Highway Materials Research Laboratory
132 Graham Avenue, Lexington 29, Kentucky

October 9, 1947

File: C-2-4
D-1-7

Memorandum to Dean D. V. Terrell
Director of Research

Attached is a report entitled "Experiments with Air Entrainment in Cement Concrete", which is a supplement to our comprehensive report on this subject issued in September, 1946. Specifically, this is a report of progress shown by the four experimental roads that have been a part of the general research endeavors with air entrainment for the past six to seven years. Principally because of the progress made along this line and the fact that our practices and specifications are abreast or ahead of those used elsewhere in highway work, no fundamental laboratory studies dealing with this subject have been conducted during the past year. Instead, preference was given to other studies of concrete such as the one on combined aggregates, or emphasis was placed on projects where other materials such as soils or bituminous mixes were involved and the majority of personnel was shifted to those projects. However, a few air-entraining materials remain for investigation at the request of the Specifications Committee, and the question of air-entrained concrete for structures remains to be settled. Both of these should get attention early this fall.

With regard to the experimental roads, this report in essence shows that two of the four projects are beginning to produce tangible results. Past inspections have failed to reveal anything of significance, so prior to this time our laboratory results could not be confirmed or refuted by data from actual installations. This year two of the roads showed definite evidence of deterioration in the concrete due to weathering, and in one case there was remarkable agreement between the indicated performance of the road and the measured deterioration of beams made originally on that job and exposed on the roof of the laboratory during the intervening time. On the other hand, results from the other of these two projects are to some extent at this stage contrary to results from original accelerated weathering tests made in the laboratory. These apply only to the relative durability of aggregates involved, for the laboratory results applicable to air-entrained versus non air-entrained concrete are being confirmed by field experiments insofar as these experiments can be judged at this stage.

Your attention is called to the data obtained through tests on cores taken from two projects this year and compared with similar data pertaining to cores taken at the same locations in 1942. On the surface it appears that the results are of no value; that core strengths are poor indicators of actual deterioration in concrete pavements. However, in view of the manner in which deterioration seems to be progressing on these pavements, there is some promise that over a period of time core strengths can serve as a quantitative measure of the weakening of pavements due to weathering forces alone. Certainly such a measuring stick is desirable in rating field experimental projects. It is with these things in mind that coring to a similar extent is planned for these projects next year; and, of course, annual inspections with accompanying photography will be continued as long as the projects seem to warrant it.

I am certain that members of the Research Board will read this report with interest and that it will receive considerable discussion at the first meeting this fall.

Respectfully submitted,

L. E. Gregg

L. E. Gregg
Associate Director of Research

LG:mbm

Copies to: Members of the Research Board
Mr. Mack Galbreath

Commonwealth of Kentucky
Department of Highways

Supplementary Report No. 1
on
EXPERIMENTS WITH AIR ENTRAINMENT IN CEMENT CONCRETE

Highway Materials Research Laboratory
Lexington

October 9, 1947

In September, 1946, the Research Laboratory prepared and distributed a comprehensive report entitled "A Summary of Experiments With Air Entrainment in Cement Concrete", which covered field and laboratory experimentation conducted over a period of six years. In February, 1947, specific recommendations based on this report and another dealing with the pressure method of determining air contents resulted in adoption of air entrainment for all concrete pavements and the pressure method as the only accepted method of control.

Among the several projects included in the six years of research were four experimental roads which, of course, are still in service. Although these roads have served their primary purpose from the standpoint of experimentation, there is still much to be gained by periodic inspection of them and careful recording of their progress, especially in view of the fact that five to six year's exposure did not cause appreciable deterioration of the pavements. Accordingly, all four projects were examined during the past summer, and this is a report of their progress as determined by these examinations.

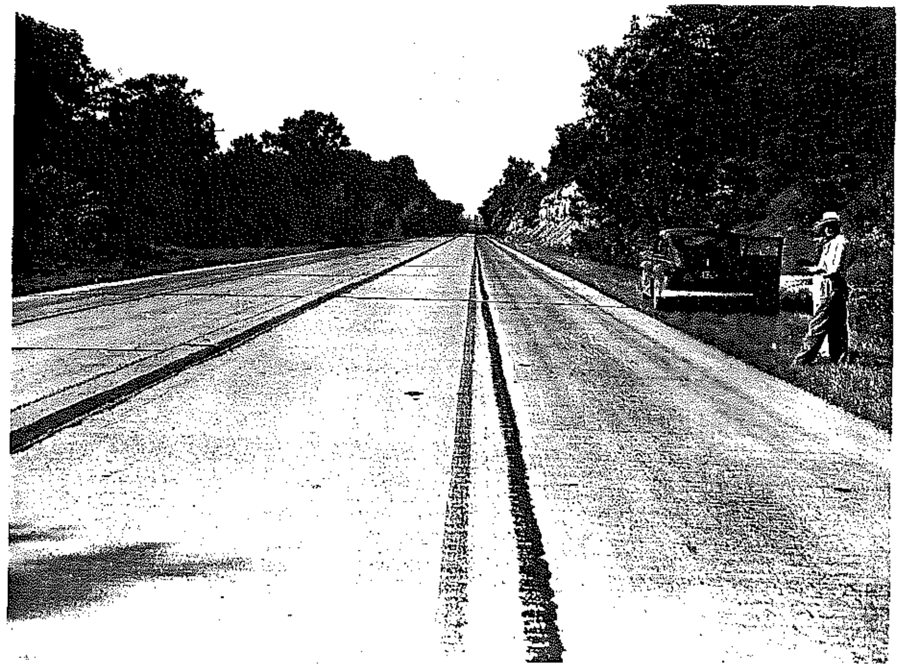
Scope

Evaluation of the pavements consisted of inspections with accompanying photography made as follows:

1. Falmouth-Cynthiana Road (Proj. FA 366-C(2)) - May 27
2. Louisville-Cincinnati Road (Proj. SN-FA 194E(3)F(3)L(2)) - June 5
3. Louisville-Elizabethtown Road (Proj. FA 79 D(2)S) - June 6 & Aug. 25
4. Louisville-Elizabethtown Road (Proj. FA 79B(5)D(4)) - June 6 & Aug. 25

and also coring of the first two roads at a total of 36 locations in late June and early July. Furthermore, a part of the project listed fourth consisted of long-time exposure of samples on the roof of the laboratory, and tests on specimens thus exposed formed a large part of the means for evaluating that project. Photographs were taken at all locations represented by pictures during the 1946 inspections, and in addition there were several other locations photographed in order to illustrate conditions that had developed during the year.

Coring was done by shot drill at almost half of the points cored originally on two of the four projects. Nineteen of the 43 original stations at which cores were taken on the Falmouth-Cynthiana Road in 1942 were included this year, while on the Louisville-Cincinnati Road 17 of the original 37 locations were cored. Cores cut this year were taken within a foot of those cut five years ago in order to make it reasonably probable that both represented the same batch poured during construction on



(1946)

(1947)

Fig. 1. Corresponding photographs taken on the Louisville-Cincinnati Road in 1946 and 1947. Although there is no detail upon which performance can be judged, it is obvious that the concrete is in good condition and that this condition has not changed during the past year. Only the two lanes on the right are experimental.

the job. No cores were taken from the two projects on the Louisville-Elizabethtown Road.

With regard to the beams for long-time exposure on the roof of the laboratory, a change in the initial plan was made a year ago because of the indicated futility of continuing with that plan for a period of 12 years. Originally, all beams set aside for this type of test were to be exposed with all faces to the air thus providing free drainage, and four beams were to be selected at random and tested for flexural strength each year. This procedure was followed through April, 1946 (the third year of exposure) with results in general indicating that the exposure was beneficial rather than detrimental to the concrete and its durability. Accordingly, in October of last year a box for storage of half the remaining beams was built, and soil was placed in the box so that each beam had only one face exposed to air, there being at least two inches of soil between the other faces and adjacent beams or the bottom or sides of the box. (See Fig. 2) Beams selected at random for this procedure were exposed six months before three were removed and tested for flexural strength in April, 1947. A companion set of three was taken at the same time from among those left to the original type of exposure.

Results

Inasmuch as the inspections made in 1946 resulted in no appreciable evidence of deterioration of the pavements due to weathering over a period of 5 to 6 years (principal failures were caused by insufficient subgrade support or abrasion by

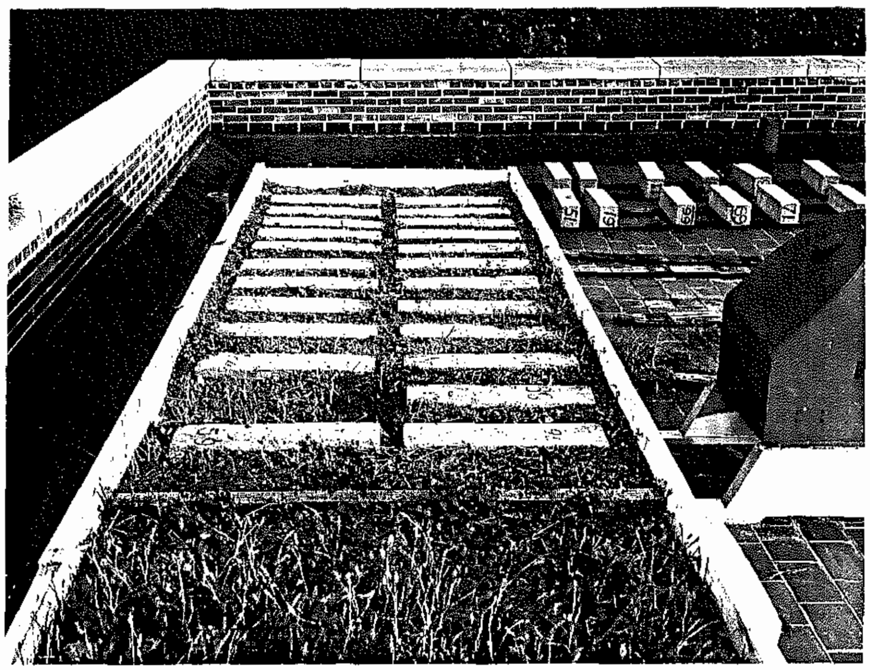


Fig. 2. Box for natural exposure of concrete beams embedded in soil so that only the top surfaces are exposed to the air. These specimens are from the Louisville-Elizabethtown Road and had $3\frac{1}{2}$ years of exposure free to air before being placed in this box in October, 1946. Corresponding samples exposed free to air are shown in the distance on the right.

military traffic), effort was concentrated on detecting changes that occurred during the past year. In some cases these were considerable, especially in view of the two time intervals involved and the tendency for little or no change during the preceding five to six years. From the standpoint of tests on cores, however, seemingly nothing of value was gained from the work. Actually, the results from tests on cores provided a good basis for judging the way in which weathering forces act on pavements and cause a number of failures that have been observed by highway engineers over a long period of time.

Falmouth-Cynthiana Road

Of the four projects inspected, the Falmouth-Cynthiana Road provided what appears to be the most significant information. In the report of data from the 1946 inspection* it was noted that "On the surface this pavement was in excellent condition, the most obvious damage being a few minute cracks.... where settlement had occurred". Throughout those sections containing limestone coarse aggregate (Sections 1-5) the same was true this year, there being no evidence of change aside from serious side-hill fill slides, and no apparent difference in the performance of pavements without air entrainment as opposed to those with it. In contrast, two of the sections containing glacial gravel coarse aggregate showed distinct signs of deterioration of the concrete, these being Section 6 with normal portland cement and Section 7 where the cement was a blend of portland and natural without a

*"Summary of Experiments with Air Entrainment in Cement Concrete", September, 1946, p. 29.

grinding aid in the natural. Neither of these was air entraining. Principal evidences of deterioration were groups of hair cracks (often referred to as "D" cracks) formed at the inside corners of slabs as illustrated in Fig. 3 and Fig. 4, or as similar sets of cracks formed parallel to joints, as illustrated in Fig. 5.

Authorities on the subject of concrete* have classified this type of damage as "deterioration due to accelerated weathering" as opposed to three other types of deterioration, and comment further to the effect that "progressive and rapid disintegration usually follows the appearance of D lines". Figures 3 and 4 indicate that in this instance the cracking represents the incipient stage in formation of inside corner breaks, and observations during the next few years will show whether disintegration is rapid on a pavement which is not heavily traveled.

It is significant that, with the exception of one joint at Sta. 750+90 in Section 9 where the cement was a blend with the grinding aid, deterioration of this type was not evident in any of the other sections containing glacial gravel, or in other words those with air entrained. Furthermore, it should be noted that results of laboratory tests indicated that failure would occur sooner in the non air-entrained concrete with limestone aggregate (Sections 4 and 5) than in like concrete with gravel aggregate (Sections 6 and 7). This was set forth by discussion on page 34 of the "Summary of Experiments With Air Entrainment

*Jackson, F. H., "Durability of Concrete in Service", A.C.I. Journal, V. 18, N. 2, pp. 165-180, October, 1946.

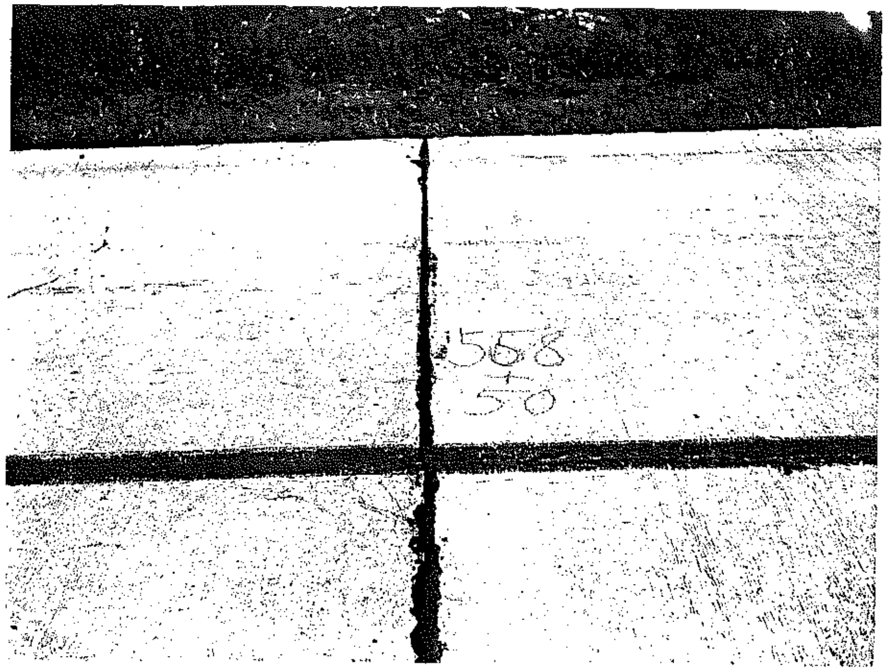


Fig. 3. Initial stages in the development of an inside corner break as evidenced by D cracks, the result of accelerated weathering. This is located at Sta. 558+50 on the Falmouth-Cyhthiana Road where the coarse aggregate was glacial gravel and the cement was normal portland. Nothing of this type was noted at the time of inspection in 1946.

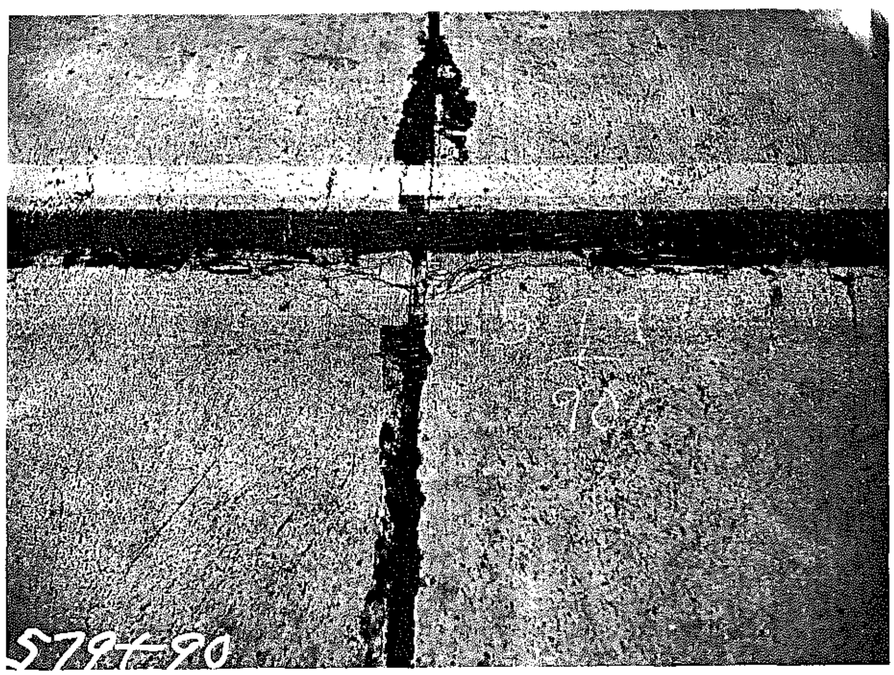


Fig. 4. A series of D cracks formed in adjacent slabs at Sta. 579+90 on the Falmouth-Cynthiana Road. The concrete contained a non air-entraining blended cement and gravel coarse aggregate. Several locations with cracks of this type that had developed during the past year are now evident in the two sections of concrete having gravel aggregate and no air entrainment.

Fig. 5. Cracks formed parallel to a transverse joint at Sta. 564+10 on the Falmouth-Cynthiana Road. The coarse aggregate in this section of the road was glacial gravel, and the cement was normal portland. Only a few cracks parallel to joints were noted in 1947, but there was none in 1946.

in Cement Concrete", and was illustrated by Fig. 24 of that report.

Results from tests on cores taken from this project in 1942 and 1947 are listed in Table I, and the percentage of increase or decrease in strength during the five years of service is shown for each individual core as well as each section of the road. The actual relationships are concealed somewhat by the lack of data for some sections caused by low cores extracted in 1942. This is particularly applicable to the non air-entrained concrete containing glacial gravel. However, the data representing other sections are erratic enough to create some doubt about the value of cores such as these in indicating the true condition of the concrete at this stage. Such a condition may be dependent more on the shortcomings of the shot-drill method of coring than on the actual condition of the concrete, for certainly the samples obtained in this manner are far from uniform in cross section.

Louisville-Cincinnati Road

In the initial evaluation of experimental roads made last year, the concrete on the Louisville-Cincinnati Road was rated best because of its outstanding durability and strength characteristics as determined by laboratory tests made on the samples prepared on the job. At that time performance of the road itself was rated excellent also, although differences among projects at that stage were slight and valid ratings were difficult to determine. No change in the condition of the pavement was noted this year, even though some of the expansion joints were in need of attention. All sections appeared to be equally good, so there

TABLE I. COMPARATIVE STRENGTHS OF CORES TAKEN FROM THE FALMOUTH-CYNTHIANA ROAD IN 1942 AND 1947

Coarse Aggregate	Cement	Sec. No.	Station	Compressive Strength lb. per sq. in. 1942	Compressive Strength lb. per sq. in. 1947	Pct. Change in Strength Over Five Year Period: Individual	Pct. Change in Strength Over Five Year Period: Ave. for Section
Limestone	Portland & Interground Vinsol resin	1	338+00 345+62	5260 5140	6480 5920	+23.2 +15.2	+19.2
	Blend--Portland & V.R. Interground and Natural	2	408+00	6000	5760	-4.0	-4.0
	Blend--Portland & Natural with Grinding Aid	3	428+00 448+00 468+00	5610 4770 5050	5640 5360 5630	+0.5 +12.4 +11.5	+7.8
	Blend--Portland & Natural	4	478+00	5870	5730	-2.4	-2.4
	Portland	5	528+00 548+00	6770 Low Core	7410 6790	+9.5	+9.5
Glacial Gravel	Portland	6	558+00	Low Core	6510	--	--
	Blend--Portland & Natural	7	578+00 598+00	Low Core Low Core	6530 6120	-- --	-- --
	Blend--Portland & V.R. Interground and Natural	8	708+00	Low Core	5380	--	--
	Blend--Portland & Natural with Grinding Aid	9	728+00 748+00 758+00	4710 6130 6140	5010 5370 5840	+6.4 -4.2 -4.9	-1.5
	Portland & Interground Vinsol resin	10	403+00 393+00 386+00	5260 5200 5720	5500 5260 6680	+4.6 +1.2 +16.8	+7.8

was no basis whatsoever for differentiating among them from the standpoint of performance.

If comparative strengths of cores are any criterion, the concrete without air entrainment has been, in general, more resistant to deterioration over a five year period than has the concrete with entrained air. This is illustrated in Table II where the average changes in strength for non air-entrained concrete in Sections 4 and 5 were +12.9 per cent and +1.9 per cent respectively, thus indicating no deterioration (or improvement), whereas the concrete with air entrainment, as represented by Sections 1, 2, and 3, were +1.6, -7.3, and -5.1 per cent respectively. However, the trend by individual cores is not consistent, for all sections (except Section 2 represented by one core) had both increases and decreases in strengths shown by individual cores. Some of these variations were quite great, such as the case of Section 4 where changes in strength ranged from -11.0 to +23.6 per cent, yet the average for five values was +12.9 per cent-- the greatest average amount of increase shown by cores from any section. Thus, in the over-all analysis, comparative strengths of cores from the Louisville-Cincinnati Road were more erratic than those of cores from the Falmouth-Cynthiana Road.

Louisville-Elizabethtown Road

On that portion of the Louisville-Elizabethtown Road where the experiment consisted of a third lane running up Muldraugh Hill and ending at the intersection of U.S. 60 and U.S. 31-W, there was little change over the condition that existed last year. Pumping was more prevalent, and more slabs were cracked because

TABLE II. COMPARATIVE STRENGTHS OF CORES TAKEN FROM THE LOUISVILLE-CINCINNATI ROAD IN 1942 AND 1947

Coarse Aggregate	Cement	Sec. No.	Station	Compressive Strength lb. per sq. in.		Pct. Change in Strength Over Five Year Period	
				1942	1947	Individual	Ave. for Section
Limestone	Portland & Interground Vinsol Resin	1	113+50 123+00 163+30 183+33	Low Core 5580 6770 4970	5900 6110 6600 4890	-- +9.5 -2.5 -1.6	+1.6
	Blend--Portland & V.R. Interground and Natural	2	203+50	6150	5700	-7.3	-7.3
	Blend--Portland & Natural with Grinding Aid	3	263+46 283+50 303+36 323+36	6010 5320 4420 6290	5540 4690 4060 6630	-7.8 -11.8 -8.1 +5.4	-5.1
	Blend--Portland & Natural	4	346+50 356+75 366+30 386+39 406+25	4900 6080 5340 5510 5390	4360 6660 6400 6660 6660	-11.0 +9.5 +19.9 +20.8 +23.6	+12.9
	Portland	5	426+34 446+49 456+75	5460 6010 5595	6480 5760 5150	+18.7 -4.2 -8.0	+1.9

of subgrade weaknesses, but features of that type are extraneous to the objectives of the experiment, consequently they were disregarded. Even with those features included in the evaluation, concrete in Sections 1, 2, 6, and 7 was rated as good. This too is worth noting, because this pavement is the oldest of all in the four projects and laboratory tests indicated that concrete here was the most vulnerable of all to deterioration under the forces of weathering. However, differences in subgrade materials, drainage features, and similar factors could account for the incipient failures on the Falmouth-Cynthiana Road at an earlier stage than on the Louisville-Elizabethtown Road.

The other experimental portion of the Louisville-Elizabethtown Road consisted of a third lane (north bound) in which only one cement-- a blend of portland and natural containing a grinding aid-- was used. Hence all the concrete was air entraining so there was no comparative feature for cements in the experiment. Long-time exposure of samples on the roof of the laboratory was predominantly the basis for judging this experiment. However, some important results could be obtained from the pavement itself, because disintegration which appears to be a weathering phenomenon had started at several points. One such location is shown indistinctly in Fig. 6. The usual location of these cracks was in the middle portion of joints rather than at corners of slabs. Moreover, their form or pattern was peculiar in that the group outline was generally triangular. Nevertheless, the cracks were progressing inward from the middle of transverse joints toward the centers of slabs, and to that extent they did conform with

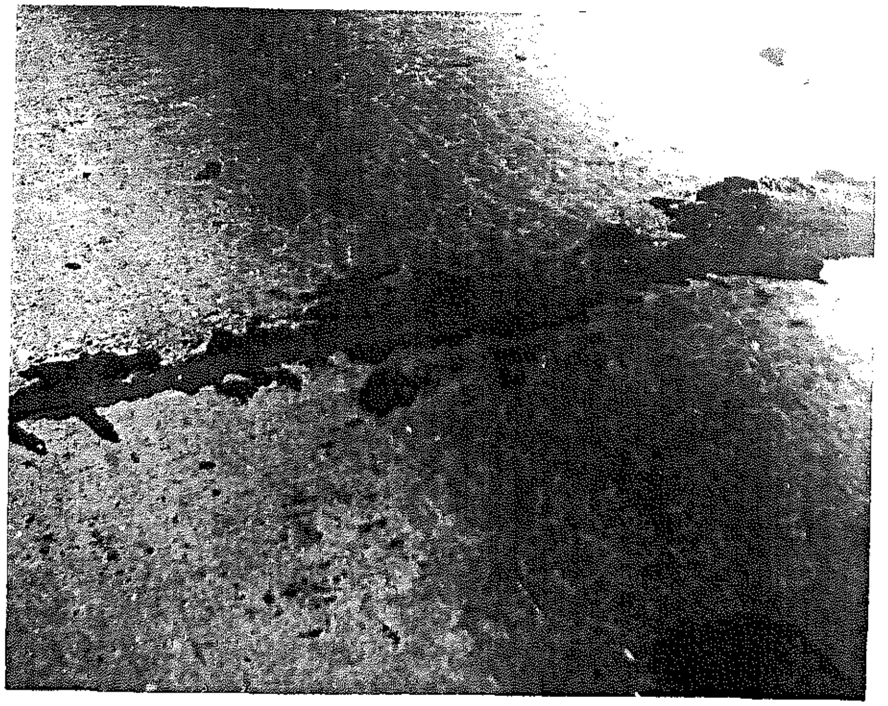


Fig. 6. Triangular formation of cracks extending longitudinally from a joint at Sta. 133+85 on the Louisville-Elizabethtown Road (North bound lane placed in 1941). The cracks are typical results of accelerated weathering, but the triangular distribution is unusual. These were formed since the inspection in 1946.

the usual manner of accelerated weathering.

A large portion of the slabs were in this condition, particularly those between Sta. 55/00 and Sta. 161/00. The most pronounced examples were at Sta. 133/85 and Sta. 135/00. At several of these joints spalling had taken place, while elsewhere abrasion and removal of concrete chips under military traffic has been extensive, particularly between Sta. 161/00 and Sta. 200/00. From that point on to the end of the experimental pavement (Sta. 266/00) the concrete was in fair to good condition.

Continuation of the long-time exposure tests during the past year resulted in data that are remarkably consistent with perform- of the field experiments. Prior to this year, there was practically no evidence of deterioration in the beams stored on the roof, and that, of course, was true for the pavement. However, as shown by Table III, the average modulus of rupture of samples exposed both in air or in soil suddenly decreased about 35 per cent from the original average modulus of 921 pounds per square inch. In contrast, the highest preceding average decrease was 6.7 per cent, and for some reason the average modulus of rupture for beams tested a year ago was 15.3 per cent greater than the original.

Even in view of these inconsistent changes for average data from one year to the next, there is almost positive evidence that the results this year are authentic-- that the concrete beams are all deteriorating-- because the highest strength among all six samples tested this year was 710 pounds per square inch, whereas the lowest strength for any of the 17 samples tested during the

TABLE III. RESULTS OF LONG TIME EXPOSURE TESTS ON BEAM SAMPLES TAKEN FROM THE LOUISVILLE-ELIZABETHTOWN ROAD

Date Tested	Years of Exposure		Ave. Modulus of Rupture for Beams		Ave. Pct. Change in Modulus of Rupture From Original
	In Air	In Soil	Stored in Air	Stored in Soil	
1943	0	--	921*	--	0
1944	1	--	859	--	-6.7
1945	2	--	863	--	-6.3
1946	3	--	1062	--	+15.3
1947	4	--	587	--	-36.9
	3.5	0.5	--	613	-33.4

RESULTS OF TESTS ON INDIVIDUAL BEAMS

Date	Beam No.	Type Storage	Mod. of Rup.	
1943	8	--	900	
	29	--	870	
	49	--	1005	
	60	--	1020	
	85	--	810	
			Ave.	921*
1944	10	Air	1028	
	42	"	810	
	63	"	893	
	87	"	705	
			Ave.	859
1945	9	Air	975	
	32	"	855	
	55	"	900	
	83	"	720	
			Ave.	863
1946	1	Air	1178	
	20	"	1035	
	50	"	1005	
	72	"	1028	
			Ave.	1062
1947	25	Air	680	
	46	"	640	
	88	"	440	
			Ave.	587
	3	Air & Soil	660	
	37	" "	710	
	58	" "	470	
			Ave.	613

*Specimens not subjected to weathering.

preceding four years was 705 pounds per square inch. The strengths listed for individual beams in Table III illustrate very well the probability of this year's averages being wholly indicative of actual deterioration of the concrete, and not dependent largely on selection of beams as might have been the case in 1946. Strength tests on beams taken out next year will undoubtedly furnish a better basis for judging this, and also give a better basis for evaluating the storage-in-soil versus the storage-in-air.

Conclusions

While results of long-time tests with experimental roads and related projects in which samples are given protracted exposure usually do not become absolutely conclusive until years of testing have passed, it is possible to state briefly at this stage some of the more certain results from these tests.

1. Contrary to the results from laboratory accelerated weathering tests, concrete in service on the Falmouth-Cynthiana Road has indicated that the inherent durability of the glacial gravel used in Sections 6 to 10 of that project is not as great as that of the limestone placed in Sections 1 to 5.

2. Accelerated weathering can be a primary cause of corner breaks in concrete slabs even when the traffic using the road is light. This, of course, was only indicated by conditions on the Falmouth-Cynthiana Road, for actual breaks in the pavement have not occurred to date.

3. Air-entrained concrete is more resistant than non

air-entrained concrete to natural weathering in service as well as to accelerated weathering in the laboratory. In other words, laboratory methods are at least fairly good indicators of performance that may be expected from concrete, although the actual length of satisfactory service cannot be predicted by using present methods.

4. Possibly a good correlation between anticipated length of service and results from laboratory tests can be reached through intermediary tests on beam samples subjected to long-time outdoor exposure. Evidences of concurrent deterioration in the pavement on the Louisville-Elizabethtown Road and in the beams prepared on that job and exposed on the roof of the laboratory offer great promise for this approach in the future.

5. Accelerated weathering begins at the edges or joints in concrete and progresses inward toward the middle of slabs. Hence, deterioration in concrete may not become active at points two or three feet from edges or joints for a long period of time, so the amount of deterioration cannot be shown by cores taken from those points until there has been sufficient time for the effects of weathering to progress inward to those locations.