State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

LEAN MIX CONCRETE BASE WIDENING

Final Report for Project IHR-13

A Research Study

by

Illinois Division of Highways
in Cooperation with
U.S. Department of Transportation
Federal Highway Administration

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ABSTRACT

An experiment was established in Illinois in 1951 on a typical widening and resurfacing project to determine whether portland cement concrete widening strips with cement contents lower than that considered standard for regular paving concrete would serve adequately under dense-graded bituminous concrete resurfacings. Cement factors of 1.31, 1.19, and 1.07 were used in addition to the Illinois standard of 1.42 for pavement concrete constructed with the aggregates used on this project. Condition surveys made periodically during the 14 years that the pavement served before a second resurfacing was placed showed no differences in pavement performance attributable to variations in the cement contents of the widening strips. This evidence was concluded to suggest that cement contents of concretes for base-widening strips can be reduced below those generally considered desirable for pavement concrete without harmful effects where environmental conditions are no more severe than those to which the experimental site was exposed.

SUMMARY

This report describes a field study in Illinois that began in 1951 with the construction of an experimental section of widening in which the cement content of the widening strips was the principal variable. The widening strips were placed next to an old and worn concrete pavement as part of a resurfacing and widening project in which the resurfacing consisted of a dense-graded bituminous concrete. The objective of the study was to determine whether widening strips of cement content lower than that normally used for pavement concrete would serve adequately in base widenings.

Concrete mixtures with cement factors (barrels of cement per cubic yard of concrete) of 1.31, 1.19, and 1.07 were used in addition to the Illinois standard of 1.42 for pavement concrete constructed with the aggregates used on this project. The corresponding design moduli of rupture of 14 days (mid-point loading) were 600, 550, 500, and 650 psi. All of the test sections were constructed of air entrained concrete except for four of eight at the 500 psi level; no air was intentionally entrained in the concrete of the latter four.

Condition surveys made periodically during the 14 years that the pavement served before a second resurfacing was placed showed no important differences in pavement performance attributable to variations in the cement contents of the widening strips.

While no indication of any reduction in performance attributable to deterioration of the widening concrete was noted, a few cores taken from the experimental widening strips in a minor coring program during the 14th year following construction showed some evidences of loss of durability at the two lower cement contents, especially where no intentionally entrained air was used. The deterioration is considered to have been associated with deicing salt solutions that had penetrated the cracks.

The evidence developed on the project is presumed to indicate that the cement factor of widening strips that receive dense-graded bituminous resurfacing could be reduced to at least as low as 1.07 barrels of cement per cubic yard of concrete without harmful effects under the environmental conditions of the test site. Before applying the results of the project, recognition must be given to the fact that these environmental conditions include a lower rate of usage of deicents than now common in such States as Illinois.

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INTRODUCTION

By 1951, the salvaging and upgrading of old and worn portland cement concrete pavements through the application of dense-fine-graded bituminous concrete (subclass I-11) overlays had become one of the major construction operations of the Illinois Division of Highways. Almost always, the total operation included the placing of pavement-strength portland cement concrete widening strips at the edges of the existing narrow pavements so that the reconstructed surface widths would meet more modern standards.

With a growing background of experience to draw upon, a belief that the widening strips need not be constructed of mixtures with the high cement contents preferred for standard pavement service began to receive support. If concrete of lower cement content could serve adequately, some economy could be realized. The experimental study that is the subject of this report was undertaken to provide information that hopefully would substantiate the belief; and also hopefully, would provide information on an appropriate mixture design.

The need for the concrete to resist the action of deicing agents was recognized at the time, but the magnitude of the problem that was to come in the future with the great increase in the use of these agents was not anticipated.

This report describes a field study that began in 1951 with the construction of an experimental section of widening in which the cement content of the widening strips was the principal variable. Placing of the bituminous concrete resurfacing was begun in 1951, but not completed until 1952. A progress report, entitled

"Study of Base Widening with Lean-Mix Portland Cement Concrete," was issued in 1962 to describe activity on the project up until that time. The present report is the final report for the study.

The experimental project is identified as IHR-13, Lean Mix Base Widening, and has been conducted by the Illinois Division of Highways, in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

Condition surveys were made periodically for a number of years following construction, the last in 1965, before a second resurfacing was placed in 1966. The study furnished reasonable evidence that cement contents lower than that being accepted as standard could be tolerated under the conditions of the test. While no indication of any reduction in overall performance attributable to exposure of the concretes to deicing agents was noted, some evidences of deterioration were found in the 14th year in the concretes at the two lower cement contents, and especially where there was no intentionally entrained air. This weakness suggests that the possibility for more serious deterioration to occur under more severe conditions of exposure to deicing salts needs to be recognized before applying the findings of the study. While reliable records of deicing-agent applications through the years of study are not available for the project, the use of deicents in Illinois has increased very significantly since the early years of the study.

LOCATION OF PROJECT

The location selected for this experiment was a portion of Section 22X, SBI Route 36, (Marked US 36), Federal Project F-45(8), Scott-Morgan Counties, in the vicinity of Riggston, Illinois. The test portion is 3.652 miles in length. The construction project consisted of widening and resurfacing an existing narrow concrete pavement, the structural condition and width of which were no longer adequately serving traffic. The location of the construction project and of the experimental section is shown in Figure 1. Environmentally, this central Illinois site is typical of a wide area of the State and of the Midwest.

LAYOUT

The old pavement, constructed in 1924, was an 18-foot-wide portland cement concrete installation of 9"-6"-9" cross section, the outside edge being 9 inches in depth and feathering to 6 inches in a distance of 2 feet. The new portland cement concrete widening is 8 inches thick and constructed to a width of 2 feet on each side of the old pavement, bringing the base to a total width of 22 feet. The widening was placed on the existing subgrade soil. The 22-foot width of base was resurfaced with 3 inches of hot-mix, dense-graded bituminous concrete, subclass I-11. A typical cross section of the widening and resurfaced pavement is shown in Figure 2.

The experimental construction consisted of placing a number of test sections of widening of different design strengths. The location, and design strength, for each of the test sections are shown in Figure 3.

SOILS

The experimental site is in an area of generally flat terrain where the old existing pavement had been placed only a few inches above the surrounding ground as was customary at the time of its construction. Practically all of the experimental widening was placed on A-7-6 soil. Available soil information indicates that the group index varies from 12 to 15 between Stations 32+00 and 92+00, and is uniform at 15 between Stations 92+00 and 224+81. The subgrade soils are generally uniform, the only exception to this being the portion of the project between Stations 32+00 and 88+00, in which area some of the paving rests on an A-6 soil. A generalized soil profile from 0- to 60-inch depth is presented below:

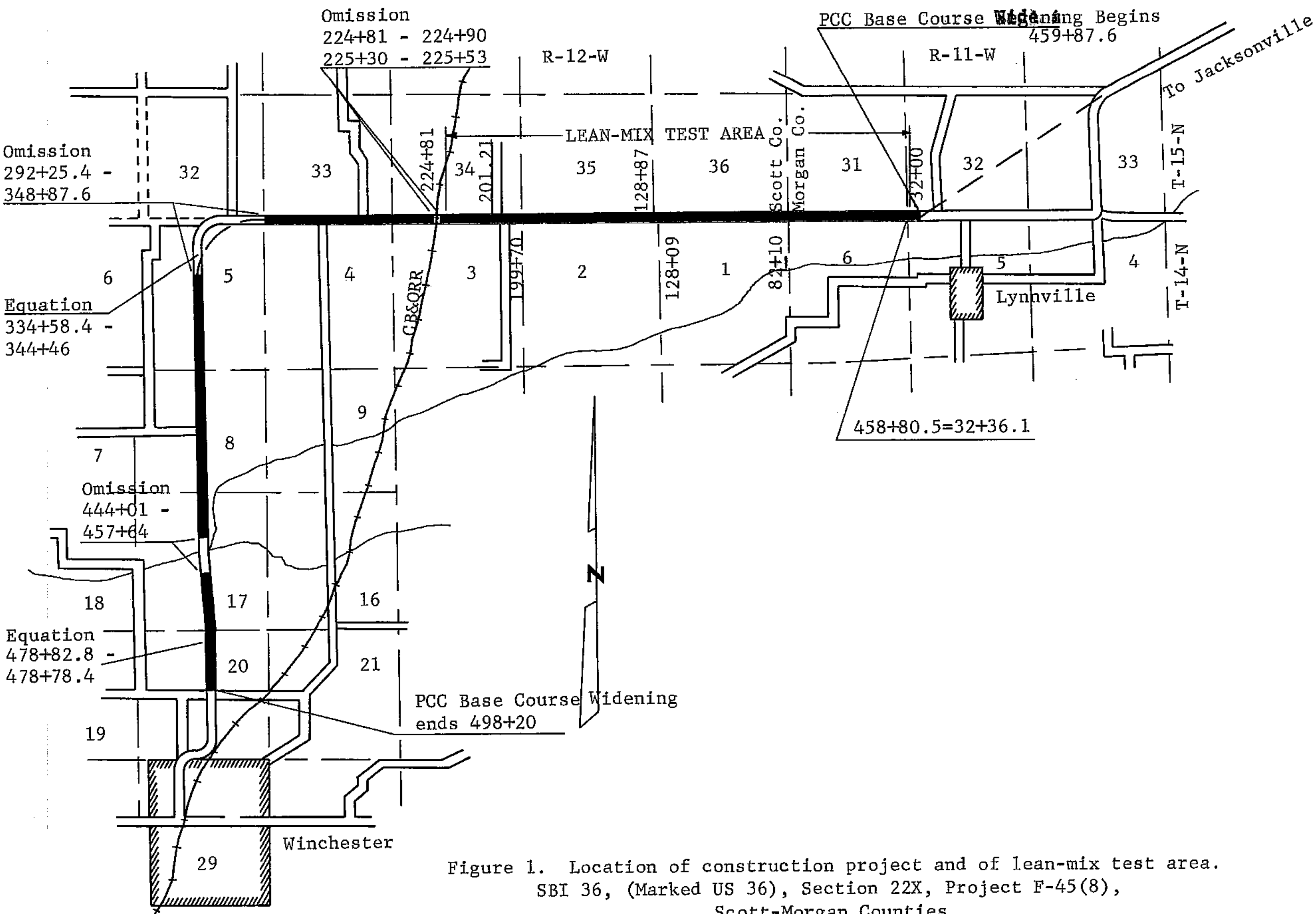

Figure 1. Location of construction project and of lean-mix test area. SBI 36, (Marked US 36), Section 22X, Project F-45(8), Scott-Morgan Counties

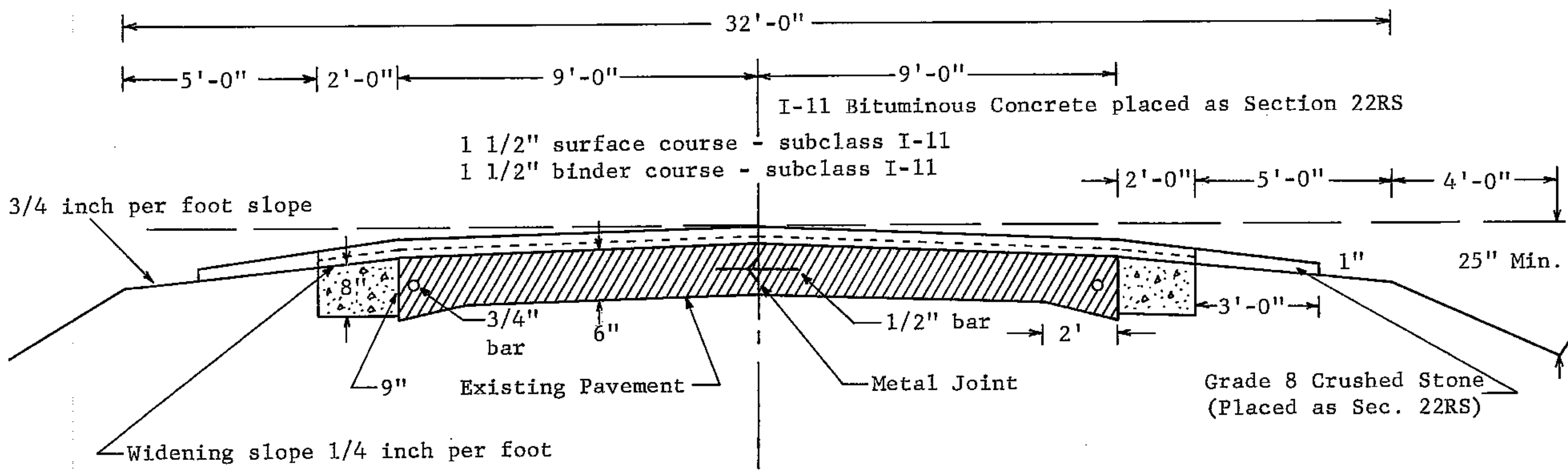

Figure 2. Typical cross section.

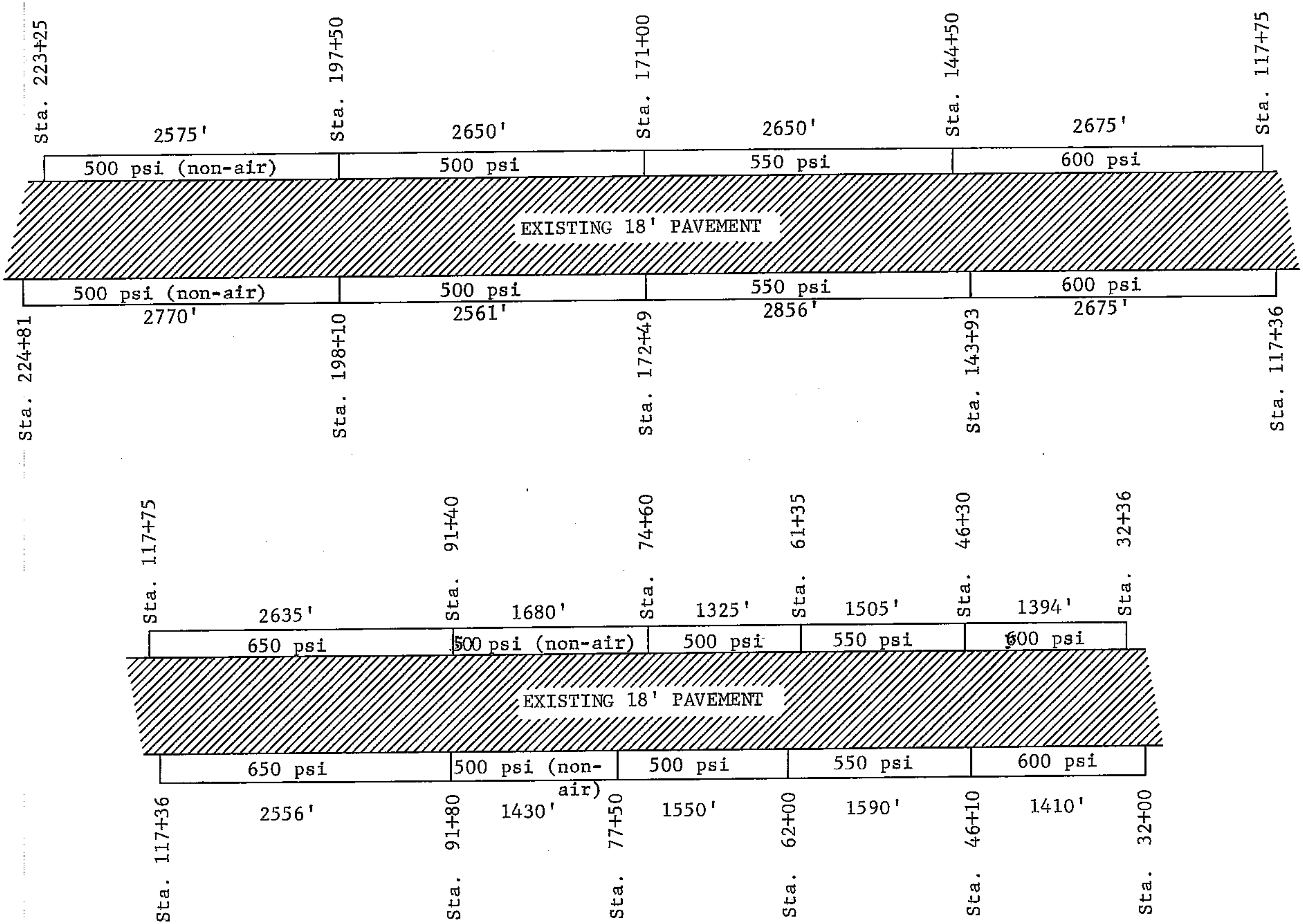

Figure 3. Lean-mix widening test section locations.

A-7-6 (12-15)	Thickness:	3-40 inches
A-7-6 (15)	Thickness:	12-20-inches
A-6 (12)	Thickness:	12-20 inches
A-4 (8)	Thickness:	0-26 inches

CONSTRUCTION

Equipment

Among the more important pieces of equipment used during the widening operation were the following:

Johnson batch plant

Marion crane, 1 1/4-yard bucket

Heltzel bulk cement plant

Multi-Foote Single-drum 34E mixer

Apsco spreader, Model 85

Caterpillar No. 12 motor patrol grade with plow attachment

Several 1 1/2-ton dump trucks

Materials

The following materials were used in the widening construction:

Crushed Stone (Coarse Aggregate)	East St. Louis Stone Co., Falling Springs, Illinois
Sand	McGrath Sand and Gravel Co., Pekin, Illinois
Cement (Type I)	Universal Atlas Cement Co., Hannibal, Missouri
Air-Entraining Agent	Darex AEA
Curing Compound	Truscon, "Trucure"

Construction Procedure

The shoulder was cut to receive the widening strip by means of a patrol grader with a plow attachment. The trench was rolled with a hand-pulled, steel-rimmed roller prior to placing the concrete. The concrete was proportioned and mixed at a batch plant and wet-batched in dump trucks to the spreader. The maximum haul in the test area was four miles. The widening concrete was placed with an Apsco spreader and finished by smoothing with a long-handled float behind the spreader. No side forms were used in the operation. Initial and final curing were effected with a membrane curing compound.

EXPERIMENTATION

Design and Strength of Concrete Mixtures

The concrete for the experimental widening was designed for 14-day modulus of rupture (mid-point loading) values of 500, 550, 600 and 650 psi. Each design strength is represented by four separate sections of widening, except the 650 psi strength which is represented by two, and the 500 psi strength which is represented by eight (see Figure 3). Four of the eight 500 psi sections were built with air entrained concrete and four without intentional air entrainment. All of the remaining sections were built with air entrained concrete. The design slump was 2 inches, and the design air content for the air entrained concrete was 4 percent. The mixes used, the cement factors, and the field measurement values for slump and air content, as measured at the mixing plant, are given in Table 1.

Under the method of placing the concrete, all mixtures worked satisfactorily with the exception of the non-air entrained mixture which appeared rather harsh; however, with some effort it was possible to obtain a satisfactory finish with this mixture. No segregation at the time of placement was reported.

Each test section was represented by 12 standard 6" x 6" x 36" test beams except for two of the 600 psi sections and two 550 psi sections for which no beams

TABLE 1

CONCRETE MIXTURE DATA AND TEST DATA FOR FRESH CONCRETE

Sta. to Sta.	Lane [1/]	Design Modulus of Rupture psi at 14 days	Mix Per Bag of Cement: Sand (lbs.)	Stone (lbs.)	Water (gals.)	Cement Factor (bbls. per cu yd)	Slump [2/] (in.)	Air Content [2/] (%)
32+00- 46+10	EB	600	240.5	372.0	5.85	1.31	1.0 -2.75	3.2-3.5
32+36- 46+30	WB	600	234.7	373.5	5.85	1.31	0.75-1.25	3.4-4.5
46+10- 62+00	EB	550	266.1	416.5	6.44	1.19	1.25-1.75	4.0-5.1
46+30- 61+35	WB	550	266.1	416.5	6.44	1.19	1.25-2.0	3.9-4.2
62+00- 77+50	EB	500	307.4	456.2	7.17	1.07	1.5 -2.25	4.3-5.3
61+35- 74+60	WB	500	307.4	456.2	7.17	1.07	1.25-2.75	4.3-4.5
77+50- 91+80	EB	500 [3/]	330.6	456.2	7.50	1.07	0.25-2.0	0.7-2.3
74+60- 91+40	WB	500 [3/]	332.2	456.2	7.42	1.07	0.75-2.25	1.6-2.3
91+80-117+36	EB	650	211.6	343.8	5.40	1.42	2.0 -2.25	3.3-3.7
91+40-117+75	WB	650	211.6	343.8	5.40	1.42	1.5 -1.75	3.5-4.0
117+36-143+93	EB	600	240.5	372.0	5.85	1.31	No tests	
117+75-144+50	WB	600	234.7	373.5	5.85	1.31	No tests	
143+93-172+49	EB	550	266.1	416.5	6.44	1.19	No tests	
144+50-171+00	WB	550	266.1	416.5	6.44	1.19	No tests	
172+49-198+10	EB	500	307.4	456.2	7.17	1.07	2.15-40	3.5-4.4
171+00-197+50	WB	500	307.4	456.2	7.17	1.07	1.5 -3.25	3.3-5.8
198+10-224+81	EB	500 [3/]	330.6	456.2	7.50	1.07	1.25-2.75	0.8-1.8
197+50-223+25	WB	500 [3/]	332.2	456.2	7.42	1.07	1.25-1.75	1.3-1.4

1/ EB = Eastbound lane
WB = Westbound lane
2/ Range of three test values
3/ Non-air entrained

were made. Because of the speed at which the widening progressed, the beams were made at the mixing plant. Since the haul of the wet concrete between the mixing plant and the job site was relatively short, the specimens and test results obtained at the mixer are believed to be representative of the concrete in place.

All test beams initially were cured for 12 to 18 hours with wet burlap. They were then removed to a sand pit which was maintained in a wet condition. Beams were tested in series of three at 7, 14, and 28 days, and at one year. The 7-, 14-, and 28-day beams remained in the wet sand until tested. The one-year beams were removed from the sand pit shortly after the last of the 28-day beams was tested in early September, and placed in an earth pit on a backslope adjacent to the experimental section. They were covered immediately with approximately two inches of soil to reduce the likelihood of unauthorized removal from the project. The soil was removed from the top surface of all beams in late October and the surface covered immediately with approximately one inch of bituminous concrete. The beams remained in this condition until tested at the age of one year.

The results of the modulus of rupture tests at 7, 14, and 28 days, and at one year, for each of the test sections are shown in Table 2. It will be noted from the table that the 14-day results are somewhat higher than the design requirements. However, it will be seen that the increase through the entire range of designs is of the same order.

Average compressive strengths for a number of cores drilled from the experimental widening and tested at the age of eight months are listed in Table 3. Additional values are shown for cores taken and tested at 14 years (1965). Some degree of consistency, but less than total, will be seen in the reported compressive strengths of the cores in relation to the design moduli of rupture of the concretes. A definite loss of strength between 8 months and 14 years will be noted.

TABLE 2

RESULTS OF MODULUS OF RUPTURE TESTS FOR BEAMS
CAST DURING CONSTRUCTION

Sta. to Sta.	Lane 1/	Design Modulus of Rupture psi at 14 days	6" x 6" x 36" Beam Test Values Modulus of Rupture - Average for Six Breaks - psi			
			7 days	14 days	28 days	1 year
32+00- 46+10	EB	600	632	709	760	977
32+36- 46+30	WB	600	586	705	833	858
46+10- 62+00	EB	550	544	641	743	797
46+30- 61+35	WB	550	530	666	782	801
62+00- 77+50	EB	500	491	565	628	748
61+35- 74+60	WB	500	452	596	711	790
77+50- 91+80	EB	500 2/	468	556	631	732
74+60- 91+40	WB	500 2/	455	624	755	833
91+80-117+36	EB	650	669	793	899	970
91+40-117+75	WB	650	682	804	897	966
117+36-143+93	EB	600	No tests			
117+75-144+50	WB	600	No tests			
143+93-172+49	EB	550	No tests			
144+50-171+00	WB	550	No tests			
172+49-198+10	EB	500	454	603	683	728
171+00-197+50	WB	500	518	573	696	747
198+10-224+81	EB	500 2/	399	604	651	744
197+50-223+25	WB	500 2/	496	629	729	805

1/ EB = Eastbound lane
WB = Westbound lane
2/ Non-air entrained

TABLE 3

COMPRESSIVE STRENGTH OF CORES

Design Modulus of Rupture at 14 days	Core Strengths at 8 Months		Core Strengths at 14 Years	
	No. Tests	Ave. Compressive Strength - psi	No. Tests	Ave. Compressive Strength - psi
500[1/]	6	4018	3	3630
500	5	4126	3	3247
550	3	4870	3	4680
600	3	5868	3	4950
650	3	5990	3	4633

1/ Non-air entrained

Durability

The original study design was concerned almost totally with the effect that the strength of the concrete widening might have on pavement performance. While the need for adequate durability was recognized, an assumption was made that all of the concrete, with the possible exception of the non-air entrained concrete used only at the 500 psi level, would be sufficiently durable for the service intended. This assumption proved to be correct insofar as service on this particular project was concerned.

While no indication of any reduction in overall performance attributable to deterioration of the widening concrete was noted, a small amount of evidence was found during the small coring program of 1965 to indicate that some losses in durability at the two lower cement contents were occurring. This was especially evident in the non-air entrained concrete used only at the lowest level of cement content.

The 1965 coring program consisted of the taking of five cores from one section of widening at each of the four levels of cement content, except that cores were taken from two sections to represent both the air entrained and non-air entrained concretes at the lowest level of cement content. Three cores in each set of five were taken where no cracks were in evidence and tested for compressive strength as previously reported. The remaining two cores in each set were taken at cracks so that the durability resistance of the concretes could be observed at these critical locations.

All of the cores taken where no cracks were present showed good durability except that the cores taken from the non-air entrained concrete showed some lack of soundness at the top surface under the bituminous concrete resurfacing. Cores taken at cracks in the concrete at the 1.42 and 1.31 cement factors also showed no loss of durability. Some of the cores taken at cracks at the 1.19 and 1.07 cement content levels also appeared to be reasonably durable, but others showed losses of material suggestive of lack of resistance to deicents. This was especially true of the cores taken from the non-air entrained concrete.

While no loss of pavement serviceability as a result of the exposure of the base widening concretes was noted on this project, the evidence of lack of durability that was found in the small coring program that was undertaken is believed to suggest that cement contents should not be lowered without giving due consideration to the probable effects that this will have on resistance to the deleterious action of deicing agents.

No records of the quantities or frequency of deicing-agent applications on the experimental project were maintained during the course of the investigation, but the general usage of deicents in Illinois has increased significantly since the early years of the study.

Traffic

Average daily traffic volumes, separated by principal vehicle types, are charted in Figure 4 for the test site for the years 1952 through 1965. It will be noted that the pavement has carried fairly substantial volumes of both passenger cars and trucks through the years of the study. Through the application of Statewide axle-load data, cumulative 18,000-lb. single-axle-load equivalencies have been computed by the procedures that have evolved from the AASHO Road Test, and which have received considerable usage. These equivalencies, in 100,000-axle increments, are also shown in Figure 4. It will be noted that about one million 18,000-lb. axle equivalencies was reached in 1965. This is about the same number of 18,000-lb. single-axle loadings as applied by the 18,000-lb. single-axle vehicles that operated on Loop 4 of the AASHO Road Test during the two-year period of that study.

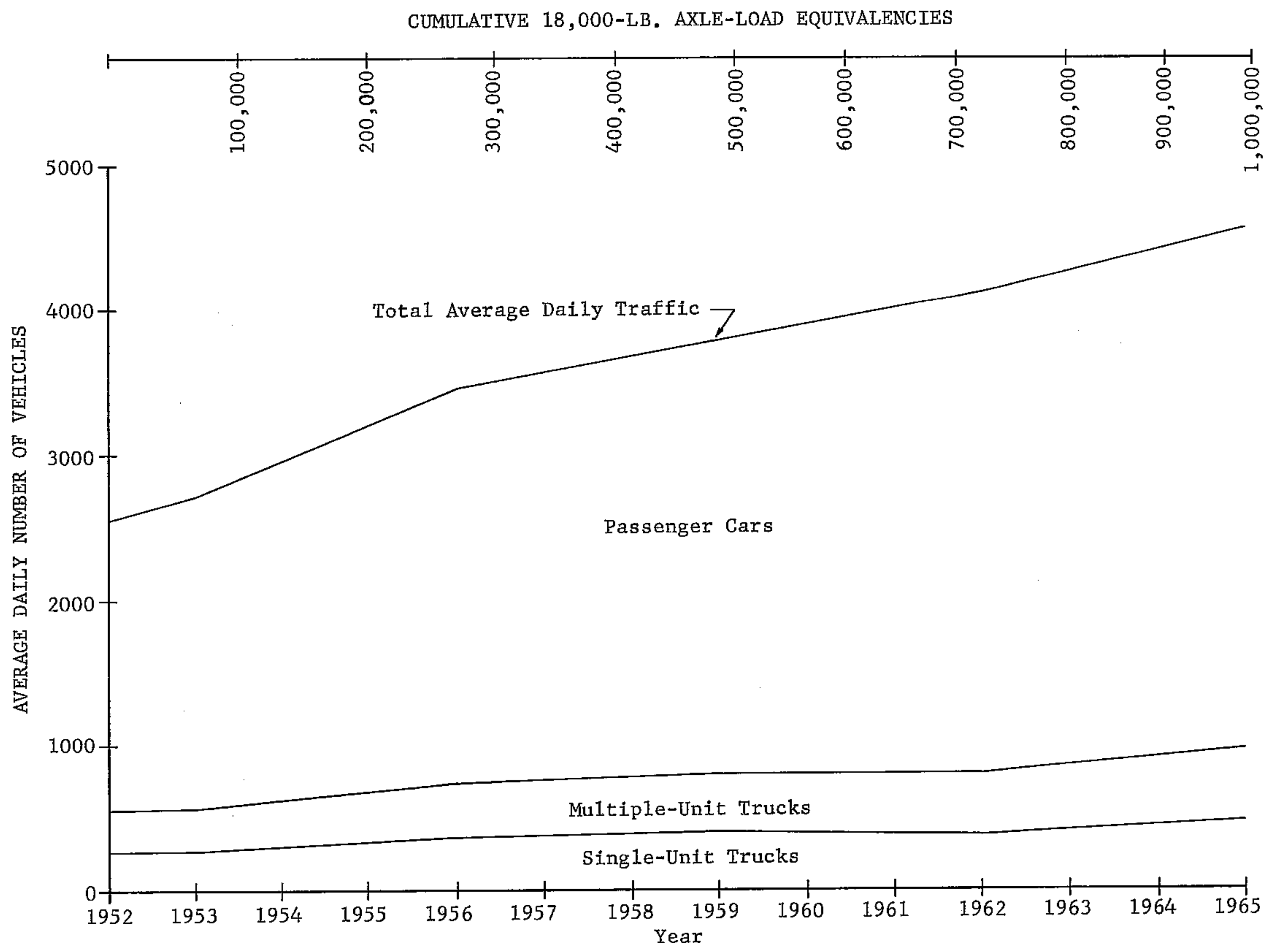

Figure 4. Traffic characteristics at the experiment location.

Condition Evaluation

Field surveys in which the visible structural condition of the overlay system was mapped in detail were conducted once each year during most of the years between the experimental construction in 1951-52 and the placing of a second overlay in 1966.

Reflection cracks were seen to occur in the bituminous concrete resurfacing over both the widening strips and the old pavement almost immediately after placing. The number of cracks increased steadily until average crack intervals had become relatively short by the time a second resurfacing was placed in 1966. Average reflection crack intervals determined during selected survey years are shown for the resurfacings over the experimental widening strips having various base strengths and for the resurfacing over the old pavement in Table 4. It will be noted that, for the widening strips, some significant variations existed in the average crack intervals until the last survey in 1965, at which time the average crack intervals for all sections had reduced to a level that is probably below the tolerable minimum for nonreinforced concrete. The reduction of the average crack interval over the old pavement with time will be seen to follow the general pattern of that for the widening strips, although the interval never became as short as that for the widening strips. The tabulated values show that during most of the years of the experiment, longer average crack intervals were associated with the lower-strength widenings. Elastic theory offers some support for this observation in that lower moduli of elasticity of the lower strength concrete should produce lower internal stresses in response to external loading and temperature warping.

No major structural failures were ever reported for the widening strips in the condition surveys. Only minor spall occurred at the transverse cracks. Longitudinal reflection cracks over the joint between the widening and the old

TABLE 4

REFLECTION CRACK INTERVALS

Widening Design Modulus of Rupture, 14 days (psi)	Reflection Crack Interval 1953 Survey (ft)	1958 Survey (ft)	1961 Survey (ft)	1965 Survey (ft)
		Over Widening		
500[1/]	242.9	90.1	40.8	11.6
500	123.2	90.1	46.9	11.2
550	122.7	76.9	26.7	11.6
600	131.7	67.1	21.1	12.3
650	162.5	77.5	19.5	9.6
		Over Existing Rigid Pavement		
	30.5[2/]			
-	178.6	73.8	47.3	16.2

1/ Without air entrainment
2/ In 1951, before resurfacing was placed

pavement became increasingly apparent through the years, but spall at these cracks never became a serious matter as has often been the case in Illinois.

After a few years of service, the surfacing was pushed upward at an occasional crack location, both over the old pavement and the widening strips. Routine removal of the raised material by burning and raking was required to restore an acceptable riding quality.

Maintenance patching also became necessary at a few locations where structural failures occurred in the old pavement, always at locations where the original condition survey made before resurfacing showed structural weaknesses to already be present.

The service rendered to traffic by the restoration of 1951-52, from an overall viewpoint, must be considered as having been up to expectations.

SUMMARY AND CONCLUSIONS

An experiment was established in 1951 on a typical widening and resurfacing project in Illinois to determine whether portland cement concrete widening strips with cement contents lower than that considered standard for regular paving concrete would serve adequately under dense-graded bituminous concrete resurfacings. Concrete mixtures with cement factors (barrels of cement per cubic yard of concrete) of 1.31, 1.19, and 1.07 were used in addition to the Illinois standard of 1.42 for pavement concrete constructed with the aggregates used on this project. The corresponding design moduli of rupture at 14 days (mid-point loading) were 600, 550, 500, and 650 psi. All of the test sections were constructed of air entrained concrete except for four of eight at the 500 psi modulus-of-rupture level; no air was intentionally entrained in the concrete of the latter four.

Condition surveys made periodically during the 14 years that the pavement served before a second resurfacing was placed disclosed no important differences in pavement performance attributable to variations in the cement contents of the widening strips.

Cores taken from the experimental widening strips in a minor coring program during the 14th year following construction showed some evidences of loss of durability at the two lower levels of cement content, and especially in the non-air entrained concrete used only at the lowest level of cement content.

The evidence developed on the project is presumed to indicate that the cement factors of widening strips that receive dense-graded bituminous resurfacings could be reduced to at least as low as 1.07 bbls. of cement per cubic yard of concrete without harmful effects under the environmental conditions of the test site.

IMPLEMENTATION

While strength is an important consideration in base widenings, the resistance of portland cement concrete widenings to deterioration from exposure to deicing-salt solutions must be considered in areas where large quantities of deicing materials are used. Recognizing that the pavement where this experimentation was conducted did not receive, in its early years, the quantities of deicents now commonly used in Illinois, prudence has suggested that, under present-day conditions, the risk of durability failure because of a reduction of cement content is too great for the small initial economy to be gained by applying the project findings in Illinois. Where small quantities of deicing materials are used, the findings of this project should receive consideration.