

Highway Materials Research Laboratory  
132 Graham Avenue, Lexington 29, Ky.

November 14, 1949

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Memo. to: Dean D. V. Terrell  
Director of Research

Re: Research Project C-23 on Blended Coarse Aggregate

At the meetings of the Research Committee on January 24, and October 14, 1947, first and second progress reports on our study of the effect of blended coarse aggregate on the durability of concrete mixes were presented and discussed in detail. You will recall that this study was initiated as a result of a 1945 survey of concrete pavements by the Division of Design in which there were indications that the general performance of concrete pavements containing Ohio River Gravel was somewhat inferior to that of concrete containing some other coarse aggregates.

Because of this the Research Laboratory was asked to investigate the possibility of improving durability characteristics through either the combination of some limestone from a source of known good quality with the river gravel, or through the use of air entrainment. As it turned out, the project included the study of both factors, but shortly after that time air entrainment was adopted as a standard for concrete pavements regardless of the aggregate.

As a result of the work in this project, a policy under which aggregates would be combined was discussed in a Research Committee meeting and adopted by the Department about as follows:

1. In concrete containing Ohio River gravel, No. 3 limestone from a known good source should be combined with the gravel (usually No. 6 size) to form a No. 36 coarse aggregate consisting of 40 per cent limestone and 60 per cent gravel by weight.
2. In concrete containing glacial pit gravel as it is normally furnished for construction in Kentucky, the advantages gained through combining limestone with the gravel would be so slight that blending of aggregates in this case should not be required.

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3. To differentiate between those gravels which should be supplemented by limestone and those which should not: if 75 per cent or more of the gravel was derived from limestone (75 per cent or greater calcium carbonate or magnesium carbonate content) the addition of limestone should not be required.

Although this policy has been in effect for two years, I know of no construction jobs where the combined aggregate was actually used.

Recently there has been considerable reason to question some of the requirements outlined above and some criticism has been received from certain gravel producers who point out the satisfactory performance of some concrete pavements containing gravels which under this policy would require an addition of high-grade limestone. Also, the Technical Director of the National Sand and Gravel Association has visited the Laboratory to discuss experimental data and the possibility of modifying this requirement to better suit the merits of the case.

In view of these circumstances, the attached Report No. 3 on this research project is submitted as a basis for further consideration of combined aggregates. This report covers a limited set of durability tests that were made on concrete specimens containing individually the different components of the gravel that was used in making up the samples with combined aggregates. Although the data may not be conclusive because of the very few samples involved, there are some striking contrasts that provide a basis for reconsideration of the policy. It was unfortunate that separation of aggregates into the different fractions was so difficult and time consuming that we were unable to make more samples, for then the effects might have been shown with more certainty.

The outstandingly poor performance of the concrete containing chert was, to some degree, expected. In contrast, the distinctly greater durability of concrete with each of the other gravel fractions was not anticipated, nor was it anticipated that air entrainment would hardly improve the durability of the concrete containing chert. Another significant thing about the results in their entirety is the fact that all of the components of the gravel taken separately and made into separate sets of concrete specimens were of approximately equal value, with the exception of the chert.

This indicates that perhaps our requirement of a certain amount of calcium carbonate or magnesium carbonate in the gravel is not very valid. Beyond this, of course, it is known that

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sound and durable concrete can be made from stone that contains practically no calcium or magnesium carbonate. Although there may be some reasons for attributing excessive deterioration to the lack of uniformity in gravel and the attendant differential stresses set up in concrete under changing conditions, these reasons have only limited support from the data thus far. For example, the original set of tests showed that the concrete with the whole gravel aggregate and no air entrainment was not half as durable as corresponding concrete with any one of the separated fractions (except chert), yet there are the concrete pavements containing non-uniform aggregate and showing good performance which must be regarded.

At this stage it appears best to concentrate on the chert fraction and leave the non-uniformity to future investigation. Even chert warrants considerably more study because it is known that among the numerous types of chert, there are some that are reasonably durable in concrete. About the best information along these lines that has been developed in research elsewhere indicates that cherts containing opaline silica are the most unsound of all, and that these can be readily identified as banded or mottled when the individual pieces are broken and the fragments observed with the naked eye. It is not yet known whether or not these particular cherts are invariably unsound in concrete mainly because of reaction with the alkalies in the cement.

With all these matters set aside for future study, it is recommended that the policy of combined aggregates be modified to the extent that combination of limestone with gravel be required for concrete pavement construction only when the gravel has a chert content greater than 10 per cent. Chert counts for this purpose will not be difficult to make once an inspector or technician has been thoroughly trained in the identification of the material described as chert.

From the standpoint of the producer, this should not be too difficult to meet either. For example, in making chert counts on a number of different samples of Ohio River Gravel obtained at different times and from different sources, we have found that the percentages of chert ranged from about 1 per cent up to 40 per cent. The majority of the counts were much lower than 10 per cent, and practically all were lower than 15 per cent. Probably the greatest difficulty will be experienced by those producers who dredge at some distances below Louisville.

With regard to the basis for establishing a 10 per cent limit, it was shown in the tests on the combined aggregate that when 40 per cent limestone was added (and thus the percentage of

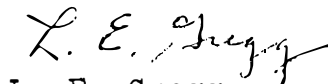
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chert in the total aggregate reduced to about 20 per cent). the durability of the concrete was reasonably good -- so good in fact that we considered this adequate from a specification standpoint. However, the data in our Report No. 2 showed that as greater percentages of the limestone were added, the durability increased appreciably even past the point where the aggregate contained 80 per cent limestone. Under those circumstances, the amount of chert would be slightly less than 10 per cent of the total aggregate. Therefore, on the face of it the 10 per cent chert content is a reasonable figure. This figure is even more reasonable when it is known that many of the producers, by selecting the bars from which they dredge, can easily reduce their chert contents to something much lower than 10 per cent.

I believe that the principal of combined aggregates is still valid if there is no alternative, but when it is possible to obtain materials that are suitable for making durable concrete, and when this can be accomplished by normal production methods, there is no need to adhere to a criterion for combinations of materials as we originally visualized it. If the recommended change is made, it will probably require some discussion with those producers who are interested, in order to definitely acquaint them with our concepts of chert. Also, it will necessitate development of rapid and simple means of identifying chert which can be used by aggregate inspectors. This has been discussed with Mr. Bitterman, and there seems to be no reason why it can not be accomplished.

It is with all these things in mind that the Research Laboratory recommends a change of the combined aggregate policy to one dependent on percentages of chert rather than percentages of calcium and magnesium carbonate.

Respectfully submitted,



L. E. Gregg  
Associate Director of Research

LG:vk

Commonwealth of Kentucky  
Department of Highways

Progress Report No. 3  
on  
Research Project C-23

A STUDY OF THE EFFECT OF BLENDED COARSE  
AGGREGATE ON AIR-ENTRAINED CONCRETE

by  
S. T. Collier  
Senior Research Engineer

November - 1949

INTRODUCTION

The purpose of this investigation was to study the durability characteristics of a river gravel, used as coarse aggregate for concrete, with respect to four major fractions separated in accordance to their general mineralogical classification. This aggregate was from the same stock of Ohio River gravel that was used in earlier phases of this Project reported in 1947.

Since this gravel consisted of several rock types varying in mineralogic constituents, it was conceivable that poor performance could possibly be attributed to some undesirable fraction or fractions, rather than to the aggregate as a whole.

The separation of this aggregate was rather general yet satisfactory for the purposes of this study and was confined to four fractions in each of which there was a preponderance of one general rock type. These four fractions were designated, for convenience, as limestone, chert, quartzite, and granite.

Evaluation of durability characteristics was made by means of freezing and thawing tests on like samples of concrete made with the different gravel components. All other features of the concrete were kept as constant as possible.

### MATERIALS

The coarse aggregate was dredged from the Ohio River a few miles upstream from Louisville. It contained pieces representing several parent sources, but its greatest bulk was differentiated into four groups described in the following paragraphs.

Within the four major fractions there were numerous variations as might be expected in anything as broad and general as rock classifications, but for the purpose of this study all aggregate was separated visually and defined specifically as follows:

#### Limestone Fraction

The white carbonaceous gravel, which constituted about 30 percent of the total material, was termed limestone. Because of the limited amount of material that could be separated conveniently, no determination of percentages of calcium carbonate and magnesium carbonate were made; however, visual classification established the fact that these were high, although some extraneous materials were known to be included in this group. On the whole, this fraction had more extraneous material than any of the other groups.

#### Quartzite Fraction

The material designated as quartzite, consisted of

heavy greenish gravel, smooth in texture and containing large percentages of ferrous minerals. By definition, true quartzite is a metamorphosed, firm, compact sandstone with highly tenacious characteristics. Colors may range through any or all gradations as the impurities vary. Fractures are irregular across the mineral grains. Approximately 25 percent of the gravel was composed of material in this group.

#### Chert Fraction

The chert fraction consisted essentially of chert, with some jasper and flint included. From the standpoint of inherent properties, all of these are composed essentially of silica with various impurities. In texture they are fine grained to cryptocrystalline. Chert is generally light colored, white or gray; flint is black to dark gray; jasper is reddish due to ferric oxide. Common impurities may be hematite, limonite, pyrite, marcasite, carbonaceous matter, and calcium and magnesium carbonates and many color changes result from oxidation. Typical chert and flint have fine texture, vitreous to waxy lustre, and a conchoidal fracture. A few are granular with irregular fractures. The fraction classed as chert was the most abundant of the four fractions, with more than one third of the total aggregate consisting of this material. Identification was principally by texture with color being a minor aid.

### Granite Fraction

A fourth fraction composed essentially of granite in various forms and colors, made up less than 10 per cent of the total aggregate. Granite is a light colored intrusive, granular, igneous rock consisting of feldspar and quartz in the main. Dark particles (which were common in this fraction of the gravel) are usually hornblende or mica.

Because of the inherent difficulties of making this four-fraction separation, there was a small percentage of the material that did not fall into a specific mineral classification. This percentage was so small that it was considered negligible in the final effect on the concrete mixes. In case some appreciable effect was produced by these minor elements, the limestone fraction suffered most from this contamination because these extraneous pieces resembled the limestone most and thus were placed in that group. Some obvious impurities such as coal, shale, and soft sandstone could be identified easily and were eliminated as much as possible.

The fractions were separated manually and identified by visual inspection. The labor and time involved greatly limited the production of the desired quantity for a complete set of specimens for each fraction. This applied particularly to the granite fraction. In grading the aggregates, the quantities of all but the limestone fraction were further reduced (see Table I) in order to make all fractions have comparable gradations equal to a Standard No. 6.



Table I. Weights and Percentages of Components in the Gravel Originally and Separated to No. 6 Size

<u>Fraction</u>	<u>Original Weight</u>	<u>Per Cent of Total</u>	<u>Graded Weight No. 6 Size</u>	<u>Per Cent of Total</u>
Limestone	214.2	29.8	214.2	33.4
Chert	265.8	36.9	207.7	32.4
Quartzite	173.5	24.1	164.5	25.7
Granite	66.0	9.2	54.0	8.4

The fine aggregate was Ohio River Sand obtained in the vicinity of Louisville and also of the same stock that was used for previous tests in this Research Project. The cement was regular portland of a standard brand. Air was entrained, in some cases by addition of a neutralized vinsol resin solution.

#### PROCEDURES

The procedures were more or less standard with respect to those followed in the laboratory durability tests, at the time that this investigation was started.

Customary designs for the six bag mix calculated on a solid volume basis were followed and the aggregates were proportioned on the basis of saturated surface-dried weights. The ratio of the fine to coarse aggregate without air-entrainment was 35:65, and since adjustments in design were necessary to compensate for increased yield in mixes with air-entrainment, the ratio was 34:66 when the concrete had air-entrained. Water cement ratios of 5 gallons per sack for non-air entrained mixes, and 4.75 gallons per sack for mixes with entrained air were used. The ranges in actual cement factors and water-cement

ratios are shown in Table II. A slump of 1-3/4-inch to 3-inches was maintained for all mixes although the objective was a 2 to 3-inch slump.

Where an air-entraining agent was incorporated mixes were designed for 4 per cent air. Actual air contents were measured in all cases by the gravimetric method (A.S.T.M. Designation: C 138-46), using a 0.5 cubic foot container. When the amount of material permitted, air contents were determined also by the pressure method.

Beam specimens were prepared with 3-x5-x20-inch molds, the placing, rodding, and finishing being in accordance with A.S.T.M. Designation: C 192-44T. There was sufficient aggregate of the limestone and chert fractions to permit preparation of six beams (three each for control and durability specimens) for both non-air entrained and air entrained mixes. For the Quartzite group, specimens were limited to two control and three durability beams for each mix. For the Granite group there was sufficient aggregate for only three beams, one control and two durability, and these were limited to a non air-entrained mix only.

After seven days of curing in the moist room, a set of specimens representing each group and termed "control beams" were loaded in flexure at the third point over an 18-inch span. At the same time the companion group of durability specimen was taken from the moist room for weight and sonic determinations. Following this they were immediately subjected to freezing in air for about 18 hours at +10°F and thawing in water for about 6 hours at room temperature (65°F to 85°F).\*

\*See Footnote Page 10

Sonic measurements were made at varying stages of the test with no specific plan of measuring at regular intervals. Tests for sonic modulus consisted of placing the beams on rubber supports, the centers of which were about 4.5-inches (0.2242 length) from the ends of the beam. The beams were then vibrated by regulated electrical impulses, the objective being to determine the natural frequencies of the specimens which are indirect measures of their soundness or structural integrity. After the average sonic modulus for a set of beams indicated as much as 50 per cent reduction in strength for the set, or after the beams had been exposed to 200 cycles of freezing and thawing (whichever came first), these samples were removed from the durability test and broken in flexure. By means of comparison between the initial modulus of rupture represented by the control specimens, and the final modulus of rupture exhibited by the durability specimens, durability indexes both individually and by sets of beams were calculated as the percent reduction in modulus of rupture per 100 cycles of freezing and thawing. Thus, a low durability index indicated concrete of high resistance to freezing and thawing. Values of durability indexes are tabulated in the last column of Table II, and changes in sonic modulus with increasing cycles of freezing and thawing are plotted in Fig. 1.

## RESULTS

The durability index (final column of Table II) expressed as the percentage decrease in modulus of rupture per 100 cycles of freezing and thawing, is a fair measure of the relative performance of the several groups. The values are negative

Durability Test Data						
General Classification of Aggregate	Durability					
	Group	Pct. Change in E	Modulus of Rupture	Pct. Change in Mod. of Rupture (4)	Durability Index (5)	
LIMESTONE 30 Pct. of Total Agg. S.G.-S.S.D. 2.66 Pct. Absorption 2.51	6	-17.4	0	-100.0	69	
	6	-9.8	6	-99.2	69	
	9	+4.8	144*	-80.4	55	
	A 0	-7.4	50	-93.2	62	
	2	+16.9	648	+3.8	+2	
	2	+16.7	672	+7.7	+4	
	5	+15.4	1056	+69.2	+34	
	B 6	+16.3	792	+26.9	+13	
	QUARTZITE 24 Pct. of Total Agg. S.G.-S.S.D. 2.76 Pct. Absorption 0.79	6	-43.9	96*	-86.7	60
		4	-40.9	138	-80.8	55
6		-1.6	214	-70.3	48	
C 8		-28.8	149	-79.3	54	
8		+16.4	792	+13.8	+7	
7		+7.8	187*	-73.1	37	
2		+11.0	624	-10.3	5	
D 4		+11.5	534	-29.2	12	
CHERT 37 Pct. of Total Agg. S.G.-S.S.D. 2.52 Pct. Absorption 3.73	9	-43.8	36	-94.4	129	
	9	-18.1	48	-92.5	127	
	9	-39.0	60	-90.6	124	
	E 6	-33.6	48	-92.5	127	
	3	-18.3	14*	-97.9	134	
	9	-36.7	84	-87.1	119	
	8	-35.5	84	-87.1	119	
	F 7	-30.2	61	-90.7	124	
GRANITE 9 Pct. of Total Agg. S.G.-S.S.D. 2.67 Pct. Absorption 0.91	G 8	-41.3	228	-72.9	50	
	1	-35.3	132	-84.3	58	
	9	-38.3	180	-78.6	54	

(1) Values in parenthesis of rupture was calculated Pressure Meter usus of rupture for the control beams.

(2)&(3) Values in parenthesis of rupture per 100 cycles of water-cement rati

of mid-section of specimens beyond A.S.T.M. C-78-44.

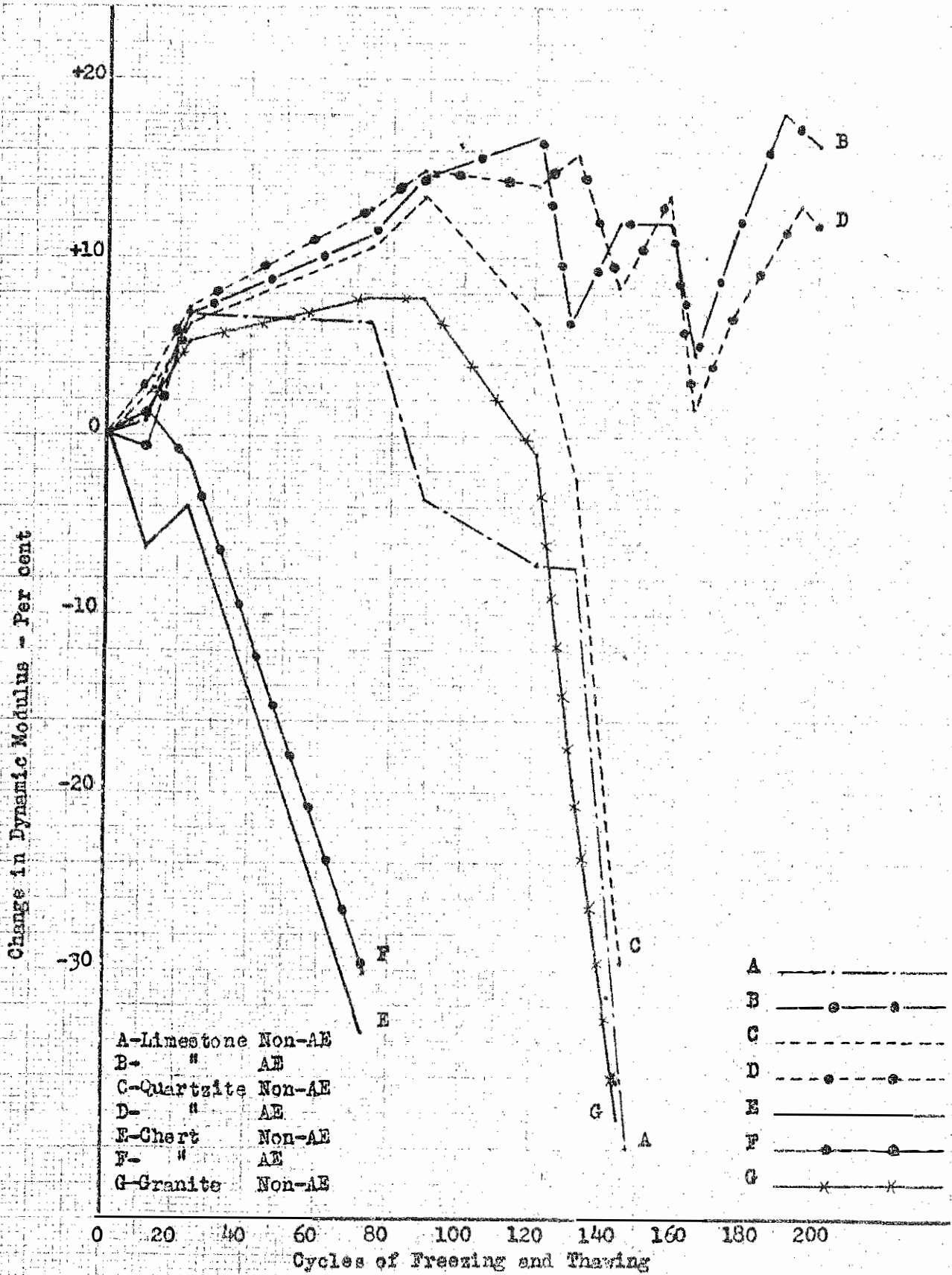


Fig. 1. Changes in Dynamic Moduli of Elasticity with Increasing Cycles of Freezing and Thawing.

quantities, and the greater the numerical value of the durability index the poorer the performance of the specimens. No indicated change in flexural strength is expressed as zero; an increase in strength is indicated by a positive sign.

A study of the summarized results reveals that concrete made with chert aggregate was by far the poorest in performance; nor were there any beneficial effects provided by air-entrainment since the performance of the specimens in both groups, E and F, are comparable. This is borne out by their respective average durability indexes - 127 for non-entrained concrete and 124 for the air-entrained. The similar condition of the specimens are in evidence in the photographs of Fig. 2.

The specimens containing limestone, quartzite, or granite aggregate and no air-entrainment showed much better performance, all showing less than half the deterioration of corresponding samples with chert and no air entrainment (as indicated by the calculated durability indexes). For the air-entrained mixes the disparity was much greater of course. It is significant that the non air-entrained concrete with limestone, quartzite, and granite had about equal resistance to freezing and thawing. The concrete with limestone aggregate was slightly less durable than the other two when there was no air entrainment. The limestone had an absorption of 2.5 per cent against less than 1 per cent for the quartzite and granite. The granite was not included in air-entrained concrete due to lack of material.

In view of the evidence presented by the data, the chert fraction was apparently the greatest factor contributing to the relatively poor performance of gravel from this source in mixes

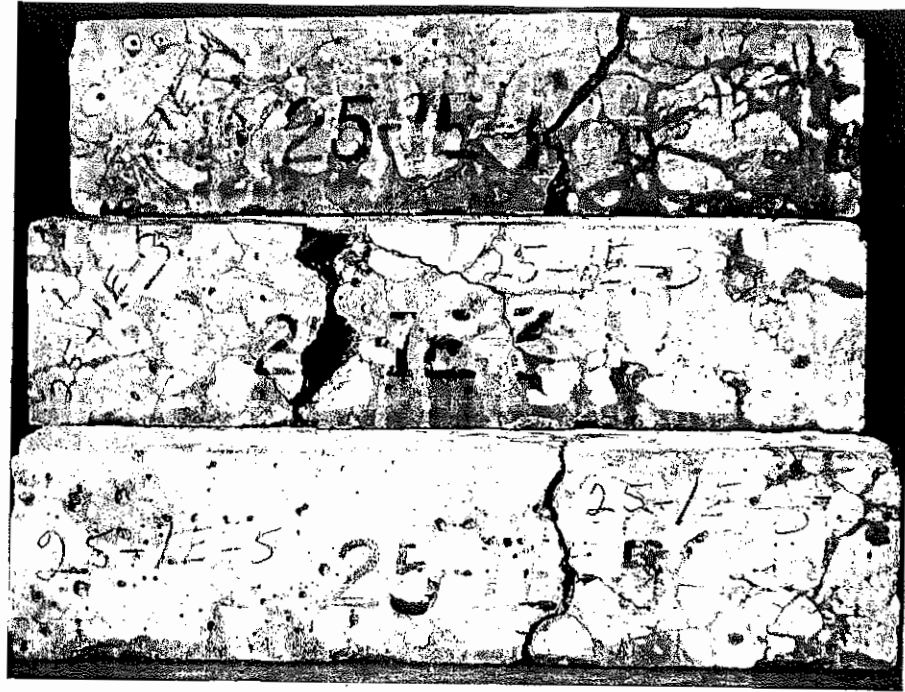


Fig. 2. Beam specimens containing chert aggregate after completion of the durability and flexure tests for final modulus of rupture. The upper samples had 1.5 per cent air and completed 73 cycles of freezing and thawing with an average modulus of rupture of 48. In comparison, the lower samples had 4.5 per cent air, were exposed to 73 cycles also, and had an average modulus of rupture of 84. (The upper beam not included in this average because of rupture near the left end) Average durability indexes of 127 and 124 respectively show that air entrainment was of little advantage in promoting durability for concrete containing chert aggregate.

made for earlier tests in this project. This is further emphasized by the fact that the durability indexes of specimens containing the whole gravel in the original tests (see Table II Report II, on this project dated October 14, 1947) indicated poorer performance than concrete containing the separate fractions. Comparisons are given in the following table;

Table III. Comparative Factors of Deterioration in Freezing and Thawing Tests

Coarse Aggregate	Air Content Per Cent	Average Durability Indexes for 7 Day Specimens
100 pct. Original Gravel	1.6	138
Chert Fraction	1.7	127
Limestone Fraction	2.3	62
Quartzite Fraction	2.0	54
Granite Fraction	0.4	54
60% Original Gravel ) 40% Cr. L. S. )	2.3	47
100 pct. Original Gravel	5.2	67
Chert Fraction	4.5	124
Limestone Fraction	4.6	+13
Quartzite Fraction	4.6	12
60% Original Gravel ) 40% Cr. L. S. )	4.7	37.5

All of the fractions show a greater resistance to freezing and thawing than the original combination in the specimens without air entrainment. The limestone, quartzite and granite performed somewhat less favorably than the 60-40 per cent com-



bination of the gravel and crushed limestone. In the specimens made with air entrained concrete only those made with the chert fraction show a poorer performance than the original stock. The specimens containing the limestone and quartzite fractions were more durable than the 60-40 per cent combined aggregate in the air entrained concrete. Although the durability of concrete is improved with the addition of higher grade aggregate to an inferior aggregate, there is also an indication that some incompatibility occurs in the combination of aggregates of various mineral types.

\*More recently the freezing and thawing tests have been revised mainly with provision for thawing at a constant temperature of 40°F; also, beam molds have been altered to provide for a 5-inch horizontal open face and a 2-inch depth as the specimens are molded.