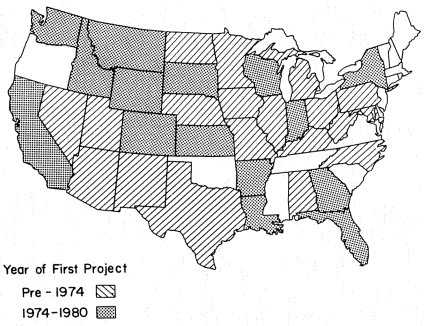
PORTLAND CEMENT CONCRETE SHOULDER PERFORMANCE IN THE UNITED STATES (1965-1980)

Charles Slavis, Portland Cement Association

During the 1960's and early 1970's several states constructed PCC shoulders to evaluate their performance and develop design standards. The earliest, and best documented of these projects include the Illinois projects of 1965, 66, 67, and 71; the Kentucky project of 1972; and the 1971 projects in Iowa, Michigan, Nebraska, Pennsylvania, and Texas. Principal variables included in these evaluation studies were thickness, pavement type (plain and reinforced), joint spacing, tie bars, and subbase. In 1973 a report, Highway Research Record 434, on the initial performance of these early pavements was prepared and presented to the Highway Research Board. The items discussed in this report included thickness, subgrade, longitudinal joint sealing, longitudinal joint key, tie bars, contraction joints, corrugated rumble strips, and reinforcement. Major conclusions of the report centered around design requirements and construction. At the time of this early study the PCC shoulders ranged in age from 0 to 7 years, with only three installations being over 2 years old. These shoulders are now a minimum of 7 years old, and the original Illinois installations have been in service for up to 15 years. The purpose of this paper is to report on the inspection and re-evaluation of these PCC shoulders. A comparison of both the conclusions of the 1973 report and an evaluation of current design practices based on 15 years of experience has been made. Recommended modifications to current design practices indicated by the current study findings are included.

Concrete shoulders were built on urban freeways in Missouri as early as 1957 (Figure 1). A period of formal experimentation with concrete shoulders began in Illinois in 1965 and was expanded nationally in 1970 by the Federal Highway Administration National Experimental and Evaluation Program (NEEP). In 1973 a report entitled "What We Have Learned to Date from Experimental Concrete Shoulder Projects," by Edwin C. Lokken, was presented to Committee A2A07 of the Highway Research Board. The report reviewed the performance of 16 projects (Table 1) located in 12 states and made recommendations on the design and construction of concrete shoulders. In 1974 the Federal Highway Administration issued Notice N5040.4, from which the following material is excerpted.

Figure 1. Portland cement concrete shoulder construction



"3. Background

a. Portland cement concrete shoulders adjacent to mainline concrete pavement have been built for evaluation over the past 12 years. Performance of the portland cement concrete shoulders built to date has been superior or equal to shoulders built with other materials and maintenance costs have been minor.

Table 1

Concrete Shoulder Construction

(1965-1973)

State	Year	Route	Length	Width	Thickness	Jointing
Ill.	1965	SR 116	5 miles	8 ft & 4 ft	6 in. P	50 ft & 100 ft
	1966	I-74	4,400 ft	10 ft & 4 ft	6 in. P	10 ft to 100 ft
	1967	I-80	1.9 miles	10 ft & 4 ft	8 in. to 6 in. P	20 ft
	1971	SR 72	7.5 miles	10 ft & 4 ft	6 in. P	20 ft
Iowa	1971	I-80	1.25 miles	10 ft & 6 ft	6 in. P	20 ft
Md.	1969		3.6 miles	3 ft to 8 ft	7 in. R	40 ft
Mich.	1971	I-69	1.5 miles	9 ft	9 in. to 6 in. P	17 ft-9 in.
Nebr.	1970-71	SR 36	10 miles	8 ft	5-1/2 in. P	15 ft, skewed
Pa.	1971	I-81	5.9 miles	10 ft & 4 ft	6 in. P	15-1/2 ft
Tex.	1971	I-30	6.9 miles	10 ft	8 in.	CRCP
Ill.	1972	E-W Tollway	69 miles	11 ft & 5 ft	8-1/2 to 6 in.	Random
Ky.	1972	US31W	3.7 miles	10 ft & 4 ft	5in., 6in., 7in.	20 ft P, 50 ft R
N.C.	1972	US 52	4.5 miles		7 in.	30 ft
Ohio	1972	I-675	4.2 miles	10 ft		
Pa.	1972	US 220	23,000 sq yd 21,000 sq yd 2,500 sq yd		6 in. P 8 in. to 6 in. P 8 in. P	15-1/2 ft " "
W.Va.	1972	I-77 I-64	30,200 sq yd 14,300 sq yd		8 in. 8 in.	20 ft "
Utah	1972-3	I-15	1 mile		9 in.	Random
N.D.	1973	I-29	14.7 miles	10 ft & 3 ft	6 in.	CRCP
Nev.	1973	I-80	1 mile			
Ala.	1973	I-59	5 miles	10 ft & 4 ft	8 in.	
Ariz.	1973	I-10		10 ft & 5 ft		Skewed and random

1 in = 25.4 mm
1 ft = 0.305 m
1 mile = 1.6 km
1 sq yd = .837 m^2

Considering original construction costs, as well as maintenance costs, portland cement concrete shoulders can now be economically justified in many areas of the country.

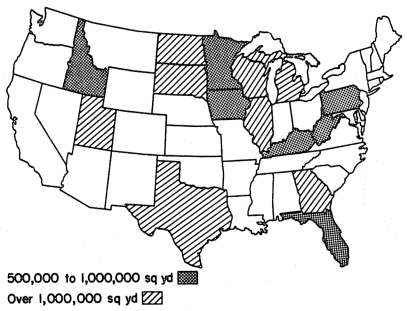
b. Performance has been such that the portland cement concrete shoulders have provided a continuously good rideable surface, resulting in added safety for traffic.

4. Action

a. Portland cement concrete shoulders adjacent to portland cement concrete mainline pavement may be approved when they are economically justified. Economic justification will require that approval of the concrete shoulders be given on a project-by-project basis."

Thirty-three states have now built concrete shoulders and 15 states (Figure 2), including 9 of the original 12 states reported by Lokken, have each built more than 500,000 sq yd of concrete shoulders (Table 2).

Figure 2. Leading states in PCC shoulder construction



The 1973 Lokken report discussed performance as it relates to the following design requirements: thickness, subbase, tiebars, keyways, longitudinal joints, contraction joints, concrete mix and reinforcement, corrugated rumble strips, and surface texture.

1980 Performance Review Scope:

The recommendations made in 1973 have been substantiated by the performance of the shoulders, as indicated by the findings of a 1980 performance review. Field inspections were made and reported of the portland cement concrete shoulder projects built in the following states in the years indicated:

Illinois, 1965
Illinois, 1966
Illinois, 1967
Maryland, 1969
Illinois, 1971
Iowa, 1971
Nebraska, 1971
Pennsylvania, 1971
Texas, 1971
Illinois, 1972
Kentucky, 1972
North Carolina, 1972
Ohio, 1972
Pennsylvania, 1972
West Virginia, 1972
Alabama, 1973
Arizona, 1973
Nevada, 1973
North Dakota, 1973

Table 2 Concrete Shoulder Awards
(In 1000 sq yd)
U.S. Only

	Total Awards to 12/31/79
Alabama	237.3
Alaska	-
Arizona	83.3
Arkansas	385.7
California	16.9
Colorado	326.0
Connecticut	-
Delaware	-
District of Columbia	-
Florida	730.9
Georgia	1,866.4
Hawaii	-
Idaho	935.3
Illinois	1,701.5
Indiana	168.4
Iowa	886.4
Kansas	-
Kentucky	848.2
Louisiana	143.0
Maine	-
Maryland	20.0
Massachusetts	-
Michigan	1,646.1
Minnesota	605.0
Mississippi	-
Missouri	179.4
Montana	163.6
Nebraska	223.9
Nevada	486.9
New Hampshire	-
New Jersey	-
New Mexico	-
New York	308.8
North Carolina	49.9
North Dakota	1,605.1
Ohio	78.0
Oklahoma	-
Oregon	-
Pennsylvania	884.1
Rhode Island	-
South Carolina	-
South Dakota	1,429.7
Tennessee	-
Texas	1,274.7
Utah	1,099.6
Vermont	-
Virginia	-
Washington	34.2
West Virginia	646.0
Wisconsin	1,101.4
Wyoming	98.4
	20,264.1

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The inspections covered the following items:

1. General appearance (Figure 3)
2. Distress (Figure 4)
   Evaluation of effect on performance
3. Longitudinal shoulder and roadway joint condition (Figure 5)
   Open
   Sealed
   Differential movement
   Faulting
4. Jointing (Figure 6)
   Seal effectiveness
   Smoothness
5. Surface (Figure 7)
   Texture
   Durability
6. Rumble strips (Figure 8)
   Effectiveness
   Wear
7. Reflective cracking (Figure 9)
   Condition of pavement in travel lanes

Figure 5. Longitudinal joint on Illinois I-80 (built-1967, thickness-tapered 8 in. to 6 in.)



Figure 3. General appearance of Nebraska SR36 (built-1971, thickness-5½ in.)

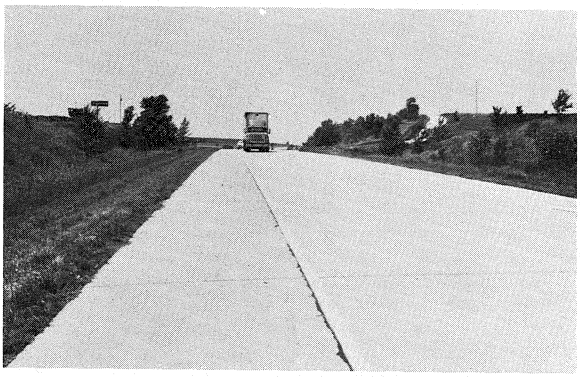


Figure 6. Transverse joint on Illinois I-80 (built-1967, thickness-tapered 8 in. to 6 in.)

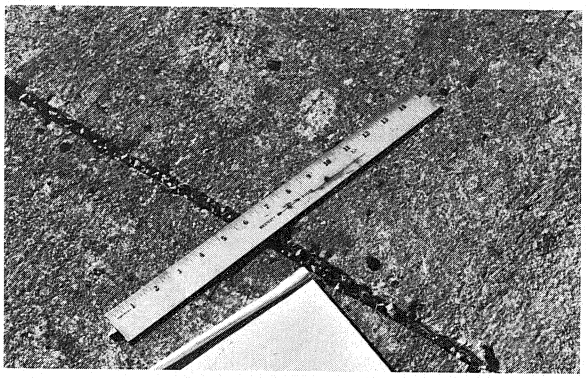


Figure 4. Distress on Illinois SR72 (built-1971, thickness-6 in.)

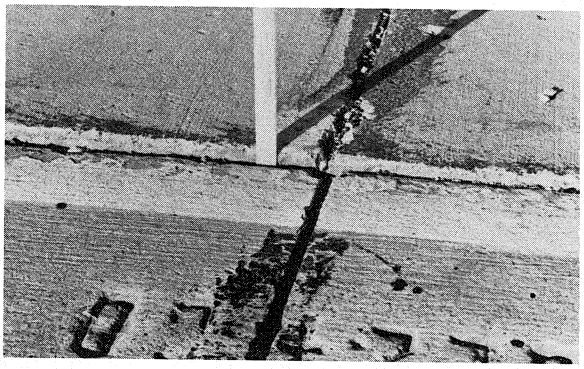


Figure 7. Surface on Kentucky US31W (built-1972, thickness-varied 5 in., 6 in., and 7 in.)

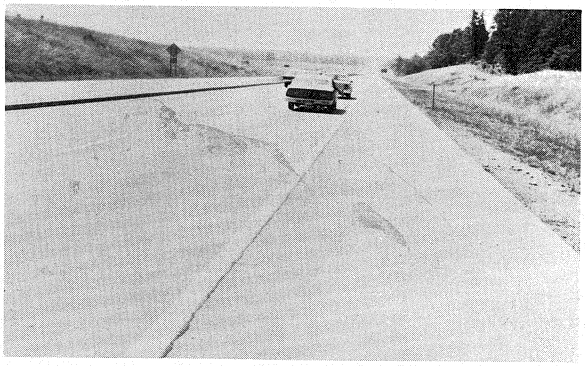


Figure 8. Rumble strips on Illinois I-80 (built-1967, thickness-tapered 8 in. to 6 in.)

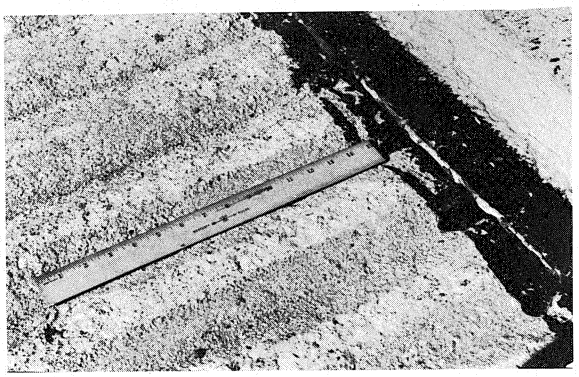


Figure 9. Reflective cracking on Illinois I-80 (built-1967, thickness-taperd 8 in. to 6 in.)

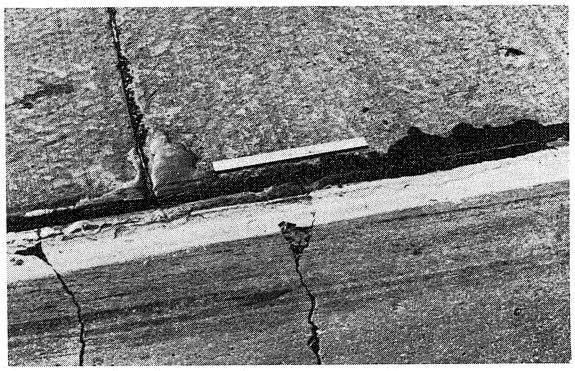


Figure 10. Shoulder on Missouri I-70 (built-1957, thickness-6 in.)

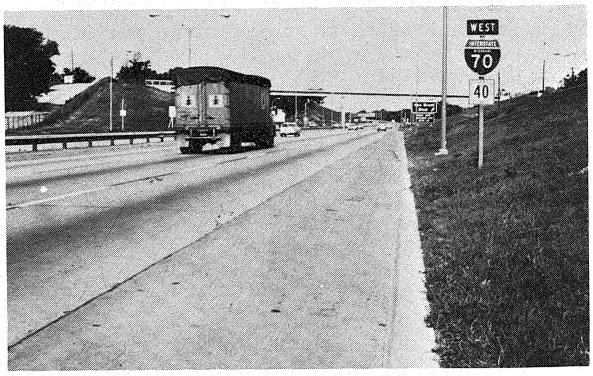
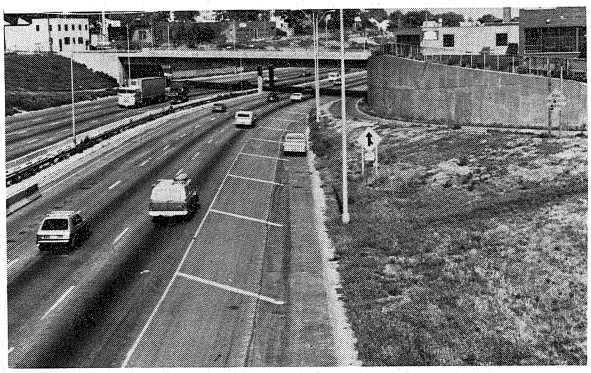


Figure 11. 1980 condition of shoulder on Missouri I-70 (built-1962, thickness-6 in.)



Figure 12. Overlay on Missouri I-70 (built-1962) thickness-6 in.)



Discussion

Although most of this discussion concerns the few examples of concrete shoulders with identified problems, the vast majority of projects have performed extremely well. By the time Illinois built its first experimental concrete shoulder on a rural highway in 1965, Missouri had been using concrete shoulders on urban freeways for over eight years and had over 17 miles of highways with concrete shoulders in service (Figure 10). The fact that much of this early shoulder has now been overlayed is due not to any failure of the shoulder (Figure 11), but to normal requirements of the mainline pavement after 20 years of service. Overlaying the mainline required covering at least part of the shoulder to meet cover and cross grade requirements (Figure 12).

The 1965 Illinois project on Route 116 is still in excellent condition after 15 years of service. Among the things demonstrated by this project were the benefits of short joint spacing (Figure 13) the potential problems of placing the joint in the corrugation (Figure 14), the value of using sealants (Figure 15) and tiebars (Figure 16), and the positive effect concrete shoulders have on holding an asphalt overlay in place (Figure 17).

The 1967 Illinois project on Route I-80 shows evidence of significant usage (Figure 18), but is still in excellent condition after 13 years. The experimental shoulders were divided into three groups: (1) tangent/grade (Figure 19), 2) tangent/level (Figure 20), and 3) curve/level (Figure 21). All pavements performed about equally well.

Figure 13. Transverse cracks between joints spaced at 100 feet on Illinois Route 116 (built-1965, thickness-6 in.)



Figure 14. Transverse joint deterioration on Illinois Route 116 (built-1965, thickness-6 in.)

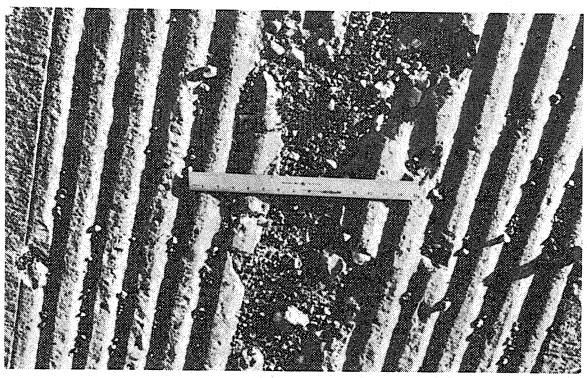


Figure 15. Seal in transverse joint on Illinois Route 116 (built-1965, thickness-6 in.)

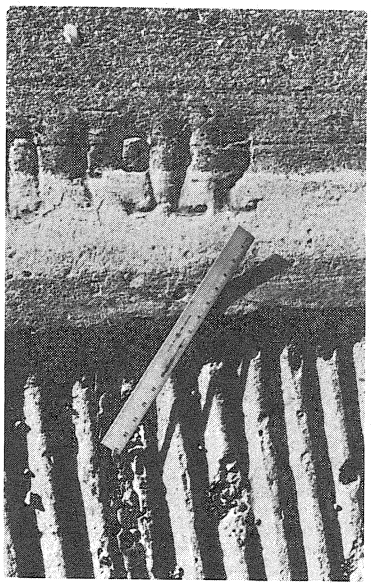


Figure 16. Longitudinal joint on Illinois Route 116 (built-1965, thickness-6 in.)

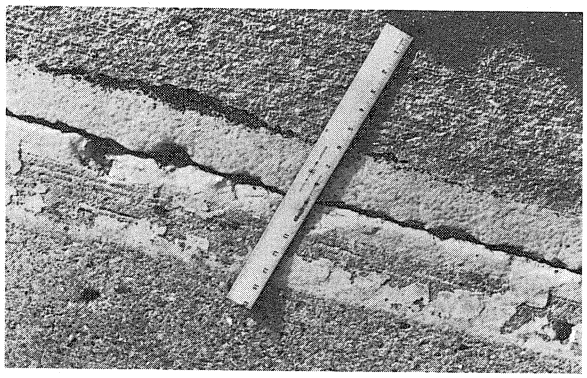


Figure 17. Add on concrete shoulder adjacent to asphalt overlay on Illinois Route 116 (built-1965, thickness-6 in.)

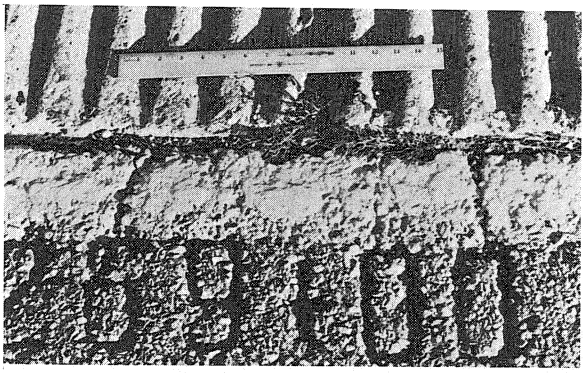


Figure 18. General appearance of Illinois I-80 (built-1967, thickness-tapered 8 in. to 6 in.)

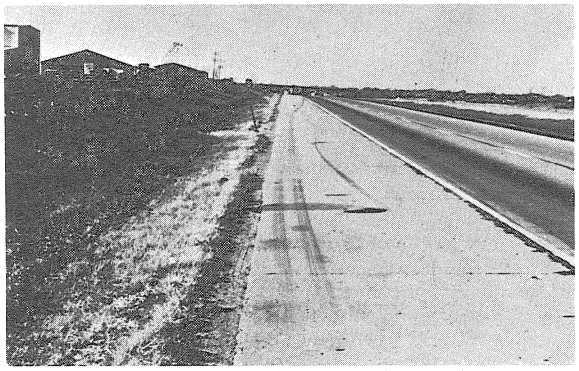


Figure 19. Longitudinal joint on Illinois I-80 (built-1967, thickness-tapered 8 in. to 6 in.)

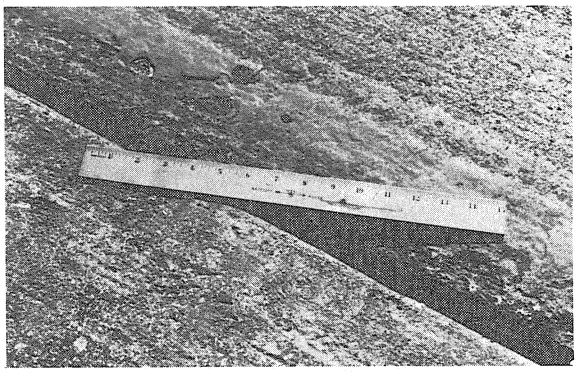


Figure 20. Longitudinal joint on Illinois I-80 (built-1967, thickness-tapered 8 in. to 6 in.)

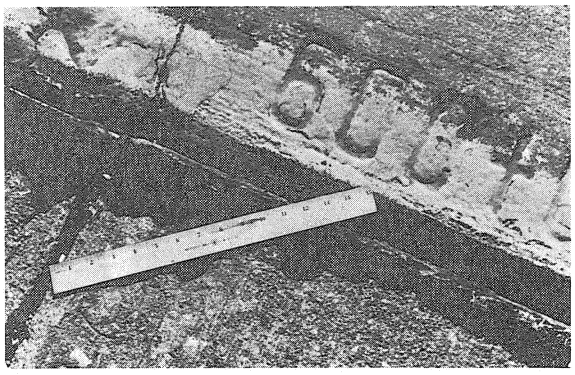
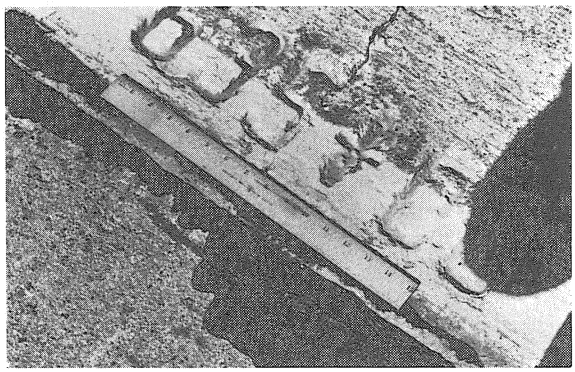


Figure 21. Longitudinal joint on Illinois I-80 (built-1967, thickness-tapered 8 in. to 6 in.)



Two other projects, the 1971 Nebraska project (Figure 22) and the 1972 Kentucky project (Figure 23) further demonstrate the excellent performance of concrete shoulders.

Figure 22. General appearance of Nebraska SR36 (built-1971, thickness-5½ in.)

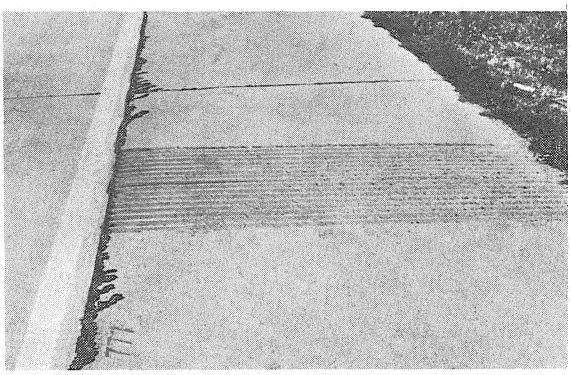
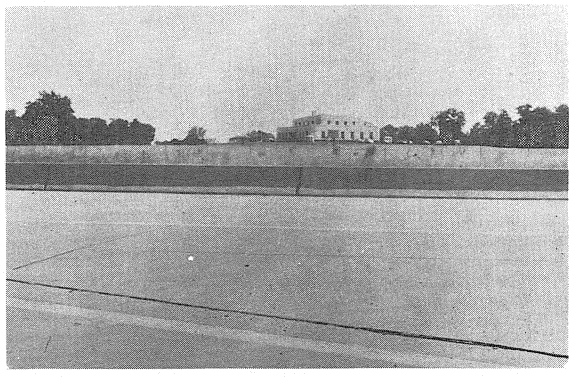


Figure 23. General appearance of Kentucky US31W (built-1972, thickness-varies 5 in., 6 in., and 7 in.)



Of all pavements inspected in the 1980 performance review only one was rated as less than excellent in general appearance (Figure 24). That one was the 1971 Illinois pavement, which was rated only "good" because of differential vertical movement of the roadway and shoulder along the longitudinal joint (Figure 25).

In general, the excellent condition of rumble strips indicated that little traffic was using the shoulders in non-urban areas, so that the need for the strips in future construction was questioned. Any assessment of the issue must consider that rumble strips act as a safety feature, warning drivers that they have left the travel lane as well as acting as a deterrent to driving on the shoulders.

Figure 24. Vertical movement of longitudinal joint on Illinois SR72 (built-1971, thickness-6 in.)



Figure 25. Typical 2 in. upward movement of shoulder on Illinois SR72 (built-1971, thickness-6 in.)



The longitudinal joint in both monolithic and add-on shoulders has proved effective in preventing reflective cracking although tiebars are used to keep the joint right (Figure 26). The 1972 North Carolina shoulder project, which is adjacent to a continuously reinforced concrete roadway pavement with a normal crack pattern, shows no sign of reflective cracking.

The only notable deficiency identified in the 1980 field investigation was the faulting in the 1971 Illinois State Highway 72 project. The failure of the tiebars in these shoulders and spalling of concrete over inadequately covered tiebars in Pennsylvania and New York projects (Figure 27) have led to the recommendation of a shoulder thickness equal to the mainline slab thickness at the longitudinal joint. This thickness will allow more reliable placement of the tiebars. The shoulder can be tapered to a 5- or 6-in. thickness at the outside edge (Figure 28).

Figure 26. Mainline crack does not cross joint into shoulder on Illinois I-80 (built-1967, thickness-tapered 8 in. to 6 in.)

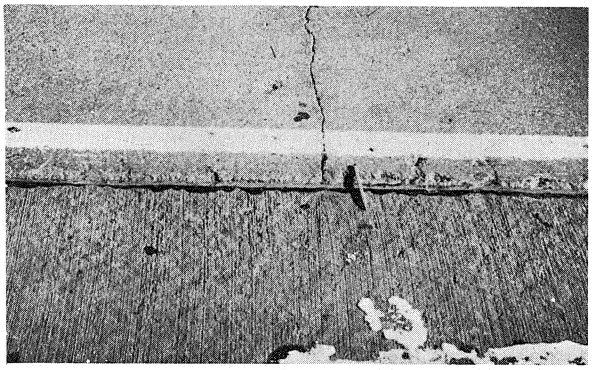


Figure 27. Tie bolt placement on New York I-88 (built-1975, thickness-6 in.)

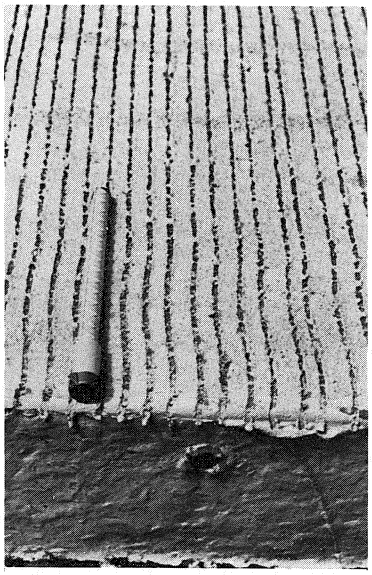
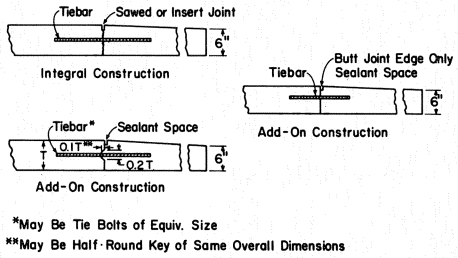


Figure 28. Typical PCC shoulder



The desirability of tiebars between mainline and shoulder pavement was established by experimental projects prior to 1973. Tiebars should be specified in accordance with standard design practices for portland cement concrete pavements. Design formulas are available for tiebar size, length, and spacing. Poor performance of properly designed tiebars and tiebolts has been attributed to improper vertical placement.

1980 Review Versus 1973 Report

Thickness

The 1973 report recommended a 6 in. shoulder slab with an alternate of a tapered slab varying from roadway pavement depth at the longitudinal joint to 6 in. at the outside edge of the shoulder. Several concrete shoulder projects, both new projects and those included in the 1973 study, have shown distress resulting from improperly placed tiebars in 6 in. shoulders. It is impossible to place the tiebars at middepth in both 6 in. shoulders and thicker roadway pavements. In some cases the tiebars have been installed above middepth.

It is recommended that the shoulder thickness be equal to the mainline slab at the longitudinal joint.

Subbase

Concrete shoulders were placed directly on in-place material on early projects constructed in Illinois (Figure 29). The excellent condition of these shoulders after more than 10 years of service confirms that shoulders are not subject to accelerated deterioration when constructed without a subbase. This is true of shoulders not subject to repeated traffic loadings. However, where the shoulders will carry traffic either temporarily as part of stage construction or at some future date as part of a widening to meet future traffic demands, the need for subbase should be considered in their design.

Tiebars

Tiebars or tiebolts are deformed steel bars. They are used across joints in concrete pavement (Figure 30) where it is necessary to hold the faces of the slab in firm contact. Tiebars alone are not designed to act as load-transfer devices. Load transfer across a joint having tiebars or bolts is provided by aggregate interlock or a keyway. Tiebars are designed to overcome the resistance of subgrade or subbase to horizontal slab movement when the pavement is contracting.

Figure 29. Surface and joint condition on Illinois I-80 (built-1967, thickness-tapered i in. to 6 in.)

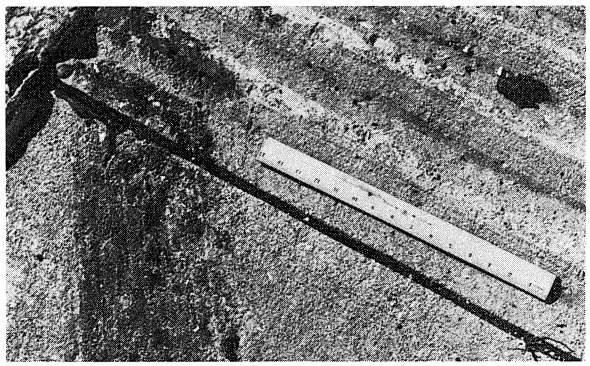
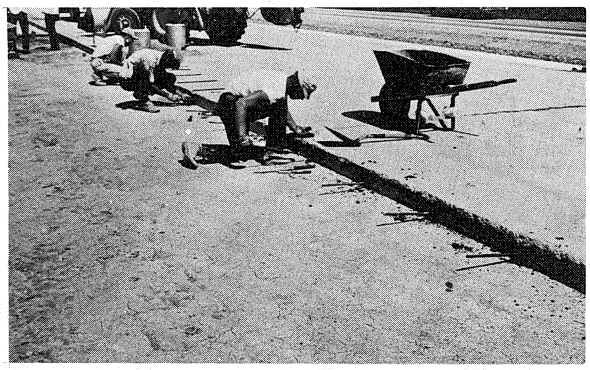


Figure 30. Tie bar placement on Illinois Route 116 (built-1965, thickness-6 in.)



Keyway

New data on shoulder performance confirm earlier recommendations that a keyway is desirable because it maximizes the support from the concrete shoulder to the roadway pavement. It does not significantly improve the performance of the shoulder itself. The vertical location of the keyway is important. An example of this can be seen in the distress of the roadway pavement along the keyed shoulder of the 1971 Iowa project (Figure 31). This project consists of a 6 in. unreinforced portland cement concrete shoulder with a standard keyway design. The outside edge of the roadway pavement is designed to be 2.4 in. thick over the key. Construction tolerances can reduce this to less than 2 in. and make the roadway susceptible to failure along the keyway. Shoulder thickness equal to roadway thickness at the longitudinal joint, better accommodates the construction tolerances and provides a stronger keyway design.

Longitudinal Joints

Performance reports based on two to seven years of data were inconclusive about the need for sealing longitudinal joints. Data from the 1980 review, however, substantiate the need for sealing longitudinal joints and maintaining the seal to ensure proper drainage to and across the shoulder and prevent pumping along the edge of the mainline pavement.

Contraction Joints, Concrete Mix and Reinforcement

The recommendations in the 1973 report for short joint spacing (10 to 20 ft), plain concrete without reinforcement, and a normal paving concrete mix for shoulders have proved consistent with performance data from subsequent years.

Corrugated Rumble Strip

The use of corrugated rumble strips has proved effective in delineating the shoulder from the roadway. The use of 1-in.-deep grooves in a series 4 to 6 ft wide, series spaced between 60 and 100 ft apart (depending on traffic, speed, and degree of urbanization), is standard. Problems that have occurred are associated with construction practices that leave the top of the corrugation above the grade of the shoulder. In northern climates, these corrugations (Figure 32) can be damaged by snowplow blades and are themselves capable of damaging the blades.

Placement of contraction joints in the corrugations is not recommended. The corrugations trap dirt and sand and increase the probability of joint failure.

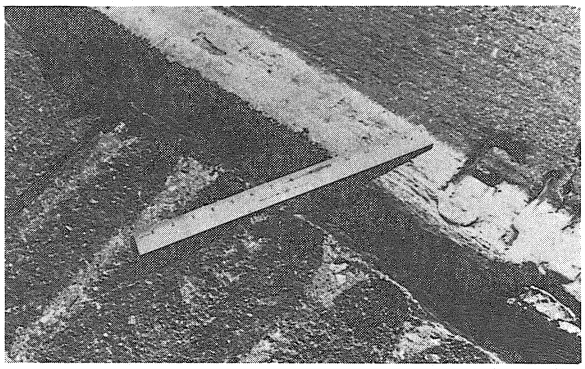
Surface Texture and Tolerance

The use of a corrugated rumble strip does not eliminate the desirability of texturing the shoulder surface to differentiate it from the roadway. Since the rideability factor is not critical in shoulder design, surface deviations of 1/4 in. to 3/8 in. per 10 ft, as identified in the 1973 report, are still adequate.

Figure 31. Longitudinal joint on Iowa I-80 (built-1972, thickness-6 in.)



Figure 32. Rumble strip on Illinois I-80 (built-1967, thickness-tapered 8 in. to 6 in.)



Summary

Concrete shoulders have now provided over 20 years of service. Several installations built specifically as research projects have accumulated up to 15 years of service. They have performed to the satisfaction of the Federal Highway Administration and received approval for normal construction funding. Concrete shoulders have now been constructed (Figure 2) in 33 states and have become a standard for use with concrete pavement in 12 states.

Few examples of distress have occurred in the more than 2500 miles of concrete shoulders built in the last 15 years. Changing the standard shoulder design (Figure 28) to provide full roadway thickness at the longitudinal joint should eliminate the kinds of distress that have been experienced.

References

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