Evaluation of Fly Ash Concrete Durability Containing Class II Durability Aggregates

Project No. MLR-85-8

Highway Division
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Iowa Department of Transportation

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Iowa Department of Transportation

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Abstract

Fly ash was used in this evaluation study to replace 15% of the cement in Class C-3 concrete paving mixes. One Class "C" ash from Iowa approved sources was examined in each mix. Substitution rate was based on 1 to 1 basis, for each pound of cement removed 1.0 pound of ash was added.

The freeze/thaw durability of the concrete studied was not adversely affected by the presence of fly ash. This study reveals that the durability of the concrete test specimens made with Class II durability aggregates was slightly increased in all cases by the substitution of cement with 15% Class "C" fly ash.

In all cases durability factors either remained the same or slightly improved except for one case where the durability factor decreased from 36 to 34. The expansion decreased in all cases.

Introduction

Current Iowa DOT specifications allow the optional use of fly ash as a partial cement replacement in Class A, B and C concrete paving mixes, provided a highly frost resistant, coarse aggregate such as Class III durability is used.

The basis for this specification is that early durability research indicated less frost resistance in fly ash concrete when an aggregate of mediocre quality was used. Research subsequently has shown that fly ash concrete with other Class II aggregate may not have reduced freeze/thaw durability.

Special study and testing where aggregates are salt treated indicates the addition of fly ash may be beneficial; furthermore, the use of fly ash in concrete is desirable for economical and environmental reasons.

Therefore, it was the purpose of this study to test durability of concrete containing several Class II aggregates to establish the effect of fly ash and further to either substantiate or refute our present position.

Scope

Eight Class II aggregates were evaluated in concrete in this evaluation study, with and without fly ash. The aggregate represented a cross-section of carbonate aggregates presently approved for use in Iowa.

The fly ash studied conformed to ASTM C-618, "Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete". Only one Class "C" fly ash was used in this study from an approved Iowa source.

Currently Iowa does not have any Class "F" ash approved for use.

This study examines the freeze/thaw durability of Class II aggregates when used in Class C-3 paving mixes with and without fly ash.

The C-3 paving mix has a cement factor of 604 pounds per cubic yard.

Laboratory Procedures

A. Materials

The following materials were used in this study:

1. Portland Cement: Type I, standard laboratory blend of the ten portland cements commonly available in Iowa, was used to prepare the concrete specimens.
2. Water: Tap water, City of Ames
3. Air Entraining Agent: Neutralized vinsol resin, Carter-Waters, single strength, Lab No. ACA5-7
4. Fly Ash: Ottumwa Ash, mildly reactive, Class "C" (self cementing) Lab No. ACF5-64
5. Fine Aggregate: Cordova sand (Mississippi River sand), Lab No. AA55-0141

6. Coarse Aggregates:

Source Name	Reason for Class II Classification
Malcom Mine	Durability Factor & Performance
Douds Mine	Durability Factor & Performance
Skiline Quarry	Durability Factor
Nelson Quarry	Durability Factor
Garrison Quarry	Performance
Carville/Bunn Quarry	Similar stone has poorer performance
Ames Mine	Durability Factor
Durham Mine	Durability Factor & Performance

B. Aggregate Classification Purpose

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. The three service life classes are:

Class 1 - Deterioration in approximately 10 years and a durability factor less than 80.

Class 2 - Deterioration in 10-20 years and a durability factor greater than 80.

Class 3 - Deterioration in over 20 years and a durability factor greater than 90.

Assignment to one of the service life classes is based on the aggregates 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 and 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.

C. Aggregate Gradation

The coarse aggregate gradation was:

Sieve No.	% Passing
1.06"	100
3/4"	89
0.525"	40
3/8"	8.0
No. 4	0.8
No. 8	0.4

D. Fly Ash Substitution Rates:

Fly ash was substituted for 15%, by weight of the portland cement. The substitution of Class "C" fly ash was on a pound-for-pound basis. The change in absolute volumes due to the fly ash substitution, was applied to each aggregate in its proper ratio. For the C-3 mix, the volumes are 55% coarse aggregate and 45% fine aggregate.

E. Concrete Controls

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 durability was accomplished by preparing test specimens in the laboratory. These specimens were made from a Class C-3 concrete mix with a cement content of 604 lb./yd^3 as defined in the standard specifications series of 1984 (1). The variables in the mixes were the aggregate sources. The specifications referenced above designate the proportions of Portland Cement-water-aggregate to be used in the mixes studied. The specifications also itemize the slump and entrained air content (see Appendix A). The former is achieved by varying the water added and latter by varying the amount of air entraining agent added.

The actual procedure, as to the preparation and mixing of the ingredients, was as outlined in ASTM C-192 (2) "Making and Curing Concrete Test Specimens in the Laboratory".

The determination of the durability factor of the concretes containing the Ottumwa ash and various 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 B). 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 and each combination 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 II durability aggregates which are associated with no deterioration of pavements in less than 10 years and only minimal deterioration in pavements of 10-20 years of age.

Test Results and Interpretation

Durability (Freeze/Thaw Test)

Table No. 1 shows the physical characteristics of the aggregate quality testing, while Table No. 2 shows the concrete mix characteristics and itemizes the freeze/thaw durability test results for the various aggregates. Each durability value indicated is the average of the three beams. The data is depicted graphically in Figure 1 to point out the relationship between the C-3 mixes with and without the substitution of fly ash for a portion of the cement when Class II and Class III aggregates are used.

TABLE NO. 1

DURABILITY OF FLY ASH CONTAINING CLASS II AGGREGATES
MLR-85-8

AGGREGATE SOURCE	COUNTY	AGGREGATE CLASS	FREEZE-THAW METHOD A %	PORE INDEX	ABSORPTION %	L. A. ABRASION %	SPECIFIC GRAVITY
Malcom Mine (Dolomite)	Poweshiek	II	1.0	16.0	2.80	30.0	2.597
Douds Mine (Dolomite)	Van Buren	II	2.0	18.0	5.04	35.0	2.525
Skyline Quarry (Dolomite/Limestone)	Winneshiek	II	1.0	20.0	1.39	25.0	2.654
Nelson Quarry (Limestone)	Henry	II	2.0	10.0	0.70	46.0	2.667
Garrison Quarry (Dolomite)	Benton	II	1.0	13.0	2.70	26.0	2.653
Carville/Bunn Quarry (Dolomite)	Floyd	II	1.0	18.0	2.99	30.0	2.630
Ames Mine (Dolomite)	Story	II	2.0	18.0	2.75	41.0	2.584
Durham Mine (Dolomite)	Marion	II	1.0	24.0	2.2	28.0	2.614

TABLE NO. 2

DURABILITY OF FLY ASH CONTAINING CLASS II AGGREGATES
MLR-85-8

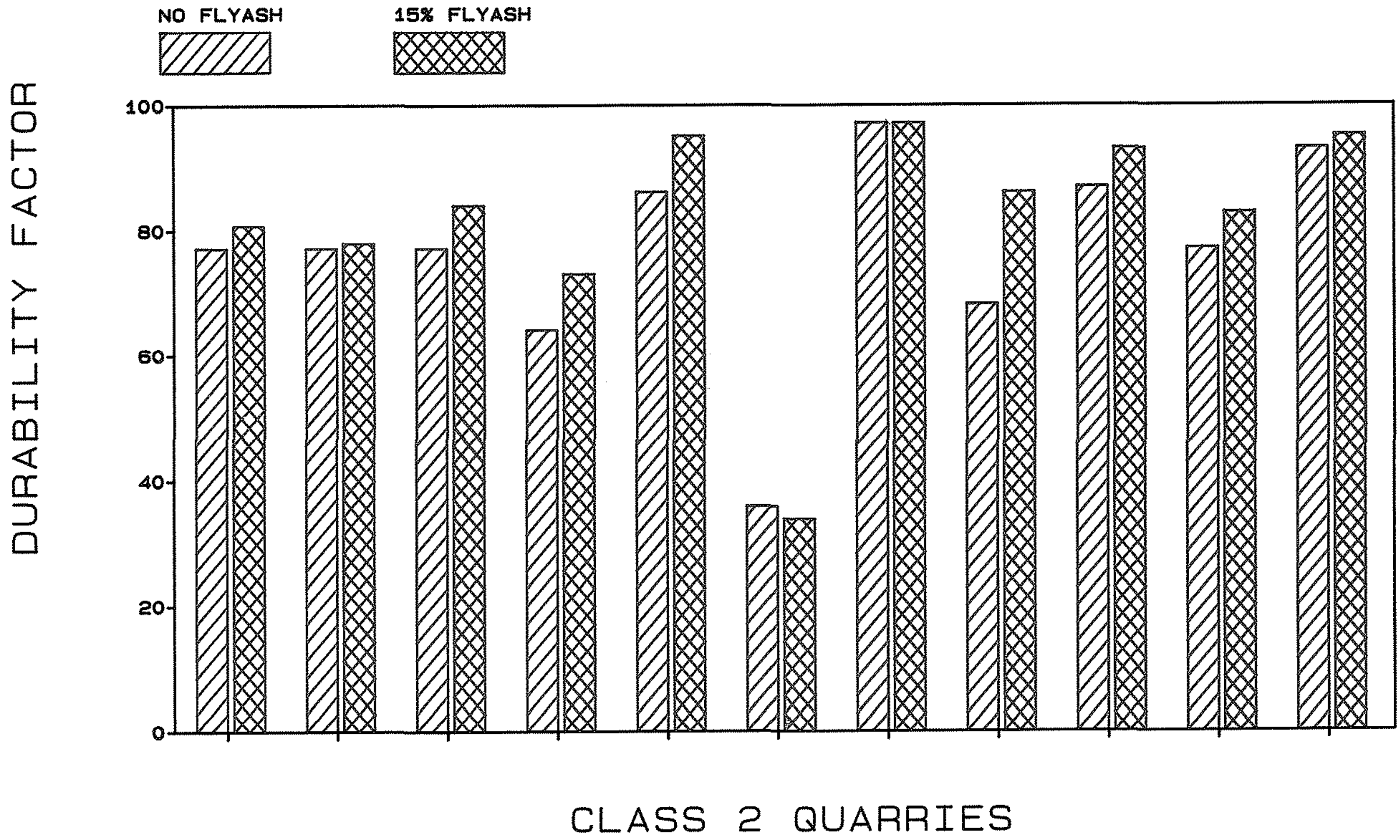
AGGREGATE SOURCE	FLY ASH SOURCE	FLY ASH CLASS	W/C RATIO CEMENT ONLY	W/C RATIO CEMENT & FLY ASH	AIR %	SLUMP (INCH)	DURABILITY FACTOR %	EXPANSION %
Malcom Mine	Control	--	0.427	-----	6.4	2.25	68	0.077
Malcom Mine	Ottumwa	C	0.466	0.395	6.5	2.50	86	0.039
Douds Mine	Control	--	0.414	-----	6.4	1.75	87	0.042
Douds Mine	Ottumwa	C	0.474	0.401	6.5	2.25	93	0.014
Skyline Quarry	Control	--	0.420	-----	6.0	1.75	97	0.014
Skyline Quarry	Ottumwa	C	0.481	0.408	6.3	2.50	97	0.013
Nelson Quarry	Control	--	0.420	-----	6.1	2.00	77	0.072
Nelson Quarry	Ottumwa	C	0.459	0.388	6.5	2.25	84	0.048
Garrison Quarry	Control	--	0.439	-----	6.0	1.75	86	0.026
Garrison Quarry	Ottumwa	C	0.489	0.414	6.1	2.00	95	0.018
Carville/Bunn Quarry	Control	--	0.420	-----	6.2	2.00	64	0.106
Carville/Bunn Quarry	Ottumwa	C	0.496	0.420	6.0	2.00	73	0.097
Ames Mine	Control	--	0.408	-----	6.1	2.50	36	0.167
Ames Mine	Ottumwa	C	0.474	0.414	6.4	2.50	34	0.122
Durham Mine	Control	--	0.477	-----	6.0	2.00	77	0.098
Durham Mine	Ottumwa	C	0.519	0.439	6.0	2.50	78	0.126

Figure #1

DURABILITY FACTORS WITH & WITHOUT FLYASH

CLASS 2 QUARRIES

IOWA DOT 239-1204 APRIL 1986 SAVECODE CL2FLY



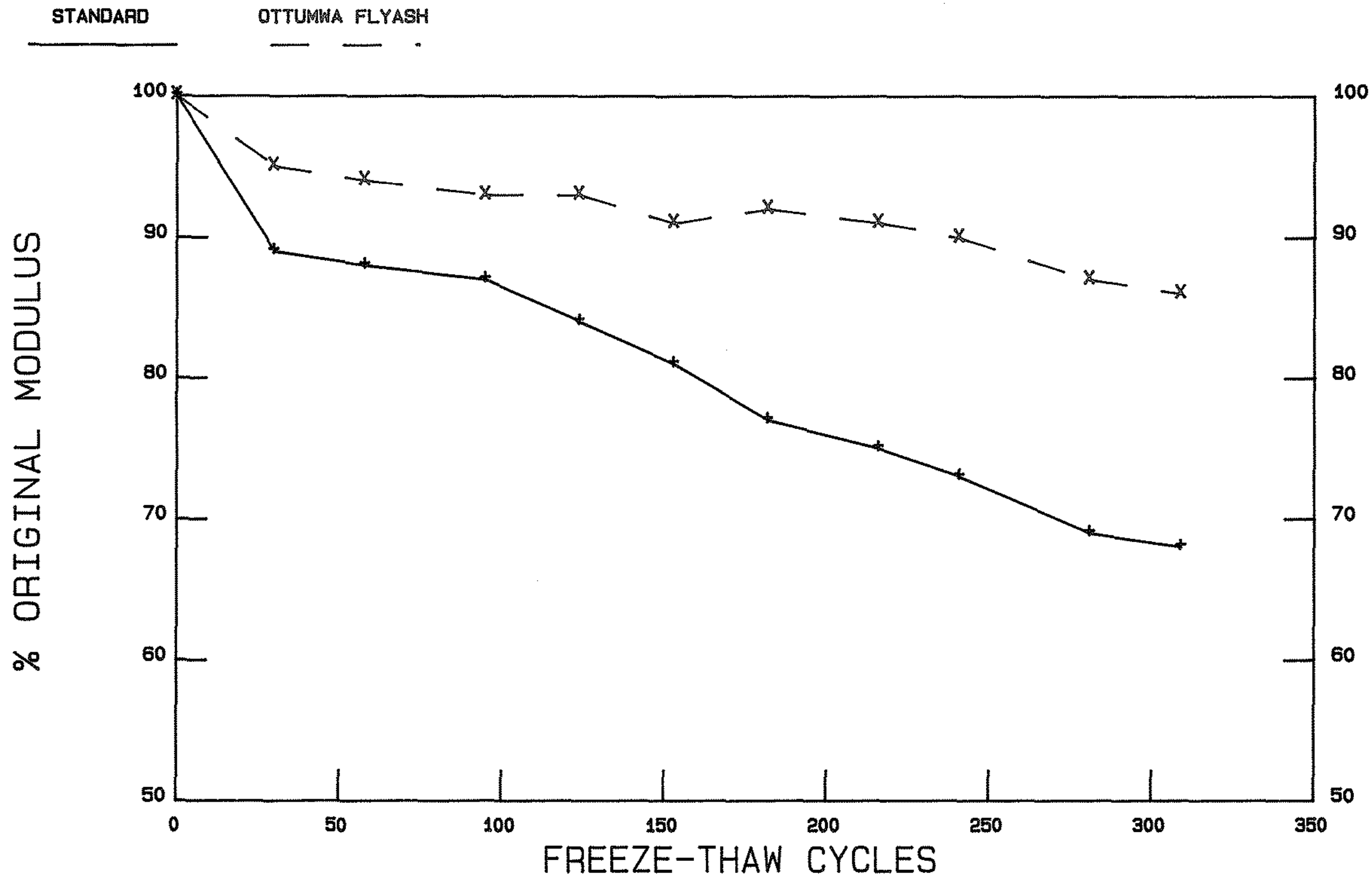
While the durability of concrete test specimens was slightly increased in most cases by the substitution of 15% of the cement with fly ash, the expansion was decreased in all cases. The results of the durability factors in combination with the fly ash used in this evaluation study are shown in Figures 2-9. The expansion factors of the same combinations are graphically presented in Figures 10-17.

Figure #2

PERCENT ORIGINAL MODULUS

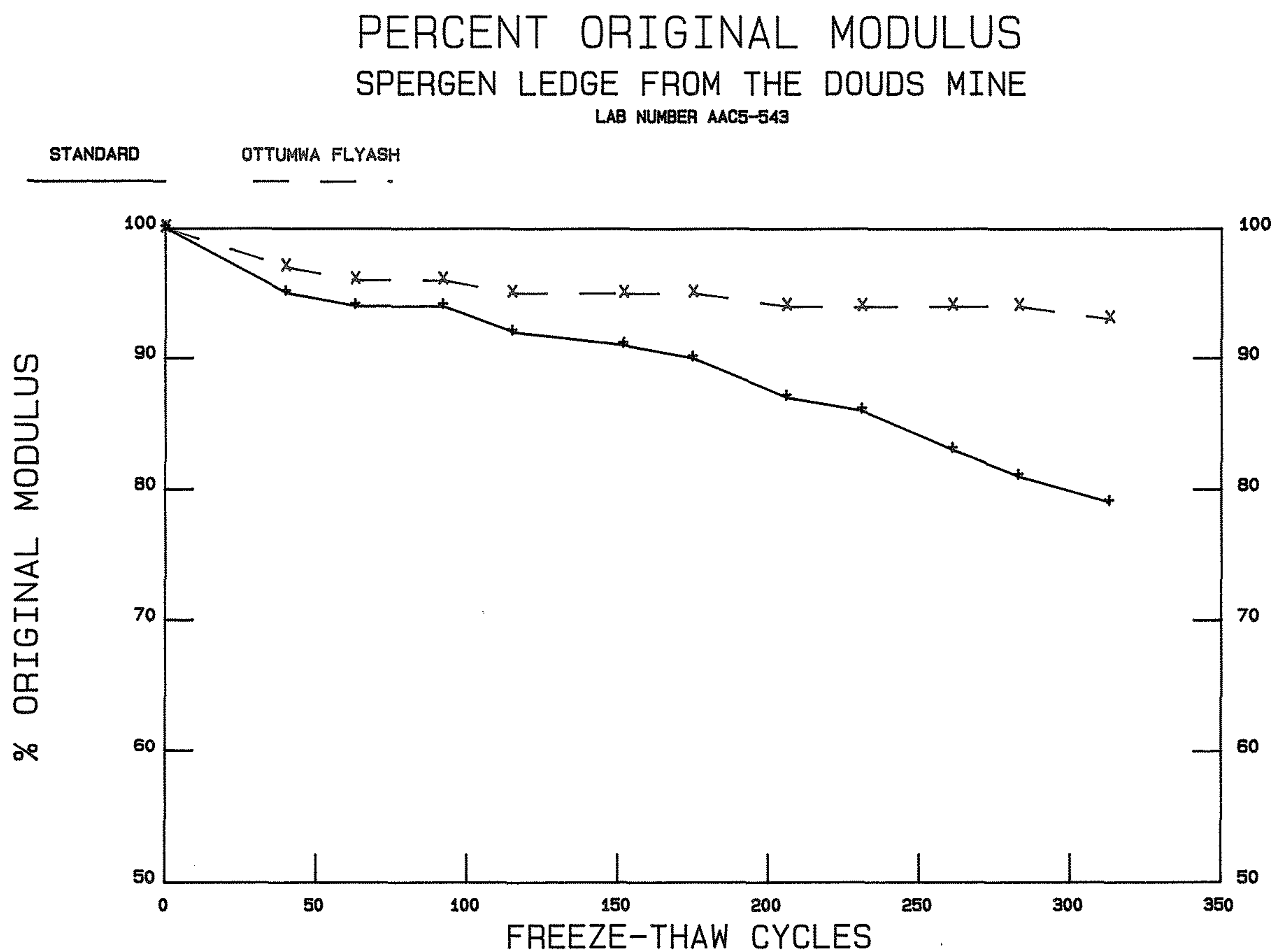
EAGLE CITY LEDGE FROM THE MALCOM MINE

LAB NUMBER AAC5-428



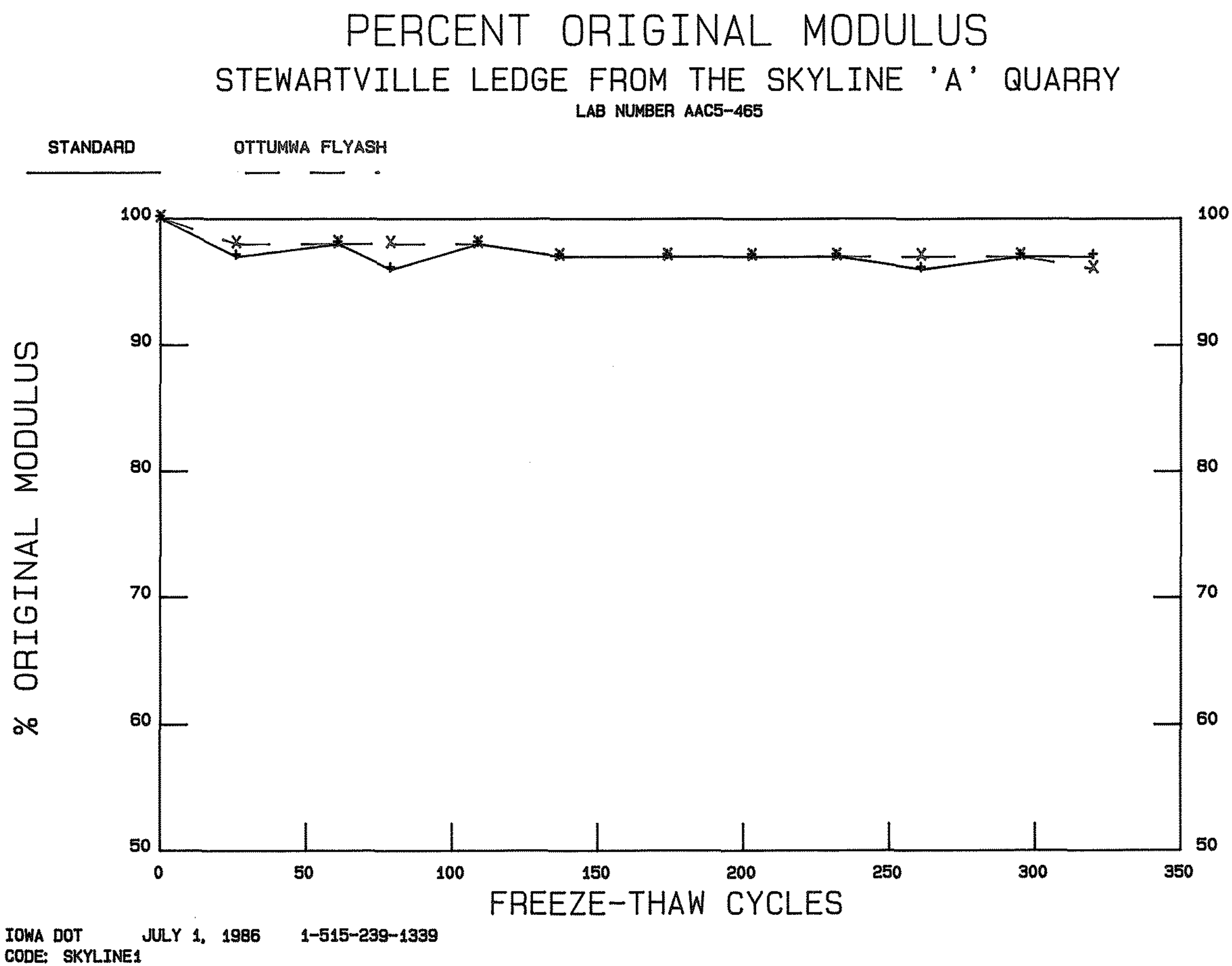
IOWA DOT JULY 1, 1986 1-515-239-1339
CODE: MALCMIN1

Figure #3



IOWA DOT JULY 1, 1986 1-515-239-1339
CODE: DOUDMIN1

Figure #4



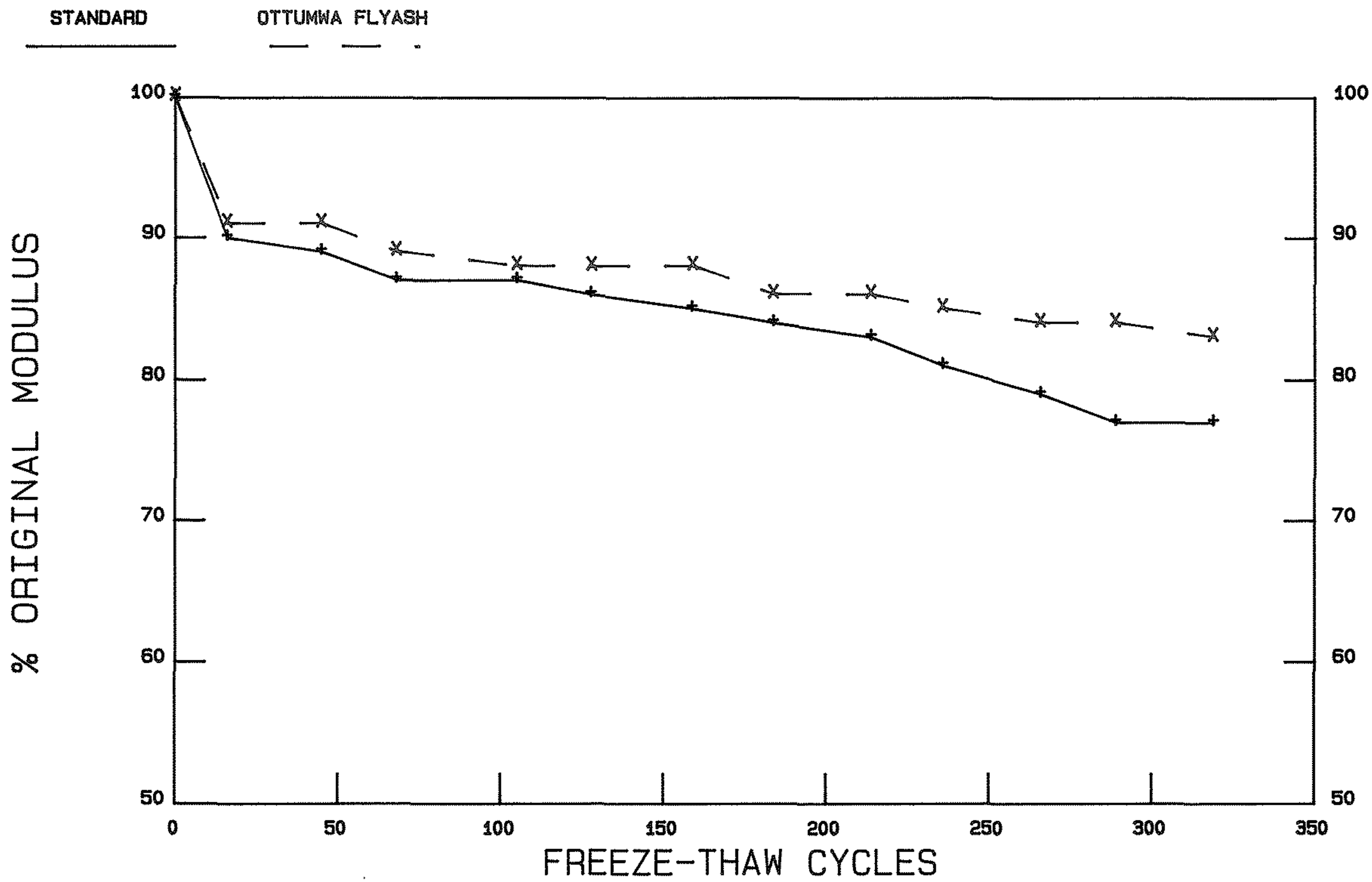
PERCENT ORIGINAL MODULUS
STEWARTVILLE LEDGE FROM THE SKYLINE 'A' QUARRY
LAB NUMBER AAC5-465
STANDARD
OTTUMWA FLYASH
100
90
80
70
60
50
0
50
100
150
200
250
300
350
% ORIGINAL MODULUS
FREEZE-THAW CYCLES
IOWA DOT JULY 1, 1986 1-515-239-1339
CODE: SKYLINE1

Figure #5

PERCENT ORIGINAL MODULUS

CEDAR FORK LEDGE FROM THE NELSON QUARRY

LAB NUMBER AAC5-523



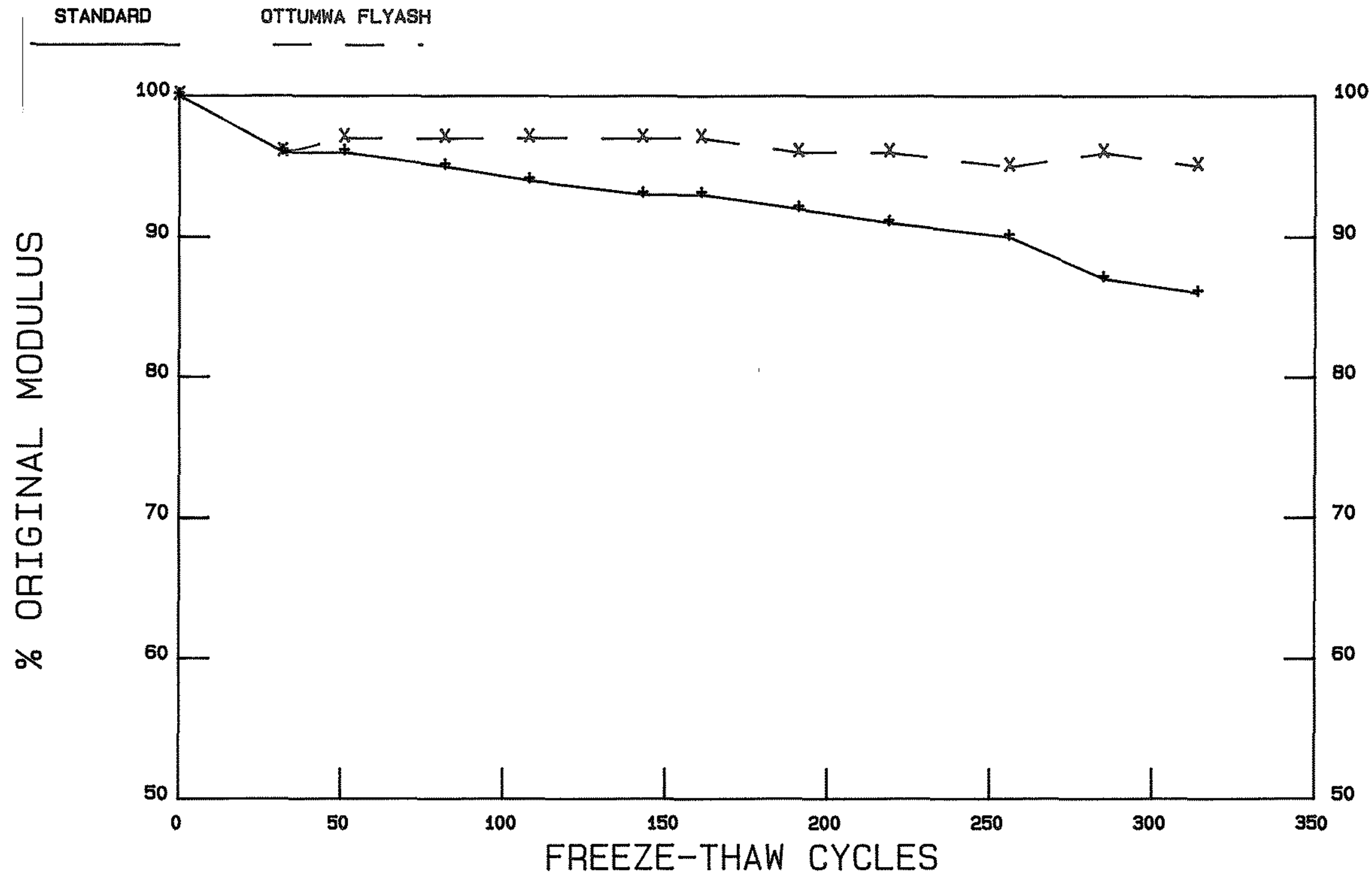
IOWA DOT JULY 1, 1986 1-515-239-1339
CODE: NELSON1

Figure #6

PERCENT ORIGINAL MODULUS

CORALVILLE LEDGE FROM THE GARRISON QUARRY

LAB NUMBER AAC5-007



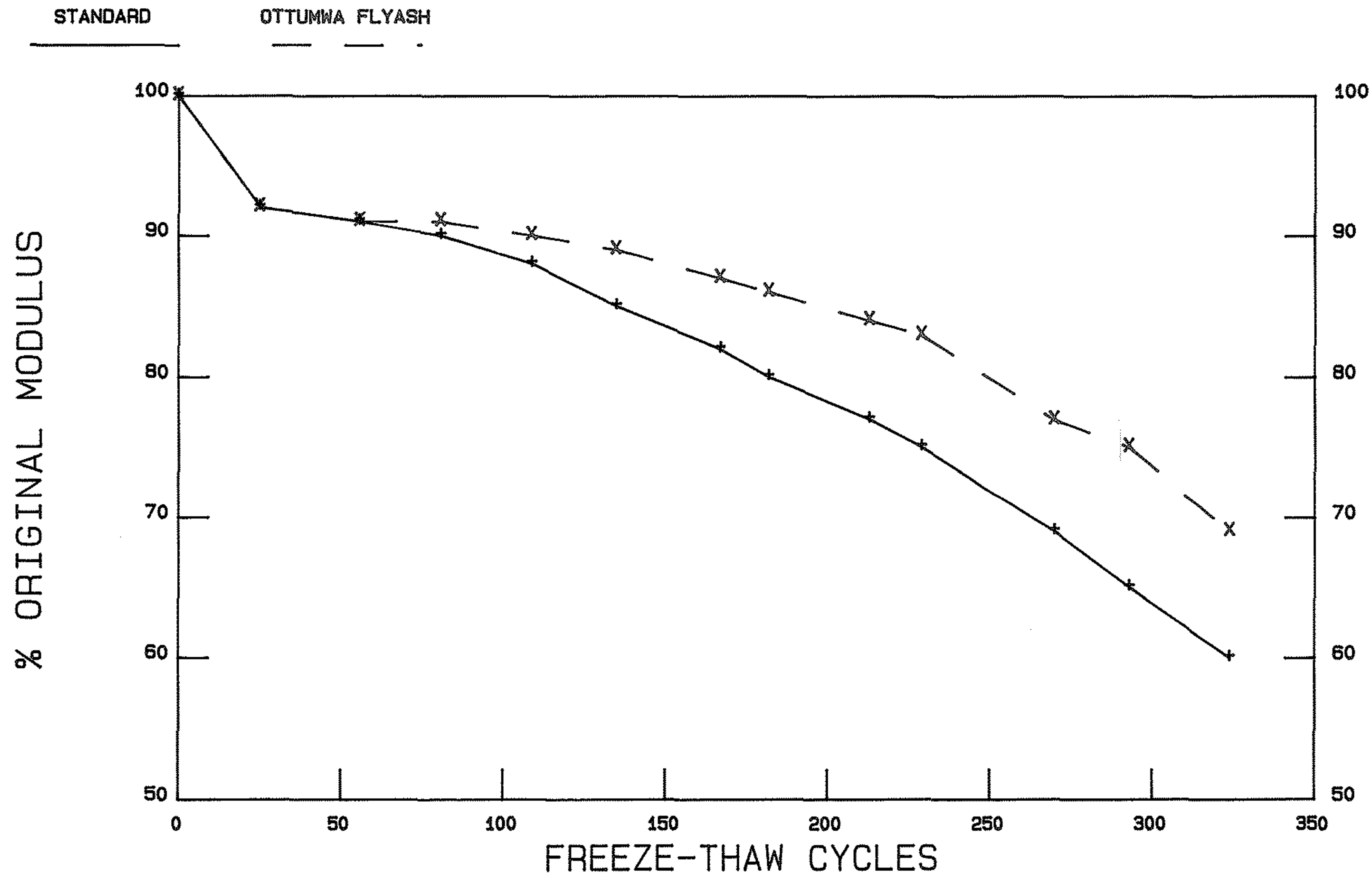
IOWA DOT JULY 1, 1986 1-515-239-1339
CODE: GARR1

Figure #7

PERCENT ORIGINAL MODULUS

CORALVILLE LEDGE FROM THE CARVILLE/BUNN QUARRY

LAB NUMBER AAC5-419



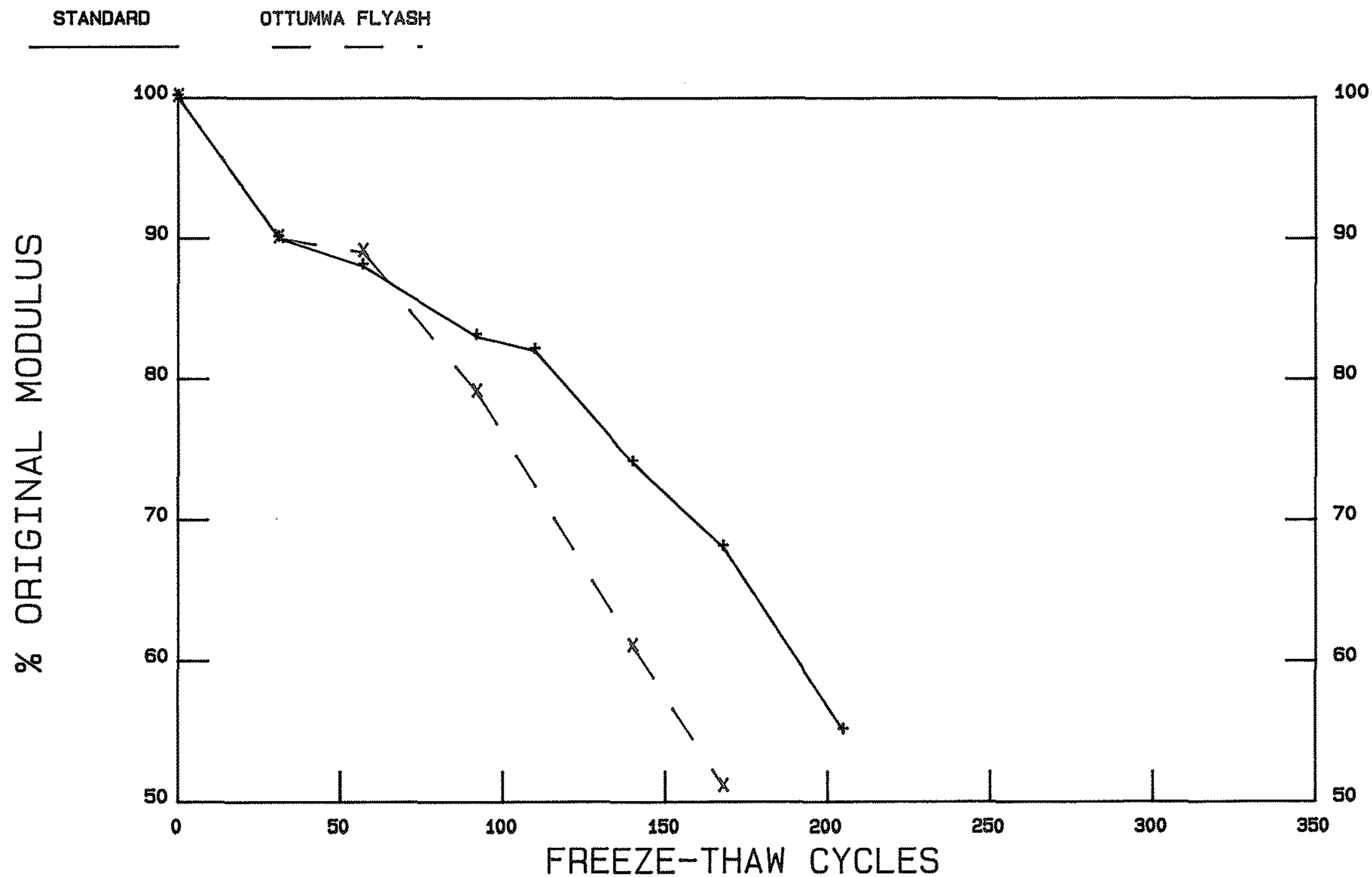
IOWA DOT JULY 1, 1986 1-515-239-1339
CODE: CARBUNN1

Figure #8

PERCENT ORIGINAL MODULUS

GILMORE CITY LEDGE FROM THE AMES MINE

LAB NUMBER AAC5-446



IOWA DOT JULY 1, 1986 1-515-239-1339
CODE: AMESMIN4

Figure #9

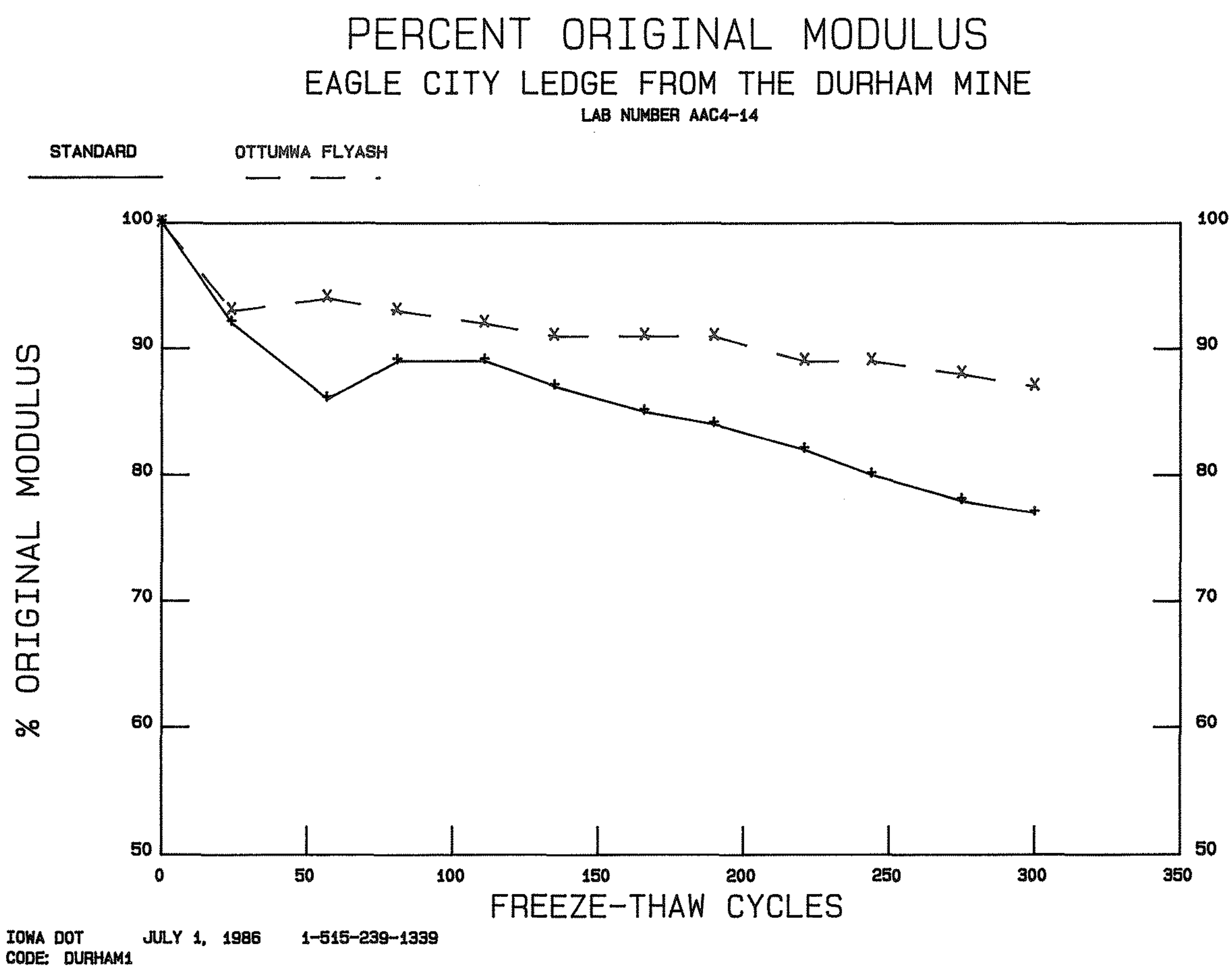
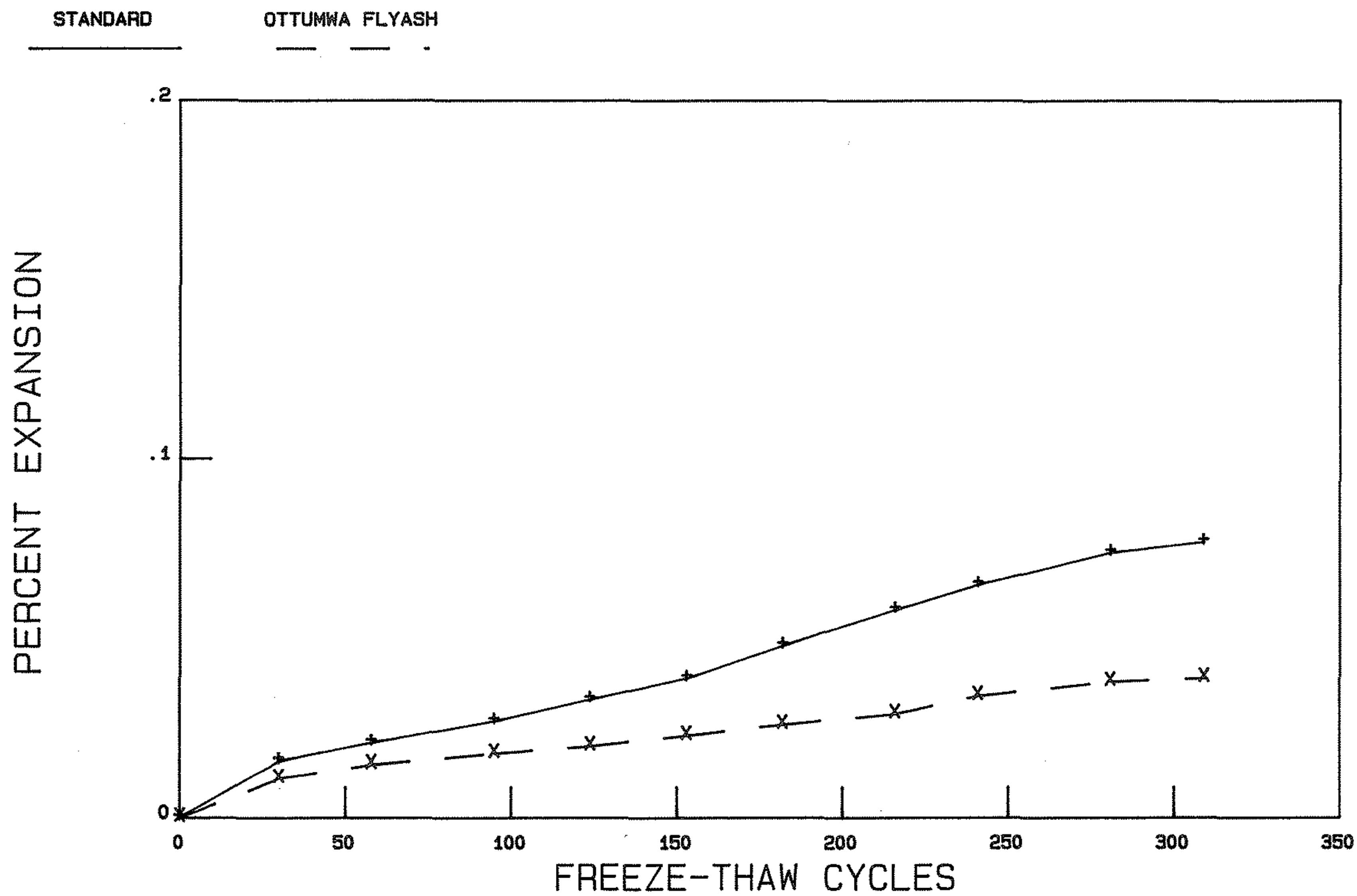

PERCENT ORIGINAL MODULUS
EAGLE CITY LEDGE FROM THE DURHAM MINE
LAB NUMBER AAC4-14
STANDARD
OTTUMWA FLYASH
% ORIGINAL MODULUS
100
90
80
70
60
50
0
50
100
150
200
250
300
350
FREEZE-THAW CYCLES
IOWA DOT JULY 1, 1986 1-515-239-1339
CODE: DURHAM1

Figure #10

PERCENT EXPANSION ASTM C666-B

EAGLE CITY LEDGE FROM THE MALCOM MINE

LAB NUMBER AAC5-428



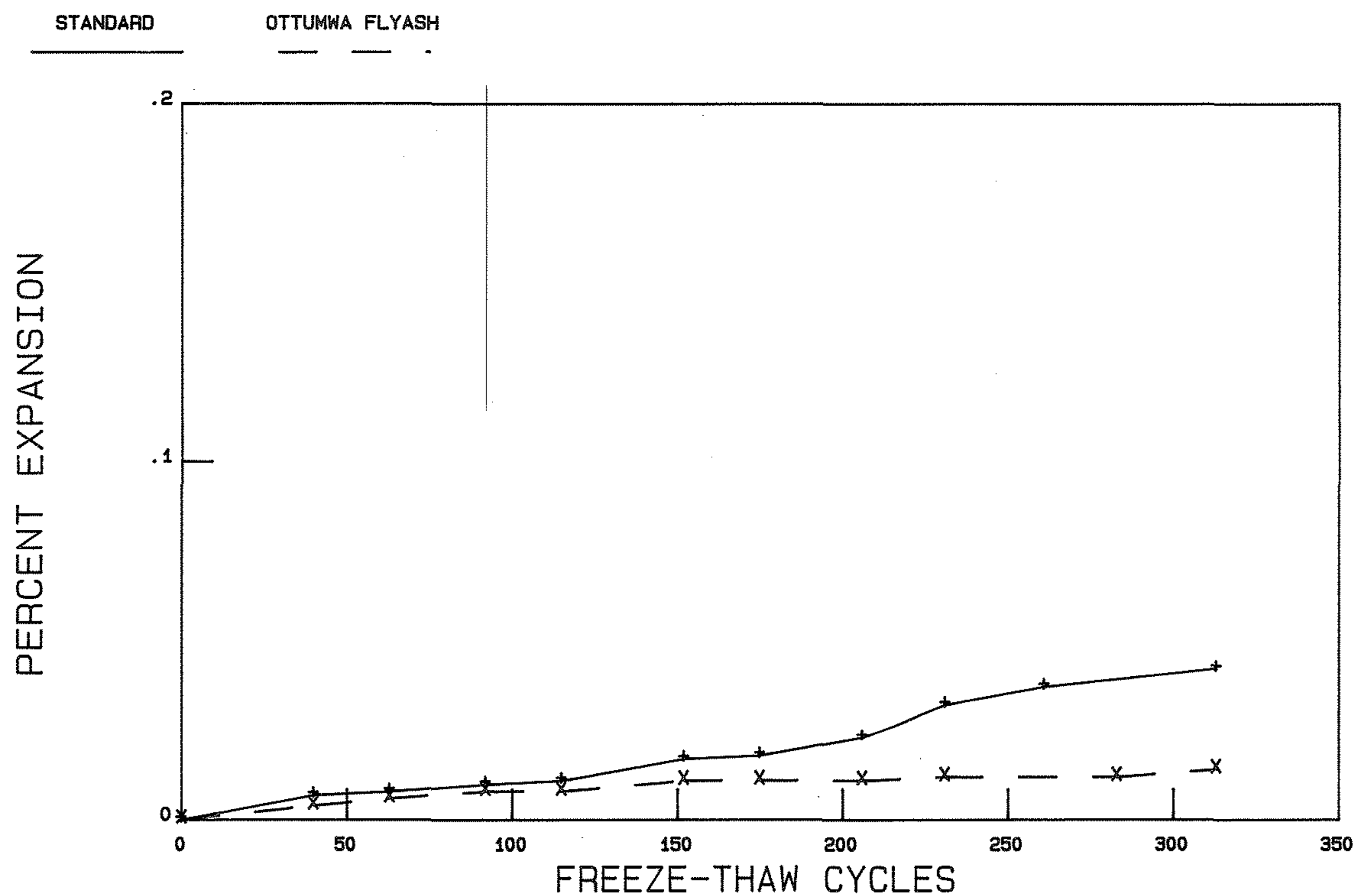
IOWA DOT FEB 04, 1986 1-515-239-1339
CODE: MALCMIN2

Figure #11

PERCENT EXPANSION ASTM C666-B

SPERGEN LEDGE FROM THE DOUDS MINE

LAB NUMBER AAC5-543



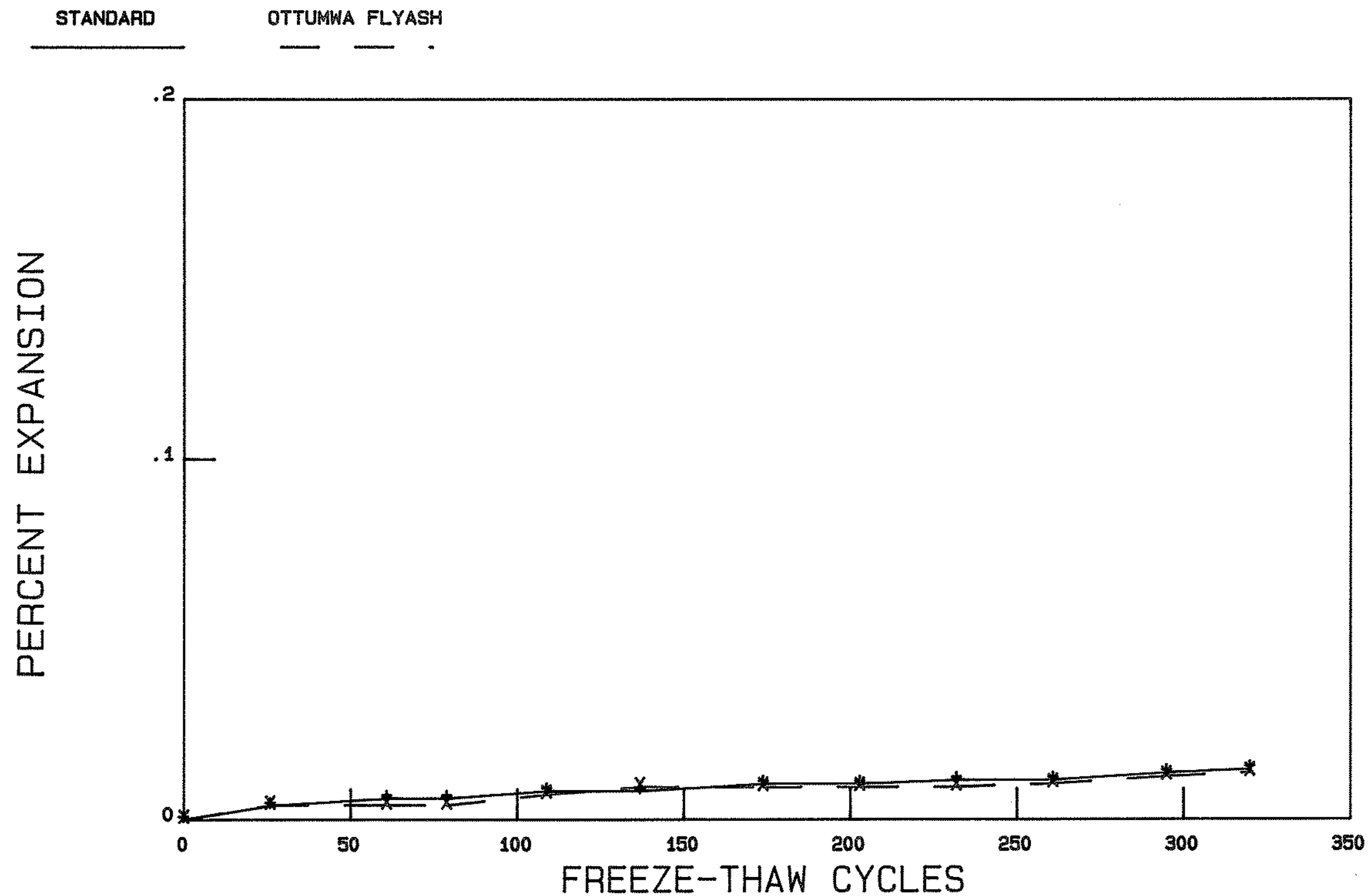
IOWA DOT FEB 04, 1986 1-515-239-1339
CODE: DOUDMIN2

Figure #12

PERCENT EXPANSION ASTM C666-B

STEWARTVILLE LEDGE FROM THE SKYLINE 'A' QUARRY

LAB NUMBER AAC5-465



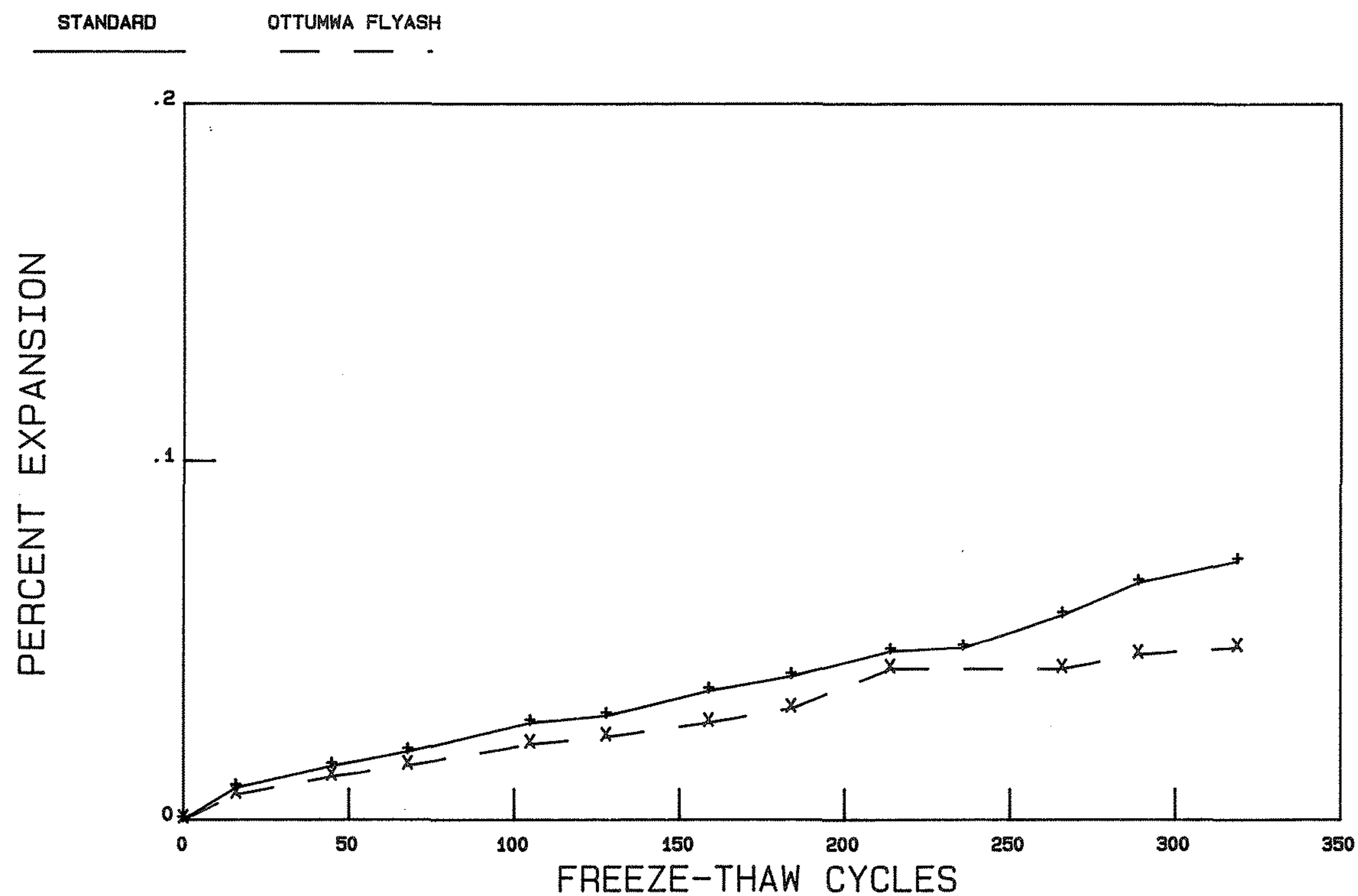
IOWA DOT FEB 04, 1986 1-515-239-1339
CODE: SKYLINE2

Figure #13

PERCENT EXPANSION ASTM C666-B

CEDAR FORK LEDGE FROM THE NELSON QUARRY

LAB NUMBER AAC5-465



IOWA DOT FEB 04, 1986 1-515-239-1339
CODE: NELSON2

Figure #14

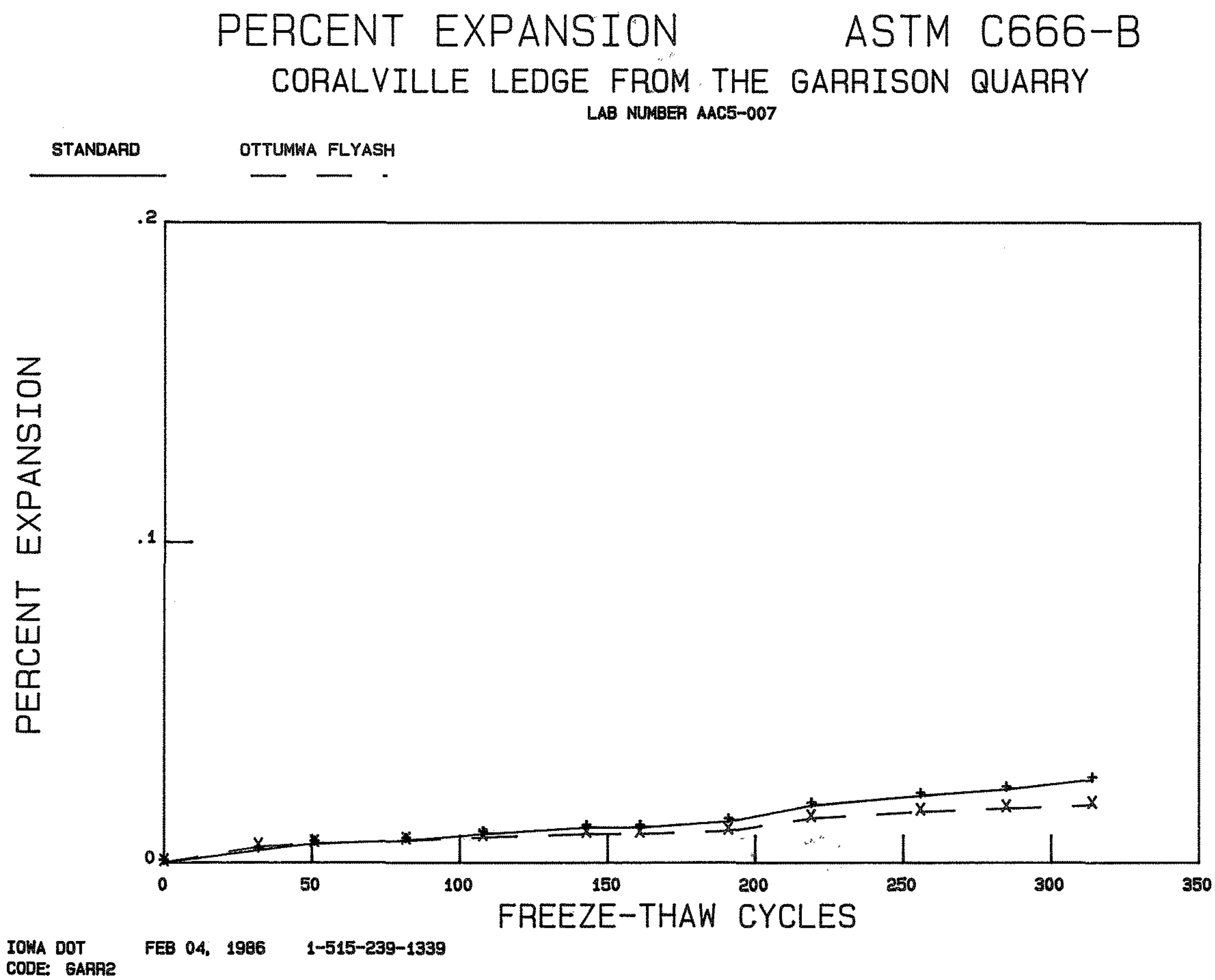
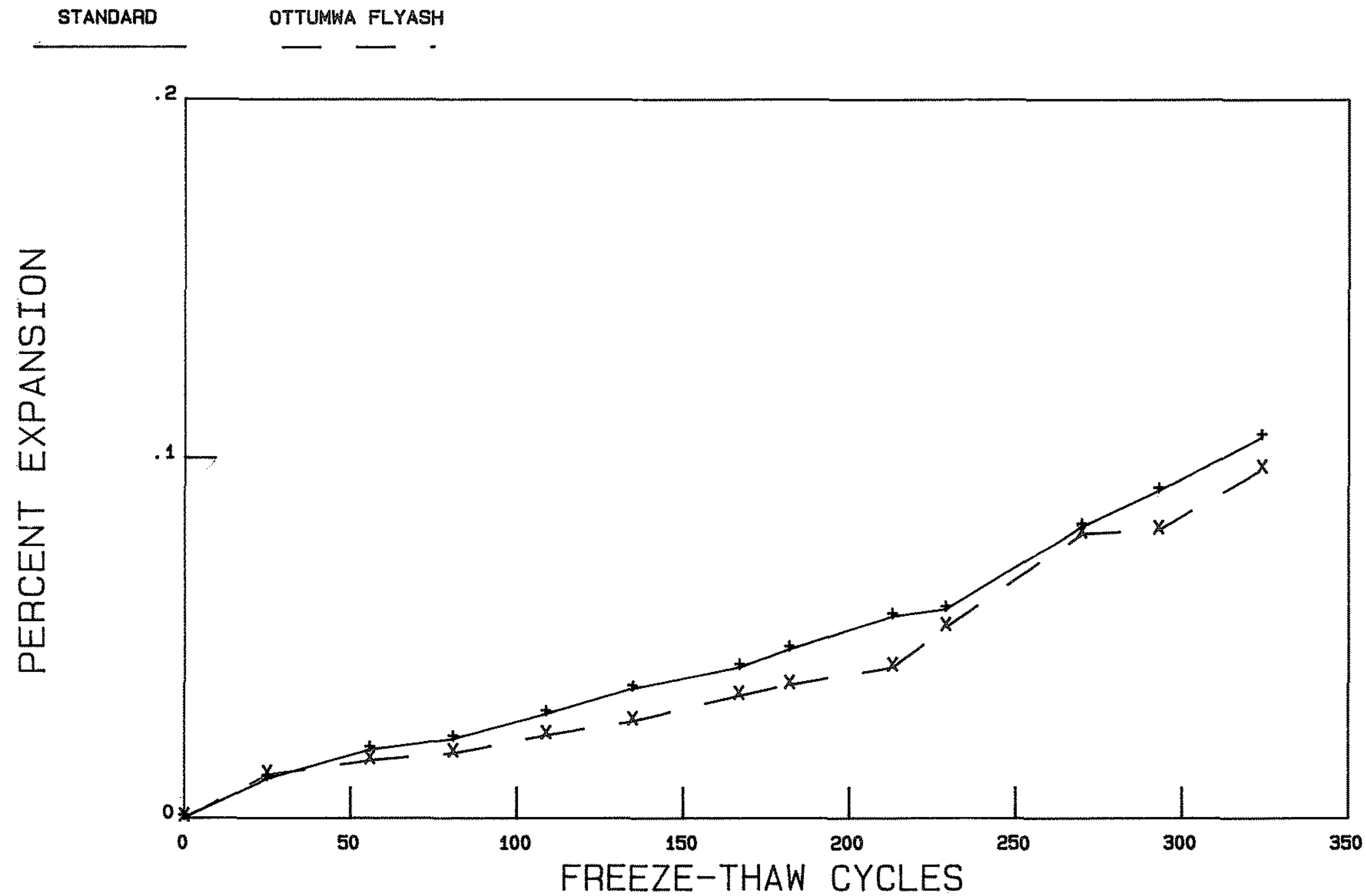

PERCENT EXPANSION ASTM C666-B
CORALVILLE LEDGE FROM THE GARRISON QUARRY
LAB NUMBER AAC5-007
STANDARD
OTTUMWA FLYASH
PERCENT EXPANSION
.2
.1
0
0
50
100
150
200
250
300
350
FREEZE-THAW CYCLES
IOWA DOT
CODE: GARR2
FEB 04, 1986
1-515-239-1339

Figure #15

PERCENT EXPANSION ASTM C666-B

CORALVILLE LEDGE FROM THE CARVILLE/BUNN QUARRY

LAB NUMBER AAC5-419



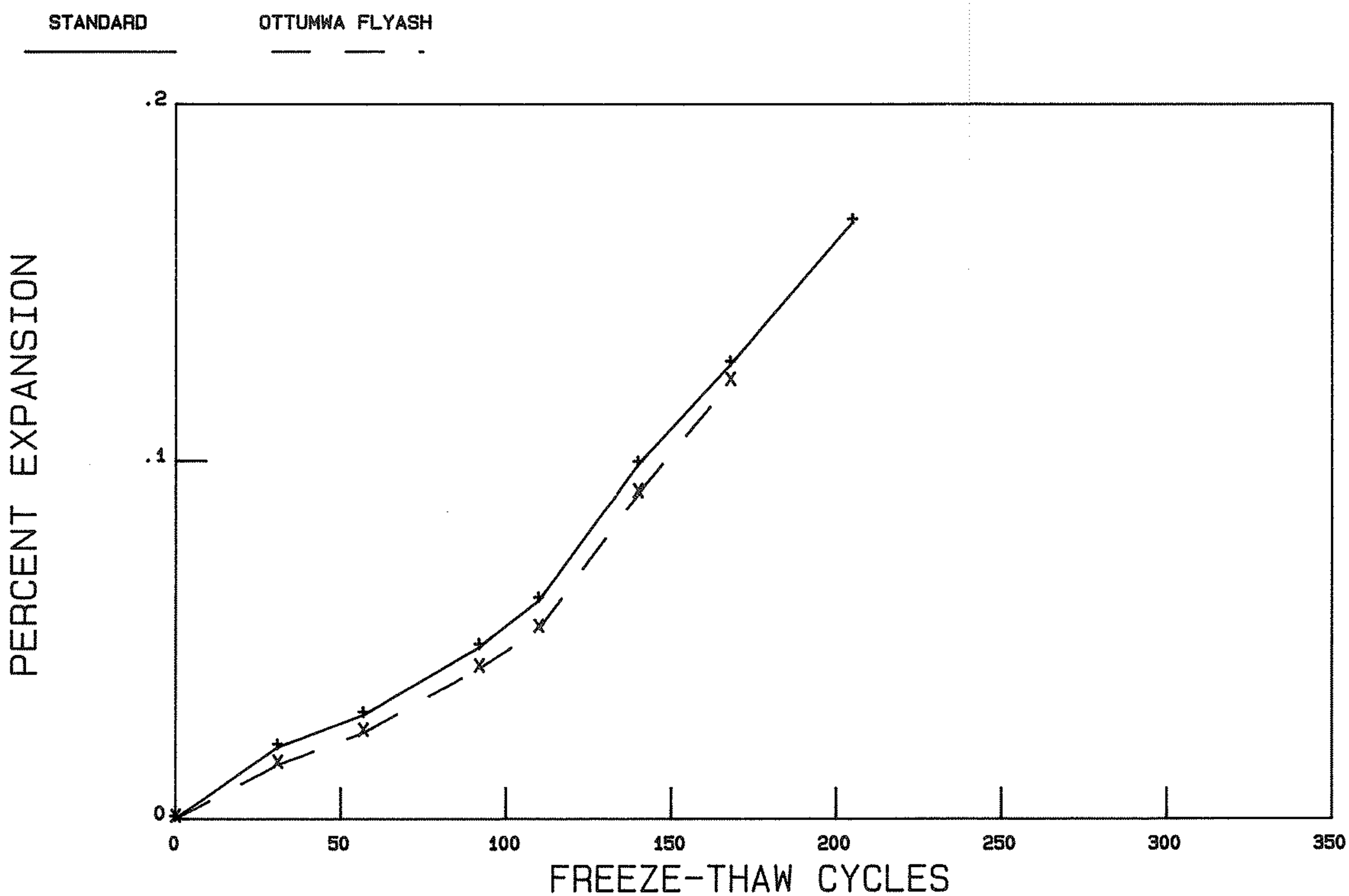
IOWA DOT FEB 04, 1986 1-515-239-1339
CODE: CARBUNN2

Figure #16

PERCENT EXPANSION ASTM C666-B

GILMORE CITY LEDGE FROM THE AMES MINE

LAB NUMBER AAC5-446



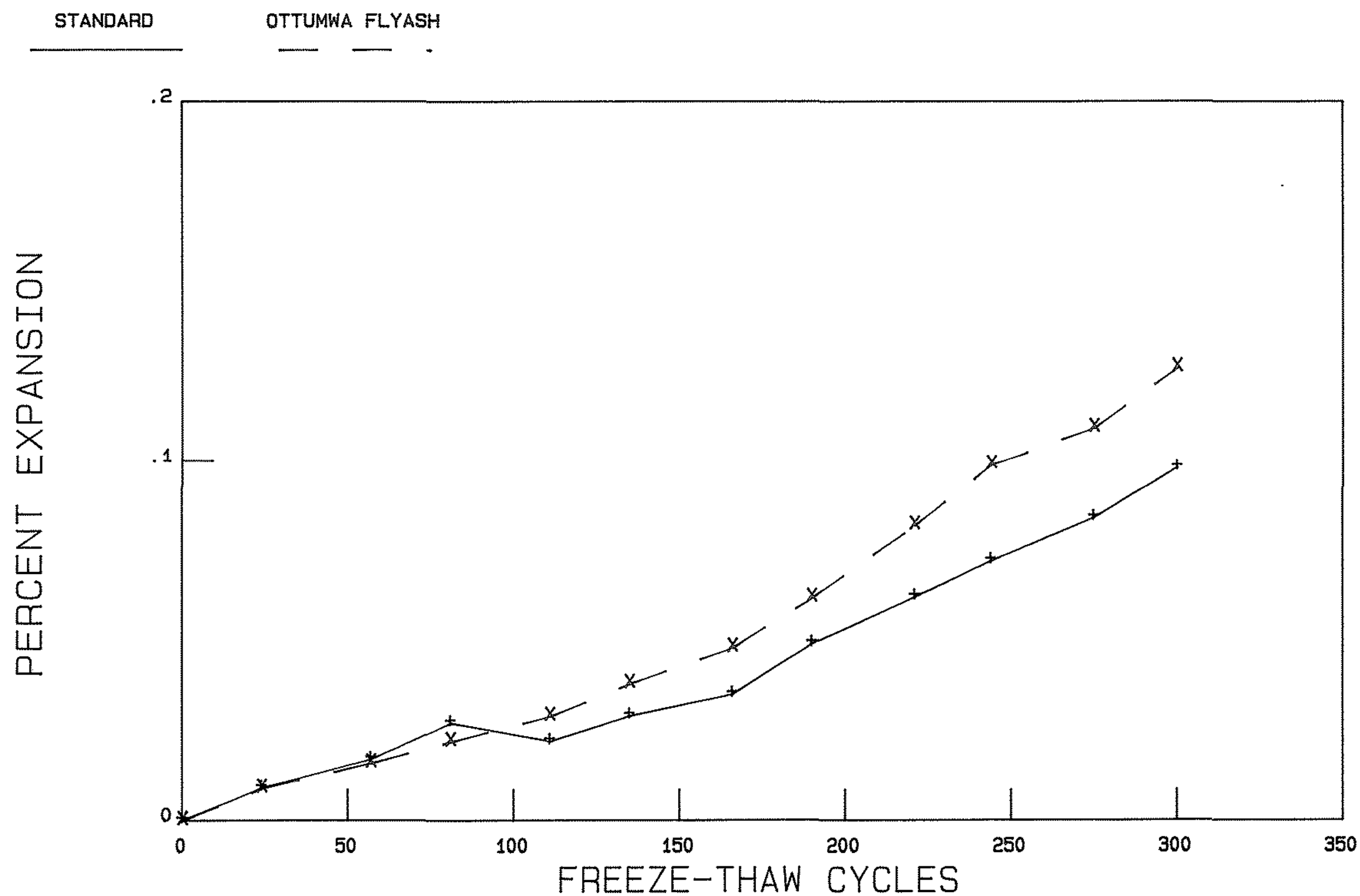
IOWA DOT FEB 04, 1986 1-515-239-1339
CODE: AMESMIN5

Figure #17

PERCENT EXPANSION ASTM C666-B

EAGLE CITY LEDGE FROM THE DURHAM MINE

LAB NUMBER AAC4-149



IOWA DOT MAY 27, 1986 1-515-239-1339
CODE: DURHAM2

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.

Discussion of Results

1. This study reveals that the durability of concrete test specimens made with Class II durability aggregates were either slightly increased or remained the same when 15% of the cement was substituted with fly ash. However, fly ash is not expected to materially affect, either favorably or unfavorably the freeze/thaw behavior of concrete in which it is used, and the general use of Class II aggregate in fly ash concrete may not insure satisfactory laboratory durability.

2. The slightly improved durability test results shown with the fly ash mixes are not regarded as significant, and can be attributed to the lower water cement ratios. The cause for the lower durability factors of Class II aggregate - fly ash concrete in past studies cannot be related directly to Class II aggregates as a whole nor is it likely to be an aggregate - fly ash reaction. It is more likely due to combination of a particular Class II aggregate with a freeze/thaw susceptible pore system. Research studies in the past have shown that some of Iowa's Class II aggregate possess a pore system that has a need to expel water during freezing if they are to retain their structural integrity.

   Some Iowa pavements, however, have undergone deterioration associated with coarse aggregates that is primarily caused by adverse chemical reactivity rather than freeze/thaw susceptibility. Other coarse aggregate do not become affected and the addition of fly ash to the concrete may restore the durability properties.

Conclusion

Based on the laboratory test data gathered in this study, the addition of fly ash as a partical cement replacement in the concrete mix can be accomplished without detrimental effects to the freeze/thaw durability of concrete. Therefore, portland cement concrete containing Class II durability aggregates should either remain largely unaffected with respect to durability or, in a few isolated cases, exhibit improved long term performance with 15% replacement of the cement with quality fly ash.

Recommendation

It is recommended that the substitution of fly ash from approved sources for up to 15% of the portland cement in concrete paving mixes containing Class II aggregates be allowed in the specifications.

References

1. Iowa Department of Transportation, Standard Specifications for Highway and Bridge Construction, Series of 1984, Iowa Department of Transportation, Section 2301 "Portland Cement Concrete Pavement".

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.

APPENCICES

APPENDIX A
STANDARD SPECIFICATIONS
MIX PROPORTIONS

Proportions for Pavement Concrete
Section 2301.04

Class C Concrete

Basic Absolute Volumes of Materials Per Unit Volume of Concrete

Mix No.	Cement Minimum	Water	Entr. Air	Fine Aggregate	Coarse Aggregate
C-2	0.110202	0.148144	0.06	0.272662	0.408992
C-3	.114172	.153840	.06	.301895	.370093
C-4	.118330	.159808	.06	.330931	.330931
C-5	.122867	.166318	.06	.358448	.292367
C-6	.127782	.173371	.06	.384308	.254539

Approximate Quantity of Dry Materials Per Cubic Yard of Concrete *

Mix No.	Cement Pounds	Fine Aggregate Tons	Coarse Aggregate Tons
C-2	583	0.6087	0.9130
C-3	604	.6739	.8262
C-4	626	.7388	.7388
C-5	650	.8002	.6527
C-6	676	.8579	.5682

*These quantities are based on the following assumptions: Specific gravity of cement 3.14; specific gravity of aggregate 2.65, water cement ratio 0.430 pound of water per pound of cement, air voids 6.0 percent.

APPENDIX B
DURABILITY TESTING
(Freeze/Thaw 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 $\pm$ 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:

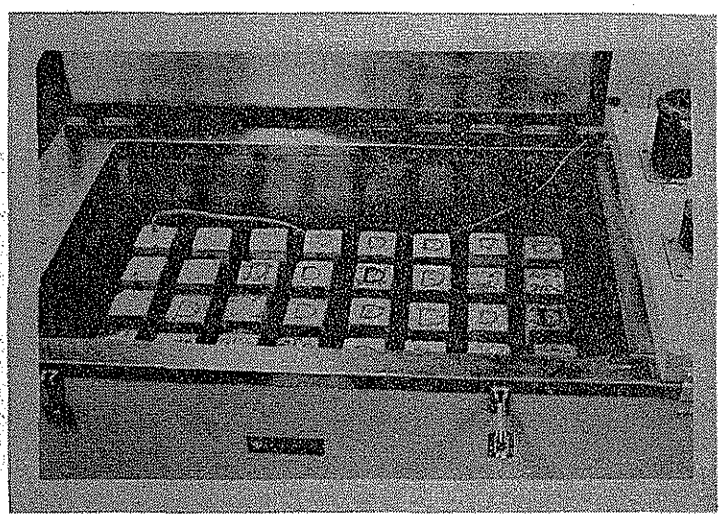
DF = the durability factor of the specimen

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

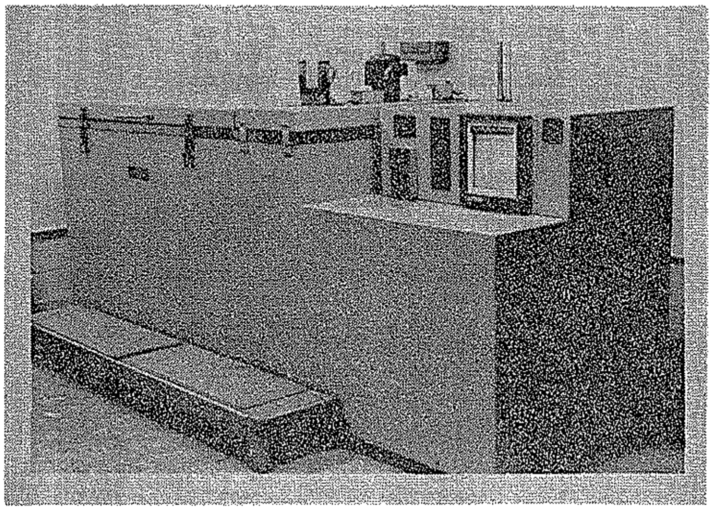
N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less

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

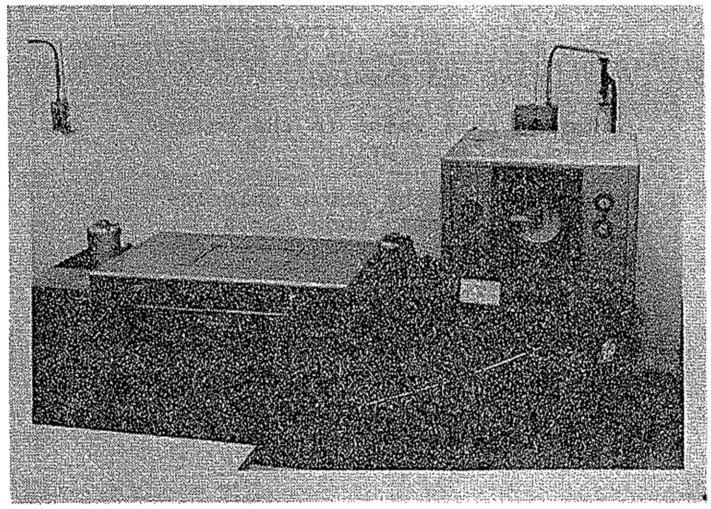
8. Report. The final report (worksheet) should be submitted to the Geology Section, and it should include all data pertinent to the variables or combination of variables studied in the evaluation. Also, any defects in each specimen which develop during testing and the number of cycles at which such defects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



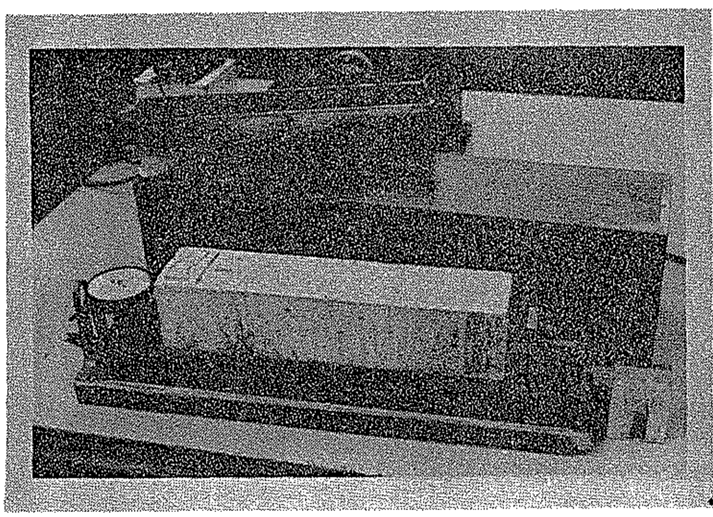
Specimens in the
Freezing & Thawing Apparatus



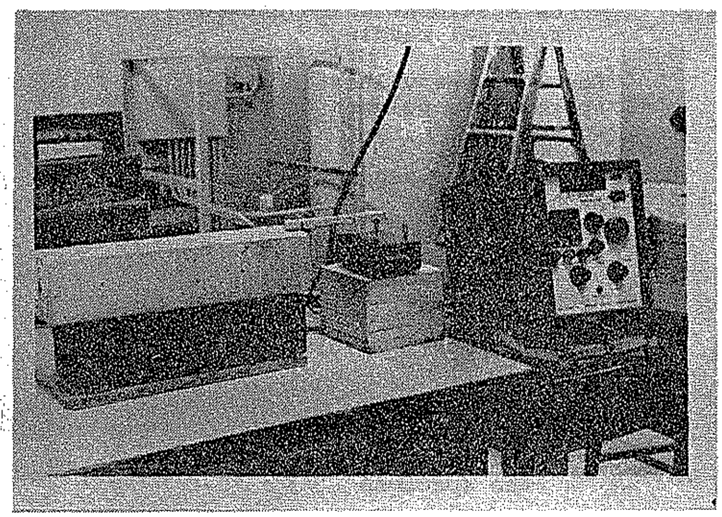
Freezing & Thawing Apparatus
"Cincinnati"



Freezing & Thawing Apparatus
"Conrad"



Beam Comparator



Dynamic Testing Apparatus

orm 821288
-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.