



**SCHOOL OF
CIVIL ENGINEERING
OKLAHOMA STATE UNIVERSITY**

**INTERIM
REPORT 1**

FLY ASH CONCRETE--2298

By

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The opinions, findings, and conclusions expressed
in this publication are those of the authors
and are not necessarily those of the
Oklahoma Department of Transportation
or the Federal Highway Administration

1. INTRODUCTION

1.1 General

Fly ash can be used to replace a portion of the portland cement in concrete. In several states, including Oklahoma, increasing amounts of electrical power are being obtained using sub-bituminous coal from western coal fields. This fly ash contains relatively high quantities of lime and is self-cementitious. Limited data exist on the influence of this ash on the characteristics of concrete.

1.2 Scope

One objective of this study was to determine whether fly ash altered the freeze-thaw resistance of concrete used for paving construction. A second objective was to evaluate the influence of casting temperatures on mix proportions and characteristics of plastic concrete. In both study areas, as much as 50 percent of the portland cement was replaced by fly ash. The purpose of this report is to provide the sponsor with results which have been obtained to date. Some data are yet unavailable for specimens still in curing. In addition, evaluation of the air void system in hardened concrete remains to be accomplished.

2. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Portland Cement

A large quantity of type I portland cement was obtained for project use during the summer of 1980. After receipt in the laboratory, the cement was broken into lots of approximately 20 sacks and double wrapped in plastic film; a desiccant was placed between the two moisture barriers to further resist pre-hydration of the cement. The cement supplier furnished a laboratory analysis of the cement (see Table 1).

2.1.2 Fly Ash

A single large shipment of fly ash was also obtained for project use during the summer of 1980. This material was also broken into small lots and sealed in plastic. Before the completion of the project, a detailed laboratory analysis of the fly ash will be obtained.

2.1.3 Fine Aggregate

Arkansas River sand was used as fine aggregate. The sand had a specific gravity of 2.64, an absorption capacity of 0.69 percent, and a fineness modulus of 2.71.

2.1.4 Coarse Aggregate

ASTM C 33, size 57 crushed limestone was used as coarse aggregate. Concrete used in the first series of freeze-thaw specimens and concrete cast at 70°F contained coarse aggregate which came from a quarry near Drumright, Oklahoma. This aggregate had a specific gravity (SSD) of 2.76, an absorption

capacity of 0.91 percent, and a dry rodded unit weight of 104 pcf. All other concrete was cast using crushed limestone quarried near Pawnee, Oklahoma. This aggregate had a specific gravity of 2.64, an absorption capacity of 1.39 percent, and a dry rodded unit weight of 98 pcf.

2.1.5 Air-Entraining Admixture

A neutralized vinsol resin conforming to ASSHTO M-194 was used in all concrete mixes.

2.2 Casting Procedures

2.2.1 Aggregate Preparation

All aggregate was initially air dried to approximately constant weight. The fine aggregate was sieved into three size fractions. In preparation for casting, the aggregate was recombined; 20.5, 38.0, and 41.5 percent of the resulting aggregate was retained on the No. 16, 30, and 100 sieves, respectively. Approximately 24 hours before casting, water equal to 5 percent of the weight of the sand was added to the fine aggregate. After mixing, the moist sand was left in a sealed container until the time of casting.

Coarse aggregate was also separated into three size fractions using the 3/4-in., 1/2-in., and No. 8 sieves. The aggregate was recombined such that 22, 43, and 35 percent of the resulting aggregate would be retained on the 3/4-in., 1/2-in., and No. 8 sieves, respectively. The aggregate was immersed in water approximately 24 hours prior to casting. As materials were being batched, the water was decanted and the weight of free water was determined.

Aggregates that were to be used in mixes cast at various temperatures were brought to approximately the desired temperature using heated or chilled

water and were placed in the mixing chamber which was maintained at the proper temperature approximately 24 hours prior to casting.

2.2.2 Batching and Mixing

The proportions of the control batches without fly ash were identical to those approved by the Oklahoma Department of Transportation in Stillwater. The proper quantities of air entraining agent and mix water were determined using trial batches of approximately 1.0 cu ft. All test batches were 3.0 cu ft and were mixed in a rotating drum mixer with a maximum usable capacity of 3.75 cu ft. The mixer was initially charged with aggregate and a portion of the mix water containing the air entraining admixture. The mixer was started; one-half of the cement, more water, the remainder of the cement, and the last of the mix was added. If visual examination of the concrete after a few moments of mixing suggested it was going to be too stiff, a small additional quantity of water was added. The mixer was operated for three minutes after the addition of water, shut off for three minutes, and run for two more minutes.

2.2.3 Casting of Test Specimens

Immediately following the mixing operation, the concrete was discharged from the mixer and the temperature, slump, air content, and unit weight were measured in accordance with ASTM procedures. If the concrete was to be used in freeze-thaw testing, six 3x4x16 in. prisms and six 6x12 in. cylinders were cast.

If the concrete was to be used to investigate the influence of mix temperature, three 6x12 in. cylinders, one 6x6x6 in. time of set mortar cube, and one 3x4x16 in. prism were cast. Unused concrete including that used in the slump and air content test was replaced into the mixer; the mixer was restarted

at a reduced speed of 2 rpm. For the next one to two hours, the temperature, slump, and air content were measured at 30-minute intervals; at these times an additional 3x4x16 in. prism was cast.

With one exception all specimens were cast in steel molds in which all seams had been sealed with wax; when specimens were cast for freeze-thaw tests, four of the six 6x12 in. cylinders were cast in steel molds and two in disposable cardboard. The two cylinders tested at 14 days, when freeze-thaw tests were initiated, and the two cylinders tested at 28 days were those cast in steel molds. At the time of this report, it is doubtful if freeze-thaw testing will be conducted on the more mature samples and compression tests may not be required on samples cast in cardboard molds.

2.2.4 Curing and Testing of Hardened Concrete

After molding, specimens were covered with plastic film and allowed to harden for at least 24 hours. Samples cast at 55°F and which contained fly ash were still very weak at 24 hours. To help avoid damage when specimens were removed from the molds, the molds containing the specimens were removed from the 55°F environment and exposed to ambient laboratory temperatures for approximately 8 hours before demolding.

Specimens which were to be subjected to freeze-thaw tests were cured in lime-saturated water at a temperature of $23 \pm 1.7^{\circ}\text{C}$ with a relative humidity greater than 95 percent.

Compression samples were tested using a universal testing machine with a capacity of 300 kips. An extensometer with a 6-in. gage length was used to measure axial deformation. Stress versus strain plots were plotted using an X-Y recorder and the modulus of elasticity was obtained for these plots.

The freeze-thaw tests were performed using a cabinet shown in Figure 1 with a capacity of 18 prisms. The apparatus met requirements for ASTM C 666, Procedure A, Rapid Freezing and Thawing in Water. One sample contained internal sensors to monitor and control temperature; five groups of three samples each were tested from five batches containing various percentages of fly ash. The two remaining samples were dummy samples and sometimes contained an embedded thermistor to verify the operation of the chamber.

At intervals of approximately 30 freeze-thaw cycles, specimens were removed from the chamber and placed in a temperature-controlled water bath at 42°F for at least 1 hour. Tests to determine the fundamental transverse frequency in accordance with ASTM C 215 were then performed using the equipment shown in Figure 2.

Equipment has been readied to evaluate the air void system in the hardened concrete, but this work has not been initiated.

3. EXPERIMENTAL RESULTS

3.1 Freeze-Thaw Tests

Results of the first test series are given in Table 2. Relatively little visual deterioration was caused by 300 freeze-thaw cycles (Figure 3); the durability factor based on the average of three specimens was greater than 90 for all batches. Weight loss did not correlate well with durability. For example, the batch with 50 percent fly ash had a relatively large weight loss but the highest durability factor. This batch also contained the largest air content.

3.2 Concrete Cast at Various Temperatures

Tables 3, 4, and 5 present data obtained from concrete mixed at 55°, 70°, and 90°F, respectively. Two batches were cast at each temperature; one batch had 5 to 6 percent air, and the other batch had 6 to 7 percent air.

3.2.1 Influence of Fly Ash Percentage

As the percent of fly ash was increased, there was a tendency for the required quantity of mix water to decrease; at the same time the amount of air entraining admixture had to be increased. The times of initial and final set were very sensitive to the percentage of fly ash; mixes with 50 percent fly ash had times of set nearly three times as great as the control batches.

The percent fly ash did not have a strong influence on the loss of air or stiffening of the mixes which were subjected to agitation after the initial mixing period. Further, the percent of fly ash did not influence the temperature of the concrete during the agitation period; all mixes remained at approximately a constant temperature.

3.2.2 Influence of Temperature

The temperature did not appear to influence the amount of air lost during agitation; the greatest air loss usually occurred during the first 30 minutes of agitation. Further tests on the hardened concrete will be required to determine whether the losses were in the entrained air or the entrapped air, or both. As the casting temperature was increased, there was a slight increase in the required mix water.

4. DISCUSSION OF RESULTS

4.1 Freeze-Thaw Durability

Data from one series of specimens indicate that concretes made with fly ash can be resistant to freeze-thaw action. However, it may be that the durability is so closely related to entrained air content that the influence of fly ash is being masked. For example, the batch with 50 percent fly ash--which contained 6.6 percent air--had the highest durability factor; all other batches had air content between 5.3 and 5.8 percent. The weight loss data do not correlate well with the durability factor. For example, the specimens from the batch with 30 percent fly ash replacement experienced the greatest deterioration (had the lowest durability factor) and also exhibited the greatest weight loss. However, the specimens from the batch with 50 percent fly ash replacement had an average weight of 262 grams. Based on the limited data presently available, it appears that weight loss will tend to increase with the percent fly ash--possibly as a result of decreasing strength.

The concrete mix proportions used in this study were developed by the Oklahoma Department of Transportation. The quantity of water required to achieve the specified slump resulted in a water-to-cement ratio much less than 0.53, which is permitted by the Standard Specifications for Highway Construction. Therefore, the concrete which has been studied to date is much higher in quality than a concrete which barely satisfies the Specifications. This high quality may be sufficient to mask the influence of fly ash on durability.

4.2 Concrete Cast at Various Temperatures

Data presently available indicate that fly ash has little influence on the loss of slump and air content. Further, fly ash did not influence the

temperature of concrete during prolonged agitation. Fly ash did retard the time of set. During hot weather this may be a very desirable action. However, during cold weather it may be necessary to limit the use of fly ash to a type of construction where time of set is not important; paving is probably one such construction activity.

Work is underway to establish the characteristics of the air void system in the hardened concrete cast during this phase of the investigation. Once these data are available, additional conclusions regarding the use of fly ash will be possible.

5. CONCLUSIONS AND RECOMMENDATIONS

1. Data presently available suggest that fly ash does not adversely influence freeze-thaw durability.

2. Because fly ash permits somewhat less mix water to be used, the compressive strength at 28 days was not strongly related to ash content.

3. When concrete is cast at temperatures between 55° and 90°F and subjected to continued agitation, the presence of fly ash does not strongly influence slump, air content, or temperature.

4. Fly ash significantly increases the time of set; the amount of increase is approximately proportional to the fly ash content.

5. In the future it is recommended that the water/cement ratio be increased to the maximum allowed by the construction specifications. In addition, it is recommended that the air content be decreased--possibly to a value slightly less than would be permitted by specifications.

TABLE 1. PORTLAND CEMENT PROPERTIES

<u>Chemical Tests</u>			
SiO_2	21.18%	C_3S	51.54%
Al_2O_3	5.45%	C_2S	21.56%
Fe_2O_3	2.75%	C_3A	9.79%
CaO	64.41%	C_4AF	8.37%
MgO	2.11%		
SO_3	3.07%		
Loss on Ignition	1.02%		
Na_2O_3	0.30%		
K_2O_3	0.70%		
Na_2O_3 Equivalent	0.76%		
Insoluble Residue	0.16%		
<u>Physical Tests</u>			
Fineness: Sq cm/gm	3866		
Blaine Air Perm.			
Autoclave Expansion	0.027%		
<u>Compressive Strength</u>			
1 day	1680		
3 days	3330		
7 days	4200		
<u>Setting Time</u>			
Initial (hrs/min)	2:40		
Final (hrs/min)	4:50		
Entrained Air	10.3%		

TABLE 2. CONCRETE DATA FOR TASK NO. 1, SERIES NO. 1

Item	Percent Fly Ash				
	0	20	30	40	50
<u>Quantities Per Cu Yd</u>					
Cement (lb)	564	452	395	338	282
Fly Ash (lb)	0	112	169	226	282
Water (lb)	254	198	194	192	199
Fine Agg. (lb)	1170	1170	1170	1170	1170
Coarse Agg. (lb)	2064	2064	2064	2064	2064
Air Ent. Agent (ml)	225	270	297	324	351
Slump (in.)	2½	1½	1½	1	3½
Air Content (%) ^a	5.8	5.3	5.7	5.5	6.6
Unit Weight (pcf)	151	148	147	149	147
Water/Cement Ratio	0.45	0.35	0.35	0.34	0.35
Concrete Temperature, °C	21	20	21	21	22
<u>Compressive Strength</u>					
14 days (ksi)	4.73	4.90	4.66	4.14	3.00
28 days (ksi)	5.56	5.97	5.76	5.18	4.06
<u>Static Modulus of Elasticity</u>					
14 days (ksi)	5110	5150	4840	5310	4210
28 days (ksi)	5030	5370	5150	5810	4840
<u>Freeze-Thaw Durability Factor</u>					
Specimen 1	100.6	97.8	87.2	94.3	97.6
Specimen 2	97.6	92.2	91.5	92.0	98.2
Specimen 3	95.6	89.9	94.4	103.0	102.3
Average	97.9	93.3	91.0	96.4	99.4
<u>Average Weight Loss (grams)</u>					
	156	171	263	243	262

^aPlastic concrete; air content data from hardened concrete not yet available.

TABLE 3. CONCRETE DATA FOR TASK NO. 2 (55°F)

Item	Percent Fly Ash									
	0		20		30		40		50	
Batch	1	2	1	2	1	2	1	2	1	2
<u>Quantities Per Cu Yd</u>										
Cement (lb)	564	564	452	452	395	395	338	338	282	282
Fly Ash (lb)	0	0	112	112	169	169	226	226	282	282
Water (lb)	230	236	221	216	209	209	188	189	182	195
Fine Agg. (lb)	1192	1192	1192	1192	1192	1192	1192	1192	1192	1192
Coarse Agg. (lb)	1887	1887	1887	1887	1887	1887	1887	1887	1887	1887
Air Ent. Agent (ml)	216	225	234	243	261	270	261	270	288	297
Water/Cement Ratio	0.41	0.42	0.39	0.38	0.37	0.37	0.33	0.34	0.32	0.35
<u>Time of Set</u>										
Initial (hrs:min)	9:54	12:00	16:48	14:36	20:12	18:12	23:54	25:24	25:48	26:36
Final (hrs:min)	14:48	17:18	22:09	20:12	26:06	23:36	33:18	32:30	35:24	37:18
<u>Slump (in.)</u>										
Time (min): 0	2 ³ / ₄	3 ¹ / ₄	3 ¹ / ₄	3 ¹ / ₄	2 ¹ / ₄	3	3	3	1 ³ / ₄	2 ³ / ₄
30	2 ¹ / ₂	3	3	2 ³ / ₄	1 ³ / ₄	2 ¹ / ₂	2 ¹ / ₄	1 ³ / ₄	1 ³ / ₄	2 ¹ / ₄
60	2	2 ³ / ₄	2 ³ / ₄	2 ¹ / ₂	1 ¹ / ₄	2 ¹ / ₄	2 ¹ / ₂	2	1 ¹ / ₂	2
90	1 ¹ / ₂	2 ¹ / ₂	2 ¹ / ₂	2 ¹ / ₄	³ / ₄	2	2	1	1	1 ¹ / ₄
120	1 ¹ / ₂	2	2 ¹ / ₂	2 ¹ / ₄	1	1 ¹ / ₂	1 ¹ / ₂	1	1	1
<u>Air (%)</u>										
Time (min): 0	5.6	6.6	5.9	7.0	5.9	7.0	5.8	6.8	5.6	6.4
30	4.9	5.0	5.0	5.6	4.6	5.0	4.6	5.1	5.0	4.6
60	4.6	5.0	5.0	5.4	4.4	5.0	4.6	4.4	4.9	4.6
90	4.4	4.6	4.9	5.0	4.5	4.9	4.6	4.4	5.2	4.6
120	4.4	4.6	4.9	5.0	4.5	4.9	4.6	4.6	5.0	4.6
<u>Unit Weight (lb/ft³)</u>										
Time (min): 0	145	143	145	142	144	142	145	143	145	144
30	147	145	146	146	147	146	147	146	146	147
60	147	145	146	147	148	146	146	147	147	147
90	147	145	147	147	148	146	147	147	147	147
120	147	145	147	147	148	147	147	147	147	147
<u>Temperature (°C)</u>										
Time (min): 0	15	14	14	14	14	15	14	14	14	14
30	16	14	15	14	15	15	15	15	14	14
60	16	14	15	14	15	15	14	15	14	14
90	15	14	15	14	15	15	15	15	14	14
120	15	14	15	14	15	15	15	15	14	14
<u>Static Modulus of Elasticity (ksi)</u>										
	4210	3900	3890	4030	4140	3840	3850	4170	4260	3970
<u>Compressive Strength</u>										
28 days (ksi)	5.51	4.85	4.89	4.96	5.70	5.39	4.84	5.48	5.77	5.49

TABLE 4. CONCRETE DATA FOR TASK NO. 2 (70°F)

Item	Percent Fly Ash									
	0		20		30		40		50	
Batch	1	2	1	2	1	2	1	2	1	2
<u>Quantities Per Cu Yd</u>										
Cement (lb)	564	564	452	452	395	395	338	338	282	282
Fly Ash (lb)	0	0	112	112	169	169	226	226	282	282
Water (lb)	241	241	198	205	203	203	189	203	194	203
Fine Agg. (lb)	1170	1170	1170	1170	1170	1170	1170	1170	1170	1170
Coarse Agg. (lb)	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064
Air Ent. Agent (ml)	225	234	270	288	297	306	324	342	342	351
Water/Cement Ratio	0.43	0.43	0.35	0.36	0.36	0.36	0.34	0.36	0.34	0.36
<u>Time of Set</u>										
Initial (hrs:min)	5:42	6:00	8:54	8:06	10:49	10:00	12:12	13:42	17:00	14:42
Final (hrs:min)	8:00	8:00	11:48	11:24	13:30	13:18	16:30	18:12	21:18	19:54
<u>Slump (in.)</u>										
Time (min): 0	3	2	1 1/4	2	1 3/4	3	2 1/4	3	3 1/4	3
30	1 3/4	1	1	1 1/2	1 1/2	1 1/2	1	1 1/4	2	1 3/4
60	1 1/4	1	1/2	1/2	3/4	1	3/4	1 1/4	1 3/4	1 1/2
90	1	1	---a	---a	---a	3/4	1/2	3/4	3/4	1
120	---a	1/2	---a	---a	---a	---a	---a	---a	---a	1/2
<u>Air (%)</u>										
Time (min): 0	5.5	6.1	5.8	6.0	5.9	6.8	5.0	6.7	5.8	6.5
30	3.6	4.7	4.2	4.4	4.7	4.4	4.8	5.4	4.4	4.7
60	3.4	4.5	4.1	4.4	4.4	4.3	4.4	4.5	4.1	4.2
90	2.4	4.5	---a	---a	---a	4.2	4.8	4.5	4.1	4.2
120	---a	3.9	---a	---a	---a	---a	---a	---a	---a	3.9
<u>Unit Weight (lb/ft³)</u>										
Time (min): 0	149	150	151	151	151	149	152	149	148	149
30	153	152	153	153	154	153	152	152	151	152
60	153	152	153	153	154	153	153	153	151	153
90	153	152	---a	---a	---a	154	152	153	152	152
120	---a	153	---a	---a	---a	---a	---a	---a	---a	153
<u>Temperature (°C)</u>										
Time (min): 0	22.0	21.0	21.0	21.0	21.0	21.0	20.5	20.0	20.0	20.5
30	21.5	21.0	21.0	21.0	21.0	21.0	20.5	20.0	21.0	21.0
60	21.5	21.5	21.0	21.0	21.0	20.5	20.5	20.0	21.0	20.5
90	20.5	21.0	---a	---a	---a	20.5	20.5	20.5	21.0	20.5
120	---a	21.0	---a	---a	---a	---a	---a	---a	---a	20.5
<u>Static Modulus of Elasticity (ksi)</u>										
	5610	4630	4800	4630	4600	4420	4440	4280	4130	4150
<u>Compressive Strength 28 days (ksi)</u>										
	4.96	5.26	6.26	6.33	5.64	5.64	5.63	5.11	4.59	4.41

^aTest terminated.

TABLE 5. CONCRETE DATA FOR TASK NO. 2 (90°F)

Item	Percent Fly Ash									
	0		20		30		40		50	
Batch	1	2	1	2	1	2	1	2	1	2
<u>Quantities Per Cu Yd</u>										
Cement (lb)	564	564	452	452	395	395	338	338	282	282
Fly Ash (lb)	0	0	112	112	169	169	226	226	282	282
Water (lb)	222	233	207	200	209	212	203	219	197	203
Fine Agg. (lb)	1192	1192	1192	1192	1192	1192	1192	1192	1192	1192
Coarse Agg. (lb)	1887	1887	1887	1887	1887	1887	1887	1887	1887	1887
Air Ent. Agent (ml)	225	243	288	306	306	324	342	369	351	360
Water/Cement Ratio	0.39	0.42	0.37	0.35	0.37	0.38	0.36	0.39	0.35	0.36
<u>Time of Set</u>										
Initial (hrs:min)	2:39	3:09	3:51	3:38	5:11	4:59	5:48	5:36	5:00	6:39
Final (hrs:min)	4:09	4:23	4:24	5:42	6:56	7:05	7:50	7:11	7:48	10:26
<u>Slump (in.)</u>										
Time (min): 0	2	2 1/4	2	2 1/2	2	2	2 1/2	3	2 1/2	2 1/2
30	1	1 1/2	1 1/2	1 3/4	3/4	3/4	3/4	2	1/4	3/4
60	1/2	3/4	1	1	1/4	1/2	1/2	1	1/2	1/2
90	1/2	1/2	3/4	1 1/2	---a	---a	---a	1	---a	---a
<u>Air (%)</u>										
Time (min): 0	5.0	6.0	5.0	6.0	5.5	6.0	5.7	6.4	5.7	6.0
30	4.3	4.5	4.5	4.8	4.0	4.5	4.0	4.8	4.2	3.8
60	4.2	4.2	4.5	4.3	4.0	4.5	4.2	4.8	4.2	4.0
90	4.2	4.5	4.5	4.3	---a	---a	---a	4.8	---a	---a
<u>Unit Weight (lb/ft³)</u>										
Time (min): 0	146	145	146	145	146	145	145	144	145	145
30	147	147	147	146	148	148	148	146	147	147
60	148	147	147	147	148	148	147	146	147	147
90	148	146	147	147	---a	---a	---a	146	---a	---a
<u>Temperature (°C)</u>										
Time (min): 0	35	34	33	33	33	33	33	34	33	33
30	34	34	33	34	33	34	33	34	34	33
60	34	34	33	34	33	34	33	34	34	33
90	34	33	33	34	---a	---a	---a	34	---a	---a
Static Modulus of Elasticity (ksi)	4040	4000	4290	3890	3930	4290	3880	3590	3800	3814
Compressive Strength 28 days (ksi)	5.02	4.99	5.65	4.75	5.27	5.57	4.78	4.25	4.71	4.60

^aTest terminated.

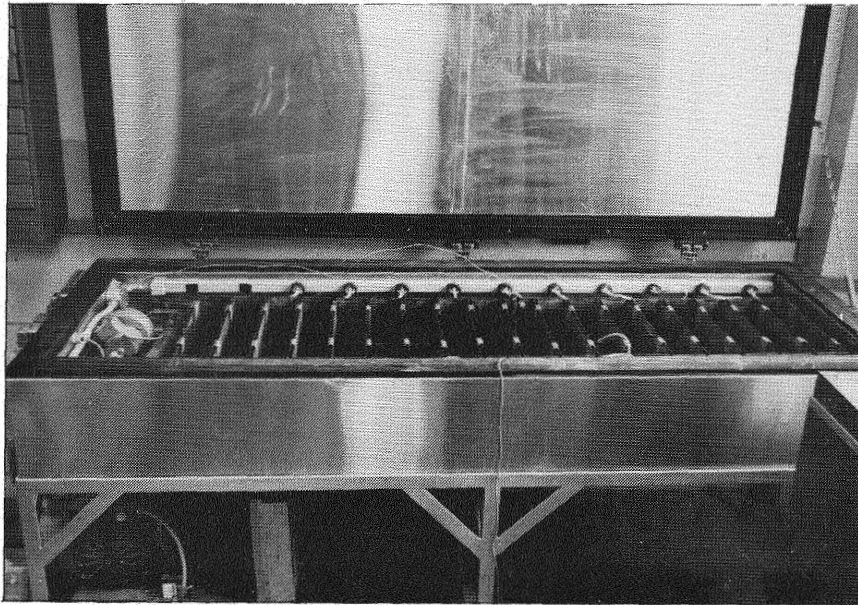


Figure 1. 18 Prism Capacity Freeze-Thaw Cabinet

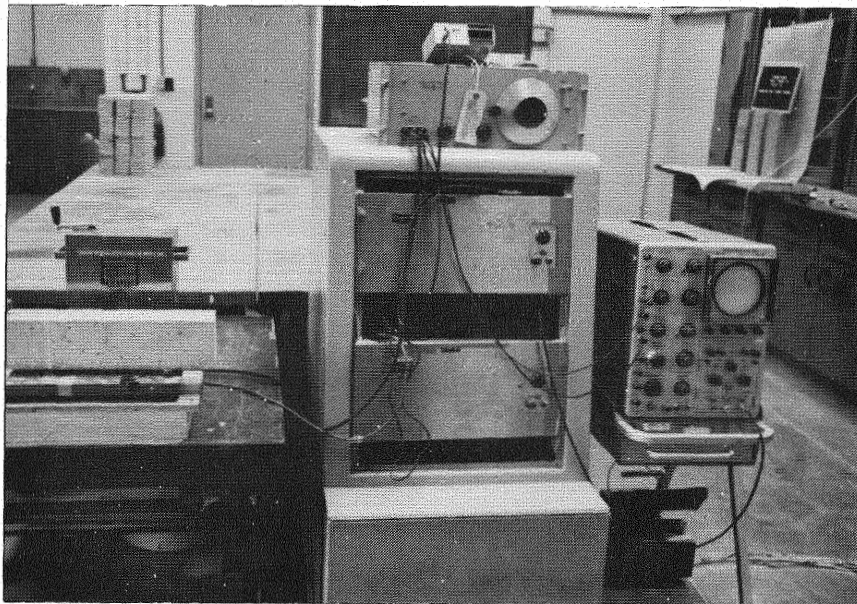
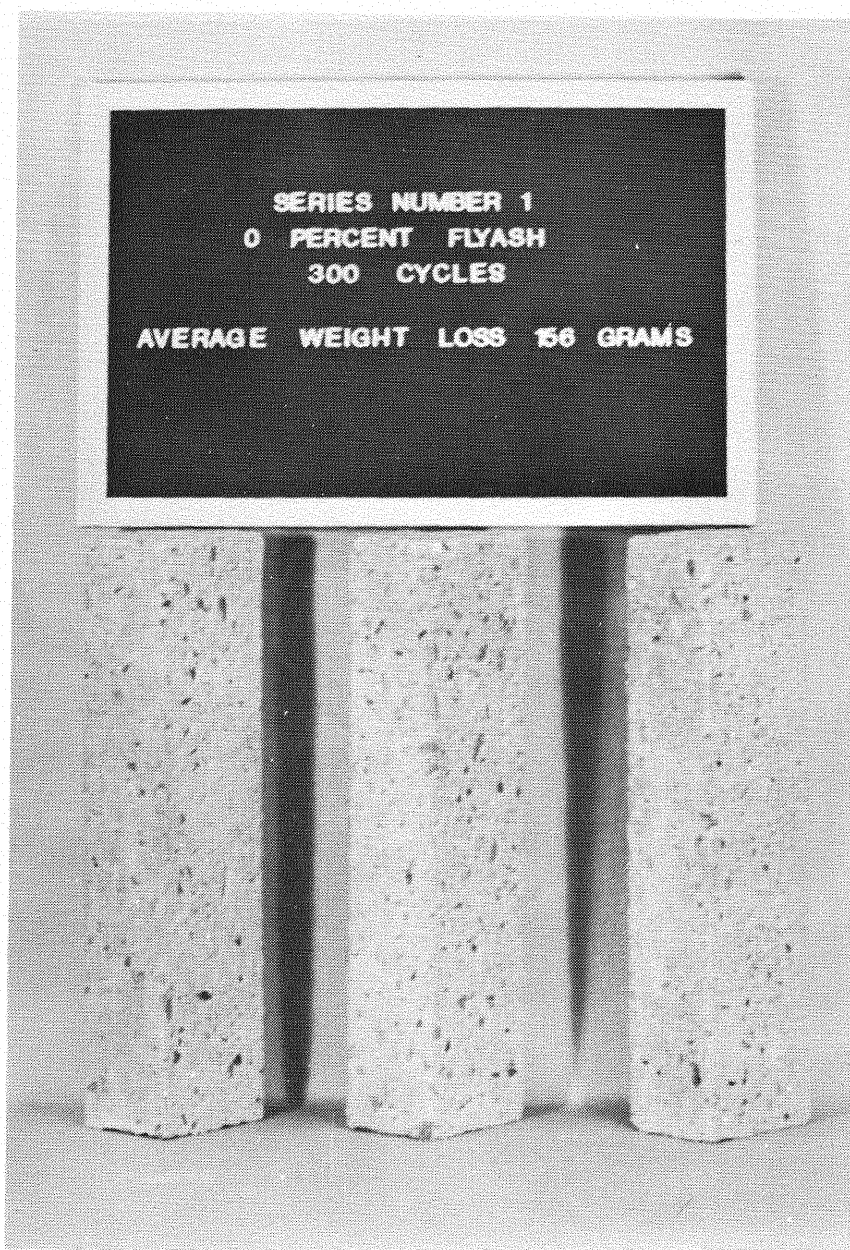
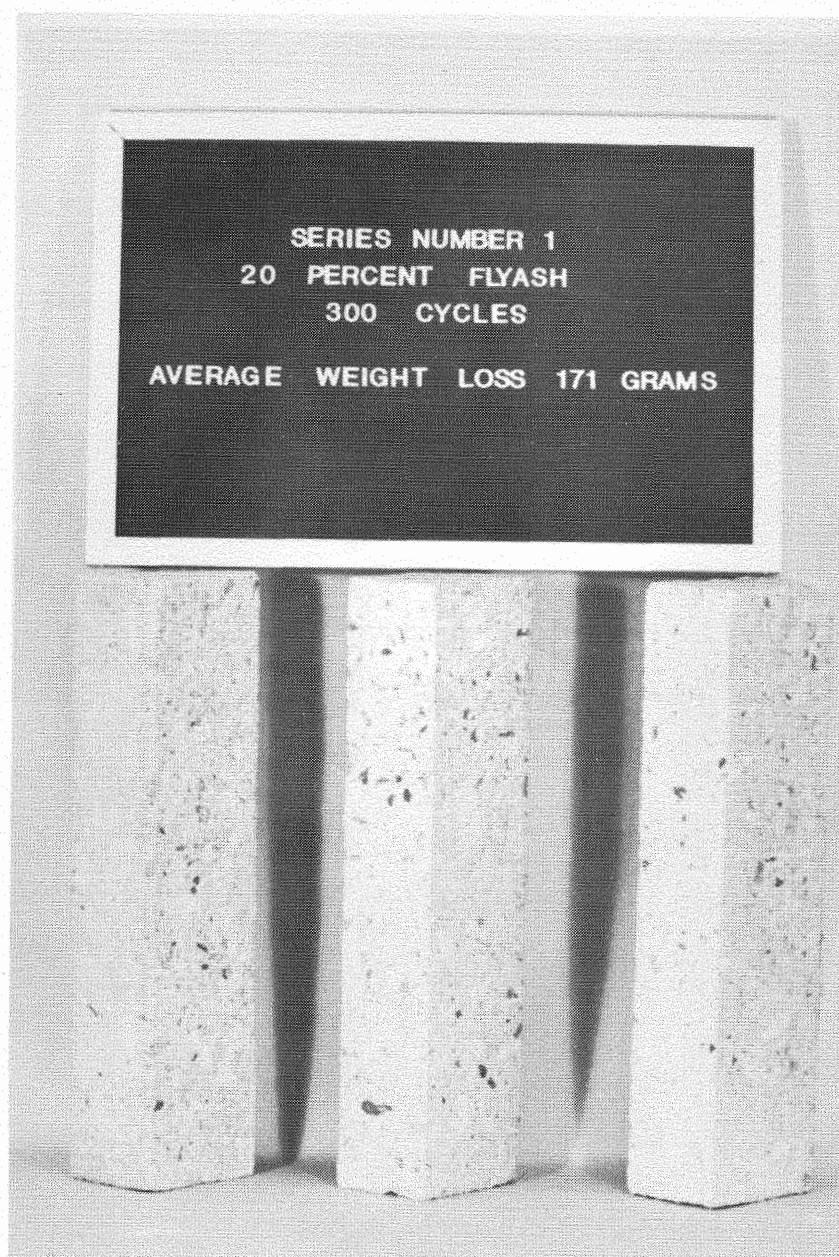


Figure 2. Equipment Used to Determine
the Fundamental Transverse
Frequency



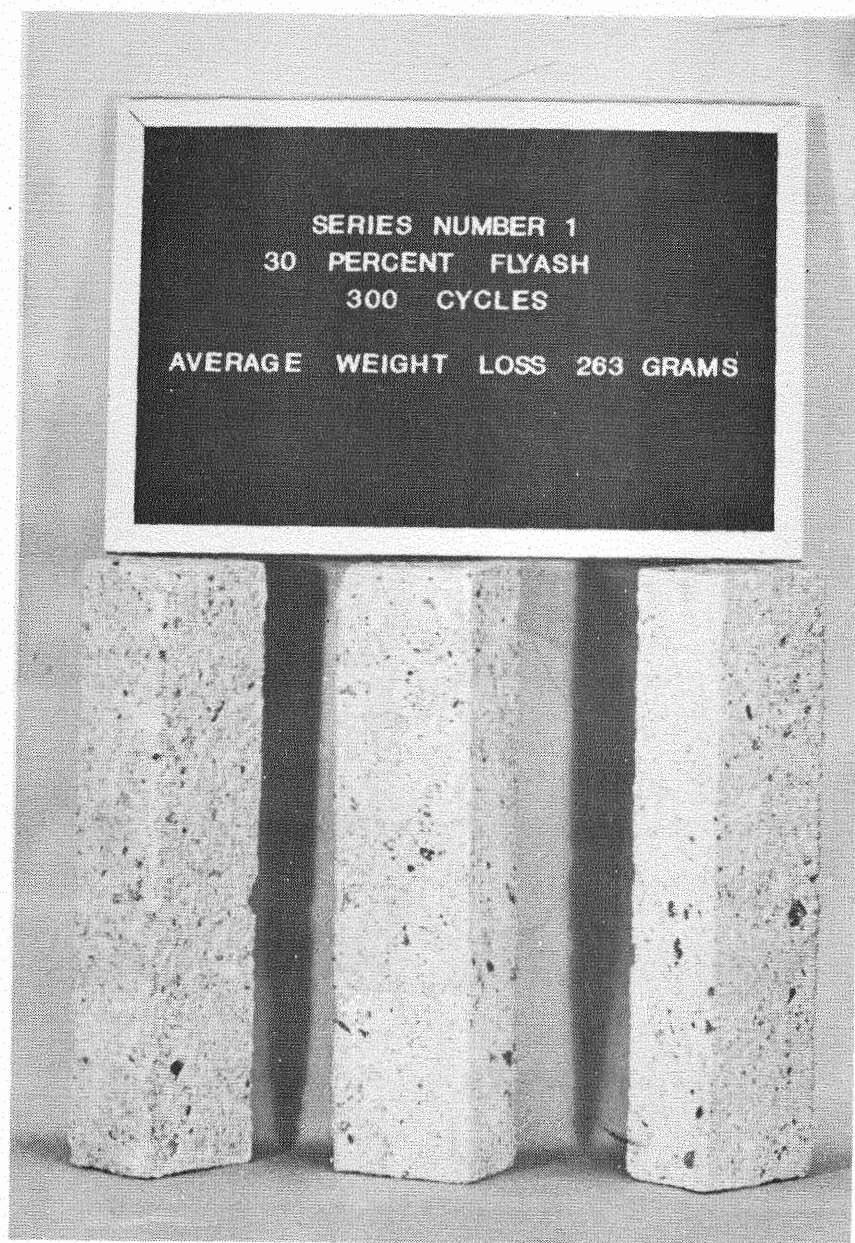
(a) 0% Fly Ash

Figure 3. Specimens After 300 Cycles of Rapid Freeze-Thaw



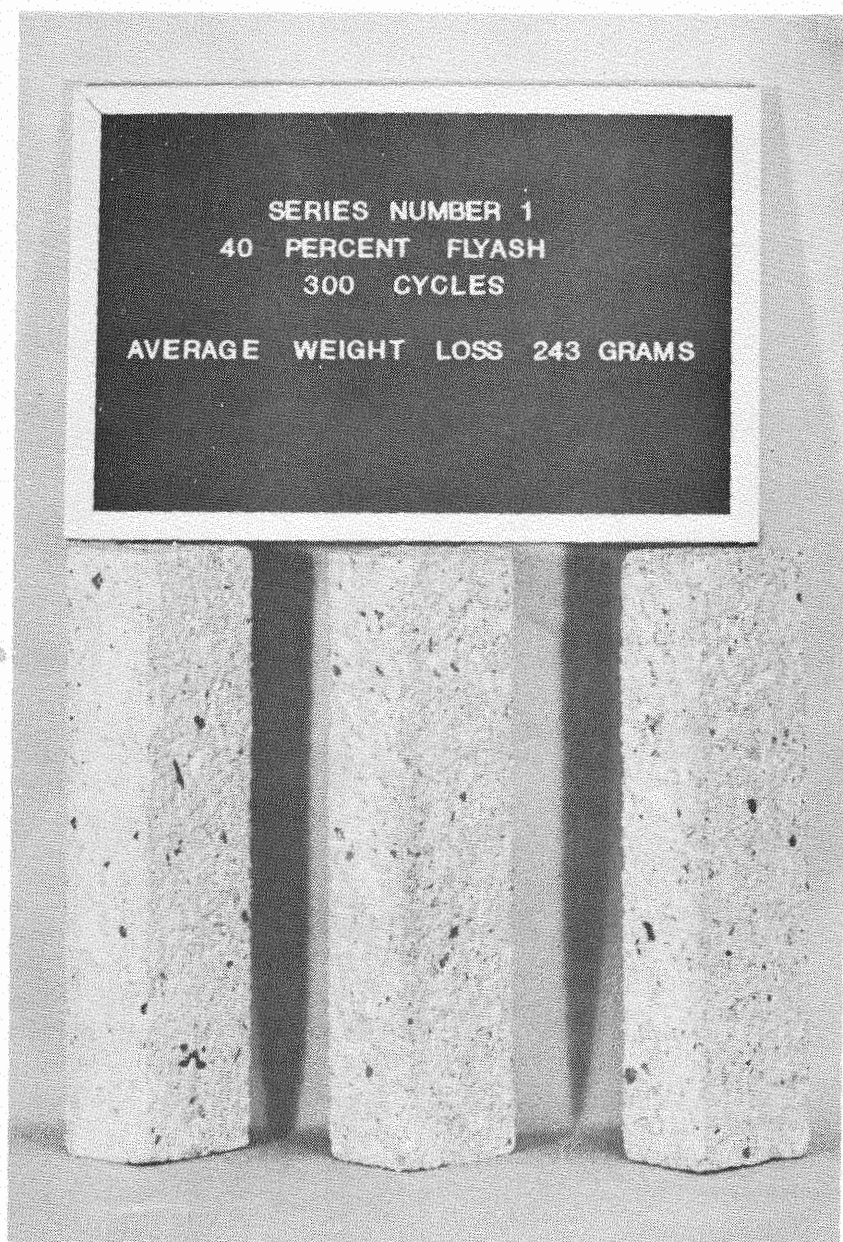
(b) 20% Fly Ash

Figure 3. Continued



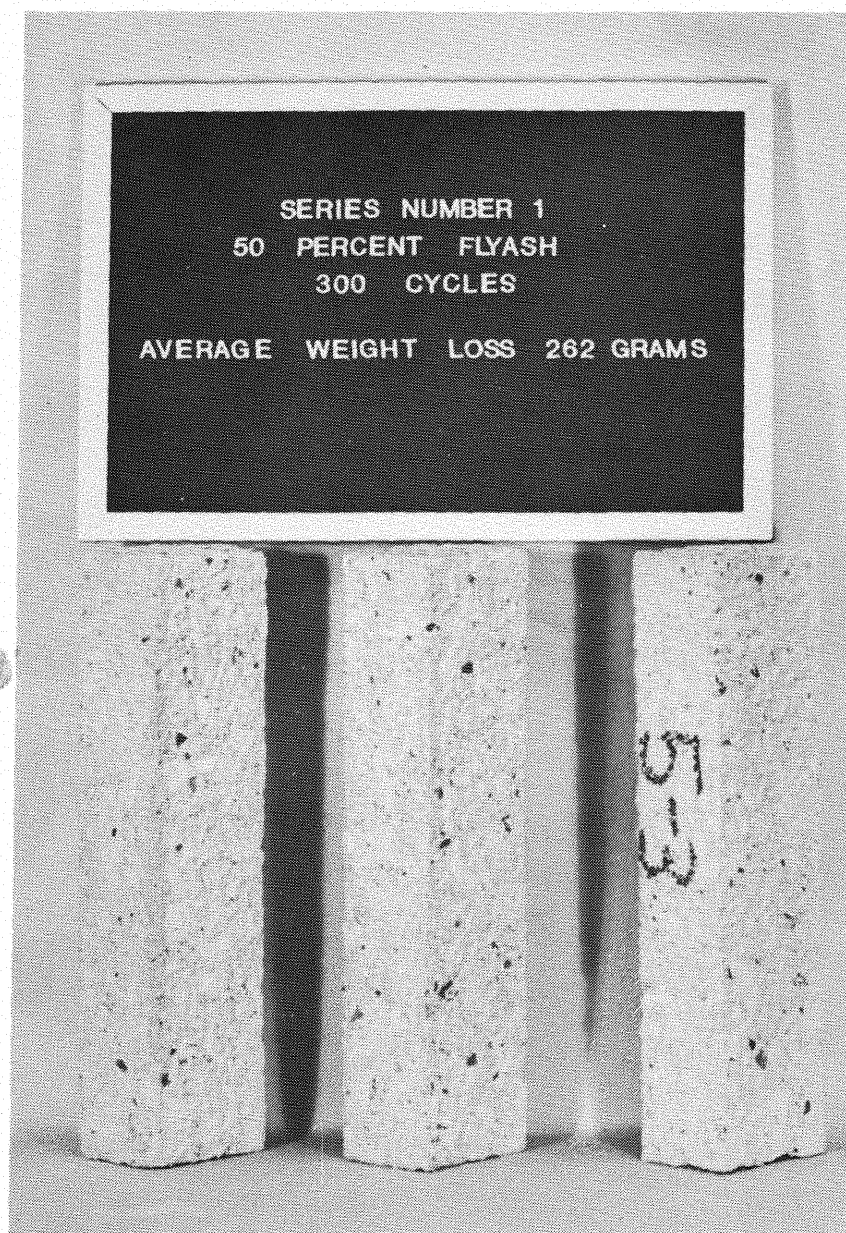
(c) 30% Fly Ash

Figure 3. Continued



(d) 40% Fly Ash

Figure 3. Continued



(e) 50% Fly Ash

Figure 3. Continued