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

PORTLAND CEMENT CONCRETE SHOULDERS

Interim Report for Project IHR-404,

Experimental Paved Shoulders on Frost Susceptible Soils

A Research Study

by

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

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ABSTRACT

The first section of experimental portland cement concrete shoulders in Illinois was built in 1965. A second section was built in 1966 and a third in 1967. These shoulders, all of which were constructed of full-strength plain concrete without reinforcement, have been placed adjacent to conventionally reinforced pavement, continuously reinforced pavement, and a bituminous concrete overlay system. Other principal variables are the presence and absence of tie-bars, the presence and absence of granular subbase, the spacing of transverse joints, and warning rumble strip treatments. Experience to date is considered to indicate that when various findings of the project are applied, the economic and long-term behavior of portland cement concrete shoulders can be viewed with optimism.

SUMMARY

The first section of experimental portland cement concrete shoulders in Illinois was built in 1965. A second section was built in 1966 and a third in 1967. These shoulders, all of which were constructed of full-strength plain concrete without reinforcement, have been placed adjacent to conventionally reinforced pavement, continuously reinforced pavement, and a bituminous concrete overlay system. Other principal variables are the presence and absence of tiebars, the presence and absence of granular subbase, the spacing of transverse joints, and warning rumble strip treatments.

The results of the experimental work are considered to show that if the following design details are given consideration, good service performance can be expected from portland cement concrete shoulders:

(1) A 6-inch thickness of plain concrete is adequate.

(2) Tiebars are necessary. No. 4 deformed bars, 2' 6" long spaced on 2' 6" centers will serve adequately.

(3) A fairly close spacing of transverse joints is desirable for the control of intermediate cracking. This is particularly important when the plain concrete shoulders are tied to continuously reinforced pavement. A spacing of about 20 feet seems to be serving with reasonable effectiveness in the experimental work.

(4) The use of a good grade of joint sealant may be fairly important in the control of spall of transverse joints.

(5) The need for subbase under the concrete shoulders was not established although there was a small amount of evidence that it may help in the reduction of transverse cracking.

(6) Rumble strips consisting of 4- to 6-foot-wide groupings of corrugations, one inch in depth, and with the groupings spaced at from 60- to 100-foot intervals, serve effectively as a traffic warning measure.

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INTRODUCTION

Durable shoulders capable of receiving emergency incursions of vehicles traveling at high rates of speed, and of returning the vehicles safely to the traffic flow, are essential features of modern high-speed highways. These shoulders must be capable of withstanding the same magnitudes of loading as applied to the adjoining pavements, although the capability for resisting great numbers of repeated loadings is not to be expected.

The process of developing a reasonably satisfactory shoulder component for high-speed, high-travel volume highways in Illinois has been one of evolution and upgrading. An early belief that a relatively low-cost shoulder structure could serve adequately was not borne out by experience.

Based on many years of successful use of aggregate roads in low-traffic volume situations, the first presumption made was that this type of surfacing would serve as a suitable replacement for the earth shoulders that had been found inadequate. Experience soon proved otherwise; serious loss of stability occurred during wet weather, and an intolerable amount of subsidence created a need for continual maintenance.

The addition of a bituminous seal surfacing on the aggregate base proved to be of no particular value. Replacement of the light surface treatment with a bituminous concrete surfacing improved stability, but a persistent tendency of the shoulder structure to heave above the pavement surface to create a condition under which traffic caused extensive cracking in the vicinity of the pavement-shoulder joint, discouraged further use of this design.

In the belief that a stabilized shoulder base would serve more adequately, attention was directed toward the use of bituminous-aggregate mixtures (BAM), cement-aggregate mixtures (CAM), and pozzolan-aggregate mixtures (PAM), as shoulder bases, the latter two in combination with bituminous concrete surfaces. Of these three types, only the BAM was found to provide reasonably acceptable performance; the CAM and PAM combinations were found to perform much the same as their bituminous concrete-surfaced aggregate base predécessor.

While the BAM shoulder type has been giving good service in Illinois in most instances, it has not been inexpensive. Therefore, the possible economic advantage of having a competitive type and the desire for further improvement have led to experimentation with portland cement concrete as a possible shoulder structure alternative.

The first experimental portland cement concrete shoulders in Illinois were bui built in 1965 as part of the reconstruction and rehabilitation of a five-mile section of Route Illinois 116 near Peoria, identified as SBI Route 116, Section (101-102)-1, Project U-604(19), Tazewell County. The second concrete shoulder installation was placed near Goodfield in 1966 as part of FAI Route 74, Section (90,X3)16, Project I-74-4(103)108, Woodford County. The third and last portland cement concrete shoulder installation placed up to the present time was included in a major shoulder experimentation project in which the construction was identified as FAI Route 80, Section 99-4-1, Project I-80Θ4(139)135, Will County. CAM, PAM, and BAM shoulder types, in addition to portland cement concrete, were included in this construction whibh took place in 1967. This last experimentation is described in detail in Illinois Research and Development Report No. 24, "Experimental Paved Shoulders on Frost Susceptible Soils" (1969). The locations of all of the experimental concrete shoulder sections are shown in Figure 1.

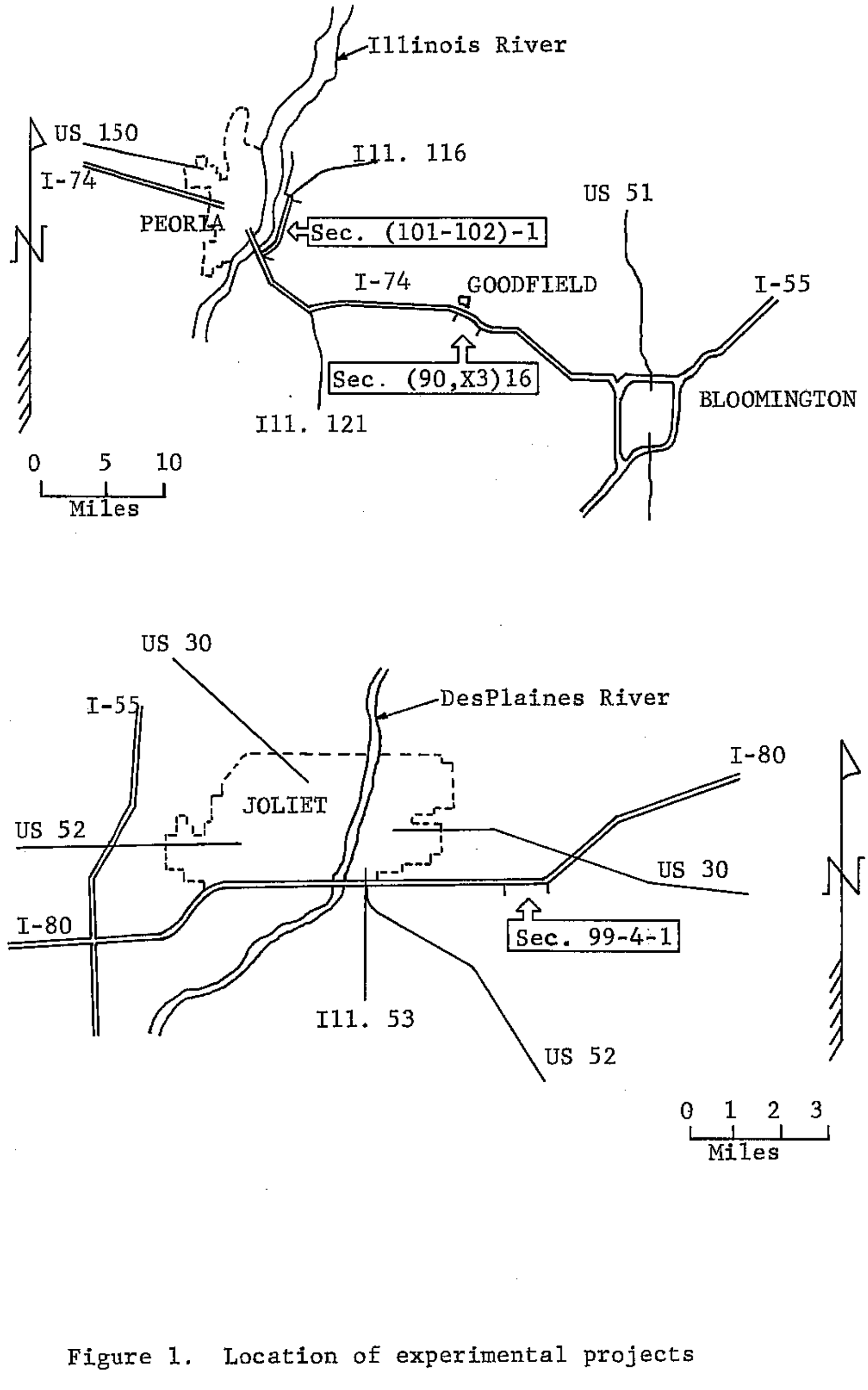


Figure 1. Location of experimental projects

Numerous variables, including the presence and absence of ties between the shoulder and the adjoining pavement, the type of the adjoining pavement (conventional or continuously reinforced), transverse joint spacing, subbase usage, rumble strip treatment, and others, have been included in the experimentation. All shoulders have been constructed of plain concrete without steel reinforcement.

Although all of the cost figures that are available have been obtained under conditions unique to experimental shoulder construction, results indicate that the initial cost of portland cement concrete shoulders will not be completely out of range in comparison with the costs of the other high types of shoulder that have been used. Figures from the I-80 experimental shoulder project showed less than $5,000 per mile (inside and outside shoulders adjacent to one pavement) separating the four shoulder types that had been used, with the portland cement concrete shoulders costing the most.

All of the portland cement concrete shoulder installations are showing good performance under typical conditions of service. One such installation, that on I-80, is shown in the photograph in Figure 2. While it is too early to pass judgment on the ultimate service life to be expected from this type of shoulder, indications up to the present time are very encouraging.

In addition to showing that good performance can be expected from portland cement concrete shoulders, the experimentation with which the present report is concerned has produced information on a number of design features, especially on transverse jointing, the use of ties at the pavement-shoulder joint, and rumble strip treatment, that will aid in maximizing the performance of this type of shoulder.

original in
March 1972 report

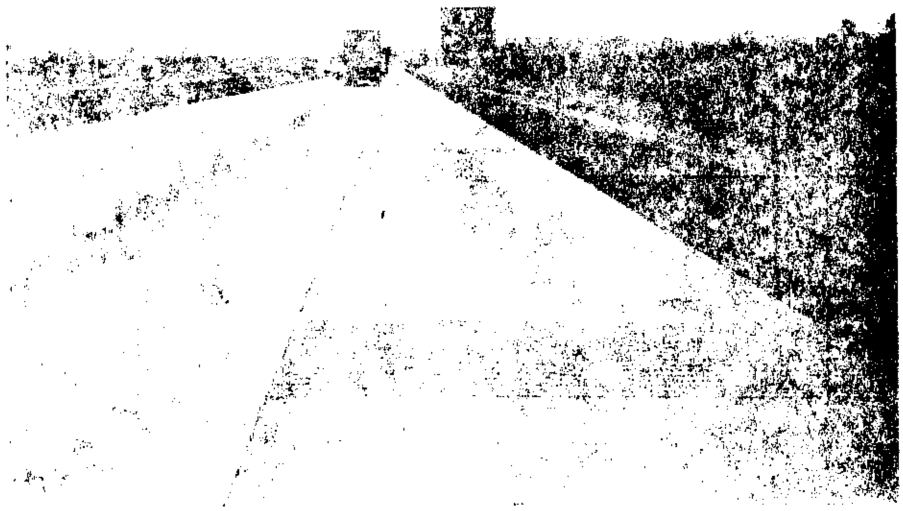


Figure 2. Outer portland cement concrete shoulder
adjacent to [illegible] pavement on I-80

LOCATION AND DESIGN

General

Average annual rainfall in the area of the experimental shoulders ranges from about 33 inches at the I-80 location to 36 inches at the Illinois 116 and I-74 locations. Average annual frost penetration is about 30 inches at the I-80 location and about 25 inches at the Illinois 116 and I-74 locations. Temperatures occasionally drop below zero in winter and usually reach above 90F a few times each summer.

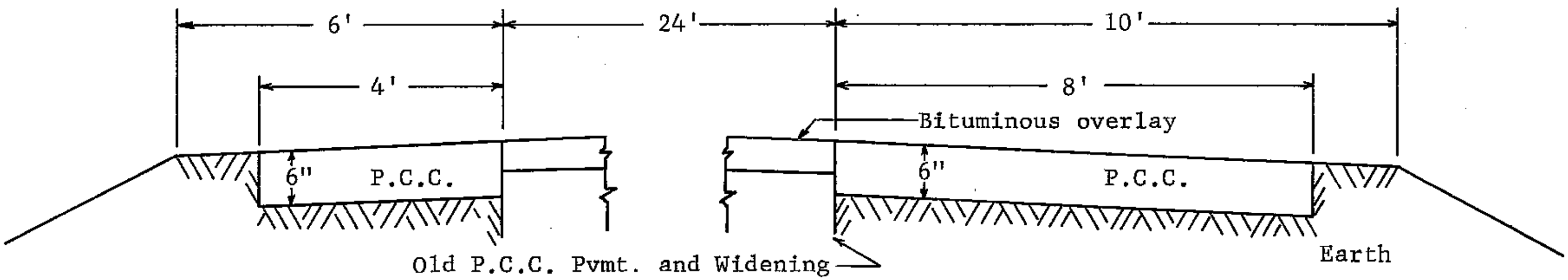
Illinois 116

Illinois 116 is a four-lane divided highway carrying an ADT volume of about 12,000 vehicles at the location of the concrete shoulder experimentation. The roadway lies near the foot of the eastern Illinois River valley slope where coarse to moderately fine-textured terrace and flood plain soils predominate. Muck was removed to varying depths at some locations during embankment construction, and replaced with firmer material.

The portland cement concrete shoulders on the project were placed adjacent to both a conventionally reinforced concrete pavement, constructed under the same contract, and an overlay pavement system in which an older pavement was resurfaced with bituminous concrete as part of the construction work. The overlay construction included widening as well as resurfacing.

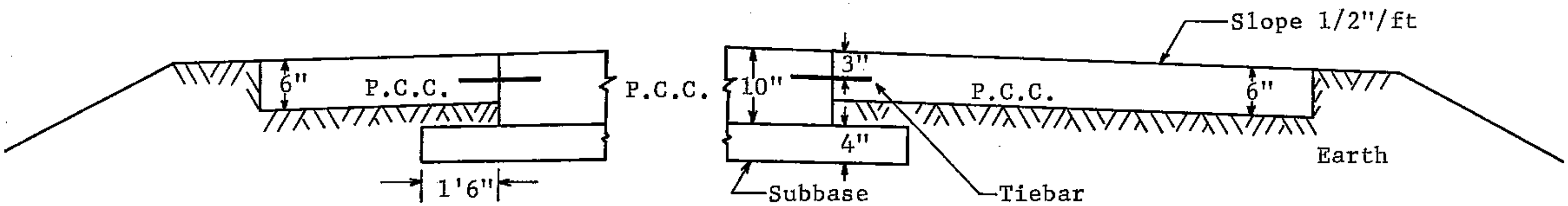
The concrete shoulders on this project are 6 inches in thickness and placed on the natural soil subgrade. Typical cross sections are shown in Figure 3. The outer shoulders are 8 feet wide and the median shoulders are 4 feet wide.

Four different methods were used in joining the pavement and shoulders together. Where the new shoulder was placed adjacent to the overlay pavement system, a simple joint was



Test Section (1)

ADJACENT TO RESURFACED PAVEMENT



Test Section (2) - No. 5 tiebars, 2'-0" long at 2'-6" ctrs., grouted 9" in hardened pvmt. concrete
Test Section (3) - No. 5 tiebars, 2'-6" long at 2'-6" ctrs., placed in plastic pvmt. concrete
Test Section (4) - Metal plate keyway; no tiebars

ADJACENT TO NEW PAVEMENT

Figure 3. Typical cross sections for Illinois 116 portland cement concrete shoulders

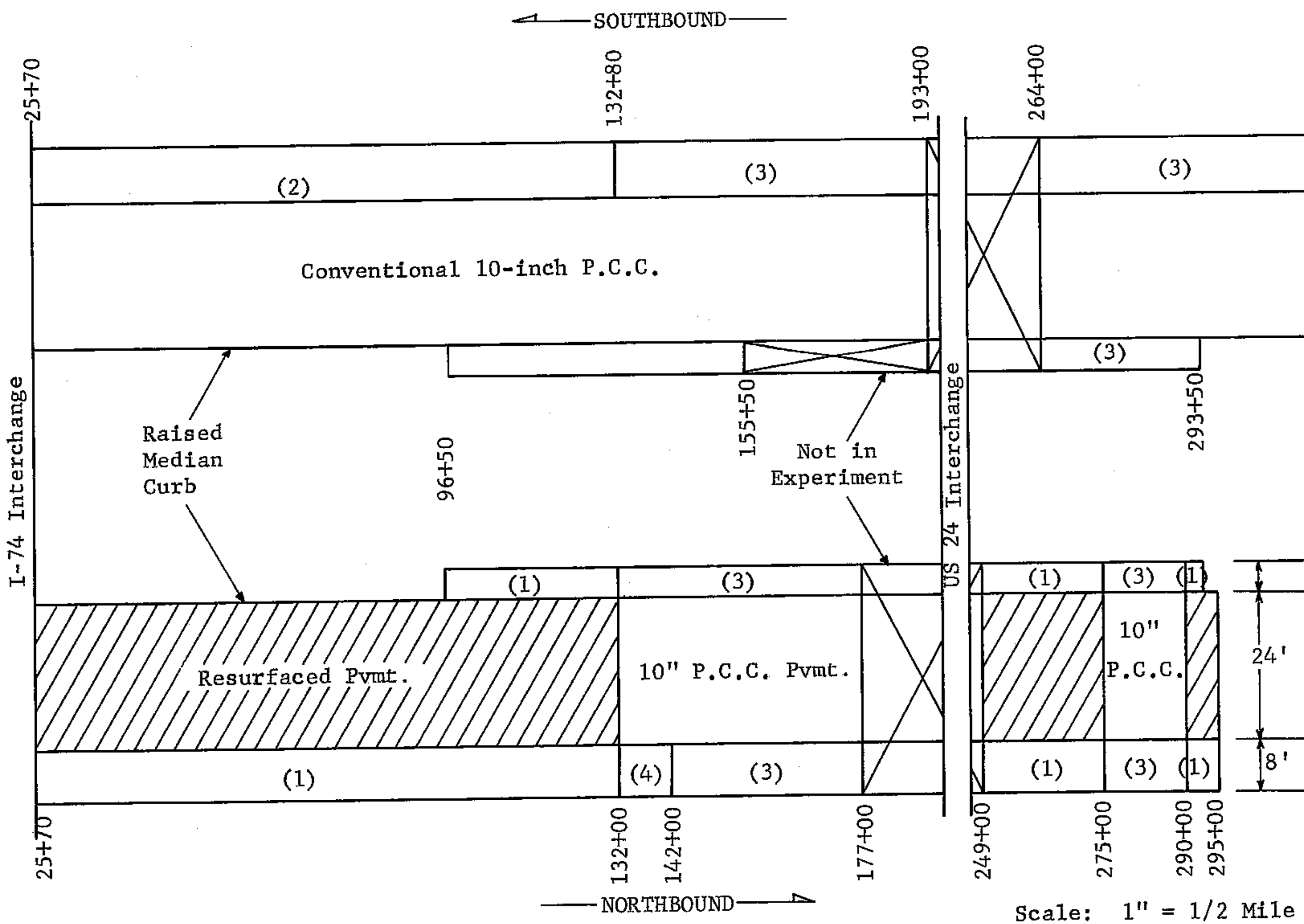
joint was used with neither keyway nor tiebars. Where the shoulder was placed adjacent to new concrete pavement, the longitudinal jointing system included a keyed joint without tiebars, No. 5 tiebars 2' 0" long, grouted into holes drilled in the hardened pavement concrete a 2" 6" centers to a depth of 9 inches, and No. 5 tiebars, 2' 6" long, installed in the plastic concrete of the pavement slab at 2" 6" centers. A layout of the locations of these treatments is shown in Figure 4.

Dummy-groove joints were placed in the shoulder concrete at 50-foot intervals on some portions of the project; and at 100-foot intervals on others. Where the shoulder was plaeed adjacent to new pavement, a shoulder joint was made to coincide with each of the pavement joints which were spaced at 100-foot intervals. Joints locations in the resurfaced pavement were not taken into consideration in spacing joints in the adjoining shoulders.

Warning strips consisting of 3-foot-wide groupings of closely-spaced corrugations were centered over each transverse joint where 50-foot spacings were used. The same 50-foot spacing of strips was used in the areas of 100-foot joint spacing, but the strips layout was such that the strip locations were never coincident with the joint locations. The strip corrugations were impressed in the plastic concrete to a depth of about 3/4 inch.

I-74

I-74 is a four-lane divided highway with an ADT volume of about 6,000 vehicles at the location of the experiment. Soils in the vicinity are medium to moderately fine-textured upland soils in a glacial till area in which the till is covered with loess to depths of from 5 to 8 feet.



LEGEND

(1) No tiebars
(2) Grouted tiebars
(3) Standard tiebars
(4) Longitudinal keyway only

Figure 4. Layout of Illinois 116 portland cement concrete shoulder experiment

The mainline pavement is continuously reinforced portland cement concrete, 8 inches thick and 24 feet wide. This pavement is placed on a 4-inch-thick trenched subbase that extends 18 inches outside the edges of the pavement.

The concrete shoulders on this project are 6 inches in thickness and 10 feet wide on the outer side of the pavement, and the same thickness and 4 feet wide on the median side of the pavement. Typical cross sections are shown in Figure 5.

The I-74 shoulder experiment includes four sections with the following treatments:

(1) shoulder concrete on trenched granular subbase, tiebars at shoulder-pavement joint.

(2) shoulder concrete on natural subgrade soil, tiebars at pavement-shoulder joint.

(3) shoulder concrete on granular subbase extended to side slope, no tiebars at pavement-shoulder joint.

(4) shoulder concrete on natural subgrade soil, no tiebars at pavement-shoulder joint.

Each of the four sections is 1100 feet long. In the section where the shoulder subbase was placed in trench, corrugated metal pipe underdrains were placed 550 feet apart to drain water through to the shoulder slope. One half of each subbase section was constructed with coarse aggregate of 1 1/2-inch maximum size for concrete, and the remaining half with coarse aggregate of 1-inch maximum size for concrete. Tiebars are No. 4 size, 2' 6" long, spaced at 2' 6" intervals. A longitudinal keyed joint was used throughout. The median shoulders, except for width, are the same design as the outer shoulders, and include the same experiment variations. Warning rumble strips consisting of 4-foot-wide groupings of corrugations 1 inch deep were centered on dummy-groove transverse joints spaced at 10, 20, 50, 75, and

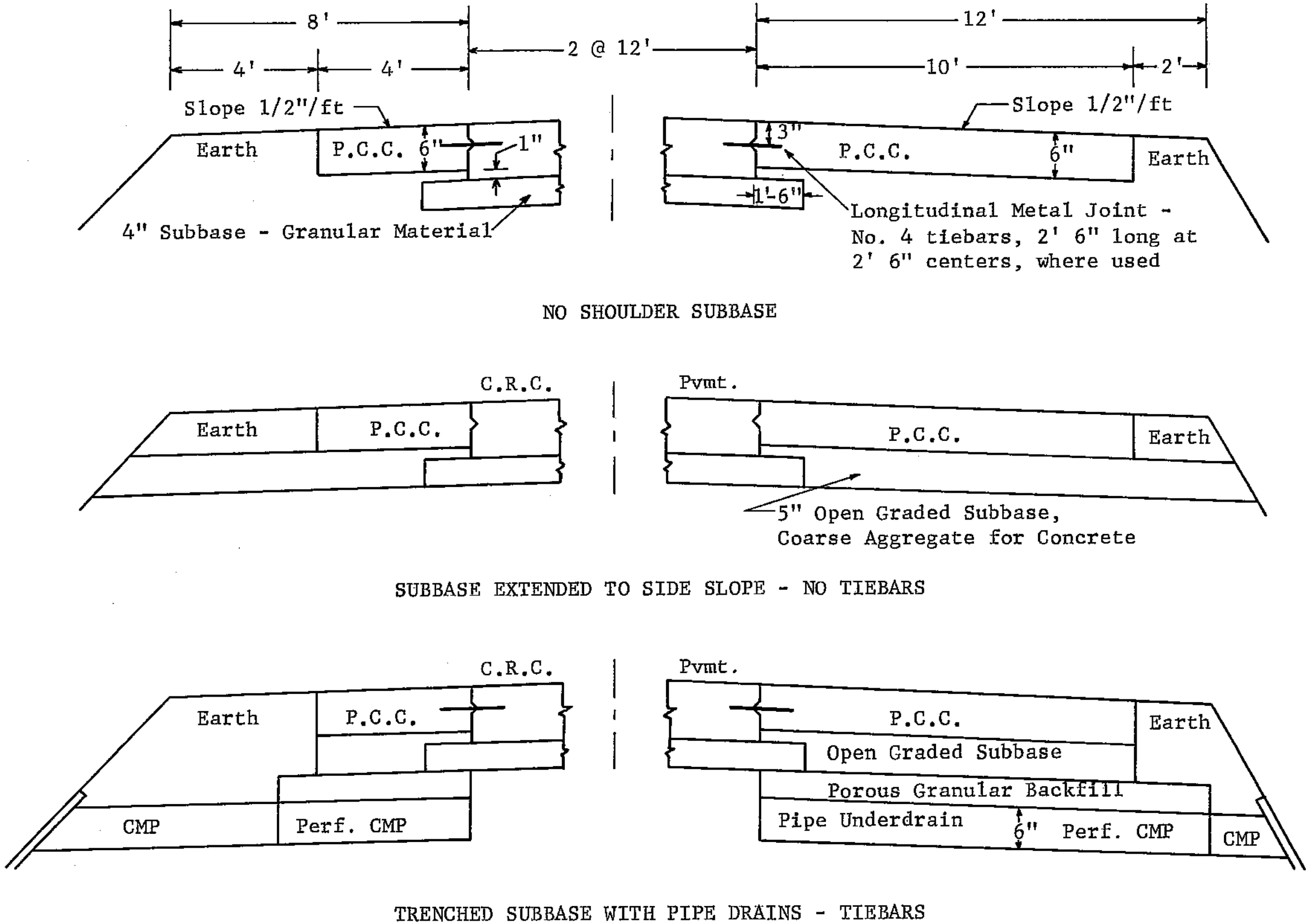


Figure 5. Typical cross sections for I-74 portland cement concrete shoulders

100-foot intervals. Alternating 40- and 60-foot, and 40- and 80-foot spacings also were included. A layout of the experimentation is shown in Figure 6.

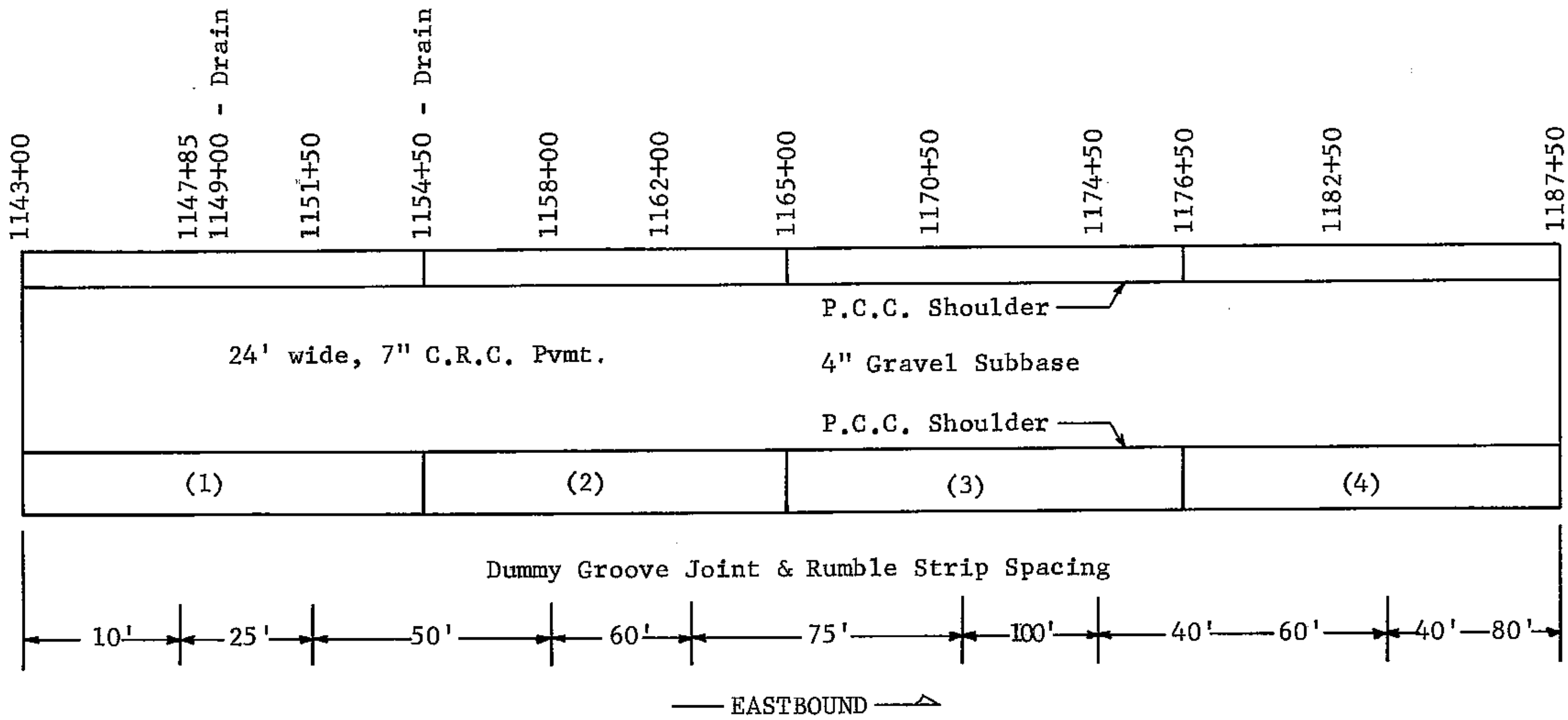
I-80

I-80 is a four-lane divided highway which carries about 14,000 vehicles per day over the experimental section. This site is located in an area of fine-grained soils derived from shallow glacial drift without a loess cover.

The mainline pavement at the I-80 experimental site is continuously reinforced concrete, 8 inches in thickness, 24 feet wide. The pavement subbase in the test area is a cement-aggregate mixture 4 inches in thickness, extending 18 inches beyond the pavement edges.

Based on experience gained from the earlier trials, the I-80 paved shoulders were designed to taper from an 8-inch thickness where they adjoin the pavement to 6 inches at their outer edges. This was done to simplify construction. The shoulders were tied to the mainline pavement throughout the experimental section with No. 4 hooked bolts of 15-inch length, turned into 2-inch snapoff expanding end anchors set into the edge of the pavement slab at 30-inch intervals with a pneumatic hammer. These ties replaced conventional tiebars that were inserted in the pavement concrete when it was placed by the slipform process, but which could be found only with great difficulty when shoulder construction was undertaken.

Tn the I-80 test, individual sections of paved shoulder were placed on open-graded granular subbase of three different gradations, and on earth subgrade. The subbases extended out to the sideslopes. One half of each individual section included a saw cut 3/4-inch deep and 1/2-inch wide at the pavement-shoulder joint, filled with a hot-poured rubber asphalt joint-sealing compound. The remaining half was neither cut nor sealed. Typical cross sections of the experiment are shown in Figure 7. A layout of the test sections is shown in Figure 8.

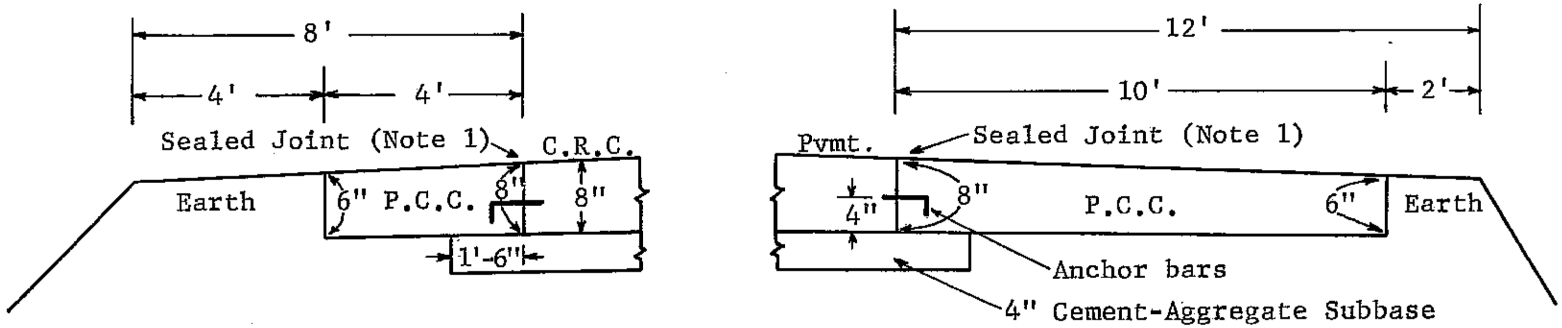


Scale: 1" = 500 ft.

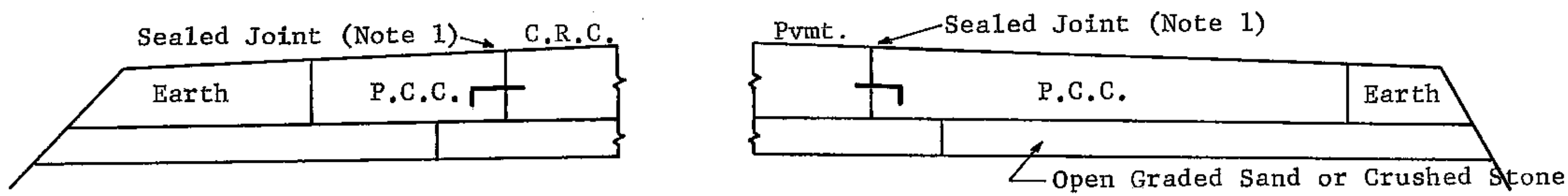
LEGEND

(1) Trenched subbase, pipe drains - with tiebars
(2) No subbase - with tiebars
(3) Subbase extended to side slope - no tiebars
(4) No subbase - no tiebars

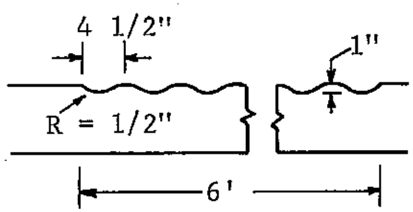
Figure 6. Layout of I-74 portland cement concrete shoulder experiment



EARTH SUBGRADE



WITH SUBBASE



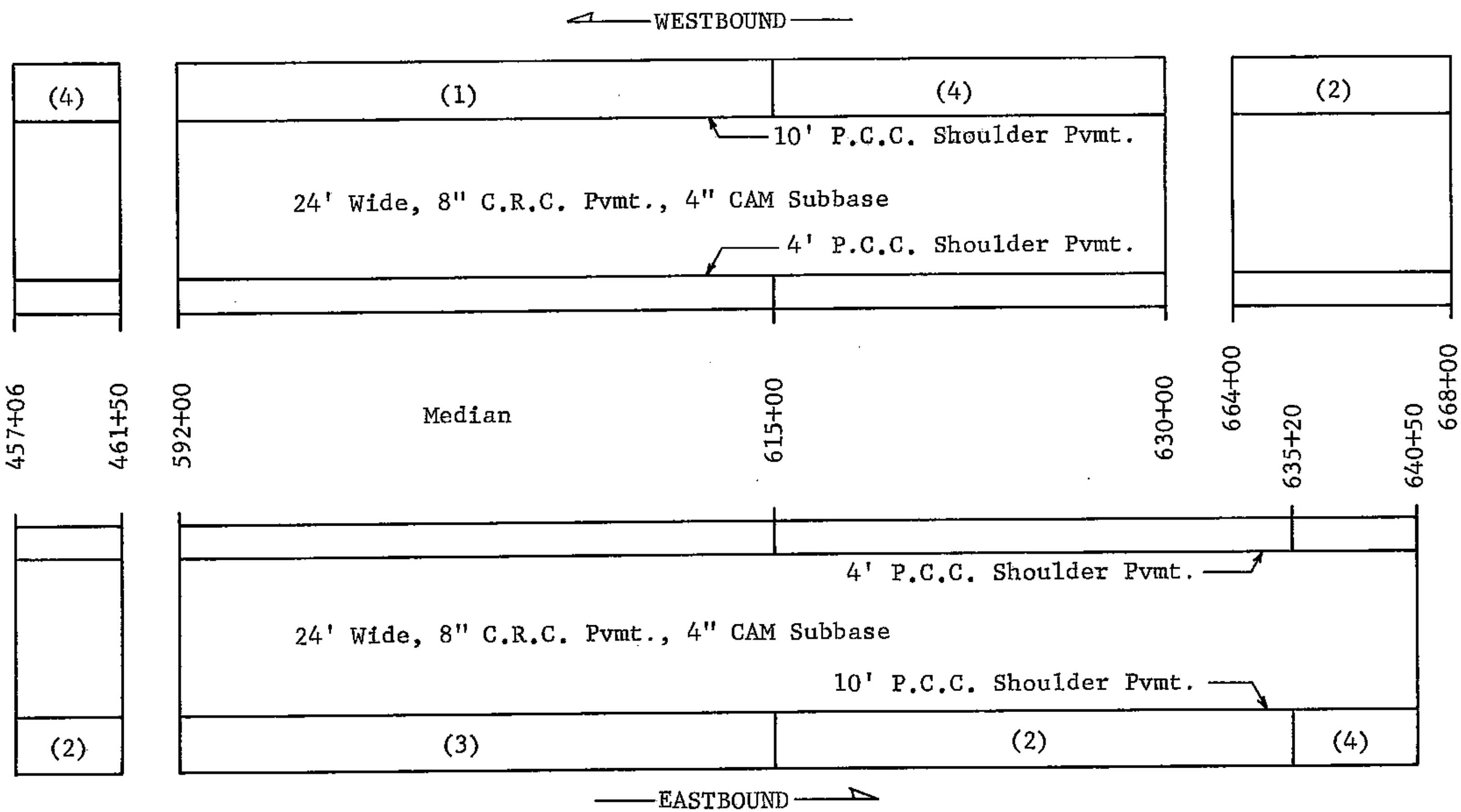
RUMBLE STRIP DETAIL

Note 1: The longitudinal joint in half of each test section is sawed 1/2" wide by 3/4" deep and sealed with a hot-poured rubber-asphalt joint sealant.

Note 2. Surface is transverse broomed. Dummy groove transverse joints at 20' intervals.

Note 3. Rumble strips 6' wide @ 60' intervals.

Figure 7. Typical cross sections for I-80 portland cement concrete shoulders



Scale: 1" = 600 ft.

LEGEND

(1) Sand subbase
(2) Crushed stone subbase (coarse)
(3) Crushed stone subbase (intermediate)
(4) No subbase

Figure 8. Layout of I-80 portland cement concrete shoulder experiment

MATERIALS AND CONSTRUCTION

The materials of which the portland cement concrete shoulders were constructed and the construction procedures were in accord with the Illinois Standard Specifications for Road and Bridge Construction.

The portland cement concrete mixtures conformed with the standard specifications for portland cement concrete for pavement. Cement factors range between 1.42 and 1.46 barrels per cubic yard of concrete. Air entrainment in the range of four to seven percent was specified. Mixtures were designed to provide a minimum modulus of rupture (center point loading) of 650 psi at 14 days. The coarse aggregate was furnished in two sizes, with the coarser of the two aggregates having a maximum size of 1 1/2 inches.

The experimental shoulders at all three locations were built by the slipform process. The inside edge of the slipform paver rode on the pavement edge, while the outer edge, which was fitted with a skid, slid over the subgrade or subbase surface (Figure 9). A heavy rubber-tired tractor with a tow cable attached was used to pull the slipform along the pavement edge. A motor patrol following behind held the rear end of the slipform tight against the pavement edge by means of a line attached to the rear of the slipform. Concrete was wet-batched to the job site in agitator trucks. Following placing, the concrete was consolidated ahead of the strikeoff by spud vibrators mounted on the slipform. The outer edge of the shoulder slab was shaped by a special trailing shoe attached to the rear of the outer form. A burlap drag attached to the rear of the paver was used to finish the surfaces at the Illinois 116 and I-74 sites. On I-80, the surface was broomed in the transverse direction. Finishing crews following behind the slipform pavers formed the rumble strips with special floats fabricated from sections of corrugated

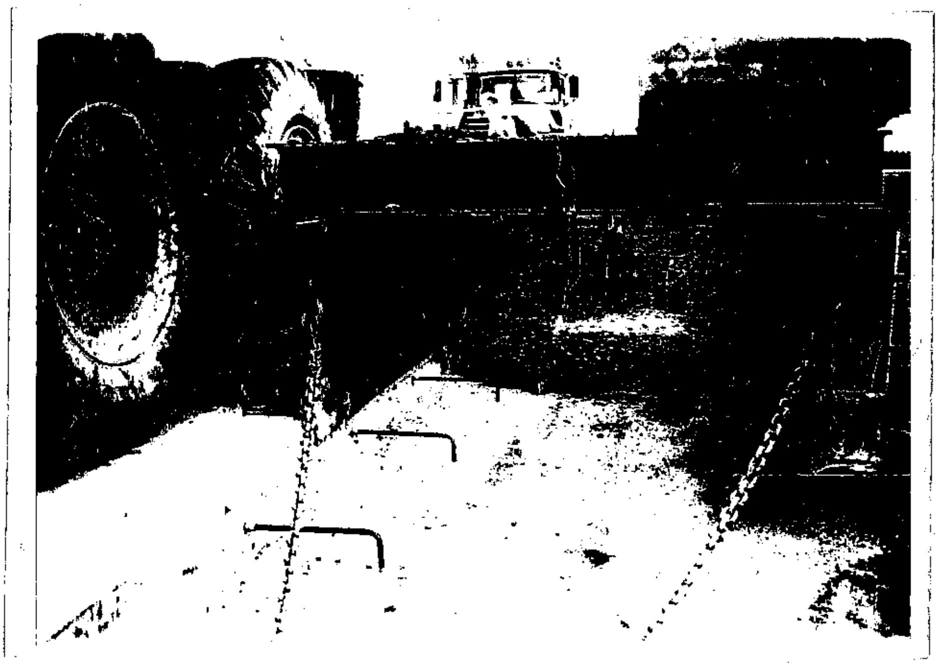


Figure 9. Placing the median shoulder of the I-80 experimental project

steel. The finisher worked the float across the fresh concrete surface while a helper supported the outer edge of the plastic concrete with a 6-inch plank. Three passes of the float were sufficient to shape the corrugations.

Dummy-groove transverse joints were formed to 1 1/2-inch depths in the Illinois 116 and I-74 shoulders. Throughout the I-74 project, and through much of the Illinois 116 project, the joint-forming process took place coincidentally with the formation of the rumble-strip corrugations. The dummy-groove transverse joints of the I-80 shoulders were cut with hand trowels and were not associated with rumble strips. After the concrete had hardened, the I-80 troweled joints were deepened to 1 1/2 inches with a saw. Both the transverse and longitudinal joints of the Illinois 116 and I-74 projects were sealed with a conventional asphalt material. A high-grade hot-applied rubber-asphalt compound was used on the I-80 project.

The Illinois 116 and I-74 shoulders were cured with a membrane curing compound. The I-80 shoulders were cured with waterproof paper and, in cold weather, with straw.

At the Illinois 116 site, tiebars were grouted into holes drilled into the hardened pavement concrete at some locations. At other locations, the tiebars bent at 90 degrees were placed in the plastic pavement concrete. These were straightened over the shoulder area prior to shoulder paving. The tiebars for the I-74 shoulders were placed in the plastic concrete in the same manner. This procedure also was used on the I-80 project, but the bars became buried too deep during the slipform placing of the pavement concrete, and could be relocated only with great difficulty. These were replaced with hooked bars turned into snapoff end anchors set two inches deep in the hardened pavement concrete.

PERFORMANCE

Illinois 116

The Illinois 116 concrete shoulders, constructed in 1965, have been in service almost five years at the time of writing this report. With some exceptions that will be discussed in detail, performance has been satisfactory.

It will be recalled that the usage and omission of ties between pavement and paved shoulder was a principal variable on this project. Where L-shaped tiebars were placed in the plastic pavement concrete and straightened in the customary manner before placing the shoulder concrete, no horizontal or vertical movement of the shoulder with reference to the pavement has been observed. The longitudinal joint remains as tight as originally constructed.

Where tiebars were grouted to a depth of nine inches in the hardened pavement concrete, performance has been similar to that where the tiebars were placed in the plastic pavement concrete, except at one location where the shoulder has separated in excess of one inch from the pavement (Figure 10). An investigation at this location which involves the outer shoulder of the southbound roadway between Stations 131+00 and 134+00 has shown a general outward and downward movement of the outer portion of the fill to have taken place. Reference to the preconstruction soil survey reveals this to be a muck area where removal and replacement with satisfactory material was to have taken place. It is obvious that the correctional treatment was not entirely effective. The tiebars can be observed in place through the opening that has occurred between pavement and shoulder, and it is presumed that a failure probably has occurred in the grouting.

In the short section (about 1000 ft) where a keyway was used without tiebars, no movement of the shoulder with reference to the adjoining pavement is perceptible.

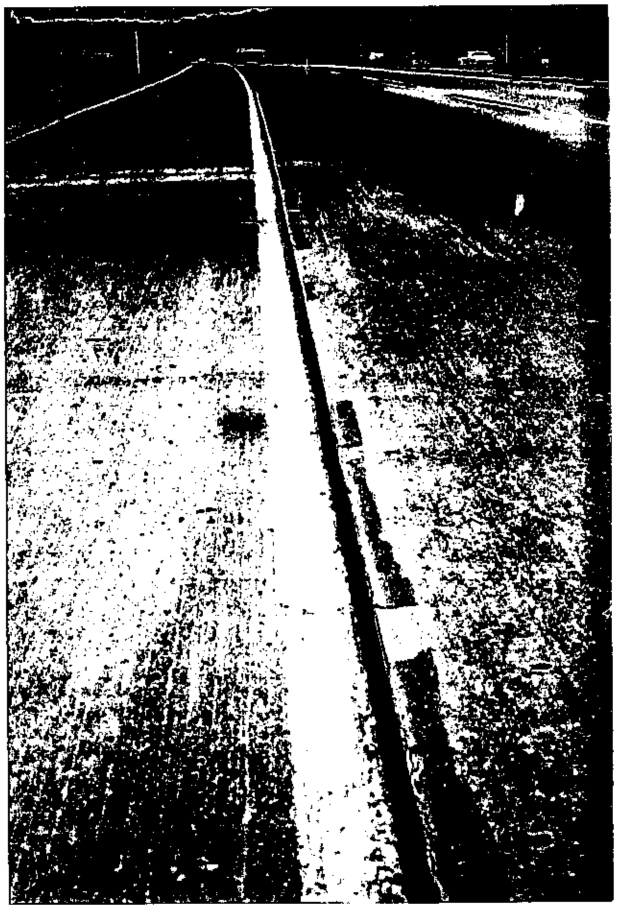


Figure 10. Separation of pavement and shoulders caused by embankment subsidence in spite of presence of tiebars.

Where the concrete shoulder was placed adjacent to the bituminous overlay system without ties or keyway, upward winter movements of the shoulder with reference to the pavement of about one-half inch have been observed. These shoulders have returned mostly to their normal positions following each winter season.

A record of the transverse cracking that was present in the outer shoulders in 1969 is shown for the Illinois 116 experiment, and for the I-74 and I-80 experiments as well, in Table 1. The new mainline pavement of Illinois 116, it will be recalled, was conventionally reinforced concrete with transverse contraction joints spaced at 100-ft intervals. A transverse joint was placed in the adjacent shoulder concrete to coincide with each pavement joint, and on certain sections an intermediate joint was placed to create a 50-ft joint interval. Jointing of the old pavement that was widened and resurfaced with bituminous concrete before shoulder construction was not taken into consideration in laying out the joints in the adjacent shoulders. It will be seen from Table 1 that only a small amount of intermediate transverse cracking has occurred thus far in the shoulders of the Illinois 116 project where the 50-ft joint spacing was used, and that the use of tiebars has had no appreciable influence on the occurrence of transverse cracks. It will also be seen that the crack frequency for the 100-ft spacing is about double that for the 50-ft spacing.

Slight to moderately severe spall has occurred at several of the transverse joints on this project. The spall is of the type usually associated with the entrapment of incompressible material, and a fair amount of this material lies on the shoulder surfaces. Retention of the asphalt seal placed in the joint grooves has been poor. The spall that has been observed thus far has not been found to be especially related to either the longer joint spacing or to the location of corrugation

TABLE 1

TRANSVERSE CRACK FREQUENCY
(Surveyed 1969)

Tiebars	Granular Subbase	Joint Spacing (ft)	Crack[1/] Frequency (no./1000 ft)
	I-74 - CRPC Mainline Pavement		
Yes	Yes	10	4.6
"	"	25	16.4
"	"	50	33.3
"	No	50	37.5
"	"	60	45.0
"	"	75	43.3
No	Yes	75	4.0
"	"	40-80	5.0
"	"	100	10.0
"	No	40-60	10.0
"	"	40-80	16.7
	I-80 - CRPC Mainline Pavement		
Yes	Yes	20	5.5
"	No	20	8.2
	Illinois 116 - PCC Mainline Pavement		
Yes	No	50	4.2
"	"	100	10.5
No	"	50	5.5

1/ Surveys covered outside shoulders only grooves over the joints, both of which could be suspect as contributing factors. However, it is not believed that this should be accepted as assurance that such relationships are not likely to be found as the study progresses (Figure 11).

A meandering generally longitudinal crack about 150 feet long has developed in the outer shoulder of the northbound pavement near Station 142 (Figure 12). A keyway, but not tiebars, was used at the shoulder-pavement joint at this location. So far, no serious movement has occurred at this joint, and the crack has not opened appreciably. It was noted in a field examination of the site that a relatively high number of large trucks are using the paved shoulder in the vicinity of the crack as a deceleration lane preparatory to turning onto an intersecting industrial road. This offers a possible explanation for the occurrence of this crack in the six-inch shoulder pavement.

The rumble strips on this project consist of corrugations that reach 3/4 in. in depth from crest to trough. In the opinion of a number of people who have driven these rumble strips and the strips having the 1-in.-deep corrugations on the other two projects, the latter design is preferable as a warning measure.

<u>I-74</u>

The concrete shoulders of I-74, constructed in 1966, are without major defects in 1970.

It was previously noted that the principal variables of this project are the presence and absence of tiebars at the pavement-shoulder joint, and the use and nonuse of granular subbase under the shoulder pavement. Several different transverse joint spacings also are included.

The pavement-shoulder joint has remained tightly closed where tiebars were used. Where tiebars were not used, a generally noticeable separation, reaching

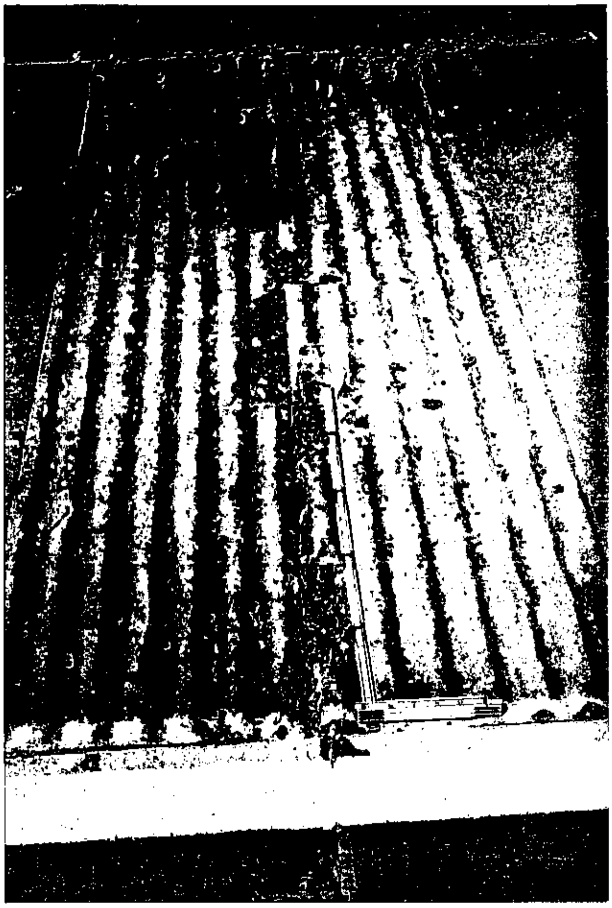


Figure 11. Rumble strips accumulate small amounts of highway debris.

Figure 12. Longitudinal crack in this test section is caused by use of shoulder as a right-turn lane by heavy vehicles. Intersection can be seen in the background.

to about one-half inch, has occurred. No appreciable differential vertical movements of the shoulders with respect to the adjacent pavement have been observed to accompany the outward movements thus far. Whether or not the apparent lack of vertical offsetting is attributable to the keyway that was used at the pavement-shoulder interface throughout the project is not known. The outward movement has not seemed to be related to the presence or absence of subbase.

Transverse cracks have occurred with varying frequency with almost all of the combinations of variables that are being examined. The crack frequency data are summarized in Table 1 on page 22. It will be noted, first of all, that a short spacing of transverse joints is particularly necessary for crack control where the plain concrete shoulders are tied to the continuously reinforced concrete pavement. Even at a spacing of only 25 feet, the occurrence of intermediate cracks is perhaps more frequent than desirable. It will be noted further that only a few transverse cracks have occurred where ties were not used between pavement and shoulder, even though the joint spacings were in the 40- to 100-ft range. The crack frequency data also indicate a favorable effect of the granular subbase on transverse cracking, but this apparent relationship does not appear to be as strong as that between joint spacing and transverse cracking.

The 1 1/2-inch depth of groove used to form the contraction joints appears to have been fully effective in causing a separation to form. Although the joints have been sealed with asphalt, seal retention has not been good.

While the opinions of various individuals who have driven the rumble strips to test their adequacy as a warning device are highly subjective, most have agreed that the four-foot strips and one-inch corrugation depths used on this project serve well, and that the spacings within the range of 60 to 100 feet are the most satisfactory.

As on the Illinois 116 project, a number of occurrences of spall, a little of which might be considered relatively severe, have been noted at the contraction joints. Most of this is at interior locations along the joints, but in a few instances is at the outside corners. This spall is of the type usually seen where incompressible materials enter open joints, although in some instances it seems here to be associated also with deleterious coarse aggregate particles. The centering of rumble-strip corrugation troughs over the joint grooves, as was done on this project, logically could be expected to encourage and accelerate the spalling action through the entrapment of incompressible particles at this critical location, but this has not been proven.

In some instances the spall at joints includes one or both of the raised corrugations adjacent to the trough over the joint. The alternative possibility that this spall is in reality mechanical damage caused by snow plowing operations rather than by incompressible material in the joint openings has been considered, but without additional evidence has not been accepted.

Early slope erosion caused by the concentration of runoff water adjacent to some of the rumble strips (Figure 13) suggests that early application of erosion control measures is desirable at these locations.

I-80

The concrete shoulders of I-80 placed in 1967 are the most recent of those that have been constructed. Some experiences with those that had been constructed previously could be drawn upon at the time these were designed, and deficiencies that had been observed could be avoided. In this experimentation, ties at the pavement-shoulder joint were used throughout. Also, a transverse joint spacing of 20 feet, which evidence from the I-74 project indicated might serve to control intermediate cracking adequately adjacent to continuously reinforced pavement, was

Figure 13. Shoulder slope erosion caused by concentration of runoff water in rumble strip grooves.

used throughout. Additionally, the rumble strips, spaced at 60-ft intervals, were placed so as not to be associated with the transverse joints in the belief that this might help to reduce spalling.

The variables on this project were the granular subbase materials and the presence and absence of granular subbase, and the presence and absence of sawing and sealing of the pavement-shoulder joint.

The only defects that have been observed thus far on this project have been a few transverse cracks and a single break that was caused by a heavy piece of construction equipment during topsoil placement operations.

The frequency of occurrence of transverse cracks up to the present time has been moderately low, as will be seen from Table 1 on page 22. While the frequency is indicated to be somewhat lower where granular subbase is present, a longer period of service is believed necessary to show whether or not a relationship between the presence or absence of subbase and crack frequency truly exists.

The pavement-shoulder joint has remained tightly closed throughout the project, except at one location where a recent inspection has shown signs of an outward movement over a 75-ft length where the bar anchors that were embedded to a 2-inch depth in the pavement concrete have been pulled from the concrete. The reason for the outward movement is not apparent at the present time.

Whether or not the sawing and the sealing of the longitudinal joint with a rubber-asphalt sealing compound has any beneficial effect remains to be determined.

The transverse joints, which on this project are not associated with rumble strips, are relatively free of spall. While the separation of the rumble-strip corrugations from the joints and the consequent lessening of the amount of available spall-causing debris, and the short joint spacings may be factors in protecting the joints of this project against spall, the higher type of seal that was applied and which is still in place may be the prime factor.

FINDINGS

Up to five years of field experience with plain portland cement concrete shoulders adjacent to conventionally reinforced portland cement concrete pavement, continuously reinforced portland cement concrete pavement, and a bituminous concrete overlay system, has shown that this type of shoulder can be constructed economically and will serve efficiently. While the period during which service has been observed has not been long in relation to the hoped-for ultimate life of portland cement concrete shoulders, the good service that they are giving thus far permits an optimistic view of the future. Whether or not such shoulders can be cost competitive with other shoulder types now in use on an initial cost basis remains to be established.

Field experience supports the following findings with respect to shoulder design details for shoulders constructed of normal paving concrete, and which serve under the environmental conditions of the experimental work.

(1) A 6-inch thickness of plain concrete is adequate.

(2) Tiebars are necessary. No. 4 deformed bars, 2' 6" long spaced on 2' 6" centers will serve adequately.

(3) A fairly close spacing of transverse joints is desirable for the control of intermediate cracking. This is particularly important when the plain concrete shoulders are tied to continuously reinforced pavement. A spacing of about 20 feet seems to be serving with reasonable effectiveness in the experimental work.

(4) The use of a good grade of joint sealant may be fairly important in the control of spall of transverse joints.

(5) The need for subbase under the concrete shoulders was not established although there was a small amount of evidence that it may help in the reduction of transverse cracking.

(6) Rumble strips consisting of 4- to 6-foot-wide groupings of corrugations, one inch in depth, and with the groupings spaced at from 60- to 100-foot intervals, serve effectively as a traffic warning measures.

IMPLEMENTATION

Good service performance can be expected from portland cement concrete shoulders designed and constructed in accordance with the findings of this project under the variety of environmental conditions covered by the research.