EVALUATION OF FLY ASH CONCRETE

SUBJECT TO

RAPID FREEZING AND THAWING

PART II

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 types were plain 3000 psi hard rock mix and the Dolese Company designated Class A mix with and without Fly ash added. The materials for the test as well as the batch weight were provided by The Dolese Company. The batch weights and corresponding code numbers are given in Appendix A, Table A.1.

Three samples of each of the four mix designs 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 1A, 1B and 1C for the 3000 psi mix and 3A, 3B, and 3C for the Class A mix. 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.

With the remaining concrete, one standard 6 in. diameter by 12 in. test cylinder was cast. (Batch size was such that only enough concrete was available for one cylinder.) The Specimens were cast and cured in accordance with the applicable requirements of ASTM C192. The freeze-thaw specimens 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. The cylinders were kept in the lime bath until they were tested. Specimens measured approximately 4 1/8 in. by 4 1/8 in. by 15 7/8 in.

Testing Equipment. 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 and 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.

Sonometer instrumentation was used to determine the resonant frequency of the specimen as set forth in ASTM C666-77. The sonometer was composed of a driver, Model CT 367A as manufactured by Soiltest, a Model 3310B function generator, a Model 5381A frequency counter and a Model 120B oscilloscope all manufactured by Hewelett-Packard, and two amplifiers; the driver amplifier, Model MPA-20 manufactured by Realistic, and the phono pickup amplifier, manufactured by Pace. 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 plotting the driver frequency against the response frequency from the specimen on the oscilloscope. The resonant frequency is then converted to the dynamic Young's modulus of elasticity.

TESTING PROCEDURE

Immediately after the specified curing period, the specimens were brought to room temperature and the fundamental transverse frequency, weight and overall dimensions determined in accordance with ASTM C215-60. The specimens were then placed in the 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, and tested for fundamental transverse frequency and then returned to the cabinet. The testing required approximately 1 1/2 hours.

Testing began on July 29, 1981 and was completed on November 23, 1981. Testing was interrupted for periods of up to one week because of equipment malfunction or laboratory vacation period.

A 200,000 lb. capacity universal testing machine as manufactured by Baldwin, Model UNIV, was used to test the compressive strength of the cylinders in accordance with ASTM C39-72. The cylinders were tested on the last day of the test period, November 23, 1981.

TEST DATA

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, percent.

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 disintegration 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:

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

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 RESULTS

The data obtained at the time of casting consists of slump, percent air and unit weight and is shown in Appendix A, Table A.2. Test data taken before each cycle period consists of sample weight, sample dimensions and fundamental frequency. Sample weight and size is shown in Table A.3 and measured frequencies in Table A.4 to A.11. Results of the cylinder compressive strength tests are given in Table A.12.

Calculated data consists of the relative dynamic modulus of elasticity and durability factor and are shown in Tables 1 and 2, respectively. The average relative dynamic modulus of elasticity results for each specimen group are plotted versus number of freeze-thaw cycles in Figures 1 and 2 for the 3000 psi mix and the Class A mix, respectively.

All sample groups showed approximately the same amount of wear throughout the testing. However, the surface of the flyash samples held sample identification markings longer than the plain mixes. At the end of 300 cycles all samples were still in tact and in relatively good condition.

Table 1

Average Relative Dynamic Modulus of

Elasticity Values

Relative Dynamic Modulus of Elasticity,* %				
Sample Group	1	2	3	4
Batch / Cycles	Code #0224 3000 3/5 AEA	Code #33 3000 -3/5 AEA, FA	Code #S23B Class A AEA, 3/5	Code # S36F Class A AEA, FA 3/5
0	100	100	100	100
50	97.0	98.2	96.6	98.4
143	87.2	95.9	91.7	96.5
166	93.5	93.5	89.0	91.4
200	96.6	89.8	82.1	95.8
227	80.0	86.1	76.5	85.2
263	87.5	77.4	74.5	84.7
300	88.5	75.2	76.5	80.1

*Average of three samples.

Table 2

Durability Factors

Sample Group	Batch Classification	Durability Factor*, %
1	Code #0224 3000 3/5 AEA	88.5
2	Code #33 3000 3/5 AEA, FA	75.2
3	Code #S23B Class A AEA, 3/5	76.5
4	Code #S36F Class A AEA, FA, 3/5	80.1

*Average of three samples.

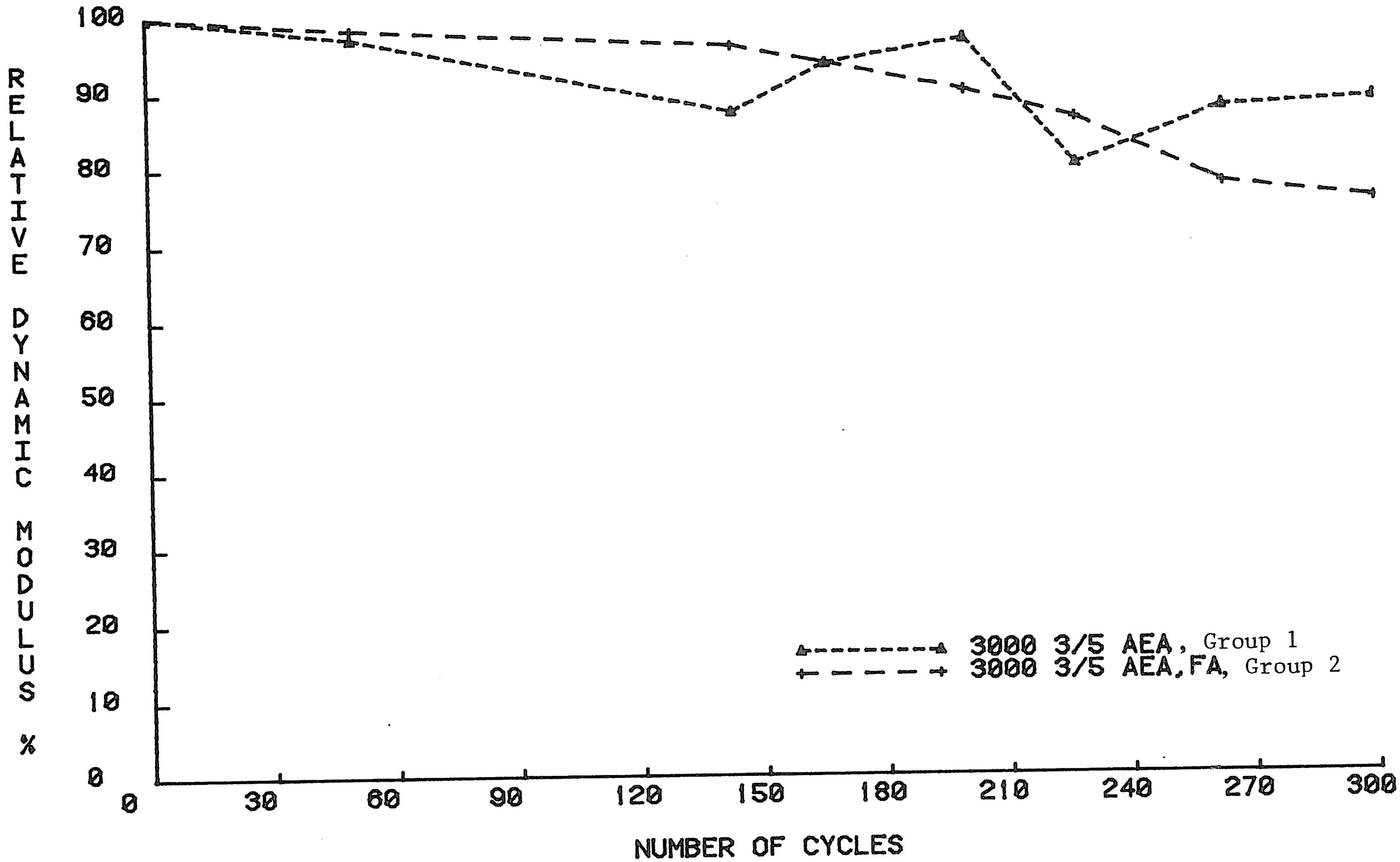

Figure 1. Relative Dynamic Modulus of Elasticity, 3000 psi Mix

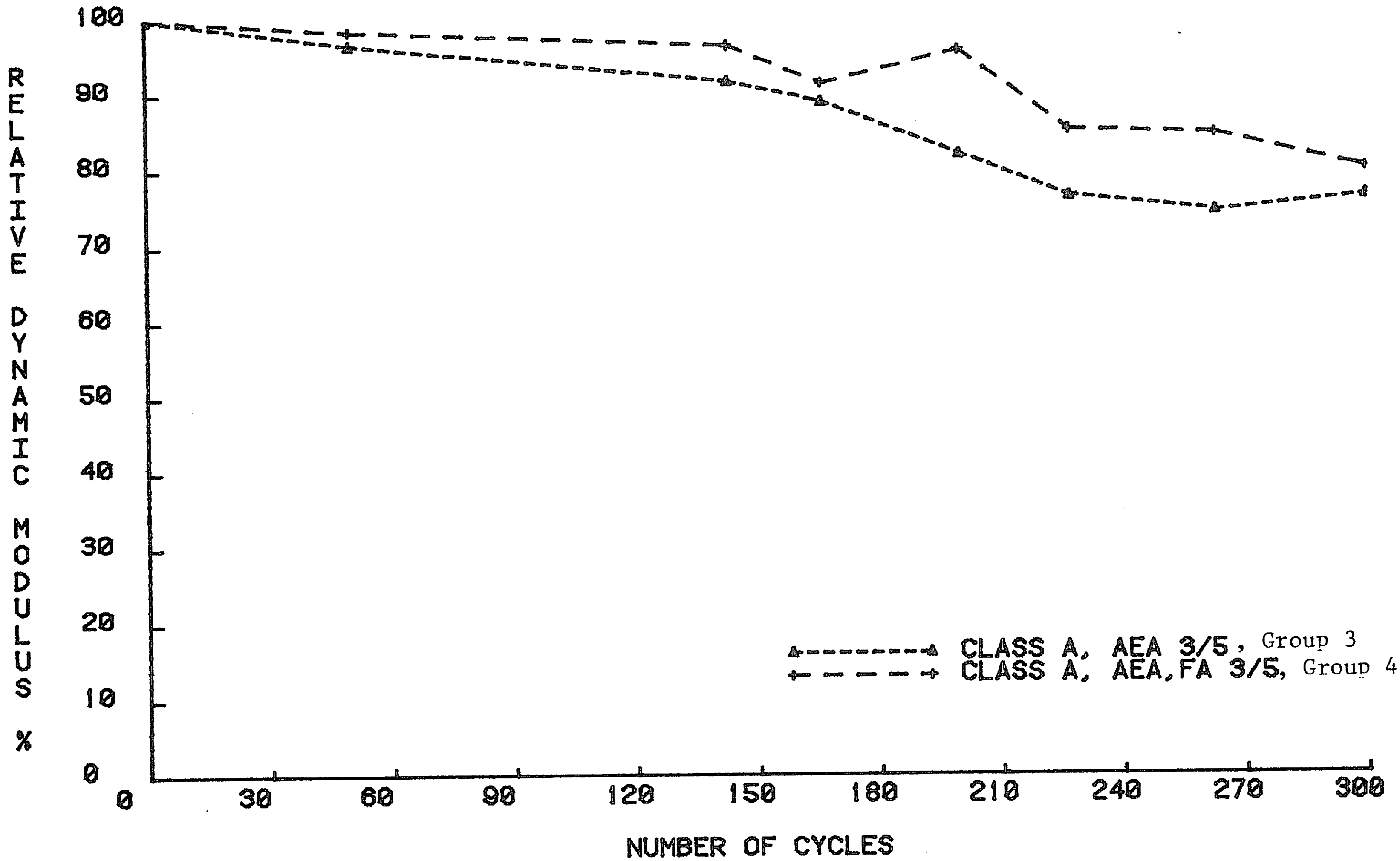

Figure 2. Relative Dynamic Modulus of Elasticity, Class A Mix

Appendix A

TEST DATA

Table A.1

One Cubic Yard Mix Proportions

Material	Code #0224 3000 3/5 AEA	Code #33 3000 3/5 AEA, FA	Code #S23B Class A, AEA 3/5	Code #S36F Class A, AEA,FA 3/5
Cement	478 lbs.	397 lbs.	564 lbs.	479 lbs.
Fly Ash	- - - -	120 lbs.	- - - - -	105 lbs.
Sand	1,303 lbs.	1,264 lbs.	1,169 lbs.	1,255 lbs.
Stone	1,921 lbs.	1,861 lbs.	1,951 lbs.	1,911 lbs.
AEA	4.5 oz.	5.0 oz.	7.0 oz.	7.0 oz.
Water	25 gal.	25 gal.	23 gal.	23 gal.

Table A.2

Batch Test Data

Sample Group	Slump in.	Percent of Air %	Unit Weight lbs.
1	2.0	5.0	33.0
2	1.0	3.8	33.2
3	0.75	4.0	33.9
4	2.0	5.0	33.2

Table A.3

Specimen Sample Data

Sample No.	Length in.	Height in.	Width in.	Initial Weight lbs.
1A	15.875	4.106	4.301	22.0
1B	15.875	4.195	4.246	21.8
1C	15.875	4.1375	4.2815	21.7
2A	15.875	4.133	4.036	21.0
2B	15.875	4.159	4.185	21.5
2C	15.875	4.172	4.337	22.6
3A	15.875	4.184	4.1745	21.7
3B	15.875	4.001	4.028	21.1
3C	15.875	4.211	4.51	21.9
4A	15.875	4.149	4.027	20.7
4B	15.875	4.106	4.116	21.9
4C	15.875	4.200	4.3	25.5

OF CYCLES = 0

SAMPLE	FREQUENCY hz	WEIGHT lbs	DYNE lbs/in^2	REL E %
1	2413.00	24.25	6269160.0	100.0
2	2405.00	24.16	6316340.4	100.0
3	2391.00	23.81	6084516.5	100.0
4	2394.00	23.19	6618786.7	100.0
5	2399.00	23.60	6465162.6	100.0
6	2429.00	24.84	6243329.0	100.0
7	2433.00	23.84	6731453.5	100.0
8	2481.00	23.36	7433903.3	100.0
9	2479.00	24.13	5575684.9	100.0
10	2387.00	22.83	6490995.3	100.0
11	2389.00	22.77	6133909.0	100.0
12	2414.00	23.94	6054641.1	100.0

Group #1 - Samples 1, 2, 3

Group #2 - Samples 4, 5, 6

Group #3 - Samples 7, 8, 9

Group #4 - Samples 10, 11, 12

Table A.4 Frequency Related Data at 0 Cycles

OF CYCLES = 50

SAMPLE	FREQUENCY hz	WEIGHT lbs	DYNE lbs/in^2	REL E %
1	2370.00	24.19	6032752.8	96.5
2	2376.00	24.14	6159827.8	97.6
3	2353.00	23.79	5887702.0	96.8
4	2394.00	23.17	6613078.4	100.0
5	2363.00	23.55	6259293.4	97.0
6	2399.00	24.84	6090061.6	97.5
7	2402.00	23.83	6558256.9	97.5
8	2427.00	23.36	7113821.0	95.7
9	2438.00	24.07	5379369.0	96.7
10	2384.00	22.83	6474689.7	99.7
11	2348.00	22.78	5927777.6	96.6
12	2399.00	23.86	5959649.8	98.8

Group #1 - Samples 1, 2, 3

Group #2 - Samples 4, 5, 6

Group #3 - Samples 7, 8, 9

Group #4 - Samples 10, 11, 12

Table A.5 Frequency Related Data at 50 Cycles

OF CYCLES = 143

SAMPLE	FREQUENCY hz	WEIGHT lbs	DYNE lbs/in^2	REL E %
1	2294.00	21.00	4906695.3	90.4
2	2048.00	21.20	4019149.9	72.5
3	2374.00	20.70	5214819.7	98.6
4	2380.00	20.30	5726368.5	98.8
5	2391.00	20.60	5558952.5	99.5
6	2309.00	20.80	4724118.7	90.4
7	2267.00	20.80	5098997.0	86.8
8	2390.00	20.40	6024437.6	92.8
9	2423.00	21.00	4635685.5	95.5
10	2324.00	20.00	5390174.0	94.8
11	2332.00	19.90	5108015.0	95.3
12	2408.00	21.00	5284720.1	99.5

Group #1 - Samples 1, 2, 3

Group #2 - Samples 4, 5, 6

Group #3 - Samples 7, 8, 9

Group #4 - Samples 10, 11, 12

Table A.6 Frequency Related Data at 143 Cycles

OF CYCLES = 166

SAMPLE	FREQUENCY hz	WEIGHT lbs	DYNE lbs/in^2	REL E %
1	2266.00	20.60	4696453.2	88.2
2	2343.00	21.00	5210774.8	94.9
3	2358.00	20.50	5095056.3	97.3
4	2315.00	20.20	5391166.0	93.5
5	2293.00	20.40	5105581.7	91.4
6	2374.00	20.70	4969828.2	95.5
7	2228.00	20.60	487770[illegible].6	83.9
8	2317.00	20.10	5578772.7	87.2
9	2429.00	20.80	4614304.1	96.0
10	2258.00	19.80	5037483.2	89.5
11	2215.00	19.80	4585161.6	86.0
12	2399.00	20.60	5145379.9	98.8

Group #1 - Samples 1, 2, 3

Group #2 - Samples 4, 5, 6

Group #3 - Samples 7, 8, 9

Group #4 - Samples 10, 11, 12

Table A.7 Frequency Related Data at 166 Cycles

OF CYCLES = 200

SAMPLE	FREQUENCY hz	WEIGHT lbs	DYNE lbs/in^2	REL E %
1	2342.00	20.40	4968061.0	94.2
2	2381.00	20.60	5278669.2	98.0
3	2361.00	20.10	5008360.2	97.5
4	2260.00	19.80	5036297.9	89.1
5	2231.00	20.10	4762139.9	86.5
6	2354.00	20.15	4756610.2	93.9
7	2148.00	20.30	4467689.4	77.9
8	2222.00	19.90	5079625.9	80.2
9	2327.00	20.60	4194187.4	88.1
10	2387.00	19.55	5558430.1	100.0
11	2339.00	19.50	5035435.7	95.9
12	2311.00	20.50	4751639.5	91.6

Group #1 - Samples 1. 2. 3

Group #2 - Samples 4, 5, 6

Group #3 - Samples 7, 8, 9

Group #4 - Samples 10, 11. 12

Table A.8 Frequency Related Data at 200 Cycles

OF CYCLES = 227

SAMPLE	FREQUENCY hz	WEIGHT lbs	DYNE lbs/in^2	REL E %
1	2087.00	20.50	3964435.9	74.8
2	2211.00	20.60	4551799.7	84.5
3	2149.00	20.20	4169958.4	80.8
4	2246.00	19.90	4999216.2	88.0
5	2199.00	20.20	4649527.1	84.0
6	2257.00	21.30	4622238.2	86.3
7	2038.00	20.30	4021821.4	70.2
8	2075.00	20.05	4463146.3	69.9
9	2344.00	20.60	4255692.9	89.4
10	2328.00	19.60	5300569.9	95.1
11	2028.00	19.60	3804818.7	72.1
12	2271.00	20.60	4610958.6	88.5

Group #1 - Samples 1, 2, 3

Group #2 - Samples 4, 5, 6

Group #3 - Samples 7, 8, 9

Group #4 - Samples 10, 11, 12

Table A.9 Frequency Related Data at 227 Cycles

OF CYCLES = 263

SAMPLE	FREQUENCY hz	WEIGHT lbs	DYNE lbs/in^2	REL E %
1	2249.00	20.30	4558877.5	86.9
2	2240.00	20.40	4626628.6	86.7
3	2253.00	20.10	4560641.8	88.8
4	2156.00	19.80	4583445.2	81.1
5	2125.00	20.00	4298875.0	78.5
6	2070.00	21.10	3851525.2	72.6
7	2051.00	20.30	4073293.8	71.1
8	2077.00	19.90	4438299.6	70.1
9	2250.00	20.50	3902175.0	82.4
10	2283.00	19.60	5097631.5	91.5
11	2210.00	19.40	4472272.7	85.6
12	2118.00	20.40	3971657.7	77.0

Group #1 - Samples 1, 2 3

Group #2 - Samples 4, 5, 6

Group #3 - Samples 7, 8, 9

Group #4 - Samples 10. 11, 12

Table A.10 Frequency Related Data at 263 Cycles

OF CYCLES = 300

SAMPLE	FREQUENCY hz	WEIGHT lbs	DYNE lbs/in^2	REL E %
1	2229.00	20.20	4456095.4	85.3
2	2337.00	20.50	5060689.8	94.4
3	2216.00	20.05	4401101.8	85.9
4	2079.00	19.80	4261902.5	75.4
5	2054.00	19.90	3996326.0	73.3
6	2129.00	21.20	4093518.7	76.8
7	2121.00	20.30	4356079.1	76.0
8	2247.00	19.95	5207623.6	82.0
9	2098.00	20.50	3392756.4	71.6
10	2170.00	19.60	4605492.6	82.6
11	2113.00	19.60	4130447.1	78.2
12	2154.00	20.60	4148091.7	79.6

Group #1 - Samples 1, 2, 3

Group #2 - Samples 4, 5, 6

Group #3 - Samples 7, 8, 9

Group #4 - Samples 10, 11, 12

Table A.11 Frequency Related Data at 300 Cycles

Table A.12

Compressive Strength of Cylinders

Sample Group	Batch Classification	Compressive Strength*, psi
1	Code #0224 3000 3/5 AEA	5107
2	Code #33 3000 3/5 AEA, FA	5914
3	Code # S23B Class A AEA, 3/5	5968
4	Code # S36F Class A AEA, FA, 3/5	5443