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FLY ASH CONCRETE

COMPRESSIVE STRENGTH &

FREEZE-THAW DURABILITY

DEPARTMENT OF TRANSPORTATION

IOWA

HIGHWAY DIVISION

OFFICE OF MATERIALS

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FLY ASH CONCRETE

COMPRESSIVE STRENGTH AND FREEZE-THAW DURABILITY

by

Ken Isenberger

Office of Materials

HIGHWAY DIVISION

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ABSTRACT

The current study investigated the effect of fly ash class, source and amount on the compressive strength and freeze-thaw durability of fly ash concrete. Concrete aggregates of varying quality were also included as test variables.

The current results and those obtained from previous laboratory and field work indicate that compressive strength can be affected by fly ash class, source and amount while aggregate quality is shown to have no effect on strength. Freeze-thaw durability of fly ash concrete is strongly affected by aggregate quality and to a lesser degree by fly ash class, amount and source.

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INTRODUCTION

The Iowa Department of Transportation's in-depth involvement with the use of fly ash in laboratory and field projects began in 1977. At that time, the installation of a dry collecting system at the Sioux City Port Neal #3 generating plant made fly ash available in sufficient quantities so as to warrant consideration of its use. Since that time ash in quantity has become available at several other locations and by 1982 will be available at enough sites that its geographic distribution and transportation should cease to be a major deterrent to its potential use.

Laboratory projects involving fly ash have covered such areas as: Fly ash variability within and between sources[1/]; fly ash as a soil stabilization additive [2,3/] and fly ash as a portland cement replacement in cement-treated subbases and econocrete[4/].

Field projects involving the substitution of fly ash for part of the portland cement in concrete have been completed on primary highways in Hamilton (1980) and Woodbury (1978)[5/] counties and on secondary projects in Monona (1978)[6/], (1980) county.

In view of the fact that Iowa has some concrete aggregates that cause premature concrete failure, a dual classification 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 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 & Thawing - Procedure B"[7/] 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 "marginal aggregates". The addition of a further potentially complicating factor, such as fly ash, to the field performance of a concrete containing marginal aggregates needed investigation.

Phase A of the present study was designed as a preliminary look into the effect of aggregate quality upon the durability and strength of fly ash concrete. The durability results were significant to the point that an expanded scope Phase B was undertaken involving aggregates of varying quality and several fly ash sources.

MATERIALS

Fly Ash

Six fly ash sources were sampled for inclusion in the study.

Class C Ash (self-cementing)

Council Bluffs No. 3 Unit

Port Neal No. 4 Unit

Nebraska City

Lansing

Class F Ash (non-cementing)

North Omaha

Clinton

Prior work has built up a data file on the Class F ash from the Port Neal No. 3 generating unit and they are included in this report.

Aggregates

The following aggregates were chosen for the study:

Fort Dodge Mine - Limestone - High Quality

Malcom Mine - Dolomitic Limestone - Medium Quality

Montour Quarry - Limestone - Marginal Quality

Clarksville Pit - Gravel - Medium Quality

All the above aggregates are Class II (extra-service life) aggregates and the terms High-, Medium-, and Marginal-Quality refer to their ranking within that Class.

Portland Cement

The standard laboratory blend of the nine portland cements commonly available in Iowa was used to prepare the concrete specimens.

Air Entraining Agent

The air entraining agent used was a neutralized vinsol resin.

LABORATORY PROCEDURES

The investigation of the effects of aggregate and fly ash source on concrete strength and durability was accomplished by preparing test specimens in the field and laboratory. These specimens were made from concrete prepared as either a B-3, B-4, B-6, C-3 or C-4 mix as defined in the Standard Specifications, Series of 1977[8/]. The variables in a specific mix were aggregate source, fly ash source, the percent of portland cement replaced by fly ash and 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 various mixes. They also specify the slump and entrained air content to be strived for (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[7/] "Making and Curing Concrete Test Specimens in The Laboratory".

The testing of the compressive strength specimens (in Phase A) was done in accordance with Iowa Test Method 403A[9/] "Method of Test for Compressive Strength of Molded Concrete Cylinders" (see Appendix B). This is a modification of AASHTO procedure T-22[10/] only in that the bearing blocks/plates of the testing machine have different dimensions.

The determination of the durability factor of the concretes containing the various ashes and aggregates was done according to Iowa Test Method 408A[9/] "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[7] in that the 4" x 4" concrete beams are 18 inches in length rather than 14 to 16 inches and a 90 day moist room cure is substituted for the 14 day lime water cure.

During Phase A a time constraint developed concerning the availability of the durability factor information. In an effort to obtain an earlier indication of the expected durability factor of the test concretes, two sets of beams were prepared for each aggregate-ash combination. One set was subjected to the ASTM standard curing period of a 14 day lime water soak while the other set was cured for 90 days in the moist room.

Upon completion of the appropriate curing period, the beams were subjected to cyclic freezing and thawing with periodic sonic modulus readings taken. This was continued until 300 cycles of freezing and thawing had been performed or until the amount of remaining sonic modulus was less than 60% of the original.

TEST RESULTS AND INTERPRETATION

Compressive Strength

Early work with concrete containing fly ash, including field projects[5,6], was with the higher cement content B-4, B-6 and C-4 mixes. It was felt that the higher cement content was necessary to achieve adequate strengths in view of the replacement of part of the portland cement by fly ash. Representative laboratory results obtained in an effort to establish the optimum substitution ratio of Class F fly ash for portland cement are shown in Table 1.

Table 1. Concrete Compressive Strengths (PSI) of Laboratory Cylinders - Class F/Port Neal No. 3 Ash

Mix	1:1 Substitution 7 Day	1:1 Substitution 28 Day	1.5:1 Substitution 7 Day	1.5:1 Substitution 28 Day
B-4 No ash	3650	4700	3650	4700
B-4 10% ash	3360	3960	3350	4740
B-4 15% ash	3160	3980	3250	4760
B-4 20% ash	3060	4320	3120	4170
C-4 No ash	4780	5910	4780	5910
C-4 10% ash	4780	5890	4630	6290
C-4 15% ash	3880	5240	4380	5820
C-4 20% ash	4090	5490	3790	4890

Based on this information, the substitution ratio for Class F ashes was tenatively set at 1.5:1 (one and a half pounds of ash added for every pound of cement removed). The data also show a loss of compressive strength when the amount of ash added equals 20%. Thus, the fly ash paving projects in Monona and Woodbury counties limited the amount of ash added to 15% maximum.

These two paving projects had test sections containing various amounts of fly ash added at varying substitution ratios. The pavements were cored at specific ages to obtain compressive strength specimens and the data are shown in Table 2. Examination of these results shows that the substitution ratio to produce strengths equivalent to those of regular concrete lies somewhere between 1:1 and 1.5:1. Accordingly, the substitution ratio for Class F ashes has now been set at 1.25:1. Considering this ratio and the strength results as shown in Table 2, the maximum amount of Class F ash to be added to B mixes has been set at 10% and the maximum amount added to C mixes at 15%.

Table 2. Concrete Compressive Strengths (PSI) of Field Cores Class F Fly Ash/Port Neal No. 3

Mix	Strength Average		
	7 Day	28 Day	1 Year
Monona County Project			
B-4 No Ash	3960	4220	5710
B-4 10% Ash @ 1.5:1	3320	4890	5940
B-6 No Ash	3150	4370	5010
B-6 15% Ash @ 1.5:1	2870	3720	5210
B-6 15% Ash @ 1:1	2980	3690	5140
B-6 10% Ash @ 1.5:1	2980	3930	5390
Woodbury County Project			
C-4 No Ash	3380	4610	6670
C-4 10% 1.5:1	3140	4350	6290
C-4 15% Ash 1:1	3390	5210	6310
C-4 15% Ash 1.5:1	3270	4610	6850

In the Phase A study, the concrete mixes were a B-3 and a C-3. These mixes are the standard ones used in most research; therefore data comparisons will become more feasible. These mixes contain less cement than those previously used in field and laboratory projects; however, their popularity as field mixes equals that of the B-4 and C-4 mixes.

Since Class C ashes, by definition, have cementitious

Table 3. Concrete Compressive Strength (PSI) Class C Fly Ash - Port Neal No. 4 - 1:1 Substitution

Mix	Montour Coarse Aggregate (Marginal Quality)			Fort Dodge Mine Coarse Aggregate (High Quality)		
	7 Day	28 Day	56 Day	7 Day	28 Day	56 Day
B-3	3080	4250	4880	3437	4590	5050
B-3 10% Ash	3750	5300	6000	3580	4740	5260
B-3 15% Ash	3940	5260	5600	3820	4930	5560
B-3 20% Ash	3770	4970	5660	3770	5050	5740
B-3 25% Ash	3690	5220	6070	3880	5390	6020
C-3	4520	5890	6370	4530	5870	6560
C-3 15% Ash	5350	7110	7690	5630	6460	6710
C-3 20% Ash	5140	6830	7480	4320	6350	6770
C-3 25% Ash	4490	6350	7420	4490	5870	6630
C-3 30% Ash	4990	6750	7350	4510	6370	6770

properties, it was assumed that the substitution ratio need not be as high from them as for the Class F ashes. Thus, considering the 1.25:1 Class F ratio, the ratio was initially set at 1:1 for the Class C ash to be used in the Phase A study.

The Phase A compressive strength results are shown in Table 3 for concrete containing Class C ash from the Port Neal No. 4 plant and the high and marginal quality aggregates selected. The results indicate that on the basis of a 1:1 substitution ratio, optimum strengths are produced in C-3 mixes by replacing 15% of the portland cement with Class C ash. The strength results of the B-3 mixes do not show such a clear relationship. In view of the lower initial cement content of B mixes, it is felt that less ash should be incorporated into them in comparison to C mixes. Until such time that further research indicates otherwise, the amount of Class C ash to be added to B mixes will be set at 10%.

In summary, acceptable concrete strengths can be produced using either Class F or Class C ash provided the proper substitution ratio and percent replacement is used. Data available at this time indicates that Class F and Class C ashes should be used at a replacement percentage of 10% in B mixes and 15% in C mixes. A substitution ratio of 1.25:1 should be used for Class F ash and a ratio of 1:1 for Class C ash.

Durability Factor Determination

A. Early Work. Since Port Neal No. 3 ash was the first to be made available for use, early laboratory work concentrated on concrete made with it. For the same reason, the first field projects involving fly ash concrete were in the marketing area of the Port Neal No. 3 ash (Northwest Iowa).

Prior to the writing of the specifications for these paving projects, laboratory studies of the durability of fly ash concrete were initiated. Table 4 shows the durability factor results obtained with the marginal quality Montour aggregate and varying percentages of fly ash replacement of portland cement.

Based on the data presented in Table 4, the amount of portland cement replaced was limited to 15% on the Monona and Woodbury paving projects. As these projects were under construction, durability beams were cast on the job site out of the various concrete mixes. These beams were delivered to the Central Laboratory and tested for durability factor in the standard method. The results for these beams are shown in Table 5.

The Monona county projects results show little effect from the removal of portland cement and its replacement with Class F ash. The coarse aggregate used was a gravel from Peters Construction Company's Rodney Pit located in northern Monona county. This gravel has an excellent service record and is predominately made up of sound igneous material. It is classified as a Class II concrete aggregate and would be considered a high quality source.

The Woodbury county results exhibit something quite different. The Hawarden gravel from western Sioux county used in this project has prior durability factors of 37 and 42 and has been observed to exhibit D-cracking on several projects. Even if the current study value of 13 (Table 5) is considered nonrepresentative and the prior durability factors are used, then the addition of fly ash has improved the durability of the concrete

Table 4. Durability Factor. Montour Coarse Aggregate - Class F Ash (Neal No. 3)

Mix	Substitution Ratio 1:1	Substitution Ratio 1.5:1
B-4 0% Ash	77	77
B-4 10% Ash	75	72
B-4 15% Ash	78	52
B-4 20% Ash	59	47
C-4 0% Ash	76	76
C-4 10% Ash	68	74
C-4 15% Ash	72	77
C-4 20% Ash	59	57

Table 5. Durability Data. Beams cast in field from project concretes

1978 Monona County Fly Ash Concrete Class F Ash - Neal No. 3
Rodney Gravel Coarse Aggregate

Mix	Durability Factor
B-4	86
B-4 10% Ash @ 1.5:1	86
B-6	92
B-6 10% Ash @ 1.5:1	92
B-6 15% Ash @ 1:1	92
B-6 15% Ash @ 1.5:1	88

1978 Woodbury County Fly Ash Concrete Class F Ash - Neal No. 3
Hawarden Gravel Coarse Aggregate

Mix	Durability Factor
C-4	13
C-4 10% Ash @ 1.5:1	60
C-4 15% Ash @ 1:1	49
C-4 15% Ash @ 1.5:1	50

containing this aggregate. This potential improvement of normally low durability factor concrete may have practical application and should be investigated further.

Keeping in mind that all the data presented so far are for Class F ashes, it would appear that 10% ash at a substitution ratio of either 1:1 or 1.5:1 provides the optimum durability. The actual use of ash thus becomes one of economics, i.e., considering the price of fly ash vs. portland cement, is the use of fly ash cost effective?

B. Phase A. To further investigate the effect of aggregate quality upon the durability of fly ash concrete, a laboratory study was begun involving a high and marginal qualify Class II concrete aggregate. A C-3 mix was used and the source of the ash was Port Neal No. 4. This is a Class C ash and had just become available for use. The data are presented in Table 6 for the durability factor test using the standard 90 day moist room cure and the special 14 day lime water cure.

Although the 14 day lime water cure is the suggested ASTM method, the data in Table 6 indicate that its use does not result in significant losses upon freezing and thawing concrete beams cured in this manner. The 90 day moist room cured beams do show significant changes upon freezing and thawing and durability factor numbers obtained in the past (utilizing the 90-day cure) correlate reasonably well with field performance.

The data indicate a lowering of concrete durability with

Table 6. Durability Factor. Class C Ash - Port Neal No. 4
1:1 Substitution Ratio

Mix	Montour		Fort Dodge
	Std. Cure	14 Day	Std. Cure
B-3	87	94	90
B-3 10% Ash	78	86	91
B-3 15% Ash	82	90	91
B-3 20% Ash	70	89	92
B-3 25% Ash	65	93	89
C-3	78	92	93
C-3 15% Ash	64	90	92
C-3 20% Ash	64	93	92
C-3 25% Ash	44	82	90
C-3 30% Ash	65	88	88

increasing ash content when an aggregate of marginal quality is used. This effect is not evident with the concrete containing the high quality aggregate. The optimum fly ash percentage is seen to be 15% for concrete using marginal quality aggregate. Since present aggregate tests can not identify all aggregates that give marginal performance, the 15% is recommended as a maximum for Class C ashes.

C. Phase B. During the time span covered by the early paving projects and Phase A, several additional sources of fly ash became available. Phase B was undertaken to further study the effect of aggregate quality on the durability of fly ash concrete and also to study the effect of fly ash source.

All concrete was prepared according to the C-3 mix proportions. The replacement percentage of portland cement was 15% with Class C ash substituted at a 1:1 ratio and Class F ash at a 1.25:1 ratio. The results for the high quality Alden aggregate, the medium quality Clarksville and Malcom aggregate, and the marginal quality Montour aggregate (all Class II aggregates) in combination with the six ashes are shown in Figure 1. The adverse effect of incorporating Class II marginal aggregate into fly ash concrete is shown by the lowered freeze-thaw durability. This effect appears to be somewhat influenced by the Class of the fly ash with the work to date showing that Class F ashes tend to lower results more than Class C ashes. The effect of ash source or class is not evident for medium to high quality Class II aggregates.

The cause for the significantly lowered durability factors of marginal aggregate-fly ash concrete can not be the aggregate itself (no ash control beam = 88 D.F.) nor is it likely to be an aggregate-fly ash reaction since the effect is exhibited in a relatively short time (4-5 months). It is more likely due to the combination of an aggregate with a freeze-thaw susceptible pore system and a concrete paste with a freeze-thaw susceptible pore system. Research has shown that some Iowa aggregates possess such freeze-thaw susceptible pore systems and thus have a need to expel water during freezing if they are to retain their structural integrity. Other higher quality aggregates seem to be able to internally accommodate the hydraulic pressures associated with freezing. In regular concrete, the paste pore system seems to act as a reservoir for the water expelled from the freeze-thaw susceptible aggregates. However, it appears from the results of the current study, that the addition of fly ash changes the pore structure of the paste to the point where it cannot adequately protect freeze-thaw susceptible aggregates.

Other Observations

A. Air Content of Fly Ash Concrete. One problem encountered with the use of fly ash concrete has been 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 various 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 varies proportionally with the amount of ash in the concrete. In the case of a 10-15% cement replacement, the necessary increase has been approximately 10% for Class F ash and 0 to 8% for Class C.

B. Setting Time of Fly Ash Concrete. The retardation of concrete setting time experienced when Class F ash is added to concrete has been reported numerous times in the literature. 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[10/], were made on two identical concretes - one containing Class F Port Neal No. 3 ash and the other containing Class C Port Neal No. 4 ash. The resultant retardation curves were nearly identical with a retardation value of 51 percent. No other obvious differences were noted.

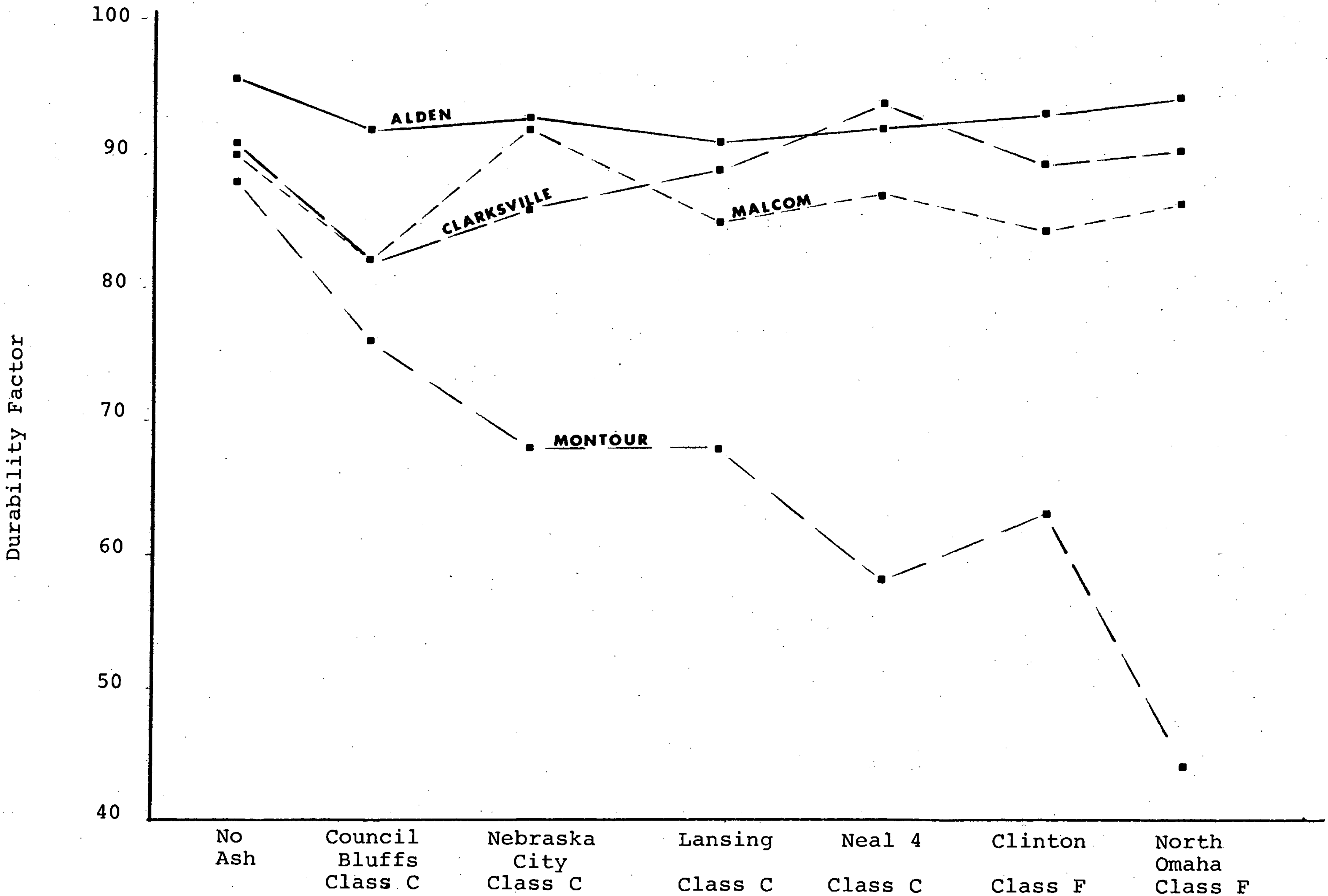

Figure 1. Ash Source

CONCLUSIONS

The results indicate that, while fly ash-concrete compressive strengths are not significantly influenced by the durability of the aggregate used, the fly ash class, source and percent added can have significant effects. Optimum fly ash-concrete compressive strengths are obtained at cement replacement values of 10% in Type B concrete mixes and 15% in Type C mixes. To counteract the removal of the portland cement, Class F ashes must be added back to the concrete at a substitution ratio of 1.25:1 (one and one-fourth pounds of ash added for every pound of portland cement removed) while the Class C ashes may be substituted on a 1:1 ratio.

The freeze-thaw durability of fly ash concrete can be significantly effected by the quality of the aggregate - marginal quality Class II aggregates can produce concrete of unacceptable freeze-thaw durability. The creation of a Class III category of concrete aggregates is recommended. This class would include those aggregates exhibiting superior field and laboratory performance and thus suitable for use in fly ash concrete.

RECOMMENDATIONS

Based on the test results, the addition of fly ash to concrete as a partial cement replacement can be accomplished without detrimental effects to the strength or freeze-thaw durability of concrete. This holds true as long as the proper replacement percentages and substitution ratios are used and the effect of aggregate quality is recognized. Since the current Class II concrete aggregate category obviously contains some aggregates that should not be used in fly ash concrete, some modification of that class is recommended.

The identification of those Class II aggregates that are of marginal quality and should not be used in fly ash concrete or in high-traffic-area concrete is difficult. Instead, the selection of those aggregates that have exhibited superior field performance and laboratory quality tests is more feasible. Therefore, the creation of a category termed Class III is recommended. These Class III aggregates would then be superior aggregates that could be used without reservation in fly ash concrete and in concrete placed where extended service life is required.

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APPENDICES

APPENDIX A

Standard Specifications

Mix Proportions

B. Class B Concrete. The proportions used for Class B concrete with other than Class V aggregate shall conform to one of the following:

Basic Absolute Volumes of Materials Per Unit Volume of Concrete*

Mix No.	Cement Minimum	Water	Entr. Air	Fine Agg.	Coarse Agg.
B-2	0.088033	0.147757	0.06	0.281684	0.422526
B-3	.090539	.152017	.06	.313850	.383594
B-4	.093164	.156726	.06	.345055	.345055
B-5	.095945	.161942	.06	.375162	.306951
B-6	.098936	.167049	.06	.401409	.269606
B-7	.102064	.172788	.06	.432346	.232802
B-8	.105426	.178632	.06	.459159	.196783

Approximate Quantity of Dry Materials Per Cubic Yard of Concrete*

Mix No.	Cement Pounds	Fine Agg. Tons	Coarse Agg. Tons
B-2	466	0.6288	0.9432
B-3	479	.7006	.8563
B-4	493	.7703	.7703
B-5	508	.8375	.6852
B-6	523	.9028	.6019
B-7	540	.9651	.5197
B-8	558	1.0250	.4393

* The total quantity of free water in the concrete, including the free water in the aggregate, shall not exceed 0.600 pound of water per pound of cement.
These quantities are based on the following assumptions: Specific gravity of cement, 3.14; Specific gravity of aggregate, 2.65; Water-cement ratio, 0.536 pound of water per pound of cement; Air voids, 6.0 percent.

C. Class C Concrete. The proportions used for Class C concrete with other than Class V aggregate shall conform to one of the following:

Basic Absolute Volumes of Materials Per Unit Volume of Concrete*

Mix No.	Cement Minimum	Water	Entr. Air	Fine Agg.	Coarse Agg.
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 Agg. Tons	Coarse Agg. 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

* The total quantity of free water in concrete, including the free water in the aggregate, shall not exceed 0.488 pound of water per pound of cement.
These quantities are based on the following assumptions: Specific gravity of cement, 3.14; Specific gravity of aggregates, 2.65; Water-cement ratio, 0.430 pound of water per pound of cement; Air voids, 6.0 percent.

APPENDIX B

Compressive Strength Testing

Test Method No. Iowa 403-A
March 1973

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.

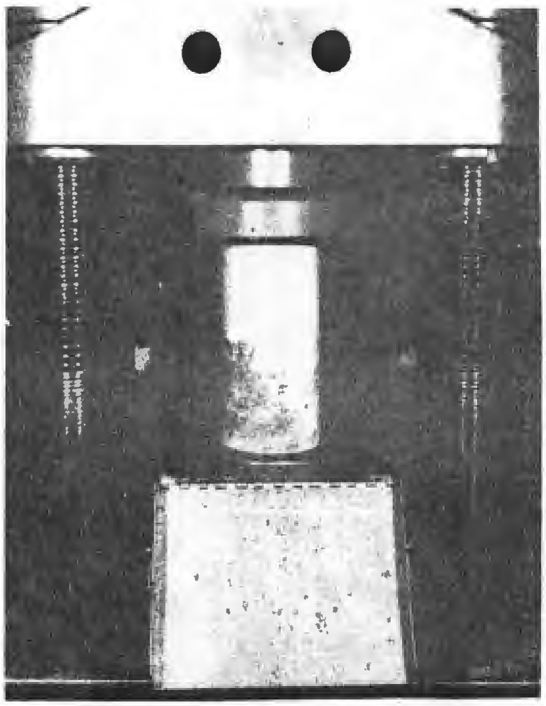


Fig. 1
Concrete Cylinder In Testing Machine

APPENDIX C

Durability Factor 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:

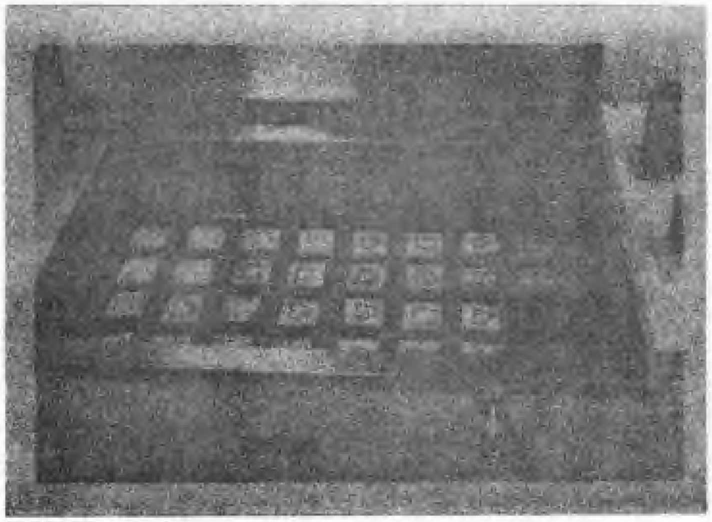
DF = the durability factor of the specimen

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

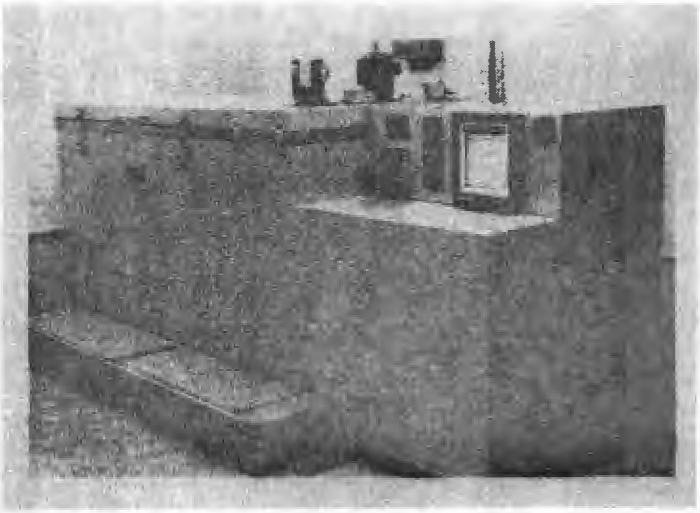
N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less

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

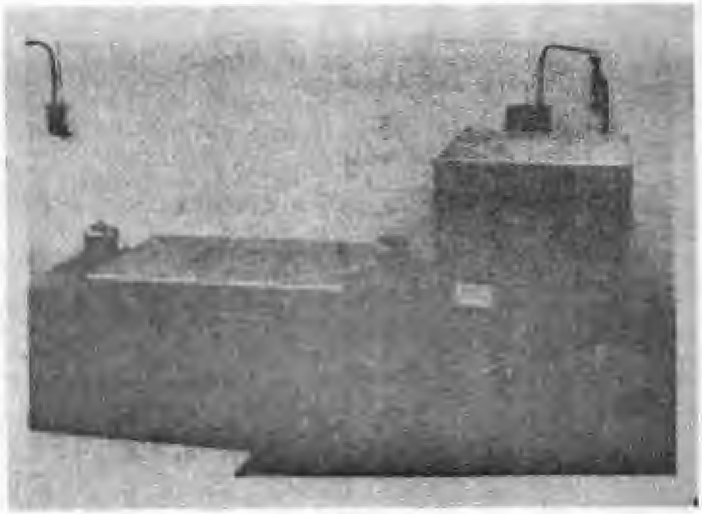
8. Report. The final report (worksheet) should be submitted to the Geology Section, and it should include all data pertinent to the variables or combination of variables studied in the evaluation. Also, any defects in each specimen which develop during testing and the number of cycles at which such defects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



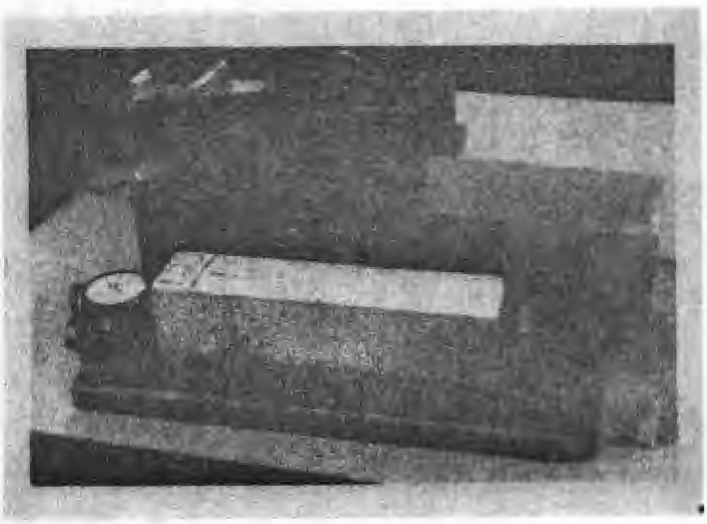
Specimens in the
Freezing & Thawing Apparatus



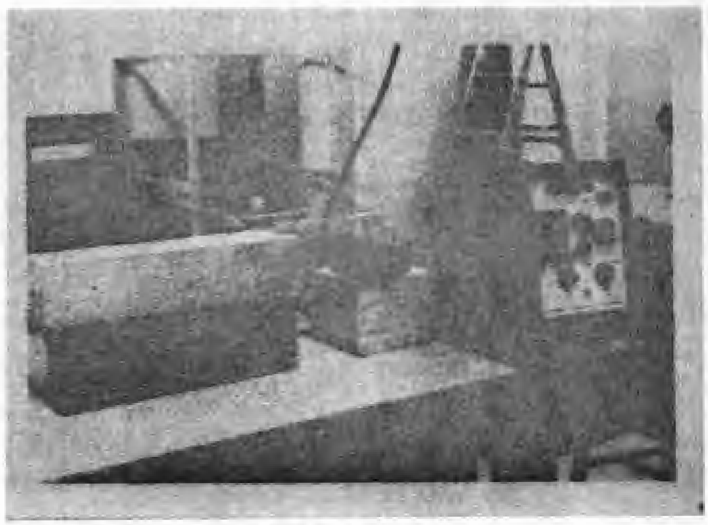
Freezing & Thawing Apparatus
"Cincinnati"



Freezing & Thawing Apparatus
"Conrad"



Beam Comparator



Dynamic Testing Apparatus

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: ____________

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.