

New Concepts in Prestressed Concrete Pavement

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At least three potential benefits of prestressed concrete pavement (PCP) compared with conventional concrete pavement are indicated by previous research and testing. These include (a) more efficient use of construction materials; (b) fewer required joints and less probability of cracking; and (c) reduced overlay thickness that not only reduces the required quantity of concrete, but also would be advantageous where clearance is a problem under bridges, for example. Although several prestressed pavements have been constructed in the United States, the authors believe that the approaches used in these projects do not use the full potential of PCP. Other concepts should be explored that could more fully realize the benefits of PCP in highway construction. Seven new PCP concepts are introduced and developed in this paper: (a) central stressing of slip-formed pavement; (b) precast joint panels and slip-formed pavement; (c) precast joint panels, central stressing panels, and slip-formed pavement; (d) composite prestressed concrete pavement Type I (CPCPI); (e) composite prestressed pavement Type II (CPCPII); and (f) continuous composite concrete pavement (CCCP). The introduction to each new concept includes descriptions of its most important features and the principles involved. In addition, the characteristics of the seven new PCP concepts are compared to determine (a) the relative ability of the concept to address the problems encountered on previous projects, (b) the relative ability of each concept to effectively utilize the potential of PCP, and (c) what, if any, new problems are created with each concept.

In 1983 the Texas State Department of Highways and Public Transportation, commissioned the Center for Transportation Research, University of Texas, Austin, to study the design and construction of prestressed concrete pavement (PCP), with particular emphasis on overlay applications. A thorough review of the available literature to ascertain the current state of the art of PCP and a critical evaluation of the design, construction, and performance of several FHWA sponsored projects constructed during the 1970s led to the need for new concepts for the design and construction of PCP.

BACKGROUND

The objective of this paper is to describe the salient features of the PCP concepts developed by the project staff.

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Scope

The PCP concepts are present in the following order: (a) central stressing of slip-formed pavement; (b) precast joint panels and slip-formed pavement; (c) precast joint panels, central stressing panels, and slip-formed pavement; (d) composite prestressed concrete pavement Type I (CPCPI); (e) composite prestressed concrete pavement Type II (CPCPII); (f) segmentally precast prestressed concrete pavement (SPPCP); (g) continuous composite concrete pavement (CCCP); and (h) others.

In the next section a description of each concept is provided, followed by a detailed comparison of the most important characteristics of the various PCP concepts.

DESCRIPTION OF NEW CONCEPTS

Concept 1: Central Stressing of Slip-Formed Pavement

All of the past FHWA-sponsored PCP projects consisted of consecutive slip-formed slabs separated by short openings to permit posttensioning of the prestressing tendons from the slab ends. Because of the slab lengths and correspondingly high strand and subgrade frictions, it was necessary to stress each strand from both ends. After the posttensioning had been applied and the elastic shortening and most of the creep had occurred, the openings were filled with concrete gap slabs.

One of the objectives was to find a method of posttensioning the strands that would eliminate gap slabs and the problems associated with their use, but still permit taking advantage of the slip-form method of pavement construction. The most promising alternative was central stressing. Central stressing is a procedure by which the strands are stressed at internal blockouts or stressing pockets. The blockouts are filled with concrete after the posttensioning force has been applied.

Another objective was to investigate alternative methods for transversely prestressing pavement. It was believed that transverse prestressing is important to resist the applied wheel loads, prevent longitudinal pavement cracking, and prevent possible separation of separately placed pavement lanes or longitudinal pavement strips.

This concept is illustrated in a plan view of the pavement shown in Figure 1; an enlarged plan view of a stressing pocket is shown in Figure 2. The advantages and disadvantages of using a looped transverse tendon configuration are discussed in detail later in this paper. This design was accepted by the Texas

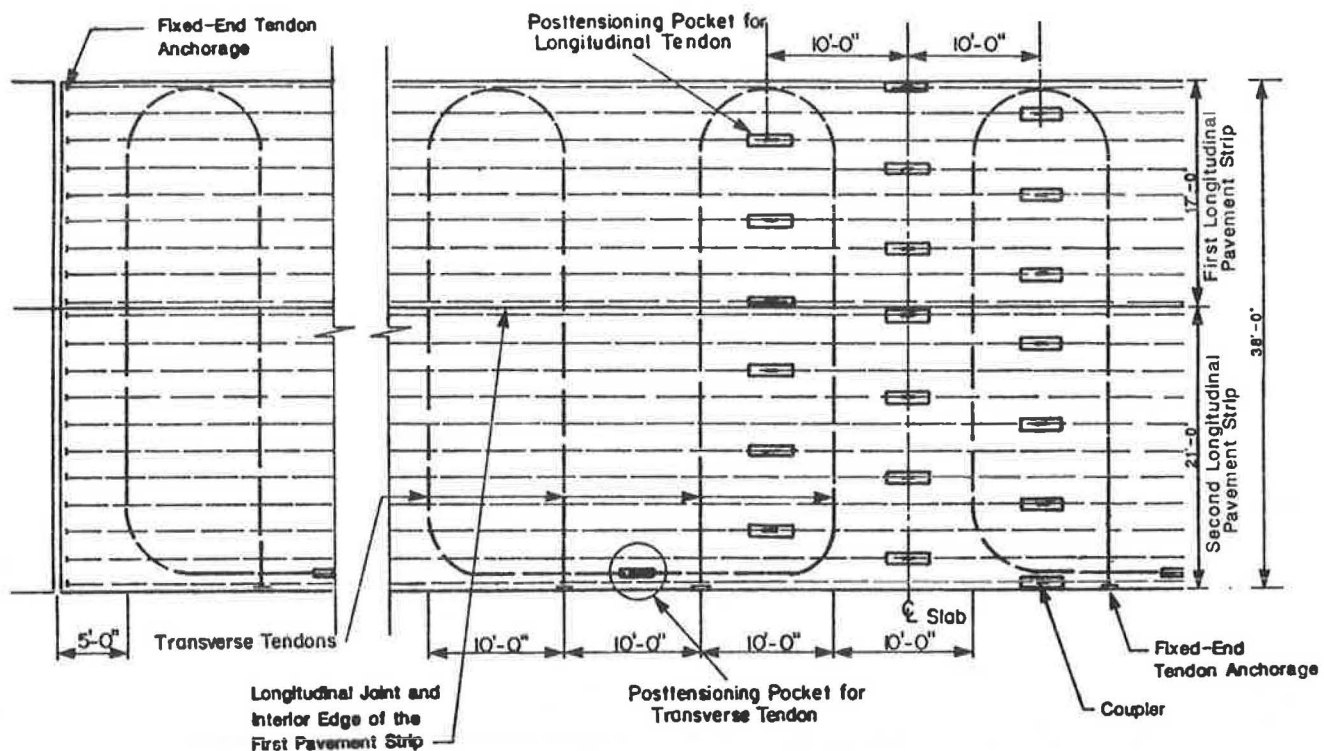


FIGURE 1 Plan view of the pavement during central stressing.

State Department of Highways and Public Transportation (SDHPT) for construction of the 1-mi demonstration overlay project on U.S. Interstate 35. The project will be located near Waco, Texas.

Concept 2: Precast Joint Panels and Slip-Formed Pavement

As implied by its name, precast concrete joint panels are used with precast joint panels and slip-formed pavement. The remainder of the pavement would be slip-formed. Concept 2 is shown in Figures 3 and 4.

The panels would most likely be cast off the job site in a precast plant or in a construction yard nearby and would then be transported to the site and set in place.

The precast panels would be provided in pairs, one on each side of every transverse joint. The same type of transverse joint assembly used in Concept 1 would also be used with this PCP concept. Each pair of joint panels would contain an entire transverse joint assembly, including the steel extrusion into which the neoprene seal is inserted, associated headed studs or deformed bar anchors, base angle (if required) to support the steel extrusion, dowels, and dowel expansion sleeves.

Each panel would contain the pockets for stressing the longitudinal pavement tendons and a single rigid transverse duct that

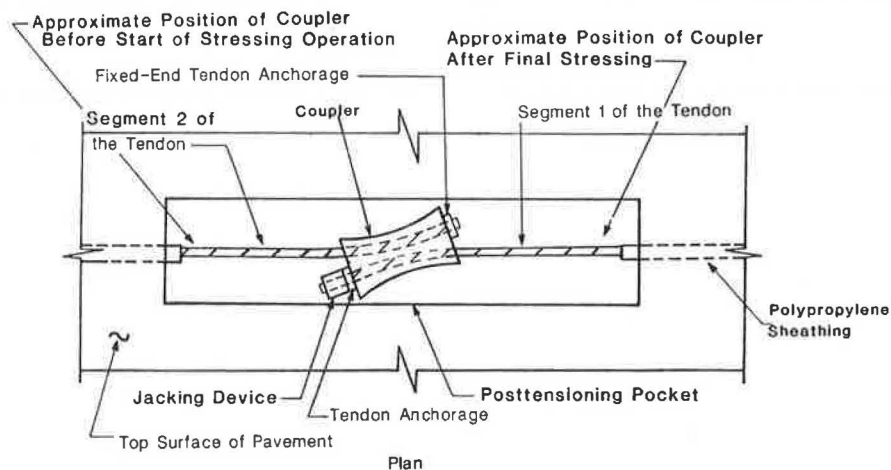


FIGURE 2 Stressing pocket detail.

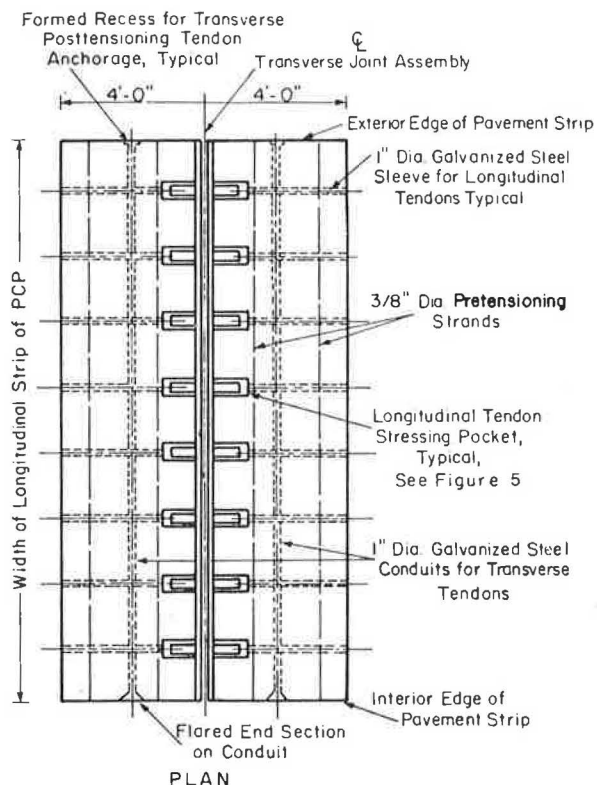


FIGURE 3 Precast joint panels.

would be used for posttensioning the precast joint panels together in the first and second pavement strips.

Each individual panel would be prestressed on the casting bed in the precast plant to a level sufficient to prevent it from cracking as a result of either lifting and handling before placement, or traffic loads after the panel is in its final position in the pavement.

Concept 3: Precast Joint Panels, Central Stressing Panels, and Slip-Formed Pavement

This PCP concept uses precast concrete joint panels as described in Concept 2 (see Figures 3 and 4). In addition, precast concrete stressing pavement are also used. These stressing panels would be located at the midlength of each pavement segment and would contain stressing pockets in which the longitudinal tendons would be jacked (see Figures 5 and 6). They would also contain a rigid transverse duct that would be used to posttension two adjacent stressing panels together. These panels would also permit the use of couplers for stressing the longitudinal tendons.

All the panels would be cast off the job site, transported to the site, and set in place with a truck crane. The remainder of the pavement would be slip-formed.

Concept 4: Composite Prestressed Concrete Pavement Type I (CPCPI)

Precast concrete joint panels similar to those used with PCP Concepts 2 and 3 would also be used with this PCP concept (see Figure 3). These joint panels were described in Concept 2. Central stressing panels similar to those used in PCP Concept 3 could be used with this concept if central stressing is desired (see Figure 5).

In addition, still another type of precast panel used with this PCP concept is the base panel shown in Figures 7 and 8. Like the panels used with the previous concepts, these panels would be cast off the job site. They would be prestressed on the casting beds to compensate for both handling and some in-place stresses. In addition, each base panel would contain a hollow transverse conduit.

All of the various types of precast panels would be transported to the job site and set in place with a truck crane. The

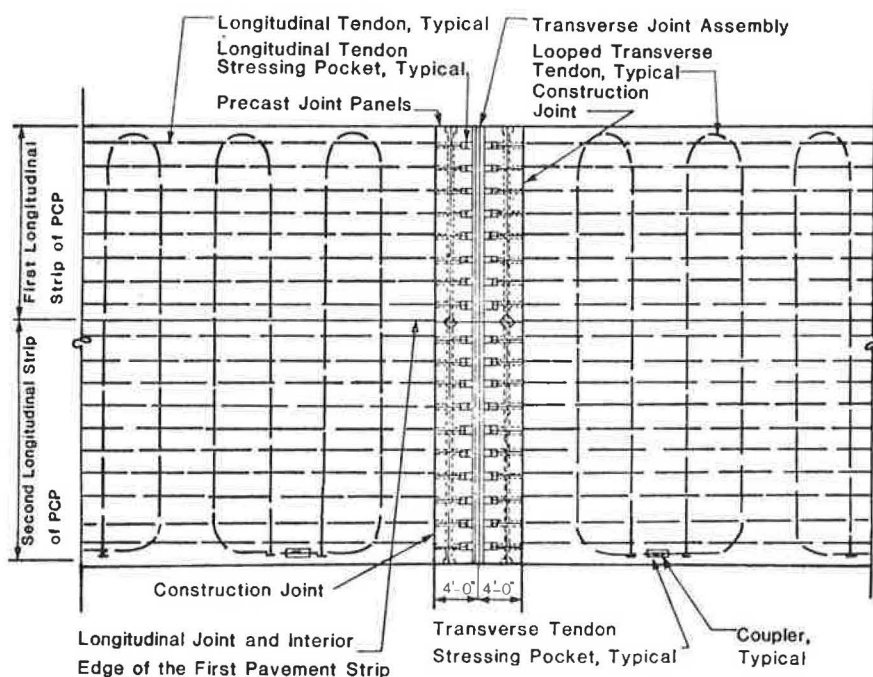


FIGURE 4 Precast joint panels and slip-formed pavement.

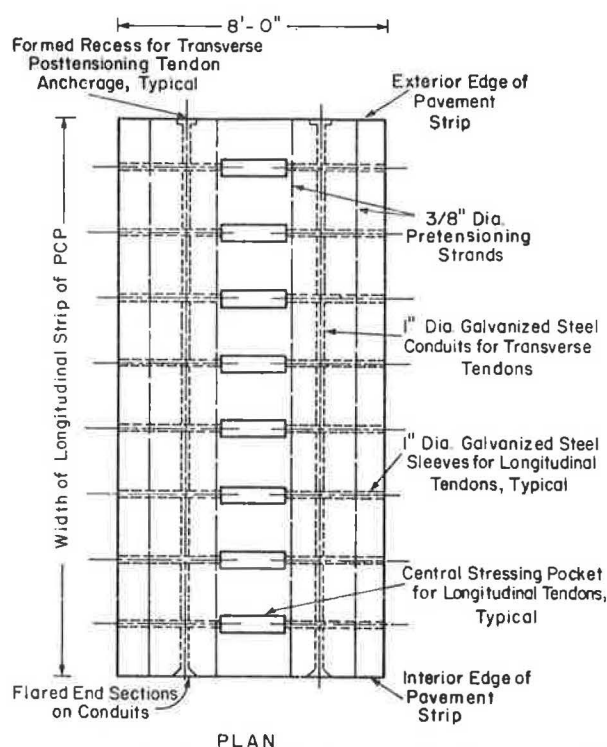


FIGURE 5 Central stressing panel.

concrete wearing course would be slip-formed in place after placement of the precast panels.

Concept 5: Composite Prestressed Concrete Pavement Type II (CPCPII)

Precast concrete joint panels similar to those used in PCP Concepts 2, 3, and 4 would be used for CPCPII. Also, central

stressing panels similar to those used in PCP Concept 3 could be used with this concept if the central stressing technique is desired (see Figure 5).

Base panels used for CPCPII would be similar to those used for CCPI in that they would be cast off the job site and contain a hollow transverse conduit. However, the base panels for CPCPII would be thicker than those used for CPCPI; the top surface of the panels would be grooved (which would allow the longitudinal tendons to be located at, or slightly below, the centroidal axis of the panel); and the edge of the panel would be formed to permit grouting of the joints between adjacent panels after they are set in place at the job site (see Figures 9 and 10).

Concept 6: Segmentally Precast Prestressed Concrete Pavement (SPPCP)

Precast concrete joint panels similar to those used in PCP Concepts 2 through 5 would also be used with Concept 6 (see Figure 3). In addition, central stressing panels similar to those used in PCP Concept 3 could be used with this concept if central stressing is desired (see Figure 5).

A panel type, referred to in this section as a full-depth pavement panel would be used with PCP Concept 6. This panel is shown in Figures 11 and 12. Like all the panels used with the previous concepts, these panels would also be cast off the job site. They would be prestressed on the casting beds to compensate for both handling and some in-place stresses. In addition, each full-depth panel would contain hollow longitudinal conduits and a single hollow transverse conduit.

All of the various types of precast panels would be transported to the job site where they would be set in place with a truck crane. No slip-formed concrete wearing course would be used with this concept.

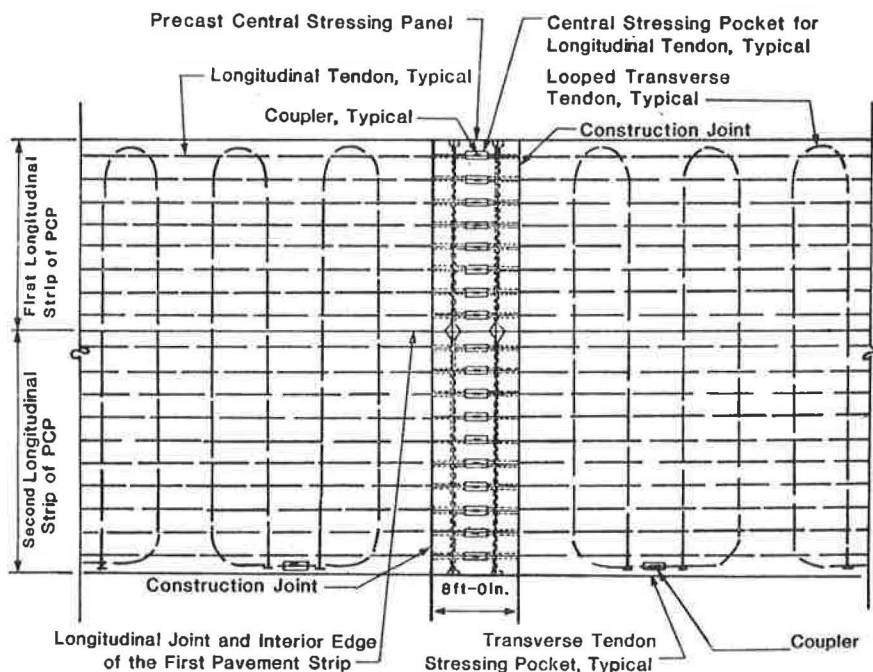


FIGURE 6 Precast joint panels, central stressing panels, and slip-formed pavement.

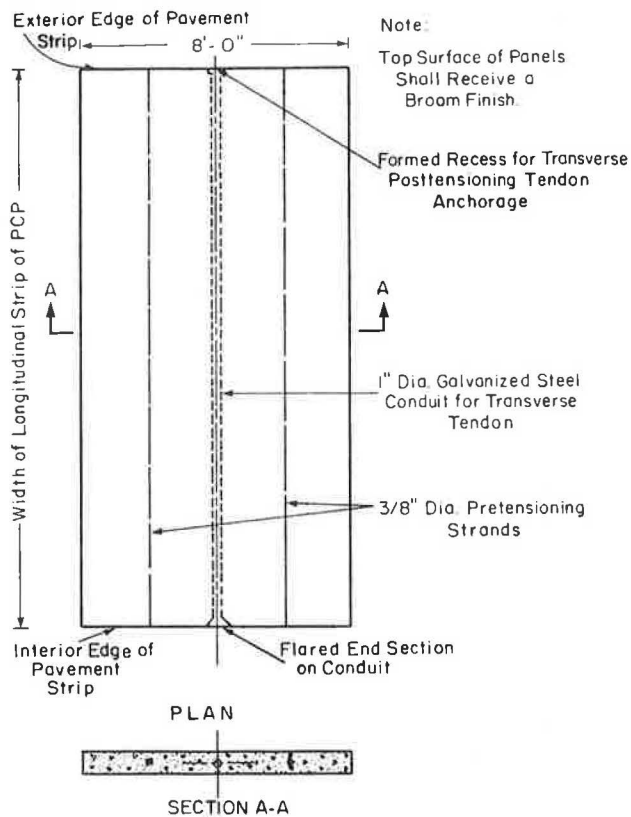


FIGURE 7 CPCPI base panel.

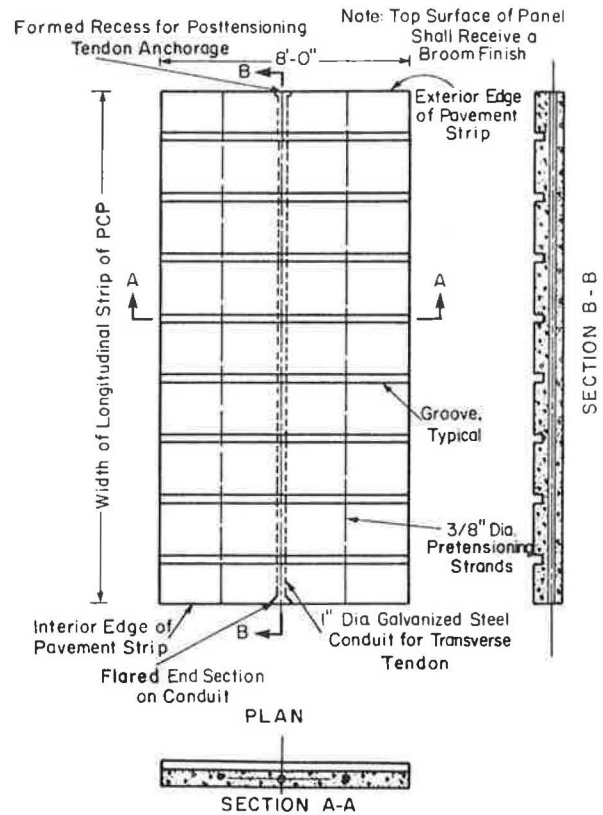


FIGURE 9 CPCPII base panel.

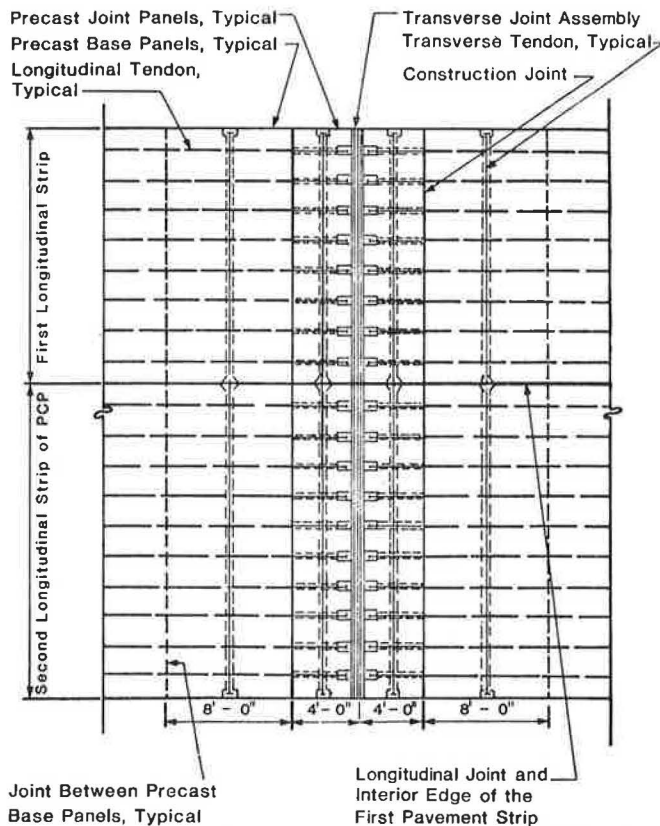


FIGURE 8 Composite prestressed concrete pavement Type I (CPCPI).

Concept 7: Continuous Composite Concrete Pavement (CCCP)

CCCP is very different from any of the concepts discussed thus far, and, in reality, is more similar to the concept of continuously reinforced concrete pavement, as will become apparent in the following discussion.

No joint panels would be used with CCCP because no transverse joints would be required, except where construction joints are needed when the paving operation is interrupted or where expansion joints are needed, for example, at bridges. Only precast concrete base panels (as shown in Figures 13 and 14) would be used in CCCP construction. These panels would be cast off the job site in the same manner as panels used in the previously discussed concepts. They would be prestressed in both directions on the casting bed to compensate for all handling and in-place stresses. In addition, the panels would contain grooves or slots that would be perpendicular to the panel edges. These grooves would accommodate tie bars between adjacent panels.

The precast concrete panels would be transported to the job site to be set in place with a truck crane. The concrete wearing course would be slip-formed in place after placement of the precast panels.

COMPARISON OF CONCEPT CHARACTERISTICS

Summarized in Table 1 is the relative ability of each of the foregoing new concepts to address the problems encountered

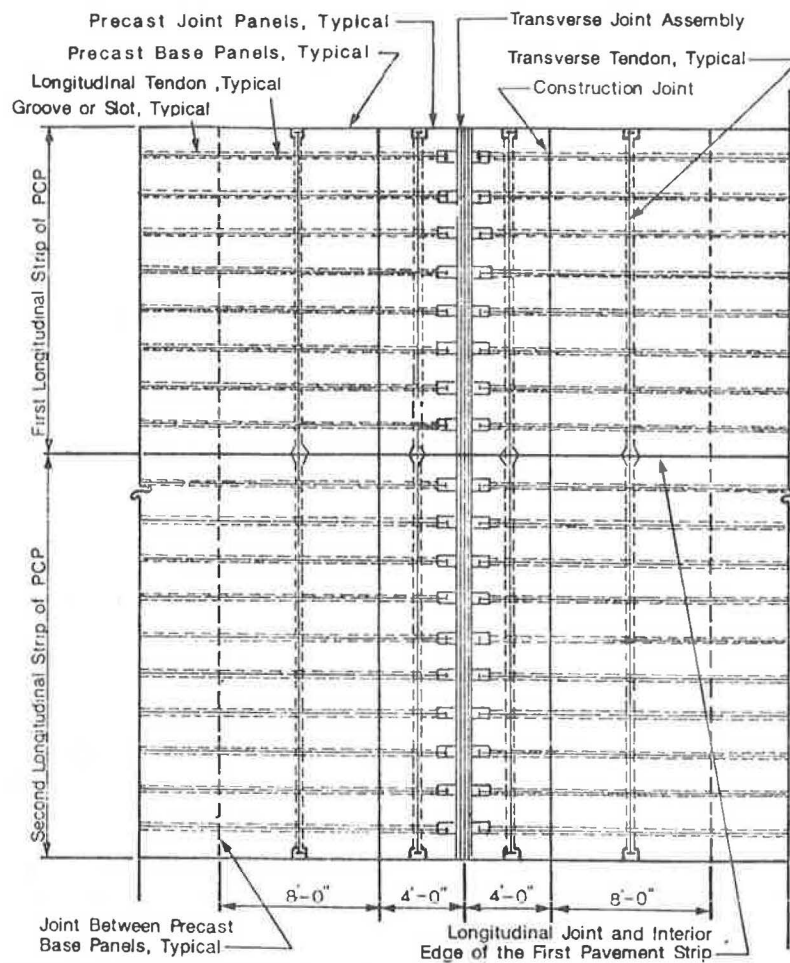


FIGURE 10 Composite prestressed concrete pavement Type II (CPCPII).

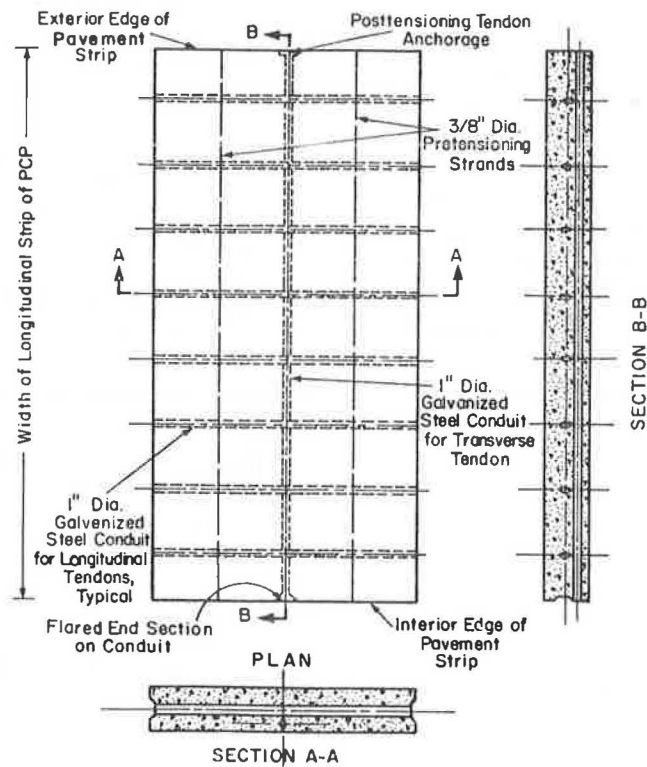


FIGURE 11 Full-depth pavement panel.

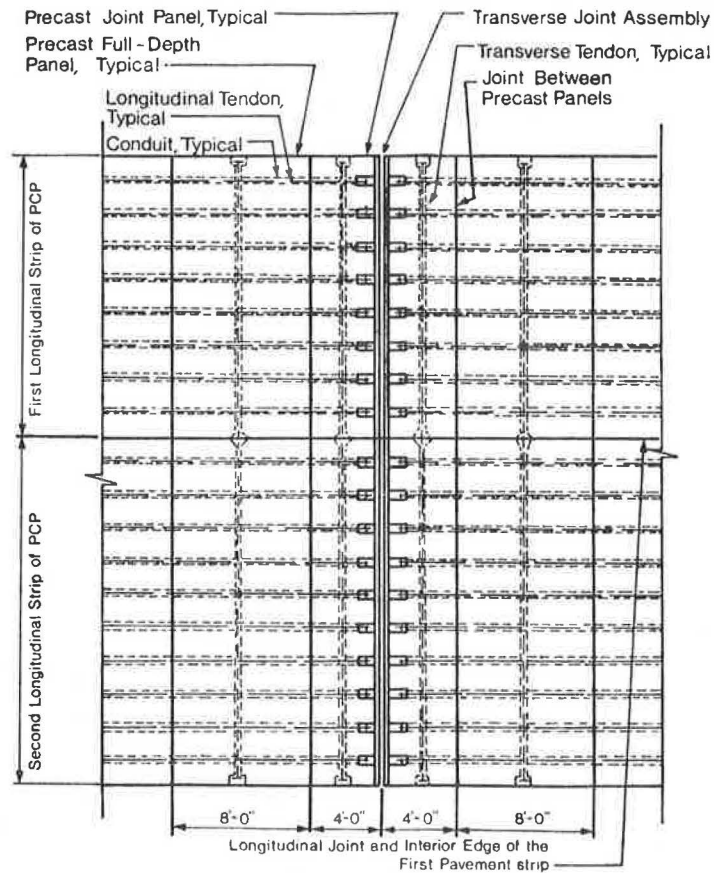


FIGURE 12 Segmentally precast prestressed concrete pavement (SPPCP).

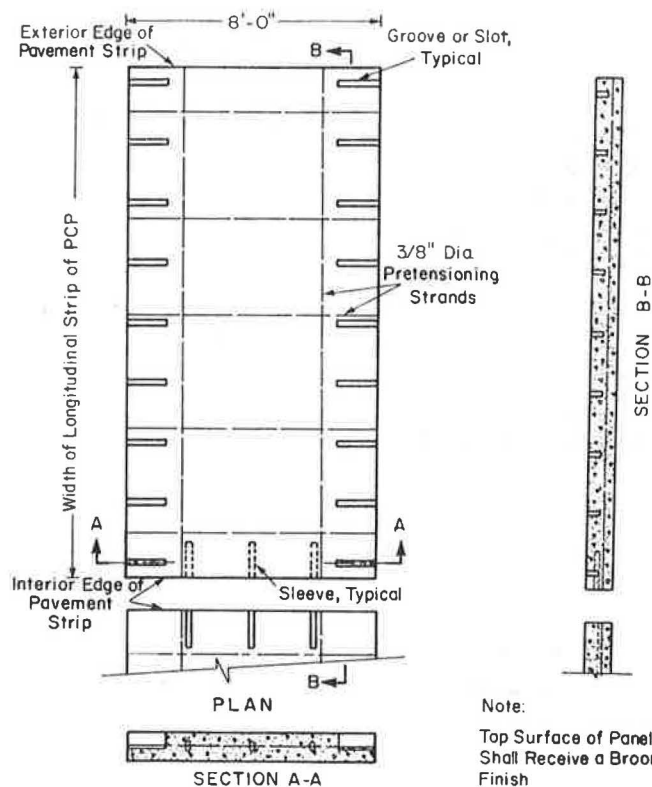


FIGURE 13 CCCP base panel.

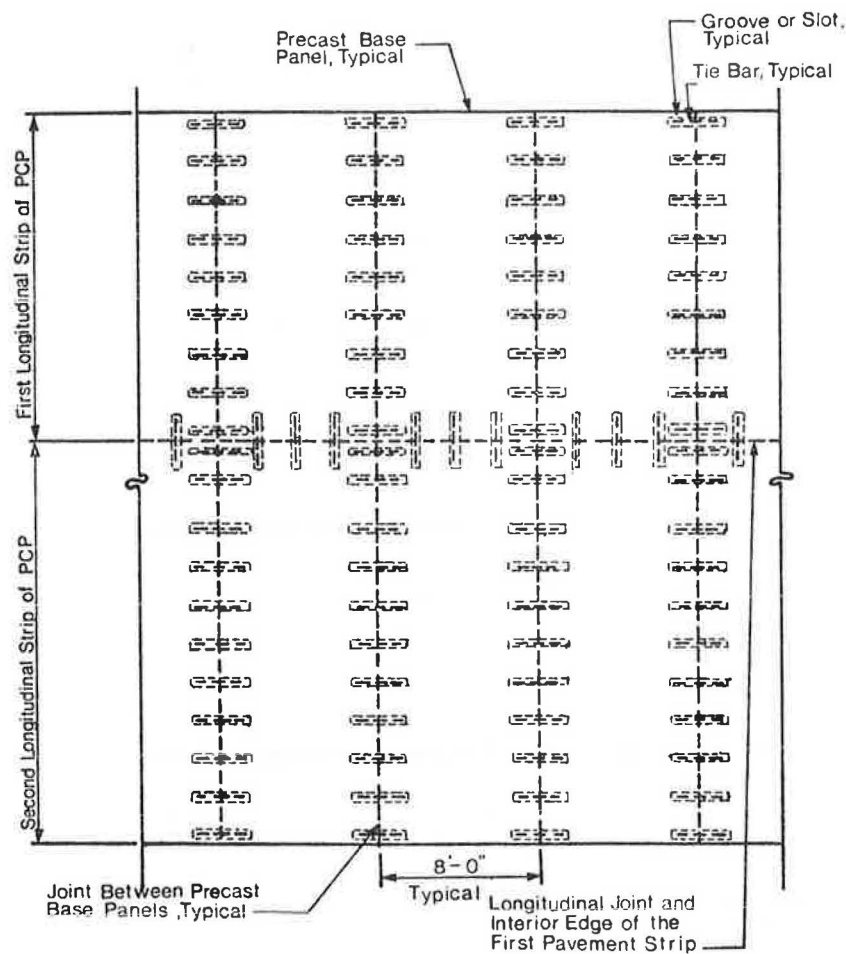


FIGURE 14 Continuous composite concrete pavement (CCCP).

TABLE 1 COMPARISON OF PCP CONCEPT CHARACTERISTICS

CHARACTERISTIC	PCP CONCEPT NUMBER						
	1	2	3	4	5	6	7
Precast Concrete Panels							
- Utilization of high quality, mass produced, precast, prestressed concrete panels:							
(a) Significant				X	X	X	X
(b) Less significant		X	X				
(c) None used	X						
- Relative importance of the fact that the precast panels must be transported to the job site:							
(a) Significant				X	X	X	X
(b) Less significant		X	X				
(c) Not a factor	X						
Bonded vs. Unbonded Tendons							
- Suited to the use of unbonded tendons	X	X	X	X	X	X	NA*
- Relative difficulty associated with the use of bonded tendons							
(a) Significant	X	X	X				
(b) Less significant				X			
(c) Least significant					X	X	X

TABLE 1 *continued*

CHARACTERISTIC	PCP CONCEPT NUMBER						
	1	2	3	4	5	6	7
- Number of posttensioning operations required for each longitudinal tendon:							NA
(a) One					X	X	
(b) Three	X	X	X	X			
- Less expensive unsheathed posttensioning strands could be used					X	X	
Transverse Prestress							
- Difficulties associated with laying out and holding the transverse tendons in a looped configuration	X	X	X				
- Pavement transversely prestressed before being subjected to construction traffic				X	X	X	X
- Transverse prestress level in adjacent lanes can be varied in accordance with the anticipated traffic volumes				X	X	X	X
- Eliminate all posttensioning operations in the field							X
Friction-Reducing Mediums							
- Relative difficulty associated with handling and placing polyethylene sheeting:							
(a) Significant	X	X	X				
(b) Less significant				X	X	X	
(c) None							X
- Construction operations (i.e., setting tendon chairs, placing tendons, and slip-forming pavement) would be conducted in direct contact with polyethylene sheeting	X	X	X				
- Polyethylene sheeting would be protected from construction operations				X	X	X	
- Eliminate the need for polyethylene sheeting							X
Gap Slabs vs. Central Stressing							
- Elimination of gap slabs	X	X	X	X	X	X	X
- Number of tendon stressing pockets which must be formed in the field:							
(a) Greatest	X						
(b) Minimal		X	X				
(c) None				X	X	X	X
- Couplers for posttensioning tendons:							
(a) Required	X		X				
(b) Optional				X	X	X	
(c) None used		X					X
- An additional concrete placement operation is required to fill the stressing pockets after completion of final posttensioning operations	X	X	X	X		X	NA
Prestress Force Transference							
- Level of compressive stress which can be applied by posttensioning at early concrete age is dependent on:							NA
(a) Concrete strength	X	X	X	X	X	X	
(b) Tendon anchorage size	X						
(c) Tendon spacing	X						

TABLE 1 *continued*

CHARACTERISTIC	PCP CONCEPT NUMBER						
	1	2	3	4	5	6	7
- Application of initial prestress force:							NA
(a) Prestress force transferred from tendons to immature concrete via individual tendon anchorages, thus limiting the amount of prestress that can be applied at early concrete age	X						
(b) Prestress force transferred from tendons to precast joint panels and then to the immature concrete, allowing greater initial prestress force to be applied at early concrete age		X	X	X	X	X	
- Possible long-term problems due to tensile stresses at the end of each pavement section caused by prestressing							
(a) Possible	X						
(b) Significantly decreased likelihood		X	X	X	X	X	
(c) No likelihood							X
Tendon Placement							
- Chairs required to support tendons during slip-forming	X		X				
- No chairs required to support tendons during slip-forming				X	X	X	X
Transverse Joints							
- Relative difficulty associated with holding the transverse joint assembly stationary while applying tension to the longitudinal tendons before the pavement concrete is placed:							NA
(a) Significant	X						
(b) Less significant		X	X				
(c) None				X	X	X	X
- Difficulties associated with concrete placement and consolidation in the vicinity of the transverse joint assembly in the field	X						
Multiple Longitudinal Strip Construction							
- Problems associated with transverse tendons protruding from the first pavement strip	X	X	X				
- Concrete formwork required along the interior edge of the first pavement strip	X	X	X				
Concrete Compaction							
- Reduced difficulty in obtaining good compaction of slip-formed concrete because of reduced cast-in-place concrete depth				X	X	NA	X
Protection of Tendon Anchorages							
- Tendon anchorages completely encased and protected in the concrete pavement	X	X	X	X	X	X	X
Adverse Construction Conditions							
- Reduction in required quantity of cast-in-place concrete which reduces vulnerability to adverse construction conditions:							
(a) Significant				X	X	X	X
(b) Less significant		X	X				
(c) None	X						

TABLE 1 *continued*

CHARACTERISTIC	PCP CONCEPT NUMBER						
	1	2	3	4	5	6	7
- Problems associated with stopping construction at intermediate points:							
(a) Significant	X	X	X				
(b) Less significant				X	X	X	X
- Possibility of being able to quickly open the pavement to traffic						X	X
Alternate Uses							
- Possibility of being used for a special purpose, temporary, reusable pavement						X	
- Damaged sections easily repaired							X
Alternate Materials and Methods							
- In addition to strand, high-strength bars can be used for transverse posttensioning				X	X	X	
- Possibility of using high-strength bars for longitudinal posttensioning					X		
- Couplers for posttensioning tendons:							
(a) Required	X		X				
(b) Optional				X	X	X	
(c) None used		X					X
- Possibility of using alternate wearing course materials							X
Unfamiliarity							
- Organizations responsible for selecting pavement systems are unfamiliar with the concept	X	X	X	X	X	X	X
- Paving contractors unfamiliar with the concept	X	X	X	X	X	X	X

*NA = Not Applicable

on previous projects and to effectively utilize the potentials of PCP together with possible new problems created with each concept. The comparison is made with regard to the following aspects:

1. Bonded versus unbonded tendons,
2. Transverse prestressing and looped tendons,
3. Friction-reducing mediums,
4. Gap slabs versus central stressing,
5. Prestress force transference,
6. Tendon placement,
7. Transverse joints,
8. Multiple longitudinal strip construction,
9. Concrete compaction,
10. Protection of tendon anchorages,
11. Adverse construction conditions,
12. Alternative uses,
13. Alternative materials and methods, and
14. Unfamiliarity.

SUMMARY

The purpose of this paper was to introduce seven new PCP concepts.

The introduction to each new concept included descriptions of its most important features and discussions of the anticipated sequence that would be used in the construction of a section of PCP utilizing the concept. In addition, the characteristics of the seven new PCP concepts were compared to determine (a) the relative ability of each concept to address the problems encountered on previous projects, (b) the relative ability of each concept to effectively utilize the potential of PCP, and (c) what, if any, new problems are created with each concept.

No attempt was made to identify the best concept because each has its own strengths and weaknesses and different situations may require the use of one concept instead of another. Additional testing is needed to further develop the concepts and determine their viability.

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The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the FHWA. This paper does not constitute a standard, specification, or regulation. Material brand names that may appear in the text are solely for purposes of illustration or clarity and should not be construed as an endorsement of any kind.

Mechanical and Environmental Stresses in Continuously Reinforced Concrete Pavements

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The examination of the combined effects of mechanical and environmental stresses on continuously reinforced concrete (CRC) pavements is accomplished by superimposing the effects of the one onto those of the other. The mechanical stresses are evaluated by a three-dimensional analysis and thermal stresses by two-dimensional analysis. It has been demonstrated that environmental loads constitute the severest loads the pavement is subjected to. Also studied is the comparison of stresses due to one single axle 18-kip load to stresses due to two trucks and a car on a three-lane highway. The ratio of maximum stresses by two loadings may be very useful for a comprehensive understanding of pavement performance when it is designed by the equivalent 18-kip concept.

A major concern in the design of rigid portland cement concrete (PCC) pavements is to control undesirable cracks by using the proper control joints. Despite the efforts to establish the ideal type of joints, most of the undesirable features of natural cracks accompany their use. In response to this problem an effort was made to eliminate the joints and in 1921 the first continuously reinforced concrete (CRC) pavement was constructed by the U.S. Bureau of Public Roads.

On the other hand, to overcome difficulties in maintenance operation, the FHWA proposes the use of zero maintenance pavements which require no maintenance during their first 20

years and only minor repairs during the following 10 years before rehabilitation.

The present study reviews some of the existing methods for pavement stress evaluation and examines a premium pavement using a refinement of a model proposed by Saxena et al. (1).

EXISTING ANALYSIS METHODS

Mechanical Loads

Westergaard (2, 3) expanded the theory of slabs created by Hertz (4) to include the so-called Winkler foundation. In order to solve the basic differential equation for medium-thick plates, the deflection at any point on the subgrade surface is assumed directly proportional to the vertical stress applied at that point in Winkler foundations; this proportionality is also assumed constant. Therefore, the foundation is represented by individual springs with stiffness k , which is commonly referred to as modulus of subgrade reaction. The values of this constant are determined from plate loads tests.

Some years later Hogg (5) and Holl (6) solved the same problem with the assumption that the slab is supported by an elastic solid. In their solution, they incorporated the Boussinesq's classic solution for the deflection of an elastic solid resulting from a point load.

Both the aforementioned solutions are available in most of