EVALUATION OF FLY ASH CONCRETE
SUBJECT TO
RAPID FREEZING AND THAWING

Submitted to
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by

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INTRODUCTION

Tests were performed at the Fears Structural Engineering Laboratory, University of Oklahoma, Norman, Oklahoma for The Dolese Company of Oklahoma City to compare the resistance of two types of hard rock concrete mix to rapid freezing and thawing. The test procedure conformed to ASTM C666-77 Standard Method of Testing for Resistance of Concrete to Rapid Freezing and Thawing, Method A. The mix type were plain 3,000 psi hard rock mix with fly ash added. The materials for the test as well as the batch weight were provided by The Dolese Company.

Three samples of each mix design were subjected to three hundred cycles of freezing and thawing. Fundamental frequency measurements were taken at various points during the test period and from these measurements quantitative values were computed and compared. The control mix samples are identified as PL1 to PL3 and the fly ash samples as FA1 to FA3. A complete description of the testing procedure and test results follows.

TEST DETAILS

<u>Test Specimens</u>. Test specimens were cast in specially made plywood forms with nominal dimensions of 4 in. by 4 in. by 16 in. The specimens were cast and cured in accordance with the applicable requirements of ASTM C192. The specimen. were removed from the forms 24 hours after casting and stored in saturated lime water for seven days prior to placement in the testing chamber. Specimens measures approximately 4 1/8 in. by 4 1/8 in. by 15 7/8 in.

<u>Testing Equipment</u>. A 18.2 cubic feet freeze thaw cabinet manufactured by Logan Refrigeration Co., Logan, Utah, Model No. ECAM-0075-1AA was used to perform the testing. Test specimens were placed in copper containers in the cabinet. Shims were used so that 1/8 in. of water covered the exterior sides of the specimens. Daily checking of water depth was made to insure a 1/8 in. water cover on top.

The chamber is completely automatic and was set at a temperature range of 90° F to -5° F throughout the testing. Temperature is monitored by a prode placed inside a specimen identical in size to the test specimen but not part of the test program. The cabinet cycled approximately four times per day.

A sonometer, Model CT-366 as manufactured by Soiltest, Inc. was used to determine the resonant frequency of the specimen as set forth in ASTM C666-77. The specimen's mechanical resonant frequency is determined by driving it with sound vibration at a known frequency. The driving frequency is then varied until a resonant condition is achieved as verified by indicating devices on the instrument. The resonant frequency is then converted to dynamic Young's modulus of elasticity.

TESTING PROCECURE

Immediately after the specified curing period, the specimens were brought to room temperature and the fund-amental transverse frequency, weight and overall dimensions determined in accordance with ASTM C215-60. The specimens were then placed in a freeze-thaw cabinet and the cycling initiated. The specimens were checked daily for sudden signs of deterioration and to add water if necessary.

The specimens were weighed and tested for fundamental transverse frequency approximately every 36 cycles. At the end of the cycle prior to testing, the cabinet was opened and the specimens were left at room temperature until completely thawed. The samples were then removed from the cabinet, weighed, measured and tested for fundamental transverse frequency and then returned to the cabinet. The testing required approximately 1½ hours.

Testing began on November 11, 1980 and was completed on February 21, 1981. Samples PL1 to PL3 were tested for 151 cycles and FA1 to FA3 for 298 cycles. Testing was interrupted for periods of up to one week because of equipment malfunction or laboratory vacation period.

TEST RESULTS

Dynamic Young's Modulus. Calculation of dynamic Young's modulus of elasticity, E, in pounds per square inch from the fundamental transverse frequency, weight, and dimensions of the test specimen was done as follows:

$$\text{Dynamic } E = CWn^2$$

where:

- W = weight of specimen, lb.
- n = fundamental transverse frequency, Hz.
- C = 0.00245 (L^3T/bt^3), s^2/in^2 for a prism.
- L = length of specimen, in.
- t,b = dimensions of cross section of prism, in. t being in the direction in which it is driven.
- T = a correction factor which depends on the ratio of the radius of gyration, K, (for a prism K is t/3.464), to the length of the specimen, L, and Poisson's ratio. Values of T for Poisson's of 1/6 were obtained from Table 1 of ASTM C215.

RELATIVE DYNAMIC MODULUS OF ELASTICITY

The calculations for the numerical values of relative dynamic modulus of elasticity were done as follows, (ASTM C666-77):

$$P_i = (n_i^2/n^2) \times 100$$

where

- P_i = relative dynamic modulus of elasticity after i cycles of freezing and thawing, per cent
- n = fundamental transverse frequency at 0 cycles of freezing and thawing.
- n_i = fundamental transverse frequency after i cycles of freezing and thawing.

Note: The calculation of relative dynamic modulus of elasticity is based on the assumption that the weight and dimensions of the specimen remain constant throughout the test. This assumption is not true in many cases due to disintergration of the specimen. However, if the test is to be used to make comparisons between the relative dynamic moduli of different specimens or of different concrete formulations, P_i as defined is adequate for the purpose.

DURABILITY FACTOR

The calculation of the durability factor was done as follows:

$$DF = PNM$$

where:

DF = durability factor of the test specimen

P = 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 the exposure is to be terminated.

TEST DATA

Test data consists of the weight and dimensions of each specimen at each test cycle and are given in Appendix A, Table A.1. The dynamic modulus of elasticity and the relative dynamic modulus of elasticity are given in Appendix A, Table A.2, and average values for the relative dynamic modulus of elasticity are given in Table I. The durability factor is given in Table II.

At 110 cycles, the plain mix design samples began to show more wear than the samples with fly ash. At 151 cycles into the test, the plain mix samples became hard to remove from the cabinet due to a large amount of decay. At 203 cycles, all the plain mix design samples were so decayed that they broke in half when they were removed from the cabinet. At 203 cycles, the surface of the samples with fly ash had decayed to a point where the markings could no longer be read.

The average results for each group of specimens is plotted in Figure 1. The curves show the value of relative modulus of elasticity against time expressed as the number of cycles of freezing and thawing.

Table I

Relative Dynamic Modulus of Elasticity Average Values

Cycles	Relative Dynamic Modulus of Elasticity PL %	FA %
0	100	100
39	88.6	102.7
76	36.6	77.5
110	18.8	41.1
151	0.0	22.9
203	-	0.8
256	-	0.2
298	-	0.1

TABLE II

Durability Factor for 60% of Initial Modulus

Sample Group	Durability Factor
PL	11.9
FA	18.5

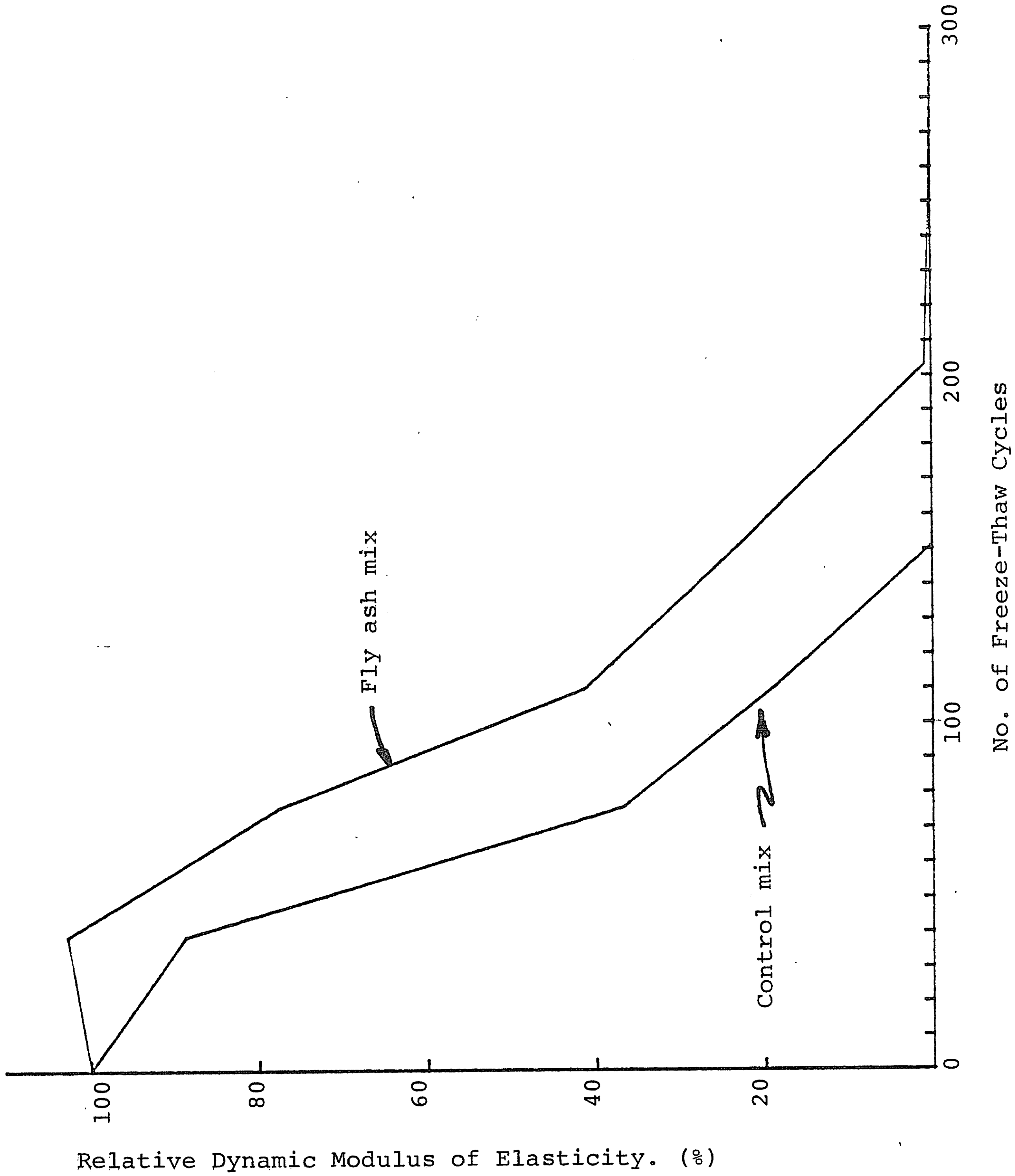
Fly ash mix
Control mix
0
100
200
300
No. of Freeze-Thaw Cycles
100
80
60
40
20
Relative Dynamic Modulus of Elasticity. (%)

Figure 1.

Appendix A

TEST DATA

Table A.1

Specimen Sample Data

Sample	Length in.	Height in.	Width in.	Initial Weight lbs.	Coeff. C s^2/in^2
PL1	15.875	4.125	4.125	21.7	0.0484
PL2	15.875	4.125	4.125	21.3	0.0484
PL3	15.875	4.125	4.188	21.9	0.0477
FA1	15.938	4.186	4.125	21.6	0.0471
FA2	15.875	4.125	4.186	21.7	0.0477
FA3	15.875	4.125	4.186	21.8	0.0477

Table A.2

Dynamic Young's Modulus of Elasticity

Sample	Cycle	Frequency cps	Weight lbs	Dynamic Young's Modulus $lbs/in^2 \times 10^6$	Relative Dynamic Modulus %
PL1	0	17900	21.7	336.5	100.0
PL2	0	1800	21.3	334.0	100.0
PL3	0	1800	21.9	338.0	100.0
FA1	0	17500	21.6	311.6	100.0
FA2	0	17500	21.7	317.0	100.0
FA3	0	17700	21.8	325.8	100.0
PL1	39	17300	21.4	310.0	84.9
PL2	39	17300	21.1	305.6	83.7
PL3	39	18000	21.6	333.8	97.2
FA1	39	17900	21.4	323.8	107.5
FA2	39	18000	21.5	205.0	109.7
FA3	39	17400	21.5	190.4	90.8
PL1	76	14300	21.6	213.8	40.4
PL2	76	14100	21.3	205.0	37.7
PL3	76	13500	21.9	190.4	31.6
FA1	76	18900	21.6	363.4	136.0*
FA2	76	16300	21.7	275.0	75.3
FA3	76	16800	21.6	290.8	79.7
PL1	110	13800	21.5	198.2	34.7
PL2	110	10500	21.2	113.1	11.7
PL3	110	10200	21.8	108.2	10.2
FA1	110	16700	21.6	283.7	82.9*
FA2	110	13700	21.7	194.3	37.6
FA3	110	14500	21.7	217.6	44.6

*Data was dropped in average values.

Table A.2 Con't.

Sample	Cycle	Frequency cps	Weight lbs	Dynamic Young's Modulus $lbs/in^2 \times 10^6$	Relative Dynamic Modulus %
PL1	151	2000	21.0	4.066	0.0
PL2	151	1060	21.0	1.142	0.0
PL3	151	1600	20.2	2.467	0.0
FA1	151	11900	21.4	142.7	21.0
FA2	151	10800	21.4	119.7	14.1
FA3	151	13600	21.4	188.8	33.6
PL1	203	-	-	-	-
PL2	203	-	-	-	-
PL3	203	-	-	-	-
FA1	203	4600	21.0	20.93	0.5
FA2	203	5300	21.1	28.27	0.8
FA3	203	5800	21.0	33.70	1.1
PL1	256	-	-	-	-
PL2	256	-	-	-	-
PL3	256	-	-	-	-
FA1	256	3910	20.3	14.62	0.2
FA2	256	3590	20.3	12.48	0.2
FA3	256	4100	20.1	16.12	0.2
PL1	298	-	-	-	-
PL2	298	-	-	-	-
PL3	298	-	-	-	-
FA1	298	2910	20.0	7.977	0.1
FA2	298	2000	19.9	3.797	0.0
FA3	298	3210	19.8	9.732	0.1

- value cannot be computed sample destroyed