Effect of Pozzolans Added to Sand-Gravel Concrete Pavement

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A MAJOR part of Kansas has no local sources of coarse aggregate for concrete. Silicious and granitic sands and gravels from streams or dry pits are used extensively for concrete in these areas. Many of these sand gravels are reactive with cement and subject to abnormal expansion in concrete.

In 1949 a six mile experimental pavement project was completed to explore the possibilities of inhibiting this type of expansion by additions of various pozzolans. Sections were constructed using these pozzolans, as a replacement for equal amounts of portland cement and, as a basis for comparison, sections with no additions, and sections to which additions of crushed limestone were made. All of these types of concrete were constructed in sections with and without air-entrainment, and with five brands of cement widely used in this area.

This paper is a summary of the observations made, and data accumulated, during the five years which have elapsed since the construction of this project.

● THE McPherson Test Road is a concrete pavement on Route US 81 in McPherson County, Kansas. The portion of this route comprising the test sections is a by-pass around the city of McPherson, Kansas. It was constructed in the summer of 1949 as an experimental pavement by the Kansas Highway Commission in cooperation with the U.S. Bureau of Public Roads. Other agencies which have cooperated with the Kansas Highway Commission in the construction of the road and the preparation of this report are the Bureau of Highways, Nebraska Department of Roads and Irrigation, Kansas State College, and the Portland Cement Association.

OBJECTIVES

There is widespread use in Kansas of sand-gravel aggregates for concrete, due to lack of sound limestone, or other stone deposits. Much of the concrete produced from these sand-gravel aggregates is subject to deterioration resulting from cement-aggregate reaction. This deterioration is evidenced by map cracking, and by abnormal expansion. Figure 1 is an example of what we have termed map cracking. All sand-gravel aggregates in Kansas are affected to some degree.

The McPherson Test Road, a full-scale field experimental project, is the culmination of many years of field and laboratory studies made in an effort to discover adequate and economical curative measures for inhibiting the abnormal expansion common to much of the sand-gravel concrete produced over a wide area in the state.

The primary objective of this experimental construction is a study of the effect of the addition of pozzolanic materials to concrete containing sand-gravel aggregate under field conditions.

The McPherson Test Road was built from sand-gravel aggregates produced from the Republican River, one of our most reactive aggregates. Moline limestone was used in those sections which required "sweetened" mixed aggregate.

PREVIOUS STUDIES

Realizing the economic importance of the use of sand-gravel aggregate in concrete, due to lack of acceptable sources of coarse aggre-

Figure 1. Typical map cracking in concrete made from sand gravel aggregate.

gate in the western two-thirds of the state, the Kansas Highway Commission, in cooperation with the Kansas State College Engineering Experiment Station and the Portland Cement Association, began early studies of the problem.

Data was accumulated from a survey of map cracked Kansas pavements made by White (*1*), and from a study by Gibson (*4*) of a method of testing cement-aggregate combinations for reaction by means of accelerated laboratory tests.

Work done in the laboratory during and after 1942, (*5*) and (*6*), with pozzolan admixtures including flyash, and investigations reported by Davis (*10, 11*) seemed to further justify a full scale field experimental project.

PLANS AND LAYOUT

Location of Project

The McPherson Test Road is located in the center of McPherson County which is slightly to the southeast of the center of the state. The terrain is flat to gently rolling with poor drainage.

The climate is typical of the midwest plains states. The average annual precipitation is 29.84 inches and the average mean temperature range is 31 F. to 79 F. with numerous periods of freezing and thawing temperatures during the winter months.

Route US 81 is one of the most heavily traveled roads in Kansas. Truck traffic originating in the oil fields and from the refineries in Wichita, El Dorado and McPherson uses this route to the north. A great many heavy oil transports and industrial trucks travel over this highway and during the harvest season it is a major route for harvesters and grain haulers, both north and south.

The location of the McPherson Test Road in relation to the city of McPherson and connecting routes is shown on the accompanying Location Map, Figure 2. The character of the climate, the traffic, and the type of terrain over which this road was constructed combine to impose severe conditions of test on the experimental concrete.

Layout of Project

The McPherson Test Road is 5.987 miles in length. The entire length of the road is composed of concrete of an experimental character. The pavement slab is divided into sections approximately 488 feet long. The project was laid out in such a manner that an expansion joint is located in the center of each experimental section.

The pavement is 22 feet wide, 9 inches thick, and mesh reinforced. Grooved type contraction joints formed and finished manually are spaced at 20 feet 4 inches. Only expansion joints and construction joints are doweled.

The experimental concretes contain 3 pozzolanic materials, 5 brands of cement, 2 aggregates, and air-entrainment. The various combinations of these materials produced a total of forty-six different types of concrete in 6 classes divided as shown in Figure 3.

THE SUBGRADE

The project was graded the year preceding paving. Just prior to paving the subgrade was scarified to a depth of 6 inches and re-rolled.

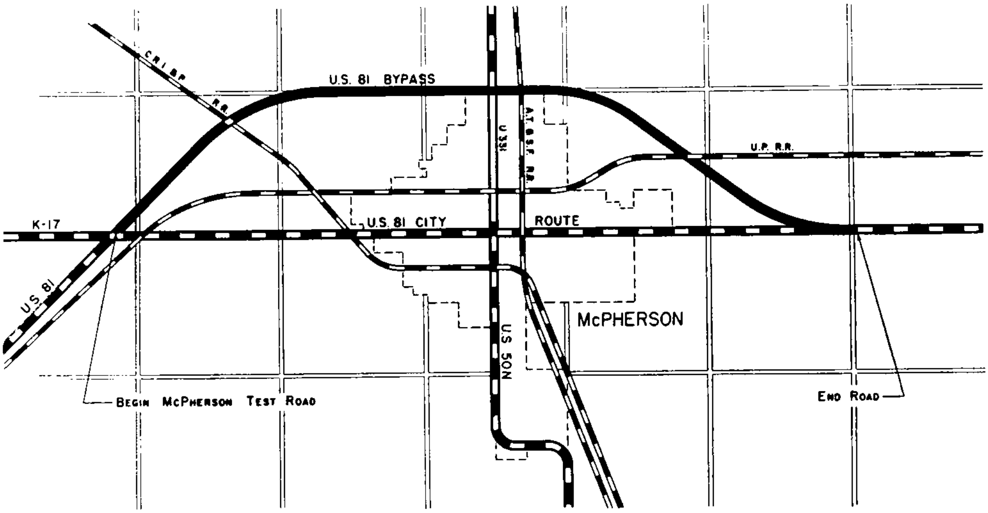

Figure 2. Location of test road.

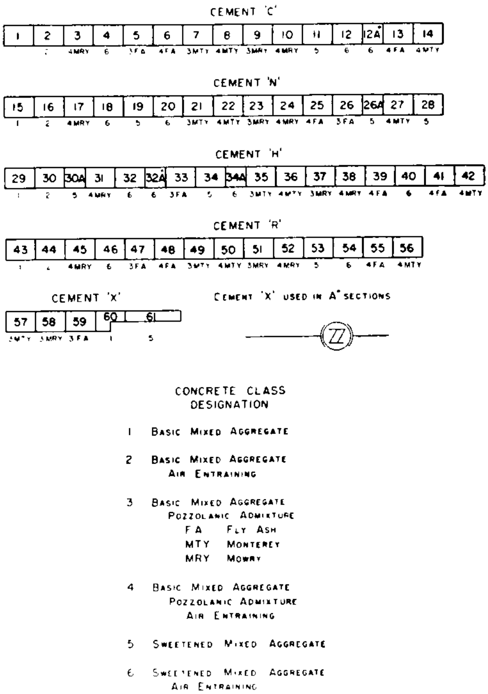

Figure 3. Test section layout.

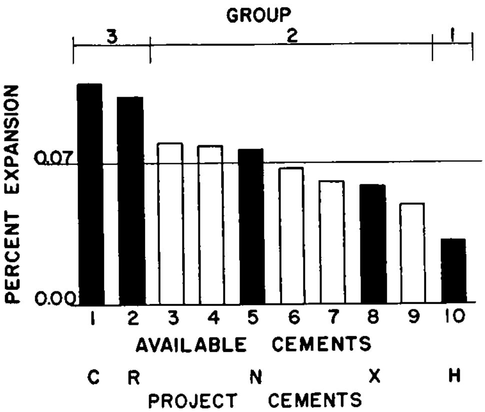

Figure 4. Results of accelerated expansion tests.

A dense type granular subbase, 4 inches thick was applied and both the subgrade and subbase were brought to satisfactory density. Granular material used had from seventy to ninety percent retained on the two hundred mesh sieve (*12, 13, 14*).

PAVING MATERIALS

Cements were chosen for the project in the following manner. Ten brands available in the area of the project were tested for expansion by accelerated laboratory methods (see Figure 4). Of these ten cements, five were selected, two with excessive expansion, cements "C", and "R", one with very little, cement "H", and two cements "N", and "X", midway between these two extremes. All cements were

Type I, conforming to the requirements of ASTM Designation C150-46, with the additional requirement that the cements be in compliance with the "Weight per liter" test used in Kansas.

Pozzolans chosen were selected principally due to the fact that they were available. Flyash for use on the project came from the Chicago area, and was delivered to the site in paper bags.

Mowry shale was quarried near Laramie, Wyoming, and was calcined, ground, and sacked at a Kansas cement plant. Monterey shale was produced near Colton, California, and is from the same source as that which has been used by the Bureau of Reclamation in the Davis Dam. Stanton *(15)* has reported on the effectiveness of calcined Monterey shale in reducing excessive expansion between certain cements and aggregates.

Two aggregates were used, a sand-gravel or "mixed aggregate", and a crushed limestone which was added to the sand-gravel in certain sections to produce a "Sweetened mixed aggregate". The sand-gravel was produced from the Republican River near Wakefield, Kansas, and numerous field surveys and laboratory investigations *(1, 4, 5, 6)* have indicated this material to be highly reactive when incorporated into portland cement concrete. The crushed limestone was quarried near Moline, Kansas, and was the closest commercial source of coarse aggregate. Sweetened mixed aggregate was produced by combining 70 percent basic aggregate with 30 percent crushed limestone by weight. Basic sand-gravel had a top size of ¾ inch with 90 percent passing the four mesh. Crushed limestone used for sweetening had a top size of 1 inch.

CONCRETE MIX DESIGN

Concrete mixes were designed using a maximum of 5½ gallons of water per sack of cement and a minimum of 1.60 barrels of cement per cubic yard of concrete. When the shales or fly ash were included in the mix they replaced an equal weight of cement and appeared as cement in the computations. The slump was to fall between ½ and 1½ inches and the entrained air content between 6 percent and 9 percent for basic aggregate mixes and between 5 percent and 8 percent for limestone sweetened aggregate concrete.

FIFTH YEAR REPORT

The following comments are made after examination of all data available at the end of the fifth year. The sources of this data are listed below, and all of it has been obtained at 6 month intervals for the entire sixty month period, unless otherwise noted. This should not be considered a final report, but merely a summing up at the midpoint of the anticipated ten years of observation of this project: (a) test beams, (b) surveys of condition, (c) soniscope readings of slab, (d) soniscope readings of beams (started 18th month), (e) strain gage readings, (f) measurement of faulted joints, (g) count of panels pumping and blowing, (h) count of mudjacked panels, (i) measurement of test beam deflections, while under test load and at instant of fracture (started 4th year), (j) weather records, (k) traffic data, (l) construction notes, (m) initial reports made soon after completion of project, and (n) durability tests by freezing and thawing.

SEMI-ANNUAL SURVEYS

Table 1 is a condensation of all the tabulations made at the end of the fifth year of semi-annual surveys. The number of half panels of each class of concrete, of each cement, and of air-entrained and non-air-entrained groups, is listed, and weighted averages for both left and right lanes were then developed for the following: (a) percentage of map cracked panels of each degree, faint map, Map I, and Map II; (b) lineal feet of transverse cracks per one hundred half panels; (c) lineal feet of longitudinal cracks per one hundred half panels; (d) percentage of faulted joints; (e) percentage of mudjacked panels; (f) percentage of map cracked half panels, in all degrees; (g) an arbitrary value for severity of map cracking, obtained by adding the percentage of faint mapped half panels to twice the percentage of Map I half panels, and to three times the percentage of Map II half panels; and (h) a weighted average of the left and right hand lanes to arrive at a final value for degree of map cracking for each class of concrete and brand of cement.

Visual Observations

1. Air-entrained sections, with all classes of concrete and brands of cement averaged together, have a map cracking factor of 1.52,

as against 1.36 for non-air-entrained sections. This same grouping produces an average of 1417 lineal feet of transverse and 160 lineal feet of longitudinal cracks per 100 half panels in the air-entrained sections, and 875 lineal feet and 77 lineal feet, respectively, in the non-air-entrained group. This trend holds true for all classes of concrete and brands of cement analyzed individually with the exceptions of those sections containing fly ash and sections containing cement "H", in which it is reversed.

2. Sections grouped on the basis of cement brands were studied relative to all types of cracking. One brand, cement "X", was not used with air-entrainment so cannot be compared directly with the other brands. Cement "R" sections contain about half as much map cracking as each of three brands "C", "N", and "H", and fewer cracks of all kinds. These field results do not parallel expansion tests in the laboratory prior to construction which indicated greatest expansion for cements "C" and "R". Cement "H" had least expansion in laboratory tests but sections in which this cement was used are second only to those sections using cement "N" in severity of map cracking.

3. At the present time none of the pozzolan admixtures have inhibited map cracking on a scale comparable with results obtained from limestone sweetening.

4. Flyash mixes, with air-entrainment, show some improvement over basic mixed aggregate sections, with regard to map cracking. Mowry shale sections show no improvement over basic aggregate, and Monterey shale sections have higher map cracking factors than do basic mixed aggregate sections. (See Table 1)

5. A count of mudjacked and faulted joints reveals that 75% of all joints in the right hand, or north bound lane are faulted, or have been mudjacked to correct a faulted condition. This compares with 47% in the south bound, less heavily traveled, lane. The right lane also contains 600 lineal feet of transverse and 69 lineal feet of longitudinal cracks per hundred half panels, as compared to 547 lineal feet and 50 lineal feet in the left hand lane. The right hand lane has a map cracking "factor" of 1.50, as compared to 1.38 in the left hand lane.

Test Beams

A four foot by ten foot slab, nine inches thick, was cast near the right-of-way line in each experimental section. These slabs had partial depth wood dividers at six inch centers to separate the slab into test beams having, roughly, an "I" beam cross section. These slabs were cured in an identical manner with the pavement proper and have been given no special handling since then other than an occasional shouldering up. They are tested at six month intervals without soaking or other preparation. Twelve beams from each set have been tested to date, and the remaining eight will be tested in the next five years. The 10 day beams on the charts are 6- by 6- by 36-inch test beams.

SURVEY DATA BY CONCRETE CLASS

Basic Mixed Aggregate Sections

Class 1 and 2 beams, without and with air-entrainment, made from mixed aggregate not utilizing limestone sweetening or pozzolanic admixtures, have lost flexural strength steadily since the first few months. These losses have, however, tended to diminish during the last eighteen months and small gains were recorded at the end of year five, over the fifty four month tests (see Fig. 5).

Class 1 beams have average modulus of rupture, at the end of five years, of 489 psi, although they averaged 648 psi at ten days age and 845 psi at three months. Class 2 beams follow the same trend.

Based on the pavement condition survey there is no indication however that these basic aggregate sections are in any immediate danger. While they are inferior to the limestone sweetened sections, they are in general equal to or better than the "admixture" sections.

Mowry Shale

Test beams from concrete utilizing Mowry shale have declined in flexural strength since the twenty-fourth month but still average over 750 psi, a gain of about 100 psi over 10 day strength.

The condition survey shows practically no difference between Mowry shale sections and basic aggregate sections, on the basis of map, transverse, or longitudinal cracking.

Monterey Shale

Of all the test sections the ones containing Monterey shale have the poorest field record to date. The flexural strength tests are very erratic, particularly with cements "R" and "X", losses or gains of as much as fifty percent

TABLE 1
TABULATION OF SURVEY DATA

	No. Half Panels		Tr. Cracks Lin. Ft. per 100 Panels		Long. Cr. Lin. Ft. per 100 Panels		Faulted Jts. per 100 Panels		Mud JKD Panels per 100 Panels		Map Cracking						Percent of Panels Map Cr.		FM + 2(M1) + 3(M2)		Total Map Cracking FM + 2(M1) + 3(M2)	Sections Included
											Lt. lane			Rt. lane								
	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	FM	M1	M2	FM	M1	M2	Lt.	Rt.	Lt.	Rt.		
Class 1	90	90	407	537	4	127	33	56	8	26	11	46	17	8	44	24	74	76	1.54	1.67	1.61	1, 15, 29, 43, 60
Class 2	91	91	733	807	17	50	44	61	3	10	21	34	30	21	36	40	85	97	1.79	2.11	1.95	2, 16, 30, 44
Class 3 FA	81	81	311	421	82	47	44	59	4	36	24	63	0	19	65	12	87	96	1.50	1.70	1.60	5, 26, 33, 47, 59
Class 4 FA	163	163	514	639	27	20	37	51	10	46	35	40	7	29	50	4	82	83	1.34	1.41	1.38	6, 13, 25, 39, 41, 48, 55
Class 3 MTY	79	79	947	939	44	119	35	58	8	35	30	59	8	6	72	19	97	97	1.70	2.06	1.88	7, 21, 35, 49, 57
Class 4 MTY	184	184	1199	1328	242	256	37	53	17	52	17	48	36	12	50	38	100	73	2.19	2.26	2.23	8, 14, 22, 27, 36, 42, 50, 56
Class 3 MRY	91	91	413	322	16	44	42	55	8	30	37	47	1	31	67	2	85	100	1.71	1.53	1.62	9, 23, 37, 50, 58
Class 4 MRY	188	188	688	759	60	114	42	59	17	31	27	43	17	19	53	15	87	87	1.61	1.68	1.65	3, 10, 17, 24, 31, 38, 45, 52
Class 5	121	121	30	48	6	0	24	39	7	17	2	0	1	11	0	0	3	11	.05	.11	0.08	11, 19, 26A, 28, 34, 53, 61, 62
Class 6	184	184	221	238	4	11	37	45	8	24	22	7	1	31	5	1	30	37	.39	.44	0.42	4, 12, 18, 20, 32, 40, 46, 54
Cement "C"	325	325	596	570	22	21	40	58	2	15	27	47	10	16	54	17	84	86	1.51	1.75	1.63	1 through 14
Cement "N"	318	318	650	787	74	67	40	62	18	43	11	57	14	7	62	15	82	84	1.67	1.76	1.72	15 through 28
Cement "H"	319	319	512	712	101	211	35	48	8	37	20	40	22	16	36	28	82	80	1.66	1.72	1.69	29 through 42
Cement "R"	310	310	427	446	3	21	34	47	7	27	33	11	1	35	24	1	45	60	0.58	0.86	0.72	43 through 56
Cement "X"	150	55	277	102	35	0	54	21	15	10	52	5	0	33	17	0	57	50	0.62	0.67	0.63	57 through 61, non AE
Non air	462	462	422	453	30	47	36	53	7	29	21	43	5	15	50	11	69	76	1.30	1.41	1.36	All odd numbered classes
Air entr.	810	810	671	746	70	90	39	54	11	33	24	33	18	22	39	20	75	81	1.46	1.58	1.52	All even numbered classes
All panels	1272	1272	547	600	50	69	38	44	9	31	23	38	12	19	45	16	72	79	1.38	1.50	1.44	1 through 56—no cement "X"

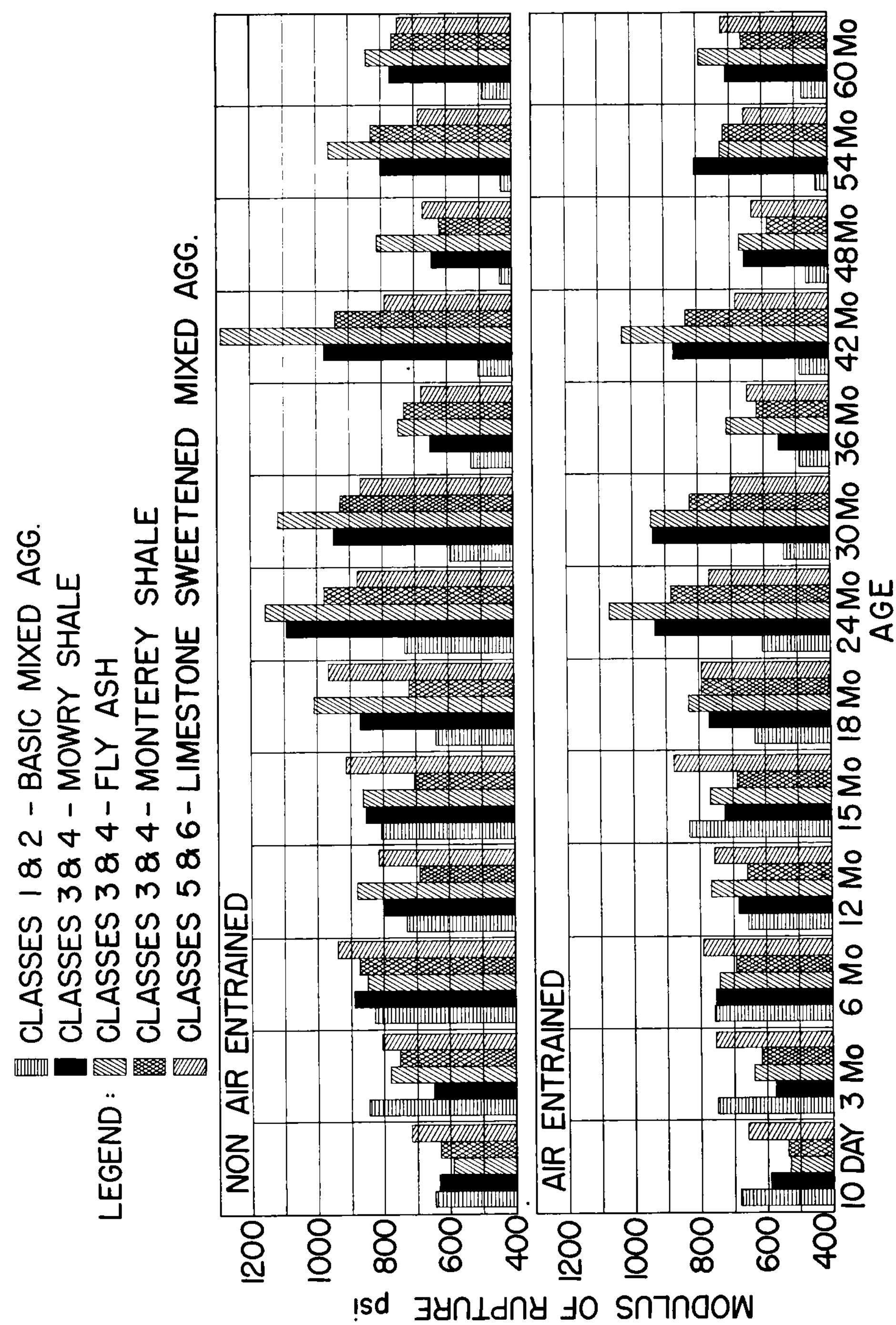

Figure 5. Flexural strength—classes of concrete.

being common from one six months test period to the next. At 60 months test beams average 760 psi, 100 psi more than at 10 days. Monterey sections contain more cracking of all kinds than any of the other sections. Monterey panels have a large number of longitudinal cracks, and some sections are approaching a condition that may require some extensive maintenance. The concrete adjacent to many of the cracks is becoming laminated, in horizontal planes, and is in some cases beginning to spall out.

Flyash

Test beams made from concrete containing flyash show wide variations in strength from spring to fall, but still have much higher average strengths in flexure than any of the other classes of concrete. At 60 months flyash beams average well over 800 psi, as compared to less than 600 psi at ten days.

The condition survey shows air-entrained flyash-concrete sections to be less severely map cracked than the basic aggregate sections, and much less than either of the shales. Air-entrained flyash sections were the only sections having less map cracking than their non-air entrained counterparts.

Basic Aggregate with Limestone Sweetening

The limestone sweetened sections on the project are in generally excellent condition, with all brands of cement. Beam strengths average over 700 psi at 60 months and are slightly stronger than at ten days age. Beam strengths were at their peak at 18 months and have slowly declined since that time. Limestone sweetened sections have virtually no map cracking and fewer cracks of other types than any of the other classes of concrete.

EFFECT OF AIR-ENTRAINMENT

While the decrease in strength due to entrained air was expected, (see Fig. 6) some other results were not. The condition surveys have revealed that nearly every type of deterioration is present in greater degree in air-entrained sections than in the non-air-entrained sections. Map cracking, as well as transverse and longitudinal cracking, are from slightly more, to two or three times as extensive in those sections where air-entrainment has been employed. Flyash sections, however, reverse this trend. Air-entrained flyash beam strengths are lower, about 8 percent, than non-air-entrained beams, but map cracking is less severe and there are fewer longitudinal

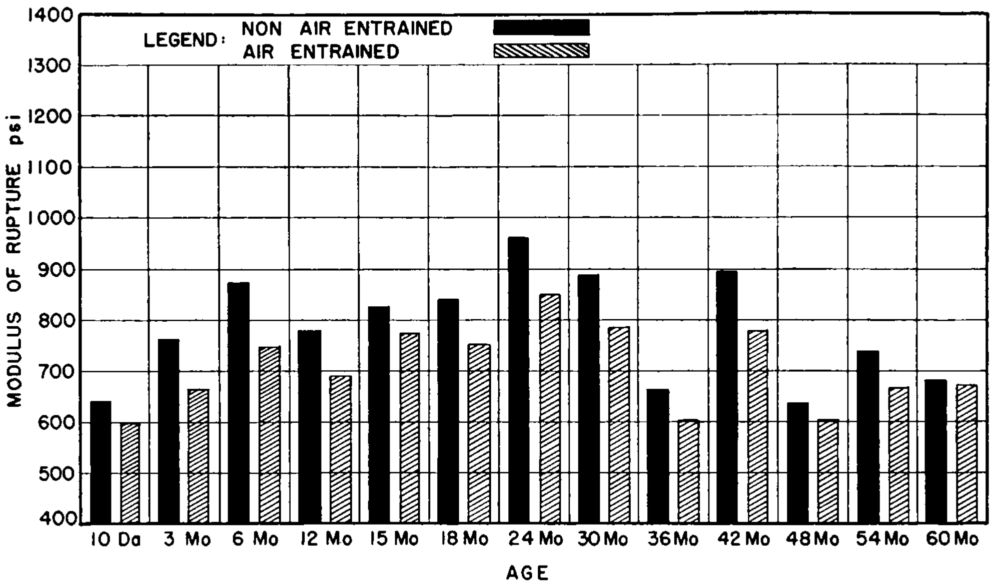

Figure 6. Flexural strength—with and without air-entrainment.

cracks. The total for transverse cracks is still highest in the air-entrained sections. None of the sections are scaled whether air-entrained or not.

Results of Nebraska Durability Tests

During construction of the project twelve 3- by 4- by 16-inch test specimens for each section were made and sent to the Nebraska Testing Laboratory for directional freezing and thawing tests. The beams were frozen from one side only but were thawed uniformly. The degree of expansion and the loss in sonic modulus were used as measures of the durability of the specimens.

The durability of all classes of concrete except the flyash admixture was increased greatly by the addition of entrained air. The flyash concrete was, however, benefited slightly. For most classes of concrete, the durability did not vary greatly for the different cements.

SURVEY DATA BY CEMENT BRANDS

Four brands, cements "C", "H", "N", and "R" were used in each class of concrete so are used in all comparisons of sections by class or brand. Cement "X" was used in all classes of concrete without air-entrainment, but no air-entrained sections were built with this cement so it has been omitted from a large part of the tabulations. Flexural strengths of test beams followed the same general seasonal trends regardless of brand of cement. (See Figs. 7 & 8) However, highest strengths were recorded for cement "R" at almost every test period. The peak strength for cement "R" occurred at 24 months.

The condition survey reveals that sections built with cements "R" and "X" have the least map cracking, and less transverse and longitudinal cracking than any other brand. The other cements "C", "H", and "N" are nearly equal to each other in map cracking, transverse cracks, and longitudinal cracks, but in each case the values are about double those recorded for cements "R" and "X". Observations of the project to date indicate that some qualities inherent in cements "R" and "X" are in themselves inhibitors of map cracking and other difficulties associated with sand-gravel concrete pavement.

Tendency Towards Declining Flexural Strengths of Test Beams

When all beam strengths were averaged (see Fig. 9), it was evident that flexural

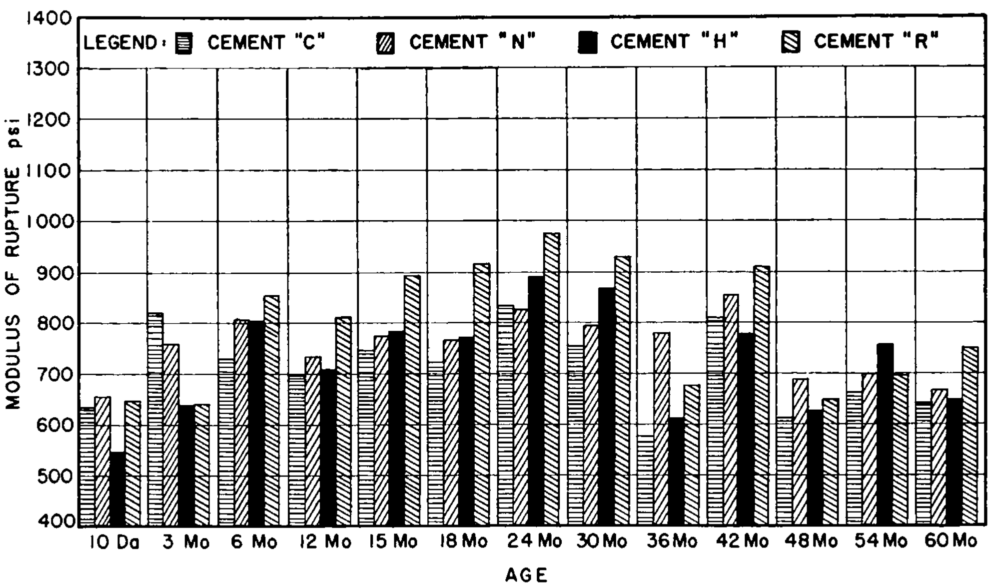

Figure 7. Flexural strength—four brands of cement.

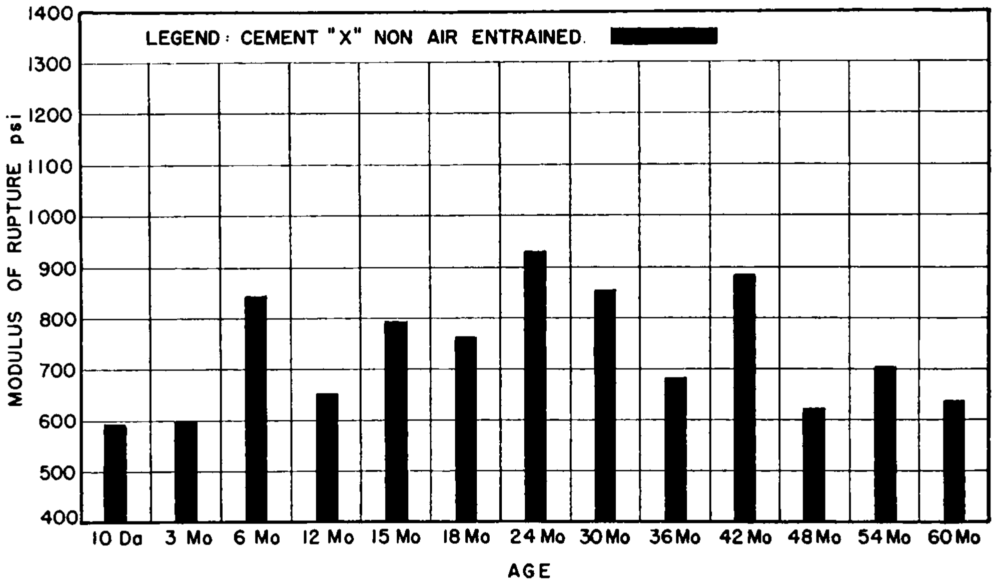

Figure 8. Flexural strength—cement "X".

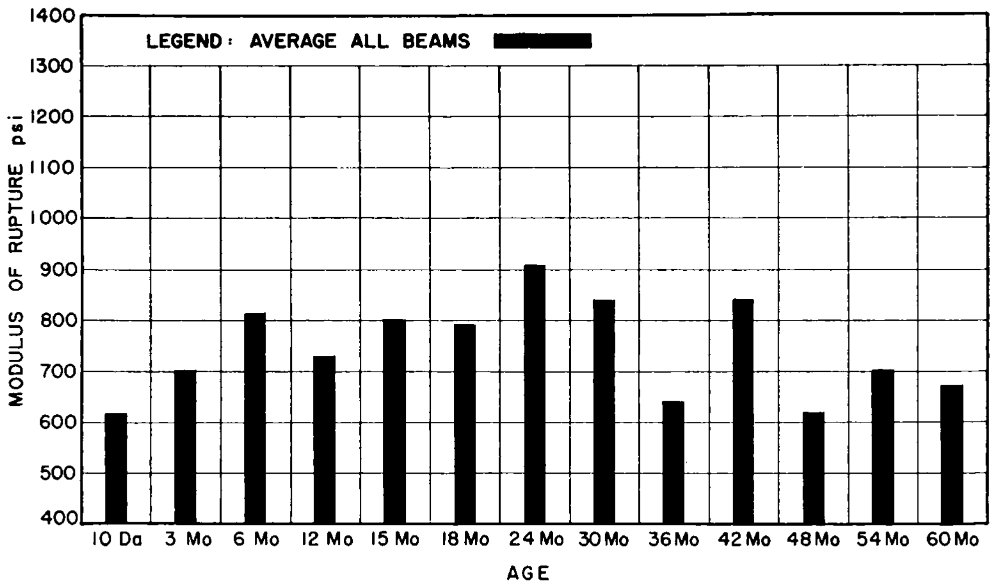

Figure 9. Flexural strength—all beams.

strengths have declined since about the end of the second year. Each cycle is a little lower than the previous year's. At the end of year five, the average strength of all beams is 695 psi in flexure, as compared to 605 psi at 10 days age, and 900 psi at 24 months. Concrete containing limestone sweetened aggregate, which is a standard aggregate for the state, is also following this trend on this project, though at the end of year five it has not decreased as radically as the basic aggregate sections.

WEATHER EFFECT ON BEAM STRENGTHS

When the project was planned it was assumed that considerable variation in flexural strengths could be expected due to extremes in

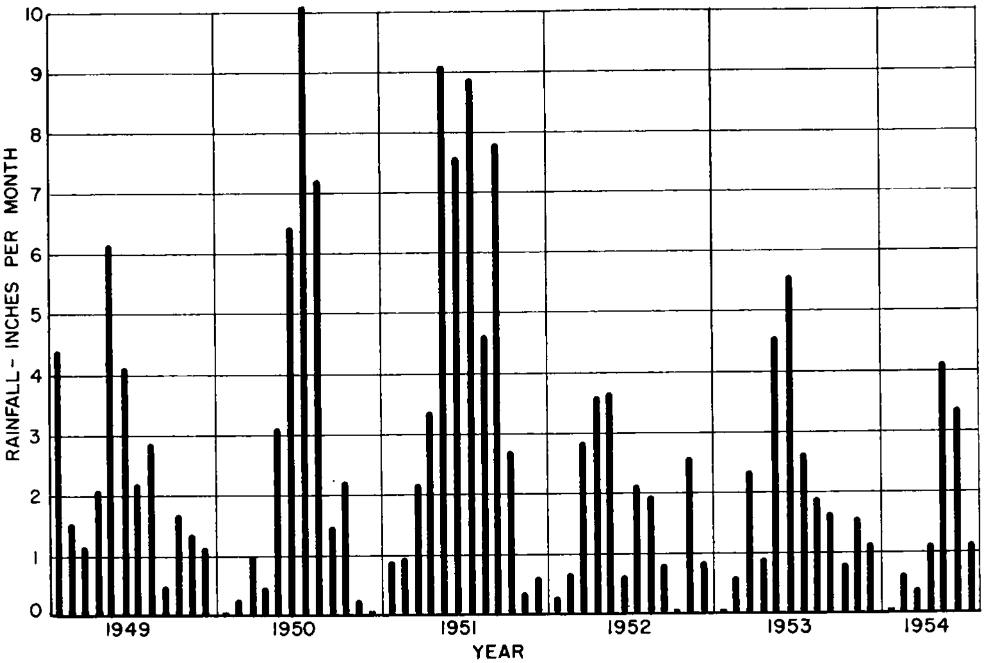

Figure 10. Monthly rainfall at McPherson, Kansas.

weather, both temperature and moisture. These variations have, however, greatly exceeded that expected. For example, flyash beams, without air-entrainment, and with cement "H", dropped from 1215 psi in the spring of 1952 to 650 psi that fall, and recovered to 1300 psi the next spring. Beams in this series, after a hot, dry summer, 1953, were down to 750 psi and after a winter with moderate moisture, were up to 1030 psi in the spring of 1954. When tested in the fall of 1954, after a hot, dry summer, they were at 946 psi.

The above example is an extreme case but large variations occur in all beams containing flyash, Monterey shale, or Mowry shale, and small variations in those beams made with basic mixed, or limestone sweetened aggregate. (See Fig. 10)

EFFECT OF TRAFFIC

During the five year period that this project has been under observation north bound traffic has averaged somewhat heavier than that headed south. (See Table 2) This is due to fuel tanker traffic originating at McPherson, El Dorado, Wichita, and Augusta. Almost all types of damage are a little more pronounced in the north bound lane.

TABLE 2
LOAD CONDIDION SURVEY
Number of Axles by Axle Load Groups—Directionally for 1950 to 1954
County: McPherson; Route: US 81 By-pass; Station No.: 059–081; Location: North of US 50N

Axle Load in Pounds	Average Daily Frequency									
	Southbound					Northbound				
	1950	1951	1952	1953	1954	1950	1951	1952	1953	1954
Under 8000	663	665	782	966	1126	497	561	659	770	773
8000–9999	54	52	53	60	94	49	46	64	83	75
10000–11999	25	33	36	39	39	27	20	34	48	43
12000–13999	45	76	75	71	61	49	23	66	62	65
14000–15999	107	205	181	175	99	168	202	242	235	314
16000–17999	113	145	139	94	95	219	284	209	201	234
18000–19999	35	33	48	20	34	35	66	40	27	42
20000–21999	1									
22000–23999	1				1				3	
24000–25999							3			
26000–27999		2								
28000–29999										
30000–33999							3			
Total axles counted	1044	1211	1314	1425	1549	1044	1208	1314	1429	1546

EFFECT OF SHOULDER MAINTENANCE

During the wet periods of 1950 and 1951 the shoulders of this project became badly eroded, and in some places ruts reached the bottom of the slab. During 1952 a great number of slabs were pumping, blowing, and faulting. This condition was corrected during the fall and winter of 1952 and shoulders have been well maintained since that time. This maintenance, plus much drier weather, has almost eliminated pumping and blowing.

MUDJACKING (TWO METHODS)

Along with the intensive shoulder maintenance program instituted in 1952, considerable mudjacking was done to correct faulted joints. Holes were drilled approximately 3 feet from the joint, and 3 feet in from the edge, and a cement-silt slurry was pumped in. Slabs were raised about ¼ inch higher than the adjacent edge, and were found to subside very nearly flush under traffic.

A few slabs were raised by introducing a pipe under the edge, and raising the slab under traffic, which eliminated the necessity for guessing the amount of subsidence which would occur when traffic was turned back on. While this method at first seemed to be favorably received, it was later abandoned for the more generally used procedure. The principal objection seemed to arise from the edge preparation necessary to prevent slurry seeping out while pumping.

TABLE 3

	% Expansion
Class 1	.030
Class 2	.020
Class 3 FA	.004
Class 4 FA	.004
Class 3 MTY	.006
Class 4 MTY	.001
Class 3 MRY	.010
Class 4 MRY	.010
Class 5	.001
Class 6	.010
Cement "C"	.0125
Cement "N"	.0059
Cement "H"	.0024
Cement "R"	.0125
Cement "X"	.0132

TABLE 4
MAP CRACKING

Class of Concrete or Brand of Cement	Map Cracking Factor (FM + M1 × 2 + M2 × 3)	
	Non air-entrained	Air-entrained
Class 5	0.08	
Class 6		0.42
Class 4 FA		1.38
Class 3 FA	1.60	
Class 1	1.61	
Class 3 MRY	1.62	
Class 4 MRY		1.65
Class 3 MTY	1.88	
Class 2		1.95
Class 4 MTY		2.23
Cement "R"	0.69	0.76
Cement "X"	0.78	
Cement "C"	1.43	1.83
Cement "H"	1.73	1.65
Cement "N"	1.52	1.86
No air-ent. (av. all)	1.36	
Air ent. (av. all)		1.53

STRAIN GAGE READINGS

Strain gage points, two pairs in each section, were placed in the edge of the slab on 20-inch centers. The points were protected with grease and screw caps and most are still in good condition. However, almost half of these gage points are no longer in use because of cracks falling between points.

Readings were taken, in inches, spring and fall during the entire five year period. Table 3 presents a summary of gage readings at 5 years compared to those at 6 months.

It will be noted that expansions as read in the field are small as compared with laboratory results, and that cements fall in somewhat different order.

MAP CRACKING

Since map cracking is held to be indicative of abnormal expansion in concrete, this project has been examined in detail twice each year for evidence of such cracking. At the end of the fifth year particular care was taken to assure that all sections were examined under similar light conditions, all work being done during early morning and late afternoon hours.

Map cracking was classified according to its severity as follows:

Faint map is that which is just discernible. The cracks are very fine and tightly closed. Faint cracking is more easily found when the concrete surface containing it is damp, or painted. It is the initial stage of map cracking.

Map I, the second stage of development, is that which may be easily seen in concrete surfaces. The cracks are still tightly closed and the "map" pattern may not be completely outlined, i.e., there may be more cracking in one direction than in another.

Map II, the third stage of development, is discernible in concrete surfaces from some distance or from a moving car. The full "map" pattern is present, unless the concrete is heavily reinforced or confined. In this stage the cracks are open slightly, and some slight spalling may have occurred, especially in vertical surfaces.

Map III, the final stage of development, is easily identified. The full "map" pattern is present and the cracking often extends throughout the particular project under examination. The cracks are open, more so than in the previous stage of development. General displacement is usually found in horizontal slabs, creating a rough, rolling surface. Spalling and pop-outs are present in various degrees of severity; reinforcing steel may be exposed. The general appearance of a structure or slab suffering from Map III is one of partial or total disintegration.

Each panel of the pavement on the project has been evaluated and the number of map cracked panels of each degree totaled for each class of concrete. These figures have been adjusted to read "Map cracked panels per 100 panels, FM, M1, etc."

Then for purposes of comparison between classes, factors have been obtained for each class by doubling the Map I panels and tripling the Map II panels, and adding these figures to the "faint map" total.

Table 4 is a rearrangement of the map cracking data in Table 1, in order of severity.

DEFLECTION MEASUREMENTS

In the fall of 1953 deflection measurements were begun on the test specimens in an effort to discover a "toughness" or other quality which might account for the discrepancies found between flexural strength and the actual condition of the pavement. As the beams were loaded to failure the deflection of the specimen and the applied load were recorded on a two-channel Brush oscillograph.

The load was measured with an SR-4 strain gage pressure cell which was connected to the hydraulic system of the beam testing machine. The beam deflections were measured with a specially designed strain gage deflectometer which was clamped to the beams during testing.

Deflection measurements have been made on the McPherson test beams at 48, 54 and 60 months of age. The averages of the deflections at the point of rupture are tabulated in Table 5. Small differences in deflection were found for the several classes of concrete. Basic mixed aggregate without air-entrainment had the largest average deflection. Basic mixed aggregate with limestone sweetening had the lowest deflection values. The beams without air-entrainment deflected slightly more before failure than did those with entrained air.

The deflections for the several brands of cement are nearly equal. Cement "C" had the largest deflections and cement "R" had the smallest.

The energy absorbed by a specimen before rupture is a measure of the specimen's "toughness". The energy input is equal to the area under the load deflection curve. Since the load-deflection curves were almost linear the energy values recorded in Table 5 were computed by taking half of the product of the load and deflection at the point of rupture.

The specimens containing flyash admixture without entrained air absorbed the most energy before rupture. Basic mixed aggregate with entrained air absorbed the least. The energy values for the several cements were almost equal. The sections containing no entrained air absorbed slightly more energy than those having entrained air.

The apparent modulus of elasticity for the several classes and cements was calculated from the deflection values and the load at failure. These values are recorded in Table 5. Basic mixed aggregate without air had the lowest modulus of elasticity. The beams with Monterey shale were the next lowest; flyash and Mowry shale had the highest values. Specimens containing cement "C" had the lowest modulus of elasticity and those with cement "R" had the highest. No difference between air-entrainment and non-air-entrainment was noted.

SONISCOPE OBSERVATIONS

As a supplement to the information gained from visual inspections and the regular testing of beams, pulse velocity measurements have been made regularly with the Soniscope on the several test sections. A high pulse velocity is thought to be indicative of good concrete quality and a low velocity to indicate a poorer quality (*20*).

Velocity determinations have been made on the pavement sections at permanently marked locations at 1 month of age, at 12 months of age and at 6 months intervals since that time. Beginning with the 18 month tests, velocity

TABLE 5

Class of Concrete	Deflection, inches × 10^4				Energy, inch lbs.				Modulus of Elasticity, lbs./sq. in. × 10^{-6}			
	48 mo.	54 mo.	60 mo.	Avg.	48 mo.	54 mo.	60 mo.	Avg.	48 mo.	54 mo.	60 mo.	Avg.
1	27.0	28.0	31.2	28.7	8.2	8.4	10.2	8.9	2.03	2.01	1.97	2.00
2	23.0	26.5	28.0	25.8	6.9	6.9	8.4	7.4	2.70	2.15	2.21	2.35
3 MRY	23.2	24.0	25.7	24.3	9.8	12.3	12.9	11.7	3.64	4.36	3.84	3.95
4 MRY	23.0	26.2	26.5	25.2	9.6	13.1	11.7	11.5	3.63	3.98	3.68	3.76
3 FA	25.0	30.0	26.3	27.1	14.3	21.1	15.3	16.9	4.15	4.33	3.95	4.15
4 FA	22.0	25.0	26.7	24.6	9.0	11.6	13.1	11.2	4.04	3.83	3.89	3.92
3 MTY	20.7	30.3	28.0	26.3	8.0	17.3	14.3	13.2	3.54	3.61	3.40	3.52
4 MTY	23.5	26.2	30.0	26.6	8.2	11.8	14.1	11.4	3.25	3.51	3.04	3.27
5	23.0	26.0	25.0	24.7	9.8	11.9	12.5	11.4	3.77	3.36	3.76	3.63
6	23.0	24.0	24.5	23.8	9.2	10.2	12.0	10.5	3.48	3.49	3.67	3.55
Cements												
"C"												
Non-air	24.6	28.6	29.0	27.4	10.2	13.1	12.8	12.0	3.16	3.08	2.84	3.03
Air	24.2	26.8	26.8	25.9	9.7	10.8	10.9	10.5	3.16	2.96	2.90	3.01
"N"												
Non-air	23.4	26.6	26.8	25.6	9.1	13.0	13.9	12.3	3.36	3.71	3.75	3.61
Air	23.0	26.0	28.0	25.7	8.2	10.4	12.9	10.5	3.33	3.28	3.24	3.28
"H"												
Non-air	22.8	28.2	27.8	26.2	9.9	15.4	13.2	12.8	3.47	3.71	3.07	3.42
Air	23.0	25.2	28.6	25.6	8.9	11.5	11.5	10.6	3.47	3.65	3.02	3.38
"R"												
Non-air	25.3	25.3	25.2	25.3	10.9	11.9	12.2	11.7	3.35	3.44	3.70	3.50
Air	21.6	24.7	25.2	23.8	7.8	10.4	12.2	10.1	3.69	3.69	4.00	3.79
"X"												
Non-air	21.5	26.2	24.0	23.9	9.1	12.0	10.6	10.6	4.04	3.50	3.74	3.76
Average, non-air	23.8	27.4	27.2	26.2	9.9	13.6	13.1	12.2	3.36	3.49	3.33	3.39
Average, air	22.9	25.6	27.1	25.2	8.6	10.8	11.8	10.4	3.41	3.39	3.29	3.36
Total average	23.3	26.5	27.1	25.7	9.1	12.2	12.4	11.3	3.38	3.44	3.31	3.38

NOTE: Cement "X" was not included in the class averages or in the overall average.

measurements have also been made on the beams prior to being tested.

The changes in velocity for the several test sections and specimens have generally followed a seasonal pattern (Fig. 11). Higher velocities have been found in the spring than in the fall. The changes in velocity follow in a general way the changes in flexural strengths but the fluctuations in velocity are much smaller. The average velocities for all test beams have stabilized at near 15,000 ft. per sec., and for the slab at about 14,500 ft. per sec. The beams tend to fluctuate more than does the slab and on concrete types which show decreasing velocities the beams have decreased much more than the slab.

The pulse velocity varies somewhat with the moisture content of the concrete. This, undoubtedly has contributed to some extent to the seasonal fluctuations in velocity found on the McPherson Test Road.

Charts of the average velocities of all classes of concrete for the several brands of cement (Figs. 12 and 13) have patterns which are similar. Cement "R" has consistently had the highest velocities, with cement "X" the next highest. Cement "N" has shown the least fluctuation in velocity from one class to another. Cements "C" and "H" have had on the average the lowest velocities and have been the least consistent from class to class.

A chart of velocities for the several types of concrete without regard for the brand of cement is shown in Figure 14. The velocities shown are the average of the air-entrained and non-air-entrained classes for each type of concrete. The sections containing flyash admixture and those containing limestone sweetening have had the highest velocity and have shown no tendency to decrease with age on the pavement slab or the test beams. The concrete containing Mowry shale has had a rising tendency and now is holding constant. The sections containing Monterey shale have consistently had the lowest velocity but have not decreased. The concrete with basic mixed

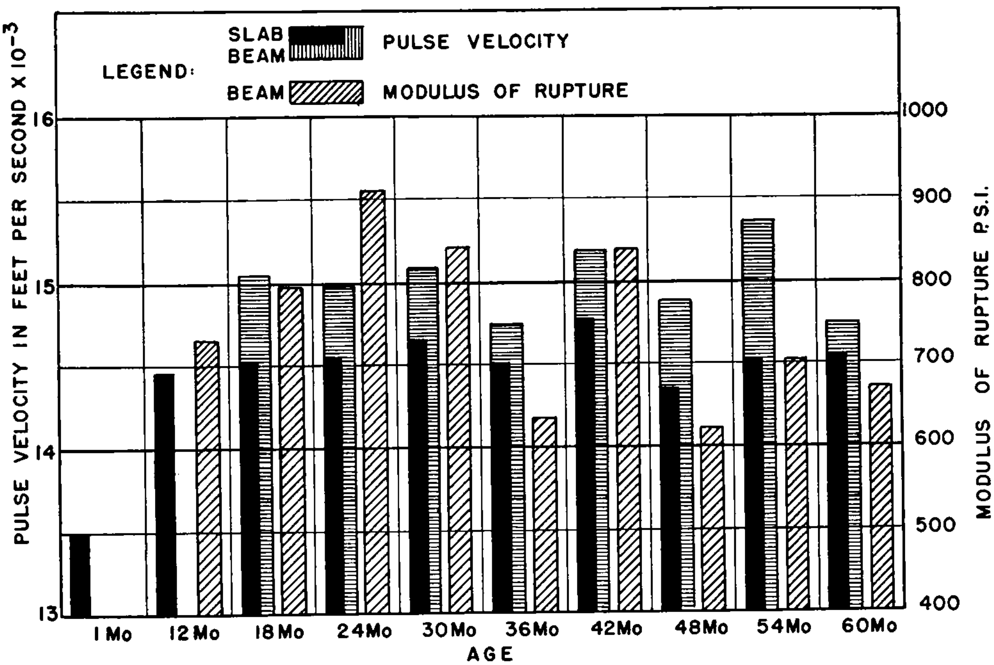

Figure 11. Correlation of pulse velocity and flexural strength.

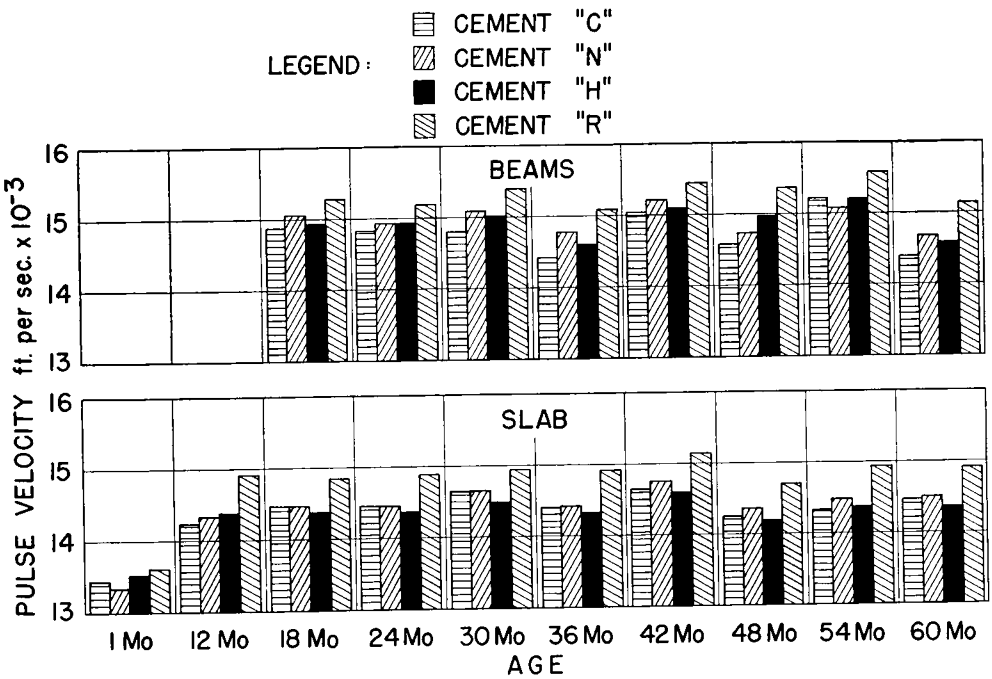

Figure 12. Pulse velocity—four brands of cement.

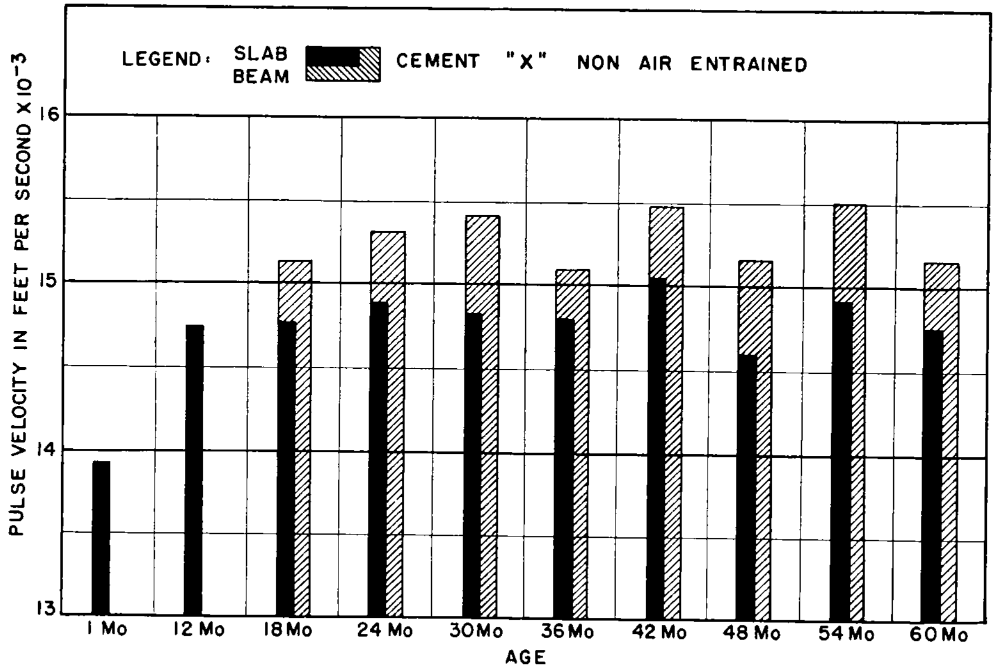

Figure 13. Pulse velocity—cement "X".

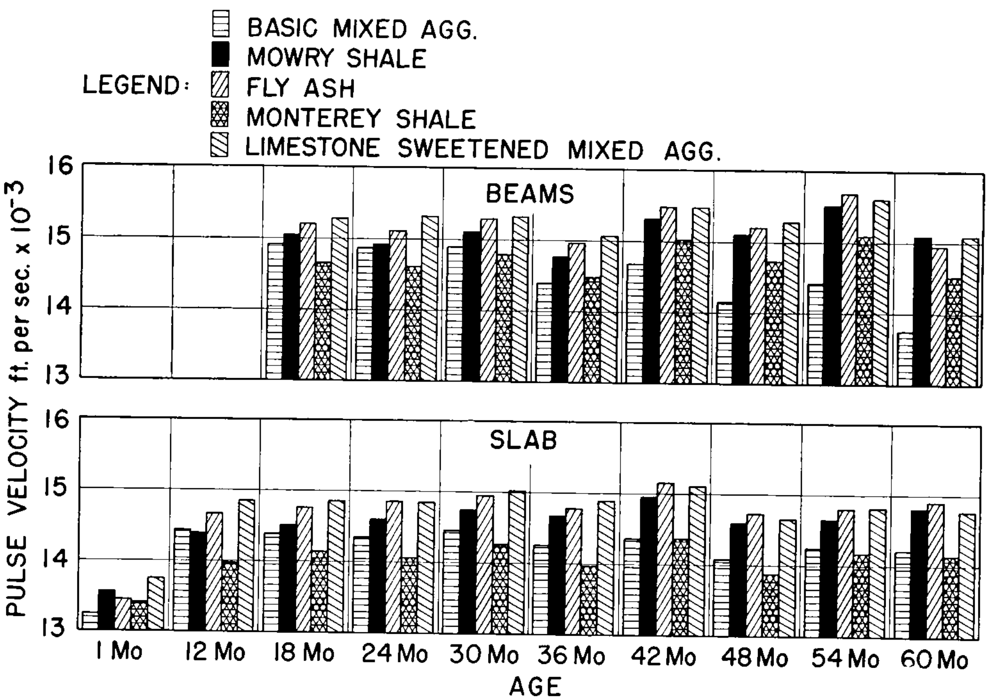

Figure 14. Pulse velocity—types of concrete.

aggregate has shown a slight decrease in velocity on the slab and has fallen off considerably on the test beams.

The air-entrained sections have almost identical velocity patterns as their counterparts without air but on the average have 400 to 600 ft. per sec. lower velocities. This holds true for the slab as well as for the test beams.

For the pavement sections containing basic mixed aggregate, the only classes which have decreasing velocities with age, cement "R" has the highest velocity and has shown no decrease with age. Cements, brands "C", "N", and "H" all have decreased appreciably in velocity since 12 months of age. For the test specimens cement "R" has evidenced only a slight decrease in velocity while the other cements have all decreased considerably. Specimens containing cement "H" without entrained air and cement "C" with entrained air have now decreased in velocity from about 14,500 ft. per second at 15 months to 12,600 ft. per second at 60 months of age.

SUMMARY

Five years of physical observations and tests on this project have indicated that the results of the full scale, out-of-doors experiment do not parallel the results of the preliminary laboratory tests. Also the physical appearance of the various test sections as detailed by semi-yearly condition surveys does not, in many respects, conform to conditions that could have been predicted from either the laboratory data or that of the field tests if considered independently.

None of the three pozzolanic materials used on this project have as yet been effective in inhibiting map cracking in sand-gravel concrete on a scale comparable with the crushed limestone treatment, used as a standard procedure in this state. Of the three pozzolans used only the flyash concretes indicate some degree of effectiveness for this purpose when compared to the basic mixed aggregate concrete.

The character of the concrete on this project as determined by both condition survey and field tests has been greatly influenced by the brand of cement used in the various sections. One brand of cement produced concretes with the highest flexural strength, best field performance, highest pulse velocity and modulus of elasticity, and lowest deflection before fracture. The influence of this cement overshadows the effect of the admixtures in the inhibition of map cracking when used with this particular sand-gravel aggregate.

Air-entraining concretes on this project contain increased amounts of all types of cracking including map cracking compared to the non-air-entraining concretes. Conversely, the Nebraska Laboratory, using specimens from this project exposed to a directional freezing and thawing test determined that durability of all classes of concrete, except the flyash classes, was greatly improved by the use of entrained air. Only a slight improvement in durability was noted in the flyash concrete when air-entrainment was employed.

The average flexural strength of all the test beams made on the project has declined since the second year. The rate of decline has been greatest in the basic mixed aggregate sections. The flyash sections have the best record in this respect. All other classes fall within these two extremes.

Classes of concrete with the best record of field performance have the lowest deflections and highest pulse velocity. However, these classes do not have the highest modulus of elasticity; this factor is only moderately high here. Expansion measured on the project in all classes of concrete has, to date, been slight. In the basic mixed aggregate classes it has been small compared with that which might have been expected from the results of accelerated laboratory tests made prior to construction of the project. This class is the only one for which such tests are available.

These data obtained from five years of observation and testing on this project are in many respects contradictory. It is obvious at this time that if any one of the three methods of examination, laboratory exposures and tests, field exposure and observation under traffic loading, or field exposure and testing without traffic loading, had been used independently, three differing ideas as to the ability of the pozzolanic materials to control the deterioration of sand-gravel concrete would have been produced. It is planned to continue the observation of this project for

another five years, if possible. It is conceivable that in the course of time some of the differences now apparent may be resolved.

Adjacent to the McPherson Test Road project there are two short experimental sections composed of mixed aggregate concrete containing both limestone and pozzolanic admixtures. These sections have been observed for the same period of time as the main project and in the same manner. Since the conditions of test (design, traffic, aggregate type, etc.) are different from those on the main project the results of this work have not been included in this report. The results of this installation have been satisfactory and little or no deterioration of any type is evident. At the present time it is thought that, based on the evidence available from all of this work, by using a suitable combination of limestone and the best of the pozzolans, flyash, a superior mixed aggregate concrete with the properties of high flexural strength, high durability and freedom from map cracking could be produced at a lower cost. The use of pozzolanic materials in this manner would make possible the economic use of a greater number of sand-gravel sources farther removed from sources of satisfactory crushed limestone.

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DISCUSSION

G. K. RAY, *Engineer, Highway and Municipal Bureau, Portland Cement Association*—The report on the McPherson Kansas Test Road contains much information which should be of value to engineers concerned with highway research. This project clearly illustrates the need for full-scale field projects.

As Peyton and Stingley reported, the pozzolanic admixture which seemed to cure abnormal expansion in laboratory tests did not stop map cracking in the pavement itself when subjected to normal Kansas traffic and weather. The need for full-scale field projects for testing new developments is also demonstrated by the lack of correlation between the actual performance of the pavement and between the flexural strengths obtained from the field beams.

Engineers from the Portland Cement Association, with the approval of the Kansas Highway Commission, have maintained close contact with this project, being present as observers during the construction of the pavement and during the semi-annual condition surveys. The Kansas Highway Commission is to be congratulated on the conduct of this test and the preparation of the report just presented. We have confirmed the findings to date which they have reported and we find them to be accurate in all respects. Unlike many well-intentioned field research projects, they have continued to make regular observations during the past five years covering all phases of this project. When the need for additional tests became apparent the program has been revised to provide them whenever possible. The Research Department of the Kansas Highway Commission has found that cooperation from the Construction Department and Maintenance Department is absolutely necessary during the construction and observation of a test road. The presence of research engineers during construction guaranteed accurate construction reports on concrete mixes, air contents, slump, curing and unusual construction operations which occurred during the paving. Cooperation by the Maintenance Department in maintaining shoulders and mudjacking the faulted joints prevented structural failures in this test road which would have partially destroyed the effectiveness of this pavement for the research purposes originally intended. Even the Traffic Department has cooperated in making regular periodic traffic counts and loadometer surveys in order to insure accurate evaluation of traffic effects on the pavement.

The apparent close correlation between the results of the flexure tests on the failed beams and the test with the soniscope deserve special attention. Judging from the results to date, the soniscope seems to parallel closely the strength of the concrete, even though the concrete strengths do not parallel the performance of the pavement with regard to map cracking.

The research engineers for the Kansas Highway Commission are also to be congratulated for the restraint they have shown in utilizing the observations of the first five years on this project. The report presented includes only a summary of the observations and testing which have been conducted to date. No attempts have been made to draw conclusions or write recommendations based on the performance of this test road during the first five years. Although some conclusions may be indicated in the light of information thus far developed, no recommendations for adoption of new standards have been made. Results in the next five years of the test may confirm the findings to date. On the other hand, findings may be reversed during the next five years. On research projects of this type engineers too often try to confirm certain preconceived ideas and they are quick to jump at early indications of differences in performance. The effects of weather and traffic do not become evident overnight, or even in a few years.

Specific Gravity of Aggregates in Asphaltic-Paving Mixtures

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WEIGHT-VOLUME relations are widely used as criteria for the design of bituminous paving mixtures. The determination of specific gravity of the various constituents of the paving mixture is therefore a necessary part of the design procedure. However, a uniform procedure for determining specific gravity of aggregates for use in the design of bituminous paving mixtures has not been adopted. This report compares values of specific gravity obtained by several procedures. Three procedures were studied which yield the specific gravity of the aggregate directly: bulk specific gravity, apparent specific gravity and bulk impregnated specific gravity. Two other procedures were studied which measure the specific gravity of the bituminous mixture directly: aerosol and vacuum procedure and aerosol and pycnometer procedure.

The bulk-impregnated specific-gravity procedure and the aerosol and vacuum procedure were both found to yield values of specific gravity considered to closely represent the probable weight-volume relationships in bituminous mixtures. The aerosol and vacuum procedure required less time than the bulk, apparent, and bulk-impregnated procedures.

● REQUIREMENTS for percent voids, percent of maximum density and percent voids filled with bitumen are all used for the design of plant mix bituminous mixtures. Practically all design procedures used today involve the use of one or more of these criteria for establishing the proper mixture.

The practical use of these design criteria raises two very pertinent questions in the experienced engineer's mind. The first question concerns the problem of whether or not his laboratory compacted specimen really represents the density which can be expected in the actual pavement after it has been under traffic for several years. The second question concerns the problem of how the specific gravity of the loose mixture, or the ratio of the weight of material to the space actually occupied by the constituents of the mixture, is to be determined. This report deals with the second question.

Traditionally the volume occupied by the loose mixture has been found by determining either the apparent or the bulk specific gravity of each component of the mixture and using these values together with the weight proportions of each component to find the volume occupied (solid volume) by the total mixture or in other words the weighted specific gravity of the total mixture. Assume for example that a mixture of 100 gm is composed of 60 gm of aggregate A, 35 gm of aggregate B and 5 gm of asphalt with apparent specific gravities of 2.60, 2.65 and 1.02 respectively. The solid volume of the 100 gm of mixture would then be (60/2.60) (35/2.65) (5/1.02) = 41.19 cc and the weighted specific gravity would be (100/41.19) = 2.43. If the compacted mixture in the pavement occupies a volume of 43 cc per 100 gm the volume of voids or air space is then (43 − 41.19) = 1.81 cc and the percentage voids, by volume, is (1.81/43) 100 = 4.21.

The method is specific and the procedure is