innovations in design and construction of concrete pavement for illinois tollway extension

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Based on recommendations of a 1970 engineering report, a 68.9-mile, fully controlled-access, dual-lane, 70-mph facility was proposed that would meet or exceed Interstate standards. The goals of the project, an extension of the Illinois East-West Tollway, were that the facility be of an improved design that could be constructed at a low cost and yet make use of readily available construction materials. To meet these goals, the design made allowances for (a) soil conditions along the corridor with special attention to high groundwater level and frost susceptibility characteristics, (b) ease and speed of construction, (c) safety, (d) riding comfort, and (e) expected performance and ease of maintenance. Four pavement types were examined: 10-in. reinforced pavement on permeable subbase, 8-in. continuously reinforced concrete pavement, flexible pavement, and the adopted design consisting of a 10-in. unreinforced concrete pavement on a 4-in. plain concrete base. When contracts were let, however, the contractors proposed an alternate of 14 in. of unreinforced pavement. This proved to be satisfactory for roadway traffic and provided easy maintenance and speedy construction. To date, only performance and need for maintenance remain to be tested. Soil moisture and temperature gauges have been installed at six critical soil locations to monitor long-term soil moisture-density conditions and to study frost action. As segments of the extension were completed, profilometer records were obtained to be used with future maintenance records and ridability determinations.

•As a result of enabling legislation passed in 1953, which created the Illinois State Toll Highway Commission, a 187-mile-long toll highway facility was opened to traffic in December 1958. The Commission (later changed to an Authority) was charged with incorporating the benefits of advanced engineering skill, design, experience, and safety factors into a system of toll highways to eliminate existing traffic hazards so as to prevent automotive injuries and fatalities. Additional routes were studied and recommended for incorporation into the initial phase; however, traffic reviews indicated that sufficient revenues would not be generated to justify their construction as part of the original system.

In 1969, the Toll Authority authorized an engineering report and a traffic and earning report for a corridor from Aurora to Sterling-Rock Falls. These studies indicated the generation of sufficient revenues to sustain a bond issue.

The 68.9-mile extension of the East-West Tollway (Ill-56) begins at the western terminal point of the existing east-west route near Aurora, extends in a westerly direction, runs south of the communities of Sycamore, DeKalb, Rochelle, and Dixon, and terminates about 3 miles east of the cities of Sterling and Rock Falls (Fig. 1).

The roadway proposed in the engineering report is a fully controlled-access, four-lane, 70-mph highway that meets or exceeds Interstate standards. Local road overpasses have horizontal and vertical clearances, which meet federal standards for highways and drainage structures. Both pipe and box culverts and bridges have been designed to accommodate the runoff of a 50-year design storm. The pavement for the two-lane roadway will be 25 feet wide and designed for heavy vehicle traffic.

DESIGN CONSIDERATIONS

As consultants to the Illinois State Toll Highway Authority, we have had the opportunity to observe with a critical eye the performance of a facility that was constructed to design criteria materially different from those adopted for the extension. The performance of the original facility during the first 12 years of service under extremely heavy traffic has been outstanding.

Improvement of the roadway section, reduction of costs, and the use of readily available construction materials compatible with soils conditions prevailing in the area were our goals.

Development of Design Study Program

To achieve these three goals required that any effort to hold costs down take place in three categories of construction expenditures: earthwork, pavement, and structures.

Cost information was carefully analyzed, and adjustments were made for the variables in the anticipated construction schedule, special processing of aggregates, anticipated increases in material and labor costs, and lack of readily available local materials.

The serviceability index method of analysis was not used although records, when available, were reviewed and considered. The final pavement section was arrived at by using data from the Asphalt Institute, the Portland Cement Association, and the Continuously Reinforced Pavement Group along with reports from the AASHO Road Test and the Highway Research Board on pavement performance.

Traffic Considerations

The East-West Tollway extension is within a corridor now served by outmoded highways, US-30 and Ill-64, -72, and -38. The cities of Sycamore, DeKalb, Rochelle, Dixon, Rock Falls, and Sterling have demonstrated above-average growth, and this increased population must rely on an antiquated highway system that cannot be substantially improved for a number of years.

In 1969, Wilbur Smith and Associates made a traffic study and prepared a report containing projections of traffic volumes, vehicle classifications, and revenue for the proposed facility (6). Vehicle classification counts were made for a 24-hour period, and origin and destination surveys were taken at five stations that made up the major traffic screenline.

Passenger cars were, by far, the largest vehicle category recorded at each of the survey locations. Overall, passenger cars and two-axle, four-tire trucks accounted for 83.9 percent of the total traffic passing through the survey stations; large commercial vehicles accounted for the remaining 16.1 percent. A breakdown of the five truck or commercial categories indicated that five-axle vehicles accounted for 53 percent of the total truck traffic through a survey station. Two-axle, six-tire vehicles made up an additional 20.4 percent, followed by four-axle vehicles with 14.7 percent and three-axle vehicles with 11.9 percent.

Soils

The proposed alignment for the East-West Tollway extension passes through an area consisting principally of Pleistocene glacial material with minor amounts of preglacial material. These soils have a wide range of physical properties depending on the nature of their deposition and the length of time they have been acted on by the weathering processes.

The materials found in the upper soils strata are mainly A-4, A-6, and A-7 soil types derived from the Sterling, Argyle, Esmond, Lee Center, and Tiskilwa glacial tills (Table 1). These materials are silty and highly frost susceptible. Only in the eastern and western portions of the project are underlying deposits of sand and gravel found. Throughout the central portion of the corridor, water tables are high and drainage is relatively poor. Spangler and Pien (4), investigating the frost susceptibility of glacial soils in Illinois and Iowa, consistently observed a capillary rise of 40 in. or more, a 45 percent strength reduction during thaw, and at least 2 in. of heave when frozen.

These soils conditions cause wet, unstable cuts both at grade and in the backslopes, excessive settlement of embankments, and below optimum compaction in embankments.

TYPICAL SECTION STUDIES

Inasmuch as pavement, subbase, and shoulders are closely allied, studies of typical sections should include all three items. It was decided that each typical pavement section to be studied would be designed for soil conditions generally prevailing within the route corridor and that each design would be as structurally equal and as capable of handling the load repetitions expected for the facility as possible.

Given structural equality and equal life expectancy with respect to load repetitions, factors of importance are

1. Expected performance and maintenance considerations,
2. Availability of materials,
3. Initial cost,
4. Speed and ease of construction,
5. Safety, and
6. Riding comfort.

It was our contention that all the types studied, if constructed in strict accordance with specifications, would provide acceptable standards of safety and comfort; thus the choice was narrowed to the first four factors. Because of the interrelationship of these factors, it was not possible to make clear separations between them in our studies, so, for each typical pavement section studied, all were considered.

Eight separate pavement designs were considered in the study. However, because of various combinations, these fell into four types as follows:

1. Ten-inch reinforced concrete placed on a 4-in. granular subbase underlain with 6 in. of select material. The shoulders were 3-in. bituminous concrete. (This is the typical section used on the original facility except for a reduction in thickness of the select material layer.) This design was also studied with a 4-in. stabilized subbase.

2. Eight-inch continuously reinforced concrete on 4-in. stabilized bituminous subbase and also on 4-in. granular subbase underlain with 6 in. of select material. Various shoulder widths were studied.

3. Flexible pavement 22 in. thick consisting of 1½-in. surface course, 2-in. binder course, and 5½ in. of deep strength asphaltic concrete on 13 in. of granular subbase, stone, and select material. The shoulders were 7-in. bituminous aggregate mix.

Figure 1. Location map.

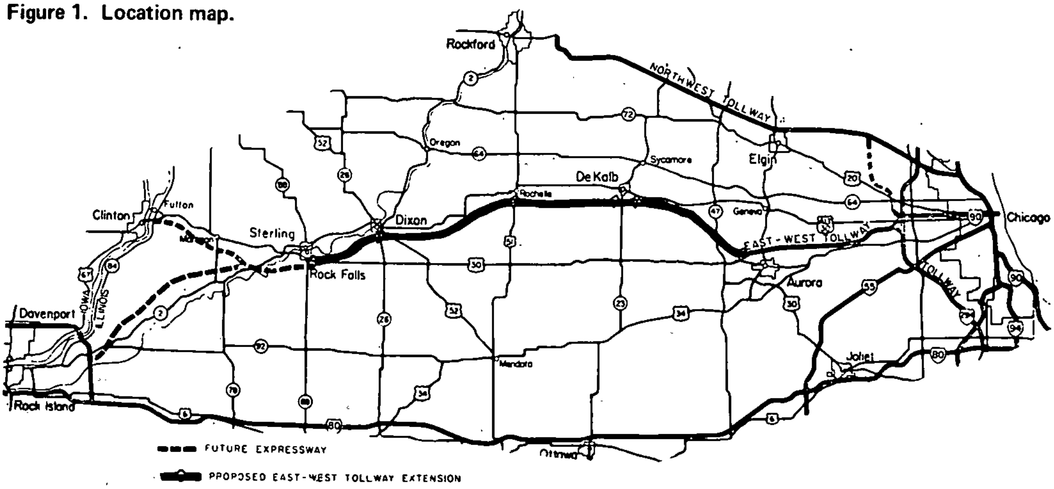
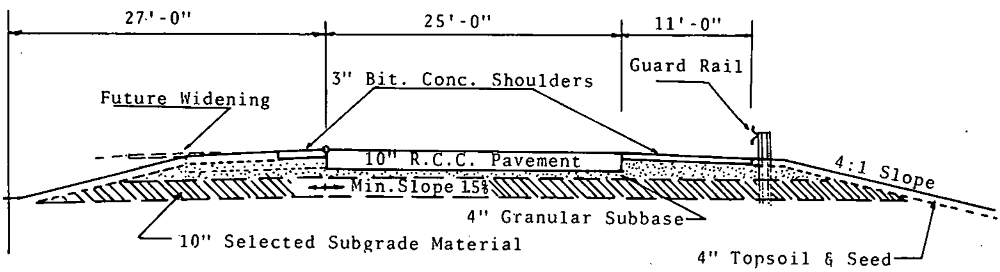


Table 1. Generalized geological and physical soils properties.

Time Stratigraphy	Rock Stratigraphy	Description
Quartenary period		
Holocene epoch	Topsoil	Black to brown clay silt
Pleistocene epoch		
Wisconsinan stage	Tiskilwa till	Pinkish to brown clay silt (A-4 to A-6)
	Lee center till and esmond till	Yellowish brown to gray silty clay (A-7-6 to A-6)
	Argyle till	Pinkish brown to reddish gray silty clay (A-6)
Illinoian stage	Sterling till	Yellowish brown to gray silty clay (A-7-6 to A-6), underlain with outwash sands and gravel
Ordovician period		
Galena	Undifferentiated	Brown to buff sandy dolomite, cherty and fractured
Ancell	St. Peter	White fine sand (A-2 or A-3), unconsolidated and dry
Cambrian period	Franconia	Greenish brown silty sand (A-4 to A-6), unconsolidated and dry

Figure 2. Typical roadway section.



4. Ten-inch plain concrete roadway slab on a 4-in. portland cement concrete subbase. Various shoulder combinations were studied.

Ten-Inch Reinforced Concrete

As background for the changes we recommended, we first examined a typical section of the original facility. The 10-in. reinforced concrete slab, 25 feet wide (37 feet for three-lane construction), was placed on a permeable, frost-free, granular subbase 4 in. thick. Under the subbase was a 10-in.-thick layer of select material (Fig. 2). Both the select material and the granular subbase extended completely through the section, showing through in the median ditch and in the embankment slope.

The subbase was then built up and compacted to form the base material under 3-in.-thick bituminous concrete shoulders. The 10-in. reinforced concrete pavement on a permeable subbase as used on the existing Tollway has served well; most problems can be traced to local deficiencies. Based on service, a duplication of this design for the extension could be considered an excellent investment. However, a comparatively large amount of granular subbase was required, and, though aggregate sources were available, cost analysis indicated that the special processing required to render the subbase material permeable by removal of all but 3 percent of the materials passing a No. 200 sieve made the cost of an already expensive material almost prohibitive. The estimated cost of this section was $16.05 per square yard.

Eight-Inch Continuously Reinforced Concrete

Eight inches of continuously reinforced concrete on a 4-in. stabilized bituminous subbase placed on 4-in. granular subbase and 6 in. of select material were estimated to cost $11.04 per square yard.

Much of the continuously reinforced pavement examined was comparatively new and in relatively good condition. Cracking at close intervals is a characteristic of this pavement type, but the cracks remain tight because of the continuous reinforcing between anchorages. Some of this type of pavement was cracked at intervals of less than 2 feet. With this condition prevailing, it was difficult to understand how future large maintenance costs were to be avoided. If replacement of entire sections of pavement becomes necessary, the continuity of the reinforcing would be broken for the entire stretch of pavement between a set of anchorages, and the continuity advantage would be lost unless special costly methods of concrete removal were employed.

To be economically competitive, continuously reinforced pavement must, of necessity, comprise a thinner slab than other types. Inasmuch as continuous reinforcing must be meticulously placed, it is evident that progress in constructing this type of pavement is slower than in other sections. When interest costs on outstanding bonds amount to $25,000 per day, time is important.

Flexible Pavement

Flexible pavement has not been widely accepted in Illinois. Even though the estimated cost of the flexible pavement section was the least of all types studied, attempting to supply the large quantities of aggregate within the time permitted by the tight construction schedule may have caused a production problem. The 22-in.-thick study section was estimated to cost $9.16 per square yard.

Bituminous aggregate mix (BAM) is used extensively by the Illinois State Division of Highways as subbase under continuously reinforced pavement. However, its cost in Illinois is more than twice the cost of similar material in neighboring states. BAM used in shoulder construction has proved to be less than satisfactory. Important in our decision to reject the use of bituminous materials as subbase in main-line construction was our attempt to accelerate construction by eliminating the need for one more major subcontractor with related bituminous paving equipment.

Final Adopted Design

The fourth section investigated in light of the six performance criteria was 10-in. unreinforced concrete on a 4-in. PCC subbase. This section offered possible solutions to inherent problems with the soil conditions prevailing along the corridor; and, because concrete has properties of rigidity and beam strength that would distribute wheel loads over larger areas of the subgrade, it tends to keep deflections small and unit pressures on the subgrade low. This property of concrete is important during periods of reduced subgrade support, which accompanies subgrade thawing.

Traffic data from Wilbur Smith and Associates and soils information used with the Portland Cement Association design recommendations (3) suggested a 10-in. unreinforced slab. Comparison with similar pavements on the AASHO Road Test indicated excellent serviceability for slabs of 9½-in. unreinforced concrete on both granular subbase and subgrade with no base material. The original 10-in. reinforced slab constructed on 4 in. of free-draining base course has performed well for over 12 years, thus substantiating the adequacy of a 10-in. slab. The next problem was the selection of the subbase and base course.

Both bituminous- and cement-stabilized subbases were investigated. A cement-stabilized subbase was not compatible with the existing soil conditions, and the use of bituminous-stabilized material appeared prohibitively costly. The use of granular material also appeared costly because extensive processing of local materials would be required to supply the large quantities of free-draining subbase. A 4-in. PCC rigid base was selected. Study of paving literature, field examination of old concrete, and the results of the AASHO Road Test indicated that such a subbase could be used successfully with the 10-in. unreinforced pavement section (Fig. 3).

The section was completed with plain concrete shoulders that had a nominal thickness of 8½ in. and that were tied to the pavement slab. They were designed to be poured directly on the subgrade. Outside and inside shoulders are 11 and 5 feet wide respectively, and each has corrugations at 100-ft intervals to provide a rumble strip for safety purposes.

The resultant 10-in. unreinforced concrete pavement on a 4-in. PCC base was estimated to cost $9.25 per square yard. Actual award unit prices varied from $8.80 to $10.50 per square yard.

With the pavement section complete, parameters for joint spacing, control of warping and creep, and load transfer at joints had to be established within the constraints of cost, maintenance, and riding comfort.

The design specifications required that allowable flexural stresses be maintained within 50 percent of the ultimate strength of the concrete, whether tensile or compressive. This was possible even with a reduction in cross section of the slab resulting from sawed joints equaling one-fourth of the slab depth. Transverse warping was minimized by use of a longitudinal joint, usually sawed and equipped with load transfer bars. Such a joint was used in the recommended pavement.

Visual inspection of the Illinois Tollway pavement indicated the presence, almost universally, of two approximately equidistant cracks between each 50-ft sawed joint. They were usually relatively tight, but, as they open, sealing is required that, in the case of irregular cracking, is difficult because of the need for routing or grooving. Design requirements, visual inspection data from the Tollway and the AASHO Road Test section and experience in California with short joint spacing of plain concrete slabs resulted in adoption of a random joint spacing averaging 15 feet. Skewing the joints and varying the spacing prevent simultaneous wheel loading and eliminate the harmonic effect (Fig. 4).

Dowel cages at each joint for load transfer would all but destroy any economy inherent in the design. Without expansion joints and with short slab length, joints can open only slightly, and load transfer will be maintained by aggregate interlock. Computations indicated a thermal shrinkage of about 0.05 in. in a slab length of 15 feet due to a 60-deg drop from placement temperature. This feature of minimum shrinkage at each joint also minimizes the opportunity for infiltration of foreign material into the joint.

Pavement creep was provided for by using 4-in.-wide slots across and entirely through the pavement near bridge structures and by filling them with a compressible polyurethane material. To compensate for loss of aggregate interlock near these slots, load transfer bars were used in the adjacent 13 transverse joints.

CONSTRUCTION

With the pavement section set as a 10-in. unreinforced concrete slab on a 4-in. PCC subbase, construction contracts were let to three prime contractors. Every effort was made in the field to control soils problems and to ensure timely performance of the contract.

Inasmuch as the ultimate performance of a pavement section depends on control of soils conditions in the subgrade, many problems were eliminated by using the following methods:

1. When water was encountered, the side ditch grades were lowered (where this was impractical, subdrainage was provided);
2. Drainage under the inner edge of the outside shoulder was provided where water is most likely to collect, e.g., in sag vertical curves;
3. Frost-susceptible soils at grade were removed or replaced; and
4. Moisture and density were carefully controlled in both embankments and cut sections.

With tolls as the only source of revenue, timely performance of the contract was a prime concern of the Toll Authority. Therefore, when the prime contractors proposed a change in construction of the pavement section in an effort to speed up the project, prompt action resulted.

Field Construction

With the roadway grading under way, each of the three prime contractors requested that the 4-in. PCC subbase be incorporated into the pavement slab, making the section 14 in. thick, and that the entire unit be slip-formed.

This request prompted a review of the pavement section to determine how these changes would affect performance under traffic conditions. Generally, automobile traffic has little detrimental effect on a pavement section; however, the estimated 16 percent or more of heavy five-axle wheel loads and special heavy loads allowed under permits cause most of the destruction of pavements at thaw. Because the addition of 4 in. of unreinforced concrete would make the flexural strength of the slab almost twice that of the 10-in. section and with special care being taken with soils conditions to provide a stable subgrade, the acceptance of the proposal depended on the ability of the contractors to slip-form the 14-in. section. Agreement to use the 14-in. section resulted in a reduction in cost to the Toll Authority. This brought the cost for the roadway pavement section into a range of $8.40 to $10.10 per square yard.

Two contractors proposed to construct the 14-in. pavement section according to alternate 1 (Fig. 5). This scheme required that the 14-in., 25-ft-wide pavement unit be placed first, with the shoulder subgrade compacted and paved later. One contractor proposed to pave the entire 41-ft-wide roadway section, including shoulders, with a single pass according to alternate 2 (Fig. 6).

Profile Control and Fine Grading

The final grade line of the pavement and the riding quality depend on the care exercised in constructing and finishing the subgrade, especially when no subbase material is used. How well the fine grading is accomplished and profile control is maintained determines the ridability of the pavement.

For alternate 1, the contractors used a standard 28-ft Autograde base trimmer controlled electronically by string line.

Both vertical and horizontal controls were maintained by electronic sensing units that adjusted the trimming action of the machine to the desired grade. The subgrade was left about 0.30 in. high, and excess material trimmed from the main line was used to construct the base for the shoulders. After completion of main-line paving, shoulders were compacted and trimmed to grade by an adjustable width unit that could be varied from 5 to 11 feet wide. For alternate 2, in which the pavement and shoulders will be constructed 41 feet wide, the trimming and shoulder shaping will be performed by using three trimming units so that the shoulders can be placed, rolled, and trimmed to form the raised section.

After proofrolling the subgrade, the 28-ft trimmer unit was able to prepare about 3,000 linear feet of base per day. Usually, the Autograder took two passes, with the subgrade being sealed after the last pass of the trimmer with a steel-wheeled roller.

Main-Line Paving

Because paving alternate 1 and alternate 2 would differ little (requiring only equipment modifications), the 41-ft-wide technique is described.

The basic 41-ft paving train consists of two 41-ft-wide double-bucket side-loaded spreaders. This is followed by a specially adapted 41-ft-wide paving machine to vibrate, meter, and finish the pavement and shoulders. This unit will place 1.41 cubic yards of concrete per linear foot of roadway, as compared with the 25-ft-wide unit that places 1.06 cubic yards per linear foot. During the pavement placement, tie rods and plastic polyethylene tape are inserted at the centerline and shoulders.

Horizontal control for the paver is maintained by a magnetic sensor reading a metal banding strip placed on the subgrade. Vertical control is maintained by a ski on the subgrade for tangent sections and dual wires in the curved and superelevated sections. Because of the extra paving train width, haul roads are provided by a cut in the outside embankment slope and the median ditch, which will be left full and then finished later.

A 41-ft-wide curing and covering machine trails the slip-form paving unit. This unit includes a rumble strip maker for the shoulder area. By scraping and vibration, a 6-ft-wide safety rumble strip is formed at 100-ft centers. With the 25-ft-wide unit, the rumble strips were formed by hand inasmuch as several attempts to use a machine met with failure.

The final step is to use two dual 41-ft, skewed, diesel-powered sawing units to cut the dummy joints. The skewed joint angle is maintained electronically by sensing the pavement edge. The unit performs the 41-ft-wide 3.0-in.-deep cut in one pass by using tandom saws. Together, both units should encounter little difficulty in sawing the pave-

Figure 3. Original design for Tollway extension.

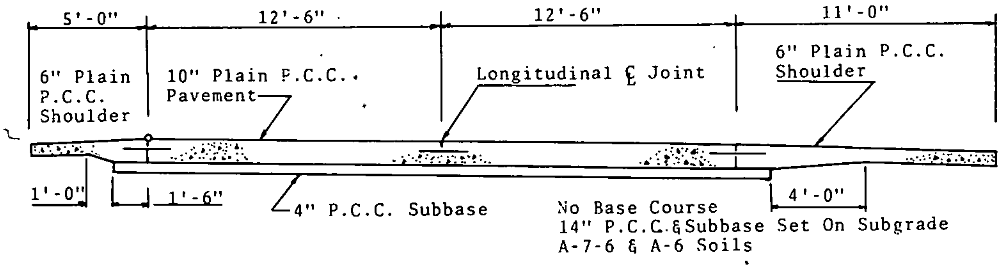


Figure 4. Typical random joint spacing.

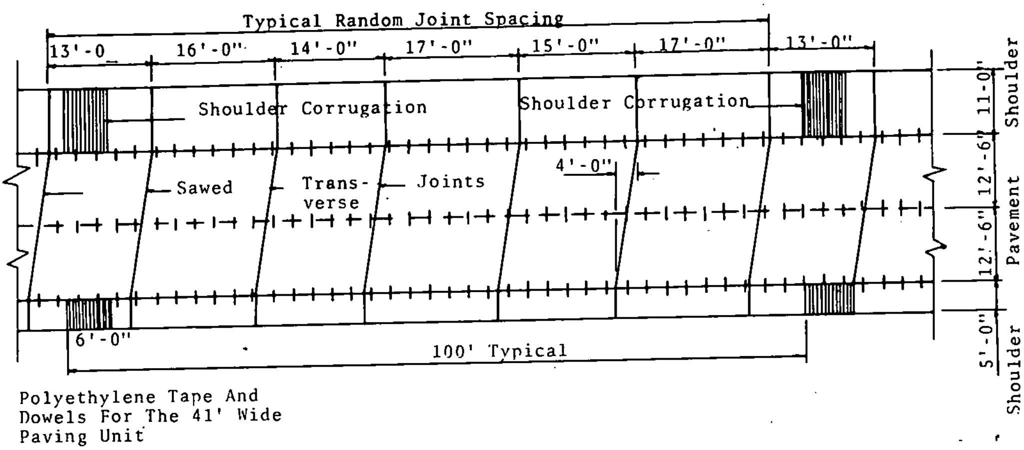


Figure 5. Paving alternate 1.

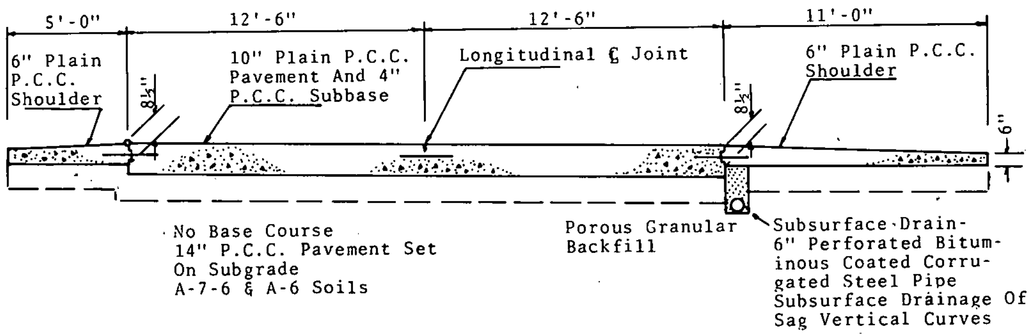
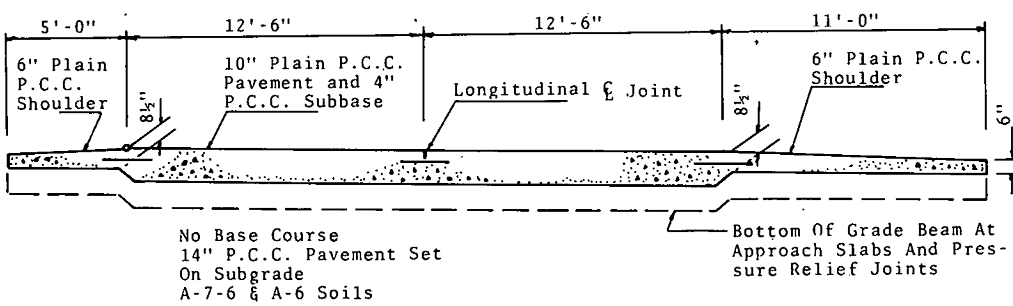


Figure 6. Paving alternate 2.



ment joints in sufficient time to prevent the formation of shrinkage cracks. In the 41-ft-wide section, the dummy joints are skew-cut the full pavement and shoulder width, whereas, in the narrower section, only the 25-ft roadway pavement dummy joints were skewed. The shoulder joints were formed perpendicular to the pavement edge.

Keyway Formation

Under alternate 2, no keyway is required, but, for alternate 1, in which the main-line pavement section is 25 feet wide, a dual keyway was required to tie the shoulders and roadway together. Because the roadway section is 14 in. thick, edge slump is more probable than with thinner sections. To alleviate this problem by providing a partial form, an automatic keyway forming and installing unit was built by the contractors. The keyway was formed from a 3⅝-in.-wide, 20 gauge strip steel. The unit was added to the paver on a separate wing and contained shaping dies, a tie rod hole punch, a unit to punch holes every 5 in. to aid in holding the keyway in place, and an insertion roller. The steel strip was spliced by brazing or crimping. Each roll weighed 400 lb and contained about 2,200 feet of keyway.

Two major problems were encountered. Because the unit was on a separate wing, the keyway tended to ride up or down on the roadway slab. By rigidly attaching the unit to the paving machine, this problem was overcome. The second problem, which was eventually solved, was with the tie rods. These had to be installed by hand, and, if they failed to clear the insertion roller, the keyway strip and a section of the pavement were damaged.

CONCLUSION

To meet the goals of an improved pavement design that could be constructed at a low cost and with the readily available construction materials, special considerations were given to

1. Soil conditions, especially the high water table and frost susceptibility,
2. Ease and speed of construction,
3. Safety,
4. Riding comfort, and
5. Expected performance and maintenance considerations.

Of the four pavement types examined, a 10-in.-thick unreinforced concrete slab on a 4-in.-thick concrete subbase met these goals most nearly. However, when contracts were let, the contractors proposed a 14-in. unreinforced pavement. This proposal proved to be satisfactory for traffic and provided ease and speed of construction.

To date, only the performance and maintenance considerations remain to be tested, and to thoroughly test these criteria requires time and traffic.

In an effort to provide long-term evaluation of the 14-in. section, soils moisture temperature gauges have been installed at six critical locations to monitor long-term moisture-density conditions and to study frost action. As the various segments of the East-West Tollway extension were completed, profilometer records were obtained, and an initial serviceability index was determined for comparison with maintenance records and future ridability determinations.

ACKNOWLEDGMENT

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