Evaluation of Fly Ash In Bridge Deck Concrete

Project No. MLR-84-2

by

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DISCLAIMER

Abstract

Fly ash was used in this evaluation study to replace 15% of the cement in Class D-57 structural concrete containing ASTM C494 Type B, retarding admixtures. 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 of the retarded mixes, with and without fly ash, were determined at 7, 28 and 56 days of age. In most cases, with few exceptions, the mixes containing the fly ash exhibited higher strengths than the same concrete mix without the fly ash. The exceptions were the 7, 28, and 56 days of the mixes containing Class F ash.

The freeze/thaw durability of the concrete studied was not affected by the presence of fly ash. The data obtained suggested that the present Class D-57 structural concrete mix with retarding admixtures can be modified to allow the substitution of 15% of the cement with an approved fly ash when Class III coarse aggregates are used.

Setting times of the concretes were not materially changed due to the incorporation of fly ash.

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Introduction

Current Iowa DOT specifications allow the optional use of fly ash as a partial cement replacement for Class A, B and C concrete paving mixes provided a highly frost resistant coarse aggregate such as Class III durability is used. Such an option does not exist for Class D-57 structural concrete. The use of fly ash in concrete is desirable for economic and environmental reasons. If the use of fly ash in bridge deck concrete is allowed, the contractor could elect to use a modified D-57 mix with or without admixtures and reduce the cement content by using fly ash and Class III durability aggregates. Therefore, information is needed to properly assess the characteristics of D-57 mixes that also contain Iowa fly ashes.

In view of the fact that Iowa has some concrete aggregates that cause premature concrete failure, a three-class system has been developed to denote a portland cement concrete aggregate's expected service life. Assignment to one of the service life classes is based on the aggregate's field performance in concrete, or in lieu of that, upon the performance of concrete containing it in a modification of the ASTM C-666 "Resistance of Concrete to Rapid Freezing & Thawing - Procedure B" test. Although the latter test can be definitive in identifying low quality aggregates, some aggregates that just pass the test give questionable field performance. These could appropriately be termed as "Class II aggregates".

Scope

This study examines the compressive strength, freeze/thaw durability, and setting time determination of Class D concrete with and without fly ash. Freeze/thaw durability testing was initially excluded from these projects be-cause the likelihood of reduced durability when these combinations were used with Class III aggregates was unlikely. The D-57 structural concrete mix has a cement factor of 710 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 a 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 retarding admixtures used in this study belong to two major chemical categories. The first of these are the metallic salt of hydroxylated carboxylic acid. Included in this category is the Plastiment 100. The second category is the modification and derivatives of carbohydrates and polyols. Included in this category is the Pozzolith 100XR.

LABORATORY PROCEDURES

A. Materials

The following materials were used in this study:

1. Portland Cement: Type I, the standard laboratory blend of the nine portland cements commonly available in Iowa was used to prepare the concrete specimens.

2. Water: City of Ames.

3. Air Entraining Agent: Neutralized vinsol resin Carter-Waters single strength, Lab No. ACA4-12.

4. Set Retarding Admixtures: Pozzolith 100XR, Master Builders, Dosage Rate 3 fl. oz./100 lbs. of cement. Lab No. ACI4-208.
Plastiment 100, Sika Chemical Corporation, Dosage Rate 3 fl. oz./100 lbs. of cement. Lab No. ACI4-209.

5. Coarse Aggregate (Strength Testing) Weaver Construction - Fort Dodge Crushed Stone - Lab No. AAC4-0003.

   Coarse Aggregate (Durability Testing) Weeping Water Mine - Martin-Marietta, Nebraska - Lab No. AAC4-0739.

6. Fine Aggregate (Strength Testing) Hallett Sand - Christensen Ames Pit - Lab No. AAS4-0001.

   Fine Aggregate (Durability Testing) Bellevue Sand & Gravel - Lab No. AAS4-0015.

7. Fly Ash

Three fly ash sources were sampled for inclusion in the evaluation study.

Lansing, Iowa - Reactive Class "C" ash (self cementing), Lab No. ACF4-5

Ottumwa, Iowa - Mildly Reactive Class "C" ash (self cementing), Lab No. ACF4-1

Clinton, Iowa - Class "F" ash (non cementing), Lab No. ACF4-4

B. Mixes

The following concrete mixes were prepared:

Mix No.	Description	Approximate Cement Content lb/yd³
1	D-57	710
2	Mix No. 1 with Lansing Fly Ash	604
3	Mix No. 1 with Ottumwa Fly Ash	604
4	Mix No. 1 with Clinton Fly Ash	604
5	D-57 with Plastiment 100	710
6	Mix No. 5 with Lansing Fly Ash	604
7	Mix No. 5 with Ottumwa Fly Ash	604
8	Mix No. 5 with Clinton Fly Ash	604
9	D-57 with Pozzolith 100XR	710
10	Mix No. 9 with Lansing Fly Ash	604
11	Mix No. 9 with Ottumwa Fly Ash	604
12	Mix No. 9 with Clinton Fly Ash	604

C. <u>Fly Ash Substitution Rates:</u>

Fly ash was substituted for 15%, 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 D-57 mix, the volumes are 50% fine aggregate, 50% coarse aggregate.

D. <u>Aggregate Gradation</u>

The coarse aggregate gradation was:

Sieve No.	% Passing
1.0"	100
3/4"	89
1/2"	40
3/8"	8.0
No. 4	0.8
No. 8	0.4

E. <u>Concrete Controls</u>

Concrete mixes were controlled to a slump of 2.0" ± 1/2" and air content of 6.0% ± 0.5%.

F. Concrete Tests

The investigation of the effects of aggregate and fly ash sources on concrete strength and durability was accomplished by preparing test specimens in the laboratory. These specimens were made from a D-57 concrete mix with a cement content of 710 lb./yd^3 as defined in the standard specifications series of 1984 1/. The variables in the mixes were aggregate source, fly ash source, the substitution ratio (pounds of fly ash added for each pound of portland cement removed). The specifications referenced above designate the proportions of portland cement-water-aggregate to be used in the mixes studied. They also itemize the slump and entrained air content (see Appendix A). The former is achieved by varying the water added and the latter by varying the amount of air entraining agent added.

The actual procedure, as to preparation and mixing of the ingredients, was as outlined in ASTM C-192 2/ "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 3/ "Method of Test for Compressive Strength of Molded Concrete Cylinders" (see Appendix B). This is a test similar to AASHTO test procedure T-22 4/. A total of nine 4-1/2" x 9" horizontal cylinders were cast from each batch of concrete. 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 concretes containing the various ashes and aggregates was done according to Iowa Test Method 408A

3/ "Method of Test for Determining the Resistance of Concrete to Rapid Freezing and Thawing" (see Appendix C). This test is a modification of ASTM C-666 Procedure B 2/ in that the 4" x 4" 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" x 4" x 18" 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 with periodic sonic modulus and change in length readings taken twice a week. This was continued until they had undergone 300 cycles of freezing and thawing or until the specimen's relative dynamic modulus of elasticity reached 60% of the initial modulus, whichever occurs first.

The coarse aggregates used in the concrete currently are approved as Class III durability aggregates which will produce concrete with an expected maximum service life.

TEST RESULTS AND INTERPRETATION

Compressive Strength and Durability

Table No. 1 shows the concrete mix characteristics and compressive strength results for the D-57 mix. The strength values for the various combinations of materials are graphically presented in Figures 1-3. Each strength value indicated is the average of three cylinders. Strength comparisons are also depicted graphically in Figures 4-6 to show the relative strengths of the mixes at 7, 28 and 56 days. In most cases, with few exceptions, the concrete containing fly ash exhibited higher compressive strengths than the corresponding control concretes without the fly ash. The exceptions were the 7, 28 and 56 days of the mixes containing the Class "F" ash from Clinton. In summary, acceptable concrete strengths can be produced using either Class "C" or "F" ash provided the proper substitution ratio and percent replacement is used.

Table No. 2 itemizes the freeze/thaw durability characteristics for the concrete studied. There was no significant difference in the frost resistance of any of the concretes studied. The results of the durability factors in combination with the three ashes and retarding admixtures used in this evaluation study are shown in Figures 7-9. The expansion factors of the same combinations are graphically presented in Figures 10-12.

Air Content of Fly Ash Concrete

It should be noted that one of the common problems which has been encountered with the use of fly ash in concrete is the effect on entrained air content. Failure to increase the amount of air entraining agent to compensate for the negative effect of the presence of fly ash can produce concrete with a lower than desired air content. This can then result in the premature failure of concrete due to the action of freezing and thawing processes.

Observations made during the preparation of the concrete mixes discussed in this report indicate that the necessary increase in air entraining agent is less when using Class "C" ash than when using Class "F" ash. The actual required increase in air entraining agent of the vinsol resin type varies proportionally with the amount of ash and cement in the concrete. In the case of a 15% cement replacement, the necessary increase has been approximately 8-10% for Class "F" ash and 5-8% for Class "C" ash.

Setting Time of Fly Ash Concrete

Since Class "F" and Class "C" ashes have markedly different cementitious properties, the resultant effect on setting time has been of concern. Therefore, time-of-set determinations, ASTM C-403 2/ were made on all of the concrete mixes used in this study. The time-of-set determinations were made on each set of four identical concretes (Lansing, Ottumwa, Clinton and the Control) along with the two different retarding admixtures used in this study. Table No. 3 and Figures 13-15 show the initial and final setting times for the concretes studied.

Table No. 1
Compressive Strength
Bridge Deck Concrete
D-57 Mix

Mix No.	Fly Ash Source	Fly Ash Class	Aggregate Source	Retarding Admixture Brand	Slump Inches	Air Content %	W/C Ratio lb/lb	W/C+F.A. Ratio lb/lb	Compressive Strength PSI 7-day	28-day	56-day
1	Control	---	Ft. Dodge Stone Hallett Sand	None	2.00	6.3	0.392	-----	5170	6580	7300
2	Lansing	C	Ft. Dodge Stone Hallett Sand	None	2.25	6.3	0.437	0.371	5210	6140	7510
3	Ottumwa	C	Ft. Dodge Stone Hallett Sand	None	2.25	6.0	0.444	0.375	5240	6800	7400
4	Clinton	F	Ft. Dodge Stone Hallett Sand	None	2.25	6.2	0.463	0.367	4540	5760	6750
5	Control	---	Ft. Dodge Stone Hallett Sand	Plastiment 100	2.00	6.3	0.370	-----	5660	6840	7830
6	Lansing	C	Ft. Dodge Stone Hallett Sand	Plastiment 100	2.25	6.0	0.407	0.346	5840	7700	8520
7	Ottumwa	C	Ft. Dodge Stone Hallett Sand	Plastiment 100	2.50	6.3	0.407	0.346	5720	7600	8040
8	Clinton	F	Ft. Dodge Stone Hallett Sand	Plastiment 100	2.00	6.3	0.429	0.352	5320	6820	7850
9	Control	---	Ft. Dodge Stone Hallett Sand	Pozzolith 100XR	2.00	6.2	0.370	-----	6150	7620	7880
10	Lansing	C	Ft. Dodge Stone Hallett Sand	Pozzolith 100XR	2.25	6.3	0.407	0.346	5700	7650	8320
11	Ottumwa	C	Ft. Dodge Stone Hallett Sand	Pozzolith 100XR	2.00	6.0	0.410	0.349	6340	7780	8200
12	Clinton	F	Ft. Dodge Stone Hallett Sand	Pozzolith 100XR	2.50	6.0	0.433	0.355	4790	7040	7340

Figure 1

COMPRESSIVE STRENGTH

BRIDGE DECK CONCRETE D-57 MIX

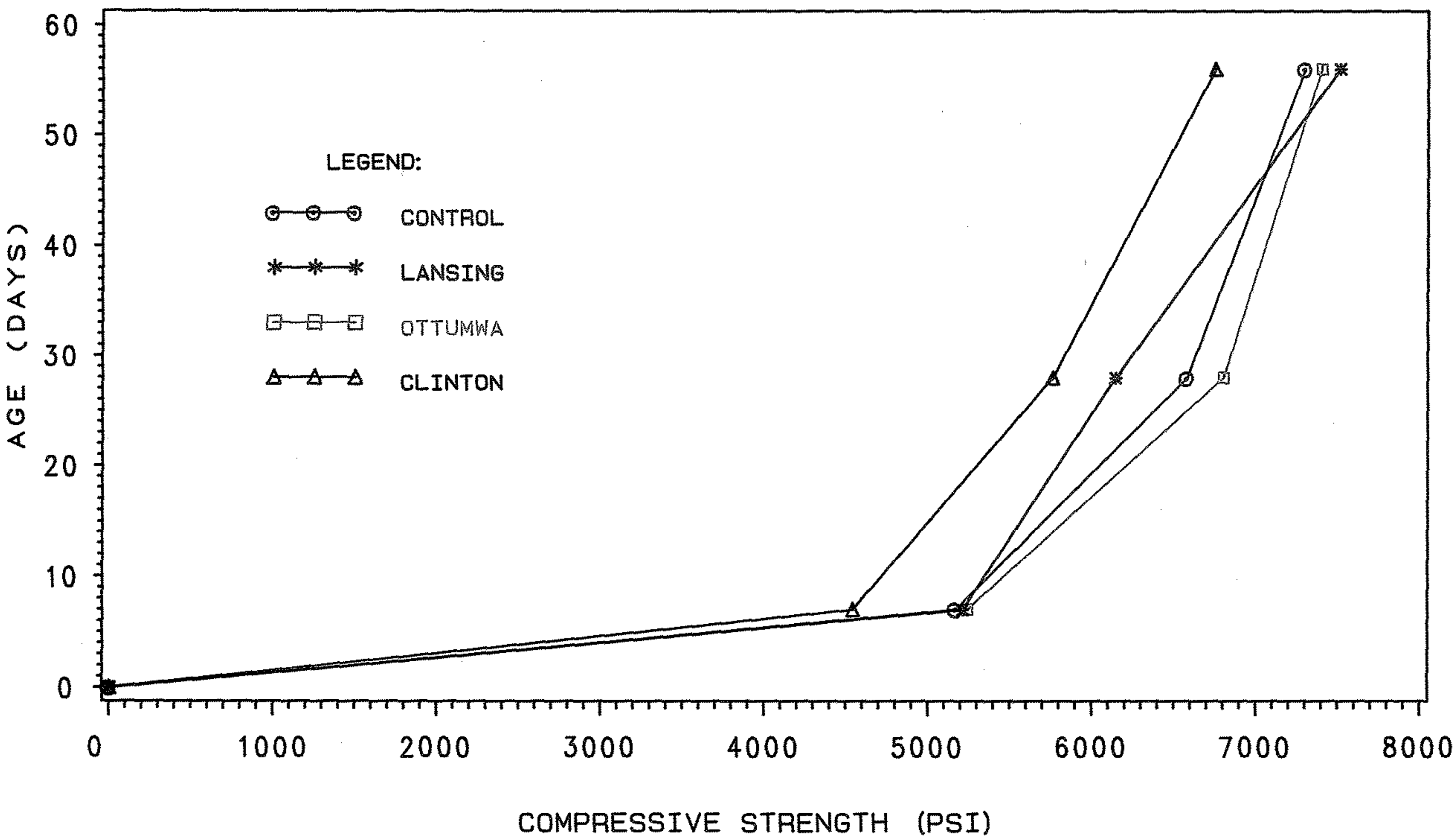


Figure 2

COMPRESSIVE STRENGTH

BRIDGE DECK CONCRETE D-57 MIX WITH PLASTIMENT 100

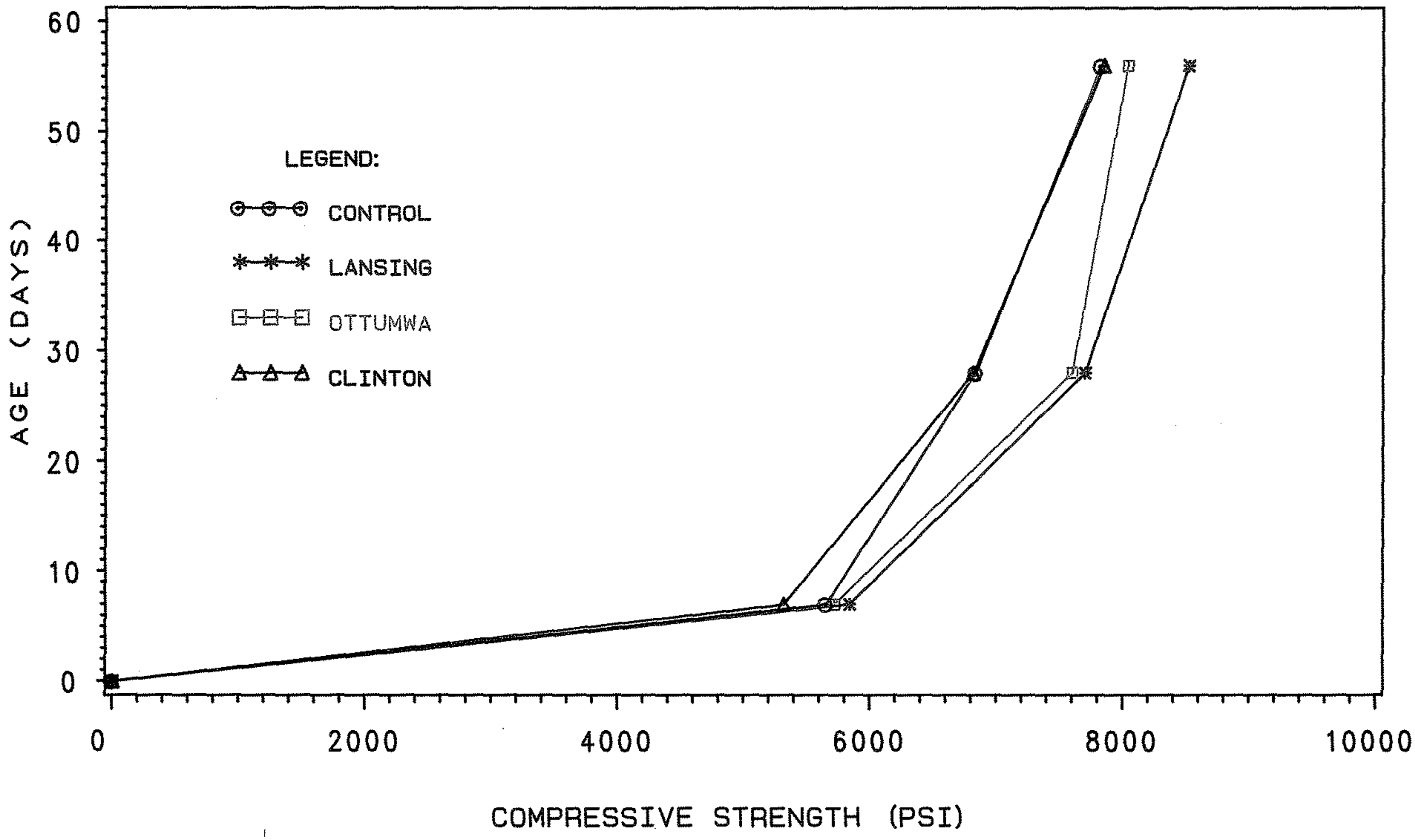


Figure 3

COMPRESSIVE STRENGTH

BRIDGE DECK CONCRETE D-57 MIX WITH POZZOLITH 100 XR

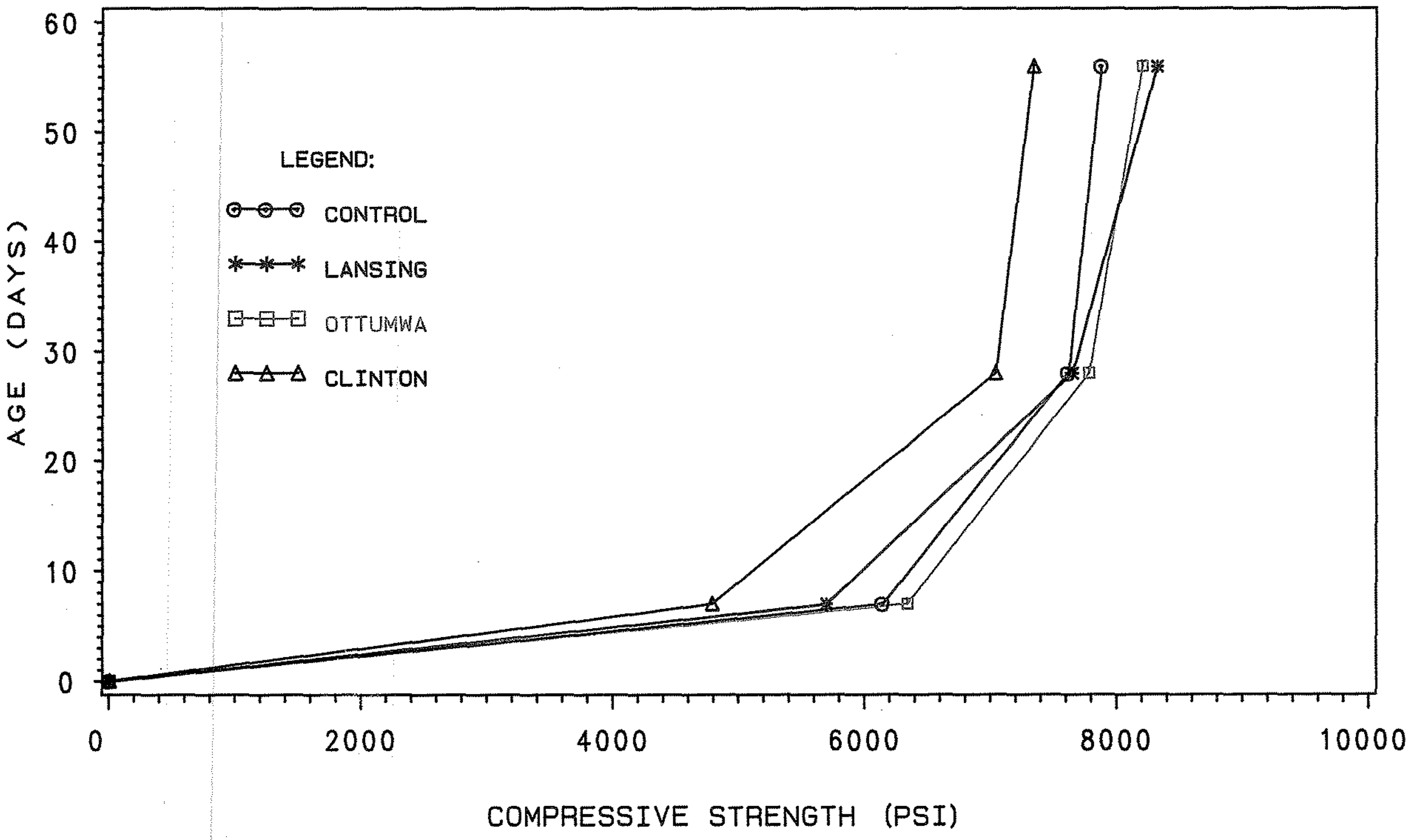


Figure 4

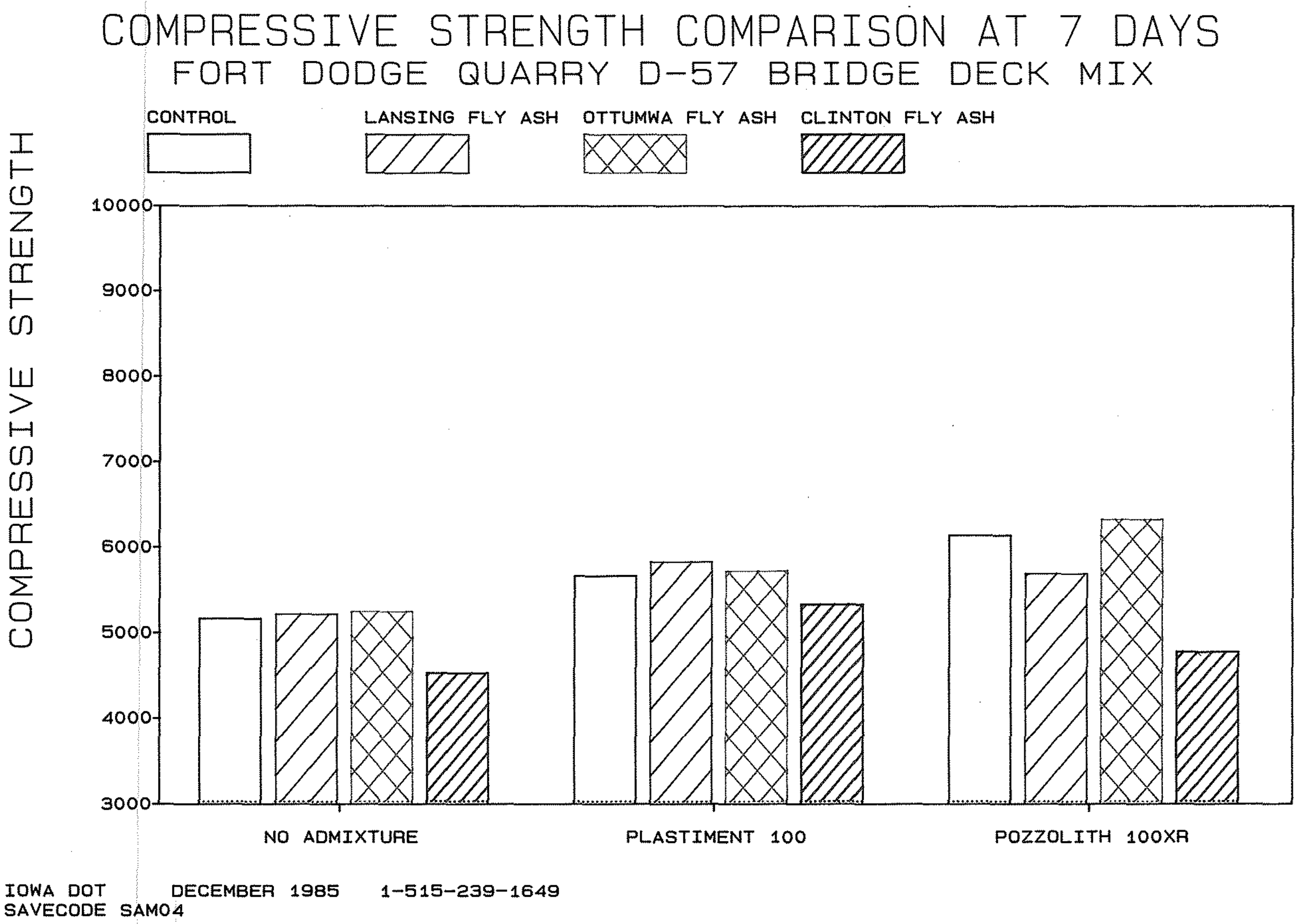

COMPRESSIVE STRENGTH COMPARISON AT 7 DAYS
FORT DODGE QUARRY D-57 BRIDGE DECK MIX
CONTROL
LANSING FLY ASH
OTTUMWA FLY ASH
CLINTON FLY ASH
COMPRESSIVE STRENGTH
10000
9000
8000
7000
6000
5000
4000
3000
NO ADMIXTURE
PLASTIMENT 100
POZZOLITH 100XR
IOWA DOT DECEMBER 1985 1-515-239-1649
SAVECODE SAM04

Figure 5

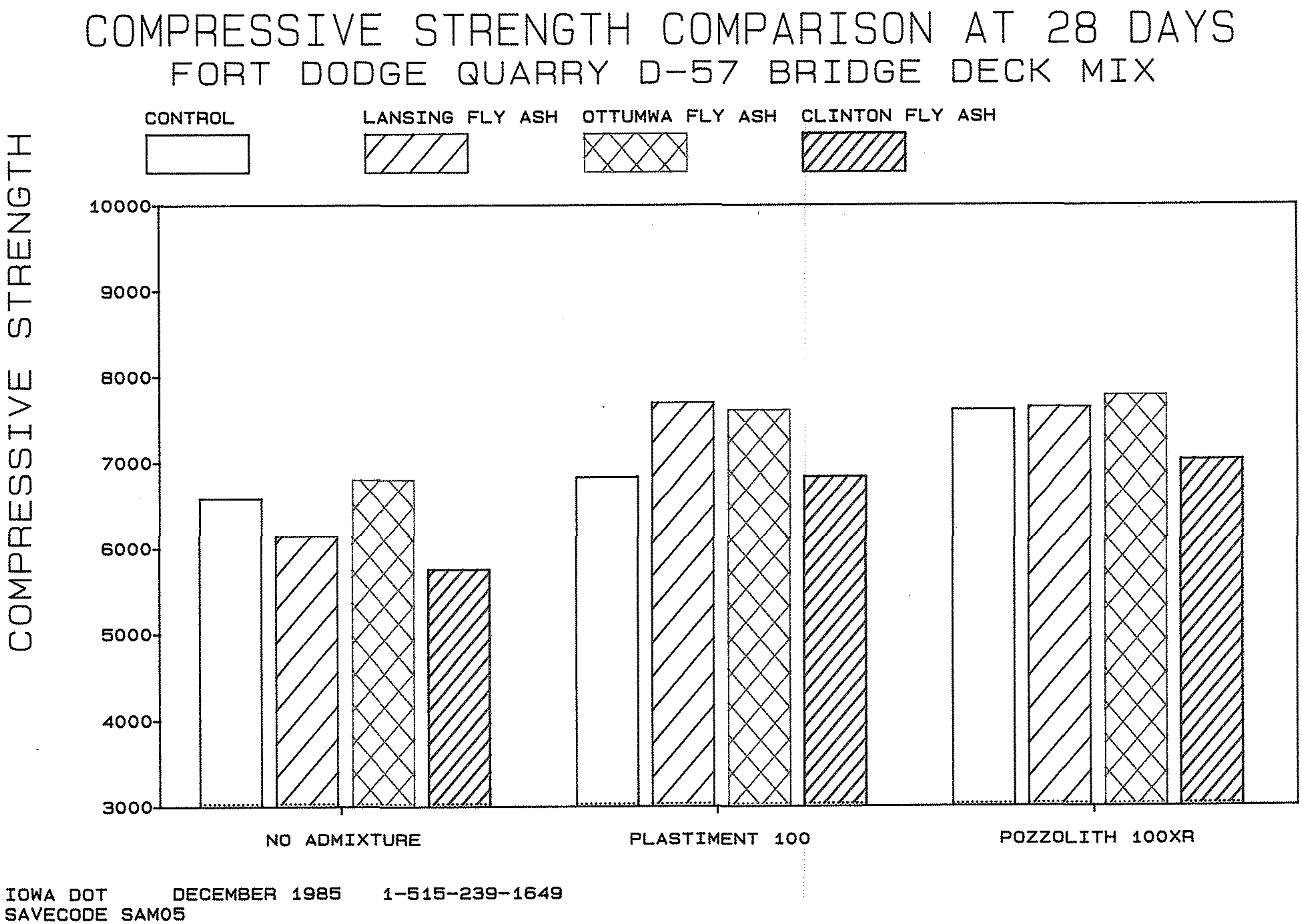

COMPRESSIVE STRENGTH COMPARISON AT 28 DAYS
FORT DODGE QUARRY D-57 BRIDGE DECK MIX
CONTROL
LANSING FLY ASH
OTTUMWA FLY ASH
CLINTON FLY ASH
COMPRESSIVE STRENGTH
10000
9000
8000
7000
6000
5000
4000
3000
NO ADMIXTURE
PLASTIMENT 100
POZZOLITH 100XR
IOWA DOT DECEMBER 1985 1-515-239-1649
SAVECODE SAM05

Figure 6

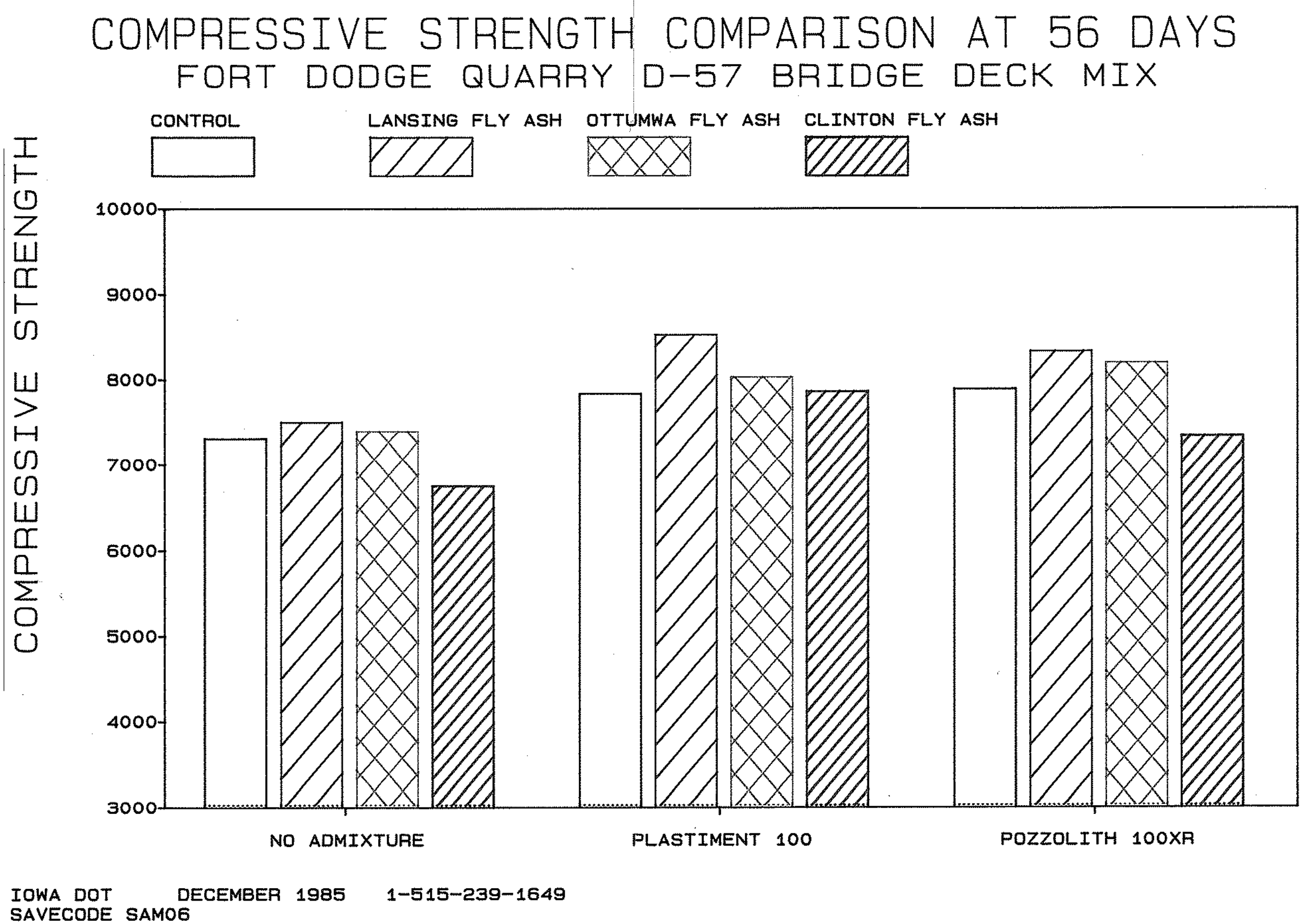

COMPRESSIVE STRENGTH COMPARISON AT 56 DAYS
FORT DODGE QUARRY D-57 BRIDGE DECK MIX
CONTROL
LANSING FLY ASH
OTTUMWA FLY ASH
CLINTON FLY ASH
COMPRESSIVE STRENGTH
10000
9000
8000
7000
6000
5000
4000
3000
NO ADMIXTURE
PLASTIMENT 100
POZZOLITH 100XR
IOWA DOT DECEMBER 1985 1-515-239-1649
SAVECODE SAM06

Table No. 2
Durability
Bridge Deck Concrete
D-57 Mix

Mix No.	Fly Ash Source	Fly Ash Class	Aggregate Source	Retarding Admixture Brand	Slump Inches	Air Content %	W/C Ratio lb/lb	W/C+F.A. Ratio lb/lb	Durability Factor %	Expansion %
1	Control	---	Weeping Water Stone Bellevue Sand	None	2.00	6.3	0.380	-----	97	0.011
2	Lansing	C	Weeping Water Stone Bellevue Sand	None	2.25	6.0	0.433	0.367	95	0.016
3	Ottumwa	C	Weeping Water Stone Bellevue Sand	None	2.25	6.2	0.425	0.361	95	0.012
4	Clinton	F	Weeping Water Stone Bellevue Sand	None	2.00	6.4	0.455	0.354	94	0.011
5	Control	---	Weeping Water Stone Bellevue Sand	Plastiment 100	2.00	6.2	0.342	-----	96	0.011
6	Lansing	C	Weeping Water Stone Bellevue Sand	Plastiment 100	2.00	6.2	0.403	0.342	96	0.012
7	Ottumwa	C	Weeping Water Stone Bellevue Sand	Plastiment 100	2.00	5.9	0.396	0.335	95	0.016
8	Clinton	F	Weeping Water Stone Bellevue Sand	Plastiment 100	2.00	5.9	0.425	0.348	96	0.019
9	Control	---	Weeping Water Stone Bellevue Sand	Pozzolith 100XR	2.00	6.3	0.392	-----	96	0.010
10	Lansing	C	Weeping Water Stone Bellevue Sand	Pozzolith 100XR	2.25	6.0	0.403	0.342	96	0.011
11	Ottumwa	C	Weeping Water Stone Bellevue Sand	Pozzolith 100XR	2.00	6.0	0.410	0.348	95	0.008
12	Clinton	F	Weeping Water Stone Bellevue Sand	Pozzolith 100XR	2.50	6.0	0.433	0.354	95	0.011

Figure 7

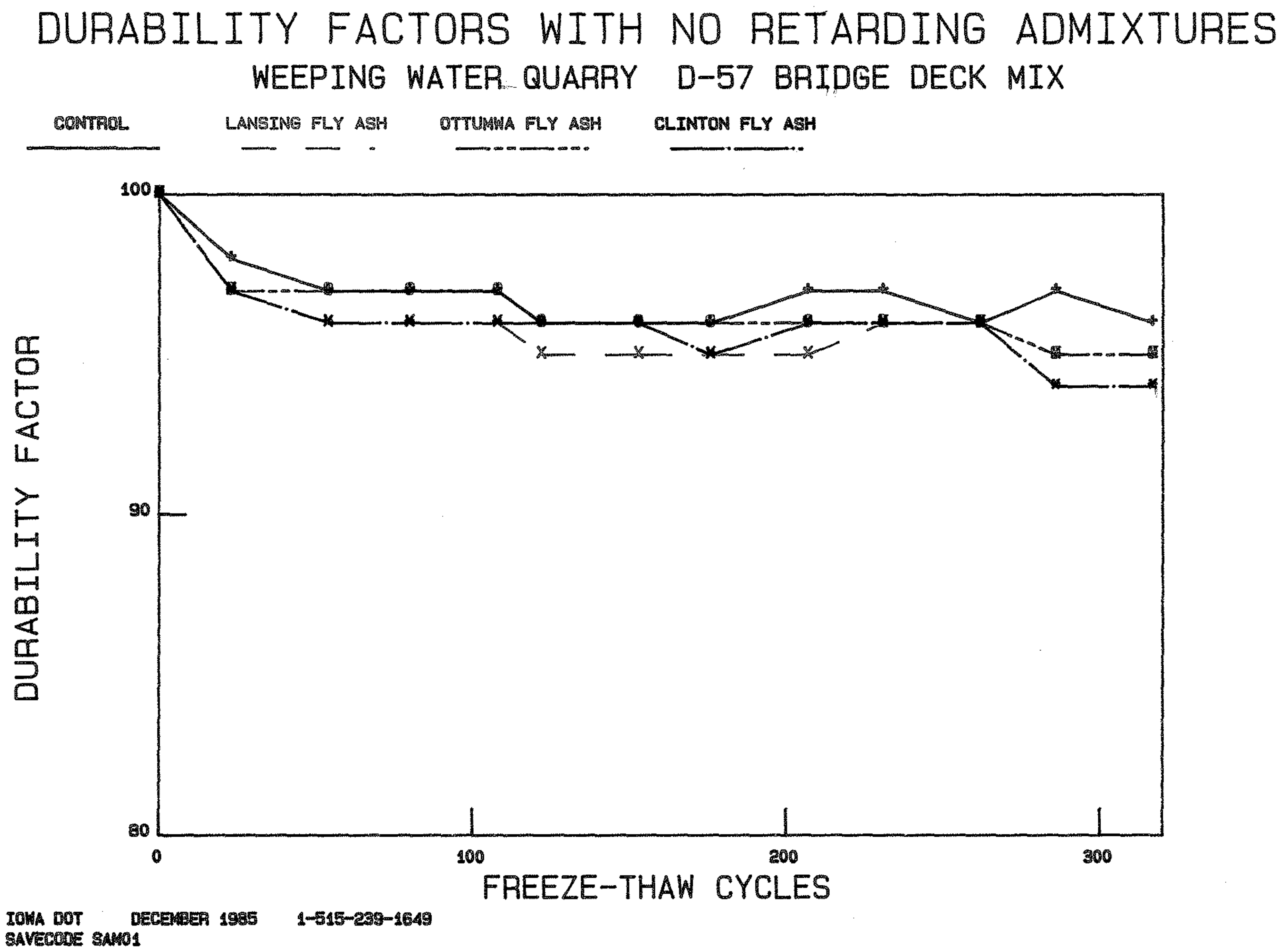
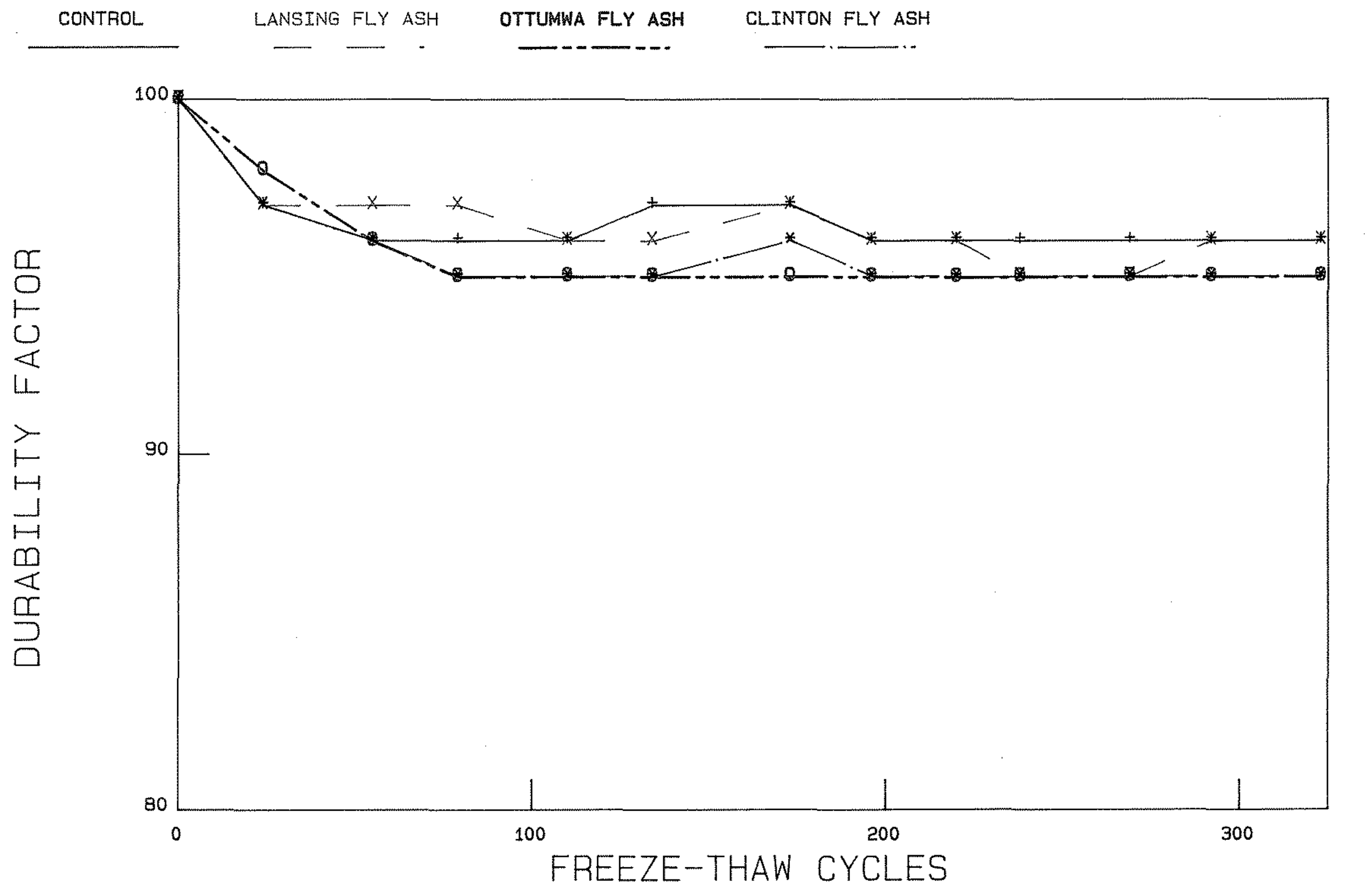

DURABILITY FACTORS WITH NO RETARDING ADMIXTURES
WEEPING WATER QUARRY D-57 BRIDGE DECK MIX
CONTROL
LANSING FLY ASH
OTTUMWA FLY ASH
CLINTON FLY ASH
DURABILITY FACTOR
100
90
80
0
100
200
300
FREEZE-THAW CYCLES
IOWA DOT DECEMBER 1985 1-515-239-1649
SAVECODE SAM01

Figure 8

DURABILITY FACTORS WITH RETARDING ADMIXTURE

(PLASTIMENT 100)

WEEPING WATER QUARRY D-57 BRIDGE DECK MIX



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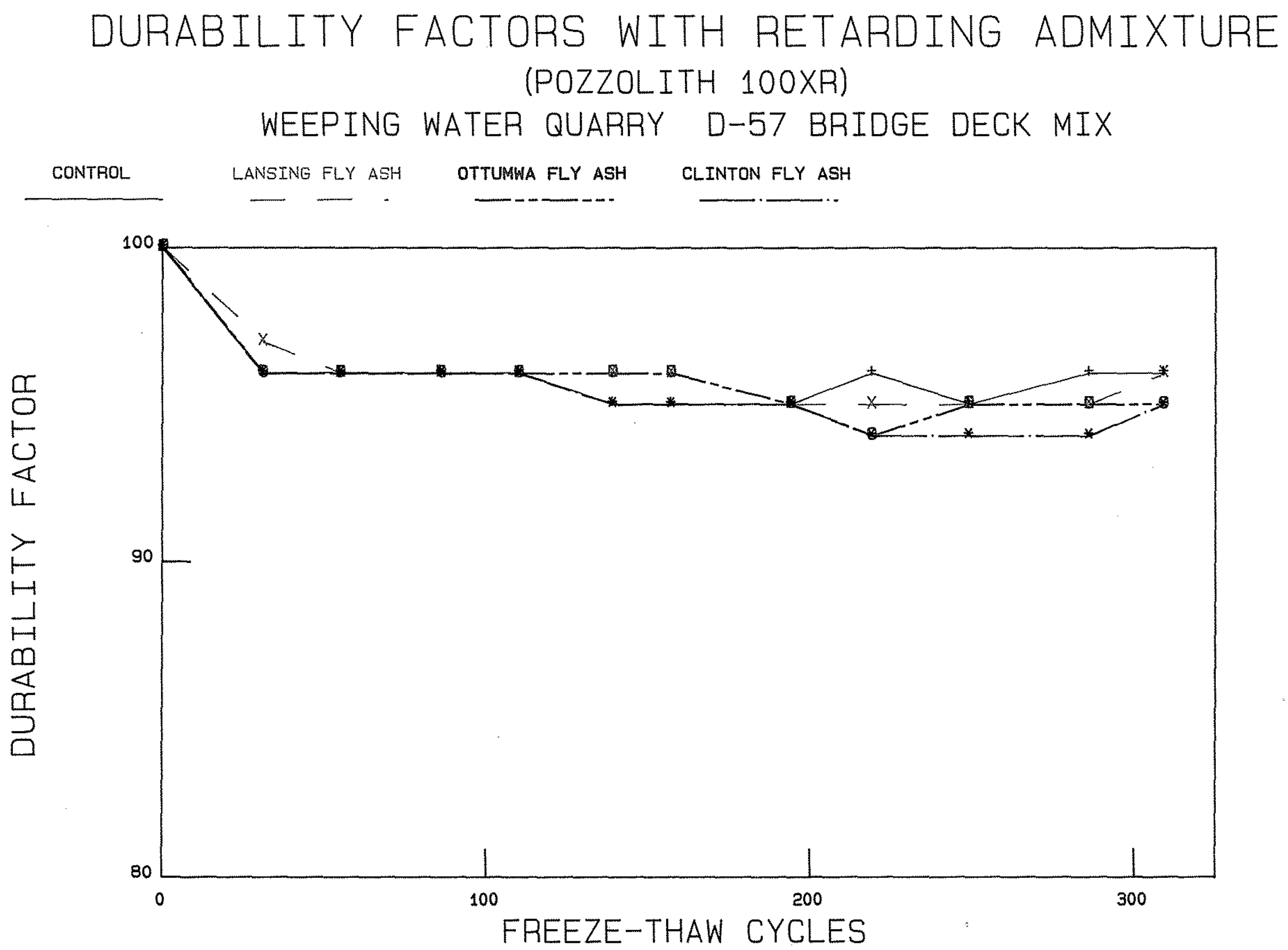
SAVECODE SAM02

Figure 9



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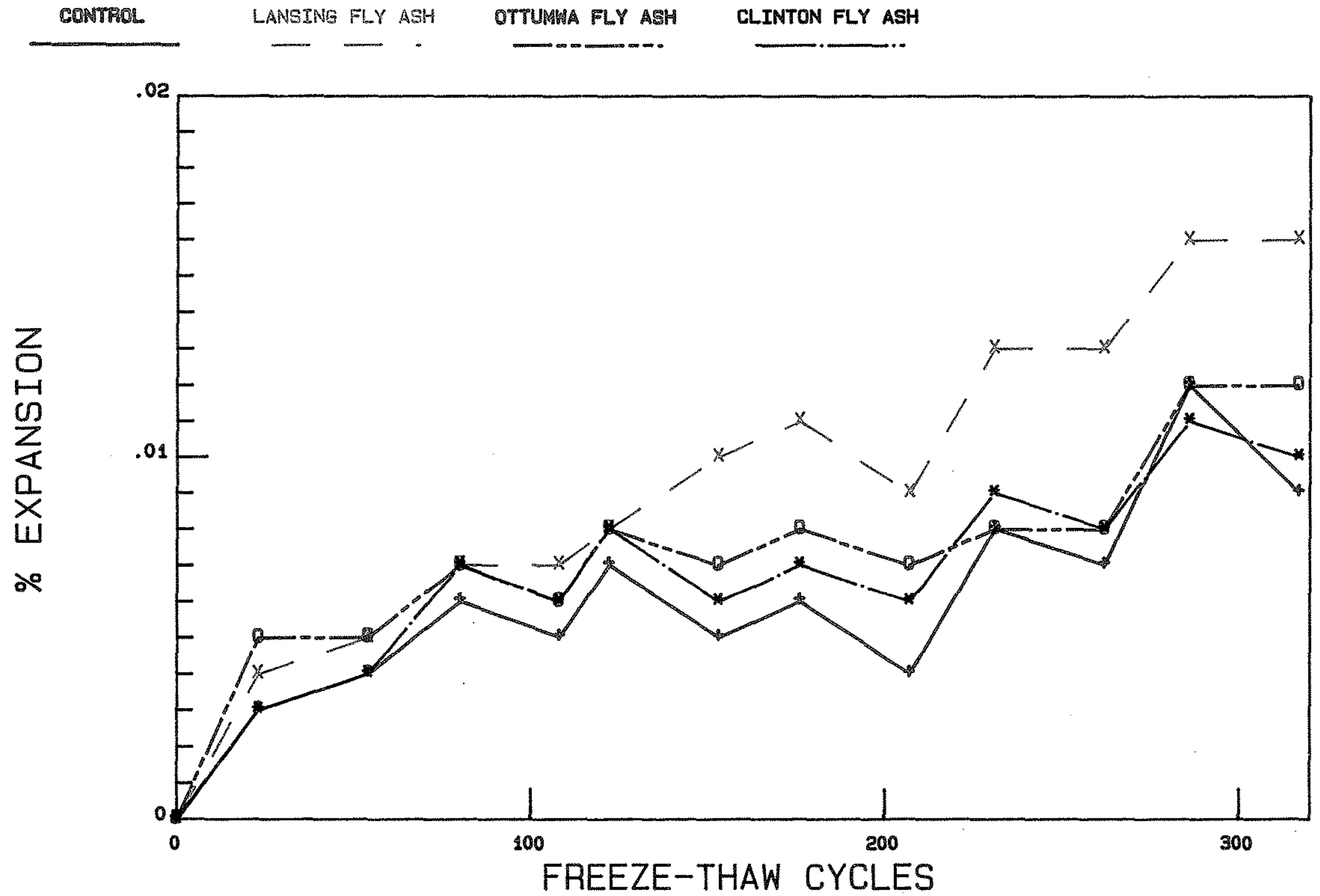
SAVECODE SAM03

Figure 10

EXPANSION FACTORS WITH NO RETARDING ADMIXTURES
WEEPING WATER QUARRY D-57 BRIDGE DECK MIX



IOWA DOT DECEMBER 1985 1-515-239-1649
SAVECODE SAM01

Figure 11

EXPANSION FACTORS WITH RETARDING ADMIXTURES

(PLASTIMENT 100)

WEEPING WATER QUARRY D-57 BRIDGE DECK MIX

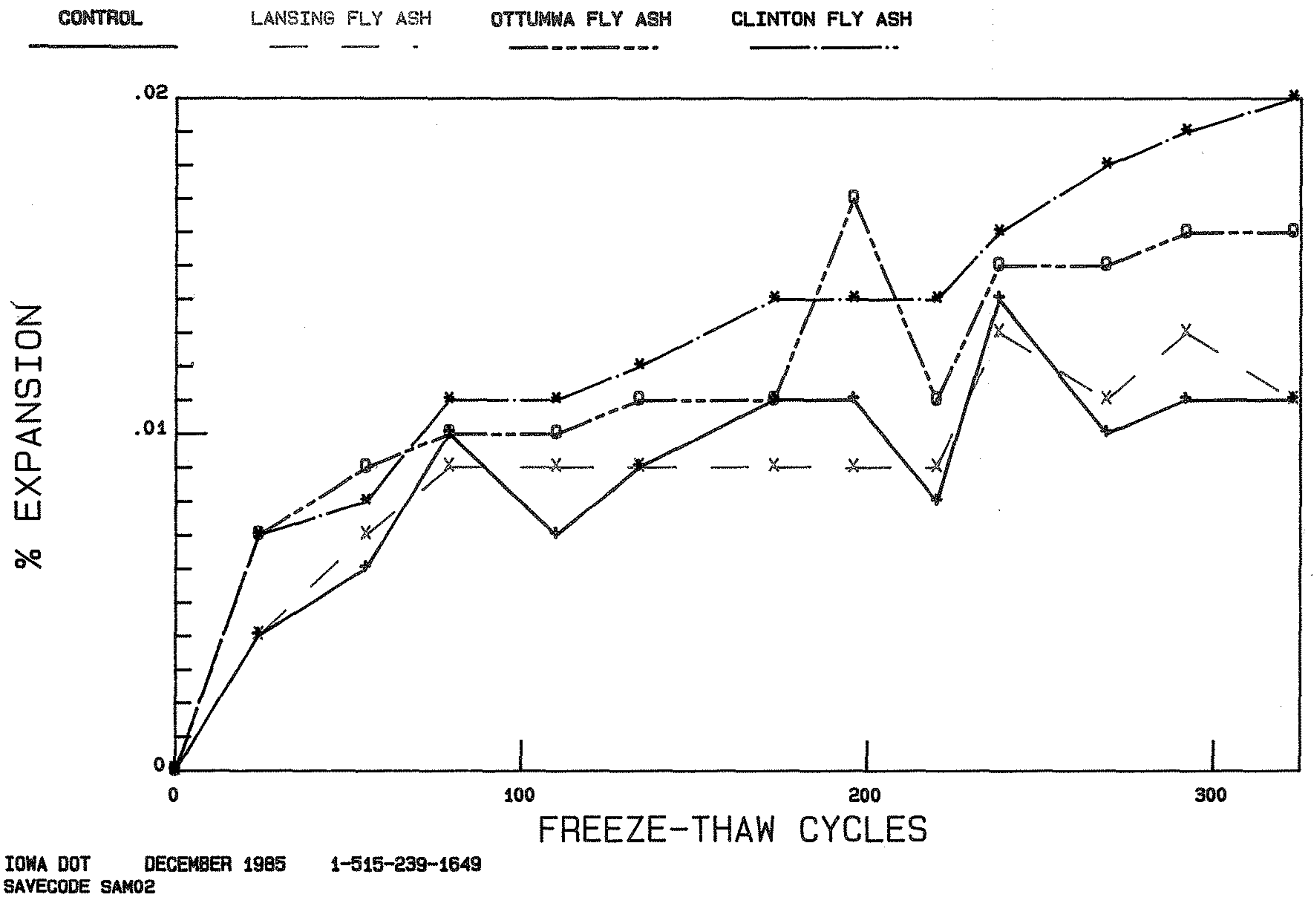


Figure 12

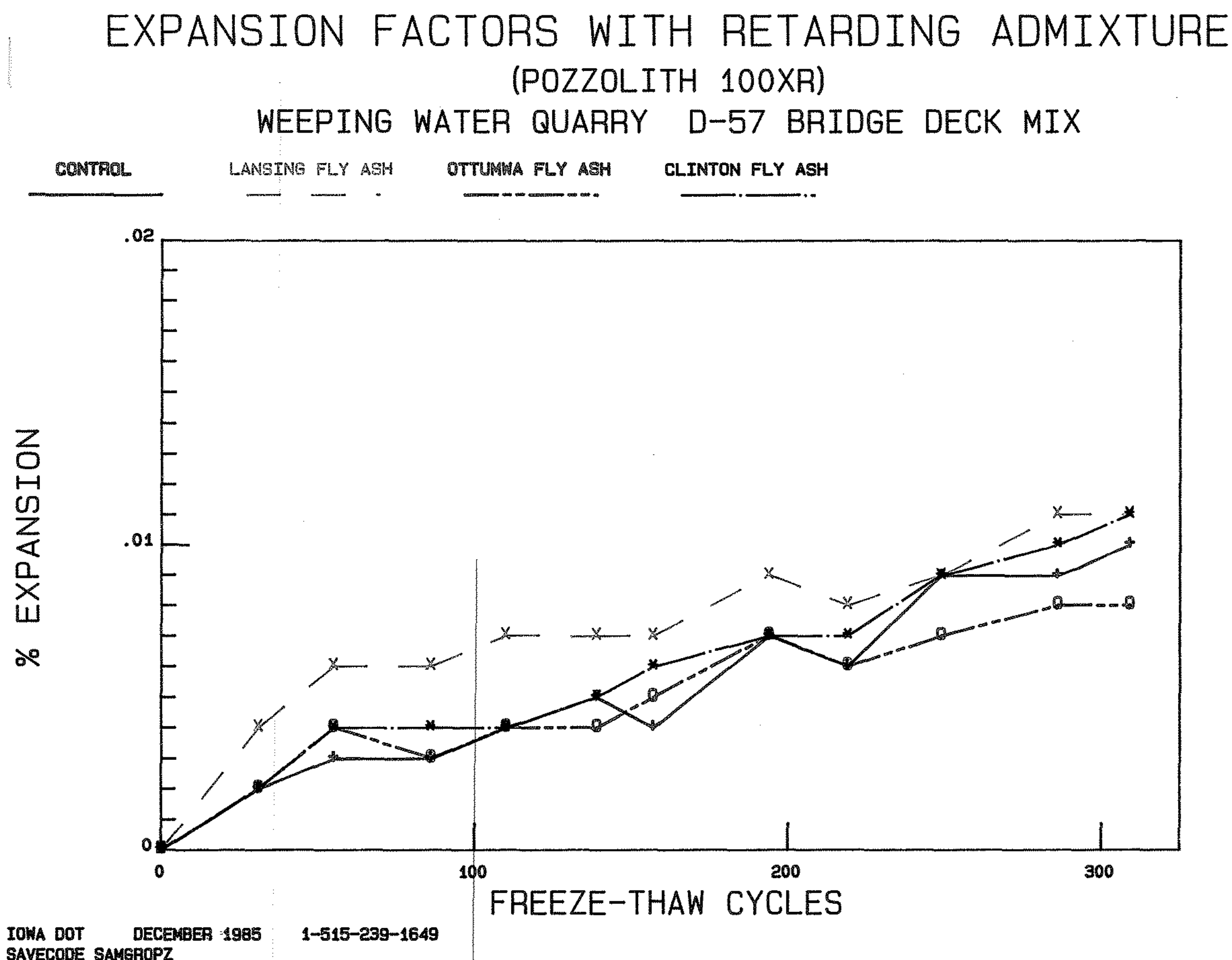

EXPANSION FACTORS WITH RETARDING ADMIXTURE
(POZZOLITH 100XR)
WEEPING WATER QUARRY D-57 BRIDGE DECK MIX
CONTROL
LANSING FLY ASH
OTTUMWA FLY ASH
CLINTON FLY ASH
% EXPANSION
.02
.01
0
0
100
200
300
FREEZE-THAW CYCLES
IOWA DOT DECEMBER 1985 1-515-239-1649
SAVECODE SAMGROPZ

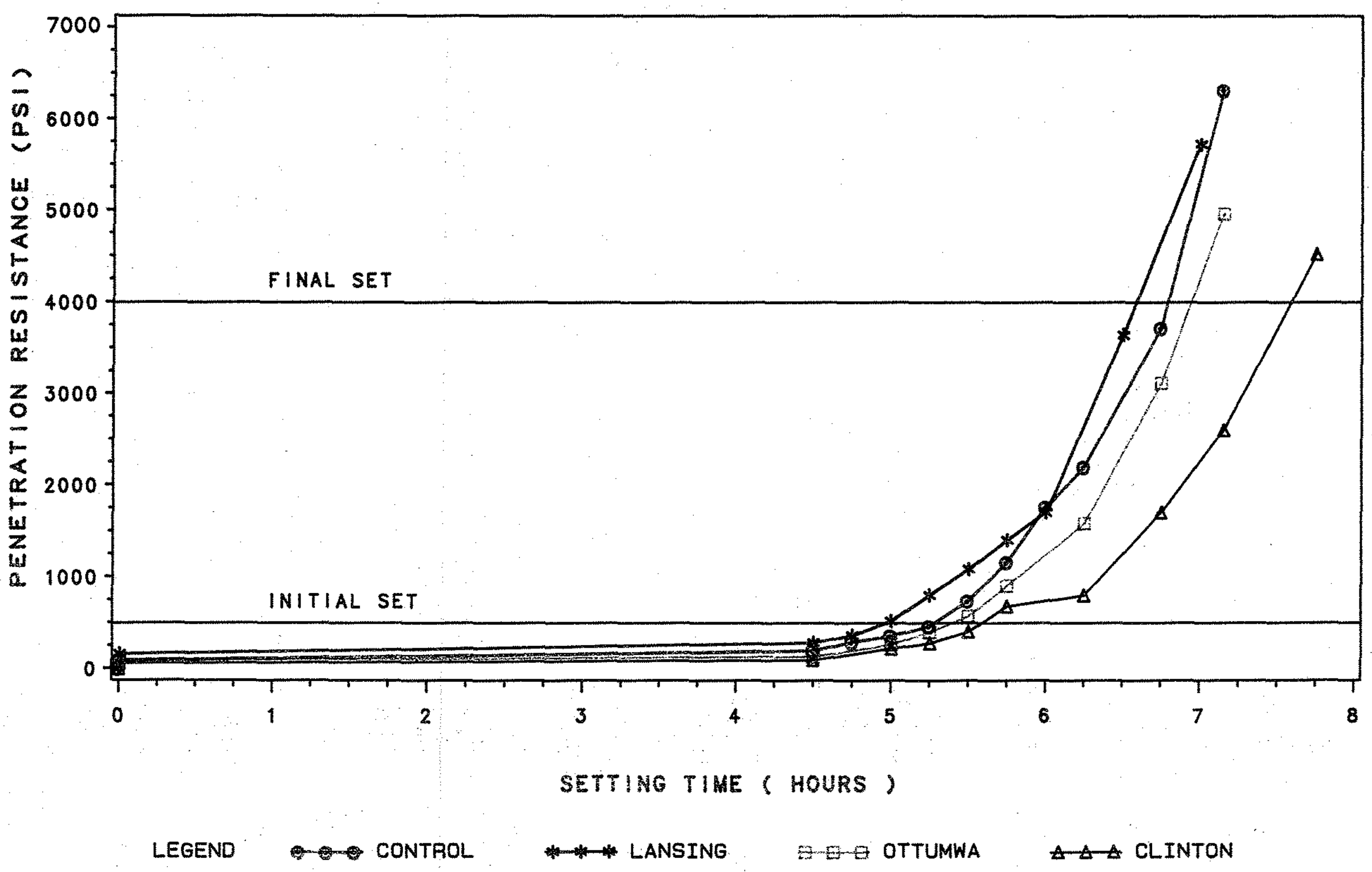
Table No. 3
Setting Time
Bridge Deck Concrete
D-57 Mix

Mix No.	Fly Ash Source	Fly Ash Class	Retarding Admixture Brand	Setting Time Initial	Setting Time Final	% Retardation (Acceleration) Initial	% Retardation (Acceleration) Final
1	Control	---	None	3 hrs. 5 min.	4 hrs. 10 min.	----	----
2	Lansing	C	None	3 hrs. 35 min.	4 hrs. 50 min.	16.2	16.0
3	Ottumwa	C	None	3 hrs. 10 min.	4 hrs. 25 min.	2.7	6.0
4	Clinton	F	None	3 hrs. 20 min.	4 hrs. 45 min.	8.1	14.0
5	Control	---	Plastiment 100	4 hrs. 50 min.	6 hrs. 35 min.	----	----
6	Lansing	C	Plastiment 100	4 hrs. 45 min.	6 hrs. 30 min.	(-1.8)	(-1.3)
7	Ottumwa	C	Plastiment 100	4 hrs. 55 min.	6 hrs. 25 min.	1.7	(-2.6)
8	Clinton	F	Plastiment 100	5 hrs. 5 min.	6 hrs. 35 min.	4.9	0.0
9	Control	---	Pozzolith 100XR	5 hrs. 5 min.	6 hrs. 55 min.	----	----
10	Lansing	C	Pozzolith 100XR	4 hrs. 50 min.	6 hrs. 35 min.	(-5.2)	(-5.1)
11	Ottumwa	C	Pozzolith 100XR	5 hrs. 15 min.	7 hrs. 0 min.	3.2	1.2
12	Clinton	F	Pozzolith 100XR	5 hrs. 30 min.	7 hrs. 40 min.	7.6	9.8

Figure 15

EVALUATION OF FLYASH IN BRIDGE DECK

D-57 MIX WITH POZZOLITH 100 XR



Conclusions and Discussion

Based on the data gathered in this study, the following conclusions are obtained:

1. The class and source of the fly ash have a limited affect on the strength of the concrete. When Class "C" ashes were used, the compressive strengths were not affected and when Class "F" ash was used, the strengths were slightly lower.

2. The compressive strength and durability of Class D-57 bridge deck concrete mixes modified with fly ash are equivalent to the standard D-57 mix when 15% of the portland cement is replaced with ASTM C-618 quality, Class "C" fly ash at the rate of 1:1 (each pound of ash added for each pound of cement deleted).

3. The compressive strength and durability of Class D-57 bridge deck concrete mixes modified with fly ash are approximately equivalent to the standard D-57 mix when 15% of the portland cement is replaced with 1.25:1 ASTM C-618 quality, Class "F" fly ash at the rate of (each 1-1/4 pounds of ash added for each pound of cement deleted).

4. Class III durability aggregates should be specified when fly ash is to be used. The aggregate sources selected for this study were a representative of the category of Class III aggregates. The satisfactory performance of these aggregates leads us to the conclusion that the test results obtained support our present position of 15% substitution when good quality fly ash is used with Class III durability aggregate. Previous studies have shown

Figure 13

EVALUATION OF FLYASH IN BRIDGE DECK

D-57 MIX

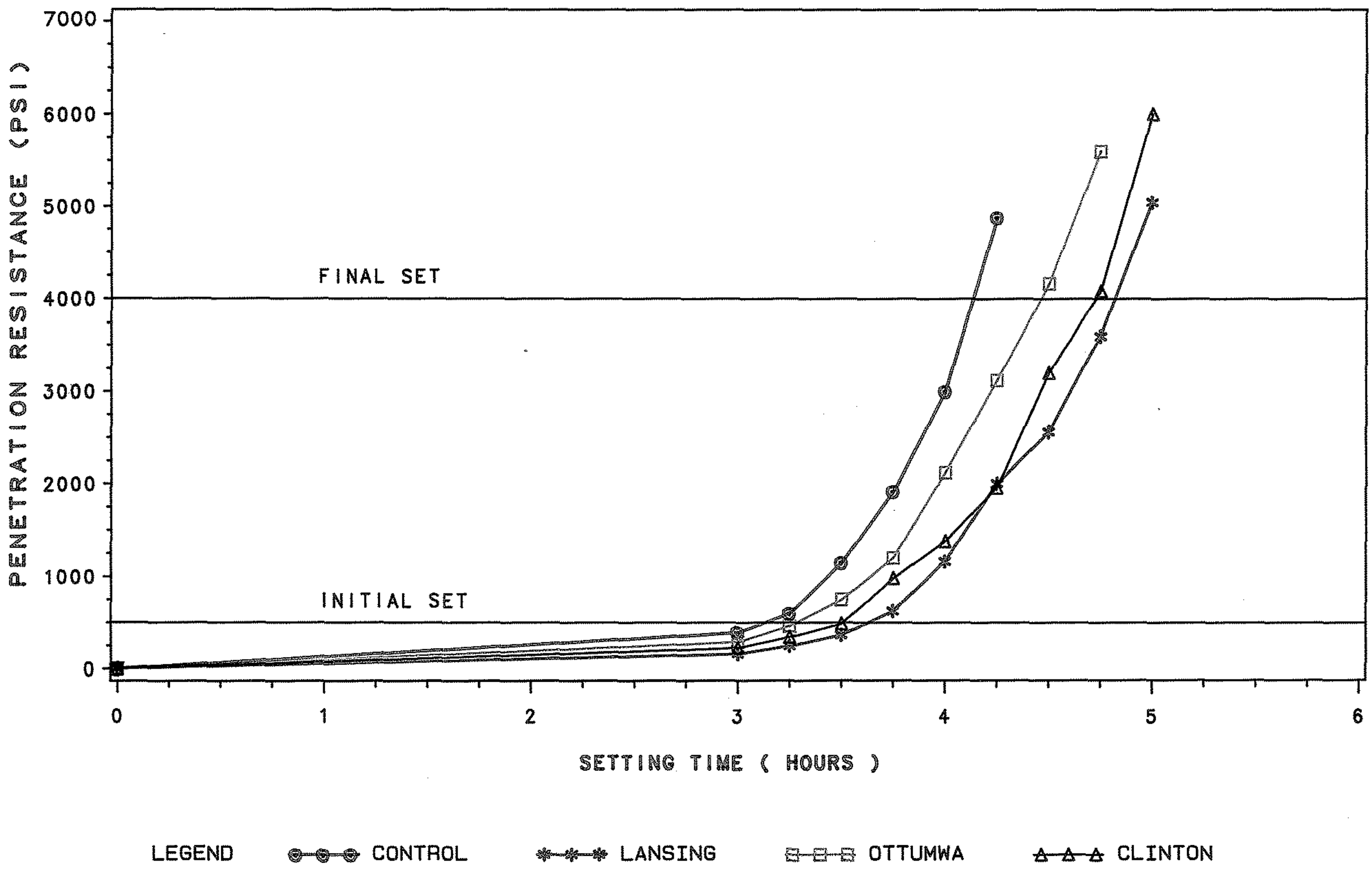


Figure 14

EVALUATION OF FLYASH IN BRIDGE DECK

D-57 MIX WITH PLASTIMENT 100

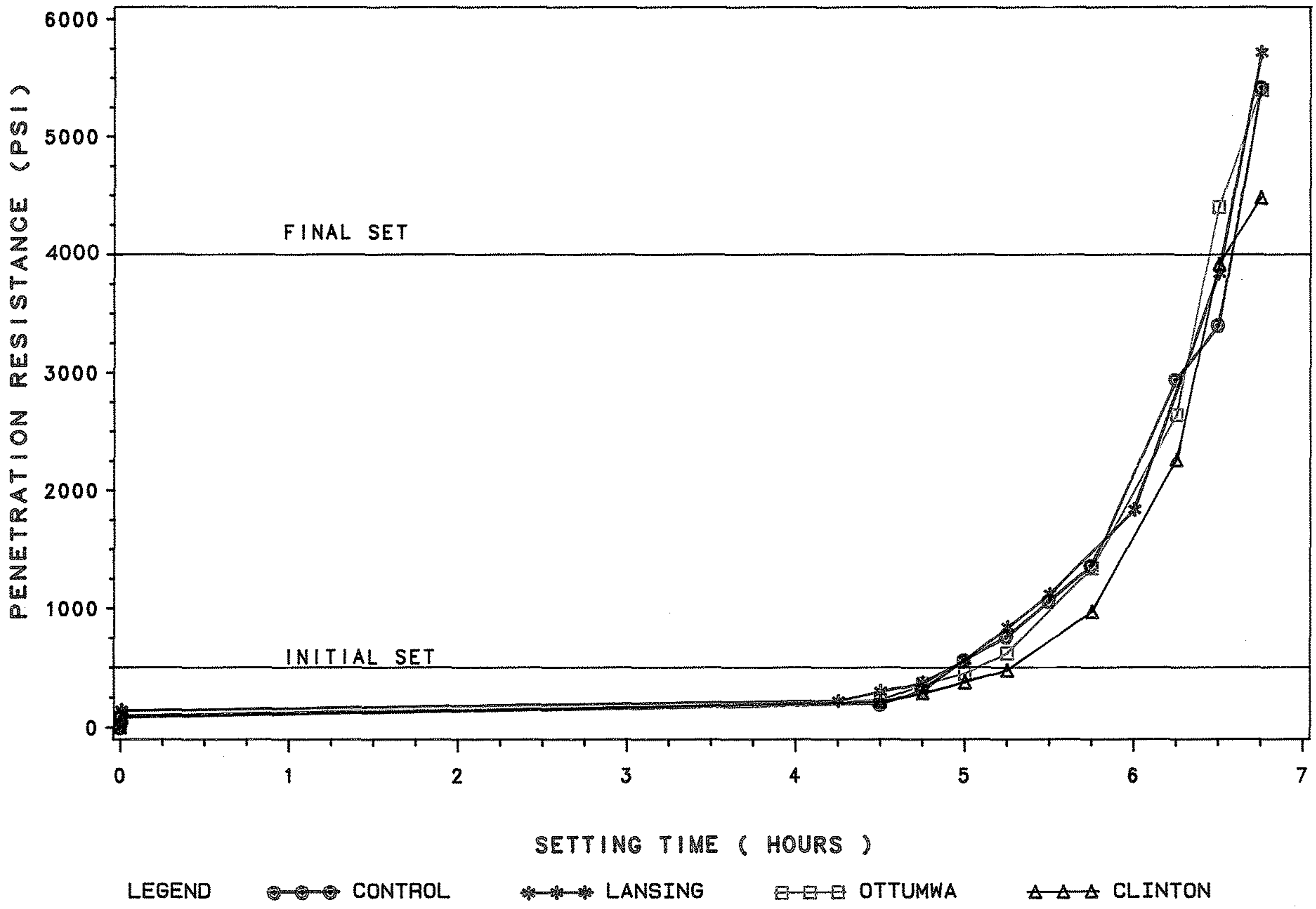
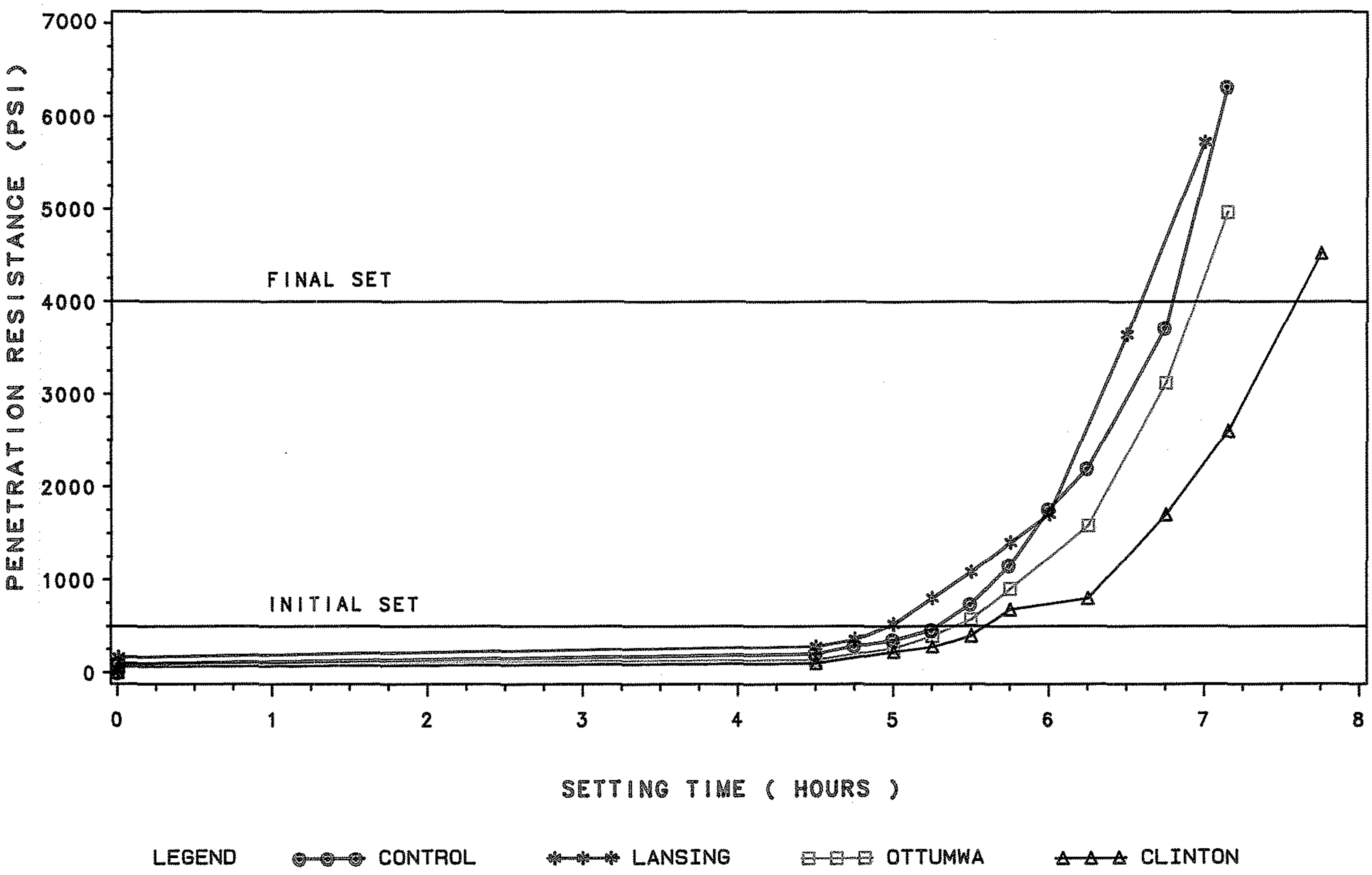


Figure 15

EVALUATION OF FLYASH IN BRIDGE DECK

D-57 MIX WITH POZZOLITH 100 XR



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2. The compressive strength and durability of Class D-57 bridge deck concrete mixes modified with fly ash are equivalent to the standard D-57 mix when 15% of the portland cement is replaced with ASTM C-618 quality, Class "C" fly ash at the rate of 1:1 (each pound of ash added for each pound of cement deleted).

3. The compressive strength and durability of Class D-57 bridge deck concrete mixes modified with fly ash are approximately equivalent to the standard D-57 mix when 15% of the portland cement is replaced with 1.25:1 ASTM C-618 quality, Class "F" fly ash at the rate of (each 1-1/4 pounds of ash added for each pound of cement deleted).

4. Class III durability aggregates should be specified when fly ash is to be used. The aggregate sources selected for this study were a representative of the category of Class III aggregates. The satisfactory performance of these aggregates leads us to the conclusion that the test results obtained support our present position of 15% substitution when good quality fly ash is used with Class III durability aggregate. Previous studies have shown

that the durability of fly ash concrete can be adversely affected when certain coarse aggregates are used. The reasons for the potential accelerated deterioration are not completely known and more studies are underway to evaluate a larger cross-section of the present Class II aggregates to either substantiate or refute our present position.

5. The use of retarding admixtures with fly ash in the D-57 mix had no significant effects. There is no reason to suspect that any reaction between good quality fly ash and retarding admixtures meeting the ASTM C-494 Type B will result in lowered durability factors nor will it affect the strengths.

6. The freeze/thaw test, although expensive and time consuming, has proven time after time to be extremely versatile since it can be used to evaluate any type and combination of aggregate and each source may be judged by its performance rather than its geologic origin or geographic location.

7. The setting time of the concrete without the chemical retarders was delayed slightly by the use of fly ash. The setting times of the mixes containing the commercial retarders were altered slightly by the use of fly ash. The setting times of the various mixes, while varying somewhat, were not materially or consistently affected.

Recommendations

Based on the test results, the addition of fly ash as a replacement to concrete containing admixtures Type A or Type B can be accomplished without detrimental effects to the strength or freeze/thaw durability of concrete. This holds true as long as good durable, high quality aggregates such as Class III and the proper replacement percentages and substitution ratios are used.

These Class III aggregates are identified as superior aggregates that could be used without reservation in fly ash concrete and in concrete places where extended service life is required. Therefore, it is recommended that fly ash can be substituted for up to 15% of the portland cement in bridge deck concrete Class D-57 mixes; whether or not the mixes contain retarding admixtures and the use be limited to mixes containing Class III durability coarse aggregate. Fly ashes should be limited to materials from approved sources.

References

1. Iowa Department of Transportation, Standard Specifications for Highway and Bridge Construction, Series of 1984, Iowa Department of Transportation, Section 2403 "Structural Concrete".

2. ASTM (American Society for Testing and Materials), Annual Book of Standards, Section 4 Volume 04.02, Concrete and Mineral Aggregates ASTM 1984.

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

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

APPENDICES

Appendix A

Standard Specifications

Mix Proportions

Proportions for Structural Concrete (2403.03)

A. Proportions for Separate Fine and Coarse Aggregate

Basic Absolute Volumes of Materials
Per Unit Volume of Concrete*

Class	Mix No.	Cement Minimum	Water	Entr. Air	Fine Aggregate	Coarse Aggregate
C	C2	0.110202	0.148144	0.06	0.272662	0.408992
	C3	0.114172	0.153840	0.06	0.301895	0.370093
	C4	0.118330	0.159808	0.06	0.330931	0.330931
	C5	0.122867	0.166318	0.06	0.358448	0.292367
	C6	0.127782	0.173371	0.06	0.384308	0.254539
X	X2	0.124379	0.165318	0.06	0.284121	0.426182
	X3	0.129105	0.171599	0.06	0.314683	0.384613
	X4	0.134209	0.178383	0.06	0.343704	0.343704
D	D57	0.134209	0.172781	0.06	0.316505	0.316505
	D57-6	0.134209	0.172781	0.06	0.379806	0.253204

Approximate Quantity of Dry Materials
Per Cubic Yard of Concrete*

Class	Mix No.	Cement Pounds	Fine Aggregate Tons	Coarse Aggregate Tons
C	C2	583	0.6087	0.9130
	C3	604	0.6739	0.8262
	C4	626	0.7388	0.7388
	C5	650	0.8002	0.6527
	C6	676	0.8579	0.5682
X	X2	658	0.6345	0.9515
	X3	683	0.7025	0.8585
	X4	710	0.7675	0.7675
D	D57	710	0.7066	0.7066
	D57-6	710	0.8480	0.5650

*These quantities are based on the following assumptions:

Specific gravity of cement 3.14, specific gravity of aggregate 2.65, water cement ratio, Class C concrete 4.84 gal./bag (0.430 lb/lb). Water cement ratio, Class X concrete 4.77 gal./bag (0.423 lb/lb). Water cement ratio, Class D concrete 4.63 gal./bag (0.410 lb/lb). Weight of water 62.4 lbs/ft^3. Air voids Class D-57 concrete, 6.0%. Air voids, Class X concrete 0.00%.

Appendix B

Compressive Strength Testing

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.

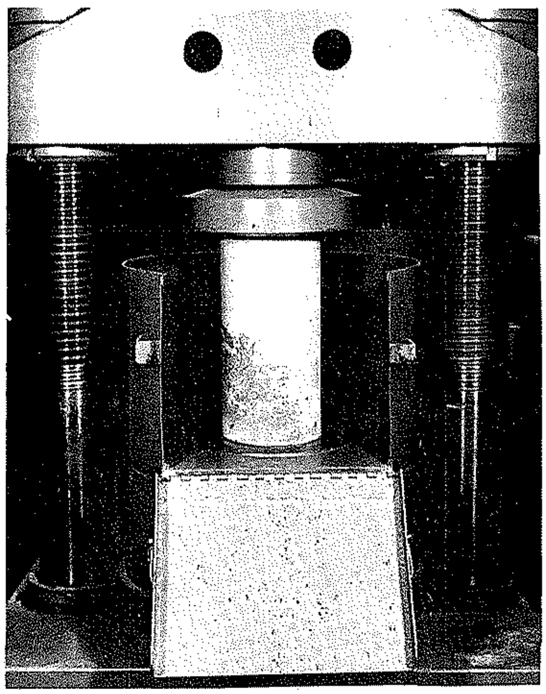


Fig. 1
Concrete Cylinder In
Testing Machine

Appendix C

Durability Testing

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:

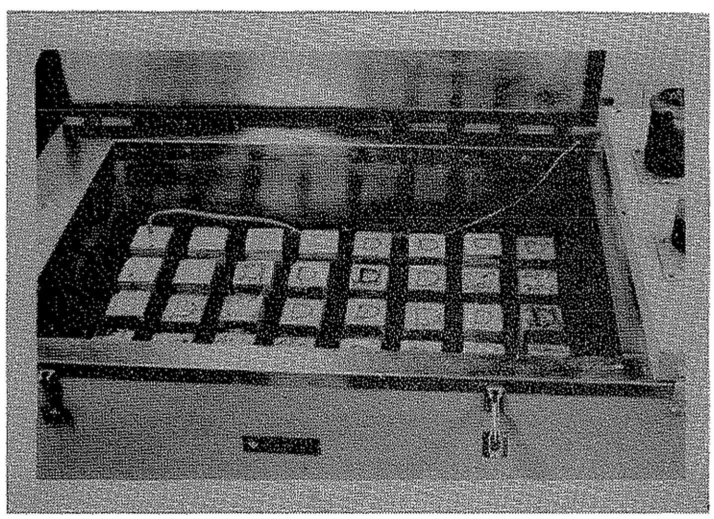
DF = the durability factor of the specimen

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

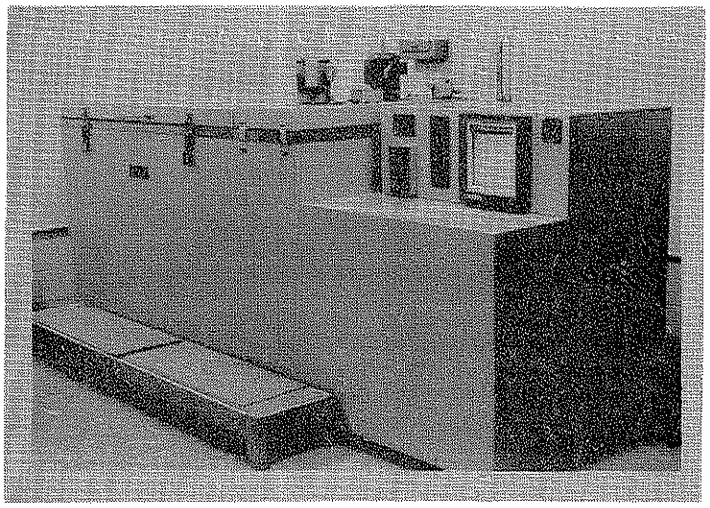
N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less

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

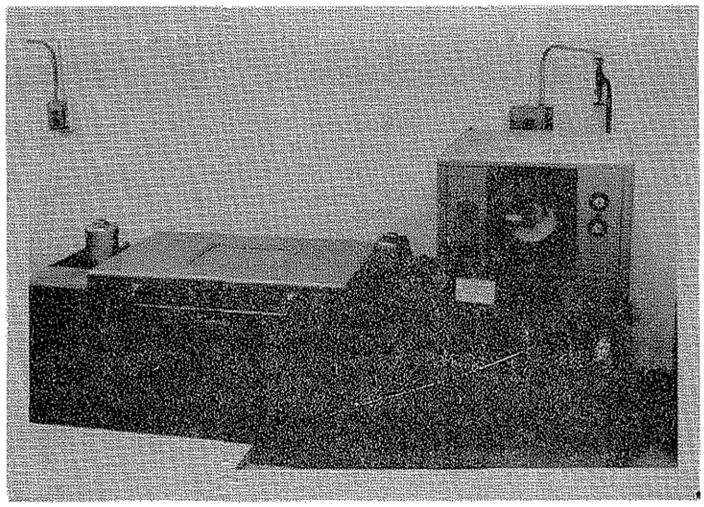
8. Report. The final report (worksheet) should be submitted to the Geology Section, and it should include all data pertinent to the variables or combination of variables studied in the evaluation. Also, any defects in each specimen which develop during testing and the number of cycles at which such defects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



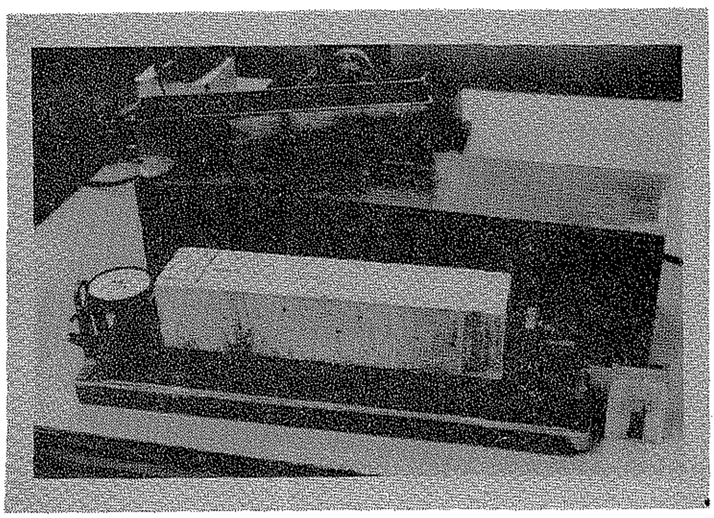
Specimens in the
Freezing & Thawing Apparatus



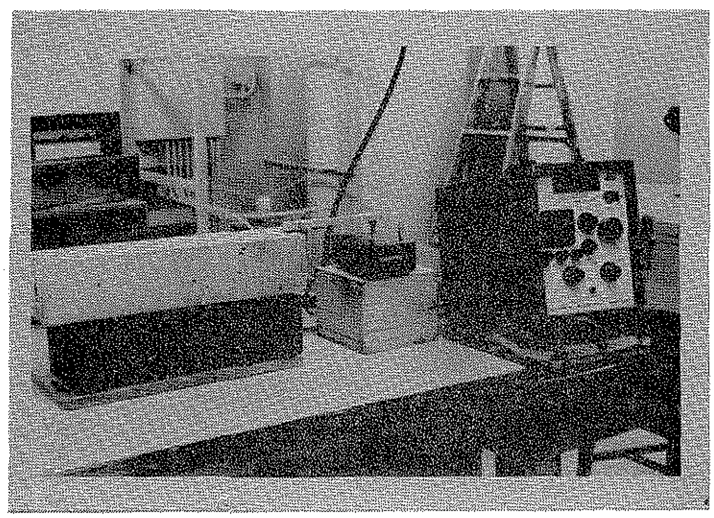
Freezing & Thawing Apparatus
"Cincinnati"



Freezing & Thawing Apparatus
"Conrad"



Beam Comparator



Dynamic Testing Apparatus

Test Method No. Iowa 408-A

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: ____________

AEA ____________ @ ______ fl. oz./sk.

Admixture ____________ @ ______ fl. oz./sk.

Date	Weight Grams

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