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REPORT OF AN INVESTIGATION OF THE EFFECT OF CERTAIN CONSTITUENT MATERIALS OF BETHANY FALLS COARSE AGGREGATE ON SOME PROPERTIES OF CONCRETE

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INTRODUCTION

Within a band along the west boundary of Missouri, one hundred miles wide and extending from the Iowa line to some 75 miles south of Kansas City, quarries in the Bethany Falls formation are the principal sources of coarse aggregate for concrete. Some beds of the formation include shale which occurs as seams, ranging from one foot thick to very thin, and also dispersed through and intimately mixed with the limestone. As a result of the different modes of occurrence of the shale the crushed product from the quarries contains shale-contaminated particles ranging from pure shale, through thinly laminated shale, to finely divided shale dispersed through the stone. The field inspection forces visually classify these contaminated particles into two categories, "Deleterious" material and "Objectionable" material.[1]

The primary purpose of this investigation was to determine whether or not these contaminants are harmful to the strength and frost resistance of concrete containing Bethany Falls stone as coarse aggregate. The experimental work consisted of two phases, a laboratory phase and an outdoor exposure phase, both involving small, laboratory-fabricated concrete specimens. The two phases are tied together in that, for any specific combination of experimental factors, specimens for both phases were fabricated from each batch of concrete. Eventually this should provide the data for quantitatively relating the results of accelerated laboratory freezing tests to results that occur under natural, outdoor

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(1) For a more complete description, see Appendix 2.

exposure. To date there has been no evidence of deterioration of any of the specimens subjected to outdoor exposure; nor is any expected for several years. This report, therefore, is confined to the results obtained in the laboratory phase of the investigation.

LABORATORY PHASE

SECTION 1 In essence the Laboratory phase of the investigation consisted of testing, under four different arbitrary test conditions, the resistance to laboratory freezing of twelve concrete mixtures, each containing Alpha cement and Missouri River sand but a different coarse aggregate. The four test conditions (1) were as follows:

(A) Normal mortar - concrete soaked 30 days; (2)

(B) Aerated mortar - concrete soaked 30 days; (2)

(C) Normal mortar - concrete soaked 119 days; (2)

(D) Aerated mortar - concrete soaked 119 days. (2)

As collateral information the 37 day flexural strength was determined on one specimen from each batch of concrete.

SECTION 2 The twelve coarse aggregates tested consisted of three reference aggregates, Blackwater and Plattin limestones and Meramec gravel; plus nine Bethany Falls limestones differing from each other in their percentage content of so-called "Deleterious" and "Objectionable" material. All of these aggregates, and the symbols used to designate them throughout the report, are listed below.

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(1) For further information concerning test conditions, materials, concrete proportions, batching and mixing procedure, and test methods see Appendix 1.

(2) After curing 7 days in moist room.

Blw	Blackwater limestone
Pl	Plattin limestone
Mer	Meramec Gravel
D_0O_0	Bethany Falls limestone with 0% Deleterious and 0% Objectionable
D_0O_6	" " " " 0% " " 6% "
D_0O_{13}	" " " " 0% " " 13% "
D_5O_0	" " " " 5% " " 0% "
D_5O_6	" " " " 5% " " 6% "
D_5O_{13}	" " " " 5% " " 13% "
D_8O_0	" " " " 8% " " 0% "
D_8O_6	" " " " 8% " " 6% "
D_8O_{13}	" " " " 8% " " 13% "

SECTION 3 The experimental design (i.e., the mode of association of a beam specimen with the concrete batch from which it was obtained, the test condition to which it was subjected, and the various experimental factors)is shown schematically and described in Appendix 3. The design was such that the data of the the experiment could be (and were) analysed statistically in accordance with about ten different approaches, each including a different combination of the test conditions and the experimental variables. Details of several of these analyses are presented in the Appendices.

Reference Aggregates and Test Conditions

SECTION 4 In some twenty series of laboratory freezing and thawing tests of the past, Meramec gravel and Blackwater or Plattin or Bethany Falls limestones have been used as reference aggregates for two purposes: first, to indicate whether some extraneous factor, associated with the concrete mixture or test procedure, was causing unusual results in the particular series of tests under scrutiny; and second, as bases with which to compare test results of other aggregates in order to establish relative durability ratings for the latter. In all such series of tests the qualitative frost resistance ratings have been as follows:

Blackwater or Plattin, best;

Bethany Falls, definitely inferior to these, but definitely superior to Meramec;

Meramec, definitely inferior to the other three.

This is essentially the same as the relative performance records of pavements containing these aggregates.

With this in mind let us examine the top four horizontal lines of Table 1 which give the test results for Blackwater, Plattin, Meramec, and Bethany Falls D.O. coarse aggregates, tested under all four test conditions listed in Section 1. Considering first the results obtained under the test condition of Normal mortar and 30 days soaking, several anomalies are apparent:

(1) Plattin is vastly inferior to Blackwater;

(2) Plattin is even inferior to Meramec;

(3) Bethany Falls is superior to Plattin and on a par with Blackwater.

Next, considering the results for Normal mortar and 119 days soaking the same anomalies exist, except that Bethany Falls is here inferior to Blackwater; however, based on all past experience, it is too much inferior to Blackwater and too little superior to Meramec.

TABLE I

NUMBER OF FROST CYCLES REQUIRED(1)
TO REDUCE DYNAMIC "E" BY 60% OF ORIGINAL

	Mortar			
	Normal		Aerated	
Coarse	Soaking Period		Soaking Period	
Aggregate	30 days	119 days	30 days	119 days
Blackwater Lst.	23.5	63.0	406.0*	300.0*
Plattin Lst.	14.5	21.5	400.0*	290.0*
Meramec Gravel	17.9	24.8	121.8	87.8
Beth. Falls D_0O_0	24.2	27.9	395.7	156.0
Beth. Falls D_0O_6	25.0	25.8	318.7	131.0
Beth. Falls D_0O_{13}	25.3	24.8	293.0	141.2
Beth. Falls D_5O_0	18.7	19.1	318.0	157.8
Beth. Falls D_5O_6	26.0	22.9	259.9	139.7
Beth. Falls D_5O_{13}	20.3	25.5	251.7	114.1
Beth. Falls D_8O_0	20.8	20.9	269.5	118.0
Beth. Falls D_8O_6	22.7	21.8	267.3	116.1
Beth. Falls D_8O_{13}	27.0	22.7	252.0	130.0

*Tests stopped when
(Blackwater Conc. Frozen at 37d. showed 8% Loss
(@ Av. of 406 Cy.
(Blackwater Conc. Frozen at 126 d. showed 22%
(Loss @ Av. of 299.5 Cy.
(Plattin Conc. Frozen at 37 d. showed 6% Loss
(@ Av. of 399 Cy.
(Plattin Conc. Frozen at 126 d. showed 11% Loss
@ Av. of 290.5 Cy.

(1) Each tabular value is an average of results on 4 specimens.

SECTION 5 The most likely inference to be drawn from the above is that some effect must have existed in this series of tests which had not been present in previous series, and changed the previously obtained indications regarding the relative frost resistance of the concretes containing these aggregates. The type of sand used in this series was the only factor known to be different. For all prior series, having evaluation of frost resistance of coarse aggregate as the objective, Reading sand in an air-dry condition was used as fine aggregate; but in the present series Missouri River sand was used as fine aggregate. There was a twofold reason for use of a different fine aggregate in this experiment:

(a) Reading sand was no longer available; and

(b) Bethany Falls stone will almost invariably be used with Missouri River or a similar sand in construction work.

Offered as an explanation of the difference in behavior of the reference aggregates in previous series with Reading sand, as compared with their behavior with Missouri River sand in this experiment, is the following:

> Reading sand being a highly porous material and Missouri River sand one of low porosity, and both having been placed in the concrete air-dry, it is reasoned that the Reading sand contains unsaturated pore space even after the concrete has undergone prolonged soaking, whereas the Missouri River sand does not. It is further reasoned that because of this,

Reading sand mortar is considerably more frost resistant at early ages (several months) than Missouri River sand mortar; and that, in accelerated freezing tests of concretes containing the former, differences in indicated frost resistance are reflecting a coarse aggregate effect, whereas the Missouri River sand mortar (under our test procedure of continuous soaking) has so little frost resistance that any differences in coarse aggregate effect are masked.

Whether or not the above reasoning outlines the actual cause, the effect existed. It was not entirely unexpected since another series of tests, in progress but incomplete when this series was started, had indicated the possibility; also other investigators had encountered similar anomalies when testing frost resistance of coarse aggregates in Unaerated mortars. Fear of the possibility was one of the principal reasons for duplicating the complete set of combinations of experimental variables using both Normal and Aerated mortars.

SECTION 6 Since the indicated differences in frost resistance of concretes containing the reference aggregates tested in Normal mortar were unreliable, it was concluded that indicated differences among the various Bethany Falls combinations with Normal mortar should not be trusted. Therefore, results from the two test conditions, in which Normal mortar was used, were not considered in evaluation of the effect of different quantities of "Deleterious" and "Objectionable" materials in Bethany Falls rock.

Bethany Falls Combinations Tested in Aerated Mortar

SECTION 7 Returning now to Table I, consider the concretes containing Aerated mortar and the four reference aggregates. Blackwater and Plattin concretes deteriorated so much more slowly than the other concretes that tests on the former were stopped long before either had reached 60% loss in E. However, for both soaking periods, the tests were carried far enough to demonstrate that these two concretes showed far greater frost resistance than either of the other two, and also that the Bethany Falls D_cO_c was superior to Meramec. This is in line with previous laboratory test results as well as pavement performance in the field. Because of this it is inferred that when the concretes were made with Aerated mortar, differences in indicated frost resistance of the concretes were, to a large extent, due to differences in the coarse aggregates.

Having established the frost resistance of "clean" Bethany Falls stone (D_cO_c) with respect to the reference aggregates, the data were analysed for the effects of adding "Deleterious" material, "Objectionable" material, or both. For this analysis all test results with the various Bethany Falls stones in Aerated mortar were considered. The results obtained on the concretes soaked 30 days and the results on the concretes soaked 119 days were separately analyzed.

Effect of "Deleterious" Material

SECTION 8 Freezing and thawing test results for Aerated concretes soaked 30 days are shown in the fourth column of Table 1 and in a modified form in the third column of Table 2. Each value in the field of the Tables is an average of results on four replicate specimens, expressed in terms of the number of cycles required for 60% loss in sonic modulus.

If, for a specific level (e.g.,0%) of "Deleterious" material tested, one averages the results obtained at the three tested levels of "Objectionable" material there is obtained an estimate of the frost resistance to be expected from concretes containing 0% "Deleterious" material and some random quantity (between 0 and 13%) of "Objectionable" material. This has been done for each of the three tested levels of "Deleterious" material and the results shown in the second column of Table 3. Inspection of these values shows that the indicated frost resistance is roughly inversely proportional to the amount of "Deleterious" material in the concrete; i.e., the frost resistance of the concrete decreased as the percent "Deleterious" material increased.

SECTION 9 The operation described in Section 8 was repeated for the specimens tested after soaking for 119 days, the averages being tabulated in the fourth column of Table 2 and the third column of Table 3. Again the trend indicates a decreasing frost resistance with increasing quantities of "Deleterious" material.

TABLE 2

FROST RESISTANCE (1) OF AERATED CONCRETES CONTAINING BETHANY FALLS LIMESTONE WITH VARYING QUANTITIES OF "DELETERIOUS" AND "OBJECTIONABLE" MATERIALS (2)

Per Cent Deleterious	Per Cent Objectionable	Soaking Period 30 Days	Soaking Period 119 Days
0	0	396	156
	6	319	131
	13	293	141
	Avg.	336	143
5	0	318	158
	6	260	140
	13	252	114
	Avg.	277	137
8	0	270	118
	6	267	116
	13	252	130
	Avg.	263	121

TABLE 3

FROST RESISTANCE (1) OF AERATED CONCRETES CONTAINING BETHANY FALLS LIMESTONE WITH DIFFERENT (2) QUANTITIES OF "DELETERIOUS" MATERIAL (3)

Per Cent Deleterious	Soaking Period 30 Days	Soaking Period 119 Days
0	336	143
5	277	137
8	263	121

(1) As measured by the number of laboratory freezing and thawing cycles causing 60% loss in Dynamic Modulus of Elasticity.

(2) For each indicated level of "Deleterious" material, the tabular value is an average of the results obtained for the three tested levels of "Objectionable" material.

(3 Each tabular value in Tables 2 and 3 is an average of results on four and twelve test specimens respectively.

Effect of "Objectionable" Material

SECTION 10 The average values, for concretes containing the various combinations of the two classes of contaminants and frozen after 30 days soaking, were retabulated as shown in Table 4. For each level of "Objectionable" material tested, the results were averaged across the three tested levels of "Deleterious" material, and the values so obtained tabulated in the second column of Table 5. Analagous to Section 8 on "Deleterious" material, a value in Table 5 provides an estimate of the frost resistance to be expected from concrete containing a specific quantity of "Objectionable" material and some random quantity (between 0% and 8%) of "Deleterious" material. Considering the three values in the second column of Table 5 it is apparent that the trend is for the average frost resistance of the concrete to decrease as the percent "Objectionable" material increased.

SECTION 11 An analysis, similar to that described in the previous paragraph, was performed on the data from the concretes soaked 119 days prior to freezing. The results are tabulated in the fourth column of Table 4 and the third column of Table 5. It is apparent that the same trend exists as was exhibited by the concretes tested after 30 days soaking.

SECTION 12 From the data and discussion presented in Sections 8 through 11, it would appear that the frost resistance of concretes, as measured after either 30 days or 119 days

TABLE 4

FROST RESISTANCE (1) OF AERATED CONCRETES CONTAINING BETHANY FALLS LIMESTONE WITH VARYING QUANTITIES OF "DELETERIOUS" AND "OBJECTIONABLE" MATERIALS (3)

Per Cent Objectionable	Per Cent Deleterious	Soaking Period 30 Days	119 Days
0	0	396	156
	5	318	158
	8	270	118
	Avg.	328	144
6	0	319	131
	5	260	140
	8	267	116
	Avg.	282	129
13	0	293	141
	5	252	114
	8	252	130
	Avg.	266	128

TABLE 5

FROST RESISTANCE (1) OF AERATED CONCRETES CONTAINING BETHANY FALLS LIMESTONE WITH DIFFERENT (2) QUANTITIES OF "OBJECTIONABLE" MATERIAL (3)

Per Cent Objectionable	Soaking Period 30 Days	119 Days
0	328	144
6	282	129
13	266	128

(1) As measured by the number of laboratory freezing and thawing cycles causing 60% loss in Dynamic Modulus of Elasticity.

(2) For each indicated level of "Objectionable" material, the tabular value is an average of the results obtained for the three tested levels of "Deleterious" material.

(3) Each tabular value in Tables 4 and 5 is an average of results on four and twelve test specimens respectively.

soaking, decreases with increasing quantities of either "Deleterious" or "Objectionable" material. This is a correct picture of the facts providing:

(a) that uncontrolled variables were not affecting the test results to such a degree that the average values used in the analysis are of highly uncertain validity; and

(b) that there was no interaction between the effect of "Deleterious" material and the effect of "Objectionable" material; i.e., that the effect of "Deleterious" material is of the same magnitude regardless of the quantity of "Objectionable" material with which it is combined.

The experiment was so designed as to yield data for investigating the above provisos. The method of investigation is by application of statistical analyses of the variances of the test results. Details of these are presented in Appendices 4 and 5 for concretes soaked 30 and 119 days respectively.

The analysis in Appendix 4 shows the magnitude of the effect, associated with increasing quantities of either "Deleterious" or "Objectionable" material, to be greater than that introduced by uncontrolled variables; and sufficiently greater that the trends indicated in Tables 3 and 5 are statistically significant and hence can be inferred to be real. Furthermore, the influence of the interaction between the effect of "Deleterious" material and the effect of "Objectionable" material is not of significant magnitude, in fact is even smaller than that due to uncontrolled variables.

The results for specimens soaked 119 days were separately analyzed (Appendix 5). For these tests the "Deleterious-Objectionable" interaction was statistically significant; but, when this component of the total effects was isolated, the effects of "Deleterious" and "Objectionable" materials were each of statistically significant magnitude, although the trends are not so consistent as in the case of the beams soaked only 30 days.

It thus has been demonstrated that under the laboratory freezing and thawing tests for both 30 days soaking and 119 days soaking, the trend for a decreased frost resistance of concrete with increasing quantities of either "Deleterious" or "Objectionable" materials is sufficiently pronounced that there is a remote (less than 5%) chance of it being due to the effect of uncontrolled variables.

SECTION 13 While the trend has been established, nothing has been developed about the actual magnitude of the effects of the two types of contaminants. To examine this, studies were made of the relation between the percents of "Deleterious" and "Objectionable" materials and the number of cycles of freezing and thawing required to reduce Dynamic E by 60%. These are outlined in Appendices 6 and 7. Under the assumption that the relationship is linear, equations of the "lines of best fit" were calculated for the data, and graphs of these are shown as Figs. 1 and 2.

Figure 1

CALCULATED RELATION BETWEEN FROST RESISTANCE OF CONCRETE AND PERCENTAGES OF "DELETERIOUS" AND "OBJECTIONABLE" MATERIALS

(Aerated Concretes Frozen and Thawed at 37 days.)

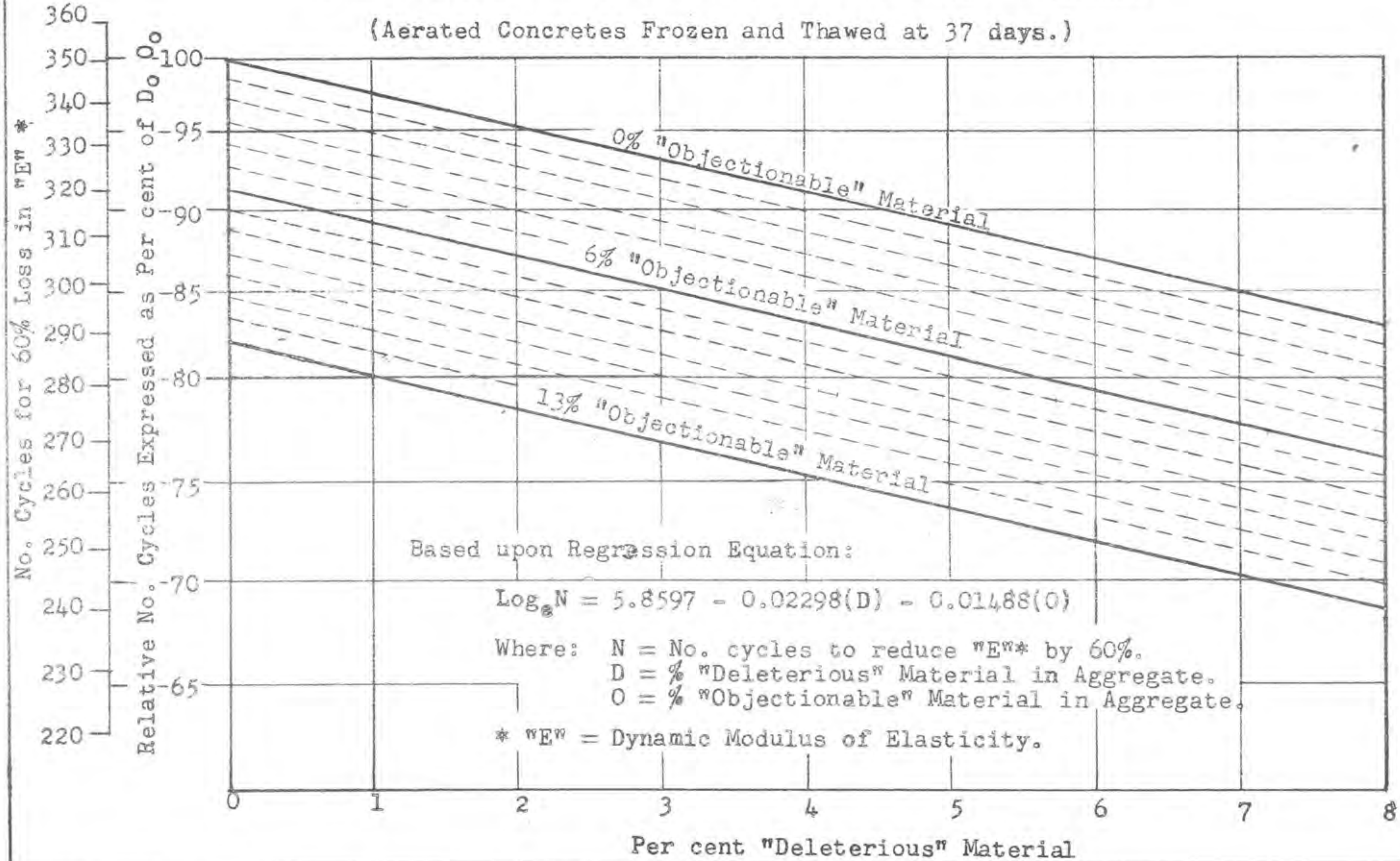

Figure 2

CALCULATED RELATION BETWEEN FROST RESISTANCE OF CONCRETE AND PERCENTAGES OF "DELETERIOUS" AND "OBJECTIONABLE" MATERIALS

(Aerated Concretes Frozen and Thawed at 126 days.)

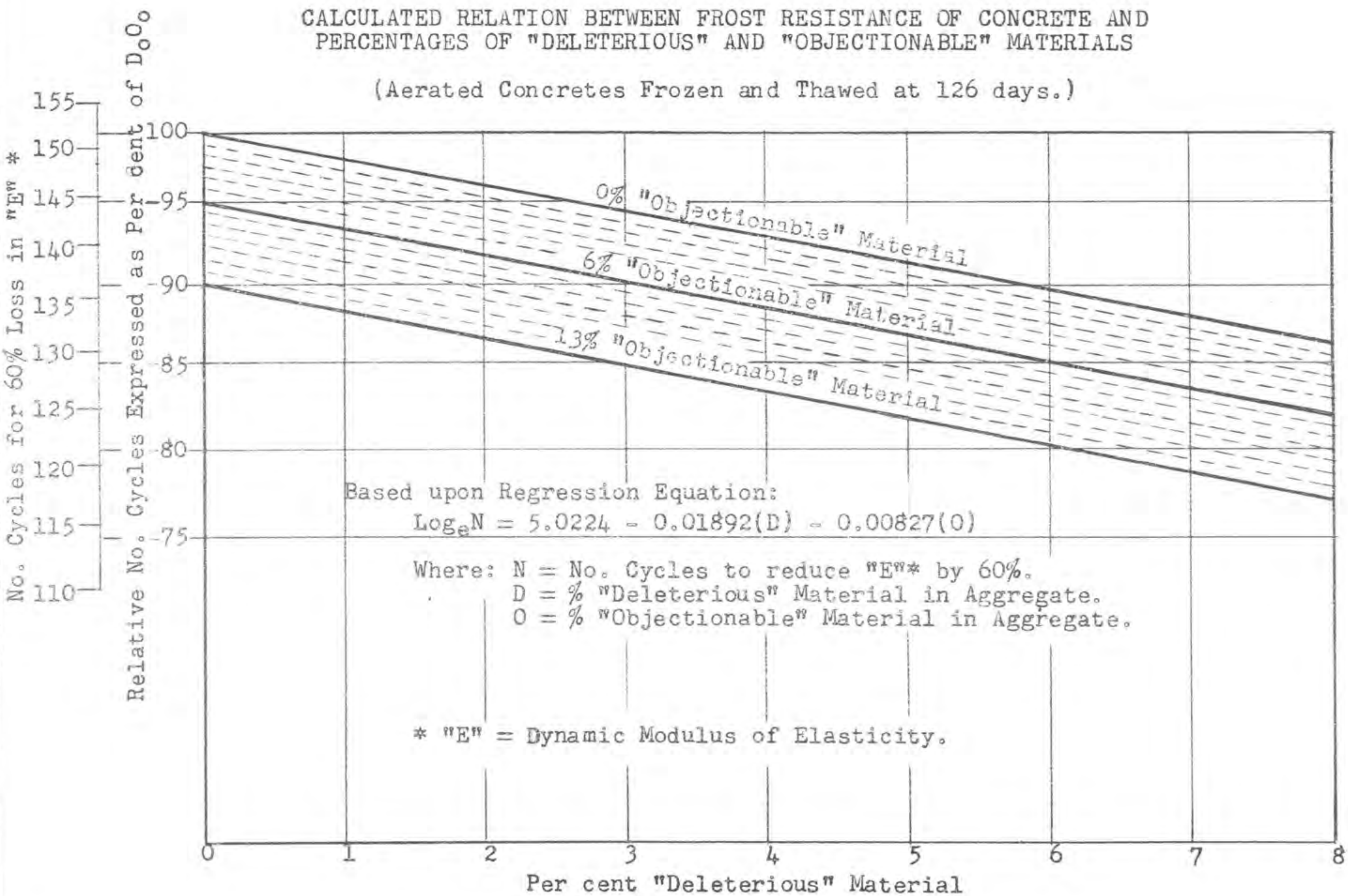

Fig. 1 shows the relation for concretes frozen after 30 days soaking; Fig. 2, that for concretes frozen after 119 days soaking. Study of these graphs reveals the following:

(a) Each added percent of "Deleterious" material resulted in a decrease of 1.6 to 2.1% in the frost resistance of the concrete relative to the frost resistance of concrete containing clean Bethany Falls stone (D_0O_0);

(b) Each added percent of "Objectionable" material resulted in a decrease of 0.77 to 1.4% in the frost resistance of the concrete relative to that containing D_0O_0;

(c) For the two test conditions studied, the effect of "Deleterious" material is approximately 1-3/4 times as great as the effect of "Objectionable" material.

SECTION 14 Actually, the indicated magnitude of the effect of "Deleterious" material and its ratio to the effect of "Objectionable" material may be unrealistically small. Examination of specimen faces exposed by flexure tests revealed fewer of the larger "Deleterious" particles, representative of the sub-classes consisting principally of shale, than would have been expected. Furthermore, on the beams that were frozen, there was practically no evidence of surface pits such as are usually found in concrete containing large aggregate particles made up partly or wholly of pure shale. It was known that some of this material had disintegrated to powder under the standard 2 hour soaking period, to which all the coarge aggregate was subjected prior to incorporation in the concrete. To investigate how extensive this degradation of shale particles may have been, a set of four beams, two made with pre-soaked and two with air-dry "Deleterious" material were fabricated, sectioned, and examined for shale content by a microscopic linear traverse. These tests definitely demonstrated that the specimens made with pre-soaked "Deleterious" material contained only 20 to 25% as much recognizable shale as those made with air-dry "Deleterious" material. A seemingly plausible explanation is that pre-soaking softened the shaly particles, and that the succeeding batching and mixing process reduced these to sizes too small to be recognizeable as shale in the microscopic examination. Experience indicates that porous particles of small size (-4 mesh) are much less damaging to the frost resistance of concrete than the larger counterparts. It is, therefore, reasoned that the magnitude of the detrimental effect ascribed to "Deleterious" material in this investigation was materially less than would have been the case had the "Deleterious" material not been pre-soaked.

Offered as purely an opinion is the investigators' idea that the magnitude of the effect of "Deleterious" material would have been considerably greater had this material not been pre-soaked; and also that in many instances in actual pavement construction, a greater proportion of the larger-size, shaly particles will exist as such after placement in the concrete than was the case in these tests. If this be so, concrete containing the larger quantities of "Deleterious" material could be expected to show a greater reduction in frost resistance when used in pavements, than was indicated by the laboratory tests.

SECTION 15 The discussion thus far has dealt exclusively with the general trends regarding the effects of the "Deleterious" and "Objectionable" materials. These trends were deemed more important than the differences indicated by comparisons of specific pairs of aggregates; however, these can be studied for each test condition, and Table 6 shows such comparisons for the results obtained on Aerated concretes tested after 30 days soaking.

The various aggregates tested are shown along the upper margin and repeated along the left-hand margin of the Table. In each cell of the Table there is a figure and a letter. The figure is the number of cycles for 60% loss in Dynamic E for the aggregate in the row minus this value for the aggregate in the column. The letter tells whether the numerical value is statistically significant at the 5% risk level. The letters have the following meaning:

S in a cell means that the frost resistance of concrete containing the aggregate in the row was significantly superior to that containing the aggregate in the column;

I means the frost resistance of concrete containing the aggregate in the row was significantly inferior to that containing the aggregate in the column;

TABLE 6

DIFFERENCES IN INDICATED FROST RESISTANCE[1] FOR EACH POSSIBLE PAIR OF AGGREGATES AND THE STATISTICAL SIGNIFICANCE OF EACH AT THE 5% RISK LEVEL

AERATED CONCRETES SOAKED 30 DAYS

	Plt.*	BLW.*	BF D_0O_0	BF D_0O_6	BF D_5O_0	BF D_0O_{13}	BF D_8O_0	BF D_8O_6	BF D_5O_6	BF D_5O_{13}	BF D_8O_{13}	Mer.
Plattin*		+ N	+104 S	+191 S	+192 S	+207 S	+230 S	+233 S	+240 S	+248 S	+248 S	+378 S
Blackwater*	- N		+104 S	+191 S	+192 S	+207 S	+230 S	+233 S	+240 S	+248 S	+248 S	+378 S
BF D_0O_0	-104 I	-104 I		+77 S	+78 S	+103 S	+126 S	+128 S	+136 S	+144 S	+144 S	+274 S
BF D_0O_6	-191 I	-191 I	-77 I		+1 N	+26 N	+49 N	+51 N	+59 S	+67 S	+67 S	+197 S
BF D_5O_0	-192 I	-192 I	-78 I	-1 N		+25 N	+48 N	+52 N	+58 N	+66 S	+66 S	+196 S
BF D_0O_{13}	-207 I	-207 I	-103 I	-26 N	-25 N		+24 N	+26 N	+33 N	+41 N	+41 N	+171 S
BF D_8O_0	-230 I	-230 I	-126 I	-49 N	-48 N	-24 N		+2 N	+10 N	+18 N	+18 N	+148 S
BF D_8O_6	-233 I	-233 I	-128 I	-51 N	-51 N	-26 N	-2 N		+7 N	+16 N	+15 N	+146 S
BF D_5O_6	-240 I	-240 I	-136 I	-59 I	-58 N	-33 N	-10 N	-7 N		+8 N	+8 N	+138 S
BF D_5O_{13}	-248 I	-248 I	-144 I	-67 I	-66 I	-41 N	-18 N	-16 N	-8 N		0 N	+130 S
BF D_8O_{13}	-248 I	-248 I	-144 I	-67 I	-66 I	-41 N	-18 N	-15 N	-8 N	0 N		+130 S
Meramec	-378 I	-378 I	-274 I	-197 I	-196 I	-171 I	-148 I	-146 I	-138 I	-130 I	-130 I	

FOOTNOTES FOR TABLE 6

(1) As measured by number of cycles of freezing and thawing causing 60% loss in Dynamic E.

* Concrete made with Plattin Stone showed 6% loss at 399 cycles and concrete made with Blackwater Stone showed 8% loss at 406 cycles. For purpose of calculating the tabular differences the number of cycles for 60% loss in "E" was arbitrarily set at 500 cycles for both concretes.

N means that there was no significant difference between the frost resistance of the concretes containing the aggregate in the row and the aggregate in the column; it does not mean that there was actually no difference; but rather that if there was a difference, it was so small (relative to the variation in frost resistance of supposedly identical specimens) that it could not be inferred to be a real difference with a maximum 5% chance of being wrong.

SECTION 16 The relative frost resistance of any pair of aggregates can be found by locating the row containing one of the aggregates, the column containing the other, and noting the figure and letter in the cell common to both. It will be observed that all Bethany Falls combinations (even D_0O_0) were inferior to the reference aggregates, Plattin and Blackwater; and all were superior to Meramec. Considering only the Bethany Falls combinations, it appears that these line up as would be expected from the regression equation of Fig. 1, with the one exception that the positions of D_5O_6 and D_8O_6

along the upper and the left-hand margins should have been interchanged.

In Table 6, the comprehensive picture, as contrasted with the segmental pictures obtained from the individual comparisons between pairs of aggregates, reveals the same trends with regard to the effects of "Deleterious" and "Objectionable" materials as have previously been pointed out and discussed. While these data are actually the same as those previously used, still they can be considered as furnishing substantiating evidence. They show that each tested level of the contaminants contributes to the over-all effect, as contrasted with a possible condition where eight of the nine Bethany Falls combinations might have produced essentially similar results with only one differing materially therefrom.

SECTION 17 In Table 7 the test results for the Aerated concretes soaked 119 days are presented in a manner similar to that used in Table 6 for the concretes soaked 30 days. The comprehensive picture is essentially the same as that presented by Table 6, and the discussion in Section 16 would generally be appropos for Table 7.

SECTION 18 Table 6 (and Table 7) also depict the over-all variability in the entire group of aggregates tested, and in a sense provide an estimate of the discriminatory power of the test procedure. Consider the two halves of the Table on each side of the diagonal line. If the test results had been such that each aggregate showed a frost resistance statistically different from that of every other aggregate, there would

TABLE 7

DIFFERENCES IN INDICATED FROST RESISTANCE(1) FOR EACH POSSIBLE PAIR OF AGGREGATES AND THE STATISTICAL SIGNIFICANCE OF EACH AT THE 5% RISK LEVEL

AERATED CONCRETES SOAKED 119 DAYS

	Plt.*	BLW.*	BF D_0O_0	BF D_5O_0	BF D_0O_{13}	BF D_5O_6	BF D_0O_6	BF D_8O_{13}	BF D_8O_0	BF D_8O_6	BF D_5O_{13}	Mer.
Plattin*		+100 S	+244 S	+242 S	+259 S	+260 S	+269 S	+270 S	+282 S	+284 S	+286 S	+312 S
Blackwater*	-100 I		+144 S	+142 S	+159 S	+160 S	+169 S	+170 S	+182 S	+184 S	+186 S	+212 S
BF D_0O_0	-244 I	-144 I		-2 N	+15 N	+16 N	+25 S	+26 S	+38 S	+40 S	+42 S	+68 S
BF D_5O_0	-242 I	-142 I	+2 N		+18 N	+18 N	+27 S	+28 S	+40 S	+42 S	+44 S	+70 S
BF D_0O_{13}	-259 I	-159 I	-15 N	-18 N		+2 N	+10 N	+11 N	+23 S	+25 S	+27 S	+53 S
BF D_5O_6	-260 I	-160 I	-16 N	-18 N	-2 N		+9 N	+10 N	+22 N	+24 S	+26 S	+52 S
BF D_0O_6	-269 I	-169 I	-25 I	-27 I	-10 N	-9 N		+1 N	+13 N	+15 N	+17 N	+43 S
BF D_8O_{13}	-270 I	-170 I	-26 I	-28 I	-11 N	-10 N	-1 N		+12 N	+14 N	+16 N	+42 S
BF D_8O_0	-282 I	-182 I	-38 I	-40 I	-23 I	-22 N	-13 N	-12 N		+2 N	+4 N	+30 S
BF D_8O_6	-284 I	-184 I	-40 I	-42 I	-25 I	-24 I	-15 N	-14 N	-2 N		+2 N	+28 S
BF D_5O_{13}	-286 I	-186 I	-42 I	-44 I	-27 I	-26 I	-17 N	-16 N	-4 N	-2 N		+26 S
Meramec	-312 I	-212 I	-68 I	-70 I	-53 I	-52 I	-43 I	-42 I	-30 I	-28 I	-26 I	

FOOTNOTES FOR TABLE 7

(1) As measured by number of cycles of freezing and thawing causing 60% loss in Dynamic E.

* For the purpose of calculating the tabular differences in number of cycles to produce 60% loss in E, the numbers of cycles for Plattin and Blackwater stones were arbitrarily set at 400 and 300 respectively.

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have been an S in every cell above and an I in every cell below the diagonal. On the other hand, had there been no statistical difference in the frost resistance of the members of any possible pair of aggregates, every cell both above and below the diagonal would have contained an N. Thus, under the assumption that there is in actuality some difference in the frost resistance of every aggregate, the proportion of N's provides an estimate of the discriminatory power of the test procedure. Sharper discriminations would have been possible if the number of replicate batches of concrete had been greater. However, the enlargement of the experiment necessary to have achieved this would not have been warranted since, in the investigators' opinion, differences of the magnitude of those assigned an N would not be practically significant, even though established as being statistically so.

The Influence of Air Entrainment and Length Of Soaking Period on Experimental Results

SECTION 19 Thus far the data of this experiment have been treated as though derived from four separate experiments, one for each of the test conditions described in Section 1. However, the experiment was so designed that the data from the nine Bethany Falls stones obtained under all four test conditions can be analysed as though derived from one comprehensive factorial experiment. Through such an analysis, the direct effects of two elements of the test conditions (air-content and length of soaking period) can be measured; also the influence of these, on the effects produced by the principal experimental factors, can be evaluated.

Under such an experimental layout, the experimental factors become:

(a) "Deleterious" material, tested @ levels of 0, 5, and 8%;

(b) "Objectionable" material, tested @ levels of 0, 6, and 13%;

(c) Length of Soaking and Curing, tested @ levels of 30 and 119 days;

(d) Air Content, tested @ levels of Normal and 4%.

The results of the statistical analysis of variance are presented in Appendix 8. Since this analysis throws no additional light on the effects of "Deleterious" and "Objectionable" materials, only the effects of air-entrainment and length of soaking period are here discussed. Both of these, and the interaction between them, are shown in Appendix 8 to be of statistically significant magnitudes.

Effect of Aeration

SECTION 20 In Columns (1) through (4) of Table 8, the results of the freezing test on each Bethany Falls combination are shown for each type of mortar and each soaking period. Comparison of results in Column 1 vs. results in Column 3, and Column 2 vs. Column 4 shows that in every case the concretes containing Aerated mortar were much more resistant to laboratory freezing than the corresponding concretes containing Normal mortar. The same picture is presented by the figures in Columns 5 and 6, where the test results are averaged across both soaking periods.

Effect of Soaking Period

SECTION 21 The effect of length of soaking period on Normal mortar concretes can be seen by comparing results in Column 1 with Column 2; and on Aerated mortar concretes by comparing Column 3 with Column 4. It is apparent for the Normal mortar concretes that increasing the soaking period from 30 days to 119 days had only a small effect for any aggregate; that the effect was inconsistent, indicating sometimes a decrease and sometimes an increase in frost resistance; and that, the average effect for all the aggregates was nil. On the other hand,

TABLE 8

NUMBER OF CYCLES REQUIRED TO REDUCE DYNAMIC "E" BY 60% OF ORIGINAL(1) FOR EACH BETHANY FALLS COMBINATION UNDER ALL TEST CONDITIONS

COLUMN	1	2	3	4	5	6	7	8
	Mortar				Avg. for both Soaking Periods		Avg. for both Mortars	
	Normal		Aerated					
	Soaking Period		Soaking Period					
Coarse Aggregate	30 D.	119 D.	30 D.	119 D.	Normal Mortar	Aerated Mortar	30 Day Soaking	119 Day Soaking
Beth. Falls D_0O_0	24.2	27.9	395.7	156.0	26.05	275.85	209.95	91.95
Beth. Falls D_0O_6	25.0	25.8	318.7	131.0	25.40	224.85	171.85	78.40
Beth. Falls D_0O_{13}	25.3	24.8	293.0	141.2	25.05	217.10	159.15	83.00
Beth. Falls D_5O_0	18.7	19.1	318.0	157.8	18.90	237.90	168.35	88.45
Beth. Falls D_5O_6	26.0	22.9	259.9	139.7	24.45	199.80	142.95	81.30
Beth. Falls D_5O_{13}	20.3	25.5	251.7	114.1	22.90	182.90	136.00	69.80
Beth. Falls D_8O_0	20.8	20.9	269.5	118.0	20.85	193.75	145.15	69.45
Beth. Falls D_8O_6	22.7	21.8	267.3	116.1	22.25	191.70	145.00	68.95
Beth. Falls D_8O_{13}	27.0	22.7	252.0	130.0	24.85	191.00	139.50	76.35
Avg.	23.3	23.5	291.7	133.8	23.4	212.76	157.54	78.63

(1) Each tabular value in first four columns is an average of results on four specimens; whereas each tabular value in last four columns is an average of results on eight specimens.

for every concrete containing Aerated mortar, the longer soaking period caused a decided decrease in the frost resistance, ranging in magnitude from 50 to 60%, and averaging 54%, over the nine concretes.

SECTION 22 Obviously, there is an interaction between the effect of entrained air and the effect of length of soaking period on the laboratory frost resistance of the concretes. Its nature leads to the general inference that the immature concretes subject to frost action after a short soaking period are greatly benefitted by entrained air, but that the degree of improvement is materially reduced with increased duration of soaking and age.

Flexural Strength of Concretes

SECTION 23 One beam from each batch of concrete mixed, was tested for flexural strength. Since there were four batches for each combination of experimental factors and test conditions, there were four flexure tests for each of the combinations. The beams were cured 7 days on the shelves and 30 days in water in the moist room. At 37 days these were broken in flexure, first on a fourteen inch and then on a seven inch span, using center point loading. Only the strengths obtained on the 14" span are considered here.

Coarse Aggregate	% Del. Matl.	% Obj. Matl.	Avg. Flex. Str. - 14" Span (1) Normal Conc.	Air Ent. Conc.
Blackwater			1082	1053
Plattin			1020	990
Meramec			926	871
Beth. Falls	0	0	946	937
Beth. Falls	0	6	940	939
Beth. Falls	0	13	971	929
Beth. Falls	5	0	946	952
Beth. Falls	5	6	950	934
Beth. Falls	5	13	960	938
Beth. Falls	8	0	983	910
Beth. Falls	8	6	953	937
Beth. Falls	8	13	1004	906
		Avg.	973	941

(1) Each tabular value is an average of test results from four beams.

Effect of Coarse Aggregate Upon the Flexural Strength of the Concrete

Using an average strength for the 9 Bethany Falls concretes, the flexural strengths for the different aggregates are as follows:

Coarse Aggregate	Avg. Flex. Str. - 14" Span Normal Conc.	Air Ent. Conc.
Blackwater	1082	1053
Plattin	1020	990
Meramec	926	871
Bethany Falls	961	931

These results indicate that:

1. The flexural strength of the concrete varies from one coarse aggregate to another; the highest and lowest strengths being obtained, respectively, with Blackwater stone and Meramec Gravel.
2. All of the above strengths would be considered as satisfactory for pavement grade of concrete.

Effect of Air Content Upon Strength

SECTION 24 The average strengths of the Normal and air-entrained concretes show that the average effect of the air-entrainment was to reduce the flexural strength by $100\left(1 - \frac{941}{973}\right) = 3.3$ per cent. The use of air-entrainment caused some reduction in strength with eleven of the twelve coarse aggregates tested.

These results appear in line with previous experience; namely, that air-entrainment (within specification limits) reduces the flexural strength of concrete, but not enough to be considered critical.

Effect of "Deleterious" and "Objectionable" Material in the Bethany Falls Stone Upon the Flexural Strength of Concrete

SECTION 25 The effect of the deleterious and objectionable material in the Bethany Falls stone can best be shown by the following tabulation, where each strength shown is the average of twelve measurements:

Per Cent		Flex. Str. - 14" Span	
Del. Matl.	Obj. Matl.	Normal Conc.	Air-Ent. Conc.
0	0-13	952	935
5	0-13	952	941
8	0-13	979	918
0-8	0	958	933
0-8	6	948	937
0-8	13	978	924

These results indicate that, when used in concrete in the manner employed in this investigation, the effect of the "Deleterious" and "Objectionable" material upon the flexural strength of the concrete was small. Definitely no consistent trend, similar to that noted with air-entrainment, was evidenced.

SUMMARY OF THE CONCLUSIONS DRAWN FROM THE EXPERIMENTAL DATA

SECTION 26 Below is a compilation of the principal conclusions drawn from analysis of the experimental data. Application of these to materials and exposure conditions differing from those of the experiment should be approached with caution.

It is concluded:

(1) Since indicated differences in frost resistance of the reference aggregates when tested in Normal mortar (non-aerated) did not conform with previous experience, that indicated differences among the various Bethany Falls combinations tested in normal mortar were unreliable. (Reference aggregates were included in the experimental design for the express purpose of disclosing this eventuality.)

(2) Since indicated differences in frost resistance of the reference aggregates when tested in Aerated mortar aligned themselves in accordance with their performance in pavements and numerous other laboratory tests, that this test condition was reflecting differences caused by coarse aggregate.

(3) As a result of the two previous conclusions, that only the test results on Aerated concretes should be used for evaluating the effects of "Deleterious" and "Objectionable" materials.

(4) That clean (D_0O_0) Bethany Falls stone was decidedly inferior in laboratory frost resistance to both Blackwater and Plattin stones, and definitely superior to Meramec gravel.

(5) (a) That both "Deleterious" and "Objectionable" materials were detrimental to the laboratory frost resistance of concretes;

(b) that the intensity of the effect was proportional to the percentage of such material present;

(c) that the magnitude of the effect of "Deleterious" material was 1-1/2 to 2 times that of "Objectionable" material;

(d) and that, due to presoaking and consequent (observed) degradation of some of the shale particles of the "Deleterious" material, the indicated magnitude of the effect of this contaminant may have been unrealistically small.

(6) That, regardless of the coarse aggregate used, the entrainment of 4% air was highly beneficial to the resistance of the concretes to laboratory freezing and thawing; but that the magnitude of the improvement associated with aeration was very materially decreased by increasing the soaking (and curing) period from 30 to 119 days.

(7) That, under the experimental procedures used, the 37 day flexural strength of unfrozen concrete was:

(a) satisfactory for all concretes;

(b) not significantly affected by the quantity of either "Deleterious" or "Objectionable" materials;

(c) decreased by aeration in a degree that was statistically but not practically significant.

SECTION 27 The ultimate problem posed by the presence of the "Deleterious" and "Objectionable" materials in Bethany Falls limestone, pertains to the writing of a specification for the maximum quantities of these contaminants to be allowed in the product of quarries working in the Bethany Falls formation. The purpose of such a specification being to insure satisfactory durability and strength of concrete in structures exposed to natural weathering, the optimum basis for the specifications would be factual, quantitative information on the effect of varying quantities of these contaminants on concretes exposed to actual service conditions. Unfortunately, as is almost invariably true in cases like this, the available information is not sufficiently comprehensive for the purpose. It then becomes necessary to consider the available information (largely qualitative in nature) and the opinions of the most experienced observers, in conjunction with the results of laboratory investigations such as the one described in this report. On points where there are gaps in information, conflicting opinions, or economic considerations involved, arbitrary decisions may have to be substituted for inductive inference in the final formulation of a specification governing the production of this type of material.

APPENDICES

1 - Descriptive details of the materials; concrete proportions; batching, mixing, and curing procedures; test methods; and test conditions.

2 - Description of the constituent materials composing the two classifications, "Deleterious" and "Objectionable".

The following Appendices are bound as a separate section; upon request copies will be furnished to anyone interested.

3 - General comments on the design of the experiment and the statistical analyses of the data.

4 - Statistical analysis of variance for the Bethany Falls concretes containing Aerated mortar and frozen after 30 days of soaking.

5 - Statistical analysis of variance for the Bethany Falls concretes containing Aerated mortar and frozen after 119 days of soaking.

6 - Multiple regression analysis of the Bethany Falls concretes containing Aerated mortar frozen after 30 days of soaking.

7 - Multiple regression analysis of the Bethany Falls concretes containing Aerated mortar frozen after 119 days soaking.

8 - Statistical analysis of all Bethany Falls concretes for both levels of aeration and both soaking periods, treated as a single comprehensive experiment.

APPENDIX NO. 1

DESCRIPTIVE DETAILS OF THE MATERIALS; CONCRETE PROPORTIONS; BATCHING, MIXING, AND CURING PROCEDURES; TEST METHODS; AND TEST CONDITIONS

SECTION 1 - Materials:

Cement - Normal Alpha

Air-Entraining Agent - Neutralized Vinsol resin solution.

Fine Aggregate - Missouri River sand (Jefferson City), used air-dry. The bulk specific gravity (dry basis) of this sand was 2.64, and the thirty minute absorption was 0.18%.

Coarse Aggregates - Three reference aggregates and nine Bethany Falls limestones, graded from the 1¼" sieve to the No. 4 sieve, were used. These aggregates and the specific gravity and absorption of each were:

Coarse Aggregate	Bulk Sp. Gr. (Dry Basis)	Per Cent Absorption
Blackwater Stone	2.61	1.2
Plattin	2.69	0.3
Meramec Gravel	2.45	1.9
Bethany Falls D_oO_o	2.62	1.2
" " D_oO_6	2.61	1.3
" " D_oO_{13}	2.61	1.3
" " D_5O_o	2.60	1.4
" " D_5O_6	2.60	1.5
" " D_5O_{13}	2.59	1.5
" " D_8O_o	2.59	1.6
" " D_8O_6	2.59	1.6
" " D_8O_{13}	2.585	1.7

The Bethany Falls coarse aggregates contained varying quantities of "Deleterious" and "Objectionable" materials.[1] In the preceding table the weight percentages of each are indicated by the subscripts to the letters D and O.

All the coarse aggregates were in a partially saturated condition when batched. This condition was attained by soaking the air-dry aggregate for two hours prior to batching. The per cent absorption shown for each aggregate represents the absorbed moisture content at time of batching.

SECTION 2 - Mix Design; Batching; and Mixing:

Mix Design - a. Cement factor 1.45 barrels cement per cubic yard, (no air). (Range in average cement factors was 1.438 to 1.455),

b. Volume coarse aggregate = 43% of volume of concrete.

c. Slump 2½" to 3½" desired; however, water-cement ratio was set by trial batches and was not changed when slumps deviated from desired range. (Range in average slumps was 1.9" to 3.9"),

d. Desired air content in Aerated concrete was 4.0%. (Range in average air content was 3.1 to 4.2%).

Batching Materials - All materials, except air-entraining agent, were batched by weight.

(1) See Appendix 2 for a description of these contaminants.

Mixing Concrete - Concrete was machine mixed in a Lancaster SW mixer for 30 seconds prior to adding the water and for two minutes thereafter.

SECTION 3 - Test Conditions:

This investigation consisted of testing twelve concrete mixtures, each containing Alpha cement and Missouri River sand but a different coarse aggregate. The test conditions were:

For Frost Resistance Tests

(A) Normal mortar - concrete soaked 30 days after 7 days moist curing.

(B) Aerated mortar - concrete soaked 30 days after 7 days moist curing.

(C) Normal mortar - concrete soaked 119 days after 7 days moist curing.

(D) Aerated mortar - concrete soaked 119 days after 7 days moist curing.

For Flexural Strength Tests

(A) Normal mortar - concrete soaked 30 days after 7 days moist curing.

(B) Aerated mortar - concrete soaked 30 days after 7 days moist curing.

For Outdoor Exposure Test[1]

(A) Normal mortar - concrete subjected to outdoor exposure after 7 days moist curing.

(B) Aerated mortar - concrete subjected to outdoor exposure after 7 days moist curing.

SECTION 4 - NUMBER OF BATCHES AND SPECIMENS, AND METHOD OF RANDOMIZATION WITH RESPECT TO POSSIBLE UNCONTROLLED VARIABLES:

For each coarse aggregate forty $3\frac{1}{2}$" x $4\frac{1}{2}$" x 16" beams were made. The relation between a specimen, the batch and mixing period from which it was obtained, the order of molding from a batch, and the test condition and test method to which it was subjected is shown in the following Table for all specimens containing Plattin limestone.

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(1) Two complete sets of beams (192) were subjected to this test. Originally one set of beams was to have been subjected to frost resistance test at age of one year, but the frost resistance test on this set of beams was postponed for an indefinite period.

Tabulation Showing how the 40 Beams Made with Plattin Stone Were Related to Batches, Mixing Periods, Test Conditions, and Test Methods. (Numbers in the Field Signify the Order of Molding the Five Beams from Each Batch.)

Test Condition and Test Method to which specimens were subjected	Normal Mortar				Aerated Mortar			
	Replicate Batch Identification							
	A	B	C	D	A	B	C	D
	Mixing Period							
	6	15	67	95	12	18	68	80
Soaked 30 days, Frozen in lab.	5	5	1	5	4	3	3	4
Soaked 119 days, Frozen in lab.	3	1	3	1	1	5	2	2
Cured 37 days, Tested in flexure	1	2	4	2	2	1	5	3
Placed in outdoor exposure pit	4	4	2	4	3	4	4	1
Placed in outdoor exposure pit	2	3	5	3	5	2	1	5

A similar procedure was used for the forty specimens of each coarse aggregate tested.

This tabulation shows that, for each type of mortar, four replicate batches (5 beams each) were mixed and one beam from each batch was assigned at random to each of the five combinations of test conditions and test methods. Such random assignment of the beams from a batch to the five combinations of test conditions and test methods provides the best possible insurance against any possible extraneous effect, associated with order of specimen fabrication, being systematically applied to the specimens subjected to a particular combination.

The entire experiment required ninety-six 5-beam batches and mixing periods. Available facilities permitted only twelve mixing periods per day; hence, eight mixing days spread over five weeks were necessary. Numerous uncontrolled variables are probably associated with day of mixing and even with period within a day. Among these are:

(a) Variation in quality of materials;

(b) Variation in atmospheric conditions;

(c) Variation in curing conditions in the moist room, etc.

To insure against any systematic application of these to the specimens for any particular segment of the experiment, the ninety-six batches were randomized with respect to the ninety-six mixing periods required.

SECTION 5 - Curing:

During the first seven days all beams received the following treatment:

(a) Two days in molds on shelves in moist room,

(b) Five days on shelves in moist room.

Curing after seven days was considered as a test condition (see Section 3).

SECTION 6 - Tests:

(A) Secondary

(1) On fresh concrete (each batch)

(a) Slump,

(b) Weight per cubic foot. (Used in calculating air content.)

(2) <u>On hardened concrete</u>

(a) Weight record of each beam, starting at 2 days. (Weight in water also determined at 2 days),

(b) Periodic determination of Dynamic Modulus of each beam starting at 7 days,

(c) Length measurements, 10" span on top and bottom of all beams except the 96 subjected to flexural strength test, starting at seven days.

(B) <u>Primary</u>

(1) <u>Frost Resistance (Laboratory)</u>

(a) Freezing in air to 0°F.,

(b) Thawing in water at 40°F.,

(c) Two cycles daily (except weekends, and holidays), consisting of a short daytime and a long nighttime cycle,

(d) Two hour thawing periods,

(e) End point of test, 60% loss in dynamic modulus.

(2) <u>Flexural Strength</u>

Determined on a 14" span with center loading.

(3) Outdoor Exposure

Beams placed in an outdoor test pit in special forms where only the upper surface of each beam is exposed. The test pit is so constructed that the sand base, on which the beams rest, can be and is kept in a saturated condition. A continuous record (every 10 min.) of the concrete temperature is kept.

APPENDIX 2

DESCRIPTION OF THE CONSTITUENT MATERIALS COMPOSING THE TWO CLASSIFICATIONS, "DELETERIOUS" AND "OBJECTIONABLE"

The contaminative materials in Bethany Falls limestone which have been designated as "Deleterious" or "Objectionable" are made up of several sub-classes as follows:

"Deleterious" Material

Shale
Soft Stone
Pure Shaly Stone
Cap Shale (+20%)

"Objectionable" Material

Cap Shale (-20%)
Shaly Seams
Skin Shale
Mud-Coated Stone(1)

The following description of the various types of "Deleterious" and "Objectionable" materials was furnished by the Testing Laboratory:

1. Shale

Lumps or particles of shale, substantially free of stone, stone fragments or particles. Breaks down readily on wetting or immersing in water. Generally of a laminated structure. Essentially pure shale. Black in color, when wet.

2. Shaly Stone

(Sometimes referred to as "Pure Shaly Stone" or "Heavily Contaminated Shaly Stone").

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(1) No material of this classification used in this investigation.

(A) Occurs as stone that is generally intermingled with or "shot through" with shale to a high degree. Has gray, reasonably uniform appearance, somewhat similar to some soft, absorptive stones. When particle is wet, slight rubbing removed sufficient shale from surface to cause surface water on particle to become muddy, or dirty.

(B) Also occurs in the form of shale lines, or seams, in large number and closely spaced throughout stone particle. Has a laminated or streaked appearance. (Distinguishable from "Shaly Seams", listed as No. 5, below, because of contamination to a higher degree as evidenced by greater number of shale lines or seams.)

(C) Also occurs as stone with shale coatings on two faces, somewhat similar to "Skin Shale", listed as No. 4 below, except that shale coatings are much thicker than in case of skin shale.

(D) Also may occur as combination of "B" and "C", described above.

3. Cap Shale

Occurs as a layer with a line of demarcation of the layer, or "Cap" of shale or shaly stone which generally occurs on one face of stone particle. Usually little or no other contamination on stone particle, except shale cap. Where cap exceeds 20 per cent of depth, or volume, of stone particle, it is classified

"Cap Shale (+20%)", and is considered deleterious material. In those cases where cap amounts to 20 per cent and under, the particle is classified as "Cap Shale (-20%)" and is considered objectionable material.

4. Skin Shale

Occurs as comparatively thin, continuous coating of shale, usually on two opposite faces of stone particle. Total coverage of shale coating equivalent to 50 per cent or more of surface area of particle.

5. Shaly Seams

Occurs as comparatively thin lines or seams of shale extending through particle. Number of lines depends somewhat on particle size. Lines are generally parallel, or approximately so.

6. Soft Stone

Usually classified and reported as "Soft and Porous Stone". Some types can be readily broken in two with fingers. In some cases, because of larger particle size or more rounded, or spherical shape, cannot be broken in two with fingers but small areas can be spalled, or chipped off with fingers. Or particle can be cut or broken in half, by mechanical means, after which edges of cut face can be spalled with fingers. Porosity, or high absorption, detected by rapid disappearance of surface water on particle, and by breaking or cutting particle in half and observing depth of penetration of moisture. Also includes some stone which may not be soft but is highly porous and absorptive. Soft stone in this formation usually tends toward brown or buff color.

7. Mud-Coated Stone

Stone particles which, on becoming wet, show a partial or complete coating of mud (soil, or clay, as differentiated from shale). Stone particle itself may be sound and uncontaminated, except for mud coating, or covering.

The compositions by weight of the "Deleterious" and "Objectionable" materials as used in this investigation, were:

"Deleterious" Material

Type Material	Per Cent
Pure Shale	15.8
Soft Stone	13.1
Pure Shaly Stone	37.5
Cap Shale (+ 20%)	33.6

"Objectionable" Material

Type Material	Per Cent
Cap Shale (- 20%)	30.1
Shaly Seams	11.8
Skin Shale	58.1

These compositions approximate the average of the compositions of a large number of samples from the routine production of several plants.