Final Report

STUDY OF SPECIFIC GRAVITY AS A CRITERION OF AGGREGATE QUALITY

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STUDY OF SPECIFIC GRAVITY AS A CRITERION OF AGGREGATE QUALITY

by

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SUMMARY

The purpose of this study was to determine the relationship between aggregate specific gravity and concrete durability in order to develop improved procedures for field testing and for possible application to heavy media plant process control.

The study was performed on coarse Michigan gravel and was conducted in two parts. The objectives of the first part were to determine a suitable specific gravity-based measurement for aggregate inspection, to compare the accuracy of predicting quality by the selected measurement versus that by the present Michigan Highway Department procedure (visual inspection), and if the gravity method were found to be more successful, to set up test procedures and specifications. The objective of the second part was to determine the deleteriousness of particles classified by appearance, specific gravity and size and to find a mathematical relationship between deleteriousness and the percentage of aggregate in a particular class.

In the first part, samples of float and sink product were collected from four Michigan heavy media plants. The plants were widely separated by location so that the samples would represent a good cross-section of Michigan gravels. Batches of aggregate were prepared by combining float and sink material at three different percentages. After determining the composition of the batches in terms of specific gravity, size and appearance types (soft, hard absorbent, chert and good), they were used to make up concrete beams. The beams were subjected to freeze-thaw testing (ASTM C-291) and durability factors were computed (at 30% degradation or 300 cycles). The durability factors were then correlated with the measured compositions (specific gravities, sizes and appearance types) and with various combinations of the compositions.

It was found that the specific gravity measurement most highly correlated with durability factor was the percentage less than a specific gravity of 2.50.

Although this correlation was relatively high (coefficient = 0.923), it was not as high as the correlation with total deleterious content (sum of soft, hard absorbent and chert) as presently measured by State inspectors who pick the samples (coefficient = 0.968). Since the picking method is subject to large sampling and inspection errors which would be relatively small in a specific gravity method, further calculations were made to determine if these errors would make specific gravity a better predictor of durability factor. However, the calculations showed that picking was still the most accurate method and it was concluded that the present method cannot be replaced by a simple specific gravity measurement.

In the second part, the aggregate used was from one plant. Beams were prepared by combining +2.55 gravity good aggregate with 5 or 10% aggregate of a single deleterious type and of a narrow specific gravity and size range. This permitted measurement of the deleteriousness of each specific gravity and size class of each deleterious type. Deleteriousness was measured by freeze-thaw testing, in the same manner as in the first part of the study.

The data obtained were used to derive an equation relating logarithm of durability factor with the size and percentage of a particular deleterious type and gravity. By means of the equation, coefficients of deleteriousness (a measure of reduction in log durability factor) were calculated.

It was found that deleteriousness when defined as the decrease in log DF per percent was directly proportional to size, e.g., 1-inch aggregate reduces log durability factor twice as much as 1/2-inch aggregate. A surprising result was that hard absorbent particles caused little or no reduction in durability factor. This was confirmed by the absence of hard absorbent pop-outs in the beams of the first part of the study and a very low frequency, relative to soft and chert, in the second part. Soft and chert particles of the same specific gravity were found to be about equally deleterious, suggesting that the mechanism of degradation may be the same for both types. The specific gravities of the soft and chert particles had a marked effect on deleteriousness. As the specific gravity was decreased the deleteriousness increased, reaching a maximum in the -2.45+2.35 gravity range; below -2.35 the deleteriousness decreased. The relative coefficients of deleteriousness for the four specific gravity ranges studied (-2.65+2.55, -2.55+2.45, -2.45+2.35 and -2.35) were 1, 5, 12 and 6, respectively.

These findings, while apparently not applicable for the development of a simple gravity-based method, should be of use in modifying existing procedures and specifications.

INTRODUCTION

Problem

At present, suitable objective criteria for the field inspection of concrete aggregate are not available. However, a great deal of experience has been gained by highway departments as to the appearance of particles which degrade concrete, and it is common practice for highway departments to employ inspectors who determine the percentages of these deleterious particles in lots of aggregate to be purchased for highway construction. In addition to field experience, a great deal of information has been gained through laboratory freeze-thaw tests. For example, Legg (1) showed that failure of concrete beams subjected to laboratory freezing and thawing tests was usually caused by particles which field experience in Michigan had indicated to be deleterious.

The Standard Specification for Road and Bridge Construction of the Michigan Department of State Highways (dated 1967) designates three types of deleterious aggregate: chert, hard absorbent and soft. The maximum weight percentages of soft and of total deleterious (sum of chert, hard absorbent and soft) are specified. For example, class 6A aggregate can contain a maximum of 2.5% soft and 9% total deleterious. To determine whether or not a lot of aggregate meets these specifications, a field inspector inspects a sample of about 10 pounds, split from a larger 50 to 100-pound sample. Inspection consists primarily of washing, drying, and screening, and of hand-picking the plus 3/8-inch portion to determine its deleterious content.

These procedures have been shown to be subject to large errors (3, 4, 5, 7). Visual identification of deleterious particles is a highly subjective process because individual judgement is required and because the various deleterious types are not always clearly identifiable. In addition, the relatively few deleterious particles in a 10-pound sample results in large sampling errors which can only be reduced by taking larger samples. However, larger samples would unduly prolong the inspection time or require the use of more inspectors. Thus, there is a real need for a better field method of testing aggregate quality.

In a recent study (6) of various non-subjective techniques for detecting deleterious particles, it was concluded that a specific gravity method using heavy liquids offered the best possibility for developing a useful and reliable field method for determining aggregate quality. The fact that deleterious particles are generally of a lower specific gravity than sound particles has also been shown by previous investigations (8, 9), and is the basis for the wide-spread use of the heavy media separation (HMS) process in gravel beneficiation. A specific gravity method for testing aggregate quality would have two important advantages over present methods: 1) it would be an objective method and relatively free of human error; 2) larger samples could be used so that sampling error could be minimized.

Obviously, in order for a specific gravity method to be useful it would have to be a more accurate predictor of aggregate quality than the visual inspection method. However, there are insufficient data in the literature to determine which method would be more accurate, and the basic objective of the present study was to provide quantitative data on the relationship between aggregate specific gravity and aggregate quality.

Since an increasing proportion of the aggregate used for concrete is the product of HMS plants, it is conceivable that process inspection may eventually be substituted for product inspection. If this substitution is to be accomplished it will require a better knowledge of the effect of specific gravity on aggregate quality. It also hinges upon improvement in monitoring and control of the HMS process (2).

It is recognized that certain types of deleterious particles, the most common of which are the clay ironstones, are of a range of specific gravities which includes both the good and deleterious types. Thus, in areas where these types are abundant neither gravity-based product inspection nor gravity-based HMS process inspection would insure a satisfactory product.

Objectives

The present study was divided into two parts. The objectives of the first part, entitled "Mixed Aggregate Tests", were to select a suitable gravity-based measurement for aggregate inspection, to compare the accuracy of predicting quality by the selected measurement versus that by the present Highway Department procedure, and, if the gravity method were to be more successful, to set up specifications and test procedures based on the method. The main consideration in selection of the gravity criterion other than accuracy in predicting quality was that it be the basis of a rapid and practical field inspection procedure. The objective of the second part of the study, entitled "Tests on Individual Aggregate Classes", was to determine the deleteriousness of particles classified by appearance, specific gravity and size and to find a mathematical relationship between deleteriousness and the percentage of each class. This information would supplement and extend the information obtained in the mixed aggregate tests.

Sponsor

The study was sponsored by the Michigan Department of State Highways in cooperation with the United States Department of Transportation, Federal Highway Administration, Bureau of Public Roads, as a part of the Highway Planning and Research Program. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Michigan Department of State Highways or the Bureau of Public Roads.

MIXED AGGREGATE TESTS

Scope

The primary objective was to select a suitable gravity-based criterion for prediction of aggregate quality in the field and to compare the prediction accuracy of the selected criterion with that of the present visual inspection method.

Samples of heavy media sink and float products were collected from nine Michigan HMS plants distributed by location so that the samples represented a cross-section of aggregate in Michigan. Since time did not allow testing of all nine samples, the four that were tested were chosen to cover the greatest possible geographic area. However, the southwestern portion of the state was purposely avoided because of the known occurrence of large quantities of clay ironstones.

Batches of coarse aggregate from each of the four plants were prepared by mixing heavy media sink product with 0, 10 and 30 percent float product. Relatively large percentages of float were used to insure a measurable response. Each batch was replicated three times and three concrete beams were made from each batch so that a total of 108 (4 x 3 x 3 x 3) beams were prepared. Before making the beams, particles in each batch were characterized by specific gravity, appearance, and size. The concrete beams were prepared and subjected to freeze-thaw tests according to ASTM C-291. The freeze-thaw durability factors were correlated with the characterization of the batches to determine the best specific gravity criterion which was then compared with the present picking method.

Experimental

Coarse Aggregate. The plants sampled, types of separation units used, and operating conditions are listed in Appendix IA. The four plant samples tested are identified in the appendix as 2, 5, 6, and 9. Approximately 1000 pounds of sink product and 300 pounds of float product were collected from each of the plants.

These plants were operating at the time of sampling, and gradation was in accordance with specifications for 6A aggregate at each plant. However, the samples were collected during start-up and consequently most samples did not satisfy the deleterious content requirements for 6A aggregate. This, however, facilitated accomplishment of the study objective in that a larger range of specific gravities was provided for correlation with freeze-thaw measurements.

The samples were screened to remove all plus 1-inch and minus 4-mesh particles to conform with the gradations suggested in ASTM C-192-62T. Nine batches of gravel were made up for each plant, each batch weighing about 30 pounds. Three of the nine batches were composed of sink gravel only, three contained 10% float and 90% sink, and three contained 30% float and 70% sink.

Each of the 36 batches was sized on square-opening sieves into -1"+3/4", -3/4"+1/2", -1/2"+3/8", and -3/8"+4 mesh fractions The size fractions were soaked in water and both 24-hour and 7-day absorptions were determined (ASTM C-127-68). The saturated surface-dry samples were separated into seven gravity classes using solutions of tetrabromoethane and acetone at gravities of 2.85, 2.65, 2.55, 2.50, 2.45, and 2.35. The gravity classes were further subdivided by visual inspection into four appearance types, yielding a total of 112 sub-divisions for each batch. These were converted to percentages of the batch weight, which are recorded in Appendices IB-IE.

Picking errors were minimized as follows: 1) by making one highly-trained technician responsible for all picks, 2) by allowing ample time for repicking each sample, and 3) by rejecting pieces that were not clearly identifiable.

Fine Aggregate. Six drums of sand meeting State Highway Department specifications for 2NS aggregate were obtained from the Superior Sand and Gravel Company in Hancock, Michigan. After mixing, the entire amount was split by coning and quartering into portions of approximately 100 pounds; these were placed in plastic bags which were sealed in drums. Results of tests made on the sand are tabulated below:

Test	Value	ASTM designation
Percent loss by washing	1.86	C117-62T
Fineness Modulus	2.77	C33-64
Bulk Specific Gravity (SSD)	2.68	C128-59
Percent 24-hour Absorption	1.10	C128-59

The moisture content of each bag was determined before use.

Cement. Equal portions of three brands of type 1A cement (Medusa, Penn Dixie, and Huron) were mixed by placing in a drum which was alternately rolled and turned end over end. The mixed cement was stored in a closed steel container until used. A specific gravity of 3.15 and zero percent moisture were assumed in all calculations.

Mixing of Concrete. Procedures described in ASTM C-192-68 and ASTM C-233-66T were used for mixing the concrete, with compliance to most of the suggestions made in the ASTM Manual for Concrete Testing. Mixing was accomplished in a 3-1/2 cubic foot mixer. Small quantities of an air-entraining admixture were added to obtain the desired air content. Details of the mixing procedure and a description of measurements made on the wet concrete are given in Appendix II.

Testing of Beams. The 3 x 4 x 16 inch beams were subjected to freezing in air and thawing in water in accordance with ASTM C-291-61T. The time for a complete freeze-thaw cycle was three hours. Prior to placing in the freezer and at various intervals, transverse resonant frequencies were determined on the thawed beams in accordance with ASTM C-215-60. The decrease in resonant frequency and number of cycles were used to compute durability factor in accordance with ASTM C-291. Values used in the computations of durability factor were either the number of cycles of freezing and thawing during which dynamic Young's modulus dropped 30% or the percentage drop at 300 cycles, depending upon whether or not there was a 30% reduction during 300 cycles.

Analysis and Discussion

Appendices IB-IE list the percentages of aggregate in the 112 categories for each of the 36 batches. Other data for the batches and durability factors for the concrete beams are listed in Appendix IF. The logarithm of each durability factor was computed and averaged for the three beams made from a single batch; from this average the "average durability factor" was computed. These values of durability factor (DF) and of the logarithm of the durability factor (log DF) were used to represent the batch in subsequent statistical analyses. The percentages of aggregate in various categories of interest (for instance the cumulative percentage of a batch below a specific gravity of 2.50), were obtained for each batch by adding the individual percentages making up the category, (appendices IG and IH). The reason for presenting total percentages in the various categories was to facilitate quantitative assessment of the influence of appearance, gravity, and size upon durability factor.

The results of simple linear regression analyses of logarithm of durability factor versus percentage of a category for various categories in each of the 36 batches are listed in Table 1. Correlation between log DF and percentage was found to be generally higher than correlation between DF and percentage, between DF and log percentage, or between log DF and log percentage. All but one of the correlation coefficients listed in Table 1 indicate significant correlations at the 95% probability level and most are significant at the 99.9% level.

Table 1. Regression analysis of log DF vs. percentage of category in aggregate batch.

Category: Appearance	Category: Size	Sp. Gr.	Intercept	Slope	Std. error of slope	Correl. coeff.	Std. error of est.
All	-1 +No. 4	-2.65	3.5035	-0.0442	0.0075	-0.7095	0.4423
"	"	-2.55	2.0081	-0.0550	0.0042	-0.9129	0.2562
"	"	-2.50	1.7933	-0.0633	0.0045	-0.9228	0.2418
"	"	-2.45	1.6210	-0.0717	0.0064	-0.8880	0.2886
"	"	-2.35	1.4971	-0.1487	0.0173	-0.8272	0.3527
"	-1 +3/8	-2.65	3.0423	-0.0404	0.0085	-0.6324	0.4862
"	"	-2.55	1.9708	-0.0604	0.0049	-0.9043	0.2680
"	"	-2.50	1.7693	-0.0702	0.0052	-0.9185	0.2482
"	"	-2.45	1.6092	-0.0807	0.0072	-0.8876	0.2892
"	"	-2.35	1.4899	-0.1706	0.0198	-0.8276	0.3523
"	-1 +1/2	-2.55	1.8869	-0.0810	0.0079	-0.8691	0.3104
"	"	-2.50	1.7008	-0.0956	0.0084	-0.8895	0.2868
"	-1 +3/4	"	1.5559	-0.2310	0.0282	-0.8142	0.3645
"	-3/4 +1/2	"	1.7611	-0.1539	0.0119	-0.9119	0.2576
"	-1/2 +3/8	"	1.8476	-0.2319	0.0156	-0.9310	0.2290
"	-3/8 +1/4	"	1.6673	-0.4090	0.0586	-0.7677	0.4022
DEL	-1 +No. 4	All	2.3332	-0.0592	0.0026	-0.9679	0.1578
"	"	-2.65	2.2577	-0.0596	0.0027	-0.9675	0.1588
"	"	-2.55	1.9229	-0.0580	0.0034	-0.9458	0.2038
"	"	-2.50	1.7696	-0.0634	0.0043	-0.9305	0.2298
"	"	-2.45	1.6203	-0.0717	0.0064	-0.8880	0.2886
"	"	-2.35	1.4971	-0.1487	0.0173	-0.8272	0.3527
"	-1 +3/8	All	2.3061	-0.0666	0.0029	-0.9698	0.1531
"	"	-2.65	2.2386	-0.0673	0.0028	-0.9715	0.1489
"	"	-2.55	1.8995	-0.0648	0.0039	-0.9449	0.2055
"	"	-2.50	1.7471	-0.0706	0.0049	-0.9274	0.2348
"	"	-2.45	1.6085	-0.0807	0.0072	-0.8875	0.2892
"	"	-2.35	1.4899	-0.1706	0.0198	-0.8276	0.3523
"	-1 +3/4	-2.50	1.5433	-0.2340	0.0278	-0.8216	0.3578
"	-3/4 +1/2	"	1.7399	-0.1554	0.0110	-0.9245	0.2393
"	-1/2 +3/8	-2.50	1.8291	-0.2342	0.0144	-0.9417	0.2112
"	-3/8 +No. 4	"	1.6557	-0.4090	0.0570	-0.7762	0.3957
CHERT	-1 +No. 4	All	2.0332	-0.0832	0.0076	-0.8830	0.2946
"	"	-2.55	1.8803	-0.0964	0.0064	-0.9327	0.2263
"	"	-2.50	1.7646	-0.1123	0.0066	-0.9458	0.2038
"	"	-2.45	1.6895	-0.1448	0.0084	-0.9476	0.2006
"	-1 +3/8	All	2.0382	-0.0952	0.0081	-0.8957	0.2791
"	"	-2.55	1.8593	-0.1083	0.0070	-0.9357	0.2214
"	"	-2.50	1.7313	-0.1239	0.0078	-0.9382	0.2172
"	"	-2.45	1.6606	-0.1603	0.0102	-0.9377	0.2181
HA	-1 +No. 4	All	1.8620	-0.1897	0.0316	-0.7172	0.4374
"	"	-2.55	1.6175	-0.1851	0.0301	-0.7260	0.4316
"	"	-2.50	1.5400	-0.2087	0.0339	-0.7263	0.4315
"	"	-2.45	1.4085	-0.2287	0.0430	-0.6742	0.4636
"	-1 +3/8	All	1.7899	-0.1922	0.0338	-0.6982	0.4493
"	"	-2.55	1.5911	-0.1938	0.0323	-0.7167	0.4377
"	"	-2.50	1.5214	-0.2201	0.0363	-0.7207	0.4351
"	"	-2.45	1.4026	-0.2440	0.0457	-0.6750	0.4631
SOFT	-1 +No. 4	All	2.2000	-0.2045	0.0194	-0.8747	0.3042
"	"	-2.55	1.7129	-0.1950	0.0223	-0.8317	0.3485
"	"	-2.50	1.6099	-0.2109	0.0256	-0.8158	0.3630
"	"	-2.45	1.4596	-0.2060	0.0301	-0.7608	0.4073
"	-1 +3/8	All	2.1575	-0.2365	0.0235	-0.8651	0.3148
"	"	-2.55	1.6932	-0.2242	0.0263	-0.8249	0.3548
"	"	-2.50	1.5957	-0.2427	0.0301	-0.8106	0.3676
"	"	-2.45	1.4522	-0.2386	0.0352	-0.7583	0.4092
% air entrained			0.11502	0.20513	0.298	0.117	0.636
% abs (7 day)			2.47827	-0.75610	0.086	-0.832	0.355
Bulk sp. gr.			-10.92418	4.52837	1.643	0.427	0.579

A low correlation coefficient for the percent air entrained ($r = 0.117$) indicates that the variation in air contents (approximately 4-5.5) had little effect upon the durability factors obtained.

Specific Gravity Criterion. It might seem at first, that when considering a method of inspecting the product of an HMS process all that would be necessary would be to ascertain that none of the product was below a particular gravity, say 2.55. However, when consideration is given to the limitations of such a process it becomes obvious that producing such a product would not be practical. In a practical HMS process not only does a large quantity of material below the gravity of separation end up in the product, but also a large quantity of material above the gravity of separation ends up in the reject. Consequently, a more practical criterion would be the percentage of the product below a particular gravity. Referring back to Table 1, the best correlation between log DF and the total percentage less than a particular gravity was for the gravity 2.50. Therefore, the percentage less than 2.50 was selected as the best criterion for a specific gravity based test.

Of the measurements made in this study, the one which most clearly approximates that presently used in the field by the Highway Department to predict quality is the percentage deleterious in the -1"+3/8" size category. This will be referred to as picking. (The specification allows actual samples of 6A aggregate to contain up to 5% plus 1-inch pieces). The accuracy of predicting durability by picking was compared with the accuracy of predicting durability by measuring the total percentage less than a specific gravity of 2.50, which will be referred to as gravity.

Errors in Present Method. The sources of variation in the present Highway Department sampling and inspection procedure have been separated and measured (8). The coefficient of variation of total deleterious content (standard deviation over mean expressed as a percentage) for a single inspector repicking the same sample was found to be 7%, whereas that for different inspectors picking the same sample was found to be 10%. Adding the variances brings the overall coefficient of variation due to inspection error to 12.2%. The standard deviation of total deleterious content due to sampling error was found to be related to the deleterious content of the population and to the sample weight by the equation:

$$S = K\sqrt{\frac{\%\text{ deleterious content } \times (100-\%\text{ deleterious content})}{\text{weight of sample}}} \qquad (1)$$

where S is the standard deviation and K is .144 when the sample weight is expressed in pounds.

The sampling standard deviation in a gravity measurement may also be computed by the above equation, but with "percentage less than a specific gravity of 2.50" substituted for "% deleterious content".

Comparison of Methods. In Table 1 the correlation coefficients are seen to be 0.923 for gravity and 0.968 for picking. Scatter diagrams along with least square regression lines for these correlations are shown in Figures 1 and 2. From the correlation coefficients and scatter diagrams picking is obviously better correlated with log DF. Put simply, this comparison indicates that there is a higher probability of more accurately predicting log DF from picking than from gravity data. It is important to note that this conclusion holds throughout the entire range of percentages and that the major deviations in the log DF versus gravity graph occur at low percentages, the region of interest in aggregate inspection. Thus, at this stage in the analysis it would appear that a general specification for percentage deleterious (as is presently in use) is better than one based upon specific gravity. If there were no sampling and picking errors

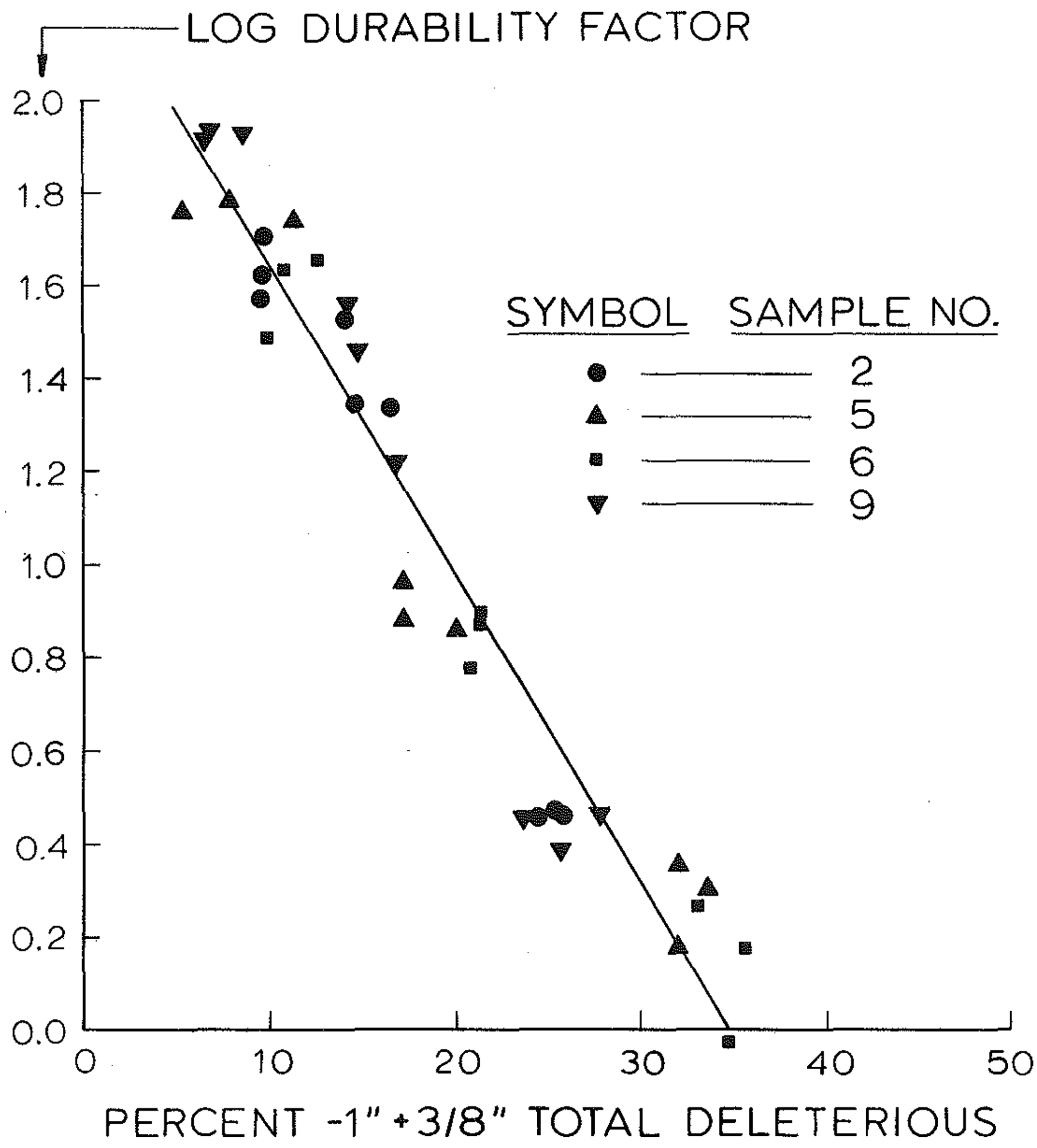

Fig. 1. Log DF vs. percentage of minus 1 plus 3/8 inch total deleterious.

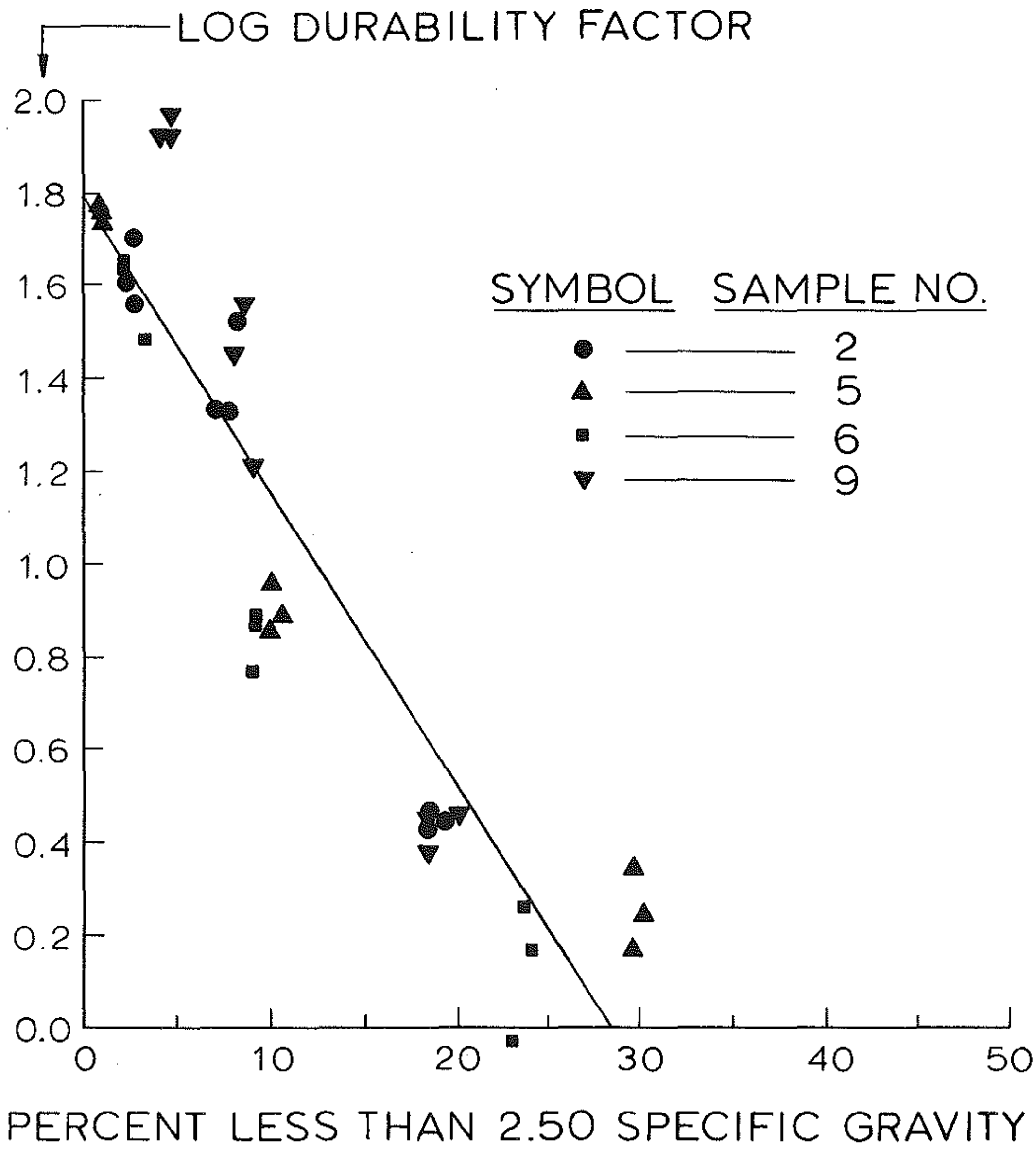

Fig. 2. Log DF vs. percentage of aggregate less than 2.50 specific gravity.

these values alone would be sufficient justification for retaining the present inspection procedure.

However, both procedures are subject to sampling error, and sampling error in the gravity method would be smaller if larger samples could be tested in the allotted time. As mentioned previously, inspection error would be virtually eliminated by the gravity based method. Therefore, to compare gravity with picking it is necessary to lump sampling and inspection errors with the prediction errors assessed in this study and determine which inspection method best predicts durability factor.

An estimation of the overall variance in log DF predicted by a measurement such as picking or gravity may be computed using the following equation:

$$S^2(\log DF) = b^2S^2(X)+S^2(\log DF')(1 + 1/N + (X-\bar{X})^2/\sum(X-\bar{X})^2)$$

where $S^2(\ )$ is the variance of the enclosed variable

DF is the durability factor

b is the slope of the regression line

X is the independent variable (either picking or gravity)

S(log DF') is the standard error of estimate of log DF

and N is the number of samples in the regression analysis (36 in this study)

The right-hand side of this equation consists of two parts: the first represents the variance of log DF due to variations in sampling and inspection; the second represents variance in log DF due to imperfect correlation between log DF and the measured value of X. The values determined for $S^2(\log DF')$ may be slightly high since they include a component due to the variation of X; however, the variation of X was probably quite small for reasons mentioned earlier.

The coefficients of variation (average of positive and negative standard deviation expressed as a percentage of the mean) of the durability factors were obtained from the variance of log DF calculated by the above equation. These are listed in Table 2 and are graphed in Figure 3 at various deleterious contents, for picking, using a 10-pound sample and for gravity, using 10 and 50-pound samples.

Table 2. Coefficients of variation (CV) of predicted durability factor for picking 10-lb samples and for gravity separations of 10 and of 50-lb samples

Picking		Gravity		
			CV	
% deleterious	CV	% less than a sp gr of 2.50	10-lb sample	50-lb sample
5	43.2			
10	49.6	2.42	62.7	60.9
15	57.5	7.68	64.1	60.6
20	66.7	12.93	66.7	61.0

The calculations indicate that: 1) when an inspection is made on a 10-lb sample by both gravity and picking, the overall errors in predicting log DF are, for practical deleterious contents, much larger in the gravity procedure; 2) even when performing the gravity test on larger 50-lb samples which reduce considerably the sampling errors, the overall errors in picking a smaller 10-lb sample are still less for deleterious contents below about 17% (the practical range). Thus, it is concluded that the present picking method is a more suitable means of determining quality than is the gravity method.

Reliability of Picking Method. To show that the picking method, although better than the gravity method, is far from perfect, confidence limits for prediction of log DF by picking are shown in Figure 4; those for prediction of DF by picking are shown in Figure 5. These confidence limits include not only

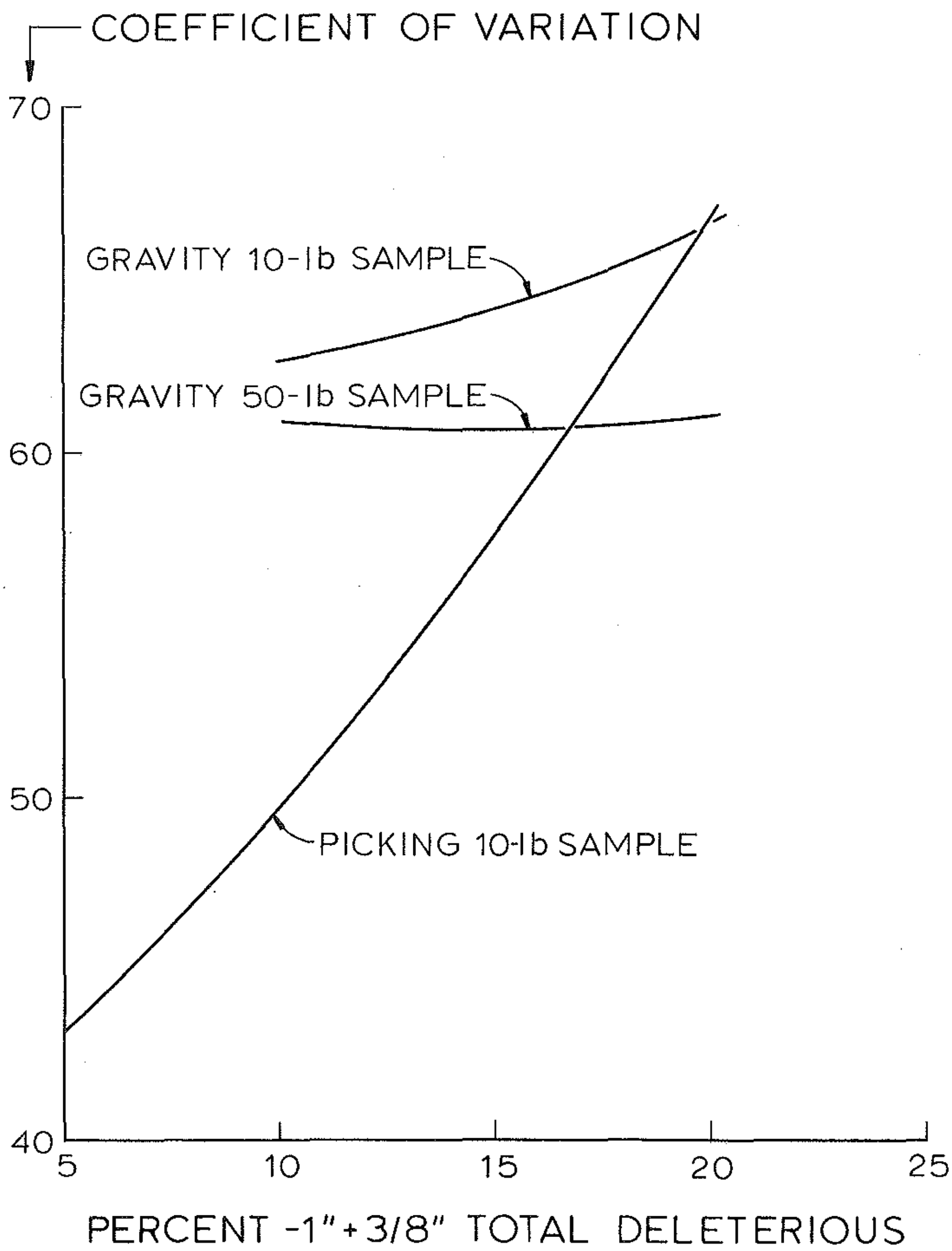

Fig. 3. Coefficient of variation of predicted durability factor vs. percentage minus 1 plus 3/8 inch total deleterious for three different test methods.

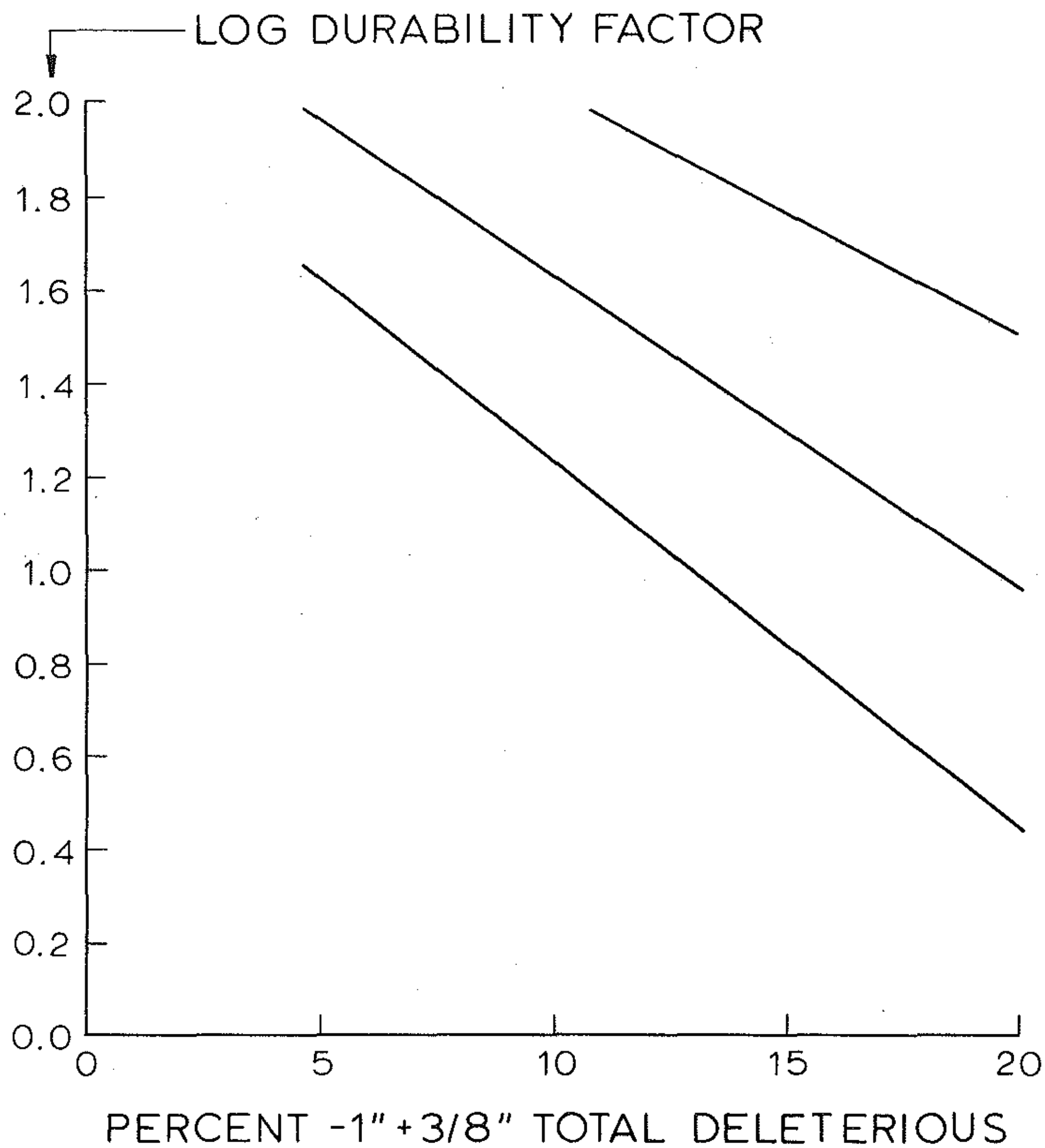

Fig. 4. Log DF vs. percentage of minus 1 plus 3/8 inch total deleterious with 95% confidence limits.

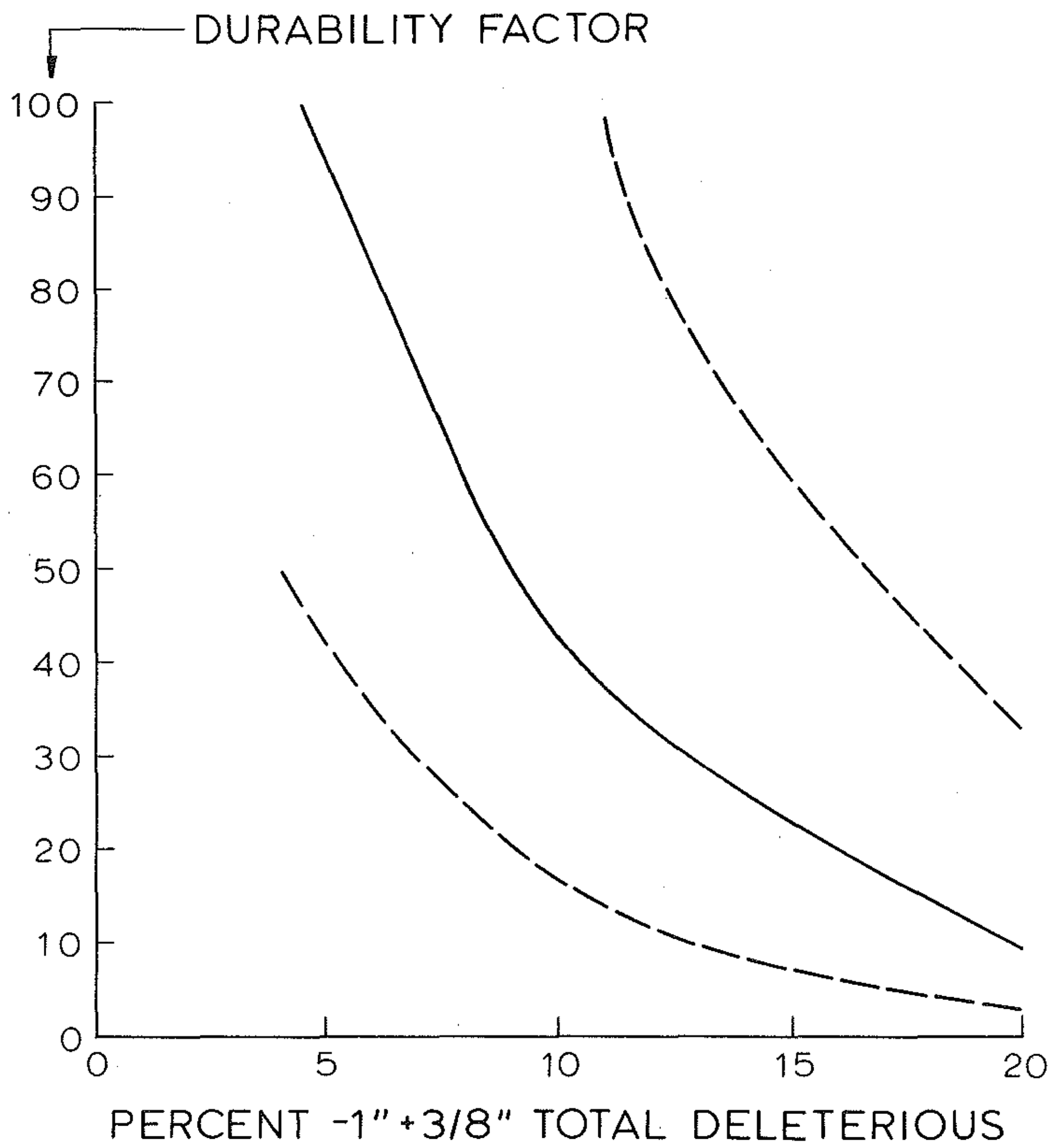

Fig. 5. Durability factor vs. percentage of minus 1 plus 3/8 inch deleterious aggregate with 95% confidence limits.

variations due to imperfect correlation found in this study, but also those due to sampling and picking errors, and assume a normal distribution of errors about the regression line. Figure 4 shows that for a 10% deleterious content, measured by the present Highway Department method, there is a 97.5% probability that log DF is above 1.23 and for a 5% deleterious content there is a 97.5% probability that log DF is above 1.68. Figure 5 indicates that for a 10% deleterious content, there is a 97.5% probability that DF is above 18, and for a 5% deleterious content, there is a 97.5% probability that DF is above 42.

TESTS ON INDIVIDUAL AGGREGATE CLASSES

Scope

The objective of this part of the study was to determine the deleteriousness of individual specific gravity classes of a given size and deleterious type. This information is necessary for relating durability factor to the specific gravity and size of a particular deleterious type. Size has been shown to be a significant variable by Verbeck and Landgren (10) who found that the hydraulic pressure developed during freeze-thaw testing increases with particle size. Bloem's results (11) indicate that durability factor is reduced twice as much with -1"+1/2" chert as with -1/2"+4 mesh chert. However, neither the effect of size nor the effect of specific gravity have been studied in sufficient detail to quantify the relationship between durability factor and the percentage of a particular deleterious type of given size and specific gravity.

The desired information could not be derived from the data of the previous section because the manner in which the aggregate batches were prepared (mixing various proportions of float and sink material) resulted in confounding of gravity, size and type effects, i.e., the variables were not varied independently. Therefore, in order to obtain the required data it was necessary to perform additional freeze-thaw tests using beams containing a known percentage of a single class of deleterious material. By a single class is meant a single deleterious appearance type (soft, hard absorbent or chert) of narrow size and specific gravity range.

The aggregate used for this part of the study was obtained from the HMS plant of the Construction Aggregate Corp. at Ferrysberg, Michigan. Three size levels, -1"+3/4", -3/4"+1/2" and -1/2"+1/4", and four specific gravity levels, -2.65+2.55, -2.55+2.45, -2.45+2.35, and -2.35, were investigated. Since time did not permit testing all levels of each of the three deleterious types, soft and hard absorbent were combined in equal proportions and tested together. Chert was tested alone. In addition, a number of tests were made on selected classes of soft, hard absorbent and good. The amount of the deleterious class in a beam was set at 5 or 10%, the balance of the coarse aggregate being good of +2.55 specific gravity. Three replicate beams were made for each percentage of each class, a total of 168 altogether. In contrast to the previous section, each beam was prepared separately rather than in batches of three; this insured that the composition of each beam was exactly known and helped to minimize experimental error. Table 3 shows the composition of each set of replicates.

Experimental

Only the high points of the procedures are presented here. A more detailed description is given in Appendix III.

Coarse Aggregate. A single experienced picker was made responsible for classification of the aggregate into the four appearance types. Good aggregate, which constituted the major portion of each of the batches, was further upgraded by heavy liquid separation in a 2.55 specific gravity solution of tetrabromoethane and acetone; the float portion was discarded. The size distribution of the good aggregate used in all tests is tabulated below:

Size, Inches	% in Size
-1+3/4	22.2
-3/4+1/2	36.8
-1/2+3/8	27.1
-3/8+1/4	13.9
	100.0

Deleterious aggregate of the three appearance types was separated by screening into three sizes and then separated into four gravity ranges (Table 3) by the use of solutions of tetrabromoethane and acetone.

Table 3. Composition of beams for freeze-thaw tests - triplicate beams of each composition

	-1"+3/4"		-3/4"+1/2"		-1/2"+1/4"	
Sp. Gr.	Chert, %	HA & Soft, %*	Chert, %	HA & Soft, %*	Chert, %	HA & Soft, %*
-2.35	5	5	5	5	5	5
	10	10	10	10	10	10
2.35-2.45	5	5	5	5	5	5
	10	10	10	10	10	10
2.45-2.55	5	5	5	5	5	5
	10	10	10	10	10	10
2.55-2.65	5	5	5	5	5	5
	10	10	10	10	10	10

Sp. Gr.	HA, %	Soft, %
2.45-2.55	5	5
	10	10

	-1"+3/4"	-1/2"+1/4"
Sp. Gr.	Good,%	Good, %
2.55-2.65	100	100
2.65-2.75	100	100

Total beams - 168

* Equal portions of soft and hard absorbent

The batches of coarse aggregate for the concrete beams were prepared in a somewhat complicated fashion since in the standard proportioning procedure (ACI 613-54) the unit weight must be known before deciding how much aggregate to use. It was necessary to calibrate a smaller than normal unit weight bucket, to measure the unit weight of a mixture containing the required proportions of good and of deleterious aggregate of the desired class, and from the measured value to compute the exact weight of coarse aggregate of the two types required for a beam.

Fine Aggregate. This material was from the same batch as previously described under Mixed Aggregate Tests, page 9.

Cement. The cement used was the same as in the Mixed Aggregate Tests, page 9.

Mixing of Concrete. A Montgomery Wards 1-1/2 cubic foot mixer (5-gallon pail type) was used in the preparation of all beams. A three-minute mixing period was followed by a three-minute rest, followed by two minutes of final mixing. Procedures described in ASTM C-192 and ASTM C-233 were adhered to as much as possible. Further details are given in Appendix IV.

Testing of Beams. The procedure used was the same as described under Mixed Aggregate Tests, page 9. The replicate beams of each class were tested at different times to randomize the effects of possible equipment and personnel changes.

Analysis and Discussion

Complete data on the composition of the beams tested in this section are given in Appendix III along with the durability factors of the beams. The durability factors and their logarithms are summarized in Table 4.

Table 4. Durability factors and logarithms of durability factors for freeze-thaw tests on individual aggregate classes.

Specific gravity	-1+3/4		-3/4+1/2		-1/2+1/4		-1+3/4		-3/4+1/2		-1/2+1/4	
	5% Chert						10% Chert					
-2.35	3.7	.568	71.5	1.854	70.8	1.850	81.0	1.908	27.0	1.431	38.5	1.585
	36.8	1.566	45.6	1.659	61.6	1.789	6.7	.826	20.2	1.305	20.0	1.301
	95.9	1.981	9.3	.968	67.4	1.828	13.0	1.114	16.1	1.207	14.9	1.173
	23.6	1.372	31.2	1.494	66.4	1.822	19.2	1.283	20.6	1.314	22.5	1.353
-2.45+2.35	18.4	1.265	33.1	1.520	70.7	1.849	7.5	.875	12.8	1.107	15.2	1.182
	8.9	.949	61.8	1.791	83.9	1.923	1.9	.279	14.1	1.149	26.2	1.418
	16.5	1.217	37.9	1.578	74.8	1.874	12.9	1.110	3.7	.568	43.8	1.641
	13.9	1.144	42.6	1.630	76.2	1.882	5.7	0.755	8.7	.941	25.9	1.414
-2.55+2.45	80.6	1.906	83.2	1.920	85.4	1.931	11.2	1.049	48.5	1.685	73.1	1.864
	84.9	1.929	86.8	1.938	79.9	1.902	16.4	1.215	55.7	1.746	78.4	1.894
	78.3	1.893	82.3	1.915	88.6	1.947	42.1	1.624	74.6	1.872	73.9	1.868
	81.1	1.909	83.9	1.924	84.5	1.927	19.8	1.296	58.6	1.768	75.0	1.875
-2.65+2.55	91.0	1.959	86.5	1.937	87.4	1.941	83.7	1.922	87.9	1.944	92.6	1.966
	88.8	1.948	89.9	1.953	93.3	1.970	42.8	1.631	78.8	1.896	92.4	1.965
	89.4	1.951	89.6	1.952	93.3	1.970	83.9	1.923	90.8	1.958	89.3	1.950
	89.7	1.953	88.5	1.947	91.2	1.960	66.8	1.825	85.7	1.933	91.2	1.960
	5% HA & Soft*						10% HA & Soft*					
-2.35	84.8	1.928	93.2	1.969	89.1	1.950	18.1	1.257	88.2	1.945	67.9	1.832
	91.2	1.960	97.2	1.987	94.9	1.977	79.5	1.900	80.5	1.905	79.8	1.902
	93.0	1.968	95.2	1.978	86.2	1.935	98.0	1.991	86.9	1.939	83.3	1.920
	89.5	1.952	95.1	1.978	89.9	1.954	52.0	1.716	85.1	1.930	76.7	1.885
-2.45+2.35	90.2	1.955	48.0	1.681	85.4	1.931	65.4	1.815	52.0	1.716	82.2	1.915
	92.2	1.964	88.5	1.947	86.1	1.935	63.4	1.802	85.2	1.930	66.9	1.825
	8.6	.934	30.3	1.481	81.8	1.912	1.6	.204	82.7	1.917	86.0	1.934
	41.5	1.618	50.5	1.703	84.3	1.926	18.8	1.274	71.4	1.854	77.8	1.891
-2.55+2.45	91.9	1.963	92.3	1.965	93.3	1.970	84.9	1.929	5.3	.724	82.0	1.914
	3.8	.580	92.2	1.964	83.8	1.923	85.2	1.930	86.8	1.938	88.0	1.944
	65.7	1.817	85.5	1.932	88.5	1.947	89.9	1.953	94.2	1.974	90.2	1.955
	28.4	1.453	89.9	1.954	88.5	1.947	86.5	1.937	35.1	1.545	86.7	1.938
-2.65+2.55	85.2	1.930	87.8	1.943	81.9	1.913	90.4	1.956	85.3	1.931	88.3	1.946
	93.1	1.969	86.9	1.939	93.4	1.970	69.2	1.840	85.8	1.933	89.4	1.951
	91.4	1.961	87.7	1.943	92.3	1.965	78.8	1.896	80.7	1.907	88.1	1.945
	89.7	1.953	87.5	1.942	88.9	1.949	78.9	1.897	83.9	1.924	88.5	1.947
			5% HA						10% HA			
-2.55+2.45			89.8	1.953					85.2	1.930		
			96.1	1.982					95.1	1.978		
			97.8	1.990					90.9	1.958		
			94.4	1.975					90.2	1.955		
			5% Soft						10% Soft			
-2.55+2.45			87.9	1.944					87.9	1.944		
			82.5	1.916					60.0	1.778		
			89.8	1.953					19.4	1.288		
			86.7	1.938					46.8	1.670		
	100% Good											
-2.65+2.55	84.0	1.924			89.4	1.951						
	84.1	1.924			92.0	1.963						
	36.0	1.556			91.2	1.960						
	63.2	1.801			90.8	1.958						
-2.75+2.65	80.4	1.905			86.3	1.936						
	93.6	1.971			88.7	1.948						
	85.1	1.930			92.3	1.965						
	86.1	1.935			89.1	1.950						

* 1/2 HA and 1/2 soft

The experimental error in determining durability factor was fairly large as shown by the variations between replicate beams of a single class. The variations were generally highest in the replicates containing the coarsest aggregate and lowest when the aggregate was fine or the durability factor was either very high or very low. The effect of size on experimental error is not unexpected if one considers the number of pieces of deleterious aggregate in a beam. For example, a beam containing 5% of -1"+3/4" deleterious aggregate would contain about 15 deleterious particles. If only a fraction of these particles were truly deleterious, or if there were large variations in deleteriousness, then the inevitable sampling error associated with few particles would produce large variations in durability factor. The reduction in replicate variations at high and low durability factors can be explained by "crowding" of the permissible range of durability factors, i.e., durability factor cannot be greater than 100 nor less than zero.

The logarithm of durability factor, rather than durability factor itself, was used in the analysis of the data. This transformation was made because the first section of the study showed that log DF is linearly related to deleterious content and that the log function helps to equalize the variance. In keeping with the emphasis on log DF, the average durability factors in Table 4 were calculated by taking the antilogs of the average log durability factors.

In spite of the rather large experimental error, the data of Table 4 reveal a number of consistent and important trends when the average log DF's are examined:

Size. The presence of a size effect on log DF is fairly obvious, but can be demonstrated more rigorously by means of a chi-square test. As seen from the major tabulations of Table 4, three sizes were investigated for each of 16 combinations of specific gravity, deleterious type and percentage (four gravities, two types and two percentages). By ranking the highest, lowest and intermediate log DF's with the three size classes of each combination, the following 3 x 3 contingency table can be set up:

		Size		
		-1"+3/4"	-3/4"+1/2"	-1/2"+1/4"
	Highest	1	3	12
log DF	Inter.	2	10	4
	Lowest	13	3	0

The number in each category is the observed frequency; the expected frequency for the null hypothesis that size has no effect is 5.33. The computed value of chi-square was 36.5, a value which could occur by chance only about 2 out of 10 million times if there were no size effect. Thus, it is definitely established that size influences durability factor and, as seen from Table 4 or the contingency table, increasing the size decreases the durability factor.

Gravity. The effect of gravity, although not as consistent as size, is also evident from Table 4. Qualitatively, the results indicate that durability factor decreases with decreasing specific gravity, the lowest durability factors being in the -2.45+2.35 gravity class. Below 2.35 the durability factors increase somewhat, an unexpected result since it is generally assumed that durability decreases continuously with decreasing specific gravity.

Chi-square tests confirmed that specific gravity is a highly significant variable.

Percentage. That the percentage of deleterious material affects durability factor is immediately obvious and requires no further discussion.

Hard Absorbent. The results from the two sets of beams containing only hard absorbent at the 5% and 10% levels were unusual in that the durability factors were as high or higher than those obtained with beams containing only good aggregate. This apparent lack of deleteriousness was checked by examining the beams from both parts of the study and identifying the pop-outs. In the beams containing equal percentages of soft and hard absorbent there were 10 hard absorbent pop-outs as compared to 72 soft pop-outs. In the mixed aggregate beams from the first section of the study, there were no hard absorbent pop-outs and 33 soft pop-outs. Thus, it can be concluded that the hard absorbent particles in the gravels studied were relatively innocuous as far as freeze-thaw degradation is concerned. For purposes of the calculations presented below, hard absorbent particles were considered good.

Good. The results from the four sets of beams containing only good aggregate indicated that coarse good of low gravity may be somewhat deleterious. However, not enough beams were tested to make this observation conclusive.

Since the above qualitative analysis of the data showed the presence of highly significant trends, an attempt was made to find an equation for relating durability factor to the size and percentage of deleterious aggregate. The simplest equation which appeared to offer a reasonable fit to the data was:

$$\log DF = A_0 - A(g,t)PS^N \qquad (2)$$

where P is the percentage of deleterious aggregate, S is the size of the aggregate, and A_0, $A(g,t)$ and N are constants. A_0 is equal to log DF when P is zero, (it is the log DF of good aggregate), $A(g,t)$ can be termed the coefficient of deleteriousness* and, in general, will vary with the type and gravity of the deleterious aggregate, and N is an exponent to allow for non-linear size effects.

* For the sake of convenience, deleteriousness is defined to be the decrease in log DF per percentage, resulting from the substitution for good of another aggregate appearance type.

Values of A(g,t) and N were found by regression analysis, using an estimated value of A_0. Although the most obvious value for A_0 would have been the average of the four sets of beams containing good aggregate (1.911), a number of beams gave considerably higher durability factors. As a compromise the value of 1.965 was used. The regression analysis yielded the value of N and eight coefficients of deleteriousness (one A(g,t) for each chert gravity and one for each soft gravity).

Sp. gr. range	A(g,t) Chert	A(g,t) Soft
-2.35	.106	.036
-2.45+2.35	.153	.122
-2.55+2.45	.051	.054
-2.65+2.55	0.10	.014

N = 1.12

The value of 1.12 for N shows that coefficient of deleteriousness defined above is almost directly proportional to particle size. This is essentially what Bloem's data on chert indicate (11).

The values of A(g,t) for chert and soft in the above tabulation were plotted against specific gravity and are shown in Figure 6. It is clear from Figure 6 that chert and soft are very similar; their coefficients of deleteriousness are almost identical at the higher gravities and both have a maximum deleteriousness in the -2.45+2.35 range. The only large difference is in the -2.35 range and the fact that this range is open-ended may account for the difference.

Because of the closeness of N to 1 and the similarity of chert and soft, a second regression analysis was performed using N = 1 and solving for a single value of A(g) for both soft and chert at each gravity. The values obtained were:

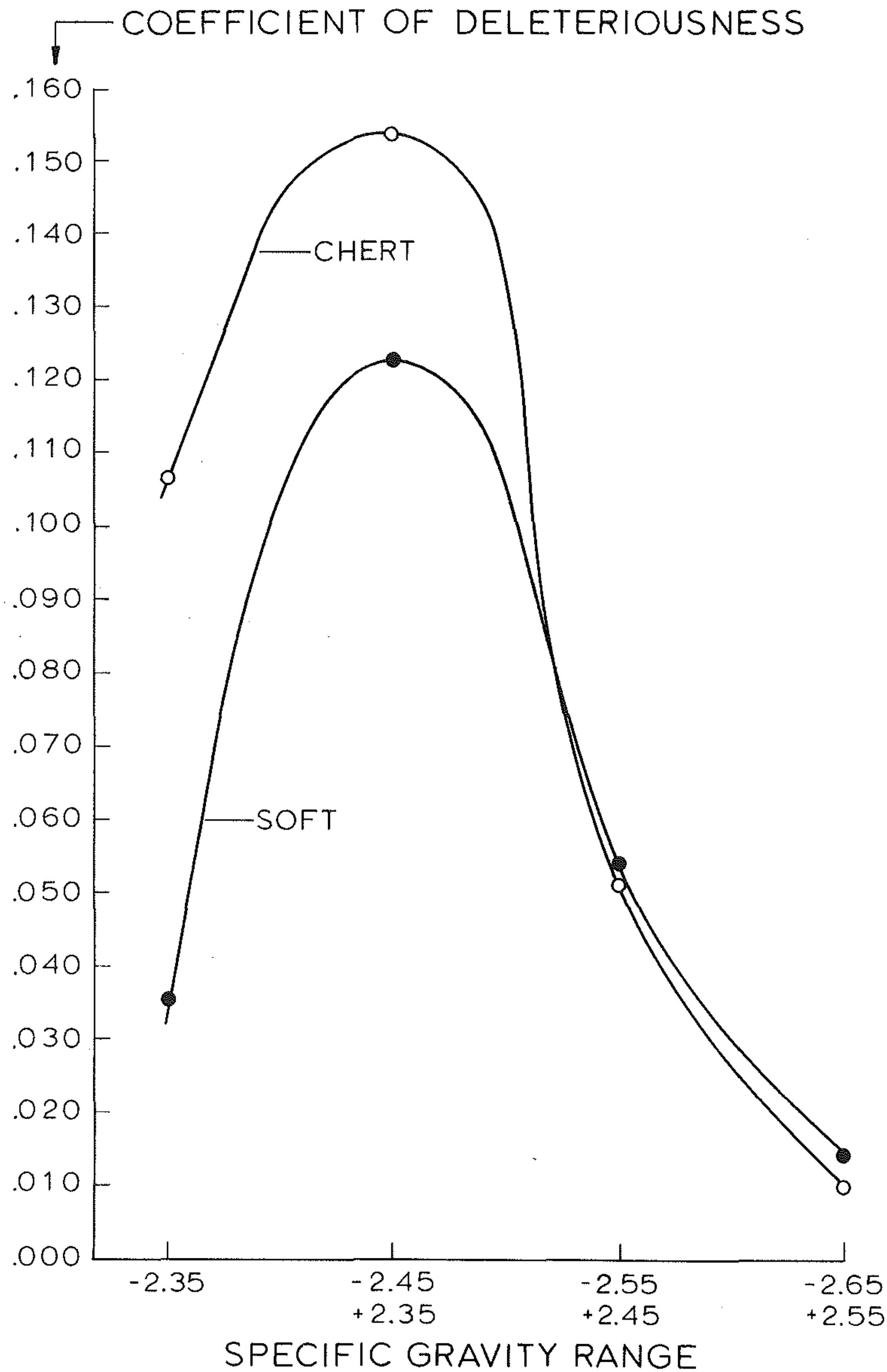

Fig. 6. Coefficient of deleteriousness vs. specific gravity of chert and of soft aggregate.

Sp. gr. range	A(g)
-2.35	.068
-2.45+2.35	.132
-2.55+2.45	.050
-2.65+2.55	.011

A comparison of the experimental log durability factors with the values predicted by the two regression equations is given in Table 5. Inspection of Table 5 shows that the predicted values of log DF agree well with the experimental values. In addition, there is little difference between the results of the two equations.

The mean squares given in the lower left corner of Table 5 confirm these observations in a more rigorous and concise manner. The total mean square represents the total variation in the experimental data. Each residual mean square represents the variation from the regression equation and is the sum of the variation due to lack of fit and experimental error. The error mean square was computed from the data on the individual beams; it is the average variance of the 50 experimental log DF's in the table. Application of the F-test to the ratio of total mean square to the residual mean squares confirms that both regression equations are highly significant. Moreover, the fit is as good as possible in terms of the available data since the error mean square is about the same as the residual mean squares. The slightly better fit of equation 1 has virtually no significance, and therefore equation 2 is preferable as it is the simpler of the two.

To summarize, the above analysis indicates that chert and soft of the same specific gravity are equally deleterious, that reduction in log DF is directly proportional to aggregate size, and that deleteriousness is highest in the -2.45 +2.35 specific gravity range, about one-half as high in the -2.35 and -2.55+2.45 ranges, and only about one-tenth as high in the -2.65+2.55 range.

Table 5. Comparison of experimental log DF with values predicted by regression equations.

Eq.1: $\log DF = 1.965 - A(g,t)PS^{1.12}$ Eq.2: $\log DF = 1.965 - A(g)PS$

Sp. gr.	A(g,t) Chert	A(g,t) Soft
-2.35	.106	.036
-2.45+2.35	.153	.122
-2.55+2.45	.051	.054
-2.65+2.55	.010	.014

Sp. gr.	A(g)
-2.35	.068
-2.45+2.35	.132
-2.55+2.45	.050
-2.65+2.55	.011

		Chert					
		P=5%			P=10%		
Specific gravity	S =	-1+3/4	-3/4+1/2	-1/2+1/4	-1+3/4	-3/4+1/2	-1/2+1/4
-2.35	Exp.	1.372	1.494	1.822	1.283	1.314	1.253
	Eq.1	1.508	1.651	1.788	1.051	1.337	1.610
	Eq.2	1.666	1.752	1.837	1.368	1.538	1.709
-2.45+2.35	Exp.	1.144	1.630	1.882	0.755	0.941	1.414
	Eq.1	1.307	1.513	1.709	0.648	1.060	1.454
	Eq.2	1.389	1.553	1.718	0.812	1.142	1.471
-2.55+2.45	Exp.	1.909	1.924	1.927	1.296	1.768	1.875
	Eq.1	1.746	1.814	1.880	1.527	1.664	1.795
	Eq.2	1.747	1.809	1.872	1.529	1.654	1.778
-2.65+2.55	Exp.	1.953	1.947	1.960	1.825	1.933	1.960
	Eq.1	1.921	1.935	1.948	1.878	1.905	1.931
	Eq.2	1.915	1.929	1.944	1.865	1.893	1.922

		Soft					
		P=2½%			P=5%		
	S =	-1+3/4	-3/4+1/2	-1/2+1/4	-1+3/4	-3/4+1/2	-1/2+1/4
-2.35	Exp.	1.952	1.978	1.954	1.716	1.930	1.885
	Eq.1	1.889	1.913	1.935	1.813	1.861	1.906
	Eq.2	1.816	1.858	1.901	1.666	1.752	1.837
-2.45+2.35	Exp.	1.618	1.703	1.926	1.274	1.854	1.891
	Eq.1	1.702	1.784	1.863	1.439	1.603	1.761
	Eq.2	1.677	1.759	1.842	1.389	1.553	1.718
-2.55+2.45	Exp.	1.453	1.954	1.947	1.937	1.545	1.938
	Eq.1	1.849	1.886	1.920	1.734	1.806	1.875
	Eq.2	1.856	1.887	1.918	1.747	1.809	1.872
-2.65+2.55	Exp.	1.953	1.942	1.949	1.897	1.924	1.947
	Eq.1	1.935	1.945	1.953	1.906	1.924	1.942
	Eq.2	1.940	1.947	1.954	1.915	1.929	1.944

Mean squares:
Total = .0908
Residual, Eq.1 = .0205
Residual, Eq.2 = .0249
Exp. error = .0286

		P=5% -3/4+1/2	P=10% -3/4+1/2
-2.55+2.45	Exp.	1.938	1.670
	Eq.1	1.806	1.647
	Eq.2	1.809	1.654

CONCLUSIONS

It is concluded that:

1. The total percentage of deleterious material as defined by the Michigan Department of State Highways is highly correlated with the logarithm of the ASTM C-291 durability factor.
2. Of the gravity criteria investigated, the one most highly correlated with the logarithm of the ASTM C-291 durability factor is the percentage of total aggregate less than a specific gravity of 2.50. However, it is not as well correlated as is percentage deleterious.
3. Even when the large sources of variation due to sampling and to human judgement in picking are taken into consideration, the total deleterious measurement is still a more accurate predictor of the logarithm of the ASTM C-291 durability factor than is the percentage less than specific gravity 2.50. Picking a 10-pound sample for percent deleterious provides a more accurate estimate of logarithm of durability factor than does a measurement of percent less than 2.50 gravity on a 50-pound sample. Changing from the present picking method to a gravity-based method would therefore not be warranted.
4. Hard absorbent is probably only slightly deleterious as measured by freeze-thaw degradation, and is much less deleterious than either chert or soft.
5. Particle size has a very significant effect on deleteriousness. For deleterious particles of the same specific gravity, reduction in log durability factor is directly proportional to particle diameter.
6. Soft and chert particles of the same size and specific gravity are about equally deleterious as measured by freeze-thaw degradation. Thus the mechanism of degradation for the two types is most likely quite similar.

7. Specific gravity is an important factor in the deleteriousness of soft and chert. Particles in the -2.45+2.35 gravity range are about twelve times as deleterious as those in the -2.65+2.55 range. The trend of increasing deleteriousness with decreasing gravity does not continue below 2.35, but begins to decrease somewhat at lower gravities.

Since the effect of specific gravity is complex, a whole series of gravity measurements would have to be made on the deleterious types in order to improve inspection. This would obviously be much too time-consuming to be of use in field testing.

RECOMMENDATIONS

Although the first part of this study showed that a single specific gravity measurement could not replace the present inspection method, the findings of the second part provide information that may be useful for modifying inspection procedures and specifications.

In the present inspection method, no allowance is made for the size of the deleterious aggregate. This could be easily incorporated into the inspection procedure by picking the size fractions from the sieve analysis separately; multiplying the percentages in each size fraction by a weighting factor for size and adding the results would then give an improved measure of aggregate quality. This modification would also fit in well with the stratified sampling scheme proposed by Hockings et. al. (7) for reducing sampling error.

The apparent lack of deleteriousness of hard absorbent and the close similarity of soft and chert suggest changes in the present limits on these materials. However, since these findings were obtained on aggregate from a single plant, confirmative tests are recommended on aggregate from other areas.

LIST OF REFERENCES

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Appendix IA

Plants sampled, types of separating units and operating conditions

Sample no.	Plant name and location	Operating yes	Operating no	HMS type	Product sampled	Sp gr aim Float	Sp gr aim Sink	Sp gr aim Sump	Sp gr actual Float	Sp gr actual Sink	Sp gr actual Sump	Media ratio, $FeSi/Fe_3O_4$
1	American Aggregate Corp., Oxford	X		Drum	5B* (Wayne County)	2.53	2.68		2.59	2.69		5/1
2	American Aggregate Corp., Brighton	X		Drum	6A (MDSH)	2.50	2.55		2.50	2.55		1.65/1
3	Nashville Gravel Co., Nashville	X		Drum	6A (MDSH)	2.58		2.64	2.58	2.68		10/1
4	Bundy Hill Gravel Co., Coldwater	X		Drum	No. 5 (Indiana)	2.68			2.66			7/5
5	Martin Block Co., St. Johns	X		Cone	6A (MDSH)	**		2.65	2.56	2.68	2.55	7/5
6	Construction Aggregate, Ferrysberg	X		Drum	6A (MDSH)	2.62 sink & float		2.68	2.62 sink & float		2.67	4/1
7	Hersey Sand & Gravel Plant, Hersey		X	Drum	6A (MDSH)	2.56	2.70	2.58				5.5/6
8	Gil-Brown Constructors, West Branch		X	Cone	6A (MDSH)	2.59	2.64					3/1
9	Straights Aggregate and Equipment, Millersberg	X		Sweep	6A (MDSH)			2.55	2.49		2.54	5.5/3

* Same as 6AA except for larger max. size.

** Attempt to keep 0.16-0.21 sp gr differential (sink to float side)

Appendix IB

Aggregate batch compositions-percentages
by appearance, size, and specific gravity

	GOOD				CHERT				HA				SOFT			
SPECIFIC GRAVITY	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4
Batch 2A1																
-2.35	0.0	0.0	0.0	0.0	0.0	0.04	0.06	0.01	0.0	0.05	0.05	0.0	0.0	0.0	0.0	0.01
2.35-2.45	0.0	0.06	0.05	0.0	0.11	0.15	0.14	0.10	0.0	0.07	0.02	0.01	0.0	0.03	0.06	0.05
2.45-2.50	0.0	0.41	0.08	0.04	0.0	0.33	0.52	0.18	0.0	0.06	0.11	0.05	0.0	0.04	0.02	0.03
2.50-2.55	0.0	0.32	0.28	0.17	0.20	0.84	0.86	0.41	0.10	0.09	0.24	0.06	0.0	0.25	0.18	0.08
2.55-2.65	3.40	10.74	9.78	4.27	0.16	1.60	1.10	0.25	0.0	0.24	0.21	0.05	0.10	0.38	0.24	0.22
2.65-2.85	6.78	21.20	18.24	6.54	0.0	0.0	0.0	0.0	0.0	0.16	0.14	0.06	0.0	0.23	0.25	0.08
+2.85	0.27	2.45	2.44	1.04	0.0	0.05	0.02	0.01	0.0	0.0	0.02	0.0	0.0	0.10	0.06	0.05
Batch 2A2																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.01	0.0	0.05	0.0	0.02	0.0	0.02	0.02	0.0
2.35-2.45	0.0	0.0	0.02	0.01	0.0	0.16	0.25	0.04	0.08	0.16	0.06	0.04	0.0	0.07	0.02	0.01
2.45-2.50	0.0	0.0	0.0	0.01	0.0	0.41	0.36	0.21	0.0	0.11	0.10	0.09	0.0	0.07	0.04	0.01
2.50-2.55	0.12	0.22	0.20	0.13	0.10	0.73	1.08	0.39	0.0	0.20	0.09	0.03	0.0	0.09	0.11	0.09
2.55-2.65	3.57	12.23	8.96	3.92	0.46	1.86	1.16	0.29	0.08	0.17	0.31	0.10	0.0	0.15	0.26	0.21
2.65-2.85	5.42	21.27	18.25	7.24	0.0	0.0	0.01	0.02	0.16	0.0	0.12	0.07	0.0	0.25	0.23	0.06
+2.85	0.35	2.88	2.64	0.89	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.12	0.03	0.06	0.05
Batch 2A3																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.02	0.0	0.0	0.02	0.0	0.0	0.03	0.06	0.03
2.35-2.45	0.0	0.0	0.0	0.01	0.0	0.21	0.27	0.12	0.15	0.11	0.07	0.05	0.0	0.12	0.02	0.01
2.45-2.50	0.0	0.03	0.12	0.04	0.0	0.43	0.48	0.26	0.0	0.14	0.05	0.04	0.0	0.03	0.07	0.04
2.50-2.55	0.10	0.21	0.34	0.15	0.23	0.86	0.82	0.30	0.0	0.08	0.07	0.04	0.14	0.08	0.07	0.04
2.55-2.65	2.79	11.60	9.56	4.51	0.10	1.53	1.81	0.57	0.21	0.03	0.26	0.07	0.16	0.20	0.43	0.19
2.65-2.85	5.18	20.17	18.06	8.04	0.0	0.08	0.04	0.0	0.0	0.07	0.11	0.10	0.0	0.18	0.20	0.13
+2.85	0.52	2.74	2.34	1.04	0.0	0.03	0.0	0.01	0.0	0.04	0.0	0.04	0.0	0.16	0.02	0.06
Batch 2B1																
-2.35	0.0	0.0	0.0	0.0	0.12	0.31	0.27	0.24	0.11	0.08	0.10	0.08	0.08	0.16	0.15	0.13
2.35-2.45	0.0	0.0	0.0	0.0	0.07	0.54	0.68	0.44	0.21	0.13	0.19	0.08	0.17	0.24	0.14	0.09
2.45-2.50	0.0	0.05	0.11	0.04	0.0	0.74	0.78	0.47	0.0	0.16	0.19	0.07	0.14	0.13	0.11	0.05
2.50-2.55	0.24	0.21	0.22	0.19	0.33	1.00	0.94	0.62	0.42	0.16	0.12	0.12	0.14	0.20	0.12	0.06
2.55-2.65	1.54	9.62	7.56	4.18	0.58	1.49	1.54	0.57	0.09	0.25	0.35	0.15	0.0	0.32	0.23	0.21
2.65-2.85	5.44	17.70	18.24	9.53	0.0	0.0	0.03	0.0	0.0	0.16	0.04	0.10	0.0	0.19	0.11	0.17
+2.85	0.80	2.66	2.08	1.04	0.0	0.0	0.01	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.03
Batch 2B2																
-2.35	0.0	0.0	0.0	0.0	0.0	0.15	0.16	0.21	0.06	0.15	0.10	0.05	0.12	0.25	0.17	0.13
2.35-2.45	0.0	0.0	0.0	0.0	0.10	0.69	0.75	0.40	0.36	0.16	0.22	0.15	0.16	0.38	0.12	0.09
2.45-2.50	0.0	0.14	0.15	0.05	0.09	0.88	0.74	0.41	0.13	0.08	0.19	0.07	0.0	0.18	0.10	0.08
2.50-2.55	0.0	0.27	0.17	0.14	0.10	0.83	0.93	0.64	0.17	0.11	0.10	0.04	0.0	0.17	0.18	0.03
2.55-2.65	2.61	9.43	8.71	4.19	0.46	1.52	1.55	0.99	0.09	0.15	0.19	0.20	0.13	0.28	0.24	0.21
2.65-2.85	4.95	17.74	17.12	9.64	0.0	0.05	0.02	0.04	0.0	0.0	0.14	0.08	0.0	0.16	0.19	0.06
+2.85	1.41	2.02	1.98	0.95	0.0	0.0	0.06	0.05	0.0	0.0	0.0	0.02	0.0	0.0	0.03	0.03
Batch 2B3																
-2.35	0.0	0.0	0.0	0.0	0.0	0.23	0.24	0.12	0.0	0.04	0.03	0.04	0.0	0.25	0.26	0.18
2.35-2.45	0.0	0.0	0.0	0.0	0.09	0.40	0.87	0.45	0.0	0.17	0.28	0.19	0.0	0.30	0.26	0.08
2.45-2.50	0.0	0.04	0.11	0.04	0.15	0.71	0.69	0.32	0.0	0.08	0.13	0.07	0.11	0.08	0.10	0.08
2.50-2.55	0.31	0.19	0.23	0.09	0.35	0.87	1.18	0.63	0.19	0.25	0.29	0.08	0.18	0.20	0.17	0.06
2.55-2.65	2.46	10.40	8.99	4.66	0.56	1.85	1.94	0.90	0.16	0.35	0.26	0.21	0.23	0.50	0.37	0.28
2.65-2.85	3.02	16.77	16.50	8.76	0.0	0.09	0.05	0.0	0.08	0.14	0.12	0.05	0.10	0.16	0.08	0.06
+2.85	0.66	2.28	2.84	1.28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.25	0.04
Batch 2C1																
-2.35	0.0	0.0	0.0	0.0	0.25	0.67	0.84	0.51	0.11	0.12	0.13	0.10	0.27	0.78	0.70	0.50
2.35-2.45	0.0	0.0	0.0	0.0	0.37	1.18	1.85	0.99	0.15	0.41	0.60	0.20	0.72	0.74	0.56	0.33
2.45-2.50	0.0	0.11	0.22	0.01	0.19	1.34	1.55	0.78	0.0	0.34	0.41	0.25	0.08	0.26	0.08	0.12
2.50-2.55	0.37	0.42	0.51	0.15	0.67	1.57	1.57	0.80	0.0	0.24	0.13	0.26	0.11	0.13	0.23	0.21
2.55-2.65	2.40	9.05	9.33	5.58	0.71	1.55	2.09	0.96	0.07	0.07	0.19	0.15	0.06	0.19	0.46	0.34
2.65-2.85	2.97	11.34	12.18	6.71	0.0	0.03	0.07	0.04	0.0	0.0	0.09	0.09	0.10	0.13	0.18	0.09
+2.85	0.69	2.37	2.20	1.21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.01	0.06
Batch 2C2																
-2.35	0.0	0.0	0.0	0.0	0.21	0.71	0.82	0.74	0.29	0.26	0.18	0.11	0.38	0.68	0.64	0.66
2.35-2.45	0.0	0.0	0.0	0.0	0.24	1.61	1.82	1.10	0.28	0.72	0.51	0.28	0.38	0.50	0.75	0.35
2.45-2.50	0.07	0.0	0.05	0.02	0.82	1.29	1.36	0.78	0.20	0.24	0.15	0.18	0.0	0.13	0.25	0.11
2.50-2.55	0.13	0.67	0.50	0.47	0.78	1.57	1.37	0.77	0.0	0.14	0.18	0.06	0.18	0.17	0.16	0.11
2.55-2.65	2.48	8.06	10.01	6.26	0.31	0.97	1.09	0.60	0.0	0.17	0.10	0.18	0.08	0.45	0.33	0.31
2.65-2.85	2.86	13.07	11.66	7.11	0.09	0.17	0.07	0.03	0.0	0.05	0.11	0.03	0.0	0.23	0.11	0.13
+2.85	0.57	2.26	1.79	0.93	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.09	0.03
Batch 2C3																
-2.35	0.0	0.0	0.0	0.0	0.20	0.75	1.05	0.76	0.20	0.38	0.27	0.11	0.67	1.11	0.95	0.67
2.35-2.45	0.0	0.0	0.0	0.0	0.07	1.39	1.90	1.17	0.0	0.76	0.32	0.19	0.11	0.52	0.49	0.22
2.45-2.50	0.0	0.05	0.11	0.0	0.34	0.99	1.05	0.67	0.22	0.09	0.26	0.14	0.14	0.18	0.06	0.08
2.50-2.55	0.0	0.21	0.23	0.07	0.57	1.35	1.88	0.84	0.22	0.22	0.35	0.14	0.21	0.12	0.09	0.15
2.55-2.65	2.37	8.81	8.85	5.82	0.62	1.83	1.97	0.75	0.07	0.07	0.21	0.09	0.33	0.35	0.28	0.32
2.65-2.85	2.91	12.70	12.89	6.29	0.0	0.08	0.03	0.01	0.0	0.0	0.08	0.03	0.09	0.20	0.10	0.06
+2.85	0.98	2.37	2.02	0.93	0.0	0.09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.04

Appendix IC

Aggregate batch compositions-percentages
by appearance, size, and specific gravity

SPECIFIC GRAVITY	GOOD				CHERT				HA				SOFT			
	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4
Batch 5A1																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.01
2.35-2.45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.01
2.45-2.50	0.0	0.0	0.0	0.0	0.26	0.06	0.05	0.06	0.0	0.27	0.0	0.00	0.0	0.37	0.0	0.02
2.50-2.55	0.46	0.24	0.13	0.04	0.12	0.57	0.33	0.06	0.0	0.30	0.09	0.00	0.0	0.05	0.07	0.04
2.55-2.65	17.50	12.54	4.44	1.81	2.33	1.17	0.75	0.11	0.56	0.87	0.07	0.04	0.54	0.65	0.27	0.10
2.65-2.85	19.06	16.17	6.63	2.55	0.13	0.0	0.04	0.04	0.22	0.41	0.12	0.06	0.22	0.38	0.06	0.06
+2.85	3.11	2.15	0.73	0.24	0.0	0.0	0.02	0.0	0.0	0.0	0.0	0.03	0.0	0.11	0.03	0.0
Batch 5A2																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.01
2.35-2.45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.0	0.01	0.0	0.0	0.02	0.0
2.45-2.50	0.0	0.0	0.0	0.0	0.0	0.19	0.08	0.13	0.0	0.06	0.02	0.06	0.0	0.13	0.0	0.04
2.50-2.55	1.82	1.02	0.24	0.22	0.23	0.47	0.29	0.10	0.0	0.09	0.03	0.01	0.0	0.14	0.12	0.02
2.55-2.65	14.06	13.31	6.21	2.81	1.24	1.23	0.68	0.29	0.54	0.55	0.13	0.12	0.14	0.44	0.15	0.16
2.65-2.85	13.68	18.61	9.13	4.41	0.0	0.0	0.03	0.0	0.10	0.15	0.10	0.02	0.10	0.29	0.08	0.02
+2.85	1.19	2.76	1.05	0.56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Batch 5A3																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.01
2.35-2.45	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.04	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.01
2.45-2.50	0.12	0.0	0.0	0.0	0.13	0.23	0.16	0.15	0.0	0.04	0.06	0.06	0.0	0.0	0.01	0.04
2.50-2.55	0.63	0.42	0.18	0.05	0.27	0.51	0.20	0.09	0.09	0.18	0.06	0.01	0.0	0.16	0.04	0.02
2.55-2.65	14.35	12.40	7.40	3.20	0.17	0.65	0.46	0.17	0.16	0.23	0.18	0.06	0.47	0.43	0.14	0.12
2.65-2.85	16.81	17.65	9.22	4.22	0.0	0.10	0.06	0.04	0.0	0.03	0.01	0.04	0.0	0.19	0.07	0.07
+2.85	3.19	2.03	1.03	0.56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.01
Batch 5B1																
-2.35	0.0	0.0	0.0	0.0	0.23	0.81	0.27	0.14	0.61	0.34	0.18	0.09	0.53	0.70	0.56	0.18
2.35-2.45	0.0	0.0	0.0	0.0	0.81	0.70	0.70	0.27	0.14	0.43	0.14	0.09	0.14	0.33	0.22	0.13
2.45-2.50	0.18	0.06	0.0	0.0	0.53	0.41	0.21	0.14	0.07	0.14	0.06	0.03	0.08	0.06	0.07	0.07
2.50-2.55	0.97	0.75	0.18	0.12	0.13	0.84	0.35	0.11	0.0	0.15	0.04	0.03	0.09	0.36	0.01	0.06
2.55-2.65	17.27	12.01	5.13	2.46	1.01	1.43	0.46	0.19	0.07	0.23	0.10	0.03	0.71	0.43	0.27	0.14
2.65-2.85	14.71	12.28	5.60	2.22	0.13	0.03	0.01	0.0	0.0	0.16	0.08	0.06	0.35	0.18	0.08	0.10
+2.85	3.12	2.43	1.07	0.38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
Batch 5B2																
-2.35	0.0	0.0	0.0	0.0	0.13	0.51	0.22	0.11	0.26	0.18	0.06	0.01	0.06	0.67	0.18	0.12
2.35-2.45	0.0	0.0	0.0	0.0	0.46	0.87	0.69	0.24	0.85	0.87	0.35	0.10	0.18	0.32	0.22	0.13
2.45-2.50	0.0	0.0	0.0	0.0	0.44	0.56	0.30	0.10	0.08	0.32	0.10	0.05	0.26	0.19	0.08	0.05
2.50-2.55	0.38	0.82	0.23	0.08	0.52	0.66	0.39	0.13	0.11	0.23	0.06	0.04	0.32	0.15	0.11	0.07
2.55-2.65	18.15	12.81	4.24	1.99	0.98	0.84	0.60	0.11	0.57	0.43	0.21	0.06	0.23	0.22	0.24	0.17
2.65-2.85	17.72	12.07	5.61	2.21	0.0	0.05	0.0	0.03	0.0	0.05	0.07	0.07	0.32	0.13	0.05	0.08
+2.85	1.75	1.89	0.73	0.31	0.0	0.0	0.0	0.0	0.16	0.0	0.01	0.02	0.15	0.0	0.01	0.01
Batch 5B3																
-2.35	0.0	0.0	0.0	0.0	0.14	0.10	0.50	0.15	0.11	0.08	0.10	0.01	0.40	0.69	0.28	0.19
2.35-2.45	0.0	0.0	0.0	0.0	0.07	1.13	0.72	0.42	0.93	0.44	0.43	0.10	0.53	0.49	0.28	0.19
2.45-2.50	0.0	0.0	0.0	0.0	0.0	0.27	0.26	0.08	0.39	0.18	0.13	0.07	0.10	0.09	0.04	0.09
2.50-2.55	0.37	0.21	0.12	0.05	0.63	0.63	0.37	0.11	0.25	0.18	0.11	0.05	0.17	0.15	0.14	0.08
2.55-2.65	18.92	13.82	4.42	1.80	1.96	1.57	0.40	0.14	0.76	0.44	0.24	0.12	0.71	0.36	0.18	0.29
2.65-2.85	10.50	13.85	6.33	2.50	0.0	0.14	0.10	0.03	0.30	0.09	0.12	0.07	0.54	0.13	0.28	0.14
+2.85	1.27	2.03	0.91	0.37	0.0	0.0	0.02	0.0	0.0	0.18	0.03	0.01	0.0	0.05	0.0	0.04
Batch 5C1																
-2.35	0.0	0.0	0.0	0.0	0.71	1.11	1.04	0.50	1.16	1.43	0.62	0.13	1.10	2.37	1.06	0.67
2.35-2.45	0.0	0.0	0.0	0.0	1.58	2.89	2.43	0.99	1.32	1.30	0.88	0.35	1.20	1.48	0.61	0.28
2.45-2.50	0.0	0.0	0.0	0.0	0.37	0.36	0.34	0.15	0.27	0.31	0.21	0.05	0.19	0.27	0.14	0.06
2.50-2.55	0.09	0.13	0.11	0.03	0.83	0.74	0.31	0.17	0.21	0.47	0.13	0.08	0.11	0.31	0.16	0.11
2.55-2.65	8.26	12.10	5.50	1.76	0.48	0.30	0.13	0.14	0.10	0.0	0.08	0.06	0.24	0.12	0.09	0.14
2.65-2.85	8.79	13.50	6.42	2.28	0.0	0.0	0.0	0.00	0.0	0.05	0.0	0.0	0.0	0.11	0.13	0.07
+2.85	1.41	1.96	1.38	0.42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02
Batch 5C2																
-2.35	0.0	0.0	0.0	0.0	0.99	1.42	1.44	0.52	0.68	1.46	0.70	0.15	1.11	1.05	1.19	0.78
2.35-2.45	0.0	0.0	0.0	0.0	1.48	2.81	2.26	0.91	0.83	1.38	0.88	0.35	1.19	1.25	0.64	0.40
2.45-2.50	0.0	0.0	0.0	0.0	0.51	0.85	0.42	0.26	0.52	0.78	0.26	0.15	0.06	0.27	0.08	0.13
2.50-2.55	0.27	0.47	0.25	0.12	0.27	0.86	0.35	0.24	0.57	0.47	0.19	0.05	0.37	0.38	0.14	0.14
2.55-2.65	8.51	11.36	5.42	2.35	0.59	0.36	0.30	0.10	0.10	0.25	0.12	0.02	0.35	0.25	0.29	0.17
2.65-2.85	8.31	11.46	6.35	2.49	0.0	0.11	0.03	0.0	0.0	0.06	0.04	0.01	0.17	0.34	0.10	0.05
+2.85	0.91	2.47	0.89	0.36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Batch 5C3																
-2.35	0.0	0.0	0.0	0.0	0.83	1.75	1.22	0.60	0.90	0.89	0.57	0.21	1.26	1.91	0.85	0.71
2.35-2.45	0.0	0.0	0.0	0.0	0.67	3.13	2.00	0.87	1.94	1.76	0.58	0.17	0.70	0.94	0.69	0.30
2.45-2.50	0.10	0.22	0.08	0.0	0.22	0.80	0.77	0.28	0.55	0.35	0.22	0.09	0.12	0.30	0.15	0.13
2.50-2.55	0.27	0.17	0.27	0.10	0.28	0.74	0.44	0.15	0.31	0.22	0.21	0.07	0.61	0.22	0.08	0.18
2.55-2.65	7.10	11.92	5.31	3.03	0.32	0.39	0.22	0.17	0.11	0.15	0.13	0.08	0.28	0.39	0.15	0.22
2.65-2.85	7.43	12.35	7.36	3.13	0.0	0.05	0.01	0.01	0.0	0.03	0.05	0.01	0.38	0.13	0.09	0.09
+2.85	0.91	2.04	1.01	0.70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03

Appendix ID

Aggregate batch compositions-percentages
by appearance, size, and specific gravity

	GOOD				CHERT				HA				SOFT			
SPECIFIC GRAVITY	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4	-1 +3/4	-3/4 +1/2	-1/2 +3/8	-3/8 +NO 4
Batch 6A1																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.05	0.0	0.0	0.01	0.03	0.0	0.0	0.05	0.02
2.35-2.45	0.0	0.0	0.0	0.0	0.0	0.11	0.34	0.14	0.0	0.04	0.03	0.04	0.0	0.03	0.07	0.06
2.45-2.50	0.0	0.0	0.0	0.01	0.10	0.20	0.37	0.24	0.13	0.06	0.03	0.02	0.0	0.0	0.02	0.02
2.50-2.55	0.0	0.12	0.05	0.04	0.0	0.58	0.43	0.25	0.13	0.13	0.03	0.05	0.0	0.03	0.05	0.02
2.55-2.65	8.89	13.80	6.44	1.85	0.68	1.68	1.13	0.41	0.19	0.23	0.23	0.15	0.53	0.74	0.67	0.39
2.65-2.85	15.38	17.65	11.11	3.99	0.13	0.17	0.09	0.00	0.0	0.40	0.25	0.12	0.57	1.50	0.58	0.20
+2.85	1.15	2.37	1.68	0.48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0
Batch 6A2																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.12	0.05	0.0	0.10	0.03	0.01	0.0	0.07	0.08	0.07
2.35-2.45	0.0	0.0	0.0	0.0	0.19	0.31	0.34	0.28	0.0	0.04	0.05	0.04	0.0	0.0	0.03	0.08
2.45-2.50	0.09	0.12	0.16	0.01	0.0	0.19	0.40	0.24	0.0	0.0	0.14	0.03	0.0	0.0	0.10	0.09
2.50-2.55	0.0	0.36	0.44	0.26	0.50	0.85	0.49	0.26	0.0	0.09	0.12	0.03	0.0	0.19	0.24	0.15
2.55-2.65	9.42	15.74	8.34	2.72	0.44	1.49	0.48	0.12	0.18	0.36	0.08	0.08	0.19	0.68	0.50	0.18
2.65-2.85	11.64	19.36	10.94	3.28	0.0	0.0	0.03	0.0	0.13	0.12	0.07	0.05	0.24	0.15	0.15	0.03
+2.85	1.19	2.14	1.61	0.37	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0
Batch 6A3																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.09	0.09	0.0	0.03	0.02	0.01	0.0	0.0	0.04	0.05
2.35-2.45	0.0	0.0	0.0	0.0	0.0	0.02	0.24	0.12	0.0	0.08	0.08	0.02	0.0	0.0	0.05	0.02
2.45-2.50	0.0	0.0	0.01	0.0	0.0	0.23	0.45	0.22	0.09	0.0	0.07	0.05	0.0	0.04	0.03	0.04
2.50-2.55	0.0	0.29	0.11	0.04	0.50	0.81	0.66	0.27	0.26	0.11	0.24	0.05	0.0	0.07	0.05	0.06
2.55-2.65	10.48	18.43	9.30	2.88	1.43	0.82	0.53	0.22	0.25	0.34	0.39	0.22	0.25	0.49	0.21	0.28
2.65-2.85	9.39	17.36	10.43	2.90	0.09	0.11	0.01	0.01	0.27	0.23	0.0	0.01	0.15	0.39	0.54	0.19
+2.85	1.78	1.96	1.30	0.51	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.0	0.0	0.05	0.0	0.0
Batch 6B1																
+2.35	0.0	0.0	0.0	0.0	0.10	0.36	0.56	0.25	0.23	0.03	0.06	0.01	0.12	0.44	0.13	0.09
2.35-2.45	0.0	0.0	0.0	0.0	0.0	1.54	1.17	0.40	0.0	0.17	0.20	0.02	0.08	0.19	0.21	0.07
2.45-2.50	0.0	0.0	0.04	0.0	0.39	1.02	0.74	0.18	0.25	0.20	0.05	0.03	0.0	0.12	0.15	0.08
2.50-2.55	0.09	0.14	0.13	0.01	0.47	1.16	0.83	0.29	0.21	0.15	0.16	0.08	0.15	0.24	0.27	0.14
2.55-2.65	6.98	13.70	6.93	2.40	1.38	2.29	0.99	0.21	0.0	0.22	0.43	0.13	0.36	0.87	0.63	0.43
2.65-2.85	8.86	17.69	10.34	3.39	0.30	0.08	0.08	0.03	0.0	0.20	0.17	0.08	0.43	0.38	0.31	0.23
+2.85	1.81	2.29	1.48	0.53	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.02	0.0	0.03	0.01	0.01
Batch 6B2																
-2.35	0.0	0.0	0.0	0.0	0.19	0.38	0.39	0.12	0.09	0.09	0.06	0.01	0.13	0.29	0.10	0.08
2.35-2.45	0.0	0.0	0.0	0.0	0.35	0.84	0.68	0.35	0.07	0.25	0.10	0.03	0.15	0.24	0.26	0.02
2.45-2.50	0.0	0.0	0.0	0.0	0.18	1.35	0.81	0.36	0.11	0.28	0.17	0.05	0.13	0.14	0.18	0.09
2.50-2.55	0.0	0.30	0.24	0.05	0.89	1.26	0.82	0.27	0.0	0.12	0.17	0.01	0.19	0.35	0.15	0.07
2.55-2.65	6.87	13.44	6.48	2.70	1.76	2.09	0.88	0.19	0.11	0.29	0.22	0.10	0.53	0.82	0.45	0.30
2.65-2.85	10.23	16.47	9.95	2.99	0.08	0.07	0.04	0.04	0.0	0.06	0.20	0.18	0.72	0.36	0.28	0.18
+2.85	2.14	2.32	1.78	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.00
Batch 6B3																
-2.35	0.0	0.0	0.0	0.0	0.17	0.70	0.48	0.29	0.0	0.07	0.03	0.01	0.09	0.26	0.18	0.12
2.35-2.45	0.0	0.04	0.0	0.0	0.37	1.20	1.06	0.42	0.27	0.21	0.10	0.03	0.0	0.12	0.13	0.08
2.45-2.50	0.11	0.11	0.05	0.01	0.37	0.66	0.73	0.30	0.07	0.07	0.09	0.03	0.0	0.22	0.14	0.05
2.50-2.55	0.41	0.41	0.10	0.03	0.76	1.48	1.03	0.37	0.0	0.16	0.07	0.06	0.19	0.17	0.10	0.17
2.55-2.65	7.69	11.33	6.75	2.65	1.91	1.44	1.16	0.36	0.09	0.38	0.18	0.09	0.20	0.86	0.55	0.37
2.65-2.85	8.56	17.82	10.79	3.53	0.0	0.27	0.20	0.02	0.22	0.16	0.33	0.13	0.43	0.50	0.64	0.26
+2.85	0.72	2.36	1.65	0.45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
Batch 6C1																
-2.35	0.0	0.0	0.0	0.0	0.56	2.06	1.20	0.41	0.27	0.31	0.21	0.06	0.42	0.64	0.46	0.25
2.35-2.45	0.0	0.0	0.0	0.0	1.15	3.21	2.15	0.80	0.29	0.41	0.20	0.04	0.38	0.19	0.23	0.14
2.45-2.50	0.0	0.0	0.05	0.0	0.45	2.44	1.73	0.50	0.12	0.43	0.30	0.09	0.10	0.28	0.20	0.10
2.50-2.55	0.27	0.65	0.26	0.07	0.95	2.15	1.05	0.33	0.59	0.04	0.05	0.04	0.13	0.46	0.17	0.11
2.55-2.65	6.91	10.31	6.50	2.34	1.50	2.12	0.83	0.23	0.22	0.26	0.25	0.07	0.34	0.49	0.51	0.42
2.65-2.85	7.68	11.92	7.64	2.74	0.22	0.27	0.06	0.03	0.42	0.21	0.03	0.04	0.32	0.46	0.22	0.15
+2.85	0.45	1.94	1.17	0.41	0.0	0.08	0.02	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Batch 6C2																
-2.35	0.0	0.0	0.0	0.0	0.63	1.69	1.41	0.44	0.0	0.13	0.19	0.03	0.29	0.98	0.44	0.25
2.35-2.45	0.0	0.0	0.0	0.0	0.96	3.14	2.11	0.71	0.62	0.37	0.21	0.06	0.42	0.45	0.28	0.18
2.45-2.50	0.15	0.29	0.03	0.0	1.58	2.65	1.38	0.32	0.26	0.27	0.28	0.14	0.19	0.20	0.24	0.12
2.50-2.55	0.27	0.58	0.34	0.06	0.63	1.93	1.28	0.31	0.29	0.60	0.21	0.09	0.38	0.46	0.36	0.12
2.55-2.65	6.79	10.96	6.44	2.17	1.05	1.93	0.93	0.21	0.15	0.18	0.09	0.05	0.49	0.51	0.49	0.26
2.65-2.85	7.01	11.88	7.06	2.67	0.40	0.15	0.11	0.01	0.18	0.24	0.14	0.04	0.44	0.42	0.15	0.12
+2.85	0.94	1.76	1.16	0.32	0.0	0.0	0.01	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Batch 6C3																
-2.35	0.0	0.0	0.0	0.0	0.57	1.44	1.17	0.39	0.15	0.17	0.10	0.01	0.43	0.77	0.48	0.32
2.35-2.45	0.0	0.0	0.0	0.0	1.47	3.61	2.49	0.68	0.37	0.46	0.25	0.04	0.07	0.53	0.21	0.17
2.45-2.50	0.28	0.19	0.05	0.0	1.30	2.35	1.44	0.46	0.26	0.15	0.22	0.04	0.12	0.33	0.15	0.11
2.50-2.55	0.31	0.96	0.49	0.13	1.21	1.45	1.01	0.28	0.17	0.07	0.22	0.04	0.07	0.39	0.27	0.17
2.55-2.65	5.74	13.20	7.30	2.78	1.13	1.66	0.40	0.11	0.33	0.21	0.08	0.06	0.30	0.45	0.49	0.39
2.65-2.85	6.83	10.98	7.55	2.70	0.21	0.25	0.08	0.03	0.17	0.12	0.11	0.06	0.47	0.44	0.19	0.17
+2.85	0.87	1.77	0.93	0.33	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix IE

Aggregate batch compositions-percentages
by appearance, size, and specific gravity

SPECIFIC GRAVITY	GOOD -1 +3/4	GOOD -3/4 +1/2	GOOD -1/2 +3/8	GOOD -3/8 +NO 4	CHERT -1 +3/4	CHERT -3/4 +1/2	CHERT -1/2 +3/8	CHERT -3/8 +NO 4	HA -1 +3/4	HA -3/4 +1/2	HA -1/2 +3/8	HA -3/8 +NO 4	SOFT -1 +3/4	SOFT -3/4 +1/2	SOFT -1/2 +3/8	SOFT -3/8 +NO 4
Batch 9A1																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
2.35-2.45	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.11	0.09	0.03	0.05	0.03	0.0	0.0	0.03	0.02
2.45-2.50	0.41	1.23	0.36	0.15	0.0	0.16	0.41	0.08	0.20	0.18	0.12	0.03	0.26	0.38	0.14	0.09
2.50-2.55	0.49	1.50	0.40	0.18	0.0	0.29	0.19	0.06	0.37	0.27	0.16	0.05	0.0	0.16	0.06	0.04
2.55-2.65	7.05	19.44	8.87	3.26	0.27	0.42	0.23	0.11	0.25	0.47	0.16	0.15	0.28	0.28	0.09	0.14
2.65-2.85	10.32	21.31	10.55	3.70	0.18	0.07	0.0	0.0	0.09	0.03	0.05	0.02	0.0	0.12	0.08	0.09
+2.85	0.71	1.46	0.63	0.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Batch 9A2																
-2.35	0.0	0.0	0.0	0.0	0.0	0.06	0.02	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.35-2.45	0.0	0.0	0.0	0.0	0.0	0.14	0.17	0.10	0.34	0.29	0.13	0.04	0.0	0.09	0.08	0.06
2.45-2.50	0.11	0.52	0.24	0.06	0.0	0.10	0.12	0.02	0.25	0.30	0.12	0.05	0.08	0.40	0.17	0.15
2.50-2.55	0.86	1.17	0.56	0.17	0.0	0.39	0.14	0.03	0.47	0.15	0.11	0.06	0.12	0.38	0.24	0.13
2.55-2.65	9.01	17.14	10.48	3.47	0.0	0.15	0.21	0.04	0.09	0.37	0.13	0.05	0.07	0.25	0.40	0.13
2.65-2.85	9.88	21.52	10.81	3.48	0.14	0.08	0.02	0.0	0.0	0.02	0.02	0.02	0.0	0.0	0.10	0.02
+2.85	0.59	1.61	0.33	0.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Batch 9A3																
-2.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.02	0.0	0.0	0.0	0.0	0.00
2.35-2.45	0.0	0.0	0.0	0.0	0.06	0.0	0.20	0.14	0.0	0.27	0.05	0.04	0.0	0.03	0.04	0.07
2.45-2.50	0.31	0.65	0.57	0.22	0.0	0.20	0.32	0.14	0.0	0.55	0.23	0.07	0.0	0.29	0.12	0.12
2.50-2.55	0.63	1.73	0.52	0.22	0.77	0.37	0.21	0.07	0.11	0.26	0.09	0.05	0.12	0.46	0.10	0.10
2.55-2.65	5.91	19.94	10.24	4.36	0.0	0.18	0.30	0.05	0.25	0.56	0.34	0.07	0.06	0.39	0.46	0.31
2.65-2.85	6.05	20.11	11.25	4.26	0.0	0.14	0.0	0.0	0.09	0.12	0.04	0.05	0.22	0.41	0.21	0.20
+2.85	0.52	1.40	0.76	0.14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02
Batch 9B1																
-2.35	0.0	0.0	0.0	0.0	0.27	0.21	0.15	0.04	0.0	0.0	0.0	0.0	0.0	0.06	0.01	0.00
2.35-2.45	0.0	0.0	0.0	0.0	0.37	0.90	0.75	0.16	0.21	0.37	0.05	0.03	0.17	0.35	0.05	0.07
2.45-2.50	0.0	0.0	0.16	0.0	0.09	0.69	0.39	0.10	0.30	0.87	0.37	0.13	0.14	0.54	0.38	0.21
2.50-2.55	0.63	3.05	1.38	0.62	0.29	0.63	0.30	0.08	0.26	0.64	0.24	0.10	0.15	0.19	0.33	0.27
2.55-2.65	6.80	21.45	12.06	4.85	0.25	0.19	0.31	0.08	0.53	0.11	0.20	0.15	0.13	0.65	0.46	0.63
2.65-2.85	5.51	15.73	7.49	1.70	0.0	0.14	0.11	0.0	0.0	0.0	0.0	0.0	0.11	0.18	0.12	0.11
+2.85	0.0	1.41	0.54	0.17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.01
Batch 9B2																
-2.35	0.0	0.0	0.0	0.0	0.38	0.21	0.22	0.08	0.12	0.02	0.0	0.0	0.0	0.0	0.01	0.01
2.35-2.45	0.0	0.0	0.0	0.0	0.08	0.59	0.65	0.10	0.08	0.84	0.13	0.01	0.0	0.43	0.09	0.03
2.45-2.50	0.22	0.59	0.14	0.04	0.33	0.48	0.60	0.11	0.34	0.60	0.16	0.13	0.56	0.69	0.48	0.24
2.50-2.55	1.22	2.98	1.70	0.80	0.23	0.74	0.44	0.12	0.41	0.44	0.14	0.14	0.49	0.71	0.64	0.29
2.55-2.65	6.37	19.02	11.02	4.41	0.67	0.52	0.31	0.11	0.83	0.31	0.33	0.07	0.36	0.61	0.42	0.42
2.65-2.85	4.47	14.70	8.06	2.34	0.10	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.07	0.33	0.23	0.19
+2.85	1.05	0.86	0.94	0.09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.01
Batch 9B3																
-2.35	0.0	0.0	0.0	0.0	0.11	0.12	0.27	0.07	0.0	0.07	0.01	0.0	0.0	0.0	0.0	0.0
2.35-2.45	0.0	0.0	0.0	0.0	0.07	0.80	0.78	0.18	0.10	0.21	0.07	0.0	0.0	0.21	0.11	0.04
2.45-2.50	0.35	0.45	0.29	0.09	0.45	0.61	0.39	0.10	0.27	0.45	0.10	0.04	0.17	0.63	0.37	0.17
2.50-2.55	0.50	3.35	1.31	0.56	0.18	0.64	0.29	0.11	0.16	0.40	0.12	0.07	0.07	0.33	0.40	0.17
2.55-2.65	6.84	18.77	9.30	3.82	0.58	1.13	0.41	0.07	0.37	0.21	0.33	0.11	0.27	0.81	0.81	0.48
2.65-2.85	7.19	17.43	8.35	2.49	0.13	0.19	0.0	0.0	0.0	0.11	0.04	0.0	0.0	0.30	0.28	0.06
+2.85	0.43	1.14	0.52	0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02
Batch 9C1																
-2.35	0.0	0.0	0.0	0.0	0.66	0.66	0.76	0.17	0.0	0.12	0.06	0.01	0.19	0.20	0.09	0.01
2.35-2.45	0.0	0.0	0.0	0.0	1.11	2.38	1.75	0.24	0.14	0.91	0.50	0.07	0.17	0.34	0.18	0.15
2.45-2.50	0.19	0.10	0.07	0.03	0.52	1.02	0.75	0.15	0.61	1.38	0.31	0.12	0.40	1.36	0.67	0.25
2.50-2.55	0.93	2.56	1.14	0.32	0.19	0.65	0.32	0.04	0.08	1.07	0.37	0.07	0.08	0.76	0.52	0.36
2.55-2.65	7.83	20.52	10.65	3.47	0.32	0.53	0.35	0.09	0.57	0.56	0.28	0.12	0.49	0.28	0.35	0.48
2.65-2.85	3.87	11.60	5.82	1.27	0.0	0.0	0.04	0.0	0.06	0.09	0.0	0.0	0.15	0.15	0.15	0.12
+2.85	0.0	0.74	0.62	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Batch 9C2																
-2.35	0.0	0.0	0.0	0.0	0.38	0.95	0.75	0.10	0.07	0.08	0.01	0.0	0.09	0.09	0.06	0.04
2.35-2.45	0.0	0.0	0.0	0.0	1.09	2.26	2.22	0.30	0.31	1.05	0.25	0.04	0.33	0.85	0.46	0.11
2.45-2.50	0.23	0.42	0.50	0.05	0.35	0.93	0.77	0.13	0.56	1.29	0.58	0.13	0.40	0.86	0.87	0.38
2.50-2.55	0.85	2.18	1.22	0.42	0.19	0.76	0.42	0.05	0.30	0.98	0.75	0.21	0.42	0.55	0.77	0.39
2.55-2.65	6.38	18.57	9.75	3.98	0.38	0.49	0.18	0.06	0.50	0.74	0.26	0.12	0.24	0.60	0.64	0.38
2.65-2.85	5.27	10.98	5.40	1.57	0.11	0.0	0.01	0.0	0.0	0.04	0.07	0.03	0.0	0.07	0.14	0.18
+2.85	0.23	1.22	0.48	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Batch 9C3																
-2.35	0.0	0.0	0.0	0.0	0.21	0.75	0.94	0.17	0.0	0.05	0.09	0.00	0.0	0.15	0.08	0.01
2.35-2.45	0.0	0.0	0.0	0.0	0.79	2.82	2.10	0.39	0.45	1.14	0.43	0.07	0.17	0.46	0.39	0.29
2.45-2.50	0.0	0.58	0.25	0.07	0.38	0.94	0.62	0.08	0.18	1.17	0.50	0.24	0.21	0.67	0.42	0.25
2.50-2.55	0.98	2.72	1.67	0.63	0.29	0.38	0.32	0.09	0.66	0.54	0.33	0.05	0.07	0.57	0.23	0.13
2.55-2.65	5.64	17.09	9.43	3.78	0.08	0.35	0.21	0.03	0.36	0.68	0.29	0.13	0.51	0.64	0.45	0.23
2.65-2.85	4.96	14.99	7.38	2.24	0.0	0.0	0.0	0.0	0.07	0.20	0.04	0.03	0.09	0.16	0.14	0.11
+2.85	0.22	0.52	0.61	0.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix IF

Raw data and freeze-thaw test results for mixed aggregate classes

	Coarse aggregate properties						Concrete mix data						Freeze-thaw results, durability factor			
Batch	% sink product	% float product	Bulk sp. gr. (SSD)	Absorption, % 24-hr.	Absorption, % 7-day	Dry rodded unit wt lb/cf.	% Dry sand tot. agg.	Actual cement sk/cyd	Net water gal/sk	Slump in	Unit wt. lb/cf	Air %	Beam 1	Beam 2	Beam 3	Average**
2 A1			2.70		1.14	(108.00)	39.09	5.58	5.10	2 1/2	148.68	4.35	30.31	34.18	46.07	36.27
2 A2	100	---	2.70		0.93	108.75	38.74	5.56	5.10	2 1/2	147.80	4.93	47.55	38.26	38.24	41.13
2 A3			2.71	0.95	0.97		38.85	5.57	5.10	2 1/4	148.70	4.51	38.50	49.63	67.01	50.40
2 B1			2.67	1.28	1.47		39.34	5.54	5.10	3 1/4	147.18	4.78	26.72	21.30	16.10	20.93
2 B2	90	10	2.68		1.56	106.61	39.45	5.53	5.10	2 1/2	147.27	4.91	37.80	39.58	24.40	33.17
2 B3			2.68		1.52		39.44	5.52	5.10	2 3/4	146.61	5.31	29.17	20.02	16.37	21.22
2 C1			2.62	1.67	2.20		39.89	5.56	5.10	2 3/4	145.64	4.88	2.32	2.96	3.66	2.93
2 C2	70	30	2.62		2.23	104.00	39.98	5.57	5.10	2 1/2	146.38	4.53	3.30	4.85	1.44	2.85
2 C3			2.61		2.38		39.84	5.58	5.10	2 1/2	146.63	4.27	1.72	3.11	3.55	2.67
5 A1			2.69		0.80		39.38	5.54	5.10	3	147.98	4.71	59.99	62.14	45.58	55.39
5 A2	100	---	2.70		0.92	107.50	39.44	5.56	5.10	2 1/2	148.04	4.76	72.98	65.07	47.56	60.90
5 A3			2.71	1.04	0.95		39.56	5.55	5.10	2 3/4	148.09	4.90	47.85	71.11	57.86	58.17
5 B1			2.66	1.51	1.67	105.64	39.66	5.53	5.10	2 1/2	146.28	5.17	6.66	20.02	3.47	7.73
5 B2	90	10	2.65		1.74	105.36	39.72	5.54	5.10	3	146.54	4.90	11.81	13.41	4.67	9.04
5 B3			2.64		1.89	105.36	39.49	5.59	5.10	3	147.38	4.14	12.08	7.04	4.49	7.25
5 C1			2.57	2.80	3.24		40.75	5.56	5.10	3	144.34	4.85	2.02	2.91	1.86	2.22
5 C2	70	30	2.56		3.28	100.72	40.69	5.56	5.10	2 3/4	144.45	4.72	1.72	2.21	1.48	1.78
5 C3			2.57		3.22		40.84	5.53	5.10	2 1/2	143.90	5.25	1.23	1.77	1.57	1.51
6 A1			2.68	0.70	0.92		38.06	5.58	5.10	2 3/4	148.15	4.35	62.38	64.38	21.65	44.30
6 A2	100	---	2.68		1.11	108.60	38.49	5.55	5.10	3	147.27	4.92	27.26	37.01	27.51	30.28
6 A3			2.69		1.02		38.65	5.57	5.10	2 3/4	148.37	4.38	47.48	32.33	51.21	42.84
6 B1			2.67	1.21	1.67		39.10	5.56	5.10	2 1/2	147.53	4.57	4.82	17.57	5.40	7.70
6 B2	90	10	2.67		1.69	106.92	39.08	5.57	5.10	3	147.56	4.55	8.64	4.73	5.10	5.93
6 B3			2.66		1.76		38.96	5.50	5.10	2 3/4	145.84	5.44	4.30	8.01	11.56	7.36
6 C1			2.61	2.00	2.60		40.95	5.56	5.10	3	145.92	4.57	1.57	0.86	0.60	0.93
6 C2	70	30	2.59		2.61	101.75	40.67	5.58	5.10	2 3/4	145.59	4.42	1.53	1.59	1.31	1.47
6 C3			2.60		2.59		40.82	5.59	5.10	2 3/4	145.90	4.40	1.89	1.78	1.85	1.84
9 A1			2.65	1.30	1.49		42.97	5.53	5.10	2 1/4	146.10	5.18	77.71	86.37	83.30	82.38
9 A2	100	---	2.65		1.52	99.84	42.95	5.55	5.10	2 1/4	146.45	4.95	86.40	80.72	83.98	83.67
9 A3			2.66		1.60		43.05	5.53	5.10	2 1/4	146.15	5.31	81.05	83.80	84.23	83.01
9 B1			2.64	1.76	1.95		43.54	5.59	5.10	2	147.34	4.27	21.10	42.87	50.87	35.83
9 B2	90	10	2.63		2.04	98.49	43.38	5.52	5.10	2 1/2	145.33	5.41	23.68	5.14	35.60	16.30
9 B3			2.63		1.88		43.39	5.52	5.10	3	145.26	5.39	9.58	33.17	69.77	28.09
9 C1			2.60	2.04	2.49		43.95	5.55	5.10	2 1/2	145.40	4.80	3.51	3.49	1.16	2.42
9 C2	70	30	2.60		2.67	96.54	43.87	5.56	5.10	2 1/4	145.66	4.58	5.54	1.23	3.46	2.87
9 C3			2.60		2.64		43.89	5.52	5.10	2 3/4	144.49	5.36	2.09	(2.77)*	3.84	2.81

* Beam 2 of 9 C3 was dropped on floor prior to freeze-thaw test, hence the data was not included in the average.
** From average of logarithms

Appendix IG

Percentages of batches of composition specified by code*

Batch	DF	Log DF	A0AL6	A0AL5	A0ALM	A0AL4	A0AL3	A83L6	A83L5	A83LM
2A1	36.27	1.5596	39.81	7.03	2.95	1.07	0.22	33.81	5.83	2.47
2A2	41.13	1.6141	39.82	6.07	2.48	1.08	0.15	34.21	4.99	2.04
2A3	50.40	1.7024	40.63	6.59	3.08	1.35	0.22	34.14	5.44	2.45
2B1	20.93	1.3207	41.65	12.96	7.84	4.79	1.81	33.85	10.27	6.15
2B2	33.17	1.5208	43.27	12.31	8.44	5.15	1.56	35.18	9.81	6.79
2B3	21.22	1.3268	46.61	12.48	7.19	4.48	1.39	38.13	10.05	5.63
2C1	2.93	0.4668	59.40	26.20	18.83	13.09	4.97	47.16	20.99	15.04
2C2	2.85	0.4542	58.59	27.17	19.90	14.23	5.68	45.48	21.41	15.55
2C3	2.67	0.4262	58.06	25.31	18.66	14.27	7.14	45.86	20.09	14.64
5A1	55.39	1.7434	47.42	3.65	1.14	0.06	0.03	45.07	3.37	1.00
5A2	60.90	1.7846	47.72	5.64	0.82	0.10	0.03	43.67	4.97	0.51
5A3	58.17	1.7647	44.67	4.09	1.16	0.16	0.05	40.55	3.52	0.77
5B1	7.73	0.8884	57.00	15.07	10.87	8.76	4.65	52.72	13.60	9.73
5B2	9.04	0.9563	56.49	14.64	10.34	7.80	2.52	52.94	13.43	9.43
5B3	7.25	0.8606	59.97	13.83	10.22	8.49	2.76	56.02	12.23	8.91
5C1	2.22	0.3463	63.47	33.96	29.96	27.23	11.91	57.79	30.38	26.77
5C2	1.78	0.2501	65.84	35.30	30.16	25.87	11.49	59.02	31.11	26.52
5C3	1.51	0.1779	64.17	34.18	29.85	25.48	11.72	56.79	30.31	26.49
6A1	44.30	1.6464	42.18	4.16	2.27	1.07	0.21	38.42	3.20	1.65
6A2	30.28	1.4811	48.47	7.45	3.47	1.89	0.53	43.76	5.85	2.57
6A3	42.84	1.6318	52.25	5.73	2.19	0.96	0.33	47.61	4.69	1.58
6B1	7.70	0.8867	51.17	14.22	9.68	6.42	2.38	46.36	12.57	8.56
6B2	5.93	0.7730	51.28	14.03	9.13	5.27	1.92	46.47	12.51	8.01
6B3	7.36	0.8667	50.93	14.92	9.40	6.40	2.38	45.49	12.96	8.07
6C1	0.93	-0.0305	63.49	30.18	22.85	16.05	6.86	57.47	27.22	20.46
6C2	1.47	0.1678	64.75	32.06	24.14	16.04	6.51	59.21	29.21	21.87
6C3	1.84	0.2647	65.73	31.09	23.85	16.36	6.01	59.53	28.23	21.61
9A1	82.38	1.9158	50.45	8.95	4.72	0.52	0.07	45.91	8.08	4.19
9A2	83.67	1.9226	51.21	9.24	4.24	1.54	0.10	46.64	8.34	3.74
9A3	83.01	1.9192	54.00	10.57	4.75	0.95	0.05	47.93	9.30	3.92
9B1	35.83	1.5543	66.63	17.78	8.64	4.25	0.76	59.11	15.97	7.90
9B2	16.30	1.2123	66.48	20.71	9.20	3.49	1.06	59.38	18.62	8.47
9B3	38.09	1.4486	61.14	16.83	8.16	3.21	0.64	55.07	15.24	7.48
9C1	2.42	0.3842	75.21	28.31	18.82	10.89	2.94	69.07	26.33	17.64
9C2	2.87	0.4575	74.10	30.83	20.35	11.92	2.62	67.21	28.48	19.08
9C3	2.81	0.4490	68.11	28.20	18.54	11.97	2.47	61.46	25.72	16.97

Batch	DF	Log DF	A83L4	A83L3	A84L5	A84LM	A86LM	A64LM	A43LM	A32LM
2A1	36.27	1.5596	0.88	0.20	3.16	1.36	0.11	1.25	1.11	0.48
2A2	41.13	1.6141	0.96	0.13	2.60	1.13	0.08	1.05	0.91	0.44
2A3	50.40	1.7024	1.11	0.16	2.93	1.24	0.15	1.09	1.21	0.62
2B1	20.93	1.3207	3.74	1.37	6.15	3.43	0.90	2.53	2.72	1.69
2B2	33.17	1.5208	4.11	1.17	5.71	4.07	1.02	3.06	2.72	1.65
2B3	21.22	1.3268	3.43	1.05	5.20	2.65	0.35	2.30	2.97	1.56
2C1	2.93	0.4668	10.45	3.87	11.61	8.10	2.15	5.95	6.94	3.79
2C2	2.85	0.4542	10.98	4.17	12.65	9.01	2.87	6.14	6.54	4.34
2C3	2.67	0.4262	11.15	5.59	11.08	8.17	1.95	6.22	6.47	4.02
5A1	55.39	1.7434	0.00	0.00	2.70	0.95	0.26	0.69	0.05	0.14
5A2	60.90	1.7846	0.02	0.00	4.16	0.39	0.00	0.39	0.13	0.31
5A3	58.17	1.7647	0.02	0.00	2.79	0.52	0.25	0.27	0.25	0.40
5B1	7.73	0.8884	7.86	4.24	10.61	7.31	3.34	3.98	2.41	1.14
5B2	9.04	0.9563	7.09	2.28	10.44	7.24	2.74	4.50	2.19	0.91
5B3	7.25	0.8606	7.43	2.41	8.76	6.16	2.69	3.48	2.75	1.30
5C1	2.22	0.3463	24.31	10.62	22.34	19.44	7.90	11.53	7.33	3.19
5C2	1.78	0.2501	22.76	10.04	22.32	18.64	7.37	11.27	7.87	3.64
5C3	1.51	0.1779	22.63	10.20	22.18	19.36	7.31	12.05	7.13	3.36
6A1	44.30	1.6464	0.73	0.11	1.67	0.67	0.24	0.44	0.98	0.61
6A2	30.28	1.4811	1.36	0.40	3.11	1.12	0.28	0.85	1.44	0.90
6A3	42.84	1.6318	0.66	0.19	2.54	0.50	0.09	0.41	1.08	0.61
6B1	7.70	0.8867	5.59	2.03	7.86	5.25	1.18	4.07	3.31	1.12
6B2	5.93	0.7730	4.66	1.71	8.38	5.26	1.40	3.87	2.75	1.12
6B3	7.36	0.8667	5.46	1.97	8.67	5.09	1.43	3.66	2.98	1.33
6C1	0.93	-0.0305	14.36	6.14	18.96	13.72	3.74	9.98	6.73	2.39
6C2	1.47	0.1678	14.35	5.78	20.43	15.29	5.12	10.17	6.58	2.27
6C3	1.84	0.2647	14.74	5.28	19.67	15.05	5.04	10.01	6.57	2.23
9A1	82.38	1.9158	0.34	0.04	6.02	2.94	0.96	1.98	1.25	0.53
9A2	83.67	1.9226	1.33	0.08	6.22	2.67	0.78	1.89	1.07	0.50
9A3	83.01	1.9192	0.67	0.02	6.83	2.37	0.38	1.99	1.55	0.83
9B1	35.83	1.5543	3.95	0.71	11.40	5.56	1.56	4.01	2.33	0.74
9B2	16.30	1.2123	3.27	0.97	13.20	5.97	2.12	3.86	2.49	0.73
9B3	28.09	1.4486	2.93	0.57	10.72	5.07	1.52	3.55	2.40	0.68
9C1	2.42	0.3842	10.25	2.75	18.84	12.49	4.01	8.47	5.15	1.18
9C2	2.87	0.4575	11.32	2.48	18.83	12.59	3.81	8.79	6.48	1.27
9C3	2.81	0.4490	11.04	2.28	17.34	11.14	2.39	8.75	5.82	1.58

Batch	DF	Log DF	D0A0A	D0AL6	D0AL5	D0ALM	D0AL4	D0AL3	D830A	D83L6
2A1	36.27	1.5596	11.41	10.18	5.61	2.31	0.96	0.22	9.70	8.67
2A2	41.13	1.6141	11.66	10.42	5.35	2.44	1.04	0.15	9.93	8.89
2A3	50.40	1.7024	12.43	11.17	5.59	2.87	1.34	0.22	10.32	9.39
2B1	20.93	1.3207	18.53	17.67	11.88	7.64	4.79	1.81	14.83	14.29
2B2	33.17	1.5208	18.32	17.40	11.38	8.09	5.15	1.56	14.33	13.69
2B3	21.22	1.3268	20.36	19.09	11.47	7.01	4.48	1.39	16.52	15.39
2C1	2.93	0.4668	32.17	31.25	24.41	18.48	13.09	4.97	25.39	24.75
2C2	2.85	0.4542	31.03	29.87	25.26	19.76	14.23	5.68	24.44	23.51
2C3	2.67	0.4262	32.38	31.54	24.64	18.50	14.27	7.14	25.94	25.23
5A1	55.39	1.7434	12.18	10.25	2.77	1.14	0.06	0.03	11.49	9.75
5A2	60.90	1.7846	8.91	8.01	2.33	0.82	0.10	0.03	7.86	6.99
5A3	58.17	1.7647	6.55	5.92	2.68	1.04	0.16	0.05	5.53	5.05
5B1	7.73	0.8884	19.09	17.89	12.81	10.63	8.76	4.65	17.20	16.18
5B2	9.04	0.9563	19.01	17.79	13.13	10.34	7.80	2.52	17.32	16.31
5B3	7.25	0.8606	22.52	20.24	13.07	10.22	8.49	2.76	20.14	18.15
5C1	2.22	0.3463	35.87	35.49	33.59	29.96	27.23	11.91	31.88	31.60
5C2	1.78	0.2501	38.01	37.09	34.19	30.16	25.87	11.49	33.58	32.74
5C3	1.51	0.1779	36.49	35.59	32.97	29.45	25.48	11.72	32.11	31.35
6A1	44.30	1.6464	15.01	10.97	3.94	2.26	1.07	0.21	12.82	9.11
6A2	30.28	1.4811	11.78	10.80	6.00	3.08	1.89	0.53	9.95	9.08
6A3	42.84	1.6318	12.83	10.72	5.28	2.18	0.96	0.33	10.89	9.00
6B1	7.70	0.8867	24.16	21.74	13.80	9.64	6.42	2.38	21.39	19.34
6B2	5.93	0.7730	23.44	21.20	13.44	9.13	5.27	1.92	20.95	19.14
6B3	7.36	0.8667	24.43	21.25	13.66	9.09	6.36	2.38	21.27	18.49
6C1	0.93	-0.0305	38.69	36.12	28.87	22.80	16.05	6.86	34.83	32.52
6C2	1.47	0.1678	39.11	36.66	30.33	23.68	16.04	6.51	35.60	33.35
6C3	1.84	0.2647	36.58	34.27	28.66	23.31	16.36	6.01	33.04	30.99
9A1	82.38	1.9158	7.85	7.11	4.24	2.58	0.52	0.07	6.79	6.16
9A2	83.67	1.9226	7.84	7.41	5.54	3.30	1.54	0.10	6.93	6.54
9A3	83.01	1.9192	10.19	8.68	5.71	3.00	0.95	0.05	8.66	7.42
9B1	35.83	1.5543	16.46	15.65	11.96	8.48	4.25	0.76	14.28	13.59
9B2	16.30	1.2123	18.96	17.97	13.01	8.21	3.49	1.06	16.91	16.11
9B3	38.09	1.4486	16.64	15.51	9.92	6.97	3.21	0.64	14.97	13.92
9C1	2.42	0.3842	28.15	27.39	22.96	18.44	10.89	2.94	25.70	25.06
9C2	2.87	0.4575	30.20	29.55	24.96	19.16	11.92	2.62	27.56	27.11
9C3	2.81	0.4490	26.10	25.27	21.30	17.64	11.97	2.47	23.80	23.10

Batch	DF	Log DF	D83L5	D83LM	D83L4	D83L3	D86LM	D64LM	D43LM	D32LM
2A1	36.27	1.5596	4.63	1.87	0.78	0.20	0.11	0.78	0.98	0.44
2A2	41.13	1.6141	4.43	2.02	0.93	0.13	0.08	1.05	0.88	0.42
2A3	50.40	1.7024	4.65	2.30	1.11	0.16	0.15	1.06	1.09	0.57
2B1	20.93	1.3207	9.43	5.99	3.74	1.37	0.90	2.48	2.61	1.65
2B2	33.17	1.5208	9.08	6.50	4.11	1.17	1.02	2.92	2.57	1.59
2B3	21.22	1.3268	9.17	5.48	3.43	1.05	0.35	2.27	2.87	1.53
2C1	2.93	0.4668	19.36	14.71	10.45	3.87	2.15	5.84	6.72	3.78
2C2	2.85	0.4542	19.99	15.43	10.98	4.17	2.80	6.14	6.49	4.32
2C3	2.67	0.4262	19.50	14.48	11.15	5.59	1.95	6.17	6.36	4.02
5A1	55.39	1.7434	2.53	1.00	0.00	0.00	0.26	0.69	0.05	0.14
5A2	60.90	1.7846	1.88	0.51	0.02	0.00	0.00	0.39	0.13	0.31
5A3	58.17	1.7647	2.17	0.65	0.02	0.00	0.13	0.27	0.25	0.40
5B1	7.73	0.8884	11.47	9.49	7.86	4.24	3.16	3.92	2.41	1.14
5B2	9.04	0.9563	11.99	9.43	7.09	2.28	2.74	4.50	2.19	0.91
5B3	7.25	0.8606	11.53	8.91	7.43	2.41	2.69	3.48	2.75	1.30
5C1	2.22	0.3463	30.04	26.77	24.31	10.62	7.90	11.53	7.33	3.19
5C2	1.78	0.2501	30.12	26.52	22.76	10.04	7.37	11.27	7.87	3.64
5C3	1.51	0.1779	29.20	26.09	22.63	10.20	7.21	11.83	7.05	3.36
6A1	44.30	1.6464	3.03	1.65	0.73	0.11	0.24	0.44	0.98	0.60
6A2	30.28	1.4811	4.67	2.19	1.36	0.40	0.19	0.72	1.28	0.69
6A3	42.84	1.6318	4.28	1.57	0.66	0.19	0.09	0.41	1.07	0.61
6B1	7.70	0.8867	12.17	8.52	5.59	2.03	1.18	4.07	3.27	1.12
6B2	5.93	0.7730	11.97	8.01	4.66	1.71	1.40	3.87	2.75	1.12
6B3	7.36	0.8667	11.73	7.76	5.42	1.97	1.32	3.50	2.94	1.32
6C1	0.93	-0.0305	25.99	20.41	14.36	6.14	3.74	9.98	6.69	2.39
6C2	1.47	0.1678	27.55	21.41	14.35	5.78	4.98	9.88	6.55	2.27
6C3	1.84	0.2647	25.93	21.08	14.74	5.28	4.75	9.82	6.51	2.23
9A1	82.38	1.9158	3.69	2.19	0.34	0.04	0.55	0.75	0.89	0.38
9A2	83.67	1.9226	4.88	2.87	1.33	0.08	0.67	1.38	0.83	0.43
9A3	83.01	1.9192	4.88	2.39	0.67	0.02	0.06	1.34	0.98	0.61
9B1	35.83	1.5543	10.76	7.74	3.95	0.71	1.56	4.01	2.17	0.74
9B2	16.30	1.2123	11.76	7.52	3.27	0.97	1.90	3.27	2.35	0.69
9B3	38.09	1.4486	8.98	6.38	2.93	0.57	1.17	3.10	2.11	0.59
9C1	2.42	0.3842	21.32	17.28	10.25	2.75	3.82	8.37	5.08	1.16
9C2	2.87	0.4575	23.08	17.93	11.32	2.48	3.58	8.37	5.98	1.22
9C3	2.81	0.4490	19.52	16.13	11.04	2.28	2.39	8.17	5.57	1.51

* See table 8

Appendix IH

Percentages of batches of composition specified by code*

Batch	DF	Log DF	COAL5	COALM	COAL4	COAOA	C83L5	C83LM	C83L4	C83OA
2A1	36.27	1.5596	3.95	1.64	0.61	7.14	3.25	1.35	0.49	6.18
2A2	41.13	1.1641	3.77	1.47	0.49	7.62	3.13	1.21	0.44	6.67
2A3	50.40	1.7024	4.04	1.83	0.67	8.21	3.34	1.43	0.53	6.93
2B1	20.93	1.3207	7.56	4.65	2.67	11.81	5.79	3.51	1.99	9.44
2B2	33.17	1.5208	7.07	4.57	2.46	11.80	5.42	3.56	1.85	9.07
2B3	21.22	1.3268	7.30	4.27	2.40	12.70	5.79	3.38	1.83	10.28
2C1	2.93	0.4668	15.11	10.50	6.65	20.56	12.03	8.22	5.15	16.48
2C2	2.85	0.4542	16.01	11.51	7.25	19.36	12.61	8.89	5.41	15.33
2C3	2.67	0.4262	14.97	10.33	7.28	20.35	11.53	7.73	5.35	16.15
5A1	55.39	1.7434	1.53	0.44	0.02	6.13	1.38	0.36	0.00	5.83
5A2	60.90	1.7846	1.56	0.46	0.06	5.04	1.27	0.28	0.00	4.46
5A3	58.17	1.7647	1.83	0.75	0.09	3.47	1.52	0.53	0.02	2.95
5B1	7.73	0.8884	6.65	5.22	3.93	9.92	5.99	4.67	3.52	9.07
5B2	9.04	0.9563	6.33	4.63	3.23	8.93	5.74	4.18	2.87	8.21
5B3	7.25	0.8606	5.58	3.85	3.23	9.94	4.82	3.20	2.66	9.02
5C1	2.22	0.3463	14.53	12.48	11.27	15.59	12.72	10.84	9.77	13.63
5C2	1.78	0.2501	15.59	13.87	11.83	17.08	13.66	12.18	10.40	15.05
5C3	1.51	0.1779	14.76	13.15	11.09	15.94	12.86	11.40	9.62	13.86
6A1	44.30	1.6464	2.85	1.60	0.69	7.15	2.18	1.17	0.50	6.07
6A2	30.28	1.4811	4.22	2.12	1.28	6.79	3.39	1.55	0.95	5.82
6A3	42.84	1.6318	3.71	1.46	0.56	6.93	3.01	1.03	0.35	5.99
6B1	7.70	0.8867	9.48	6.72	4.38	14.84	8.36	5.89	3.74	13.48
6B2	5.93	0.7730	9.25	5.99	3.29	14.41	8.15	5.17	2.82	13.07
6B3	7.36	0.8667	10.38	6.73	4.68	15.75	9.01	5.73	3.97	13.99
6C1	0.93	-0.0305	21.16	16.67	11.54	26.56	19.12	14.96	10.33	24.22
6C2	1.47	0.1678	21.19	17.04	11.11	26.02	19.40	15.57	9.95	23.99
6C3	1.84	0.2647	21.32	17.37	11.81	25.20	19.51	15.84	10.74	23.25
9A1	82.38	1.9158	1.46	0.92	0.27	2.75	1.20	0.72	0.14	2.37
9A2	83.67	1.9226	1.30	0.74	0.50	1.94	1.14	0.61	0.39	1.75
9A3	83.01	1.9192	2.51	1.09	0.43	3.18	2.13	0.78	0.26	2.75
9B1	35.83	1.5543	5.43	4.14	2.86	6.53	5.06	3.84	2.66	6.07
9B2	16.30	1.2123	5.37	3.83	2.31	7.12	4.96	3.55	2.14	6.60
9B3	28.09	1.4486	5.19	3.96	2.40	7.70	4.73	3.62	2.16	7.17
9C1	2.42	0.3842	11.37	10.17	7.73	12.71	10.77	9.62	7.32	12.02
9C2	2.87	0.4575	11.67	10.25	8.06	12.91	11.09	9.72	7.66	12.27
9C3	2.81	0.4490	11.29	10.21	8.18	11.95	10.55	9.56	7.62	11.19

Batch	DF	Log DF	HOAL5	HOALM	HOAL4	HOAOA	H83L5	H83LM	H83L4	H83OA
2A1	36.27	1.5596	0.90	0.42	0.20	1.79	0.79	0.36	0.19	1.57
2A2	41.13	1.1641	1.03	0.71	0.41	2.05	0.85	0.56	0.35	1.70
2A3	50.40	1.7024	0.82	0.63	0.40	1.74	0.69	0.53	0.35	1.40
2B1	20.93	1.3207	2.21	1.39	0.97	3.35	1.86	1.16	0.81	2.75
2B2	33.17	1.5208	2.15	1.74	1.27	3.01	1.84	1.47	1.06	2.40
2B3	21.22	1.3268	1.85	1.03	0.75	3.23	1.46	0.73	0.52	2.57
2C1	2.93	0.4668	3.46	2.83	1.83	4.13	2.65	2.28	1.53	3.07
2C2	2.85	0.4542	3.78	3.40	2.63	4.43	3.15	2.82	2.24	3.58
2C3	2.67	0.4262	3.87	2.94	2.24	4.43	3.30	2.50	1.94	3.74
5A1	55.39	1.7434	0.68	0.29	0.02	3.07	0.65	0.27	0.00	2.91
5A2	60.90	1.7846	0.29	0.16	0.02	1.99	0.20	0.08	0.00	1.77
5A3	58.17	1.7647	0.57	0.22	0.05	1.27	0.44	0.10	0.00	1.05
5B1	7.73	0.8884	2.57	2.35	2.04	3.29	2.32	2.13	1.85	2.96
5B2	9.04	0.9563	3.68	3.24	2.69	5.34	3.49	3.08	2.59	5.00
5B3	7.25	0.8606	3.56	2.97	2.20	5.93	3.33	2.79	2.09	5.49
5C1	2.22	0.3463	8.93	8.04	7.18	9.23	8.32	7.51	6.71	8.56
5C2	1.78	0.2501	9.43	8.14	6.42	10.03	8.73	7.49	5.93	9.30
5C3	1.51	0.1779	9.05	8.24	7.03	9.62	8.51	7.77	6.66	8.98
6A1	44.30	1.6464	0.73	0.39	0.14	2.31	0.60	0.31	0.08	1.90
6A2	30.28	1.4811	0.69	0.45	0.28	1.78	0.58	0.37	0.23	1.52
6A3	42.84	1.6318	1.11	0.45	0.23	2.89	0.99	0.37	0.21	2.53
6B1	7.70	0.8867	1.85	1.25	0.71	3.14	1.72	1.20	0.69	2.78
6B2	5.93	0.7730	1.61	1.31	0.69	2.80	1.51	1.22	0.66	2.41
6B3	7.36	0.8667	1.27	0.98	0.72	2.85	1.13	0.91	0.68	2.51
6C1	0.93	-0.0305	3.46	2.74	1.80	4.97	3.23	2.55	1.70	4.62
6C2	1.47	0.1678	3.76	2.57	1.62	4.84	3.44	2.34	1.52	4.42
6C3	1.84	0.2647	2.73	2.23	1.55	3.88	2.60	2.14	1.50	3.62
9A1	82.38	1.9158	1.58	0.73	0.20	2.82	1.47	0.67	0.17	2.54
9A2	83.67	1.9226	2.33	1.54	0.81	3.03	2.17	1.44	0.77	2.80
9A3	83.01	1.9192	1.74	1.23	0.37	3.27	1.59	1.12	0.34	2.99
9B1	35.83	1.5543	3.58	2.34	0.66	4.57	3.31	2.18	0.63	4.15
9B2	16.30	1.2123	2.96	1.83	0.60	4.49	2.69	1.70	0.60	4.15
9B3	28.09	1.4486	2.06	1.31	0.45	3.23	1.95	1.27	0.45	3.02
9C1	2.42	0.3842	5.84	4.24	1.83	7.53	5.57	4.05	1.74	7.14
9C2	2.87	0.4575	6.61	4.37	1.81	8.37	6.23	4.20	1.77	7.84
9C3	2.81	0.4490	5.91	4.32	2.23	7.71	5.54	4.01	2.16	7.19

Batch	DF	Log DF	SOAL5	SOALM	SOAL4	SOAOA	S83L5	S83LM	S83L4	S83OA
2A1	36.27	1.5596	0.76	0.24	0.15	2.47	0.59	0.16	0.09	1.95
2A2	41.13	1.6141	0.55	0.26	0.15	1.99	0.45	0.25	0.14	1.56
2A3	50.40	1.7024	0.74	0.42	0.28	2.48	0.62	0.34	0.24	1.98
2B1	20.93	1.3207	2.12	1.59	1.16	3.37	1.78	1.32	0.93	2.64
2B2	33.17	1.5208	2.16	1.78	1.42	3.50	1.83	1.47	1.19	2.85
2B3	21.22	1.3268	2.32	1.71	1.33	4.44	1.92	1.37	1.07	3.67
2C1	2.93	0.4668	5.83	5.15	4.60	7.48	4.68	4.20	3.78	5.84
2C2	2.85	0.4542	5.47	4.85	4.35	7.24	4.23	3.72	3.33	5.53
2C3	2.67	0.4262	5.80	5.23	4.76	7.60	4.67	4.25	3.86	6.05
5A1	55.39	1.7434	0.56	0.40	0.02	2.98	0.49	0.37	0.00	2.75
5A2	60.90	1.7846	0.48	0.20	0.03	1.88	0.41	0.16	0.02	1.63
5A3	58.17	1.7647	0.29	0.07	0.02	1.81	0.21	0.01	0.00	1.53
5B1	7.73	0.8884	3.60	3.07	2.79	5.88	3.16	2.69	2.48	5.18
5B2	9.04	0.9563	3.12	2.47	1.88	4.74	2.76	2.17	1.63	4.11
5B3	7.25	0.8606	3.93	3.39	3.06	6.64	3.38	2.92	2.68	5.63
5C1	2.22	0.3463	10.13	9.44	8.78	11.05	9.00	8.42	7.82	9.69
5C2	1.78	0.2501	9.17	8.15	7.61	10.89	7.73	6.84	6.43	9.22
5C3	1.51	0.1779	9.16	8.06	7.36	10.93	7.83	6.92	6.35	9.26
6A1	44.30	1.6464	0.36	0.27	0.24	5.54	0.25	0.18	0.16	4.85
6A2	30.28	1.4811	1.09	0.51	0.32	3.21	0.71	0.28	0.18	2.61
6A3	42.84	1.6318	0.45	0.27	0.17	3.01	0.29	0.16	0.10	2.37
6B1	7.70	0.8867	2.47	1.67	1.32	6.18	2.09	1.43	1.16	5.13
6B2	5.93	0.7730	2.58	1.82	1.28	6.23	2.31	1.62	1.18	5.48
6B3	7.36	0.8667	2.01	1.38	0.97	5.83	1.59	1.13	0.77	4.77
6C1	0.93	-0.0305	4.25	3.38	2.71	7.16	3.65	2.90	2.33	6.00
6C2	1.47	0.1678	5.38	4.06	3.31	8.25	4.70	3.50	2.87	7.20
6C3	1.84	0.2647	4.60	3.70	2.99	7.50	3.83	3.10	2.50	6.17
9A1	82.38	1.9158	0.93	0.05	0.00	2.28	0.81	0.03	0.00	1.88
9A2	83.67	1.9226	1.02	0.22	0.00	2.87	0.82	0.16	0.00	2.39
9A3	83.01	1.9192	0.67	0.15	0.00	3.72	0.48	0.07	0.00	2.93
9B1	35.83	1.5543	2.00	0.72	0.08	5.34	1.72	0.65	0.07	4.05
9B2	16.30	1.2123	2.55	0.57	0.02	7.32	2.27	0.53	0.01	6.14
9B3	28.09	1.4486	1.70	0.35	0.00	5.69	1.49	0.32	0.00	4.77
9C1	2.42	0.3842	4.02	1.33	0.49	7.91	3.61	1.18	0.48	6.54
9C2	2.87	0.4575	4.54	2.04	0.28	8.92	4.02	1.89	0.24	7.45
9C3	2.81	0.4490	3.10	1.56	0.24	6.44	2.56	1.26	0.23	5.42

CODE

1st Character indicates type

- A - ALL
- G - GOOD
- C - CHERT
- H - HARD
- S - SOFT
- D - DELETERIOUS

2nd and 3rd characters indicate size

- 2nd - TOP SIZE in 8ths of an inch, i.e. 1 = 1/8, 2 = 2/8
- 3rd - BOTTOM SIZE in 8ths of an inch
- OA - ALL SIZES

4th and 5th characters indicate specific gravity

- 4th - TOP SPECIFIC GRAVITY
- 5th - BOTTOM SPECIFIC GRAVITY
- OA - ALL SPECIFIC GRAVITIES
- 8 - 2.85
- 6 - 2.65
- 5 - 2.55
- M - 2.50
- 4 - 2.45
- 3 - 2.35
- L__ - all gravities less than number following L, i.e. L5 means all gravities less than 2.55

Appendix II

Mixed aggregate tests -
Procedure and computations for making concrete

Several types of information are required for computation of proportions for concrete by the ACI 613-54 procedure. The values used or the tests run to obtain the required values are listed below along with symbols used in the equations.

Symbol	Item		Value used in computations or test used to obtain value
A	Batch	Size desired, ft.	0.366
B	C. aggregate	Vol. % of batch (dry rodded)	0.664
C	"	Unit weight, lbs/cu. ft.	ASTM C-29
D	"	Bulk sp. gr.	ASTM C-127
E	"	7 day absorbtion, % dry basis	ASTM C-127
F	"	Moisture, % dry basis	ASTM C-127
G	"	Free water, % dry basis	F - E
H	"	Computed dry wt., lbs.	AxBxC
I	"	Actual weight used, lbs.	
J	Cement	Bags/cu. yd.	5.5
K	"	Lbs./batch	3.48 x A x J x I/H
L	Air	% assumed	5.5
M	F. aggregate	Bulk sp. gr.	ASTM C-128
N	"	24 hr. abs., % dry basis	ASTM C-128
O	"	Moisture, % dry basis	ASTM C-128
P	"	Free water, % dry basis	O - N
Q	"	Actual dry wt., lbs.	*
R	Water	Gal./cu. yd.	28.0
S	"	Total lbs./batch	0.309 x R x A x I/H
T	"	Actual lb./batch added	S- (IG + QP)/100

The total weight of a concrete batch in lbs. is: $I(1 + E/100) + K + Q(1 + N/100) + S$

The total computed volume of a concrete batch in cubic feet without air is:

$$\frac{I + IE/100}{62.4D} + \frac{K}{3.15 \times 62.4} + \frac{Q}{62.4M} + \frac{S}{62.4}$$

The computed concrete unit weight in lbs. per cubic foot is: total wt./total vol.

$$* \; Q = \left(62.4\frac{AI}{H} - \frac{I(1 + E/100)}{D} - \frac{K}{3.15} - 62.4\frac{LAI}{H} - S\right) M$$

The 3-1/2 cubic foot mixer with a 23-rpm rotational speed was dampened with water; coarse aggregate was added, followed by sand and cement and these were allowed to mix until thoroughly blended; water containing a predetermined amount of air entrainment admixture was added; the ingredients were mixed for two minutes; the mixer was stopped for one minute and then run an additional three minutes; and finally the batch was poured onto a wet surface.

Slump was measured according to ASTM C-143-66. Weight per cubic foot was measured in a 0.1 cubic foot measure according to ASTM C-138-63 and the air content was computed by the following equation:

$$\text{air content, \%} = \frac{(\text{computed wt./cu. ft.} - \text{measured wt./cu. ft.})}{\text{computed wt./cu. ft.}} \times 100$$

The concrete was placed into forms to which a light coating of petroleum jelly had been applied. Each compartment was filled to half its capacity and rodded 30 times with the standard slump rod, followed by tapping the outside of the container 10 times; each end of the container was lifted slightly and dropped 10 times; the compartments were completely filled with concrete and the same rodding, tapping, and lifting and dropping procedure was repeated; and finally the top was leveled with the rod and smoothed with a trowel.

The forms were labeled and covered with plastic to confine the moisture. Some time after 20 hours and before 48 hours of the hardening period, the forms were dismantled and the beams labeled with the sample number and date. It was found that the amount of beam damage caused by dismantling was greater when the beams were allowed to remain in the forms for 2 days; therefore, most were removed as soon as possible after 20 hours. The beams were cured by submergence in a saturated solution of lime water at room temperature. Fourteen days after mixing the concrete, the lime water was washed from the cured beams and the transverse resonant frequencies were measured in accordance with ASTM C-215-60.

The sonometer was recalibrated occasionally by making measurements on a 3 x 4 x 17 inch aluminum beam of known resonant frequency.

The beams were placed in the freeze-thaw unit and tested according to ASTM C-291-67. The batch temperature was measured by a thermocouple embedded in the center of symmetry of a standard beam made from good aggregate. Transverse resonant frequencies were measured at various intervals, whose lengths were approximately inversely proportional to the rate of degradation. Records were kept of beam location in the freeze-thaw unit so that each time a frequency measurement was made, the beam was placed in a new location.

The beams were removed from the freeze-thaw unit when computations indicated that dynamic Young's modulus had decreased by 30%. The durability factor was computed by the formulas given in ASTM C-291.

Appendix III
Raw data and freeze-thaw test results for individual aggregate classes
(Page 1 of 8)

	Coarse aggregate							Concrete mix data*				
	Deleterious											
Batch	%	Size inches	Type	Sp. gr.	Bulk sp. gr. (SSD)	7-day abs. %	Dry rodded unit wt. lb/cf	% Sand to total aggregate	Net water gal/sk	Unit weight lb/cf	Air %	D.F.
1a					2.69			38.52	4.66	145.18	6.00	3.7
1b	5	-1+3/4	Chert	-2.35	2.67	1.35	108.22	38.22	4.33	143.41	6.82	36.8
1c					2.68			38.35	4.25	147.36	4.42	95.9
Avg					2.68			38.36	4.41	145.32	5.75	45.5
2a					2.65			38.56	4.14	144.05	6.05	81.0
2b	10	-1+3/4	Chert	-2.35	2.64	1.72	106.88	38.45	4.93	146.32	4.41	6.7
2c					2.65			38.59	4.87	145.42	5.17	13.0
Avg					2.65			38.53	4.65	145.26	5.21	33.5
3a					2.67			37.79	5.02	147.09	4.42	18.4
3b	5	-1+3/4	Chert	-2.45+2.35	2.71	1.18	109.14	38.34	4.92	147.20	5.01	8.9
3c					2.70			38.21	4.86	146.81	5.11	16.5
Avg					2.69			38.11	4.93	147.03	4.85	14.6
4a					2.68			38.42	5.02	147.44	4.13	7.5
4b	10	-1+3/4	Chert	-2.45+2.35	2.67	1.37	108.16	38.24	4.33	144.82	5.90	1.9
4c					2.68			38.38	4.25	146.59	4.92	12.9
Avg					2.68			38.35	4.53	146.28	4.98	7.4
5a					2.70			38.27	4.66	144.93	6.32	80.6
5b	5	-1+3/4	Chert	-2.55+2.45	2.70	1.10	109.08	38.28	4.93	148.24	4.19	84.9
5c					2.71			38.40	4.46	146.15	5.71	78.3
Avg					2.70			38.32	4.68	146.44	5.41	81.3
6a					2.65			37.70	5.02	146.78	4.28	11.2
6b	10	-1+3/4	Chert	-2.55+2.45	2.67	1.20	108.78	37.95	4.33	143.68	6.64	16.4
6c					2.69			38.24	4.46	148.11	4.10	42.1
Avg					2.67			37.96	4.60	146.19	5.01	23.2
7a					2.70			38.16	4.67	146.78	5.13	91.0
7b	5	-1+3/4	Chert	-2.65+2.55	2.70	1.03	109.30	38.14	4.33	145.66	5.86	88.8
7c					2.71			38.30	4.86	147.16	5.05	89.4
Avg					2.70			38.20	4.62	146.53	5.35	89.7

* Actual cement sk/cyd 5.44

	Coarse aggregate							Concrete mix data*				
	Deleterious											
Batch	%	Size inches	Type	Sp. gr.	Bulk sp. gr. (SSD)	7-day abs. %	Dry rodded unit wt. lb/cf	% Sand to total aggregate	Net water gal/sk	Unit weight lb/cf	Air %	D.F.
8a					2.69			38.15	5.02	148.15	4.07	83.7
8b	10	-1+3/4	Chert	-2.65+2.55	2.69	1.08	109.08	38.11	4.33	144.01	6.75	42.8
8c					2.70			38.24	4.16	145.86	5.73	83.9
Avg					2.69			38.17	4.50	146.01	5.52	70.1
9a					2.69			38.04	5.02	145.88	5.54	89.8
9b	5	-3/4+1/2	HA	-2.55+2.45	2.68	1.12	109.25	37.86	4.29	145.02	5.93	96.1
9c					2.70			38.13	4.16	146.06	5.60	97.8
Avg					2.69			38.01	4.49	145.65	5.69	94.6
10a					2.69			39.01	5.02	146.17	5.36	85.2
10b	10	-3/4+1/2	HA	-2.55+2.45	2.69	1.24	107.44	38.97	4.27	145.75	5.63	95.1
10c					2.68			38.87	4.86	145.11	5.88	90.9
Avg					2.69			38.95	4.72	145.68	5.62	91.1
11a			HA		2.67			37.66	4.68	145.18	5.66	84.8
11b	5	-1+3/4	and	-2.35	2.67	1.41	109.21	37.67	4.93	147.47	4.17	91.2
11c			soft		2.67			37.64	4.27	146.45	4.83	93.0
Avg					2.67			37.66	4.63	146.37	4.89	89.7
12a			HA		2.66			38.78	5.02	142.35	7.33	18.1
12b	10	-1+3/4	and	-2.35	2.66	1.83	106.75	38.74	4.28	146.19	4.84	79.5
12c			soft		2.65			38.58	4.16	144.18	5.98	98.0
Avg					2.66			38.37	4.49	144.24	6.05	65.2
13a			HA		2.69			38.72	4.66	145.33	5.89	90.2
13b	5	-1+3/4	and	-2.45+2.35	2.69	1.21	107.93	38.70	4.27	144.43	6.48	92.2
13c			soft		2.69			38.72	4.46	144.12	6.68	8.6
Avg					2.69			38.71	4.46	144.63	6.35	63.7
14a			HA		2.66			38.62	5.02	147.78	5.76	65.4
14b	10	-1+3/4	and	-2.45+2.35	2.66	1.34	107.24	38.59	4.32	146.32	4.76	63.4
14c			soft		2.68			38.87	4.46	145.48	5.63	1.6
Avg					2.67			38.69	4.60	146.53	5.38	43.5

* Actual cement sk/cyd 5.44

Appendix III

(Page 3 of 8)

	Coarse aggregate							Concrete mix data*				
	Deleterious											
Batch	%	Size inches	Type	Sp. gr.	Bulk sp. gr. (SSD)	7-day abs. %	Dry rodded unit wt. lb/cf	% Sand to total aggregate	Net water gal/sk	Unit weight lb/cf	Air %	D.F.
15a			HA		2.69			38.17	5.02	147.75	4.33	91.9
15b	5	-1+3/4	and	-2.55+2.45	2.70	1.16	109.08	38.25	4.92	148.48	4.03	3.8
15c			soft		2.70			38.24	4.86	145.46	5.98	65.7
Avg					2.70			38.22	4.93	147.23	4.78	53.8
16a			HA		2.68			38.27	4.67	144.93	5.99	84.9
16b	10	-1+3/4	and	-2.55+2.45	2.68	1.33	108.42	38.24	4.16	146.63	4.88	85.2
16c			soft		2.70			38.53	4.46	145.71	6.21	89.9
Avg					2.69			38.35	4.43	145.76	5.69	86.7
17a			HA		2.70			38.12	4.67	146.98	5.00	85.2
17b	5	-1+3/4	and	-2.65+2.55	2.69	1.08	109.34	37.96	4.33	145.09	6.06	93.1
17c			soft		2.71			38.22	4.15	146.34	5.59	91.4
Avg					2.70			38.10	4.38	146.14	5.55	89.9
18a			HA		2.69			38.11	5.02	146.52	5.13	90.4
18b	10	-1+3/4	and	-2.65+2.55	2.69	1.17	109.08	38.07	4.28	145.24	5.96	69.2
18c			soft		2.71			38.38	4.86	146.83	5.27	78.8
Avg					2.70			38.19	4.72	146.20	5.45	79.5
19a					2.71			38.45	4.66	148.35	4.28	87.9
19b	5	-3/4+1/2	soft	-2.55+2.45	2.71	1.19	108.92	38.46	4.92	147.56	4.79	82.5
19c					2.71			38.42	4.15	146.08	5.74	89.8
Avg					2.71			38.44	4.58	147.33	4.94	86.7
20a					2.69			38.32	5.02	146.94	4.86	87.9
20b	10	-3/4+1/2	soft	-2.55+2.45	2.68	1.39	108.56	38.17	4.93	145.55	5.59	60.0
20c					2.69			38.29	4.46	145.62	5.71	19.4
Avg					2.69			38.26	4.80	146.04	5.39	55.8
21a					2.68			38.73	4.66	145.50	5.63	71.5
21b	5	-3/4+1/2	Chert	-2.35	2.69	1.36	107.57	38.85	4.31	145.72	5.60	45.6
21c					2.68			38.74	4.86	145.44	5.67	9.3
Avg					2.68			38.80	4.67	145.49	5.71	36.9

* Actual cement sk/cyd 5.44

	Coarse aggregate							Concrete mix data*				
	Deleterious											
Batch	%	Size inches	Type	Sp. gr.	Bulk sp. gr. (SSD)	7-day abs. %	Dry rodded unit wt. lb/cf	% Sand to total aggregate	Net water gal/sk	Unit weight lb/cf	Air %	D.F.
22a					2.65			37.82	4.67	144.56	5.74	27.0
22b	10	-3/4+1/2	Chert	-2.35	2.66	1.73	106.55	38.91	4.92	142.22	7.43	20.2
22c					2.66			38.91	4.86	145.53	5.27	16.1
Avg					2.66			38.55	4.82	144.10	6.15	21.1
23a					2.69			38.19	5.02	146.10	5.40	33.1
23b	5	-3/4+1/2	Chert	-2.45+2.35	2.68	1.18	108.92	38.02	4.33	144.98	5.96	61.8
23c					2.70			38.33	4.86	147.64	4.56	37.9
Avg					2.69			38.18	4.74	146.24	5.31	44.3
24a					2.67			38.50	4.14	145.73	5.30	12.8
24b	10	-3/4+1/2	Chert	-2.45+2.35	2.67	1.36	107.67	38.52	4.32	143.35	6.85	14.1
24c					2.69			38.82	4.86	145.51	5.78	3.7
Avg					2.68			38.61	4.44	144.86	5.98	10.2
25a					2.70			38.26	4.66	144.89	6.35	83.2
25b	5	-3/4+1/2	Chert	-2.55+2.45	2.68	1.08	109.08	37.96	4.29	144.80	6.08	86.8
25c					2.70			38.26	4.46	145.57	5.91	82.3
Avg					2.69			38.16	4.47	145.09	6.11	84.1
26a					2.68			38.86	4.31	144.56	6.24	48.5
26b	10	-3/4+1/2	Chert	-2.55+2.45	2.69	1.18	107.44	38.99	4.27	144.49	6.44	55.7
26c					2.68			38.84	4.24	146.50	4.98	74.6
Avg					2.68			38.90	4.27	145.18	5.89	59.6
27a					2.70			38.08	5.02	147.18	4.87	86.5
27b	5	-3/4+1/2	Chert	-2.65+2.55	2.70	1.03	109.31	38.17	4.92	147.84	4.45	89.9
27c					2.71			38.26	4.16	147.01	5.15	89.6
Avg					2.70			38.17	4.70	147.34	4.82	88.7
28a					2.69			38.44	5.02	144.80	6.25	87.9
28b	10	-3/4+1/2	Chert	-2.65+2.55	2.68	1.08	108.55	38.27	4.28	145.11	5.88	78.8
28c					2.71			38.71	4.86	148.06	4.46	90.8
Avg					2.69			38.47	4.72	145.99	5.53	85.8

* Actual cement sk/cyd 5.44

Appendix III

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Batch	Coarse aggregate: Deleterious %	Size inches	Type	Sp. gr.	Bulk sp. gr. (SSD)	7-day abs. %	Dry rodded unit wt. lb/cf	Concrete mix data*: % Sand to total aggregate	Net water gal/sk	Unit weight lb/cf	Air %	D.F.
29a			HA		2.67			37.87	5.02	144.45	6.13	93.2
29b	5	-3/4+1/2	and	-2.35	2.67	1.51	108.16	38.23	4.93	145.31	5.58	97.2
29c			soft		2.67			38.18	4.17	145.92	5.18	95.2
Avg					2.67			38.09	4.71	145.23	5.63	95.2
30a			HA		2.63			38.41	4.15	143.53	6.05	88.2
30b	10	-3/4+1/2	and	-2.35	2.63	2.03	106.42	38.46	4.93	144.05	5.72	80.5
30c			soft		2.63			38.46	4.87	143.90	5.82	86.9
Avg					2.63			38.44	4.65	143.83	5.86	85.2
31a			HA		2.67			37.76	5.02	144.95	5.81	48.0
31b	5	-3/4+1/2	and	-2.45+2.35	2.69	1.24	108.82	38.23	4.92	148.37	3.93	88.5
31c			soft		2.70			38.33	4.25	146.81	5.11	30.3
Avg					2.69			38.11	4.73	146.71	4.95	55.6
32a			HA		2.68			38.44	4.67	143.85	6.69	52.0
32b	10	-3/4+1/2	and	-2.45+2.35	2.67	1.49	107.31	38.68	4.32	144.23	6.68	85.2
32c			soft		2.68			38.83	4.46	144.40	6.34	82.7
Avg					2.68			38.65	4.48	144.16	6.57	73.3
33a			HA		2.70			38.25	4.32	145.46	5.98	92.3
33b	5	-3/4+1/2	and	-2.55+2.45	2.70	1.15	109.02	38.25	4.33	145.20	6.15	92.2
33c			soft		2.70			38.31	4.25	146.98	5.00	85.5
Avg					2.70			38.27	4.30	145.88	5.71	90.0
34a			HA		2.70			38.72	5.02	143.68	7.13	77.8
34b	10	-3/4+1/2	and	-2.55+2.45	2.67	1.30	107.67	38.54	4.32	145.20	5.65	86.8
34c			soft		2.68			38.70	4.46	144.58	6.22	94.2
Avg					2.69			38.74	4.66	144.88	6.15	66.0
35a			HA		2.69			37.90	4.67	145.55	5.76	87.8
35b	5	-3/4+1/2	and	-2.65+2.55	2.70	1.08	109.34	38.13	4.93	146.63	5.23	86.9
35c			soft		2.72			38.37	4.24	147.60	4.93	87.7
Avg					2.70			38.13	4.61	146.59	5.31	87.5

* Actual cement sk/cyd 5.44

Appendix III

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	Coarse aggregate							Concrete mix data*				
	Deleterious											
Batch	%	Size inches	Type	Sp. gr.	Bulk sp. gr. (SSD)	7-day abs. %	Dry rodded unit wt. lb/cf	% Sand to total aggregate	Net water gal/sk	Unit weight lb/cf	Air %	D.F.
36a			HA		2.70			38.63	4.66	147.16	4.88	85.3
36b	10	-3/4+1/2	and	-2.65+2.55	2.69	1.17	108.06	38.64	4.27	144.67	6.33	85.8
36c			soft		2.71			38.92	4.45	148.70	4.06	80.7
Avg					2.70			38.73	4.46	146.84	5.09	83.9
37a					2.67			38.77	5.02	146.63	4.72	70.8
37b	5	-1/2+1/4	Chert	-2.35	2.68	1.37	107.27	38.91	4.92	145.11	5.88	61.6
37c					2.68			38.90	4.86	147.69	4.20	67.4
Avg					2.68			38.86	4.93	146.48	4.93	66.6
38a					2.66			39.17	5.02	146.60	4.58	38.5
38b	10	-1/2+1/4	Chert	-2.35	2.67	1.76	107.01	39.31	4.92	145.20	5.65	20.0
38c					2.64			38.85	4.25	145.92	4.68	14.9
Avg					2.66			39.11	4.73	145.91	4.97	24.5
39a					2.70			38.16	5.02	146.50	5.31	70.7
39b	5	-1/2+1/4	Chert	-2.45+2.35	2.68	1.19	109.21	37.85	4.29	144.25	6.44	83.9
39c					2.69			37.98	4.16	145.44	5.83	74.8
Avg					2.69			38.00	4.49	145.40	5.86	76.5
40a					2.68			38.23	5.02	144.98	5.96	15.2
40b	10	-1/2+1/4	Chert	-2.45+2.35	2.66	1.40	108.46	37.91	4.34	144.93	5.66	26.2
40c					2.68			38.23	4.86	145.48	5.63	43.8
Avg					2.67			38.12	4.74	145.13	5.75	28.4
41a					2.70			38.16	5.02	142.93	7.62	85.4
41b	5	-1/2+1/4	Chert	-2.55+2.45	2.69	1.10	109.28	38.01	4.93	148.37	3.92	79.9
41c					2.71			38.28	4.46	146.04	5.77	88.6
Avg					2.70			38.15	4.80	145.78	5.77	84.6
42a					2.61			37.20	5.02	146.17	3.96	64.2
42b	10	-1/2+1/4	Chert	-2.55+2.45	2.68	1.21	108.59	38.22	4.93	146.76	4.81	78.4
42c					2.67			38.04	4.26	146.21	5.00	73.9
Avg					2.66			37.99	4.77	146.18	4.91	72.4

* Actual cement sk/cyd 5.44

Appendix III

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	Coarse aggregate							Concrete mix data*				
	Deleterious											
Batch	%	Size inches	Type	Sp. gr.	Bulk sp. gr. (SSD)	7-day abs. %	Dry rodded unit wt. lb/cf	% Sand to total aggregate	Net water gal/sk	Unit weight lb/cf	Air %	D.F.
43a					2.72			38.38	4.66	146.17	5.85	87.4
43b	5	-1/2+1/4	Chert	-2.65+2.55	2.70	1.03	109.40	38.08	4.28	146.12	5.55	93.3
43c					2.70			38.12	4.86	145.64	5.86	93.3
Avg					2.71			38.19	4.60	145.98	5.75	91.3
44a					2.68			38.02	5.02	147.60	4.27	92.6
44b	10	-1/2+1/4	Chert	-2.65+2.55	2.69	1.07	109.05	38.16	4.92	146.23	5.32	92.4
44c					2.70			38.29	4.86	144.65	6.51	89.3
Avg					2.69			38.16	4.93	146.16	5.37	91.4
45a			HA		2.70			38.50	5.02	144.71	6.46	89.1
45b	5	-1/2+1/4	and	-2.35	2.67	1.58	107.64	38.47	4.33	141.85	7.84	94.9
45c			soft		2.67			38.45	4.16	144.54	6.09	86.2
Avg					2.68			38.47	4.50	143.70	6.80	90.0
46a			HA		2.63			37.94	4.34	144.32	5.54	67.9
46b	10	-1/2+1/4	and	-2.35	2.64	2.17	107.18	38.07	4.18	145.15	5.17	79.8
46c			soft		2.64			38.11	4.87	144.76	5.43	83.3
Avg					2.64			38.04	4.46	144.74	5.38	77.0
47a			HA		2.68			38.13	4.67	146.26	5.14	85.4
47b	5	-1/2+1/4	and	-2.45+2.35	2.70	1.25	108.36	38.61	4.92	145.29	6.09	86.1
47c			soft		2.69			38.46	4.46	147.31	4.62	81.8
Avg					2.69			38.40	4.68	146.29	5.28	84.5
48a			HA		2.68			38.06	4.67	144.48	6.31	82.2
48b	10	-1/2+1/4	and	-2.45+2.35	2.67	1.51	108.00	38.28	4.93	145.29	5.59	66.9
48c			soft		2.68			38.42	4.86	145.37	5.71	86.0
Avg					2.68			38.25	4.82	145.05	5.87	78.4
49a			HA		2.69			38.06	4.33	145.62	5.71	93.3
49b	5	-1/2+1/4	and	-2.55+2.45	2.69	1.16	109.11	38.09	4.92	146.41	5.20	83.8
49c			soft		2.70			38.19	4.16	145.88	5.71	88.5
Avg					2.69			38.11	4.47	145.97	5.54	88.5

* Actual cement sk/cyd 5.44

Appendix III

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	Coarse aggregate							Concrete mix data*				
	Deleterious											
Batch	%	Size inches	Type	Sp. gr.	Bulk sp. gr. (SSD)	7-day abs. %	Dry rodded unit wt. lb/cf	% Sand to total aggregate	Net water gal/sk	Unit weight lb/cf	Air %	D.F.
50a			HA		2.69			38.15	5.02	144.11	6.05	82.2
50b	10	-1/2+1/4	and	-2.55+2.45	2.68	1.34	108.42	38.24	4.28	144.51	6.26	88.0
50c			soft		2.69			38.42	4.86	145.35	5.88	90.2
Avg					2.69			38.27	4.72	144.66	6.06	86.8
51a			HA		2.70			38.08	5.02	143.81	7.04	81.9
51b	5	-1/2+1/4	and	-2.65+2.55	2.71	1.09	109.44	38.22	4.92	147.71	4.70	93.4
51c			soft		2.71			38.21	4.86	146.34	5.58	92.3
Avg					2.71			38.17	4.93	145.95	5.77	89.2
52a			HA		2.71			38.25	4.66	144.93	6.49	88.3
52b	10	-1/2+1/4	and	-2.65+2.55	2.70	1.19	108.95	38.29	4.32	144.63	6.48	89.4
52c			soft		2.71			38.45	4.86	146.41	5.53	88.1
Avg					2.71			38.33	4.61	145.32	6.17	88.6
53a	All good aggregate of one size							40.09	4.65			84.0
53b	-1+3/4 and one sp. gr. -2.65+2.55				2.64	0.99	105.07	40.09	4.65	145.22	5.35	84.1
53c								39.73	4.66			36.0
Avg								39.97	4.65			68.0
54a	All good aggregate of one size							39.47	4.65			80.4
54b	-1+3/4 and one sp. gr. -2.75+2.65				2.71	0.99	107.87	39.47	4.65	148.43	4.43	93.6
54c								39.11	4.66			85.1
Avg								39.35	4.65			86.4
55a	All good aggregate of one size							40.82	4.63			89.4
55b	-1/2+1/4 and one sp. gr. -2.65+2.55				2.64	0.99	103.70	40.82	4.63	145.50	5.10	92.0
55c								40.82	4.63			91.2
Avg								40.82	4.63			90.9
56a	All good aggregate of one size							40.48	4.63			86.3
56b	-1/2+1/4 and one sp. gr. -2.75+2.65				2.73	0.99	106.50	40.48	4.63	147.31	5.46	88.7
56c								40.12	4.63			92.3
Avg								40.36	4.63			89.1

* Actual cement sk/cyd 5.44

Appendix IV

Tests on individual aggregate classes - Computations for making concrete

The volume of concrete in a 3 x 4 x 16 inch beam is 0.111 cubic feet. This consists of coarse and fine aggregate, cement, water, and entrained air. Proportions for these ingredients for concrete of various applications have been established by the American Concrete Institute (12), the procedures of which are recommended in ASTM C-233.

The recommended slump for concrete pavements has been set at 2-1/2 inches. The water required to produce this slump was found to be about 28 gallons per cubic yard in the present study. The air content recommended by ASTM C-233 is 5.5%; this value was assumed in computing proportions for all beams. The cement used was purchased locally and was a mixture of three commercial brands of type 1A (Huron, Penn Dixie, and Medusa). ASTM C-233 recommends the use of 5.5 ± .05 bags per cubic yard of concrete. The coarse aggregate content required for fine aggregate of the particular fineness modulus used (2.76) from ACI 613-54, Table 6 was 0.664 unit volumes of dry rodded aggregate per unit volume of concrete. Tests made on coarse and fine aggregate prior to computation are tabulated below:

Ingredient Tested	Physical Property Tested	ASTM desig	Symbol Value
Coarse Aggregate	Bulk sp. gr., satd surf. dry.	C-127	SGCA
" "	7-day absorption, % dry basis	"	ACA
" "	Moisture, % dry basis	"	MCA
" "	Unit wt., lbs./cu. ft.	"	Uw*
Fine Aggregate	Bulk sp. gr., dry basis	C-128	SGS
" "	24 hr. abs., % dry basis	"	AS
" "	Moisture, % dry basis	"	MS

The quantities of other ingredients required for a single beam were computed as follows:

* For these computations, unit weight is that of saturated surface-dry aggregate

Cement, assumed specific gravity (SGC) = $3.15 \times 62.4 \frac{lb}{ft^3} = 196.6\ lb/ft^3$

" weight (WC) = $0.111\ ft^3 \times \frac{5.5\ bags}{yd^3} \times \frac{94\ lb}{bag} \times \frac{1\ yd^3}{27\ ft^3} = 2.125\ lb$

Water, specific gravity (SGW) = $62.4\ lb/ft^3$

" weight (WW) = $0.111\ ft^3 \times \frac{28\ gal}{yd^3} \times 8.34 \frac{lb}{gal} \times \frac{1\ yd^3}{27\ ft^3} = 0.960\ lb$

Air, vol. (VA) = $0.055 \times 0.111\ ft^3 = .006105\ ft^3$

Coarse aggregate, abs., % dry basis = ACA

" " unit wt., satd surf dry (UwS) = Uw + Uw x ACA/100

" " wt. (WCA) = $0.111\ ft^3 \times 0.664 \frac{DR\ ft^{3}*}{ft^3} \times \frac{UwS}{DR\ ft^3} = 0.0737\ Uw$

" " specific gravity, sat'd surf. dry = SGCA

Fine aggregate, vol (VFA) = Batch vol $- \frac{WC}{SGC} + \frac{WW}{SGW} + VA + \frac{WCA}{SGCA}$

$$= 0.111 - \frac{2.125}{196.6} + \frac{0.960}{62.4} + .006105 + .0737 \frac{UwS}{SGCA}$$

" " specific gravity, dry basis = SGFA = 2.64 x 62.4 = 164.7

" " wt. (WFA) = VFA x SGFA = VFA x 164.7 = 12.96 - 0.194 UwS/SGCA

Each beam was made from a separate batch of concrete and the volume of coarse aggregate used was smaller than the standard unit weight bucket. It was therefore necessary to make and calibrate a small (about 0.07 cubic ft.) unit weight bucket. The requirement of knowing the exact composition of each aggregate batch coupled with the ACI 613-54 requirement of knowing the unit weight before computing the quantity of coarse aggregate to use resulted in a procedure whereby: 1) a smaller than required batch of coarse aggregate of the correct proportions was prepared, 2) the unit wt. was determined, corrected to the saturated surface-dry value by adding the computed weight due to absorbed water in the good and deleterious fractions, and 3) the value of the saturated surface-dry unit weight obtained

* DR stands for dry rodded

was used to compute the quantity of coarse aggregate of the two types to be used for the properly proportioned batches (or three types for HA and soft mixtures).

Since it was necessary to include the entire batch of coarse aggregate in a beam, a 10% excess of the other three ingredients (cement, sand, and water) was added to make sure the mold was filled, thus making the mix proportions slightly different than specified. It was assumed that this excess mortar was lost in the mixer and during leveling of the material in the molds. Even if this were not true it would not be expected to affect the results significantly.