNE 11, 1986

Figure #10



ERODIBILITY OF ECONOCRETE BASE MIX
400 LB. CEMENT CONTENT WITH WATER REDUCER
GLORY QUARRY STONE, WATERLOO-CEDAR RIVER SAND
15 MINUTES
30 MINUTES
DEPTH (INCHES)
1.5
1.4
1.3
1.2
1.1
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0.250
0.375
0.325
0.328
0.25
0.312
0.692
0.750
0% FLY ASH
30% FLY ASH
50% FLY ASH
70% FLY ASH
FLY ASH REPLACEMENT

Figure #11

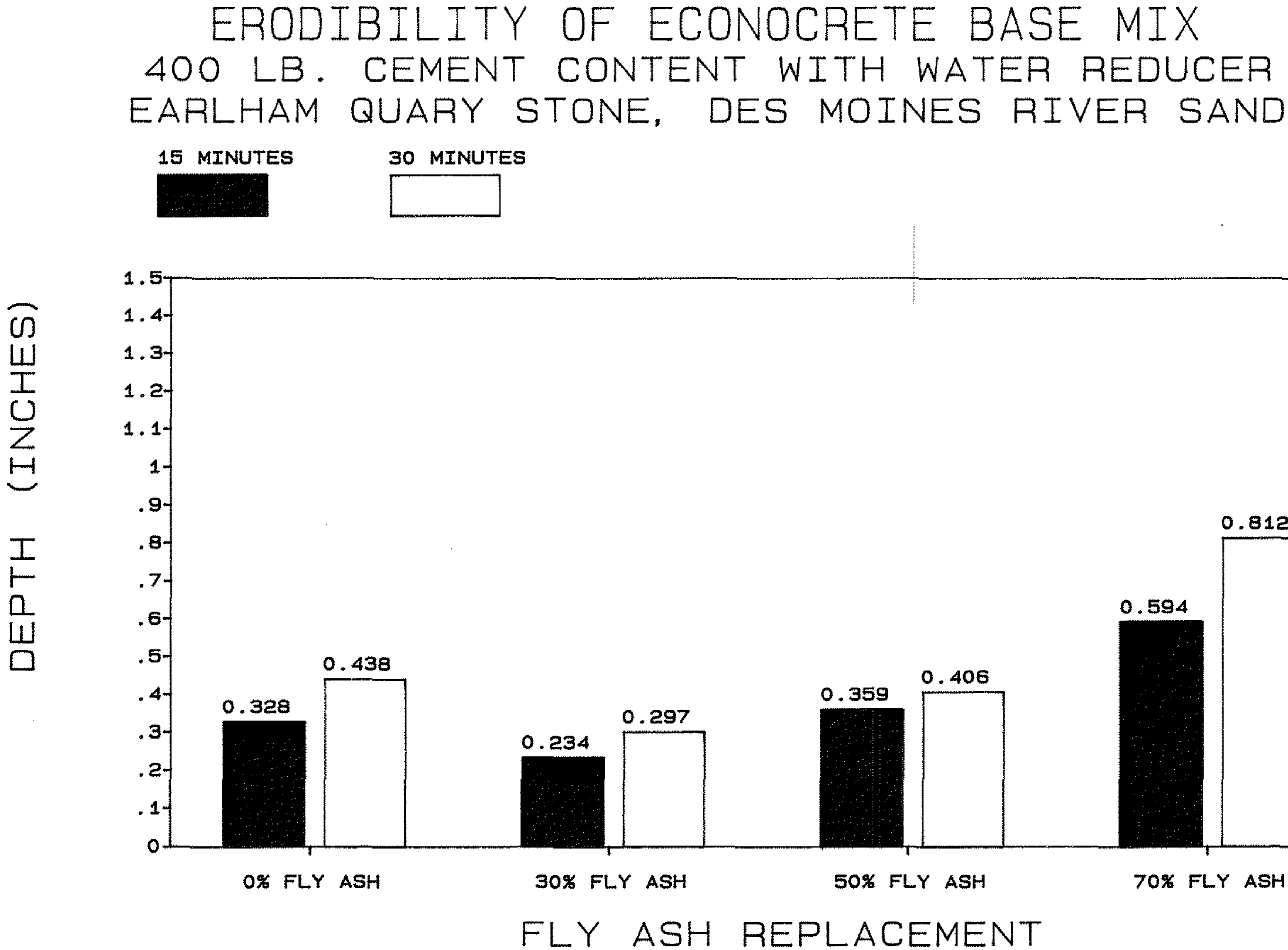

ERODIBILITY OF ECONOCRETE BASE MIX
400 LB. CEMENT CONTENT WITH WATER REDUCER
EARLHAM QUARY STONE, DES MOINES RIVER SAND
15 MINUTES
30 MINUTES
DEPTH (INCHES)
1.5
1.4
1.3
1.2
1.1
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0.328
0.438
0.234
0.297
0.359
0.406
0.594
0.812
0% FLY ASH
30% FLY ASH
50% FLY ASH
70% FLY ASH
FLY ASH REPLACEMENT

Figure #12

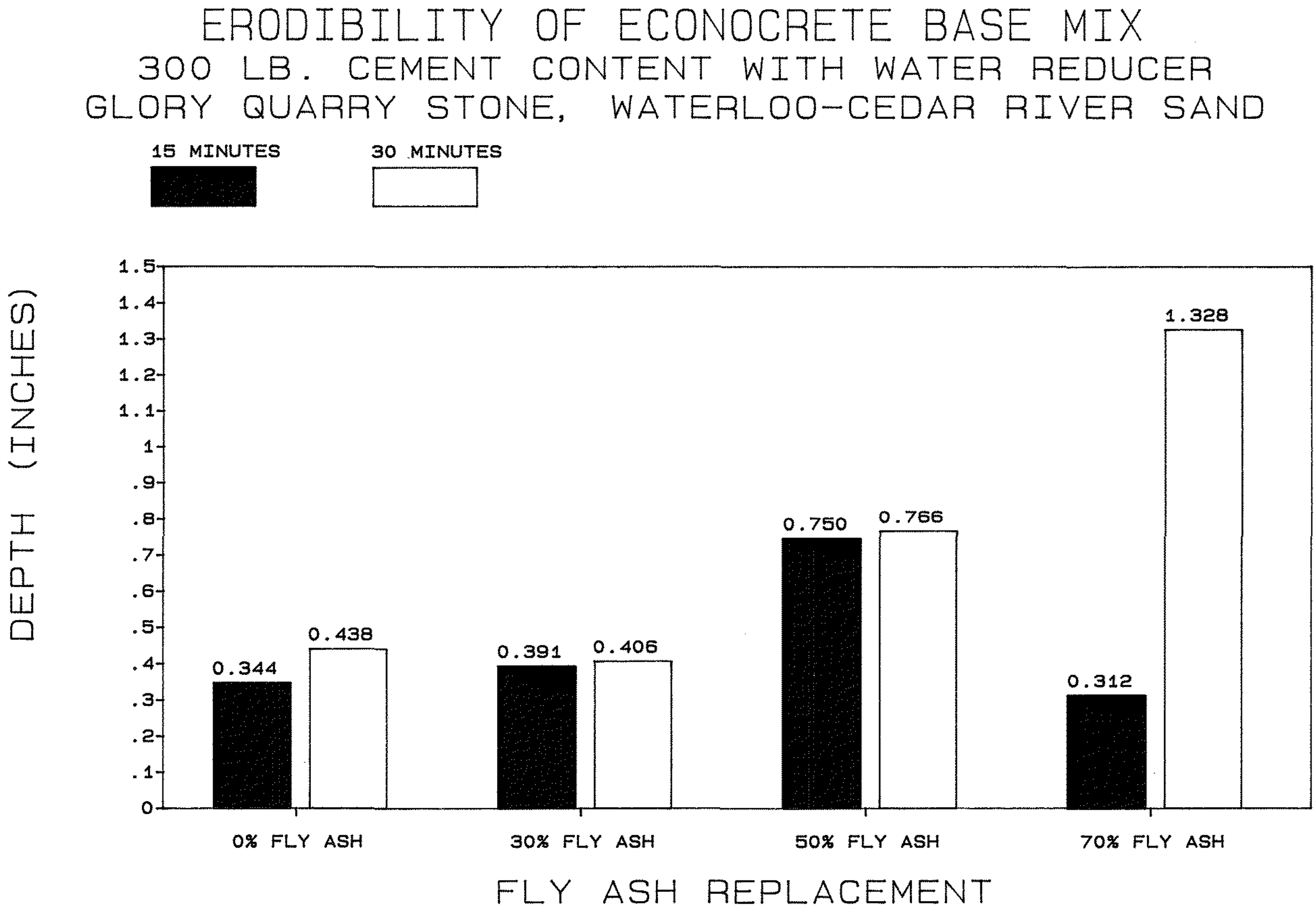
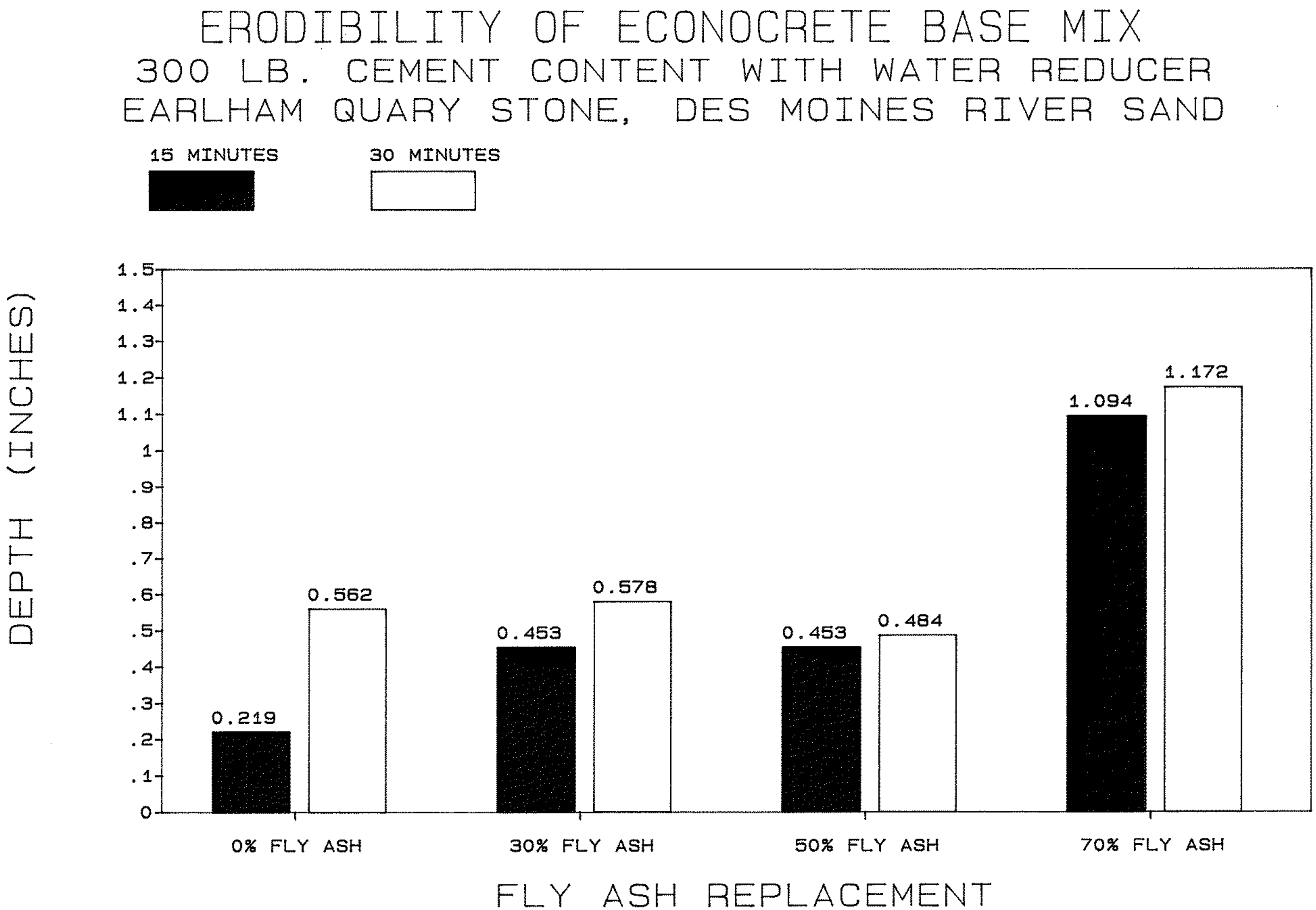

ERODIBILITY OF ECONOCRETE BASE MIX
300 LB. CEMENT CONTENT WITH WATER REDUCER
GLORY QUARRY STONE, WATERLOO-CEDAR RIVER SAND
15 MINUTES
30 MINUTES
DEPTH (INCHES)
1.5
1.4
1.3
1.2
1.1
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0.344
0.438
0.391
0.406
0.750
0.766
0.312
1.328
0% FLY ASH
30% FLY ASH
50% FLY ASH
70% FLY ASH
FLY ASH REPLACEMENT

Figure #13


ERODIBILITY OF ECONOCRETE BASE MIX
300 LB. CEMENT CONTENT WITH WATER REDUCER
EARLHAM QUARY STONE, DES MOINES RIVER SAND
15 MINUTES
30 MINUTES
DEPTH (INCHES)
1.5
1.4
1.3
1.2
1.1
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0.219
0.562
0.453
0.578
0.453
0.484
1.094
1.172
0% FLY ASH
30% FLY ASH
50% FLY ASH
70% FLY ASH
FLY ASH REPLACEMENT

Test Results & Discussion

The data gathered in this study supports the substitution of 30-50% of the portland cement in the econocrete mixes with ASTM C-618 Class "C" fly ash on a pound for pound basis, or Class "F" fly ash at a rate of 1.25 pound of ash added for each pound of cement deleted.

Compressive strengths obtained were more than adequate. A strength level in the 1200-1500 psi range at 28 days will provide a subbase with the physical properties required for performance under heavy duty pavements. Specified strength levels of 1500 psi might fall in the range of 300 lb. mix (contains 30-50% fly ash). Higher strength mixtures may induce cracking in the overlaying pavement and may require additional steps or measures to prevent reflective cracks. Subbases are normally used for the purpose of providing a stable and a uniform support for the surface pavement and further to reduce joint faulting. The "AASHTO Guide Specifications for Highway Construction" specifies a compressive strength range between 500 psi and 1500 psi at 28 days (750 psi is the suggested strength for econocrete subbase course and all air content between 4 & 9%).

Freeze-thaw durability testing was not included in the initial study (MLR-85-3) because the possibility of water reducer-fly ash combinations causing reduced frost resistance was extremely remote. However, in the second phase of the study (MLR-86-1), the laboratory work was expanded to include not only the durability testing but also the absorption and erodibility of the econocrete mixes. The durability testing ended with very surprising results. In most cases, all

econocrete mixes with and without fly ash exhibited durability far exceeding what was expected of an econocrete mix with low cement factor and low quality aggregate. It is suspected that the more dense gradation of the aggregate used in the econocrete mixes may be the reason. It was also noted that as the fly ash content increased, the mixes became more cohesive, dense and homogeneous. This assumption proved to be the same in the absorption test specimens with higher ash content absorbing less water than the specimens with low ash or no ash content.

Conclusion

In light of these investigations, it is logical to conclude that the use of approved fly ashes in water reduced econocrete mixes would have acceptable strength and durability. The water reducing admixture makes significant low cost contribution to compressive strength. This type of mix could make effective use of certain naturally graded aggregates. It is believed that such a subbase would be somewhat nonerodible and add structural integrity and stability to some pavement sections. It is believed that it might increase the service life by reducing the incidence of faulting. Econocrete mixes can be mixed in existing central mix concrete plants and placed with conventional or available concrete paving equipment.

Recommendation

Based on the test results, the addition of fly ash as a replacement to econocrete containing water reducing admixtures can be accomplished without detrimental effects to the strength or freeze/thaw durability of econocrete.

It is recommended that:

1. The substitution of fly ash from approved sources for up to 50% of the portland cement in econocrete base mixes containing Class "A" aggregates be allowed in the specifications.

2. The cement content of the econocrete mixes be reduced from 400 to 300 lb. of cement per cubic yard.

References

1. ASTM (American Society for Testing and Materials) Annual Book of Standards, Section 4, Volume 04.02, Concrete & Mineral Aggregates ASTM 1985

2. Iowa Department of Transportation, Office of Materials, Laboratory Manual

3. AASHTO (American Association of State, Highway and Transportation Officials) AASHTO Materials, Part II, Tests, AASHTO, 13th Edition 1982-1985 I

Appendix A

Compressive Strength Testing

Test Method No. Iowa 403-A
March 1973

IOWA STATE HIGHWAY COMMISSION

Materials Department

METHOD OF TEST FOR COMPRESSIVE STRENGTH OF MOLDED CONCRETE CYLINDERS

Scope

This method covers the procedure for compression tests of molded concrete cylinders. It is a modification of AASHO T 22.

Procedure

A. Apparatus

1. The compression testing machine shall comply with AASHO T 22 except:

   (a) The lower bearing block shall be at least 1 in. in thickness.

   (b) The maximum diameter of the bearing face of the spherically seated block shall be 10 in. for cylinders from 4 in. through 6 in. in diameter.

B. Test Specimens

1. Compression tests of moist-cured specimens are to be made as soon as practicable after removal from the curing room. Test specimens during the period between their removal from the moist room and testing, must be kept moist by a wet burlap or blanket covering. They are to be tested in a moist condition unless otherwise specified.

2. The ends of compression test specimens that are not plane within 0.002 in. are to be capped in accordance with Test Method No. Iowa 404, "Capping Cylindrical Concrete Specimens". Normally horizontally cast cylinders will not require capping.

3. For cylinders cast in single-use molds, determine the diameter of the test specimen to the nearest 0.01 in. by averaging two diameters measured at right angles to each other at about mid-height of the specimen. Use this average diameter for calculating the cross-sectional area of the specimen.

4. The cross-sectional area of specimens cast in the steel-walled horizontal and vertical molds commonly furnished, may be assumed to be 28.27 in.^{2} and 15.90 in.^{2} respectively for the 6 in. and 4.5 in. diameter cylinders

C. Test Procedure

1. Placing the specimen

   (a) Place the plain (lower) bearing block, with its hardened face up, on the table or platen of the testing machine directly under the spherically seated (upper) bearing block.

   (b) Wipe clean the bearing faces of the upper and lower bearing blocks and of the test specimen. Place the test specimen on the lower bearing block.

   (c) Carefully align the axis of the specimen with the center of thrust of the spherically seated block.

   (d) As the spherically seated block is brought to bear on the specimen, rotate its moveable portion gently by hand so that uniform seating is obtained.

2. Rate of Loading

   (a) Apply the load continuously and without shock. Apply the load at a constant rate within the range of 20 to 50 psi. per second. During the application of the first half of the estimated maximum load, a higher rate of loading may be permitted.

   (b) Do not make any adjustment in the controls of the testing machine while the specimen is yielding rapidly immediately before failure.

   (c) Increase the load until the specimen yields or fails, and record the maximum load carried by the specimen during the test.

(d) Note the type of failure and the appearance of the concrete if the break appears to be abnormal.

D. Calculations

1. Calculate the compressive strength of the specimen by dividing the maximum load carried by the specimen during the test by the average cross-sectional area as described in Section B, and express the result to the nearest 10 psi.

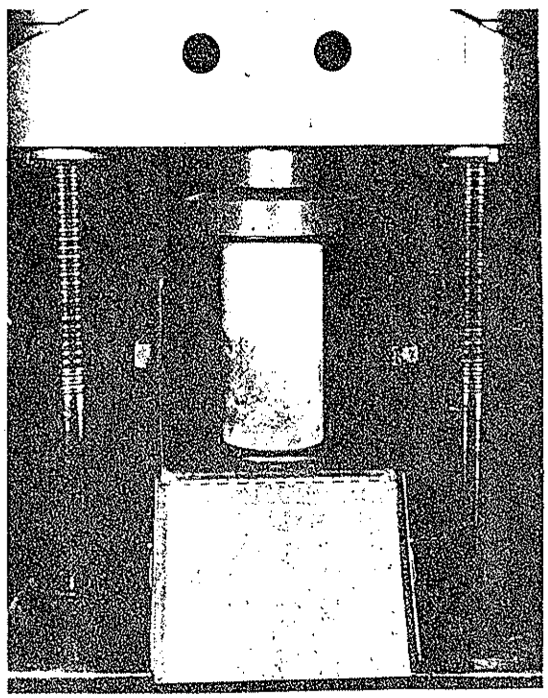


Fig. 1
Concrete Cylinder In
Testing Machine

Appendix B

Durability Testing

Test Method No. Iowa 408-A
April 1980

IOWA DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION

Office of Materials

METHOD OF TEST FOR DETERMINING THE RESISTANCE OF CONCRETE TO RAPID FREEZING AND THAWING (CONCRETE DURABILITY)

Scope

This method covers the determination of the resistance of concrete beam specimens (4"x4"x18") to rapidly repeated cycles of freezing in air and thawing in water. The Procedure is a slight modification to ASTM C-666 Procedure B.

Procedure

A. Apparatus

1. Freezing and thawing Apparatus, Temperature Measuring Equipment, Dynamic Testing Apparatus, Scales.

   The freezing and thawing apparatus, temperature measuring equipment, dynamic testing apparatus, and scales shall conform to ASTM C-666 Procedure B.

2. Length Comparator

   The length comparator for determining the length change of the specimens shall be accurate to 0.0001". An invar steel reference bar is provided for calibrating the comparator.

3. Tempering Tank

   The tempering tank is temperature controlled at 40 ± 2°F. It is to be used for cooling specimens prior to placement into the freezing chamber.

B. Freeze-Thaw Cycle

1. The freezing and thawing cycle shall be identical to ASTM C-666 Procedure B.

C. Test Specimens

1. Unless otherwise specified the test specimens shall be 4"x4"x18" prisms.

2. A polished brass button shall be cast into each end of each prism for the purpose of providing a smooth reference surface for length measurements.

3. Three specimens shall be cast for each variable under study.

D. Curing

1. Upon removal from their molds the test specimens shall be placed in the moist room for a period of not less than 89 days or not more than 128 days.

2. Twenty-four hours prior to placement in the freeze-thaw apparatus, the specimens shall be placed in the tempering tank.

E. Test Procedure

1. Beam Rotation

   Prepare the order for random rotation of the specimens as follows:

   a. Prepare paper slips with the specimen identification numbers for each specimen in the freezing chamber.

   b. Place all the paper slips in a pan.

   c. Draw out the slips one at a time and record the resulting random sequence.

   Rotate the beams in the following manner:

   a. Withdraw the first specimen in the sequence and place it to one side.

   b. Move each successive specimen in the sequence into the position of the specimen preceding it.

c. When the last specimen in the sequence has been moved, replace it with the first specimen.

2. Length Measurements

a. Before any length measurement is taken, calibrate the beam comparator to 0.0200 using the Invar steel reference bar. This bar should be cooled for approximately 30 minutes in water to 40°F. Adjust the comparator dial if needed.

b. Remove the specimen from the tempering tank or the freezer depending upon whether the beam is a new one or one with several cycles on it.

c. Place the specimen in the comparator with the identification numbers facing up at the left end of the comparator. Care should be exercised to insure that the specimen is firmly against the back stops and the right end of the comparator.

d. Allow the dial indicator to come to rest on the brass button on the end of the specimen. Read this value on the indicator to the nearest 0.0001". Record this value. Repeat the measurement by completely removing the specimen from the comparator, replacing it, and remeasuring it until two successive readings are equal.

e. If measuring three specimens at once, cover those specimens immediately after removing from the sub-zero unit with a towel soaked in the thawing water.

3. Weight Measurement

Weigh the beam on the scale to the nearest ten grams. Record the value obtained.

4. Dynamic Modulus

a. Place the specimen on the support such that the driving oscillator is midway between the end of the specimen. Make sure the specimen is firmly against the backstops of the support.

b. Place the tone arm pickup on the end of the specimen about midway between the sides.

c. On the oscilloscope, rotate the large knob slowly back and forth until an elipse shape is formed on the cathode ray tube of the oscilloscope.

d. Set the "Osc. Frequency" knob to "$_x$10" and read the frequency from the indicator on the oscilloscope. Add 1000 to this value and record the number obtained.

5. Replace the specimen in the freeze chamber inverted from its original position.

6. Repeat steps 2 through 5 for all of the specimens.

7. Continue each specimen in the test until it has been subjected to 300 cycles or until its relative dynamic modulus reaches 60% of the initial modulus, whichever occurs first.

F. Calculations

1. Record all the required data on the "P.C. Concrete Durability" lab worksheet.

2. From the recording charts, obtain the number of cycles completed since the specimens were last measured. (Mark the date read and the number of cycles to that point on the recording chart.) Add to this number the number of cycles at which the specimens were last measured. Record this cumulative value in the column labeled "Cycles".

3. Subtract the dial reading at zero cycles from the latest dial reading. Record this value in the column labeled "Gro. In".

4. Calculate the relative dynamic modulus of elasticity using the formula:

$$P_c = (n_1^2/n^2) \times 100$$

where:

P_c = relative dynamic modulus of elasticity after c cycles of freezing and thawing, percent

n = fundamental transverse frequency at 0 cycles of freezing and thawing

n_1 = fundamental transverse after c cycles of freezing and thawing

Record this value in the column labeled "% of Orig."

5. When all of the above calculations have been made for a similar set of specimens, compute the average for the set for the items "% of Orig.", "Gro. %", and "Gro. In". Compute "Gro. %" using the formula:

$$G = \frac{S}{T(18)} \times 100$$

where:

G = average growth for the set of specimens in %.

S = the sum of the growths for each specimen.

T = the total number of specimens in the set.

"T" should include only number of specimens which showed a normal reading

Record these values in the appropriate columns on the worksheet.

6. Repeat the preceding steps for each specimen.

7. Should it be desired to hand calculate the durability factor, use the following formula:

$$DF = \frac{PN}{M}$$

where:

DF = the durability factor of the specimen

P = the relative dynamic modulus of elasticity at N cycles, percent

N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less

M = specified number of cycles at which exposure is to be terminated. (Three-hundred cycles in most cases.)

8. Report. The final report (worksheet) should be submitted to the Geology Section, and it should include all data pertinent to the variables or combination of variables studied in the evaluation. Also, any defects in each specimen which develop during testing and the number of cycles at which such defects were noted should be documented on the worksheet.

Specimens in the
Freezing & Thawing Apparatus

Form 821288
2-75

P.C. CONCRETE DURABILITY

w/c: ____________ Mix: ____________ Date Made: ____________ Beam No. ____________

Cement: ____________ Lab. No.: ____________ Cem. Content: ____________ sk/yd^3

Fine Agg.: ____________ Lab. No.: ____________ Sp. Gr.: ____________

Coarse Agg.: ____________ Lab. No.: ____________ Sp. Gr.: ____________

Slump: ____________ Air: ________

Comments: ____________

Date	Weight Grams

AEA ____________ @ ________ fl. oz./sk.

Admixture ____________ @ ________ fl. oz./sk.

Date Read	Cycles	Dial Rdg.	Gro. In.	Freq.	% of Orig.		Remarks	Set Average % of Orig.	Set Average Gro. %	Set Average Gro. In.