Record of Experimental Air-Entrained Concrete 10 to 14 Years After Construction

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THIS paper describes the performance record of 14 concrete test roads in five northeastern states. Built 10 to 14 years ago with a wide range of variables, these roads provide an opportunity to compare the performance of air-entrained concrete with adjacent sections of the same construction but without air entrainment.

High durability and assured resistance to the severe exposure of repeated cycles of freezing and thawing and salt action in ice removal have been given to these concrete pavements over a period of 10 to 14 years by proper air-entrainment in the concrete mixture.

No scaling or disintegration has occurred on any of the air-entrained concrete sections of the 116 lane-miles represented. But on many adjacent sections with cement from the same mill, but without air-entrainment, scaling up to 100 percent of the area has occurred.

The use of coarse-ground normal cement compared with fine-ground cement under the same conditions has not improved the resistance to scaling and disintegration, but with air-entrainment the performance has been outstanding in all respects.

● THE most-important single development in concrete technology of the past two decades is the application of air-entrainment to the mix for the improvement of durability, workability, uniformity, and other important features.

A necessary requirement for concrete of high durability and assured resistance to the most-severe exposure of repeated cycles of freezing and thawing and salt action has been met over the past 12 years or more by proper air-entrainment in the mix. In fact, to date, such assurance has not been generally obtained for pavements in any other way.

This accounts, then, for the almost universal adoption of air-entrained concrete by state, federal, and other large users, especially in the northern states, where high resistance to freezing and thawing as well as salt action in the treatment of icy pavements must be met.

Much has been written on the action of air-entrainment in securing resistance to repeated freezing and thawing. Reduced to a very simple statement, William Lerch says (in "Basic Principles of Air-Entrained Concrete"):

"The presence of these tiny bubbles materially alters the properties of both the plastic mixture and the hardened concrete. The air bubbles serve as reservoirs that accommodate the expansion resulting from the freezing of water within the concrete. As the freezing of the water within the capillaries progresses, the expansion pressure is relieved by forcing the excess water into the air bubbles, where the expansion during freezing can occur without disrupting the concrete. When thawing occurs the air compressed in the bubbles forces the water back into the capillaries. Thus the bubbles continue to serve their purpose during repeated cycles of freezing and thawing."

EARLY TEST ROADS

The earliest use of air entrainment began in the State of New York in 1938 with the inclusion of a test section in one of the paving contracts. This was followed with the building of complete test projects as regular road contracts during 1939 through 1942 in several northeastern states. The performance of these pavements has been closely observed from time to time. Condition surveys were made in 1946 and 1948 for all projects. Now the results from the latest condition survey of the 14 test projects made during 1952 after a period of 10 to 14 years in service forms the basis of this paper. A total of 116 lane-miles of pavement were constructed on these 14 projects, eight of which are in New York State, three in Pennsylvania and one each in Vermont, Maine, and Massachusetts.

In most instances the test roads were built with a wide range of cement variables in respect to air-entraining agents, combinations with natural cement and, in some cases, using fine and coarse ground cements with and without air-entrainment. However, these projects were so constructed that cement was the only variable, in so far as possible. An excellent opportunity was therefore provided to observe long-time pavement performance on adjacent sections of air-entrained and non-air-entrained concrete constructed under identical conditions.

Similar combinations were repeated several times on most of the test projects so as to get a good range in representative results. The various air-entraining agents interground with the portland cements based on percent by weight of cement were: Vinsol resin, 0.03, 0.04, and 0.05 percent; codfish oil, 0.03 and 0.05 percent; beef tallow, 0.05 percent. Also, small amounts of beef tallow or parafin were ground with natural cements used in blends with portland cement, except in one instance where the tallow was purposely omitted from the natural cement.

Most of us know that air-entrainment has done a remarkable job in improving the durability of concrete, but the truly amazing thing is to observe this phenomenon by comparison with adjacent concrete in the same job and in job after job where the only variable is that of air-entrainment in the mix.

It is of vital importance, however, that the air content be maintained above a certain minimum based on the volume of mortar in the mix, which varies with the maximum size and grading of the coarse aggregate. For mixes requiring high mortar content, where small size coarse aggregate is used, the desirable air content is relatively high. But for the usual grading of aggregates used in paving work, the minimum entrained air is set at 3 to 4 percent by most of the northeastern states.

Fortunately for the early test roads discussed in this paper, the amount of air-entraining material used was in the range of 0.03 to 0.05 percent by weight of cement; thus, as it later developed, the air content was sufficient to insure high durability. At the time, however, very little was known about this matter.

It soon appeared that excessively high air contents reduced the strength and made the mix sticky and hard to work without tearing. Present specifications have developed from that point, together with improvements in the form of the air-entraining agent, so that these early troubles have been overcome and high durability is obtained with minimum reduction in strength.

The procedure for measuring air content on these early jobs was limited generally to the weight or gravimetric method, but only a limited number of such tests were made. For example, the approximate air content for concrete made with the various cement combinations on the Maine project was 1.0 percent for non-air-entraining cement, 4.5 percent for 0.03 percent Vinsol resin and about 9 percent for 0.05 percent Vinsol resin, the air-entraining agent being interground with the cement. Subsequent tests made with blends of portland and natural cements have shown an average air content of about 2 percent.

SURVEY PROCEDURE

The following procedures were used in making the current and previous condition surveys: (1) Line diagrams were obtained from the state highway departments showing the locations of all cement sections by lane and stations. (2) Portland Cement Association field sketch sheets, showing each pavement slab, were used for recording the data. (3) The survey was made by walking each roadway and recording observed conditions for each slab.

The information recorded on the sketch sheets included: (1) estimated amount of scaling as a percentage of each slab area; (2) occurrence of D-cracking at slab edges and width of such bands; (3) areas of progressive disintegration; (4) all cracking of whatever nature by approximate location and shape of crack (not continued after the 1948 survey); (5) extent of plus and

TABLE 1

SUMMARY OF AIR-ENTRAINED-CONCRETE TEST-ROAD CONDITION SURVEY-1952

Project	Year Constr	A-E Port Cem't				(A-E) + Nat + Fat				Non AE + Nat + Fat				Non AE + Nat. - Fat				Non AE Port Cem't			
			Slabs Scaled				Slabs Scaled				Slabs Scaled				Slabs Scaled				Slabs Scaled		
		Total Slabs	No	% Total	% Area	Total Slabs	No	% Total	% Area	Total Slabs	No.	% Total	% Area	Total Slabs	No	% Total	% Area	Total Slabs	No	% Total	% Area
1 Northern State Parkway Nassau Co , N Y	1938	2	-	-	-	2	-	-	-	6	-	-	-	-	-	-	-	6	-	-	-
2 Wurtemburg-Wey's Cross-ing - Dutchess Co , N.Y.	1939	169	-	-	-	-	-	-	-	170	3	1 8	T	-	-	-	-	175	57	32 5	2 7
3. Tupper Lake - L ong Lake Hamilton Co , N Y	1939	40	-	-	-	2	-	-	-	778	60	7 7	T	-	-	-	-	-	-	-	-
4. Wawbeck-Saranac Lake Franklin Co , N Y	1939	20	-	-	-	-	-	-	-	904	390	43 2	3 7	-	-	-	-	(a) 6	6	100	95
5 Valley Falls Rensselaer Co., N.Y	1939	10	-	-	-	-	-	-	-	10	3	30	T	-	-	-	-	-	-	-	-
6 Harpersfield-Stamford Delaware Co , N Y	1939	46	(b) 4	covered		-	-	-	-	904	(c) 711	78 6	(d) 9 2	-	-	-	-	(e) 20	20	100	-
7. West Point-Cornwall Orange Co , N Y	39-'40	150	-	-	-	414	-	-	-	458	9	2 0	T	-	-	-	-	206	146	71	13 8
8. Scarboro-Portland Maine	39-'40	469	-	-	-	-	-	-	-	192	6	3 1	T	-	-	-	-	195	191	98	50
9 Leg Route 84 Sec 10 Crawford Co , Pa	1940	140	-	-	-	-	-	-	-	-	-	-	:	-	-	-	-	210	200	95	28.3
10. Leg Route 200 Sec 3 Warren Co , Pa	1940	128	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	180	20	11 1	1 6
11 Hope Center-Wells Hamilton Co., N Y	1940	179	(f) 3	covered		-	-	-	-	302	(g) 277	91.8	(h) 32 5	178	(i) 178	100	(j) 67 8	21	(k) 21	100	(l) 59 2
12. State Line-W. Stockbridge Mass.	1940	105	-	-	-	4	-	-	-	109	-	-	-	-	-	-	-	112	-	-	-
13. Montpelier-Barre Vermont	1941	23	(b) 1 5	covered		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14 Leg. Route 271 Sec 4 Crawford Co , Pa	1942	192	-	-	-													202	147	727	10 7
	Avg. Age 12½ Yr	Total Slabs 1673 Slabs Scaled - % of Total -				422 - -				3833 1459 38				178 178 100				1333 808 60			

NOTE T = Trace of scale (less than 1 percent)
(a) Includes 4 slabs surface treated
(b) Surf treated due to frost heave and cracking
(c) Includes 513 slabs or 57 percent surf treated 1946, due to scaling
(d) Based on uncovered slabs only This would be 60 7 percent if covered slabs are 100 percent scaled
(e) Scaled heavily and surf treated
(f) Surf treated due to heavy rain wash when built
(g) Includes 75 slabs or 25 percent surf treated since 1948 due to scaling
(h) Based on uncovered slabs only This would be 49 5 percent if covered slabs are 100 percent scaled.
(i) Includes 156 slabs or 87 6 percent surf treated since 1948 due to scaling
(j) Based on uncovered slabs only This would be 96 percent if covered slabs are 100 percent scaled.
(k) Includes 2 slabs or 9 5 percent surf treated since 1948
(l) Based on uncovered slabs only This would be 63 percent if covered slabs are 100 percent scaled.

minus grades, cuts and fills, grade points at cut and fill runouts, wet ditches, frost heave and settled areas, all bridges, important culverts, road intersections and any faulting at joints; and (6) stations for all cement changes and other critical points including locations where photographs were secured.

All of these data were carefully studied for any relationship to structural and surface conditions. Most of the cracking is easily traced to subgrade conditions, drainage, frost heave, settlement, normal contraction, and restraint at fixed structures (such as catch basins and manholes). There appears to be no relationship between cracking and cement variables even in the case of the Main project where low 28-day strengths occurred for the high-air-content sections first constructed.

RESULTS FROM CONDITION SURVEY 1952

A comparison of results for all cement variables on the 14 test roads is shown in Table 1. There is no scaling or disintegration D-cracking on any of the sections using air-entraining portland cement or the blend of air-entraining cement with natural cement. It will be noted, however, that scaling has occurred to a considerable extent with other cement variables: (1) blend of portland with natural cement containing fat, 38 percent of slabs; (2) non-air-entraining portland cement, 60 percent of slabs; and (3) blend of portland cement and a natural cement with fatty material omitted, 100 percent of slabs.

These 14 test roads were constructed in 5 states over a 4-yr. period with a large variety of aggregates and cements. The extreme locations geographically are separated by 500 mi. There is, however, one relationship which has held constant throughout all of these projects: the record of uniformly high durability and resistance to all scaling and D cracking wherever air-entraining portland-cement concrete was used.

The contrasts in performance of air-entrained and non-air-entrained concrete are shown in Tables 1 to 4 and Figures 1 to 12.

Table 2 shows the scaling record by years for the cement variables on Route 30, Hope Center-Wells, Hamilton County, New York, 6.20 mi. in length, constructed in 1940. There is no scaling on any of the air-entrained concrete after 12 yr. Note that scaling developed extensively during the first year on all non-air-entrained concrete. Scaling has now progressed to the point where 35 percent of the entire project has been covered with a bituminous surface treatment since the survey of 1948.

TABLE 2

PERFORMANCE RECORD BY YEARS

Route 30 Hope Center-Wells, Hamilton County, New York
Constructed 1940

Cement	Total Slabs	Percent Scaled Area by Years				
		1941	'43	'46	'48	'52[b]
Non. A. E. + 0.03% Fish Oil[a]	179	--	--	--	--	--
Non. A. E. + Nat. + Fat (1)	302	14.1	15.0	24.2	31.4	49.5
Non. A. E. (2)	21	19.3	21.7	42.0	54.5	63.0
Non. A. E. + Nat. - Fat (3)	178	37.6	48.5	70.0	84.5	96.0

Note--35% of pavement has been surface treated since 1948 because of scaling as follows:
(1) 75 slabs (2) 2 slabs (3) 156 slabs.

[a] 3 slabs surface treated because of heavy rain wash.

[b] Based on 100% scale for covered slabs.

Figure 1 shows Route 30, Hope Center-Wells, N. Y., Station 503 + 41. The slab on near side of transverse joint is non-air-entraining portland cement with 100 percent scale. The lane on right is non-air-entraining blend of portland with natural cement severely scaled and surface treated. The lane on left ahead of joint is air-entrained concrete and shows no scaling here or elsewhere on this project. The same brand of portland cement was used throughout.

Figure 2 shows Hope Center-Wells project, Station 540 + 90. The slabs on near right and far left are air-entrained concrete (0.03 percent fish oil) and show

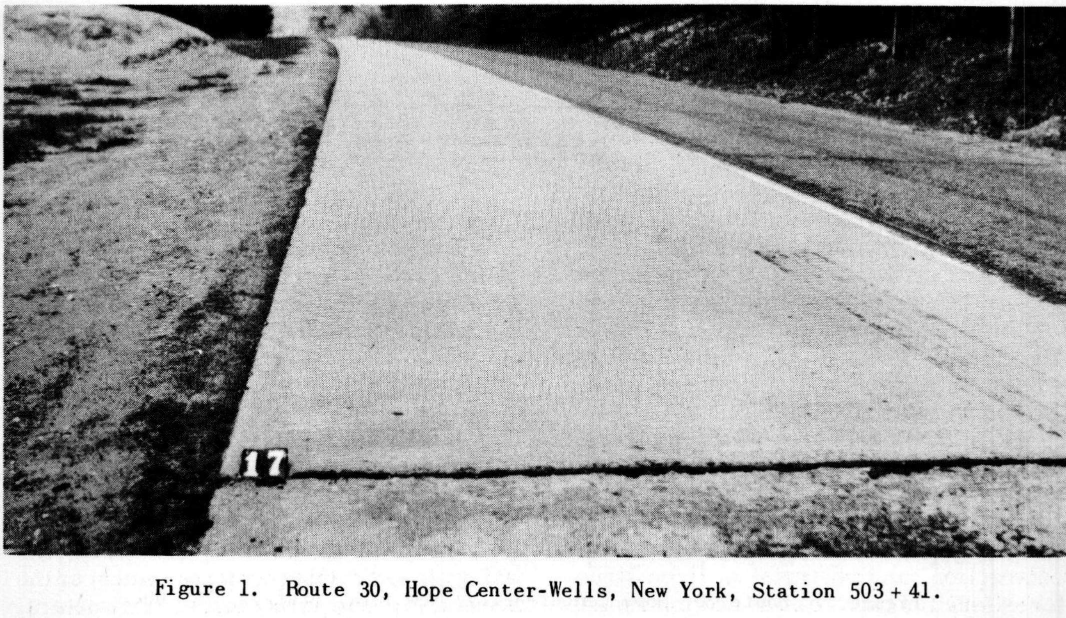

Figure 1. Route 30, Hope Center-Wells, New York, Station 503 + 41.

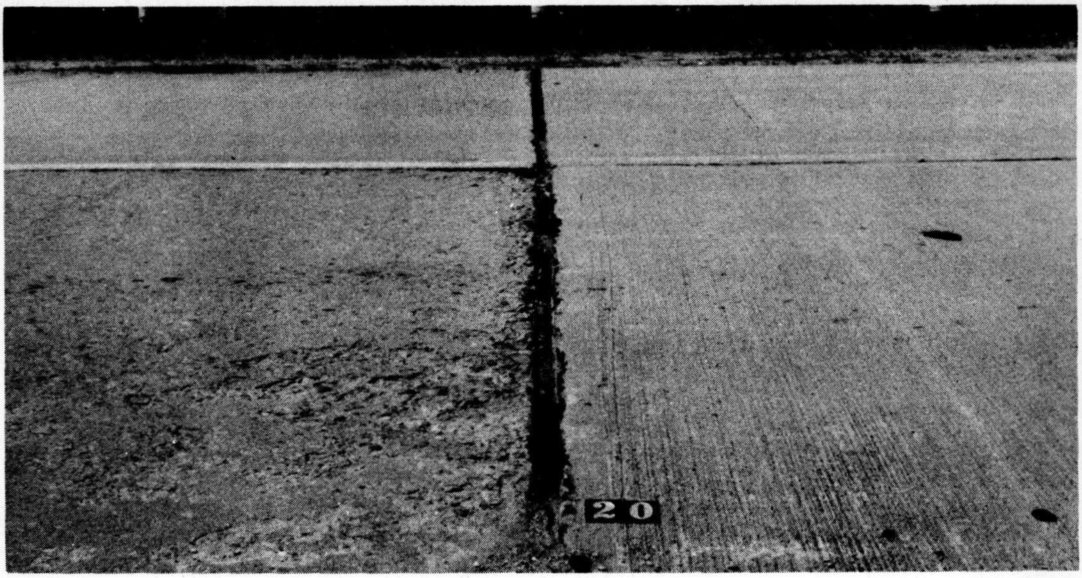

Figure 2. Route 30, Hope Center-Wells, New York, Station 540 + 90.

no scaling. The slabs on near left and far right were made with blends of non-air-entraining portland cement and a natural cement containing fat. This combination scaled for 49.5 percent of the total area.

Figure 3 is also on the Hope Center-Wells project, Station 578 + 00. The lane on right is air-entrained concrete showing no scale throughout. The lane on left is a blend of non-air-entraining portland cement with a natural cement showing 100 percent scale in this area. The two portland cements came from the same mill and are identical except for the air-entraining agent in the one which resisted scaling.

Figure 4 shows Route 23, Harpersfield-Stamford, Delaware County, N. Y., 8.30 mi. in length, constructed in 1939, Station 1337 + 00, showing air-entrained concrete in right lane with no scaling and concrete made with a blend of non-air-entraining portland cement and a natural cement in

Figure 3. Route 30, Hope Center-Wells, New York, Station 578 + 00.

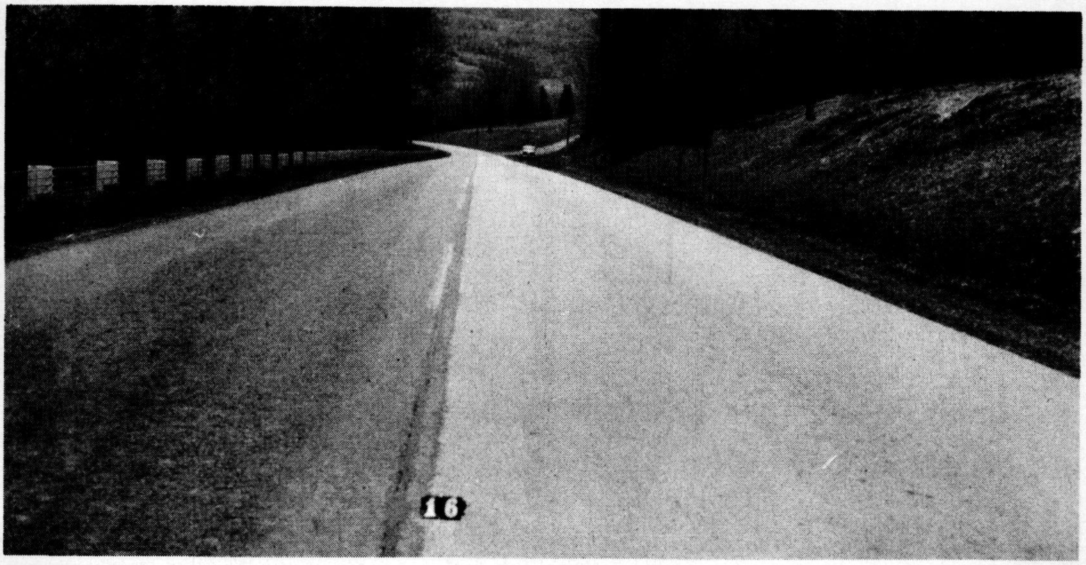

Figure 4. Route 23, Harpersfield-Stamford, New York, Station 1337 + 00.

left lane, now surface treated because of excessive scaling. Portland cement from the same mill was used in both lanes.

D-cracking, a forerunner of disintegration, has not occurred on any of the air-entrained concrete sections of these test roads nor has it been observed on any air-entrained concrete elsewhere throughout the northeast. This form of disintegration has occurred, however, on many of the test road sections where air-entrainment was not used. A typical example of this trouble is shown in Figure 5.

Figure 5 shows Route 146, Mechanicville-Clifton Park, Saratoga County New York, constructed in 1948 with non-air-entrained concrete. Severe D-cracking has occurred in wide bands as indicated. This type of defect is usually progressive, as may be seen in Figure 10.

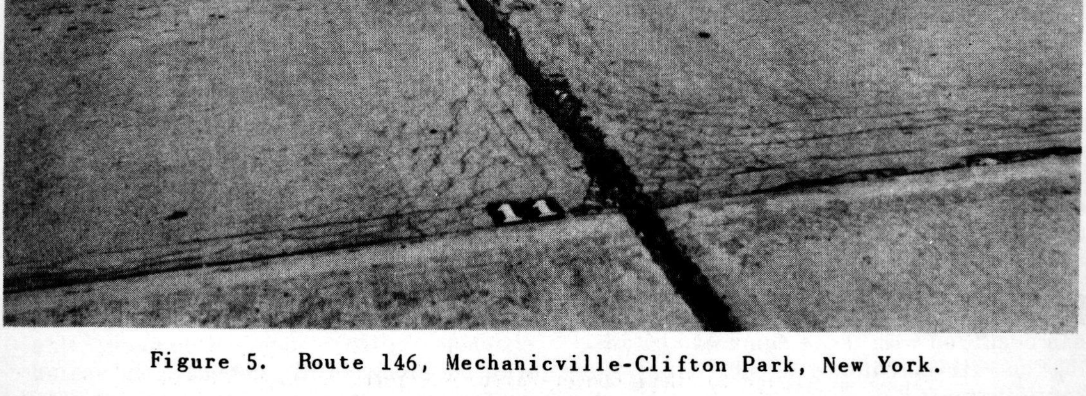

Figure 5. Route 146, Mechanicville-Clifton Park, New York.

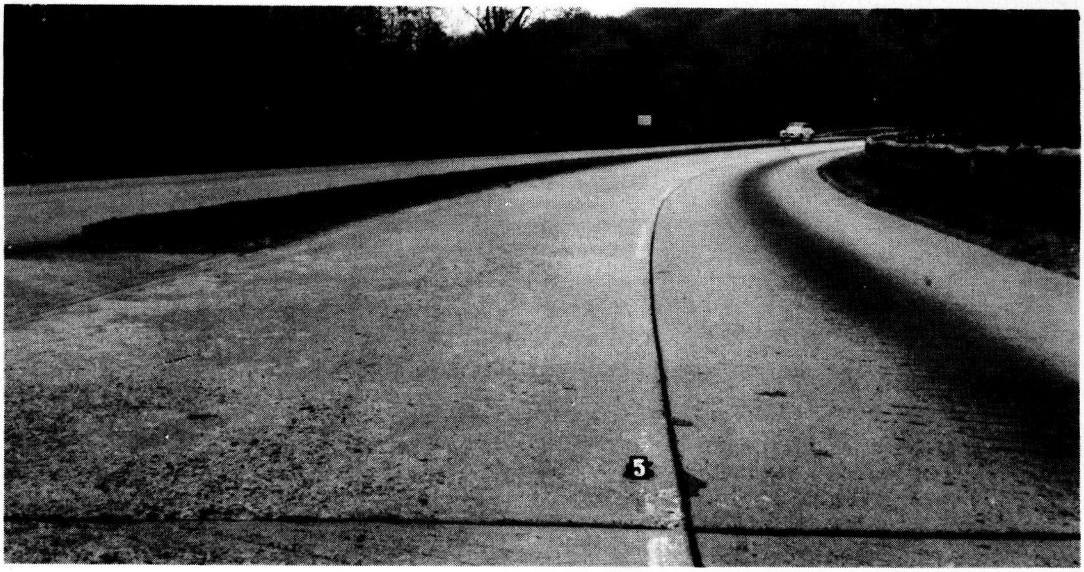

Figure 6. US 9, West Point-Cornwall, New York, Station 195 + 35.

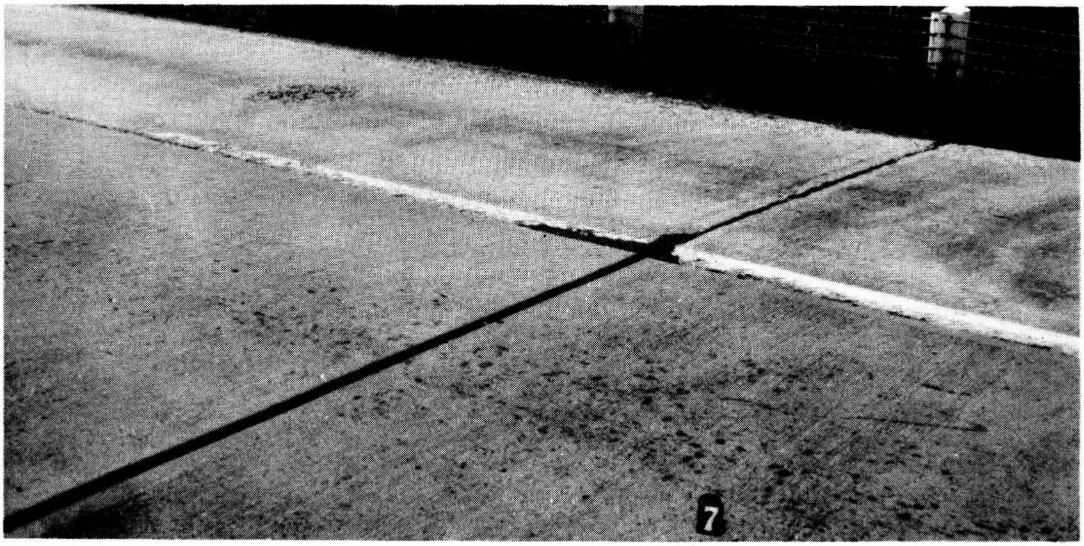

Figure 7. Route 9G, Wurtemburg-Wey's Crossing, New York, Station 211 + 60.

Figure 6 shows US 9W, West Point-Cornwall, Orange County, New York, 5.30 mi. in length, constructed in 1939-40. Station 195 + 35, showing air-entrained concrete in lane on right with no scale and non-air-entrained concrete with 70 percent scaled area on left lane. Of the non-air-entraining portland-cement-concrete slabs, 71 percent have scaled, while no scaling has occurred with these cements containing an air-entraining agent, from the same five mills.

Figure 7 is of Route 9G, Wurtemburg-Wey's Crossing, Dutchess County, New York, 4.5 mi. in length, constructed 1939, Station 211 + 60. The slabs in near lane were built with air-entraining portland cement (0.05 percent tallow) and show no scaling here or throughout the job. Note the excellent slab edges at transverse joint. This is typical of air-entrained concrete performance. Compare this with the sloughed off joint edges and scaled surface of non-air-entrained concrete sec-

Figure 8. US 1, Scarboro, Maine, Station 243 + 30.

tion in far lane where 32.6 percent of the slabs show scaling in some degree.

Another outstanding contrast in durability between air-entrained and non-air-entrained concrete is that on US 1, Scarboro, Maine, constructed in 1939 - 40, where all portland cement was made at the same mill. In the 13 years since construction, 50 percent of the entire surface of the non-air-entrained concrete sections, 1.50 mi. in length, has scaled severely with extensive deep disintegration at many joints and slab corners as shown in Figure 8. However, on the 3.50 mi. of air-entrained concrete there is no scaling whatever. Aggregates came from the same source and the same engineer supervised the construction.

Figure 8 shows US 1, Scarboro, near Portland, Maine. The right widening lane, curb and gutter 6.5 mi. in length, were constructed in 1939-40 with non-air-entraining cement, a natural blend and air-entraining cement, Station 243 + 30. The pavement shown in this slide is a section of non - air - entraining cement concrete badly scaled and disintegrated. Of the non-air-entraining cement-concrete slabs, 98 percent are scaled for 50 per-

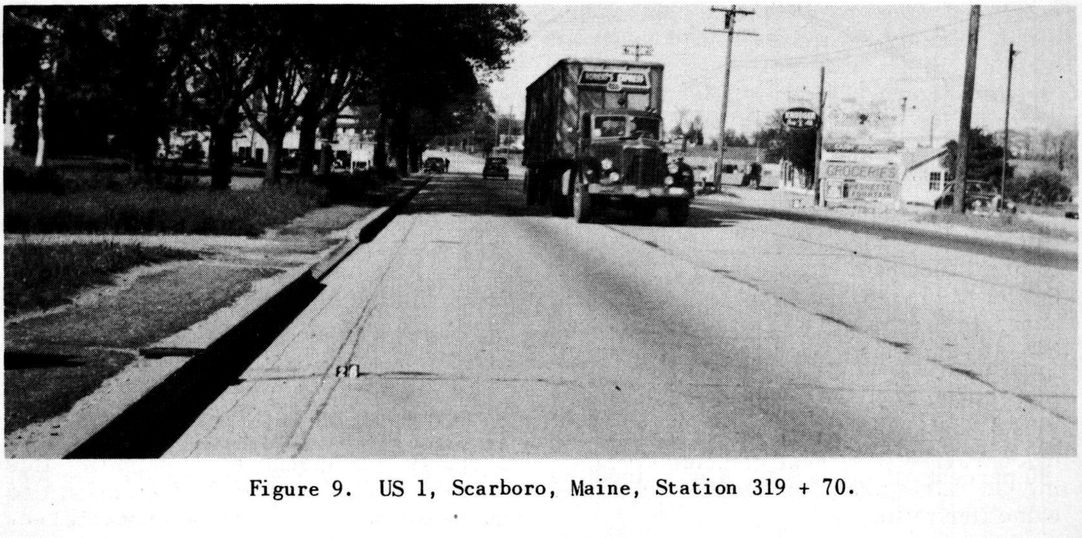

Figure 9. US 1, Scarboro, Maine, Station 319 + 70.

cent of their area. This section was resurfaced in 1952.

Figure 9 shows US 1, Scarboro, Maine, Station 319 + 70. The left widening lane with curb and gutter was constructed in 1939 with portland cement interground with 0.05 percent Vinsol resin. There is no scaling on this or subsequent sections constructed in 1939-40, using 0.03 percent Vinsol resin. All design and construction conditions were identical with those shown in Figure 8, except air entrainment.

Another comparison of performance is that between the fine-and coarse-ground cements, with and without air entrainment, which may be seen on Legislative Route 84, Section 10, (Traffic Route US 6), Crawford County test road at Meadville, Pennsylvania, as shown in Table 3. Available data on the specific surface and mortar air tests for the cement are given for this project.

Some engineers have felt that coarse-ground cements would give superior performance, but after 12 yr. there is no choice on this project between any of the cements either finely or coarsely ground without air-entrainment as both have shown marked defects. However, with entrained air both types of cement have produced concrete which appears as good today as when constructed.

Furthermore, D-cracking followed by disintegration of concrete at about 60 percent of all transverse joints has occurred on the non-air-entrained sections of this project. The D-cracking had reached an advanced stage by 1944. The slab edges at all joints of the air-entrained concrete are in perfect condition today, as may be seen in Figure 11. As a matter of further interest on this project, all of the five cement types were made in the same mill.

Table 3 is a summary performance record of fine-ground versus coarse-ground cements with and without air-entrainment of Legislative Route 84, Section 10, (Traffic Route US 6) Meadville, Crawford County, Pennsylvania, constructed 1940. Note that the coarse-ground non-air-entraining cement gave no better durability than the fine-ground non-air-entraining cement. In both cases about 95 percent of the slabs scaled for nearly 30 percent of the area. Also, about 60 percent of slab ends at expansion joints show severe D-cracking and disintegration. However, there is no scaling or D-cracking on any of the air-entrained concrete sections using either fine- or coarse-ground cement.

TABLE 3

SUMMARY PERFORMANCE RECORD FINE-GROUND VS. COARSE-GROUND WITH AND WITHOUT A-E
Leg. Route 84 Sec. 10, Meadville, Crawford Co., Pa Constructed 1940

Cement	Spec Surf.	Mortar Air	Total Slabs	Slabs Scaled No	Slabs Scaled %	% Area Scaled
A-1 Non A E fine[a]	1885	3 1	70	68	97	29 7
B-1 " coarse[a]	1340	6 2	70	65	93	26 2
C " fine (N.J.)[a]	1898	- -	70	67	96	29 1
A-2 Non A E fine + 0 05 V R	1863	15.8	68	--	--	--
B-2 " coarse + 0.05 V R.	1360	15 8	72	--	--	--

[a]About 60 percent of slab ends at expansion joints show severe D-cracking and disintegration for all three non-air-entraining cements There are no such defects where air-entraining cement was used

Figure 10 is of Legislative Route 84, Section 10, Crawford County, Pennsylvania, 2.50 mi. in length, constructed 1940, Station 85 + 52. This is fine-ground non-air-entraining cement section showing extensive scaling. Disintegration at joints started with D-cracks in wide bands. This type of disintegration has occurred at about 60 percent of joints on both fine- and coarse-ground non-air-entraining cement sections, but all air-entrained sections here, or elsewhere, show none of this trouble.

Figure 11 is of Legislative Route 84, Section 10, Crawford County, Pennsylvania, Station 132 + 23. This is fine-ground air-entraining cement section typical of all such sections on this project. There is no scaling. Slab edges at joints are sound and durable throughout where air-entrained concrete was used.

Figure 12 shows Legislative Route 271, Section 4, (Traffic Route 8), Hydetown - Centerville, Crawford County, Pennsylvania, 3.80 mi. in length, constructed 1942, Station 517 + 50. The A-2 slab on right was made with fine-ground air-entraining cement and shows no scaling throughout the project. The B-1 slab on left was made with coarse-ground non-air-entraining cement and shows about 12 percent scaled area throughout the job.

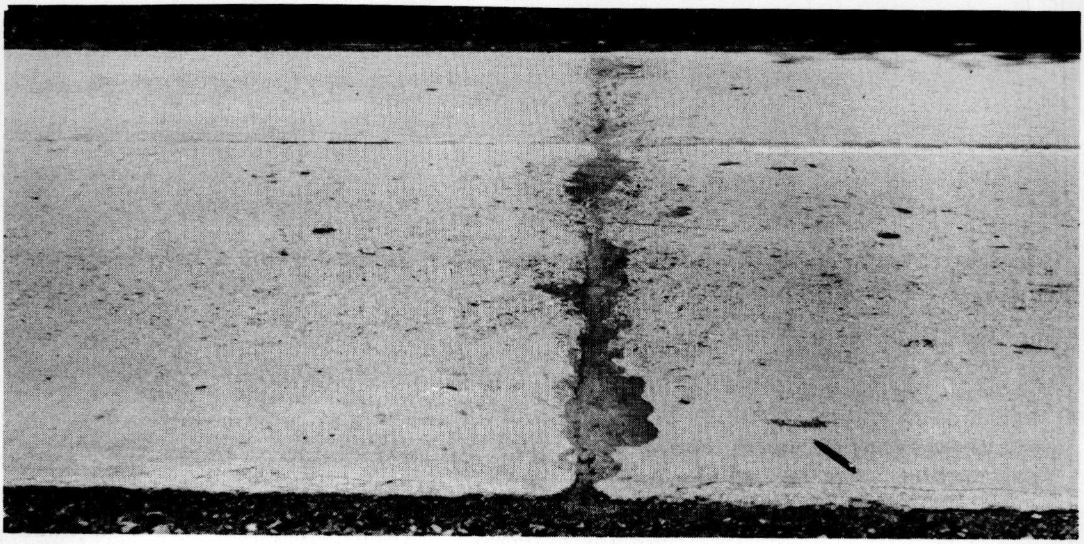

Figure 10. Legislative Route 84 Sec. 10, Meadville, Pennsylvania, Station 85 + 52.

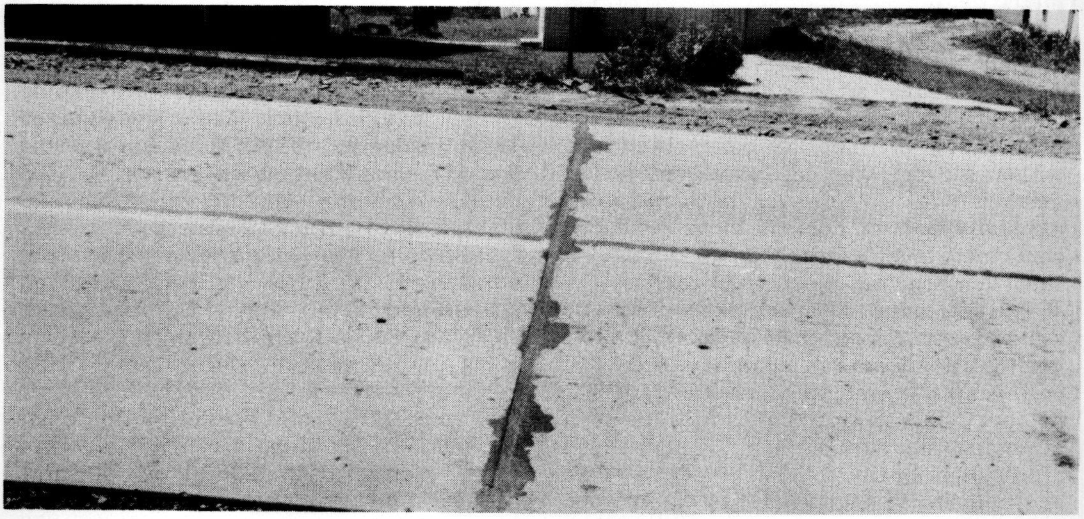

Figure 11. Legislative Route 84 Sec. 10, Meadville, Pennsylvania, Station 132 + 23.

TABLE 4

SUMMARY OF SURFACE CONDITIONS ON THE 14 PROJECTS

Cement	Total Slabs	Slabs Scaled No.	Slabs Scaled %	%Area Scaled
Air Entraining	1673	--	--	--
A-E + Nat. + Fat	422	--	--	--
Non A. E. + Nat. + Fat	3833	1459	38.0	19.2
Non-Air-Entraining	1333	808	60.6	17.5
Non A. E. + Nat. - Fat	178	178	100.	96.0

Note: 56 mi. of pavement from one to four lanes in width, or 116 lane-miles, are represented.

Table 4, summarizes the performance data given in Table 1 for the 14 test roads. Note that only air entrainment furnished complete protection against scaling, while the non-air-entrained sections showed scaling for 38 to 100 percent of the slabs.

CONCLUSION

During the 14 yr. since construction of the first test section of air-entrained concrete in New York state, the record

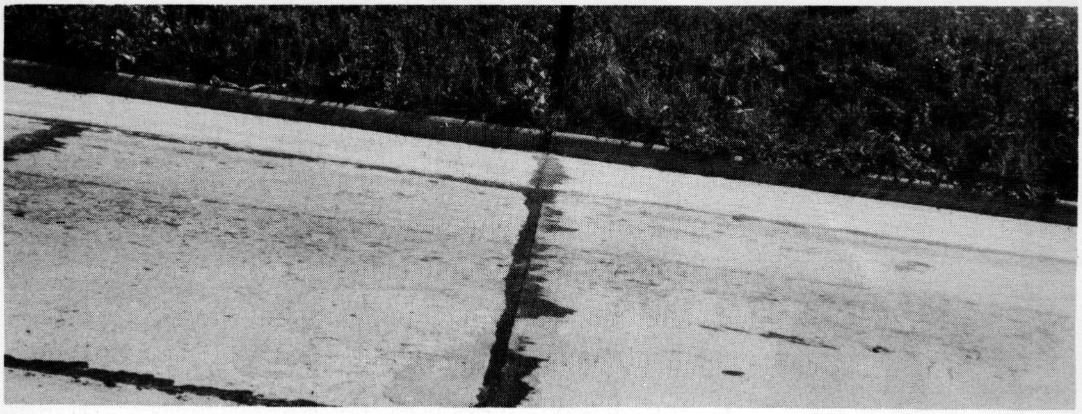

Figure 12. Legislative Route 271 Sec. 4, Centerville, Pennsylvania, Station 517 + 50.

for millions of square yards of this type of concrete has shown outstanding performance. There has been no scaling or D-cracking on any air-entrained concrete where the amount of air actually entrained has been equal to or greater than the minimum amount established for durability.

Air-entrainment is now required in concrete pavements by at least 29 state highway departments, and it is used, under certain conditions, in 10 other states.

Continued experience with the excellent durability of air-entrained concrete under the severe conditions of exposure in the northeast furnishes an outstanding and gratifying performance record in an area where scaling has otherwise been extensive.

This is the story and the record of the 14 air-entrained-concrete test roads in the northeastern states. It is a good record and has served well as the trail blazer for the present wide-spread use of air-entrained concrete in the northeast and throughout the nation.

Discussion

WILLIAM LERCH, Head, Performance Tests Group, Research and Development Laboratories, Portland Cement Association. The author is to be commended for his paper showing the superior performance of air-entrained concrete pavements. It provides one of the most comprehensive reports on the service record of air-entrained concrete available to date. The composition and fineness of the cements used on these experimental projects were not included in the paper. It is believed that many readers will be interested in having this information and that these data will be of value to state highway departments and other agencies responsible for writing specifications for portland cement.

The Research Laboratories of the Portland Cement Association made chemical analyses and fineness determinations of the cements used on seven of the experimental projects. The results of these tests are shown in Table A, together with an identification of the projects where they were used. A few of the cements were used on more than one project and that is shown by the identification of the cements in the table.

The cements used on the seven projects were made at thirteen different plants in Maine, New York, Ohio, and Pennsylvania. They were made from a wide variety of raw materials and represent a relatively wide range in chemical composition and fineness. They include cements that meet the chemical requirements of ASTM Types I and II. Some of the cements were made to meet the special requirements of the then-current specifications of the New York State Department of Public Works, the New Jersey State Highway Depart-

TABLE A

CHEMICAL COMPOSITION, CALCULATED COMPOUND COMPOSITION, AND FINENESS OF CEMENTS USED IN EXPERIMENTAL PAVEMENT PROJECTS

Cement Identification	Air Entraining Agent	ASTM Type	Spec. Surf. Wagner $cm.^2/g$	Oxide Analyses - %							Calculated Compound Composition - %			
				SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Free CaO	C_3S	C_2S	C_3A	C_4AF
DUTCHESS COUNTY, N Y , R.C. 4016, S.H 8511 - CONSTRUCTED IN 1939														
A	None	II	1835	23.09	4.73	3.45	64.62	1.19	1.43	0.40	45.1	32.3	6.7	10.5
	Tallow	IIA	1740	23.65	4.39	3.25	64.53	1.09	1.34	0.37	43.4	35.1	6.1	9.9
B	None	II	2015	22.78	4.77	3.46	64.92	1.32	1.30	0.62	47.9	27.3	6.8	10.5
	Tallow	IIA	1825	22.69	4.87	4.10	64.51	1.27	1.26	0.08	47.6	29.2	6.0	12.5
C	None	I	1730	21.81	5.58	3.85	63.47	1.46	2.09	0.18	42.9	30.3	8.3	11.7
	Tallow	IA	1480	21.79	6.12	3.98	63.36	1.56	1.60	0.16	40.2	32.2	9.5	12.1
D	None	I	1745	20.35	7.05	2.49	63.51	2.65	2.01	0.32	45.9	23.8	14.5	7.6
	Tallow	IA	1775	20.33	6.95	2.60	63.33	2.60	1.93	0.24	46.4	23.4	14.0	7.9
E	None	I	1970	20.54	6.62	2.42	62.68	3.33	1.90	1.64	39.0	29.6	13.5	7.4
	Tallow	IA	1775	20.58	6.65	2.41	62.53	3.34	1.70	1.58	38.7	29.9	13.6	7.3
F	None	I	1810	20.98	6.85	2.43	62.75	3.52	1.71	0.64	39.0	30.8	14.0	7.4
	Tallow	IA	2010	21.18	6.42	2.40	62.96	3.61	1.61	0.59	41.7	29.3	13.0	7.3
G	None	I	2120	20.35	6.15	3.58	63.65	2.54	1.74	0.72	50.1	20.7	10.3	10.9
	Tallow	IA	2340	19.95	6.42	3.46	63.95	2.52	1.65	1.78	48.6	20.6	11.2	10.5
H	None	I	1950	20.73	6.83	2.41	63.08	2.89	2.11	0.40	42.2	27.7	14.0	7.3
	Tallow	IA	1950	20.57	6.81	2.51	63.01	3.01	1.83	0.78	42.4	27.1	13.8	7.6
ORANGE COUNTY, N.Y., R C. 4027, S.H. 8500 (STORM KING BY-PASS) - CONSTRUCTED IN 1939														
I	None	II	2030	22.66	5.23	3.73	63.90	1.58	1.59	Tr.	42.8	32.7	7.6	11.3
	Vinsol Resin	IIA	1900	23.14	4.91	3.57	63.99	1.62	1.44	"	42.4	34.5	7.0	10.9
F	None	I	1790	21.01	6.73	2.39	62.75	3.56	1.64	0.75	39.3	30.6	13.8	7.3
	Vinsol Resin	IA	1850	21.22	6.79	2.39	62.83	3.56	1.61	0.53	38.7	31.8	14.0	7.3
G	None	I	2075	20.17	6.21	3.57	63.88	2.46	1.65	0.88	51.6	19.0	10.4	10.9
	Vinsol Resin	IA	1930	20.22	6.45	3.47	63.85	2.51	1.65	0.99	49.2	21.0	11.2	10.6
J	None	II	1995	22.15	4.69	2.64	63.68	3.31	1.46	0.40	49.8	26.1	8.0	8.0
	Vinsol Resin	IIA		(Made from the same clinker)										
A	None	II	1720	22.21	4.76	3.74	64.99	1.15	1.43	0.74	51.3	25.1	6.3	11.4
	Vinsol Resin	IIA	1820	21.09	5.17	4.19	64.96	1.22	1.56	0.98	54.9	19.1	6.6	12.7
I	None	II	2045	25.42	4.36	3.21	62.46	1.65	1.55	Tr.	22.7	55.8	6.1	9.8
MAINE EXPERIMENTAL PROJECT F.A. 118AB(2) - CONSTRUCTED IN 1939														
G	None	I	1460	21.24	5.86	2.60	63.59	3.00	1.80	-	49.4	23.3	10.6	8.2
	Vinsol Resin	IA		(Made from the same clinker)										
W STOCKBRIDGE, MASS. EXPERIMENTAL ROAD - CONSTRUCTED IN 1940														
A	None	II	1615	22.35	5.18	3.74	64.38	1.27	1.58	0.54	45.4	29.8	7.4	11.4
	Vinsol Resin	IIA	1820	22.96	5.07	3.29	64.37	1.27	1.60	0.51	42.2	34.0	7.9	10.0
HOPE CENTER WELLS, N.Y., R.C. 4079 - CONSTRUCTED IN 1940														
E	None	I	2000	21.68	5.17	3.97	63.95	1.87	1.67	0.55	50.5	25.4	7.0	12.0
	Codfish Oil	IA		(Made from the same clinker)										
(CEMENTS WITH VARIED FINENESS)														
WARREN COUNTY, PA., ROUTE 200 - CONSTRUCTED IN 1940														
K Normal	None	I	1945	21.16	6.53	2.92	63.72	1.80	1.75	0.61	43.1	28.1	12.4	8.9
K "	Tallow	IA	1990	21.13	6.48	3.00	63.48	1.81	1.74	0.44	43.3	27.9	12.1	9.1
K Special	None	II	1910	22.29	5.49	4.07	62.72	2.33	1.46	0.16	38.4	34.9	7.7	12.4
L Coarse	None	I	1495	22.63	5.09	2.80	64.03	2.28	1.54	1.12	41.6	33.5	8.8	8.5
L "	Tallow	IA	1445	22.59	5.02	2.89	63.85	2.28	1.60	1.09	41.4	33.5	8.4	8.8
CRAWFORD COUNTY, PA, F.A. 298-C, ROUTE 84 - CONSTRUCTED IN 1940														
M Normal	None	I	1940	20.72	5.87	3.11	63.39	2.88	1.90	1.00	47.3	23.7	10.3	9.5
M "	Vinsol Resin	IA	1920	20.66	5.95	3.13	63.29	2.92	1.77	1.12	46.6	24.1	10.5	9.5
M Coarse	None	I	1475	20.74	6.04	3.05	63.65	2.96	1.77	1.24	46.5	24.4	10.9	9.3
M "	Vinsol Resin	IA	1385	20.82	6.01	3.04	63.71	2.92	1.73	1.19	46.7	24.5	10.8	9.3
M Special	None	II	1960	21.81	5.33	4.38	63.36	1.48	1.71	0.86	41.8	31.0	6.7	13.3

ment, and the New York Board of Water Supply. One cement, with a high silica content, was a special product made for use on one of the experimental projects. Cements of normal fineness and coarse-ground cements, 1,385 to 1,495 sq. cm. per g., turbidimeter method, were used on two of the projects, Crawford County and Warren County, Pennsylvania.

The range in some of the chemical constituents and in the fineness of the cements was as follows:

SiO_2 content	- 19.95 to 25.42	percent
MgO	"	- 1.27 to 3.61	"
C_3A	"	- 6.0 to 14.5	"
C_3S	"	- 22.7 to 54.9	"
C_2S	"	- 19.0 to 55.8	"

Fineness ranged from 1385 to 2340 sq. cm. per g., turbidimeter method.

It is interesting to note from Andrews' paper that, with this rather wide range in composition and fineness there were few instances where non-air-entraining cements produced concrete pavements that were free from surface scaling or D-cracking. On the other hand, the pavements constructed with air-entraining cements, covering about the same range in composition and fineness, showed no evidence of surface scaling or D-cracking after 10 to 14 years of service.

Three different air-entraining agents, Vinsol resin, tallow, and fish oil were interground with the clinker in the preparation of the air-entraining cements used on the experimental projects. It is of interest to note that all three of these air-entraining agents provided the same superior resistance to surface scaling and D-cracking.

The results obtained from these experimental projects indicate that the use of any one particular ASTM type of portland cement, or other special limitations in chemical composition of fineness, has not improved the resistance to surface scaling or D-cracking of these projects. Air-entrainment is the answer. Jackson[1] and Jackson and Tyler[2] reached the same conclusion on the basis of the performance of the New York Test Road of the Long-Time Study of Cement Performance in Concreté. In the latter paper the authors concluded that: "The effects of air-entrainment on improving the resistance of the pavement to scaling and weathering overshadow all other variables."

L. E. ANDREWS, Closure - The analyses of the cements used in the test roads as reported by William Lerch with respect to type and chemical composition provide an important addition to the paper.

The conclusion reached by F. H. Jackson and I. L. Tyler on the Long-Time-Study Test Road in New York, as referred to by Lerch, is truly significant of experience throughout the country.

It developed that cement type and degree of fineness without air entrainment were not factors in securing resistance to scaling and D-cracking. On the other hand, as emphasized by Lerch, the use of air entrainment, irrespective of cement type, fineness, or chemical composition, produced concrete which has been highly resistant to scaling and D-cracking everywhere.

[1]F. H. Jackson, "Why Type II Cement," Proceedings Am. Soc. for Testing Mat., v 50, p. 1210 (1950).

[2]F. H. Jackson and I. L. Tyler, "Long-Time Study of Cement Performance in Concrete - Chapter 7, New York Test Road," Proceedings Am. Concrete Inst., v. 47, p 773 (1951).