

Commonwealth of Kentucky  
Department of Highways

Second Progress Report  
on  
Research Project C-23

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

by

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When the first progress report on this study of blended aggregate was prepared in January, 1947, only three of the nine groups of samples in Series I had completed the durability tests, and specimens in four of the seven groups composing Series II had not even been prepared. In contrast, at the present all samples in Series I have completed the durability tests thus concluding the results pertaining to Ohio River gravel from Louisville, and specimens in three groups of Series II (applicable to glacial gravel) have finished the durability tests. Further than that, several additional groups of samples which form a part of the over-all study of combined aggregate materials have been prepared in the interim, and some of these were placed in durability tests several weeks ago. These, however, are of doubtful ultimate value because of defects in operation of equipment, and for that reason plus the fact that nothing of significance has shown up in the tests - they are not given consideration in this report.

As shown in Table I, where the results are summarized, only four sets (or two groups) of specimens were able to withstand freezing and thawing for 200 cycles - the maximum duration of test or point at which beams were removed if failure had not occurred previously. These samples were in Series I, Group G, where the mix contained 100 percent limestone coarse aggregate and 4.3 percent air, and Series II, Group A, which had 100 percent glacial gravel and 6.1 percent air in the mix. Apparently, the unusual durability of the latter must be dependent upon its high air content, because mixes with the same aggregate but only 1.7 percent air (Series C) or even 4.1 percent air (Series B) could withstand not more than 172 cycles. Thus, for practical purposes all mixes except those with 100 percent limestone and "air entrainment" failed in less than 200 cycles.

## DURABILITY INDEX BASIS FOR RATING

From the beginning, deterioration of the concrete under freezing and thawing was measured by the amount of reduction in flexural strength or modulus of rupture. Thus, in the preparation of samples from every batch, a minimum of three beams were made for flexure tests at the end of the curing period, and at least three were poured for durability samples, which, after the curing period, were subjected to freezing and thawing, then tested in flexure. In that way, the average of valid results for these two types of samples were compared in order to determine the percentage reduction in strength caused by exposure to freezing and thawing. In the original report (on page 5) these were referred to as "control" and "durability" specimens respectively, and they are so designated in the present listing of results in Table I.

Since all specimens were not exposed for the same number of freezing and thawing cycles, the reduction in strength must be judged in combination with length of exposure in order to convert all measurements to a common denominator. This was done by means of a factor known as durability index which is calculated as the percentage reduction in modulus of rupture per 100 cycles of freezing and thawing. These values are tabulated in Table II, and are plotted graphically in Fig. 1 to show the relationship between the durability indexes and the percentage of limestone contained in the coarse aggregate portion of the mix.

It is to be noted that a high durability index is indicative of a low resistance to freezing and thawing, because those mixes with the greatest durability or most resistance have the least reduction in strength caused by exposure. Also, even with the conversion to a common basis of reduction in strength per 100 cycles of test, it is probable that the durability index is not free from influence by the length of exposure. This is so since the specimens do not deteriorate at a uniform rate, or at least sonic measurements indicate them so. On page 8 of the initial report, emphasis was placed on the fact that for some of the best mixes cured 7 days sonic values increased during the first 50 cycles. From that point on there was a progressive reduction in the sonic modulus. Hence, for samples in Groups F or G of Series I there would be a great difference in the durability indexes had they been computed for samples loaded in flexure after 50 cycles as opposed to the durability indexes computed for those actually tested after 164 or 200 cycles, as the case may be. This is true, provided the sonic values are reasonably authentic measures of structural integrity in the concrete.

Even if this is so, the modification in data is one of degree rather than direction. There is no means by which the general relationship among the different mixes could be made much different from that shown in Fig. 1. It is possible that an extension of the test in some instances would have increased the

TABLE II. DURABILITY INDEXES OF CONCRETE MIXES EXPRESSED AS A PERCENTAGE DECREASE IN MODULUS OF RUPTURE PER 100 CYCLES OF FREEZING AND THAWING

Designation		Coarse Aggregate Combination		Air Content	Durability Index	
Series	Group	Pct. Gravel	Pct. Limestone		7 Day Specimens	28 Day Specimens
I	A	100	0	1.6	138.3	169.5
	<u>B</u>	100	0	5.2	66.7	72.4
	<u>C</u>	80	20	3.9	44.6	56.7
	<u>E</u>	60	40	2.3	46.6	50.9
	<u>E<sub>2</sub></u>	60	40	2.4	55.1	54.8
	<u>D</u>	60	40	4.7	37.5	35.4
	<u>H</u>	40	60	4.2	32.9	18.1
	<u>F</u>	0	100	2.7	30.0	32.2
	<u>G</u>	0	100	4.3	18.6	18.1
II	C	100	0	1.7	55.3	58.8
	<u>B</u>	100	0	4.1	42.5	38.9
	A*	100	0	6.1	10.0	
	<u>D</u>	80	20	3.1	--	--
	<u>F</u>	60	40	1.8	--	--
	<u>E</u>	60	40	3.0	--	--
	<u>G</u>	40	60	3.3	--	--

\*Not considered in plot for Fig. 1 because of high air content.

Samples for groups underscored in red were intentionally air entrained, hence these are represented by curves on the right in Fig. 1.

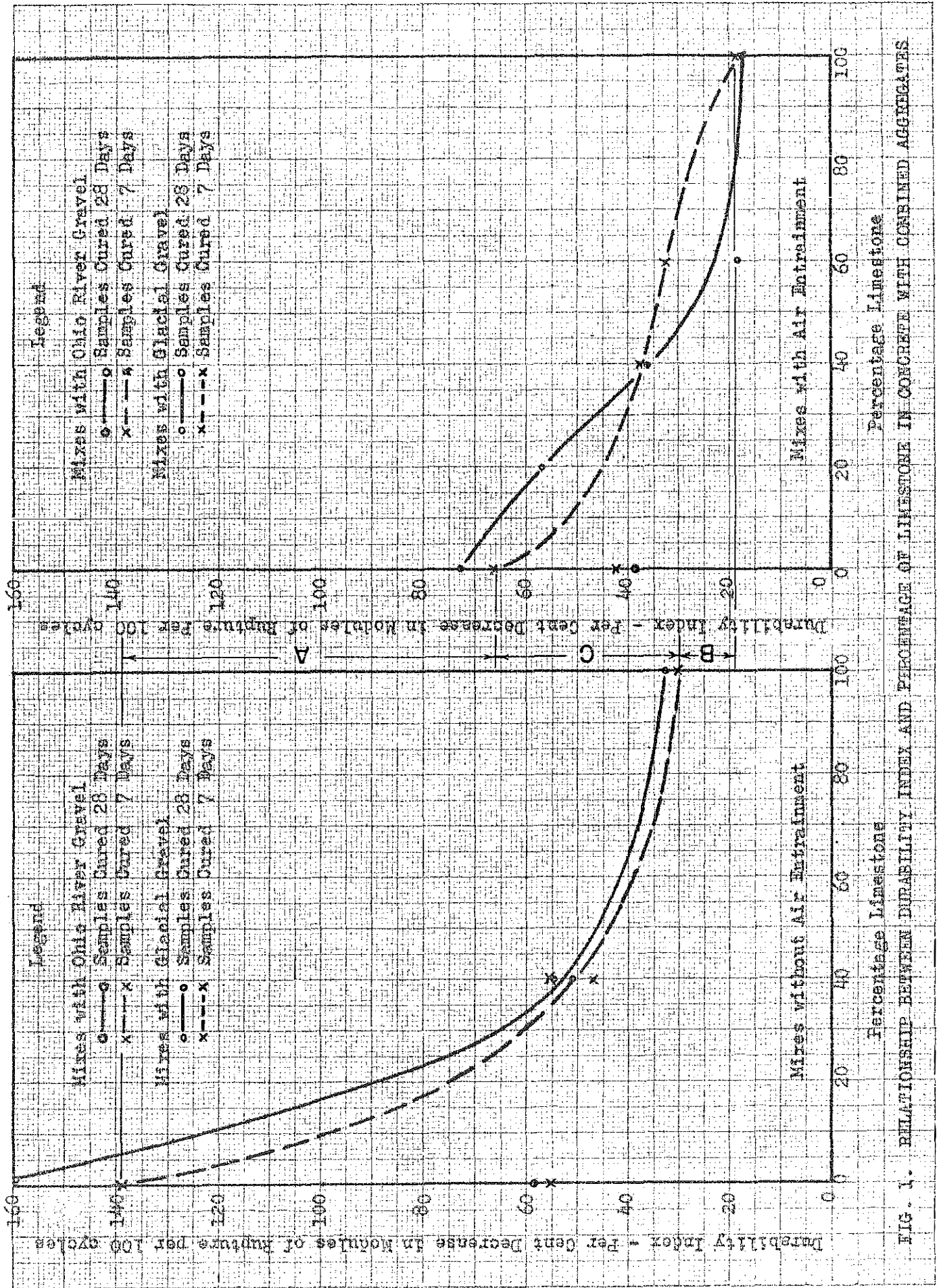


FIG. 1. RELATIONSHIP BETWEEN DURABILITY INDEX AND PERCENTAGE OF LIMESTONE IN CONCRETE WITH COMBINED AGGREGATES

percentage reduction in strength without a proportionate increase in cycles required to accomplish this. Hence the durability indexes in those instances would have been increased to a greater reduction per 100 cycles. However, for almost all the mixes with low durability indexes it would have been impossible to increase these values to a point corresponding with those for the less durable mixes, because when the tests as they are were discontinued these samples had completed more cycles than any of the samples representing the less durable mixes. That being the case, relative durability of the several mixes with respect to their resistance to freezing and thawing can hardly be different from that calculated for Table II and plotted in Fig. 1.

### SONIC VALUES ERRATIC

With regard to evaluation of mixes by the sonic method, these values were quite erratic but not wholly unreliable. Certainly the relationship of 30 percent reduction in sonic modulus being indicative of 50 percent reduction in modulus of rupture (as proposed by several investigators and used for judging mixes by several organizations including A.S.T.M.\*) did not hold in this case. In fact, the plot of change in sonic modulus versus reduction in modulus of rupture for these specimens, as shown in Fig. 2, indicates that about a 15 percent drop in sonic value would have represented a reduction of 50 percent in strength. With the exception of four, all the points fall within bounds marked by the dashed lines in Fig. 2. Even if all would conform to this, there is little reason to believe that change in sonic modulus alone would be as authentic as the method of durability indexes for representing durability of mixes.

One thing of great interest in the relationships presented in Fig. 2 is the reduction in modulus of rupture corresponding to an increase in sonic modulus. While these data are very scant and hence hardly reliable, it is possible that they explain the increase in sonic values exhibited by several specimens during the first 50 cycles and by at least one group at the end of 200 cycles. Stated differently they could mean that an increase in sonic value does not necessarily mean an increase in strength as was assumed with an attempted explanation in the initial report on this study.

### ORIGINAL CONCLUSIONS IN REVIEW

Returning to the relationships illustrated by Fig. 1, these change to some degree a part of the conclusions made in the initial report, but to a greater degree they confirm the procedures derived from those conclusions. In retrospect, the

\*"Evaluation of Air-Entraining Admixtures for Concrete", Proposed A.S.T.M. Tentative Method Approved by Committee C-9, and scheduled for early publication in the A.S.T.M. Bulletin.

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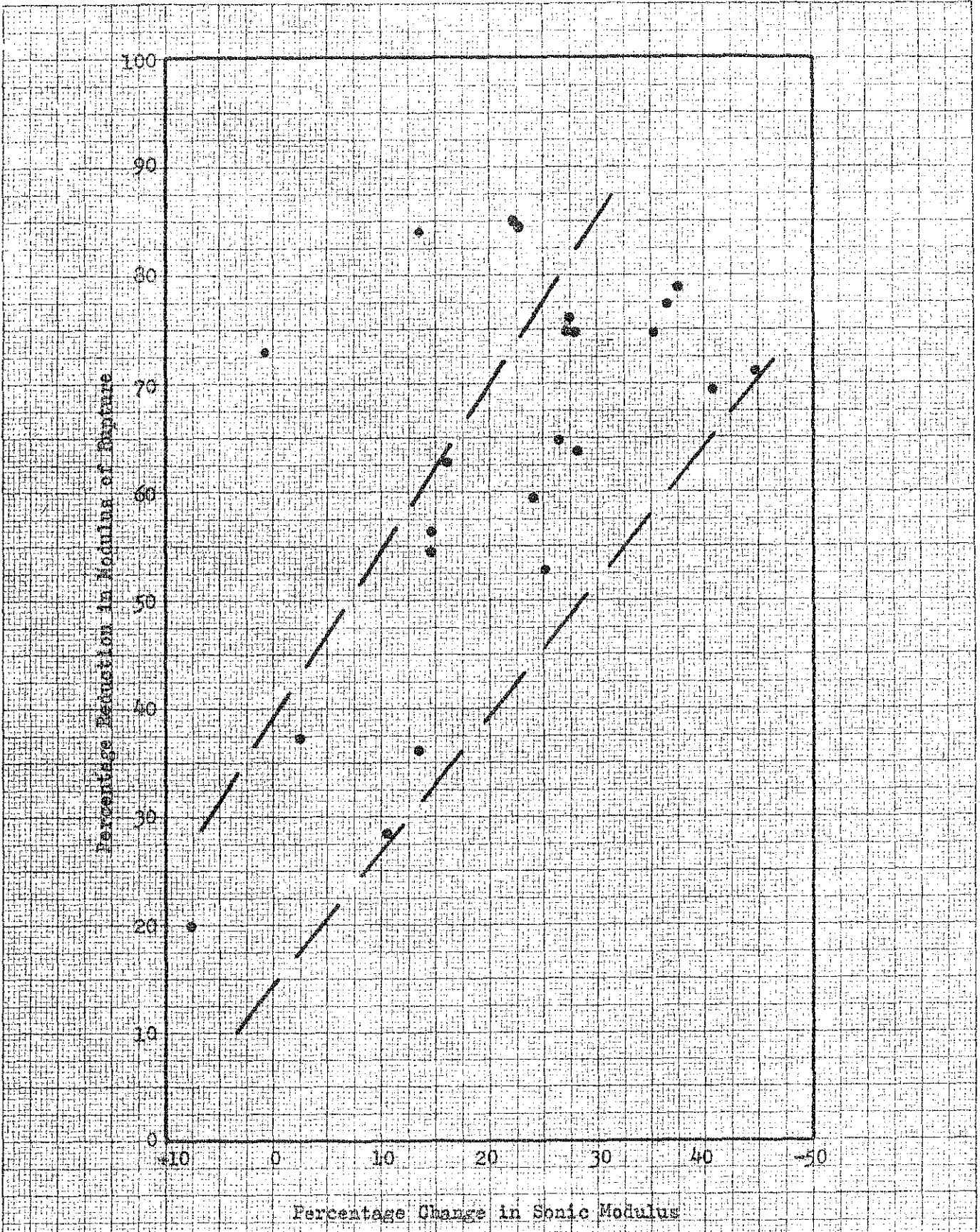


Fig. 2. Relationship Between Change in Sonic Modulus of Elasticity and Reduction in Modulus of Rupture for Concrete Beams

first seven conclusions from the initial report are listed below, and with them the qualifying features provided by new data which were not available at that time. Basis for the statements are, of course, durability indexes determined through these tests, and all but the last one refer to mixes in which Ohio River gravel was involved.

1. The substitution of any amount of limestone for Ohio River gravel in the coarse aggregate will increase the durability of concrete made with that aggregate. This, of course, is confined to river gravel from the vicinity of Louisville and more so to limestone used in this project. Any limestone of equal quality (as shown by service records) would probably be equally satisfactory.

Confirmed, and extended. Increases in durability are progressive with increases in limestone content.

2. Entrainment of air in the neighborhood of 5 per cent will improve the concrete by more than 100 percent in its resistance to freezing and thawing.

No necessity for confirmation since specimens involved had completed the test at the time of the first report.

3. With a substitution of 20 percent limestone in the aggregate, durability of the concrete with air entrainment can be increased by about 30 to 50 percent (depending upon curing conditions, etc.) in addition to that accomplished by air entrainment alone.

No necessity for confirmation since specimens involved had completed the test at the time of the first report.

4. Substitution of 40 percent limestone in the aggregate will make the concrete more durable than with 20 percent limestone, but the amount of gain in durability is not quite directly proportional to limestone content. Thus far data indicate that durability can be increased by at least 25 percent over that accomplished by substituting 20 percent limestone.

Modified but substantially confirmed. At the time of the first report, two of five samples containing 40 percent limestone and air entrainment (Group D) were removed from exposure prematurely and tested in flexure. Similarly, one of three samples representing the same mix without air entrainment (Group E) was removed. Both applied only to the samples cured 28 days. The number of cycles completed and the durability indexes both ultimate and at the time of the first report were as follows:



Group	Air Content	Cycles Completed		Durability Index	
		First Report	Ultimate	First Report	Ultimate
D	4.7	111	180	42.6	35.4
E	2.3	84	152	82.4	50.9

As shown by Fig. 1, in air-entrained concrete cured 28 days the benefit gained by adding the second 20 percent limestone was greater than that imparted by the first 20 percent addition of this material. The opposite was true in the case of samples cured 7 days. In general the shape of all curves taken collectively implies that there is a diminishing return from the substitution of limestone after the first 20 percent has been added, even when the concrete is air entrained. On the other hand the advantage gained by adding limestone up to 40 percent warrants the use of this amount especially in view of the limited gain from additions of limestone beyond that point.

The fair agreement between durability indexes for Group D determined for the first report and again after all samples had completed the test is in contrast with the disparity of like figures for Group E. On the surface this appears to be a basis for criticism of the durability index method. However, the initial durability index was determined by one sample which is never good practice; but of more significance, the final durability index for samples in Group E2 (which were made from an entirely different batch of concrete but which in air content varied only 0.1 percent from the batch for Group E) was 54.8 as compared with 50.1 for specimens in Group E, both cured 28 days. The former was determined at the end of 136 cycles whereas the latter represented samples exposed for 152 cycles. The agreement in durability indexes for samples from the same groups cured 7 days was not that close, these values being 55.1 and 46.6 respectively. The effect of this in general relationships is shown by the four points representing those mixes on the left side of Fig. 1 vertically above the abscissa representing 40 percent limestone.

5. The addition of 40 percent limestone with no air entrainment will prolong the life of concrete almost as much as the addition of air entrainment and no limestone.

Probably an understatement. The durability of concrete with 40 percent limestone and no air entrainment (actually 2.3 percent) was 30 to 35 percent better than the durability of concrete with no limestone and air entrainment (5.2 percent). Of course, an air content of 2.3 percent is unusually high for concrete considered non air entrained, and that would be advantageous to the mix containing the limestone. On the other hand, the air content of the mix without limestone was from 0.5 to 1.0 percent higher than the average percentage of air in mixes referred to as air entrained in arriving at the graph in Fig. 1.



6. While air entrainment alone will more than double the life of concrete with 100 percent river gravel, it will not accomplish as much improvement in concrete containing 40 percent limestone in the aggregate. This is in accordance with data from other experiments to the effect that the greatest amount of benefit from air entrainment is derived by the concrete with aggregates of poorest quality.

Confirmed by tests on all mixes of all types and for this instance amended to include "however, concrete having poor aggregate and the maximum benefits of air entrainment is not as durable as concrete with good aggregate and no air entrainment". This is demonstrated on Fig. 1 by the symbols "A", "B", and "C" with accompanying dimension lines in red. The dimension "A" is representative of improvement or change in durability index effected by air entrainment in mixes without any limestone. In contrast, dimension "B" is a like measure of improvement due to air entrainment in concrete containing 100 percent limestone. Finally, dimension "C" illustrates the differential between mixes with no limestone and air entrainment as opposed to mixes with all limestone and no air entrainment; the latter, of course, being superior to the former,

7. Based on comparisons between data from this experiment and those from other projects, mixes with glacial gravel and no air entrainment are almost as durable as those with 60 percent river gravel and 40 percent limestone containing air entrainment. When air entrainment is added, concrete with glacial gravel is about 2-1/2 times as durable as like concrete with 40 percent limestone as tested in this project.

Modified in extent but essentially confirmed in principle. With the development of results pertaining to glacial gravels tested in this experiment, it is no longer necessary to rely on comparisons with results from other studies. As shown on Fig. 1, mixes with 100 percent glacial gravel and no air entrainment are not quite as durable as mixes with 60 percent Ohio River gravel, 40 percent limestone, and no air entrainment. Naturally there is even greater difference between the mixes with glacial gravel and no air entrainment as opposed to the 60-40 mix of Ohio River gravel and limestone with air entrainment. Furthermore, concrete with glacial gravel and air entrainment is not 2-1/2 times as durable as like concrete with 40 percent limestone combined with Ohio River gravel; in fact, it isn't quite as durable as this concrete with blended aggregate.

This disparity of results can be explained by the fact that beams upon which initial estimates were based last January were poured on a field project and hence cured differently from samples made and cured in the laboratory; they were 5x6x20

inches in size as compared with the 3x5x20 inch beams made in the laboratory; and they were loaded at the center whereas laboratory samples were loaded at the third points. All these factors would influence results and could cause the discrepancies which are apparent in these data.

There is striking similarity between results pertaining to mixes with 100 percent glacial gravel and mixes with 60 percent Ohio River gravel and 40 percent limestone in combination. This is true for concrete both with and without air entrainment. Thus, from the standpoint of objectives of this experiment these two aggregate materials can be considered equal in durability characteristics determined in the manner of these tests.

### SUPPLEMENTARY CONCLUSIONS

Aside from those points covered by discussions and conclusions drawn heretofore and revised by more recent data, there are a few significant features requiring emphasis.

1. Concrete with 100 percent glacial gravel and no air entrainment is more durable than concrete with 100 percent Ohio River gravel and air entrainment.
2. The advantage gained through air entrainment in mixes with glacial gravel is relatively small, being only slightly greater than the advantage of air entrainment in mixes with all limestone coarse aggregate.
3. Mixes with 40 percent limestone added to the Ohio River gravel and having air entrainment are almost equal to those containing 100 percent limestone and no air entrainment.
4. In general, specimens cured 7 days are more durable than like specimens cured 28 days. On page 8 of the initial report made last January there was a discussion of increases in sonic modulus which ended with "The most plausible and most reasonable explanation for this is the tendency for concrete cured but seven days to gain in strength and integrity because of hydration of cement while the samples were immersed during the thawing periods, and that the damage caused by freezing and thawing was more than counter-balanced by increased soundness gained through hydration". This theory may apply to the general relationships between 7 day and 28 day concrete. Inconsistencies in the curves representing air-entrained concrete can be explained either as an idiosyncrasy typical of those often encountered in the testing of concrete, or it may be an indication that air-entrained concrete with durable aggregates is so resistant to freezing and thawing that the period of curing cannot be a material influence.