Service Performance of Concrete Pavement Containing a Blend of Portland and Natural Cement

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In 1939 quite a little concrete pavement was constructed containing normal portland cement blended with natural cement waterproofed by means of a grinding aid. Claims made by the producers of natural cement were that a blend composed of approximately 84 per cent portland and 16 per cent natural would improve the properties of concrete particularly resistance to freezing and thawing and resistance to scaling caused by salts used for ice removal. Because of the distinction between the chemical compositions of portland and natural cement, concrete containing natural cement gains strength more slowly than portland cement concrete and is said to have improved durability. Tricalcium aluminate and tricalcium silicate, both of which are present in portland cement, are not present in natural cement. Natural cement contains calcium carbonate which is not present in portland cement and more dicalcium silicate than portland cement.

Because of the grinding aid used in the natural cement the blended cement concrete contained a trifle more than three per cent entrained air. At the time of this construction equipment for measuring entrained air was not available, but because of the difference in unit weight of the all-portland and blended cement concrete, the entrained air content of the blended cement concrete was three per cent greater than that of the all-portland cement concrete. The air content of the latter was either zero or practically so as shown by its high unit weight. See Table 3, Report R-61. The presence of entrained air in the blended cement concrete was noted but its importance was not recognized because at that time (1939) the benefit of air entrainment was not yet established.

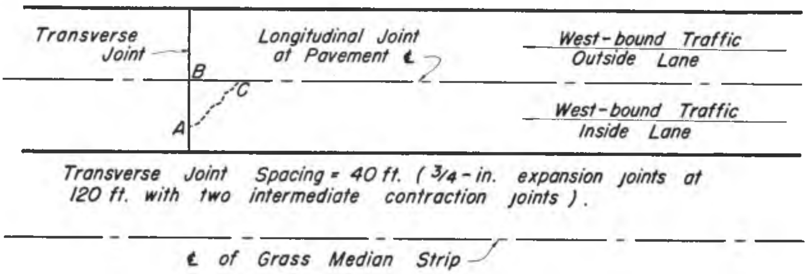
During the construction of Contracts R-1784 and R-1802, investigations were conducted which included the fabrication on the job of 6" x 12" cylinders and 6" x 6" x 43" beams for determination of compressive and flexural strength at 7, 28, and 90 days. At the age of one year cores were drilled and tested for compressive strength, absorption (by three different methods), density and resistance to freezing and thawing. The results of these tests are shown in three reports that have been issued to date.*

In all the tests to and including the age of one year, shown in the above mentioned reports, concrete containing blended cement was found to have less strength in both compression and flexure than all-portland cement concrete but a much greater durability as indicated by freezing and thawing tests.

PAVEMENT CONDITION AT THE AGE OF 11 YEARS BASED ON AN INSPECTION IN MAY, 1950

This report, which concludes the investigation, describes the condition of the pavement after 11 years service and contains compressive strength of the concrete as shown by tests on cores drilled and tested at the ages of one year and eleven years. Although previously reported test data will be avoided as much as possible certain essential information will be repeated for clarity and completeness.

On Contract R-1784 (divided lanes on U. S. 40 between Knightstown and Dunreith) the lanes carrying west-bound traffic



contain all-portland cement. Four different brands were used (A, B, C, and D). The lanes carrying east-bound traffic contain a blend

*"Physical Properties of Concrete Containing a Blend of Portland and Natural Cement" (Report R-61), October, 1940, by the Bureau of Materials & Tests.

"Progress Report on Concrete Core Study", February 19, 1941, by the Purdue Joint Highway Research Project.

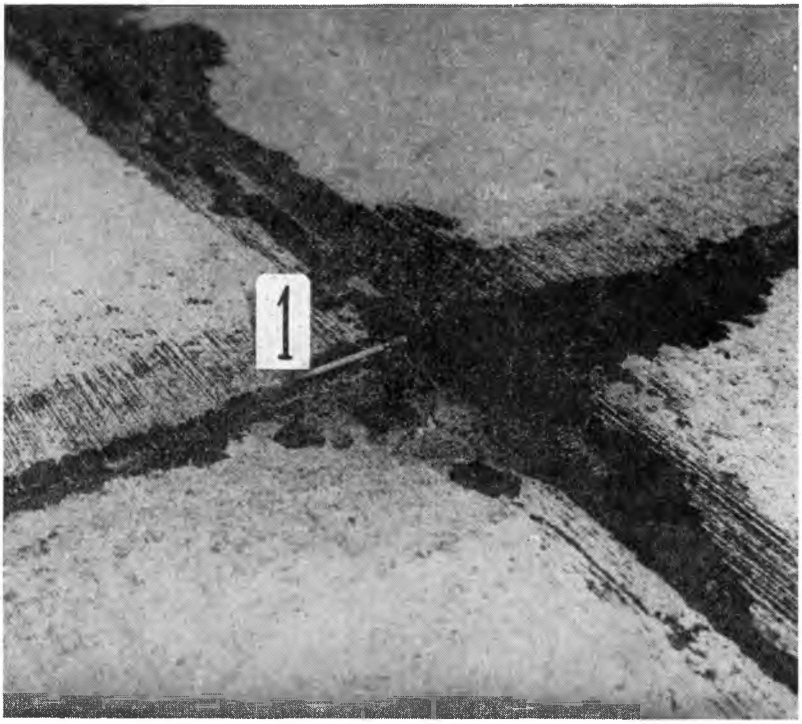
"Report No. 2 on Concrete Cores", February 9, 1942, by the Purdue Joint Highway Research Project.

of 84.1 per cent portland and 15.9 per cent natural cement (brand E), by weight, each brand of portland being located between the same stations as the same brand in the west-bound lanes. Thus the comparison of concrete containing each of the four brands of portland cement with and without the substitution of natural cement would seem to be as nearly equitable as possible. The two "types" of cement are separated only by the grass median strip so that subgrade condition should be constant at any given station.

On Contract R-1802 (dual lanes on U. S. 24 about 14 miles southwest of Ft. Wayne) all-portland and blended cement were used in the same manner (portland cement brand E with and without a 15.2 per cent substitution, by weight, of natural cement brand G). Because only one brand of portland cement was used the investigation was considerably less extensive than that on Contract R-1784. During the construction period the same observations and test specimens were made as on Contract R-1784 and cores were drilled and tested at one year and at 11 years but, because of the distance from Indianapolis, the observations of pavement condition from time to time were less frequent. For this reason the conclusions in this report with reference to the service records of concrete pavements containing the two types of cement are based entirely on Contract R-1784. In addition to the two types of cement just described, a "special" portland cement was used, on Contract R-1784, in 628 feet of pavement in the west-bound lanes. This cement (manufacturer D) was one of the early brands of air-entraining cement.

At the age of eight years on Contract R-1784, corner breaks, at the intersections of the longitudinal joint and the transverse joints, had become quite prevalent in the pavement containing all-portland cement (west-bound lanes), as illustrated in the sketch below.
At different intersections the length of Crack A-C varied from six inches to four feet. In nearly all instances the concrete along the edges of the crack had spalled or raveled, the condition being more pronounced inside the triangle A B C. In many cases the spalling was of such degree that the concrete inside the triangle was completely disintegrated. Usually this condition existed in more than one quadrant of the intersection and sometimes in all four. At two locations disintegration had spread to such an extent as to require bituminous patches, 6 ft. x 7 ft. at Station 1277+70 and 15 ft. x 20 ft. at Station 1310+50.

These failures were especially noticeable because the east-bound lanes, containing blended cement, were almost entirely free of them.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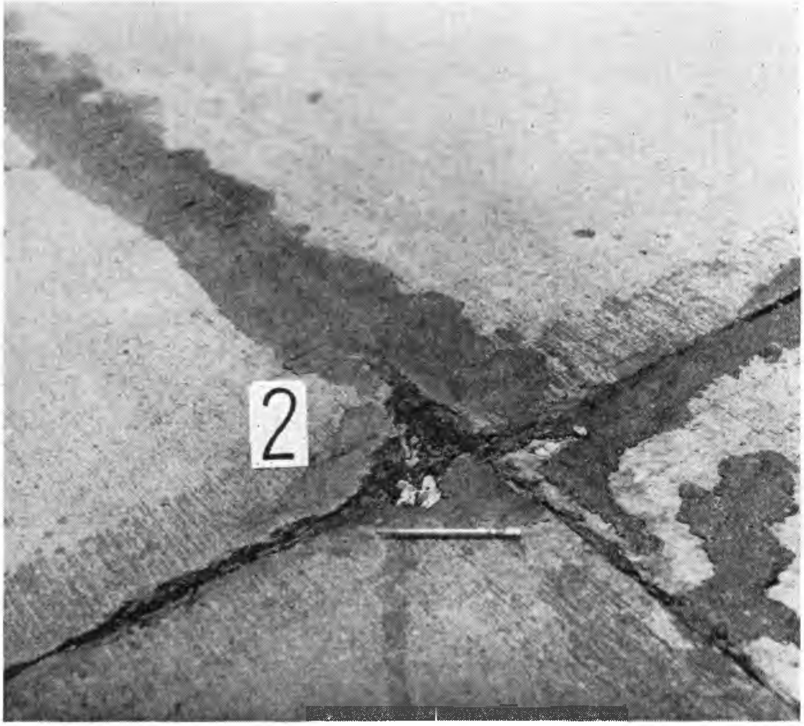
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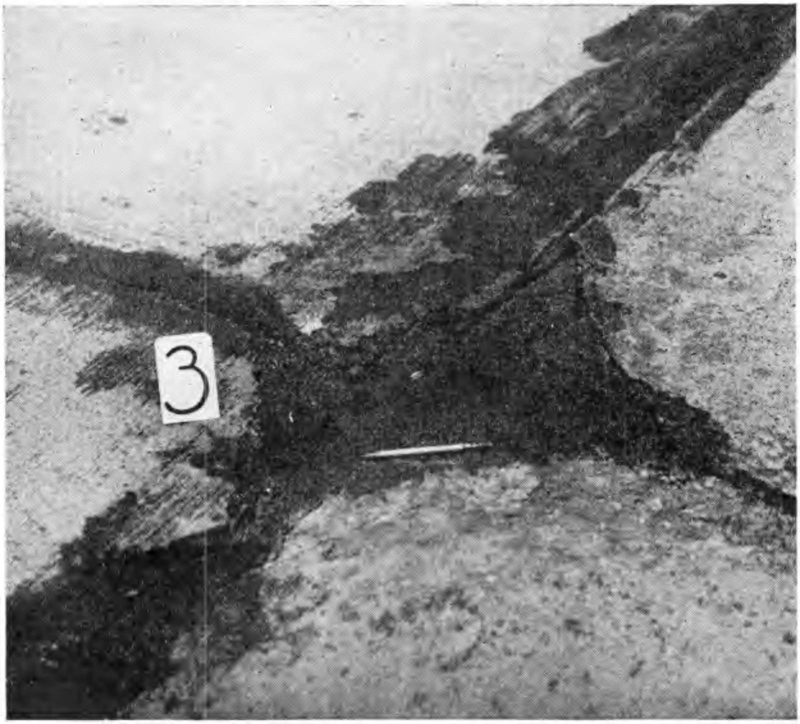
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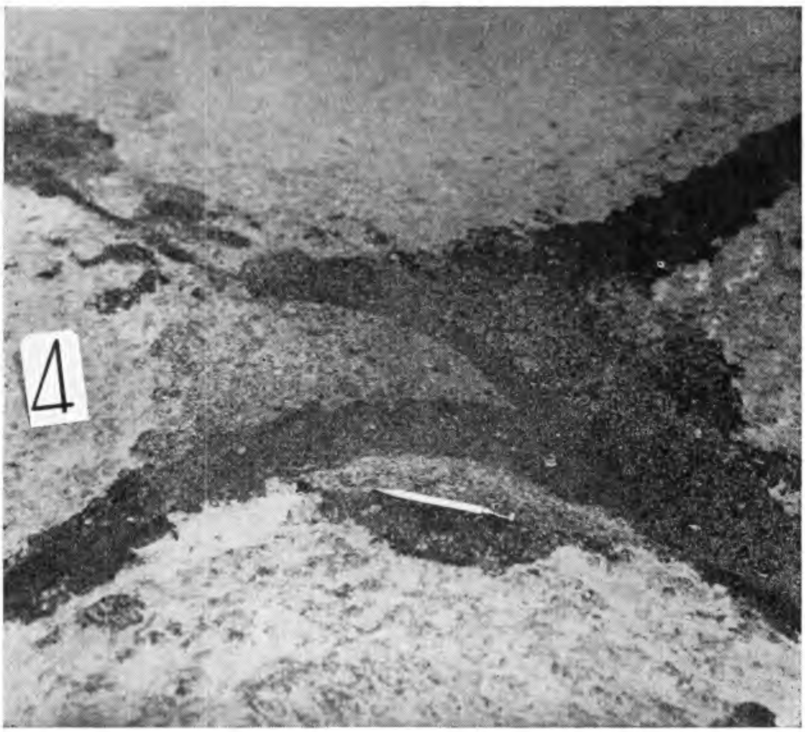
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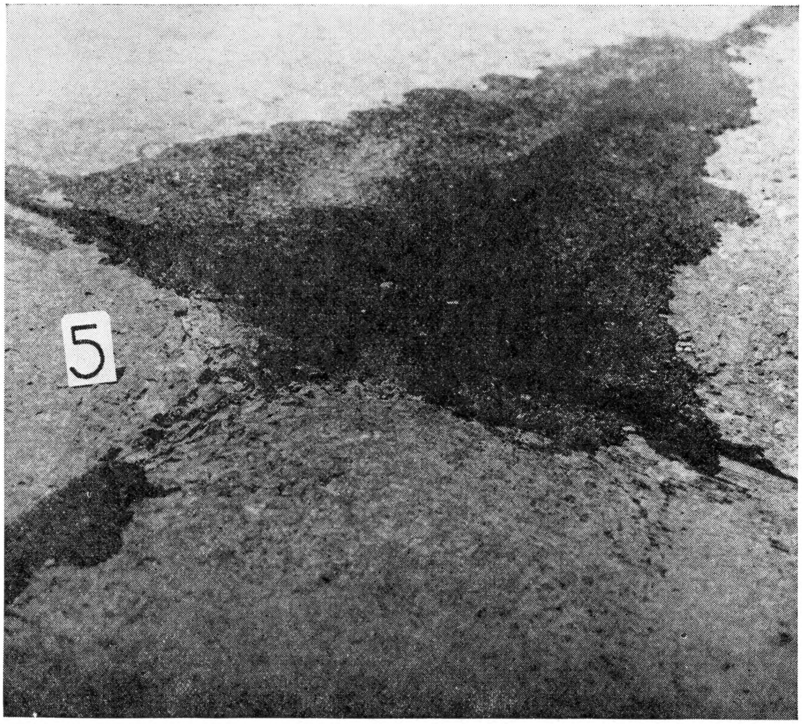
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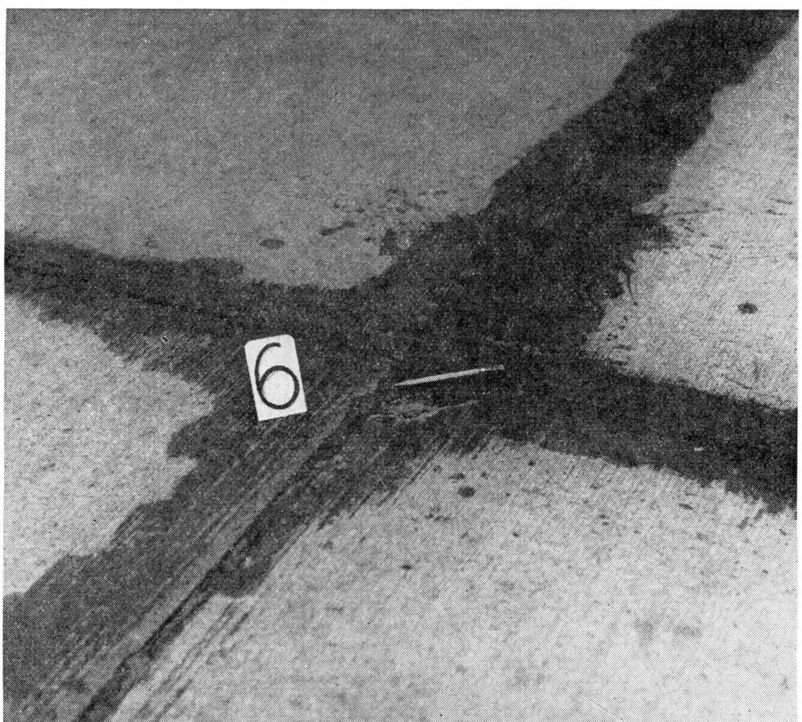
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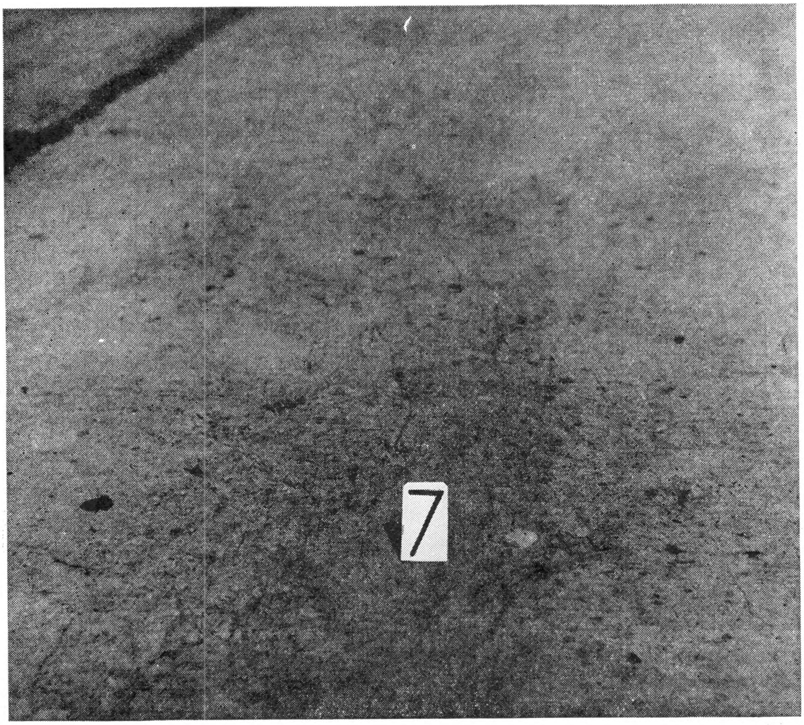
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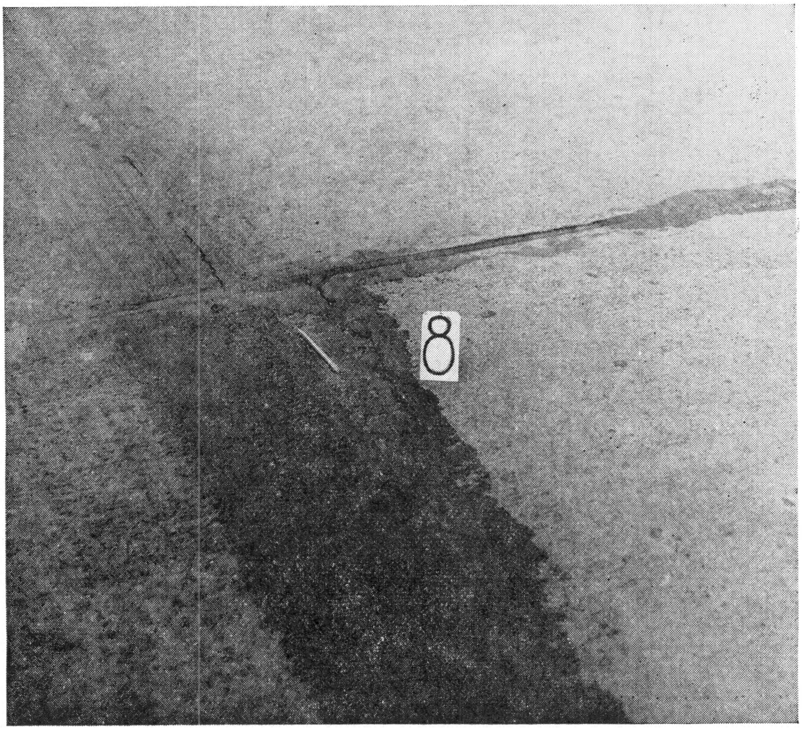
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In May, 1950, when the pavement was almost 11 years old, a detailed inspection was made to determine the number of failed intersections expressed as a percentage of the total number of intersections and the degree of failure as indicated by the size of the disintegrated triangles, for both types of cement. Figures 1 to 5, inclusive, show photographs of failures in the west bound lanes (all-portland cement). So far as the inspection was concerned, and especially the taking of pictures, it was unfortunate that crack

Figure 9

filler had been applied so liberally to the joints, cracks and disintegrated areas. However, Figure 2 is a good illustration of a typical failure in which the dimensions of the disintegrated triangle are comparatively small. Note that failure has occurred in three of the quadrants (all except the one in the background) and that disintegration to an advanced stage is present in the quadrant on the left. Scaling is present to quite an extent in some sections of the all-portland lanes (see Figure 7) but almost entirely absent in the blended cement lanes.

The most advanced single case of failure in the blended cement concrete (east-bound lanes) is shown in Figure 8. The length of the crack is 30 inches. The next worst case is shown in Figure 6. At both these intersections failure has occurred in one quadrant only. At all other locations in the blended cement lanes the failures are less pronounced than that shown in Figure 6.

SUMMARY OF RESULTS OF THE INSPECTION

In the all-portland lanes 37 per cent of the intersections have failed while in the blended cement lanes only six per cent have failed (see Tables 2 and 3). There are not only six times as many failures in the all-portland lanes as in the blended cement lanes, but the sizes of the failed areas and the extent of disintegration are much greater (see photographs). It so happens that the most numerous and most serious failures are in a 9495-ft. section of all-portland cement concrete (west-bound lanes) containing portland cement brand C (see section 19, Table 3). In this section 72 per cent of the intersections have failed and most of the failures are large in area. Photographs 1 to 5, inclusive, were all taken in this section. As will be mentioned later in this report the strongest concrete on this contract, as shown by cores drilled at both one year and at 11 years, contained this brand of cement. Directly across the right-of-way, separated from this section only by the grass median strip, is an 8590-ft. section of pavement (east-bound lanes) containing the same brand of portland cement but blended with natural cement brand F, in which only five per cent of the intersections have failed (see section 2, Table 2) and the failed areas are negligible in size. Figure 6 shows by far the most conspicuous failure in this section. In the section of all-portland cement pavement (west-bound lanes) showing next to the poorest service record, containing portland cement brand B, 30 per cent of the intersections have failed (see section 24, Table 3). In the section containing the same brand of portland cement blended with natural cement brand F (east-bound lanes) only eight per cent of the intersections have failed (see section 12, Table 2).

EXPLANATION OF THE FAILURES

Failures of this type are, at first thought, attributed to weakness of the concrete in compression. It would seem that this explanation would not apply here because the concrete containing all-portland cement is appreciably stronger than that containing blended cement at all ages up to and including 11 years (see Figure 10). The section showing the poorest service record, as indicated by percentage of failed intersections, showed the highest compressive strength of all the sections on this contract, as indicated by cores drilled and tested at one year and at 11 years (section 19, Table 3). High strength at all ages, including 11 years, accompanied by poor dura-

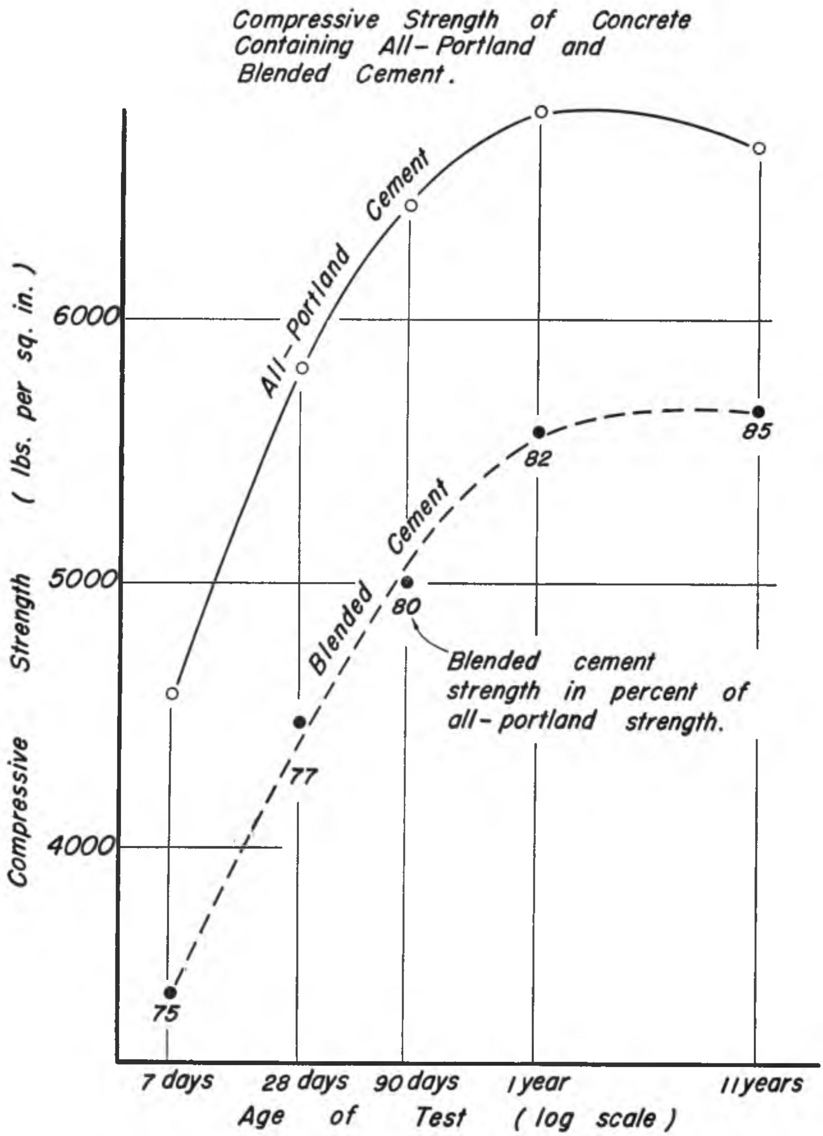

Figure 10

bility, shown by concrete containing all-portland cement, seems to be inconsistent. It would seem that the force which disintegrates the concrete at joint intersections would destroy compressive strength. However cores were purposely not drilled in the immediate vicinity of disintegrated areas because of the danger of obtaining totally unsound cores.

The comparatively poor durability of all-portland cement concrete as shown by freezing and thawing tests is no doubt the principal explanation of the failures. Laboratory tests on job-made specimens showed a loss, after 50 cycles of freezing and thawing in a 10 per cent solution of calcium chloride, of 5.8 per cent from concrete containing all-portland cement and only 0.4 per cent from blended cement concrete (see Table 2, Report R-61). Improved durability due to the use of blended cement was also shown by laboratory tests, conducted by the Purdue Joint Highway Research Project, on cores drilled at the age of one year. See their "Report No. 2 on Concrete Cores", February 9, 1942. It would seem that the results of these tests explain why the joint intersection failures are so prevalent in the all-portland cement lanes and almost entirely absent in the blended cement lanes.

SIGNIFICANCE OF ENTRAINED AIR

Why entrained air improves the durability of concrete is not at all clear. The following attempt at an explanation makes use of absorption test data on cores drilled at the age of one year, shown in Table I.

TABLE 1

ABSORPTION (PER CENT BY VOLUME)

Data from Table III, "Report No. 2 on Concrete Cores", February 9, 1942, by Purdue Joint Highway Research Project.

Test Method	Cores Containing Blended Cement	Cores Containing All-portland Cement
(1) After 24 hrs. Immersion	11.3	10.6
(2) After 1 hr. Evacuation and 23 hrs. Immersion	16.2	13.1
Method 1/Method 2 (%)	70	81

Note that the absorption of blended cement concrete is a trifle greater than that of all-portland cement concrete by both test methods. But if it is assumed that test method 2 saturates the concrete completely then the degree of saturation obtained by 24 hours immersion (absorption by method 1 expressed as a percentage of absorption by method 2) is somewhat less in blended cement concrete (70 per cent vs. 81 per cent). It seems reasonable to assume that resistance to freezing and thawing should be high if degree of saturation is low because laboratory tests show that if sufficient water is present in the pores of the concrete (degree of saturation equal to or approaching 100 per cent) when freezing and thawing occurs only a few cycles are necessary to destroy even the soundest concrete.* It is likely that the quantity of water absorbed by a concrete pavement exposed to the weather is comparable to the quantity absorbed after 24 hours immersion and if so the degree of saturation in pavement containing all-portland cement is always higher, under the same weather conditions, than in pavement containing blended cement. The locations of the failures, at the intersections of the longitudinal joint with the transverse joints, is explained by the assumption that a higher degree of absorption (causing freezing action to be of maximum severity) exists there than at points elsewhere in the pavement because of the comparatively free entrance of surface water at the joints.

This explanation does not apply to concrete pavement containing the "special" portland cement. Section 21, shown in Table 3, which contains this cement showed a perfect service record at the age of 11 years although tests on cores drilled at one year showed that 24-hour immersion produced a degree of saturation of 81 per cent, exactly equal to that of concrete cores containing all-portland cement.* This tends to refute the explanation that a low degree of saturation is necessary for high resistance to freezing and thawing.

The improved service record of the pavement containing blended cement is believed to be due to more than one reason. Improved resistance to freezing and thawing as shown by laboratory tests, regardless of the relation between freezing and thawing test results and quantity of entrained air, is probably the principal reason. However, it has been found that blended cement produces what might be described as tougher and less brittle concrete as shown by tests in which concrete was subjected to fatigue (reversals of stress) and plastic flow (under sustained compression). See Bulletin No. 47 Engineering Experiment Station, Purdue University, September,

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* See "Report No. 2 on Concrete Cores", February 9, 1942, by Purdue Joint Highway Research Project.

* See "Report No. 2 on Concrete Cores", February 9, 1942, by Purdue Joint Highway Research Project.

1934. That program of tests and the results were rather closely parallel to this investigation. The blended cement contained 21 per cent, by weight, of natural cement with no grinding aid. Blended cement produced:

1. a slight but consistant strength reduction, ranging from 14.4 to 2.3 per cent, in both compression and flexure at all test ages (7 days to 1 year);

TABLE 2

FAILED INTERSECTIONS IN EAST-BOUND LANES
BLENDED CEMENT, EXCEPT AS NOTED

Cement content=6 sacks (564 lbs.) per cu. yd., except as noted.

Section No.	From Station to Station	Length of Section (feet)	Brand of Portland Cement	Transverse Joints in the Section		
				Total Number	Failed Intersections	
					Actual Number	Percent of Total
1	1262+53 to 1263+60	107	C (all-portland)	2	0	0
2[1]	1263+60 to 1349+50	8590	C (blended)	214	11	5
3	1349+50 to 1350+31	81	C (all-portland)	2	0	0
4	1350+31 to 1415+00	6469	C (blended)	161	10	6
5	1415+00 to 1450+10	3510	A (blended)	87	9	10
6	1450+10 to 1450+96	86	A (all-portland)	2	2	100
7	1450+96 to 1473+91	2295	A (blended)	57	2	4
8	1473+91 to 1481+20	729	D (blended)	18	1	5
9[2]	1481+20 to 1481+65	45	D (all-portland)	2	1	50
10	1481+65 to 1482+25	60	D (all-portland)	1	0	0
11	1482+25 to 1487+30	505	D (blended)	12	0	0
12[3]	1487+30 to 1492+42	512	B (blended)	13	1	8
13[2]	1492+42 to 1493+00	58	B (all-portland)	1	0	0
14	1493+00 to 1507+70	1470	B (all-portland)	37	6	16
15	1507+70 to 1509+27	157	A (all-portland)	4	1	25
16	1509+27 to 1509+37	10	R.R. Crossing (ignored)			
17	1509+37 to 1511+50	213	A (all-portland)	5	0	0
18	1511+50 to 1514+00	250	C (all-portland)	6	0	0
Total of all blended (sections Nos. 2, 4, 5, 7, 8, 11, & 12)		22610		562	34	6

[1] See Fig. 6 taken at Station 1342+90.

[2] Cement content in this short section was reduced to 5 sacks per cu. yd. for experimental purposes.
See report of October, 1940.

[3] See Fig. 8 taken at Station 1489+88. This is by far the most extensive corner break in blended cement concrete.

2. only a slight improvement in durability as shown by resistance to freezing and thawing (probably due to the negligible quantity of entrained air because the natural cement contained no grinding aid) ;
3. virtually no change in modulus of elasticity in either compression or flexure at 28 days, 3 months, and 1 year ;

TABLE 3

FAILED INTERSECTIONS IN WEST-BOUND LANES
ALL-PORTLAND CEMENT

Cement content = 6 sacks (564 lbs.) per cu. yd.

Section No.	From Station to Station	Length of Section (feet)	Brand of Portland Cement	Transverse Joints in the Section: Total Number	Failed Intersections: Actual Number	Failed Intersections: Percent of Total
19[1]	1264+10 to 1359+05	9495	C	237	170	72
20[2]	1359+05 to 1363+55	450	D	11	0	0
21	1363+55 to 1369+83	628	D ("Special")	16	0	0
22[3]	1369+83 to 1402+80	3297	D	82	7	9
23[3]	1402+80 to 1472+20	6940	A	173	22	13
24[3]	1472+20 to 1507+70	3550	B	89	27	30
25[3]	1507+70 to 1509+27	157	C	5	1	20
26	1509+27 to 1509+37	10	R.R. Crossing (ignored)			
27	1509+37 to 1510+25	88	C	2	0	0
28	1510+25 to 1513+50	325	B	8	0	0
Total of all-portland sections (sections 21 and 26 are not included)		24302		607	227	37

[1] The most pronounced cases of failed intersections are in this section (see photographs 1 to 5, inclusive). Quite a little scaling is also present. (see photograph No. 7 taken at Sta. 1342+30). Bituminous patches: 6′ x 7′ at pavement centerline at Sta. 1277+70 and 15′ x 20′ in both lanes at Sta. 1310+50.

[2] There is a bituminous patch, 3 ft. square, at Sta. 1359+55 in outside lane. Pavement is cracked in vicinity of patch.

[3] Failed areas are considerably smaller than those in section 19.

General note applying to all sections: It is likely that the counts of failed intersections, recorded in the next to the last column, are too small because the bituminous crack filler probably concealed faint cracking and spalling.

4. no distinction in volume change (expansion during periods of exposure to moisture and contraction during periods of exposure to the air of the laboratory) ; and
5. virtually no change in absorption (absorption during periods of exposure to moisture and loss by evaporation during periods of exposure to air).

However, type of cement had a pronounced effect on resistance to fatigue and plastic flow. In the fatigue tests mortar columns were subjected to reversals of bending stress at the rate of 10 reversals a minute. When loaded, at the age of four months, to 60 per cent of the ultimate strength, test specimens containing all-portland cement failed at 75,000 reversals. Those containing blended cement withstood 1,300,000 reversals before failure. In the study of plastic flow 6" x 24" concrete cylinders were loaded, at the age of 28 days, to 500 psi in compression and held in compression by means of a yoke equipped with a 30,000-lb. railroad car spring. The instantaneous deformation was the same for both types of cement as would be expected because type of cement made no change in modulus of elasticity but after 11 months sustained compression the plastic flow (additional deformation) was 20 per cent greater in cylinders containing blended cement than in those containing all-portland cement. A 21 per cent increase was found after nine months of sustained compression on cylinders loaded, at the age of three months, to 800 psi. Both these tests (fatigue and plastic flow) indicate that blended cement reduces the brittleness of concrete.

These failures, so prevalent in the lanes containing all-portland cement are believed to be due to a combination of freezing and thawing and compressive stress. The fact that similar failures in the blended cement pavement are negligible in both number and size is attributed to improved resistance to freezing and thawing and to the ability of the concrete to adjust itself to stress as shown by the Purdue tests of fatigue and plastic flow. Whether or not entrained air was directly responsible for improved durability is difficult to say. As already mentioned the pavement containing the "special" portland cement, with only 1.3 percent air, shows a perfect service record after 11 years, However, other laboratory tests which unfortunately are not related to any pavement service record, have shown that this quantity of entrained air is sufficient to produce high resistance to freezing and thawing. In the tests described in Purdue Bulletin No. 47 the blended cement concrete contained only 0.8 per cent air and while its improved resistance to freezing and thawing was not great, increased plastic flow and improved resistance to fatigue were very distinct.

TABLE 4

COMPRESSIVE STRENGTH AND UNIT WEIGHT

Brand of Portland Cement	Type of Cement	Mix No.	Strength (p.s.i.) of Cores drilled and tested at		Unit Weight of Concrete lbs. per cu. ft.)		
						Saturated Surface—Dry Cores (after 24 hrs. immersion) drilled & tested at	
			1 year[6]	11 years[7]	Fresh[8]	1 year[6]	11 years[7]
C	All-Portland	2	7990	7145	152.06	153.50	153.83
	Blended[1]	1	5300	5835	147.50	149.61	149.43
	Blended/Portland		66.3%	81.7%			
A	All-Portland	4	6440	7060	151.12	153.37	153.17
	Blended[1]	3	6150	6450	148.00	150.24	150.20
	Blended/Portland		95.5%	91.4%			
E	All-Portland	14	6860	7230	158.20	158.58	157.80
	Blended[2]	13	4960	5705	153.00	152.45	151.33
	Blended/Portland		72.3%	78.9%			
B	All-Portland	7	5870	5810	152.62	153.37	154.32
	Blended[1]	9	5720	4435	147.88	148.51	149.07
	Blended/Portland		97.5%	76.3%			
	All-Portland[3]	8	6420	5170	152.58	154.75	153.68
D	All-Portland[4]	11	6780	5935	153.21	154.75	155.15
	Blended[1]	10	5775	5840	147.79	151.01	150.05
	Blended/Portland		85.2%	98.4%			
	All-Portland[3]	12	6340	6280	152.25	153.50	154.39
D	Std. Portland[5]	5	6670	6130	152.71	154.13	154.40
	"Special"	6	6810	7420	150.79	151.63	153.20
	"Special"/Std. Port.		102.1	121.0			
Average[9]	All-Portland		6790	6635	153.44	154.71	154.85
	Blended		5580	5655	148.83	150.36	150.02
	Blended/Portland		82.2%	85.2%			

[1] With natural cement brand F (15.9% substitution by weight). Contract R-1784.

[2] With natural cement brand G (15.2% substitution by weight). Contract R-1802.

[3] Cement content=approximately 5 sacks per cu. yd. (94 lbs. of portland cement was removed from the standard batch).

[4] From Car No. Pa. 254848 (presumably identical with that described in footnote 5).

[5] From Car No. Pa. 254627 (presumably identical with that described in footnote 4).

[6] With the exception of Mixes 13 and 14 these data are from Table II of "REPORT NO. 2 ON CONCRETE CORES", February 9, 1942, by Purdue Joint Highway Research Project. Cores representing Mixes 13 and 14 were tested in the laboratory of the Bureau of Materials and Tests (Nos. X-13449 to X-13456, incl.).

[7] Tested in the laboratory of the Bureau of Materials & Tests (Nos. 50-11614 to 50-11657, incl.).

[8] From Table 3 of Report R-61, October, 1940.

[9] Mixes 8, 12, 5, and 6 are ignored in computing averages.