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16. Abstract

This project involves most types of transitions that consist of a variety of joint combinations and slab configurations. In many instances, the performance of the transition areas may become the focal area for maintenance due to improper design or construction that otherwise could have been avoided. Districts regularly designing and constructing concrete pavements have developed standards and practices for some transitions and have learned from experience what the best practices are. However, these practices are not yet established for districts interested in building more concrete pavements. In this regard, information is needed to address the different types of issues that arise in everyday design that in many cases depend on the support conditions, slab geometries, aggregate type, weather, and the traffic levels expected over the service life. This project conducted a survey of Texas Department of Transportation (TxDOT) and other state highway association (SHA) practices and identified the best practices toward incorporating them into guidelines for design and construction of transition areas that will enable TxDOT engineers and designers to avoid the inappropriate practices.

The types of transitions that were addressed in this report covered a variety of concrete pavement combinations. Where possible, observed performances were documented based on survey results of many district practices and the findings of field visits. Based on these findings, improvements of various transition types were suggested to enhance the design standard for different transition types. Guidelines address the design of concrete pavements in transition areas with the joints and related details. The study of specific joint configurations associated with transitions was conducted with respect to stiffness of the joint, potential for permanent deformation, and slab restraint to translational movement at the joint. The 11 most frequently constructed types of concrete pavement transitions are introduced in this paper, and some of them have alternative designs as more options in the design guide. The promising design improvement concepts provide a complete picture of the requirement for the design of a pavement transition for a variety of pavement types and terminal configurations.

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BEST PRACTICES OF CONCRETE PAVEMENT TRANSITION DESIGN AND CONSTRUCTION

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DISCLAIMER

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CHAPTER 1
ASPECTS OF TRANSITION BEHAVIOR

TxDOT concrete pavement construction projects tend to include several types of transitions that consist of a variety of joint combinations and slab configurations. In many instances, the performance of the transition areas may become the focal area for maintenance due to improper design that otherwise could have been avoided. Districts that regularly design and construct concrete pavements have developed standards and practices for some transitions and have learned from experience what the best practices are; however, for districts that are interested in building more concrete pavements, these practices are not yet established. In this regard, information is needed to address the different types of issues that arise in everyday design that, in many cases, depend on the support conditions, slab geometries, and traffic levels expected over the service life of the pavement. This project, in part, involved a survey of TxDOT and other SHA personnel practices to identify and incorporate best practices into guidelines for the design and construction of transition areas that will enable TxDOT engineers and designers to avoid inappropriate practices.

INTRODUCTION AND BACKGROUND

Pavement transitions are key elements of pavement design. Transition details are necessary for joining pavement sections that incorporate different design elements that vary depending on pavement type and structure. Transition elements are necessary to ensure a smooth transition between two different pavement sections and to minimize future pavement performance issues. The functions of pavement transition elements are as follows:

- maintain rideability;
- allow a gradual transition in geometry (grade and cross-slope);
- allow a gradual transition in structural capacity of the pavement;
- accommodate slab end movements, as necessary; and
- minimize drainage-related issues.

Concrete pavement transition elements may involve only a single joint and a single slab panel, a series of joints and slab panels, or short sections of adjoining pavements. Improperly designed pavement transition elements lead to poor pavement performance and the need for frequent maintenance and repair. For concrete pavements, transition elements are necessary for the following cases:

- at the junction of a continuously reinforced concrete (CRC) pavement and an asphalt concrete (AC) pavement;
- at the junction of a jointed concrete (JC) pavement and an AC pavement;
- at the junction of a CRC pavement and a JC pavement;
- at the junction of a new CRC pavement and an existing CRC pavement;

- at the junction of a new JC pavement and existing JC pavement;
- at the junction of an overlaid pavement and new pavement for:
  - AC overlaid portland cement concrete (PCC) pavement and a new PCC pavement,
  - PCC overlaid PCC pavement and a new PCC pavement, and
  - PCC overlaid AC pavement and a new PCC pavement,
- at other locations such as at:
  - bridge structures,
  - CRC terminals,
  - ramps and gore areas,
  - intersections, and
  - drainage structures and inlets.

This report presents a summary of the research conducted under project 0-5320 relative to the best practices for concrete pavement transition elements. Throughout the field survey and analysis, the transition performances of current concrete pavement designs were studied. Key elements of transition behavior such as joint spacing, slab thickness, and load transfer efficiency are explained in detail for better understanding relative to design. Finally, transition design improvements and promising concepts are recommended based on both empirical and theoretical considerations. Prior to this discussion, due to the prominent role of joints in the performance of pavement transitions, a summary of basic jointing and joint stiffness concepts is reviewed.

CONCRETE PAVEMENT JOINTS

In a concrete pavement system, transition area design often evolves around the placement and detailing of joints that are placed in the pavement to control cracking and to facilitate construction. Joints divide the pavement into practical construction increments, delineate traffic lanes, and accommodate slab movements. The three types of joints commonly used in concrete pavement construction are contraction joints, construction joints, and isolation (i.e., expansion) joints. The first two joint types are used both transversely and longitudinally. Contraction joints are intended to control cracking while construction joints allow interruption during placement or are used at planned joint locations such as longitudinal separations between adjacent lanes. Isolation and expansion joints allow differential horizontal and vertical movements (if no dowels are used) anticipated between a pavement and another structure. Isolation joints are not necessarily the same as expansion joints but often perform the function of expansion joints and utilize full-depth joint filler material. Proper jointing of concrete pavements is essential to ensure good performance since it is the primary key to avoiding random cracking and irregular joint movements. Load transfer across transverse joints is an important element of joint performance. Closely spaced joints usually result in small openings and increased aggregate interlock at the joints that result in increased aggregate interlock between panels – if contraction joints are involved. Spreading the joints farther apart typically results in a higher incidence of cracking (due to violation of fundamental principles of slab jointing) plus wider openings of joints and diminished load transfer capability.

TRANSVERSE JOINTS

Most transitions do not involve the use of contraction joints, but the purpose of a contraction joint is to control cracking caused by restrained drying shrinkage and thermally induced movements of the concrete and the concomitant effects of curling and warping. Experience indicates that both construction and contraction joints should be spaced in accordance with Figure 1-1, which is based upon a fundamental engineering analysis of slab length versus curling/warping stresses discussed further in Chapter 4. Related to this design concept is the suggestion that contraction joints without dowels, if spaced closely enough, may provide the prerequisite load transfer through aggregate interlock across the joint. Otherwise, dowel bars are typically required, particularly if the requirements for load transfer at contraction joints are high. Transverse joints also extend through integral and tied curbs, which can also serve as stiffeners of the slab panel.

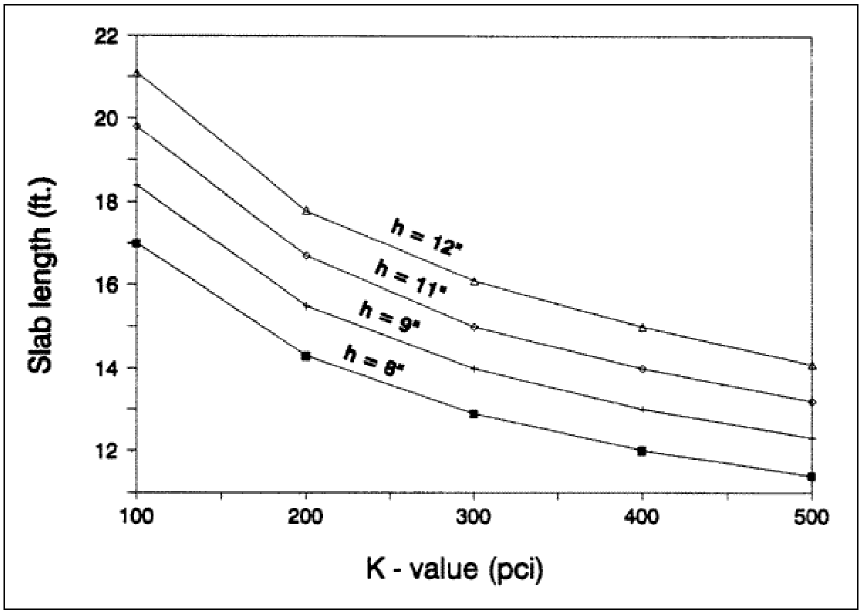


Figure 1-1 Maximum Joint Spacing for Concrete Paving (*1*).

LONGITUDINAL JOINTS

Joint patterns that delineate adjacent lanes should be as continuous as possible to maintain uniformity of movement between longitudinal lanes. Longitudinal joints are typically of the butt type, which are at times needlessly keyway type joints but perhaps more often restrained by use of deformed tie bars. Butt-type joints obviously do not inherently provide load transfer and therefore must incorporate a load transfer device in order to provide any degree of load transfer and stiffness, but fortunately in many cases it is unnecessary to do so. Additionally, keyway-type joints provide little benefit and are not recommended. However, longitudinal construction joints should be properly maintained and sealed to prevent infiltration of incompressible materials and rusting of tie bars that may otherwise cause joints to widen and degrade long-term pavement performance.

In terms of transitions, longitudinal joints are mainly of the construction type, as previously noted, but they are very useful in controlling irregular longitudinal cracking that would otherwise occur in panel widths exceeding the limits recommended in Figure 1-1. Such cracks normally develop from the combined effects of load and restrained warping behavior in many cases after pavements are subjected to traffic. The following criteria are useful for governing the spacing of longitudinal joints:

- A spacing of 13 to 16 ft (4 to 5 m) serves the dual purpose of crack control and lane delineation. Longitudinal joints on arterial streets should also be spaced to provide traffic- and parking-lane delineation. On these streets, it is customary to allow 10 to 12 ft (3 to 3.5 m) for parking that can also be used as a travel or turning lane.
- Longitudinal joints are usually required for crack control on one-way ramps where the slab width is 16 ft (5 m) or more.

Butt joints with thickened edges or a sleeper slab are recommended at T-intersections where primary lane movements are orthogonal to each other and the use of tie bars would be far too restrictive. Tie bars used for multi-lane pavements need to be spaced as a function of the pavement drag length, but a limit of 100 ft is typically used as a maximum drag length to avoid frictional-induced cracking.

ISOLATION AND EXPANSION JOINTS

Isolation and expansion joints are very useful for transition areas to effectively separate pavement segments from relatively immovable objects. These joints may open in width as much as 0.75 to 1.0 inch. Preformed joint fillers are used in the gap to aid in sealing the joint area. Joint filler material should allow up to 50 percent compression and be non-shrinking, non-absorbent, non-reactive, non-extruding and able to extend from the subgrade to the pavement surface without protruding above the pavement. In some cases, a joint sealant could also be used with the filler.

Concrete slabs must be separated from fixed objects within or abutting the paved area to accommodate differential horizontal or vertical movement. Dowels across the isolation joint must be used with caution since they inhibit horizontal displacement relative to the fixed object. These joints are typically used around light standard foundations, area drains, manholes, catch basins, curb inlets, between pavement and sidewalks, and between pavement and buildings. Isolation joints are also used at asymmetrical intersections and ramps where joint grids are difficult to align. Load transfer dowels should be avoided in these locations so differential horizontal movements can occur without damaging the abutting pavement. Where dowels are not feasible, thickened edges or the use of sleeper slab are recommended, particularly where traffic will frequently traverse the joint. Edge thickening is a pavement design issue but is typically accomplished by increasing the slab thickness approximately 20 percent (at least 2 in.) and tapered to the required thickness over a distance of 6 to 10 times the pavement thickness.

The use of expansion joints has evolved over time, and studies of pavements in service have shown that expansion joints are not needed except where a concrete slab is placed next to a structure that is not subjected to the same temperature and moisture movements as the pavement. In the past, designers placed transverse expansion joints to relieve compressive forces in the pavement to limit blowups. However, in many cases the expansion joints allowed too much opening of adjacent transverse contraction joints, which led to loss of aggregate interlock and sealant damage. Elimination of unnecessary expansion joints has allowed adjacent contraction joints to remain tight and provide good load transfer. Slabs less than 8 in. thick are thought to be too thin to support dowels, and consequently they employ thickened edges instead. Performance experience has indicated that expansion joints are only necessary at relatively fixed structures such as light pole footings, drop inlet boxes, etc., and as a consequence, these expansion joints perform the same functions as isolation joints.

JOINT STIFFNESS

Over the past decade, several advancements have been made that address various stiffness components that contribute to the transfer of load between adjacent slab segments. These advancements mechanistically account for the effect of key stiffness factors in the transfer of load at a joint or crack in a concrete pavement system in relation to the integrity of a slab transition. The stiffness of a joint depends heavily upon the degree of load transfer and the various stiffness components of the joint or crack that designers can employ between adjacent slab segments. Loss of stiffness in a concrete pavement system may lead, depending on the characteristics of the subbase support, to faulting in jointed pavements or punchouts in CRC pavements. Loss of stiffness is also important in the performance analysis of rehabilitated concrete pavements relative to longevity of the repair. The load transfer of a joint or crack has an important effect on the composite stiffness of a concrete pavement and therefore significantly affects its performance under repetitive loading.

The amount of deformation of a concrete pavement at a joint under load depends upon the resistance of the joint to load. This resistance depends upon the stiffness of the supporting medium, the pavement thickness, and opening of the joint or crack, as well as the interlayer friction between the slab and subbase/subgrade. One parameter that can be utilized to characterize this combined resistance at a joint is called the radius of relative stiffness (ℓ) and depends, in part, upon the thickness of the slab.

In terms of joint stiffness, representations of loss of load transfer and subbase/subgrade support mechanisms stand out as key joint deterioration processes that are reflected in lower ℓ-values at the joint. Relative to diminished load transfer and ℓ, a systematic design process can be employed to correlate joint stiffness to aggregate interlock, dowel bar structural stiffness, interlayer friction, slab thickness, and the details of the steel configuration at the joint. Due to the variations associated with slab transitions, combinations through this process are needed to address these particularities associated with slab transitions.

The parameter *J* represents the concept of joint stiffness as incorporated and in reference to the above process is made up of stiffness due to aggregate interlock and dowel bars (or other load transfer devices). Both of these components relate to the stiffness of a joint/crack and in combination represent a total stiffness ratio *J* (where the total *J* = stiffness due to dowel + stiffness due to aggregate), which in effect can be related to load transfer (in percent). The effect of stiffness due to dowels or aggregate interlock can be combined and taken into account to explain combined load transfer effects. However, the degree to which dowels or steel reinforcement can provide load transfer is limited. The achievement of a greater load transfer capability can only be accomplished through aggregate interlock and small crack openings – which is a key point to understand related to the design of slab transition systems. In other words, high load transfer conditions are achieved through aggregate interlock. Dowels make a significant contribution to the transfer of load from one slab to another. However, crack width is critical to achieving and maintaining a high load transfer condition, which emphasizes the role of joint/crack opening in concrete pavement transition design. This concept of joint stiffness (*J*) can also represent the effects of varying the pavement thickness at edges of the slab or the base thickness on the load transfer capability of the joint or crack.

JOINT DEFLECTION

The stiffness of the joint represented in this manner relates to:

- the deflection of the joint;
- the deflection across a transition;
- the magnitude of deflection, and;
- the acceptability of this deflection.

The load deflection limit depends on the capability at the subgrade to absorb the stresses under load. The maximum allowable stress that a native subgrade can tolerate is based on the elastic-plastic characteristics of the subgrade, illustrated in Figure 1-2, which is a typical, generic plot of stress versus strain under monotonic loading for a soil. Note that up to a stress of about one half of the ultimate, unconfined compressive stress (UCCS) at failure, the stress-strain response is linear; if a cyclic load or stress was applied up to about one half of UCCS, the strain is typically fully recoverable for each application of load or stress. The rate of permanent deformation accumulation in the subgrade (i.e., loss of support) is assumed to occur at an unacceptable rate if the cyclic stress exceeds about one half of UCCS. At this point each load or stress cycle results in a permanent or non-recoverable strain. Over time and load, this cumulative strain builds, resulting in a loss of support under a pavement structure. Loss of subgrade support is a parameter that may affect pavement performance and is a factor that should be considered in transition design.

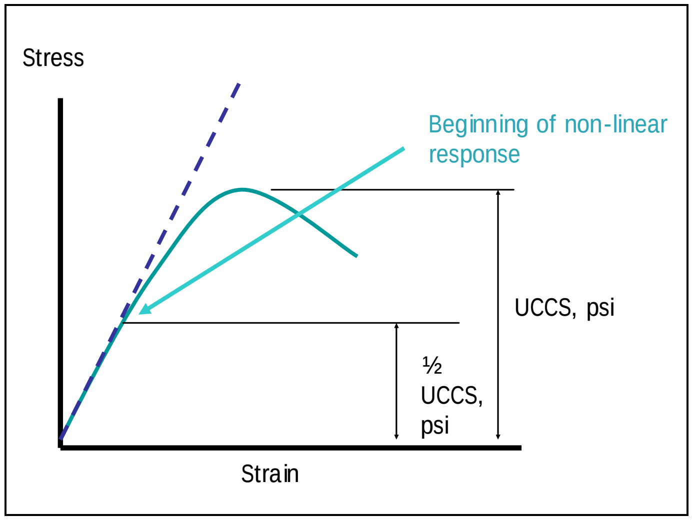


Figure 1-2 Typical Stress-Strain Response in Subgrade Soil (2).

An approach similar to this can be used to formulate a design process for a transition structure so that stresses induced in the subgrade under traffic loading will not exceed acceptable limits. Load analysis coupled with this characterization of the supporting layer allows direct consideration of the steel design, joint details, thickened edges, base transitions, and pavement type on the design of the pavement transition. The following chapters detail design criteria based on this approach.

CHAPTER 2
SURVEY OF CURRENT PRACTICES FOR CONCRETE PAVEMENT TRANSITIONS

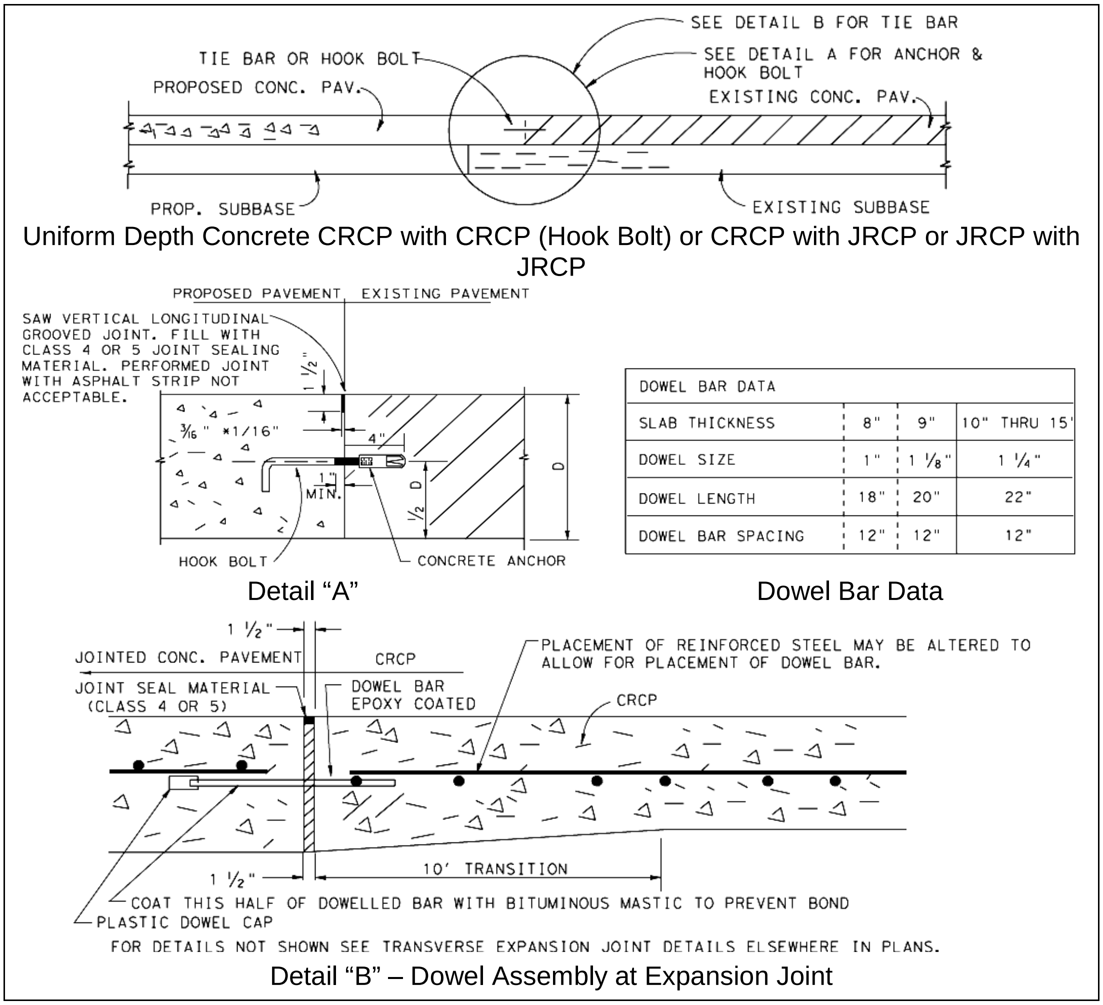
Pavement transitions are one of the keys of pavement design. Poorly designed pavement transition elements lead to poor pavement performance and the need for frequent maintenance and repair. Therefore, elements are necessary to ensure a smooth transition between two different pavement sections and to minimize future pavement performance issues. In a concrete pavement system, transition area design often evolves around the placement and detailing of joints, which are located in the pavement to control cracking and to facilitate construction. Joints divide the pavement into practical construction increments, delineate traffic lanes, and accommodate slab movements. Contraction joints are intended to control cracking, while construction joints allow interruption during placement or are used at planned joint locations such as longitudinal separations between adjacent lanes. Isolation and expansion joints allow anticipated differential horizontal and vertical movements to occur between a pavement and another structure. This chapter presents a summary of the current practices for various concrete pavement transition elements such as the junction between a PCC pavement and an AC pavement or other PCC pavement, overlaid pavement, bridge structure, intersection, etc. For each type of transition included, the design performance factors, current practices, and suggested design improvements are addressed. The functions of the pavement transition elements are maintaining rideability, allowing gradual transition in geometry and structural capacity of the pavement, accommodating slab end movements, and minimizing drainage-related issues.

TRANSVERSE CONSTRUCTION JOINT CATEGORY

Transverse joints are installed perpendicular to the paving direction and provide different functions based on transition type. This section involves general transition details of CRC to CRC pavement and CRC to JC pavement transitions. The transition of CRC to AC and JC to AC pavement are also common transition types used in practice. The seamless design is introduced as an advancement that potentially provides better rideability and less maintenance.

Transition between CRC Pavement and CRC Pavement

Figure 2-1 shows a discontinuity in the joint between the surface and the subbase layer, which can be problematic – particularly for a jointed pavement, and should be avoided as a matter of standard practice. Due to potential lack of deflection continuity at the location over the subbase joint, significant stress could cause punchouts to occur at this location. Moreover, the “hook” bolt in detail “A” is rarely used. Therefore, matching the joint location in the subbase, as shown in Figure 2-2, and providing sufficient load transfer in the joint are measures of good design practice.



DOWEL BAR DATA			
SLAB THICKNESS	8"	9"	10" THRU 15"
DOWEL SIZE	1"	1 ⅛"	1 ¼"
DOWEL LENGTH	18"	20"	22"
DOWEL BAR SPACING	12"	12"	12"

Figure 2-1 General Transition Detail between Concrete Pavement Types (3).

Figure 2-2 is somewhat related to the transition shown in Figure 2-1, in that it includes a thickness transition over a distance of 10 ft. Dowel bars provide proper load transfer between the two pavement types. Improvement of this detail would involve the inclusion of an additional joint at the end of the thickness transition and possibly the inclusion of a sleeper slab element if deflection criteria warrant it.

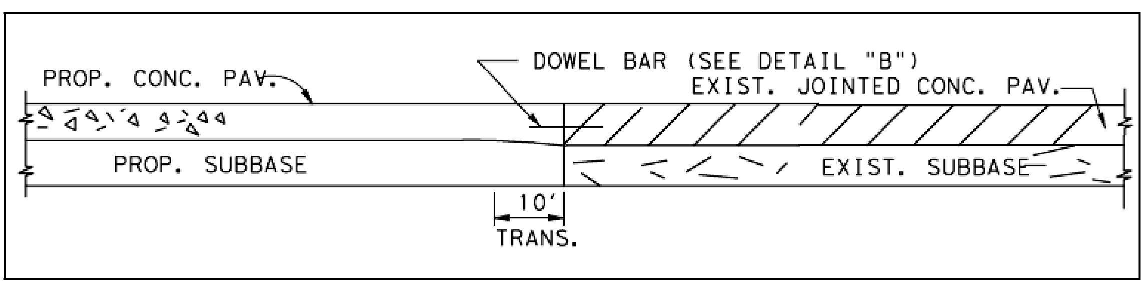
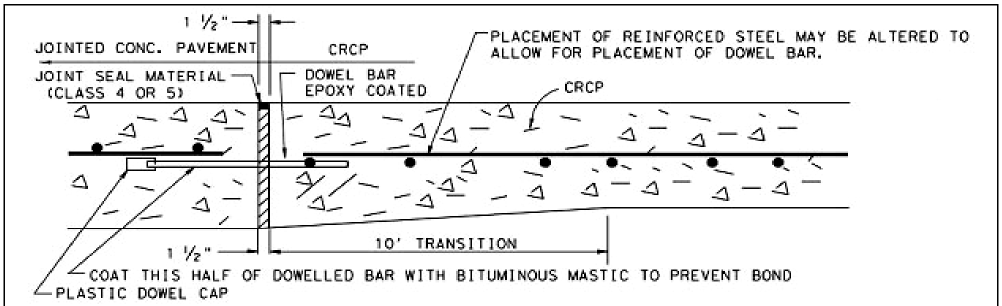


Figure 2-2 Thickness Transition between CRCP and JRCP (3).

Transition between CRC Pavement and JC Pavement

Figure 2-3 shows an expansion joint detail for the transition between JC and CRC pavements. This detail also shows a thickness transition. The plastic dowel cap is shown on the JC pavement side, but it may be more appropriate to place it on the CRC side of the joint since most of the movement is generated in the CRC pavement. Moreover, thickness transition on the JC pavement side is more preferable because constructing a thickness transition on the CRC pavement side may lead to widened cracking patterns in the CRC pavement.



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DOWEL SIZE	1"	1 ⅛"	1 ¼"
DOWEL LENGTH	18"	20"	22"
DOWEL BAR SPACING	12"	12"	12"

Figure 2-3 CRC to JC/JRC Pavement Transition (*3*).

Transitions between CRC Pavement and AC Pavement

The transition between a PCC pavement and an AC pavement is a very common, as well as problematic transition. Unless there are provisions made to gradually transition the expansion and contraction of the PCC to the AC pavement, there is a distinct possibility of developing a bump on the AC side of the transition joint. The transition for the expansion and contraction joint is made by incorporating one or two doweled expansion joints at the end of the PCC pavement. This detail also requires that for JC pavement, the transverse contraction joints near the transition be doweled.

Figure 2-4 shows a detail that has been used in the Houston District for transition from AC to CRC pavement. A thickened edge is typically used at a butt joint or on a joint where load transfer is minimal, such as that shown in this case between the asphalt and the CRC pavement. A butt joint inherently serves the purpose of an expansion joint well although there is usually no overriding need to isolate the movements of the concrete slab from the asphalt pavement section. Unless there are special measures employed to assure support uniformity across the joint between the two pavement sections, differential deflection between them can be a major issue relative to the performance of the transition. Consequently, a sleeper slab used in this detail would enhance performance given traffic and subgrade strength considerations. An additional concern with Figure 2-4 details is that there is no provision for expansion and contraction of the CRC pavement.

Typically a 1 to 1.5 in. expansion space is necessary at CRC pavement ends when there is no attempt made to restrict CRC pavement end movements. Without the expansion space between the CRC pavement and the AC pavement, uneven deformation may develop on the AC pavement at the transition joint.

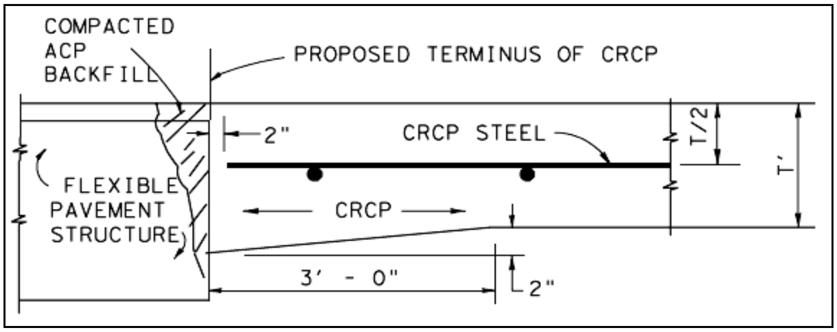


Figure 2-4 Transition Detail between CRC Pavement and Flexible Pavement (*4*).

Figures 2-5 and 2-6 show commonly used designs for the transition to a flexible pavement system that has the objective of converting the surface layer from asphalt to portland cement concrete. Performance-wise, the tapered concrete slab is intended to minimize differential deflection between the PCC and the hot mixed asphalt (HMA) pavement sections – particularly at the taper point of the concrete slab denoted as detail A. Experimental sections in the Bryan District have been under traffic for two years without any distresses. Another experimental section in the Beaumont District has transverse crack that occurred at the end of the taper slab about one year after construction. In many instances, transverse cracking initiates at this point and eventually propagates to the top of the asphalt surface. Consequently, any measures to reduce the concentration of stress at this point would constitute an improvement in the design of this transition – such as the use of a beveled edge at the end of the concrete slab taper. Moreover, careful construction will also help by reducing consolidation deformation in the HMA layer.

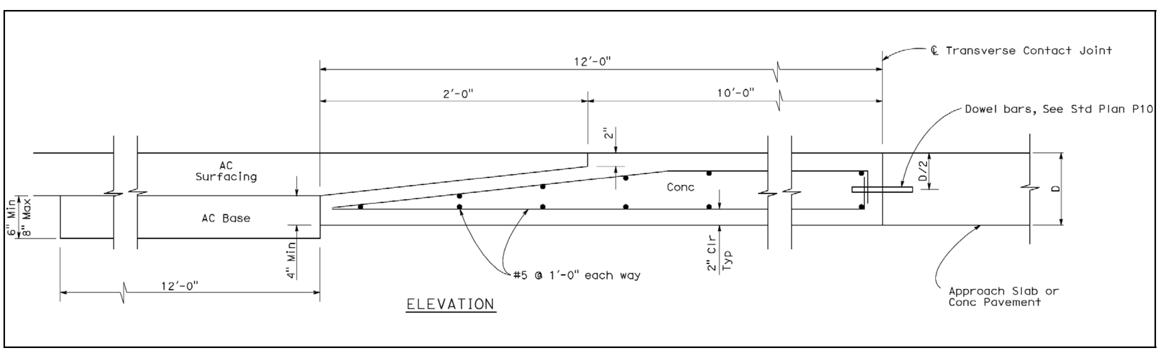


Figure 2-5 Concrete Pavement to Asphalt Concrete Pavement Transition Panel (*5*).

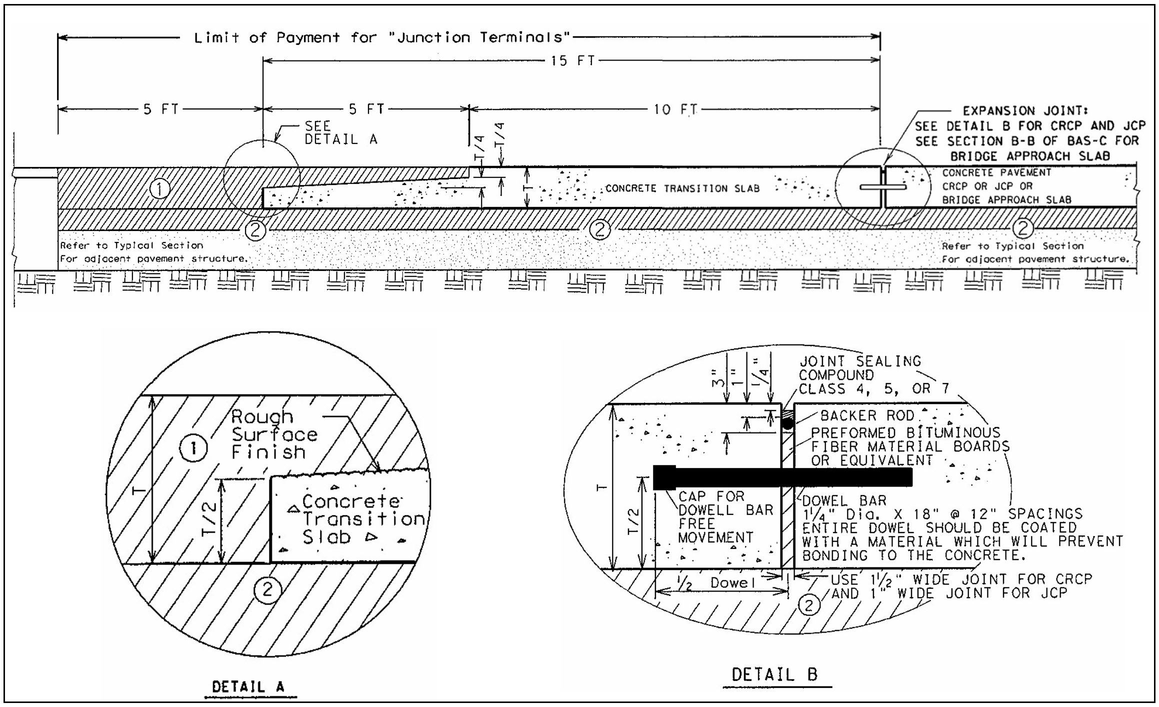


Figure 2-6 Transition between Flexible Pavement and Concrete Pavement (*6*).

As previously noted, since CRC pavement experiences a significant amount of movement at the terminal ends, an expansion joint is often justified at this location. The movement, however, at the expansion joint shown in Figures 2-5 and 2-6 is typically too much for sealing requiring, as an improvement to this detail, the use of a sleeper slab versus the use of dowels, which are more suited for a jointed pavement section (detail B shows the dowel and joint sealing). Nonetheless, the inclusion of an expansion joint effectively isolates the tapered section from the rest of the pavement. In addition to the previous comments about doweling, this detail would also work for a jointed pavement system.

Figure 2-7 shows a variation of the Figure 2-6 detail that was used on the SH 130 project in the Austin District. A form of this detail had been used previously in the Austin District, but a modification was adopted to minimize the formation of a 'shoving' bump at the end of the concrete ramp by insertion of an elastomer concrete plug between the concrete and the asphalt material to enhance the vertical deflection compatibility between the two pavement sections. Elastomer concrete is the type of material that can develop a strong bond with both material types to resist the high deflection difference at the joint while at the same time allowing freedom of movement to minimize shoving. D. S. Brown Delpatch or equal is recommended for elastomeric concrete on the SH 130 project.

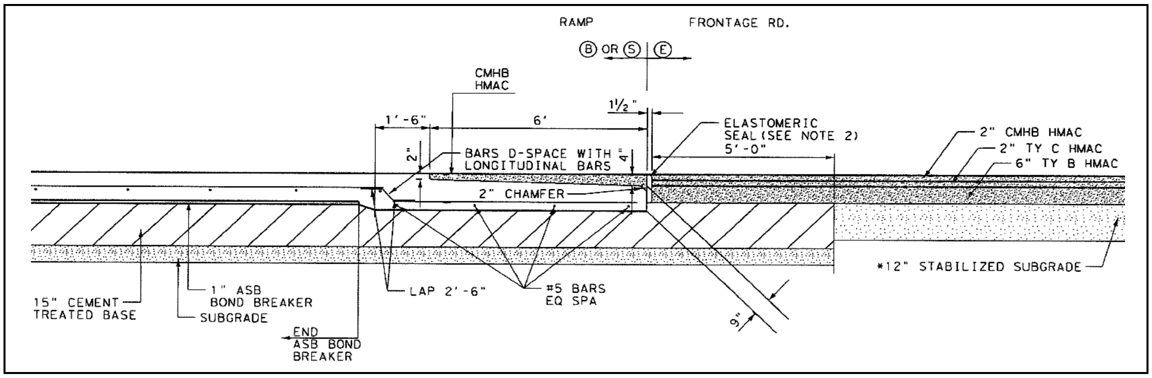


Figure 2-7 Concrete Pavement to Asphalt Pavement Tapered Transition (7).

Transitions between JC Pavement and AC Pavement

Figure 2-8 shows another example of the concrete pavement terminus at a flexible pavement, which again contains a butt joint but without a thickened edge. Contraction joints are sawcut into the last 25 ft to help reduce the joint opening at the asphalt/concrete interface (the first 10 ft interval is particularly useful in this regard where reinforced jointed pavement is present). However, a similar technique could be applicable to a continuously reinforced concrete pavement. Since a butt joint between AC pavement and the jointed concrete pavement is used, precautions are again warranted where traffic levels and subgrade strength considerations may dictate greater load transfer requirements than those provided by a butt joint. Accordingly, special measures are employed to assure support uniformity across the joint. A concern with the Figure 2-8 details is that there is no provision for expansion and contraction of the jointed reinforced concrete (JRC) pavement at the joint (similar as with CRC pavement). Without this provision, a bump may develop over a period of time on the AC pavement side at the transition joint.

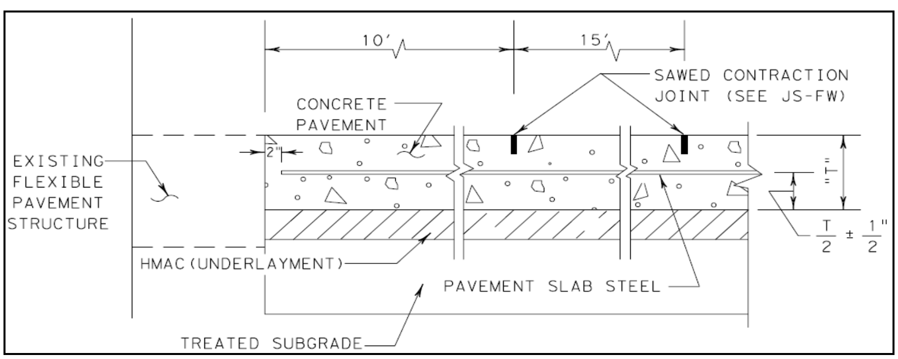


Figure 2-8 Concrete Pavement Terminus at Flexible Pavement (8).

Figure 2-9 shows another concrete pavement/flexible pavement transition used by the Fort Worth District. Incorporation of a sleeper slab ensures deflection continuity across the joint. However, the deflection patterns could generate a crack at the end of the sleeper slab unless a sufficiently stiff subgrade is utilized, which is justification for the treated subgrade. Also, a crack could be initiated due to the restraint slab movement within the transition itself at the point between concrete pavement and flexible pavement.

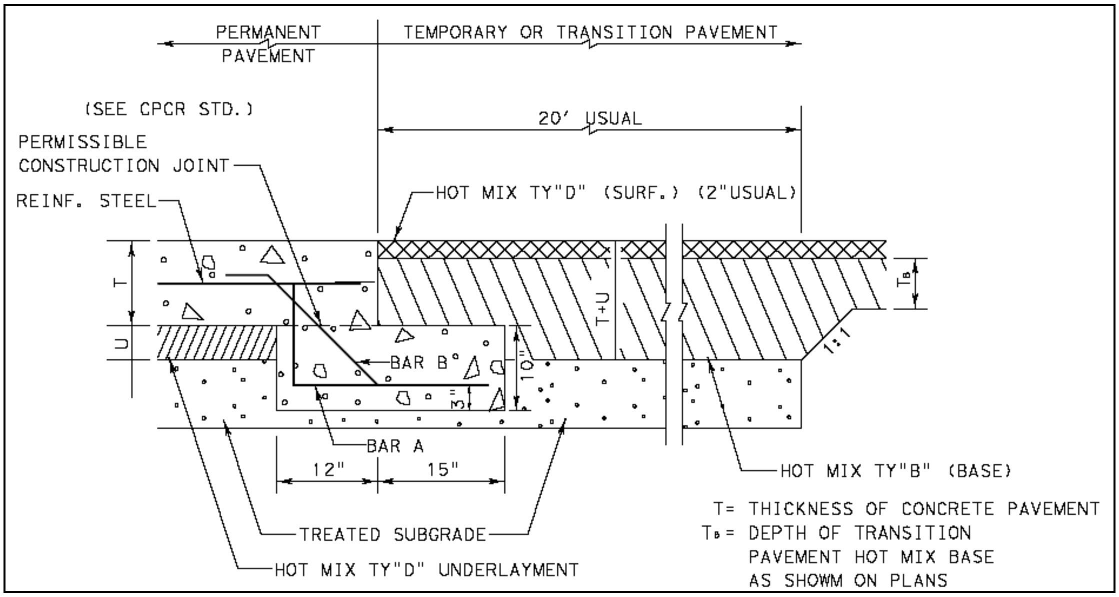


Figure 2-9 Concrete Pavement Terminus at Hot Mix Transition (*8*).

Figures 2-10 and 2-11 show a transition detail between jointed concrete pavement (JCP) and flexible pavement that is used by the Indiana DOT. Again, this detail involves a butt-type joint that consists of no special measures to ensure deflection or support continuity across the joint, which may under some circumstances of traffic and subgrade strength combinations pose a performance problem. Elaborating further, this detail may result in differential deflection between JCP and the HMA pavement sections, eventually reducing the riding quality and life of the transition. Similar to other transition details between JCP and AC pavement, a concern with Figures 2-10 and 2-11 details is that there is no provision for expansion and contraction of the JCP. Without the expansion space between the portland cement concrete pavement (PCCP) and the AC pavement, a bump can be expected to develop on the AC pavement side at the transition joint.

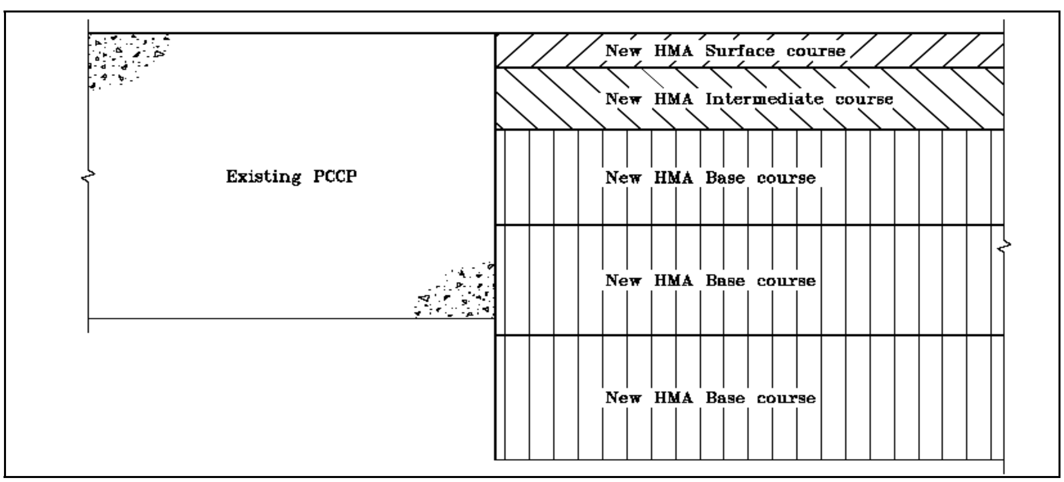


Figure 2-10 Transition Detail for Existing PCCP to New HMA Pavement (*9*).

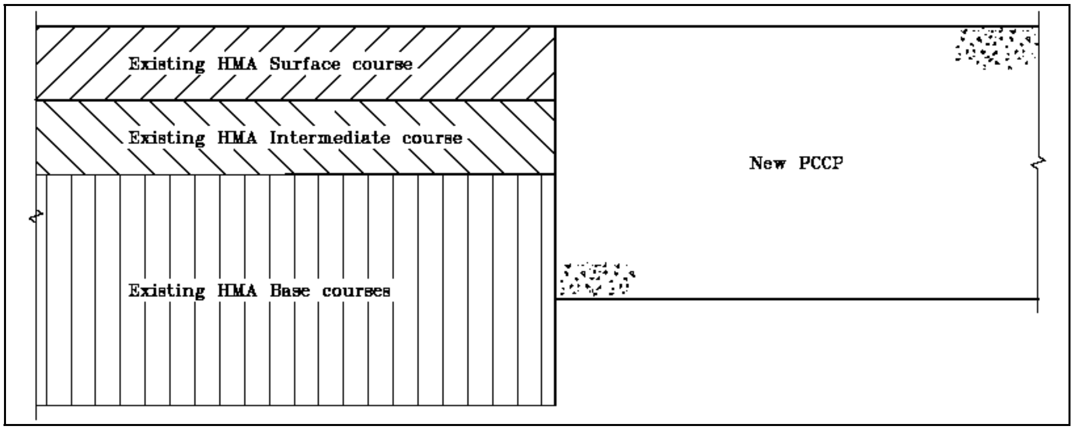


Figure 2-11 Transition Detail for Existing HMA Pavement to New PCCP (*10*).

Figure 2-12 shows a transition detail between JCP and flexible pavement that is used by CalTrans. A thickened edge is shown in this detail similarly as shown in the TxDOT standard transition detail depicted in Figure 2-4. As mentioned earlier, unless there are special measures employed to assure support uniformity across the joint between the two pavement sections, differential deflection between them can be a major issue relative to the long term performance of the transition.

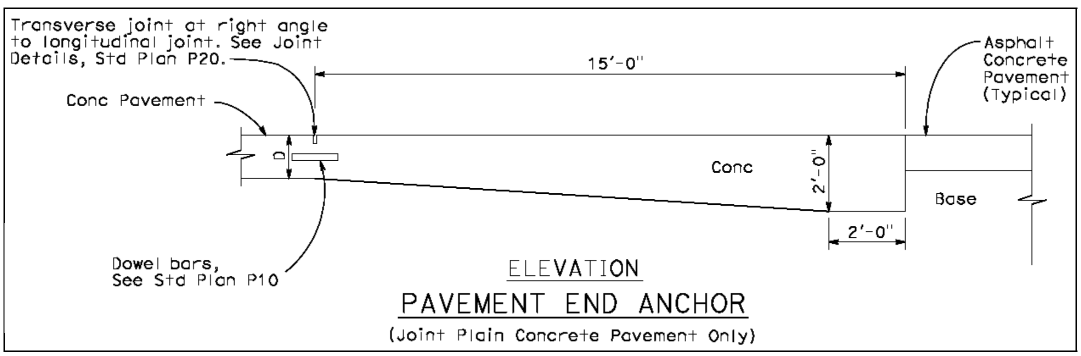


Figure 2-12 Transition Detail between JC Pavement and Flexible Pavement (5).

Terminals at Bridge Abutments

The objective of bridge terminal transitions is to facilitate change from one pavement type or structure to another pavement type or structure while maintaining a smooth vertical profile. Performance of the transition can often focus on the opening and closing of the transition joints and their ability to maintain proper stiffness throughout these openings and closings. However, differential settlements cannot be allowed to occur under the approach slab or otherwise the integrity of the transition may be threatened.

Figure 2-13 shows a terminal anchorage transition at bridge structures that had been used for many years by TxDOT and other state highway agencies. In the Houston District for instance, the standard for several years had been the use of a series of five concrete anchors, as indicated in Figure 2-13, placed at approximately 17 ft intervals, but their performance has been less than satisfactory. In many cases, the anchors simply failed to restrain the concrete and prevent excessive shoving into bridge abutments causing severe damage. The function of the anchoring system was to restrict movement of the transition joints. Improvements to this transition can perhaps be found in simplification and reduction of redundant features and the use of multiple transition joints. The design of the terminal has evolved to less restrictive configurations that focused on compensation for induced movements by the use of sleeper slabs, metal expansion joints, and similar flange-type connectors. Even with these features, failures in the vicinity of the steel flange still occurred requiring repair using elastomeric concrete materials. Nonetheless, in the opinion of many experienced pavement engineers, the less restrictive terminals are still the best option.

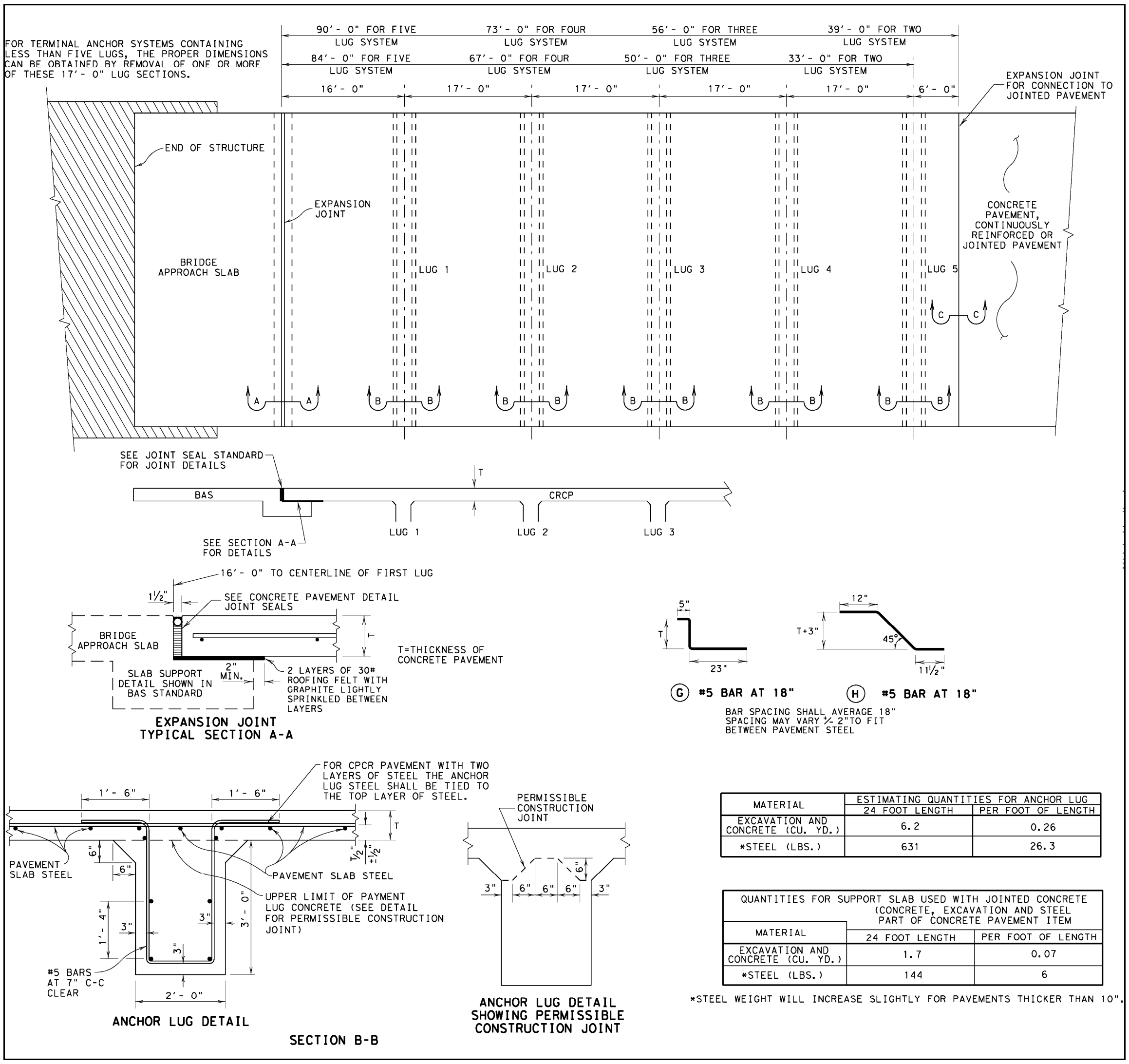


Figure 2-13 Terminal Anchorage for CRC Pavement (*11*).

Given TxDOT's history of terminal transition design at bridge structures, a new design was developed for the SH 130 project (Figure 2-14) in an attempt to improve the performance of the terminal joints. Again, the objective of the design is to isolate the movements between the pavement segments or elements while maintaining a smooth riding vertical profile through the transition. Figure 2-14 shows either a doweled joint or a sleeper slab alternative. If joint openings are expected to be more than 0.75 in., the sleeper slab option is recommended. The redundancy of previous designs were removed within the context of these two alternatives – one based on using a simple dowel joint and the other incorporating only a sleeper slab. Previously, two joints used in succession minimized potential shoving damage at the bridge abutment. The final SH 130 design employed some variation of these alternatives (i.e., dowels used in the second joint), but overall an improvement in the design is achieved, at least from an experience perspective.

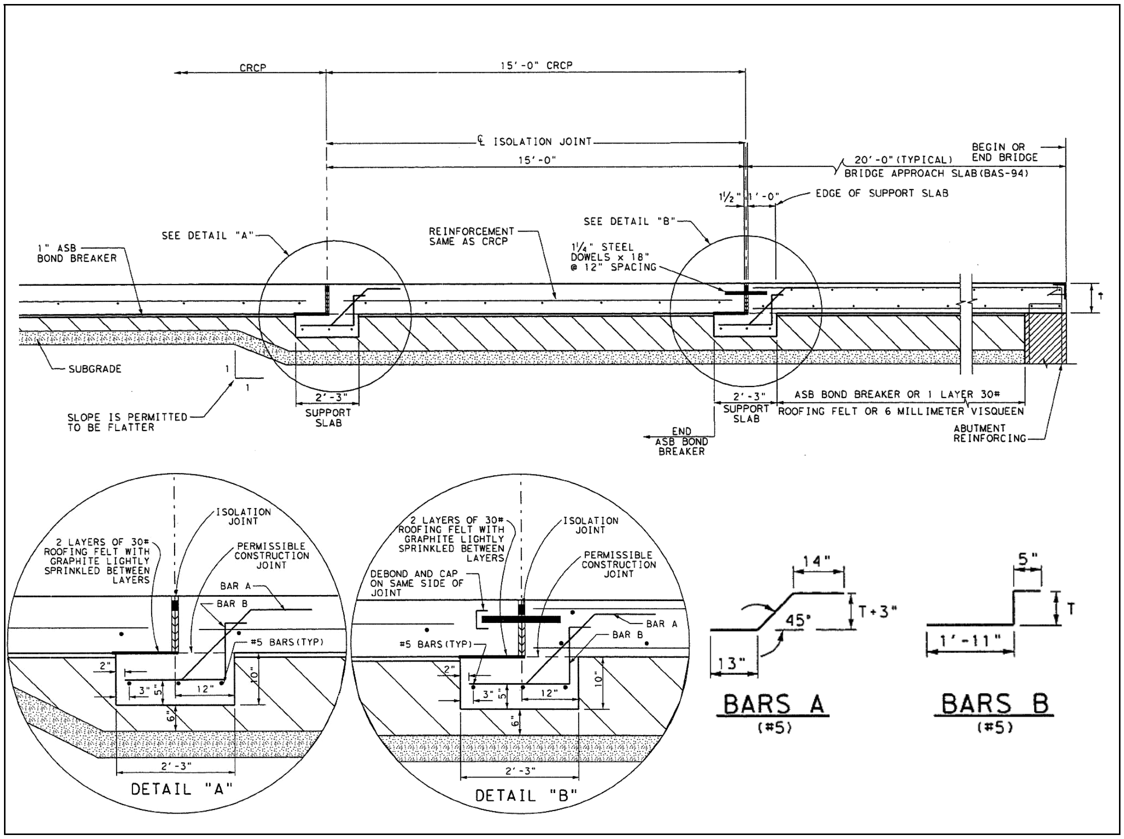


Figure 2-14 Double Sleeper Slab Transition to Bridge Approach Slab (*12*).

Figure 2-15 shows a concrete pavement bridge approach transition detail used by the Fort Worth District. Although continuous reinforcement is shown in the pavement, sawcuts are used to form joints to reduce the joint opening at the approach slab joint. The expansion joint at the approach slab is placed with a joint filler at a width of 1.5 in. and is not tied to the approach slab. Again, the objective of this transition is to isolate the movements between the bridge structure and the pavement structure but over the length of the sawcut pavement. Design issues evolve around the length of the sawcut section and the degree of friction provided by the subbase restraint.

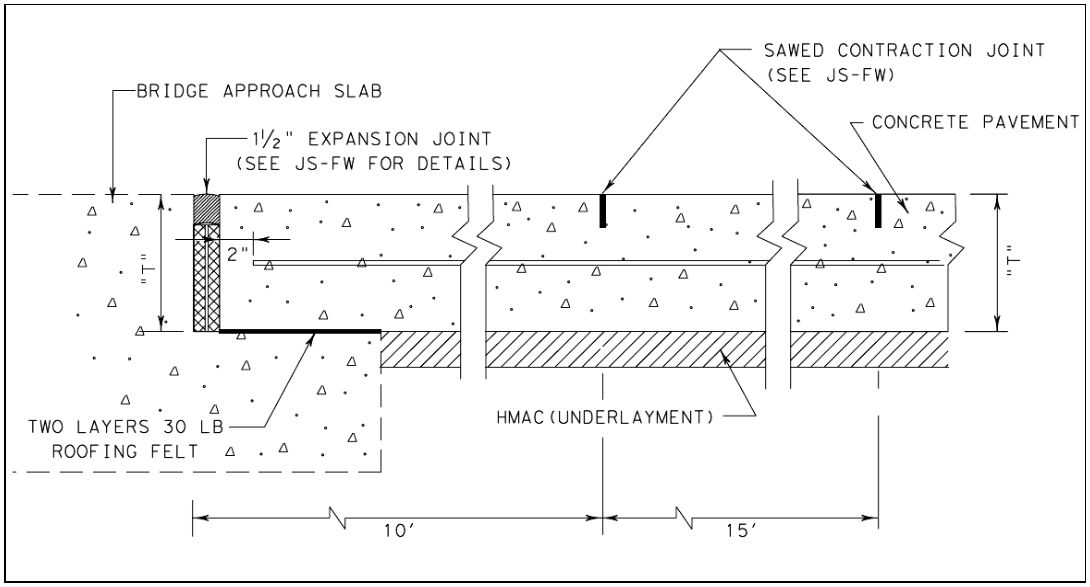


Figure 2-15 Transition to Bridge Approach Slab (*8*).

Figures 2-16 and 2-17 show design standards for transition between the approach slab and a JC pavement section used by CalTrans and Washington DOT, respectively. There is no specific information about the type of subbase used, but the subbase employed should be sufficiently stable to assure uniform support below the joint between the approach slab and the JC pavement to prevent differential deflection between them.

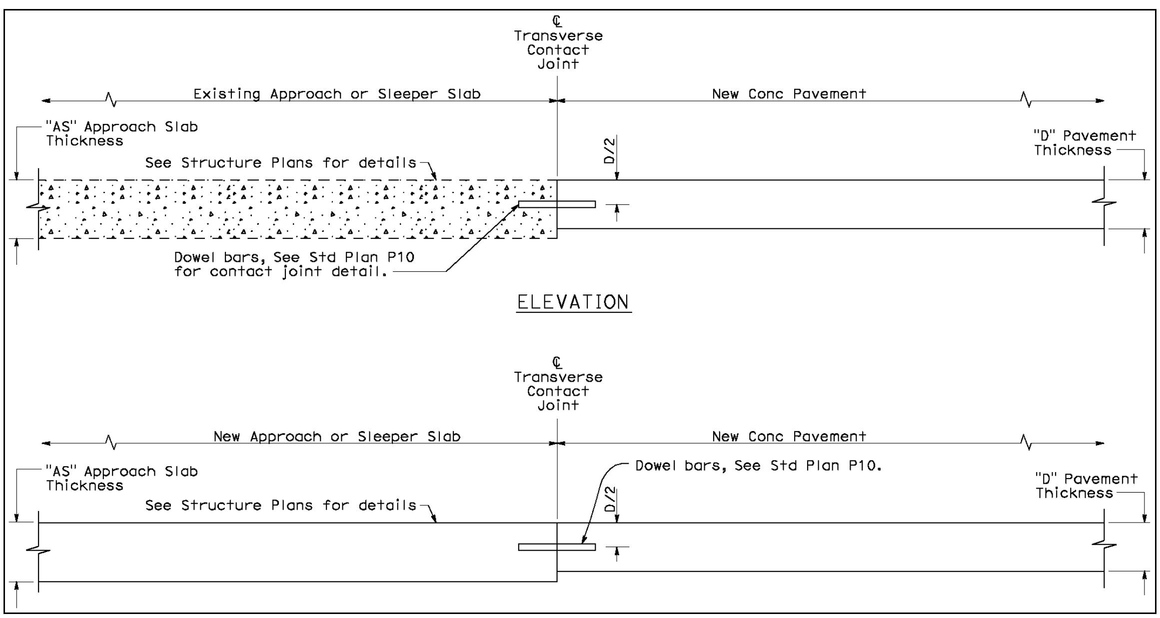


Figure 2-16 Concrete Pavement to Approach or Sleeper Slab (5).

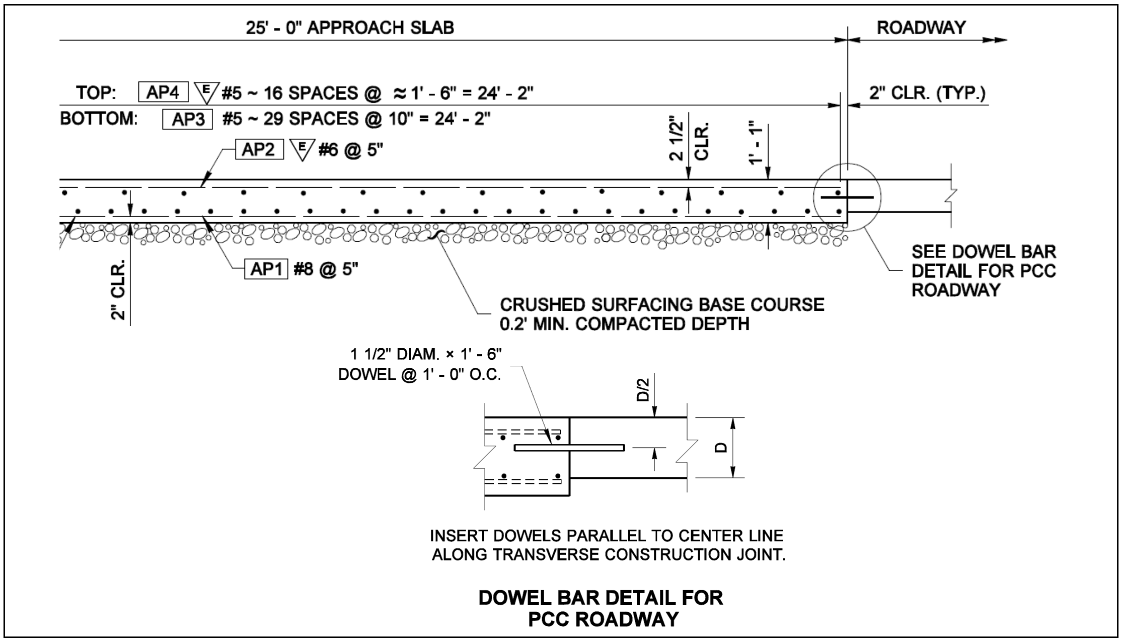


Figure 2-17 Transition between Bridge Approach Slab and Concrete Pavement (*13*).

Figure 2-18 shows a bridge approach pavement transition design used by the Illinois DOT. This design employs a sleeper slab and improved subgrade to facilitate stiffening the transition between the approach slab and concrete pavement. This detail calls for a preformed sealant but the sealant width needs to be selected based on the expected opening of the joint.

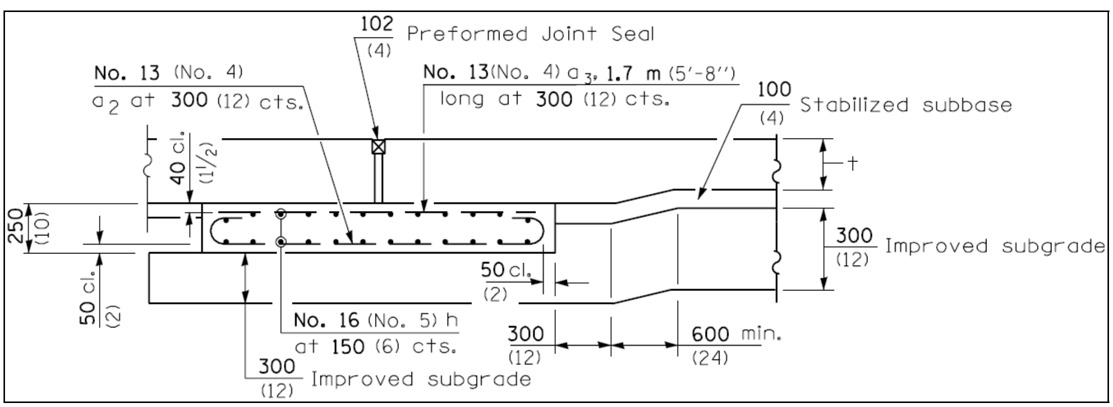
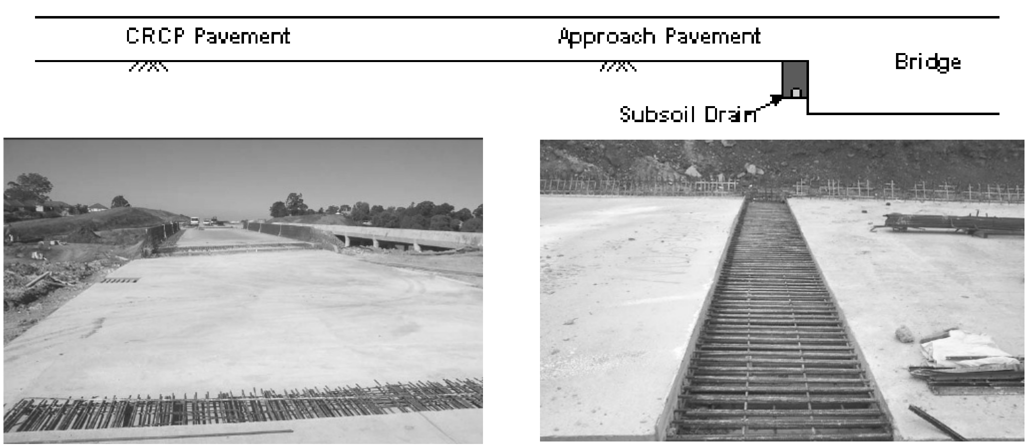


Figure 2-18 Bridge Approach Pavement Transition to Rigid Pavement (*14*).

Figure 2-19 shows a new transition concept advenced in Australia referred to as a “seamless” pavement. The objective of the seamless design is to improve constructability and remove transition joints that are often the source of maintenance issues. In this detail, the approach slab is securely linked to the bridge deck, and a closure joint is placed mid-span to facilitate movement between the bridge structure and the pavement structure during the construction process. The end product is considered as a continuum between the bridge structure and the pavement rather than individual elements. Once the closure joint has been placed (in the middle of the bridge deck placement), the continuous restraint across the bridge deck serves to maintain the position of the CRC pavement, much like it is intended in the anchored design shown in Figure 2-13. However, the integrity of this design would again be threatened if any part of the approach area was allowed to settle during the service period of the structure. This design may be best suited for CRC pavement construction but may be adopted with the appropriate jointing for jointed PCC pavement construction. The seamless concept does, however, offer several advantages, as follows (*15*):

- improved restraint not offered by other designs,
- increased simplicity in design and construction (particularly with respect to dealing with end movements and how the wing walls are tied into the approach slab),
- reduced maintenance and improved rideability,
- possibly reduced load-induced stressing on the bridge substructure, and
- simplification of the bridge deck drainage design.



Approach slab tied into deck slab.

Closure joint at mid-span.

Figure 2-19 Seamless Design Transition for CRC Pavement (*15*).

Partial Restraining/Inclusion Type Joints

The main objective of the drainage structure and pavement transitions is to isolate movement between them. Figure 2-20 shows the drainage structure and manhole covers with integral curb details.

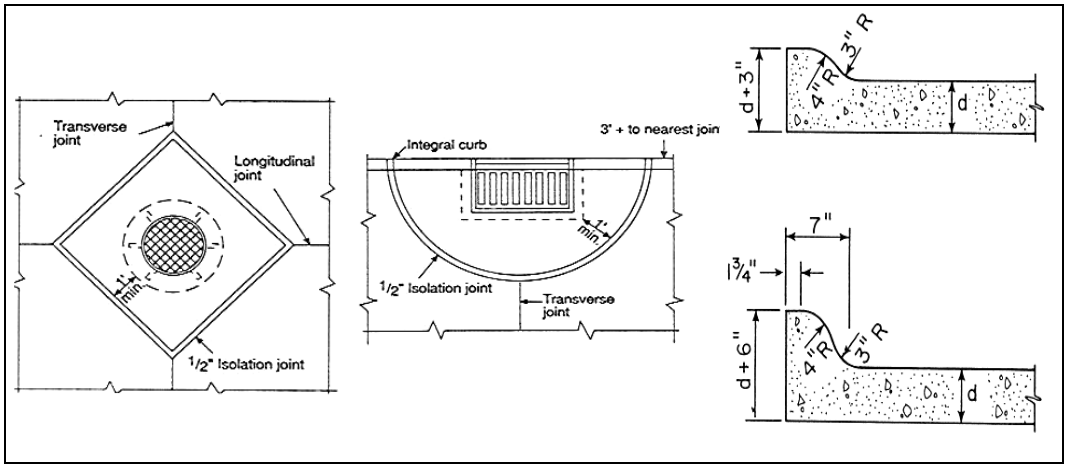


Figure 2-20 Drainage Structure, Manhole Covers, and Integral Curb (*16, 17*).

To this end, the drainage structure and the manhole cover need to be blocked out wide enough (at least 1 ft) and isolated from the pavement using an isolation joint. Construction involving an integral curb should be discontinued at the isolation joint. Doweling is only needed on the transverse joints to minimize restraint between the drainage structure and the main lanes.

LONGITUDINAL CONSTRUCTION JOINT CATEGORY

Longitudinal joints are parallel to the lanes, and construction joints are established along the edges of construction lanes while contraction joints are equipped normally between lanes by sawing or placing an insert with a deformed tie bar. Construction joints are naturally caused by the limitation of the paving equipment width, but contraction joints are used to prevent longitudinal cracking caused by the combination of curling and traffic loading. Longitudinal joints are typically of the butt type, which are at times needlessly keyed, and are typically restrained by use of deformed tie bars that may provide some load transfer between lanes and shoulders, although they are not as critical to performance as transverse joints are.

Lane/Shoulder Joints

Figure 2-21 shows a typical connection along a longitudinal joint to existing concrete and is associated with many of the factors previously mentioned. Tie bars can be drilled and placed with epoxy at mid-depth into an existing pavement structure if needed. Multiple-piece tie bars are also used.

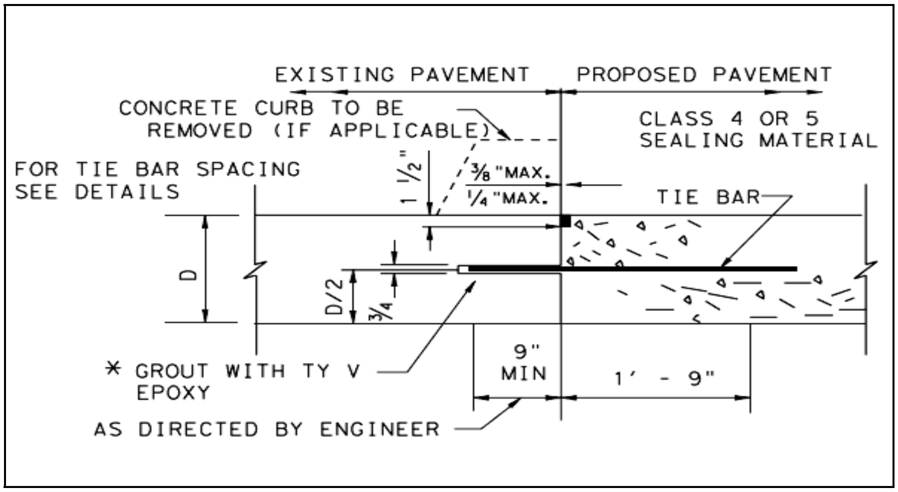


Figure 2-21 Typical Connection to Existing Concrete (*3*).

Figure 2-22 illustrates a lane-widening transition that is intended to accommodate a wider overlay than the existing supporting section. The objective for a transition of this nature is to maintain support consistency between the overlay and the supporting layer. Tie bars for load transfer between the old PCC pavement and the PCC extension slab can be placed the same as shown in Figure 2-21. This detail shows support for the widening to consist of an asphalt base layer. As long as the transition does not extend more than 12 in. beyond the asphalt/PCC interface, reflective cracking should not occur.

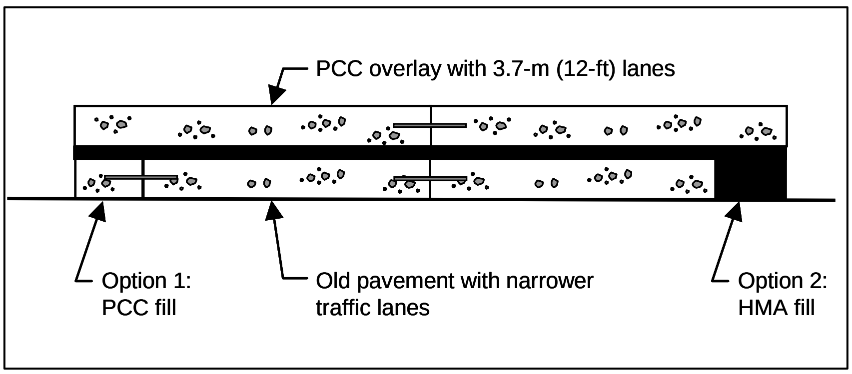


Figure 2-22 Lane Widening Transition (*18*).

Figure 2-23 shows an anchor and expansion hook bolt detail for a transition along a longitudinal joint. The objective of this type of transition is to maintain integrity and to prevent excess widening of the longitudinal joint. To this end, the longitudinal joint reinforcement is normally defined relative to the size and spacing requirements dictated by the length of 'drag' associated with the joint. The drag length can be defined as the shortest length to a free or unrestrained pavement edge and the amount of drag determined relative to the friction along the slab/subbase interface. Relative to the individual drag force applied to each rebar, the development length design can be circumvented by the use of a hook bolt although seldom used.

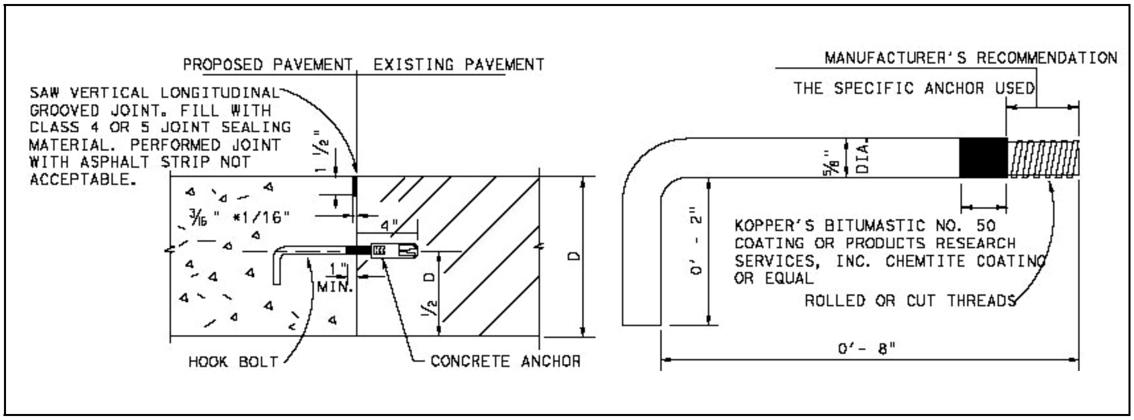


Figure 2-23 Expansion Hook Bolt Detail for Longitudinal Joint Transition (*3*).

Ramps/Gore Area Transition

A 3 ft wide squared-off end section is shown in detail "A" of Figure 2-24 where the mainline and ramp meet to terminate the end of the gore area. Although not shown explicitly, it is suggested that the squared-off segment be matched with a contraction joint in the ramp concrete to minimize the tendency for uncontrolled cracking in that location.

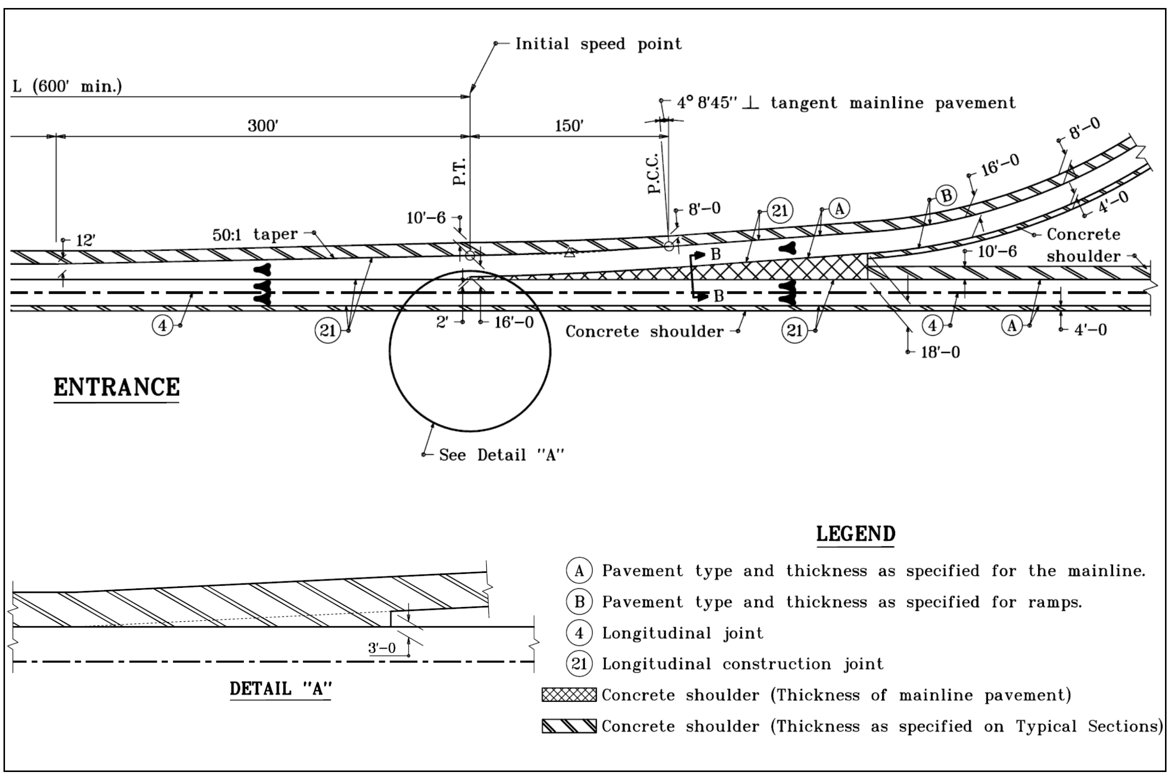


Figure 2-24 Ramp Entrance Terminal - Concrete Shoulder (*19*).

Intersections

Figure 2-25 shows transition details using CRC pavement. The interesting feature of this detail is the longitudinal steel of each lane is continuous in both directions through the center portion of the intersection (i.e., the longitudinal steel in one segment serves as the transverse steel in the other segment). Moreover, multi-piece tie bars are used on the transverse steel along the longitudinal joints. This two-way reinforced section serves as a shear key to strengthen and prevent distress at the transverse joint of the main lanes; however, it creates a restrained area in the overlap section, which may be subject to diagonal cracking in the intersection. This reinforcing scheme as been employed to facilitate construction of the intersection but as an alternative, continuous paving of the main lane pavement would help to isolate and promote directional movement of the pavement segments and minimize the degree of restraint and cracking associated with it.

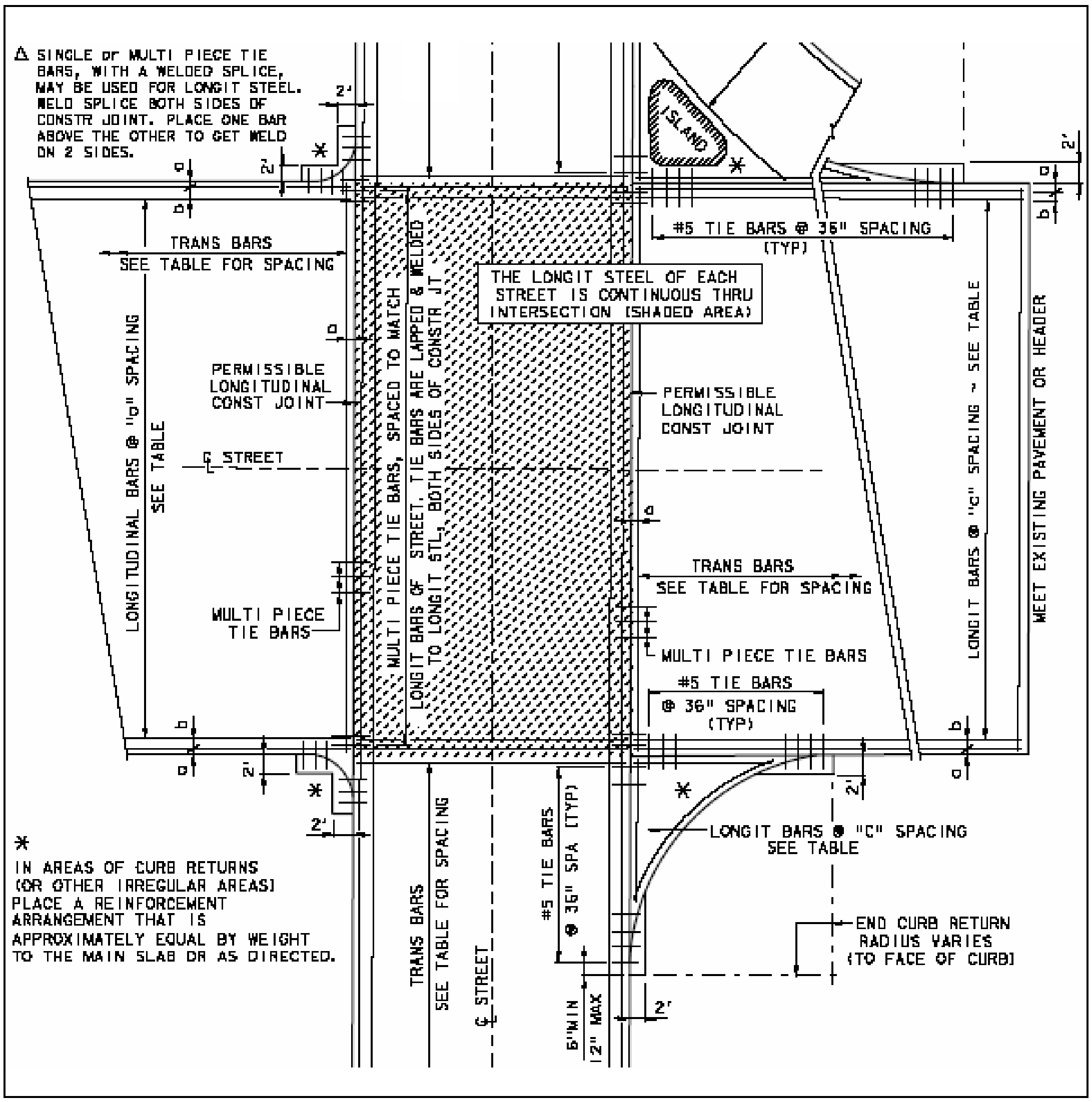


Figure 2-25 Continuous Reinforced Concrete Pavement - Intersection (20).

Figure 2-26 shows pavement joints and pattern details recommended by the American Concrete Pavement Association to minimize random cracking for jointed concrete in intersections. The joint spacing should not exceed 15 ft, and no slab corners should be cut any sharper than 60 degrees. Similar restrictions should apply for CRC pavement construction.

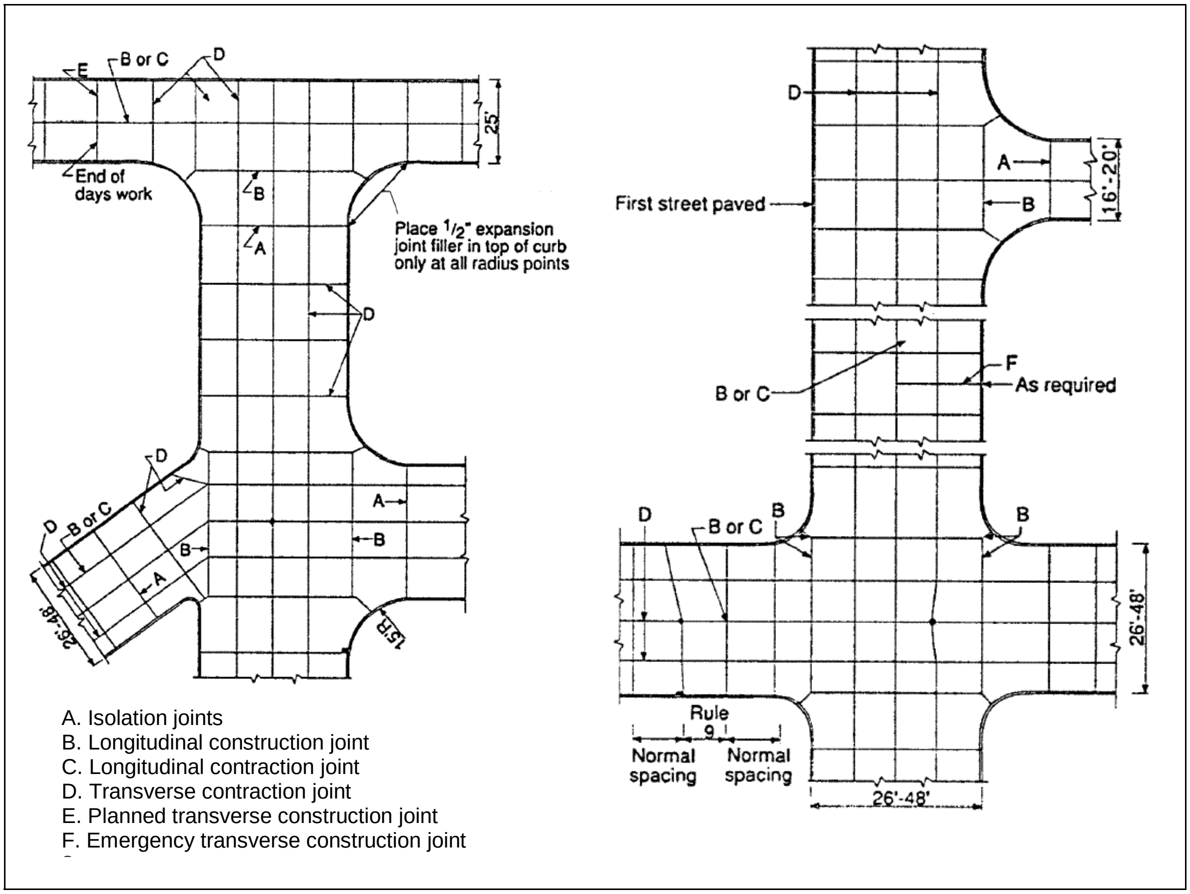


Figure 2-26 Pavement Joint and Pattern Details (*21*).

THICKNESS TRANSITION CATEGORY

Transitions between new pavement and existing pavement, main highway lane and ramp, and overlay may induce thickness change transversally or longitudinally. Thickness transitions need to provide continuity of support and continuity of deflection as well as a smooth ride through the transition between pavement segments. Recommended rates of taper for overlay are discussed below.

PCC Pavement Thickness Transition

Figure 2-27 shows the general transition between existing and new PCC pavement segments at a transverse joint. Performance-wise, this detail suggests the use of a butt joint across the transition that would lack deflection continuity unless it is doweled. To this end, use of dowel bars would help maintain load transfer across the joint. However, it is necessary to ensure continuity of support because of the different thicknesses. To this end, the use of a graduated thickness transition between the two slabs would help promote this continuity.

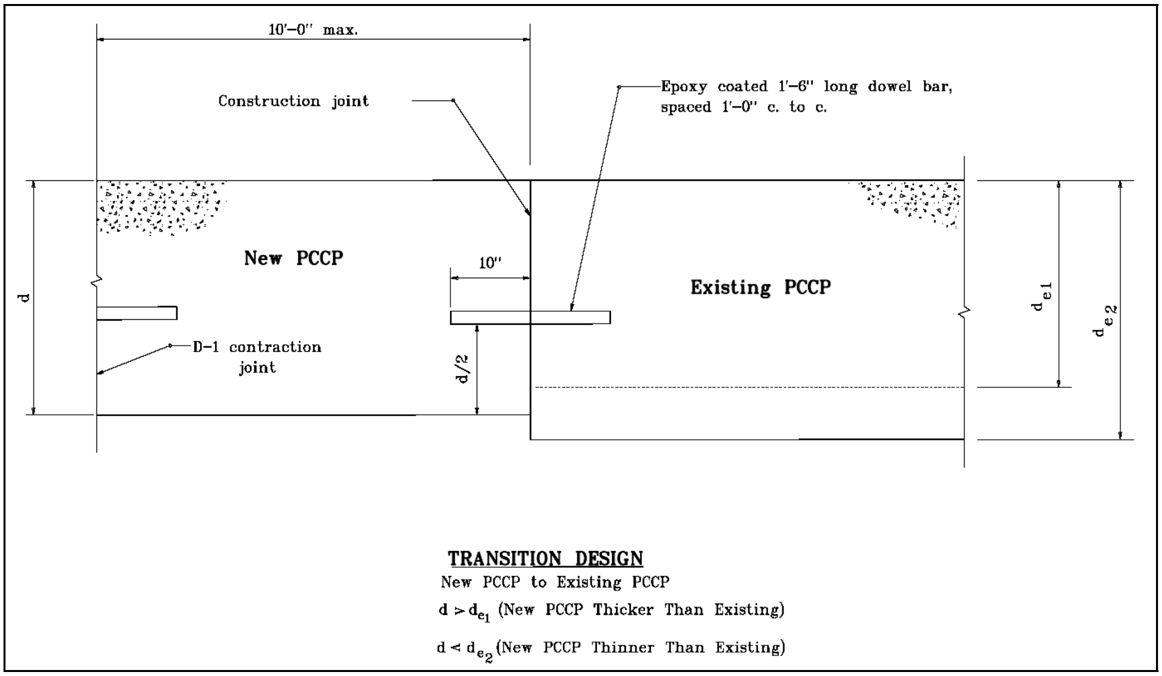


Figure 2-27 Transition Design Existing JC/JRC to New JC/JRC Pavement (*22*).

Overlays – Unbonded, Bonded, AC Transitions

Figure 2-28 shows an AC overlay transition that uses a milled notch in the surface of the existing pavement to promote the smooth transition. The transition is notched 1.5 in. and tapered over a distance of 60 ft. A tack coat is also placed to promote bonding to the HMA overlay.

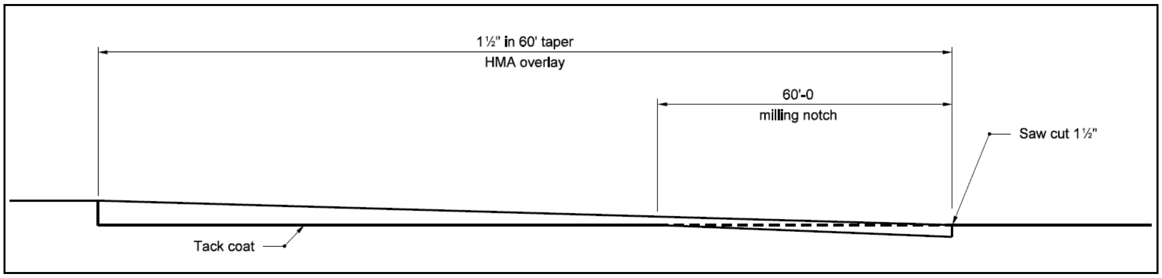


Figure 2-28 Termination of Mainline Pavement Treatment (*23*).

Figure 2-29 shows two optional overlay transitions, one consisting of milling and the other thickness transition. The thickness transition (with tack coat) for the AC overlay creates a thinner pavement section in the vicinity of the taper. A similar detail would not be recommended for a PCC bonded overlay.

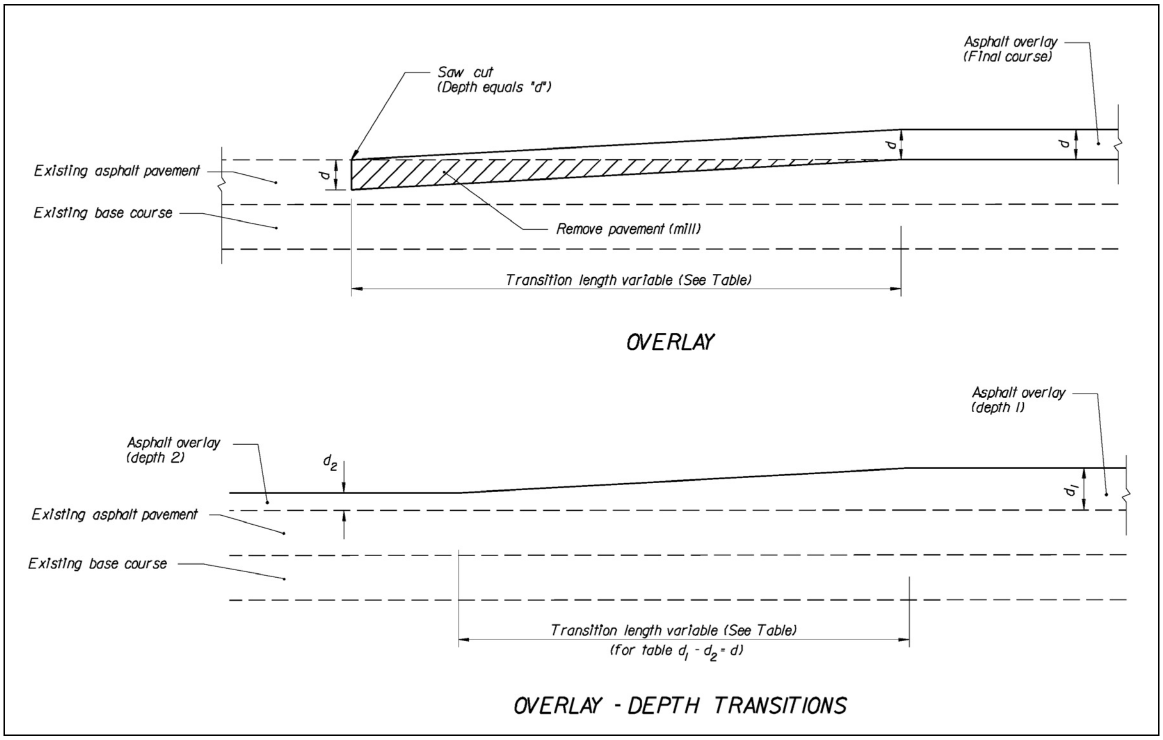


Figure 2-29 AC Pavement Overlay Transition (*24*).

The Minnesota DOT has studied transition design practices regarding the rate of transition tapers at the beginning and end of pavement overlays. Although no standard has been adopted, taper rates used throughout the state range from about 1:240 to 1:600. Experience in Minnesota indicates that a transition taper of 1:400 results in an acceptable ride a high-speeds. A recent survey of other state DOTs indicated that 1:400 is typical of taper rates used nation-wide. In order to provide pavement overlay transitions that provide a smooth ride and are economical, the rate of transition taper on pavement overlays should be determined from the values in Table 2-1.

Table 2-1 Rate of Transition Taper on Pavement Overlays (*25*).

DESIGN SPEED	RATE OF TAPER
50 mph or greater	1:400
35 to 45 mph	1:300
30 mph or less	1:200

[Figure 2-30](#) shows a transition design when new PCC pavement thickness is less than that of the overlaid slab. The thickness transition allows for a uniform thickness over a 1 ft distance from the joint. The 18 in. dowels are placed on 12 in. centers to ensure load transfer on the construction joint. A similar transition could apply for a longitudinal joint with the deformed bars replacing the dowel bars.

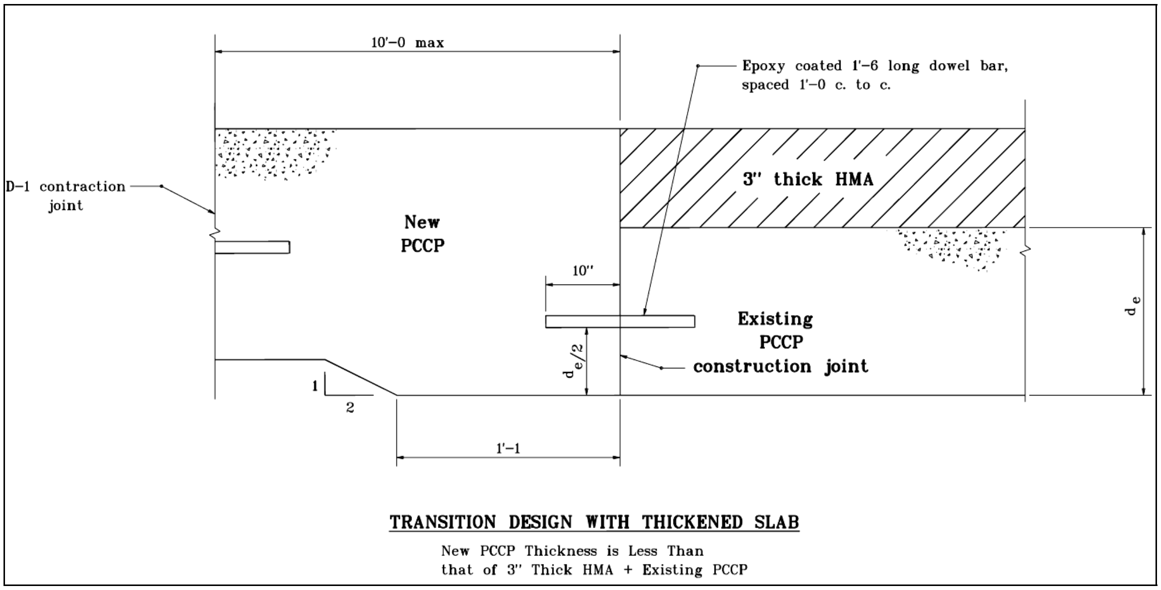


Figure 2-30 Transverse/Longitudinal Overlay Transition with Thickened Slab (*26*).

[Figure 2-31](#) shows the transition design for when new PCC pavement construction is thicker than the overlaid slab. This detail shows thickness transition occurring abruptly at the construction joint, which may promote a blockage of subbase drainage paths and create support problems. The joint is, however, doweled with an 18 in. bar on 12 in. centers. The dowel diameter would be determined based on the traffic level and the load transfer efficiency (LTE) of the joint.

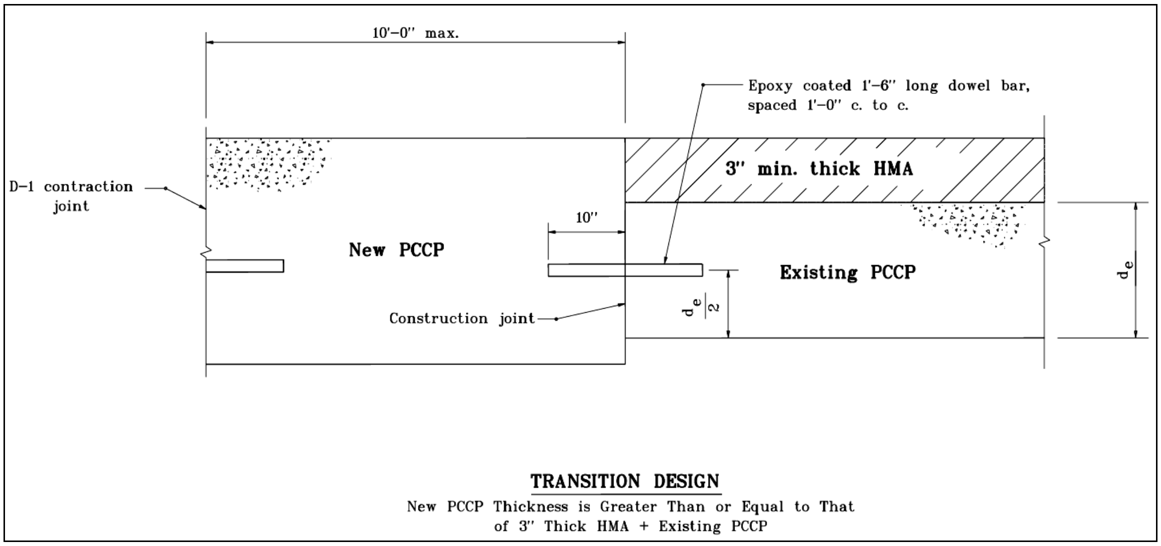


Figure 2-31 Pavement Type Transition - Transition Design (*27*).

Figure 2-32 shows a variation of the type of transitions shown in Figures 2-30 and 2-31. In this detail, the transition addresses a change in elevation between the two different elevations by maintaining a constant thickness of the concrete and subbase layer and creating a taper in the subgrade materials. When a JC pavement type is used for transitioning, transverse joints need to be employed approximately every 15 ft or less in length than maximum joint spacing of 4.44ℓ.

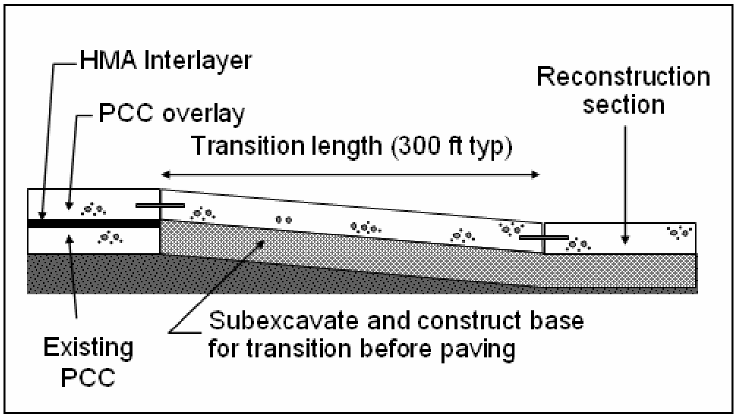


Figure 2-32 Unbonded Overlay to Existing or Reconstructed PCC Pavement Transition *(18)*.

CHAPTER 3
TRANSITION PERFORMANCE

Field visits were conducted in selected districts to survey conditions of concrete pavement transitions relative to slab cracking and associated distresses that may be related to improperly restrained segments due to inappropriate jointing practices or other design-related factors. Two older intersections on SH 225 and three recently paved intersections on US 59 in the Houston District were surveyed. Also, construction on SH 130 in the Austin District, SH 6 in the Bryan District, and recently constructed intersections in the Texarkana District are discussed below based on visual surveys of cracking distresses.

HOUSTON DISTRICT

The intersection of Center Street and SH 225 near Pasadena, Texas, was most likely constructed using a unidirectional layer of longitudinal reinforcing steel. Apparently, portions of the frontage road shown in Figure 3-1 were paved continuously through the intersection, which allowed for uniform contraction to occur across the frontage road concrete. This construction has performed well except for the restraint slabs in the radial transition areas pictured in Figure 3-1. Perhaps if the construction joint in Figure 3-1 was untied and replaced with a thickened edge or a sleeper slab, the cross street concrete may not be laterally restrained as much. These measures would help eliminate the type of cracking shown in the tied radial transition area between the perpendicular frontage road and cross street pavements shown in the figure.

Figure 3-1 Restraint Cracks in the Turning Radius Transition Area.

On the cross road connecting the frontage roads, cracks are associated with the corners of the drainage inlet box shown in Figure 3-2. The box would need to be isolated to a greater extent from the pavement structure in order to minimize the occurrence of such restraint cracking developing at the corners. The construction joint on the left side helps to isolate the restraining effects of the box on the pavement and minimizes cracking from the corner on that side. Figure 3-3 shows diagonal cracking, which could be minimized by placement of an untied construction joint between the frontage road and the cross lanes.

Figure 3-2 Restraint Cracking from Drainage Inlet Box.

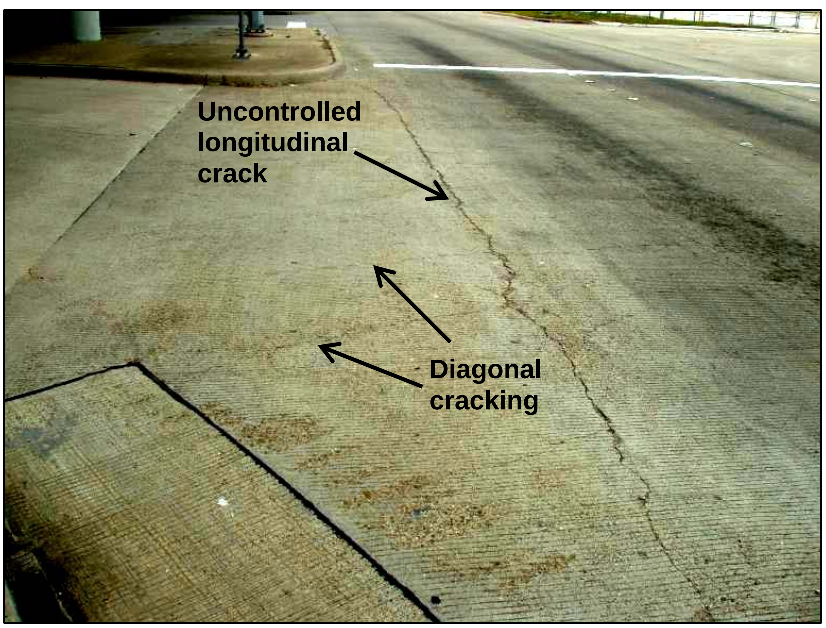


Figure 3-3 Uncontrolled Longitudinal Crack Suggests Location of an Untied, Longitudinal Construction Joint.

None of the construction joints showed distress at the intersection of East Boulevard and SH 225 near Pasadena, Texas, shown in Figure 3-4; however, uncontrolled longitudinal cracking was evident. It appears that this cracking was caused by improper location of the longitudinal construction joint in the turning ramp between the frontage road and cross street pavement. Placement of the construction joint too far into the turning radius perhaps over restrains the intersection concrete perpendicular to the ramp concrete. Unless this concrete is isolated, the construction joint should be placed at the beginning of the ramp transition to minimize the incidence of this type of cracking. Figure 3-5 shows normal development of transverse cracking in the frontage road concrete, but some relief cracking reflecting into the transition between the frontage road and the cross street paving is evident. Again, this reflection cracking could perhaps be eliminated by isolating the radial transition area.

Figure 3-4 Uncontrolled Longitudinal Cracking.

Figure 3-5 Reflection Cracking Associated with Radial Transition.

Figure 3-6 shows a construction joint on the intersection of Aldine Bender Road and US 59 near George Bush Intercontinental/Houston (IAH) airport, which appears to be part of a transition between an AC pavement section and a concrete pavement. The transition is faulted and spalled perhaps because of differential settlements. Figure 3-7 shows typical AC/PCC transition design detail used in the Houston District. It is interesting to point out that there was little provision in this design for load transfer or gradual change in cross-section deflection behavior between the AC pavement and the PCC pavements; therefore, discontinuous and sudden change of paving material may cause a significant differential deflection in the subgrade.

Figure 3-6 Faulted and Spalled AC/PCC Transition Construction Joint.

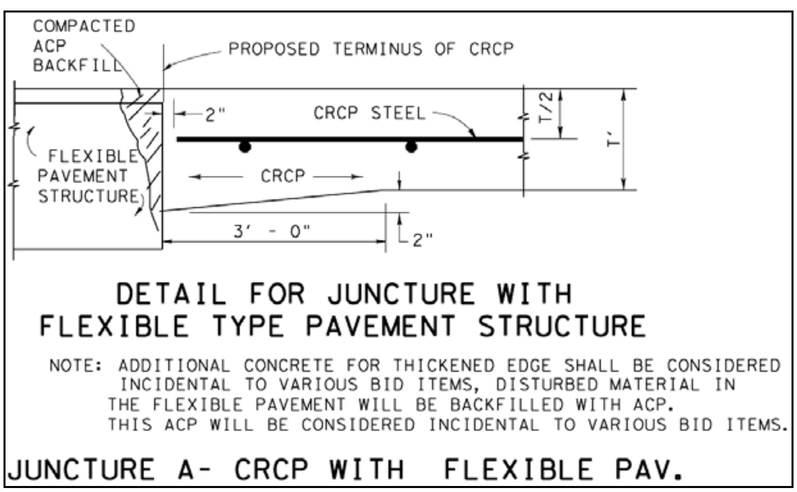


Figure 3-7 AC/PCC Transition Detail of Houston District (3).

Figure 3-8 shows a tied longitudinal construction joint between the frontage road and the cross road. This intersection was assumed to be constructed using bi-directional longitudinal reinforcing steel through the frontage road and cross street intersection. This joint appears to be performing well and has prevented uncontrolled cracking. Of all the intersections observed in this investigation, none of the construction joints at this intersection appeared to be distressed.

Figure 3-8 Good Performing Longitudinal Construction Joint.

General conditions of the recently constructed intersection at Rankin Road and US 59 in Figure 3-9 are very good. Figure 3-9 shows a longitudinal construction joint that isolates the frontage road from the cross road. Any restriction between frontage road and cross road appears to be minimized with this joint configuration. Due to the age of this intersection, it is assumed to contain bi-directional longitudinal reinforcing steel. Apparently, the longitudinal steel in the frontage road carries the shear stress induced in the cross street CRC pavement, which helps to resist the contraction movement at the construction joints in the cross street concrete and to prevent distress at these joints.

Figure 3-9 Longitudinal Construction Joint.

The intersection of Fostoria Road and US 59 in Figure 3-10 near Humble, Texas, is recently constructed and is currently in very good condition. However, it appears this intersection was constructed in a "patchwork" manner that disrupted the continuity of the pavement jointing in some areas. This problem was not widespread, but Figure 3-10 shows a discontinuity of the construction joint between the frontage road and cross road. However, no crack was visible at this vulnerable location. Figure 3-11 shows the proper location of the construction joint between the frontage road and cross road at the same intersection.

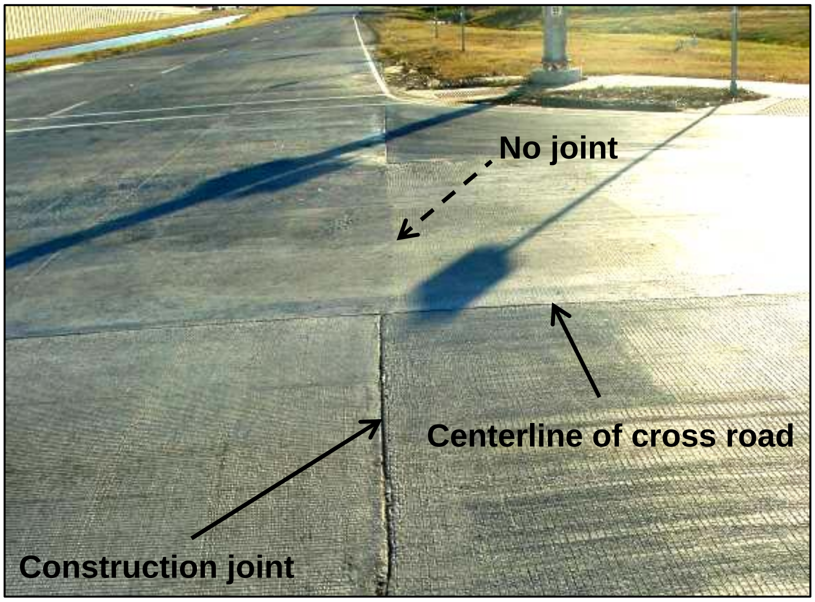


Figure 3-10 Discontinuity of Construction Joint between Frontage and Cross Roads.

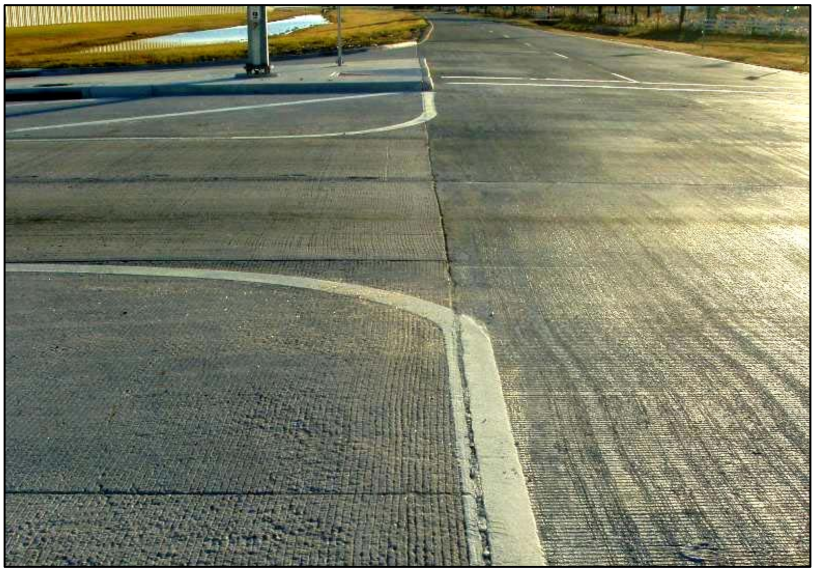


Figure 3-11 Proper Location of Construction Joint between the Frontage and Cross Roads.

BRYAN DISTRICT

Figure 3-12 shows a diagonal crack caused by the drainage inlet box. Most corners of drainage box or drop inlet structures generate a random diagonal crack in the pavement even if it is isolated from the pavement. A random crack of this nature can be difficult to avoid since the corner area is the weakest point in the slab. Figure 3-13 shows construction on Texas Avenue in College Station, Texas, where transverse sawcuts were made at the corner of the manhole structure. These sawcuts induced a transverse contraction joint in the pavement to prevent a diagonal crack from forming, effectively isolating the pavement from the manhole structure.

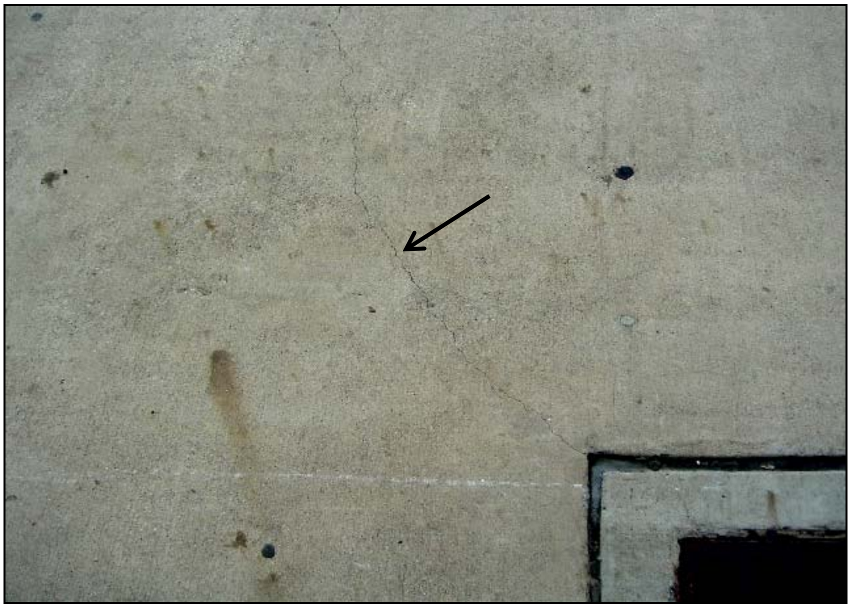


Figure 3-12 Random Diagonal Crack on the Drainage Box Corner.

Figure 3-13 Transverse Sawcuts on the Manhole Structure Corner.

At a different location in College Station, Figure 3-14 shows corner cracks in a turning radius slab – this apparently occurs rather frequently. This portion of the corner slab is rather narrow and may be susceptible to corner cracking under applied loading. Figure 3-15 shows a case of a modified corner design in the Bryan District that prevented cracking of this nature. The joint is isolated to prevent restraint cracking and configured with an obtuse angle to better resist corner cracking. Minimizing slabs with corners sharper than 60 degrees in the turning radius will help to reduce unwanted corner cracking.

Figure 3-14 Corner Crack in the Turning Radius.

Figure 3-15 Obtuse Angle Joint Corner in the Intersection.

AUSTIN DISTRICT

Figures 3-16 and 3-17 show newly constructed CRC pavement on SH 130 in the Austin District near Pflugerville, Texas, at the end of a gore area on a ramp. Where the ramp and main traffic lane meet, a 2 to 3 ft squared-off end section is normally formed. Because of this squared-off area, uncontrolled cracking is induced. The use of a transverse sawcut at the end of the gore area may help eliminate this type of cracking similar to the manhole structure shown in Figure 3-13. A transverse construction joint would also help to prevent uncontrolled diagonal cracking on the ramp concrete surrounding the gore area.

Figure 3-16 Gore Area in the Ramp Transition.

Figure 3-17 Random Diagonal Crack on the Gore Area.

TEXARKANA DISTRICT

Figures 3-18 and 3-19 show an intersection in Texarkana, Texas, with restraint cracking that occurred shortly after construction. The cause of this cracking is not entirely evident, but some may be due to late sawcutting and some due to poor alignment. Where misalignment cannot be avoided, the use of isolation joints is recommended in order to reduce the level of restraint and the potential of uncontrolled cracking throughout the intersection concrete. A similar approach may be needed to effectively isolate the frontage road pavement from the crossing road pavement in order to avoid lateral restraint caused by differential directional movement. The dowel bars should not be employed on the longitudinal joint.

Figure 3-18 Restrained Transverse Cracking.

Figure 3-19 Restrained Diagonal Cracking.

SUMMARY

In many districts, various forms of cracking were witnessed, providing a means to ascertain the causes and concepts for design improvements to prevent such cracking in future construction, such as:

- Restraint cracking in the radial transitions – Perhaps if the construction joint was untied and placed with a thickened edge, the cross street concrete may not be laterally restrained as much.
- Corner cracking associated with restrained corners of drainage inlet boxes – The box would need to be isolated to a greater extent from the pavement structure in order to minimize the occurrence of restraint cracking developing at the corners.
- Uncontrolled longitudinal cracking – This cracking may have been caused by improper location of the longitudinal construction joint in the turning ramp.
- Transition faulting and spalling between the AC pavement and the PCC pavement – Discontinuous and sudden change of paving material perhaps caused significant differential deflection in the subgrade.
- Intersection using bi-directional longitudinal reinforcing steel – The longitudinal construction joint in these designs appeared to be performing well and has not shown signs of excessive shoving or crushing. This may be due in part to the tendency of the longitudinal steel in the frontage road to carry the shear stress induced in the cross street CRC pavement, which helps to resist the contraction movement at the longitudinal construction joints in the cross street concrete.
- Intersection patchwork paving – Disrupted the continuity of the pavement jointing in some areas.
- Transverse sawcut at the corner of manhole structure – This induced transverse contraction joint on pavement to prevent random diagonal cracking
- Corner cracking in the turning radius end – Because the corner slab area is narrow and has an acute angle, it tended to be susceptible to load-induced cracking. Improved design would entail the use of an obtuse angle to better resist against corner cracking.
- Diagonal cracking at the end of the gore area on the ramp – Squared-off area tended to induce uncontrolled cracking and the use of a transverse sawcut at that location can help to prevent this uncontrolled cracking.
- Excessive restraint in intersection concrete caused by over tying pavement segments – Use of an isolation type joint on one side is recommended in order to reduce the level of restraint and the potential for uncontrolled cracking throughout the intersection concrete.

CHAPTER 4
ELEMENTS OF TRANSITION BEHAVIOR

Transitions in concrete pavements are often subjected to environmental effects such as temperature change, moisture content variation, and subgrade volume change during its service life. Temperature and moisture differences between the top and bottom of the slab generate stresses that can promote cracking under traffic loading. Subgrade volume changes by non-uniform settlement or expansion is controllable to some extent by the use of treated base materials.

Another source of stress due to traffic loadings is permanent deformation below the slab, especially at the corner area. A corner loading is of particular concern if load transfer between adjoining slabs is low, but if load transfer devices are present in the joint, deflection could be reduced by 50 percent. This chapter discusses the major factors of transition behavior such as;

- radius of relative stiffness (RRS or ℓ-value);
- modulus of subgrade reaction (k-value);
- combined slab thickness and elastic modulus;
- joint stiffness (J-factor);
- load transfer efficiency, and;
- reliability considerations.

ENVIRONMENTAL INDUCED CRACKING STRESS

Joint spacing, slab thickness, and joint stiffness are the prime factors in the performance of concrete pavement transitions. Maximum joint spacing is a function of environmental factors such as temperature and moisture changes in the pavement. When joint spacings are short, curling stress in the pavement is low, and small joint openings between two adjoining slabs can be small. Short joint spacings result in smaller openings and good load transfer by aggregate interlocking; however, it may reduce rideability with an increased number of sawcut joints. The advantages of longer joint spacing are lower construction and possibly better rideability but with greater vulnerability to cracking due to a combination of traffic and climatic factors with the possibility of wider joint openings and decreased LTE. Dowelled joints could compensate for the loss of aggregate interlock and LTE; therefore, proper joint spacing needs to be balanced against economy for dowelling and good performance design.

Joint Spacing

Joint spacing for jointed concrete pavement can be calculated based on theoretical considerations tied to subgrade strength, slab thickness, and curling and warping behavior of the slab. Curling and warping behavior will induce uncontrolled cracking if the joint spacing is improperly selected. Since maximum joint spacing depends on subgrade strength, appropriate evaluation of the modulus of subgrade reaction, k-value is important for proper joint design. Subsequent discussion about subgrade strength and slab thickness elaborates on how they are related to joint spacing.

Figure 4-1 represents the relationship between a curling-related stress coefficient, C and slab length, L and the ℓ-value. The stress in the slab increases radically when slab length is greater than 3ℓ. Joint spacing for jointed pavement could vary according to the subgrade k-value and slab thickness, but the maximum joint spacing should not exceed 4.44 times the ℓ-value since the maximum stress occurs at a distance of $\pi\ell\sqrt{2} \approx 4.44\ell$ from the slab end. A high potential for transverse cracking exists for slab lengths exceeding 4.44ℓ.

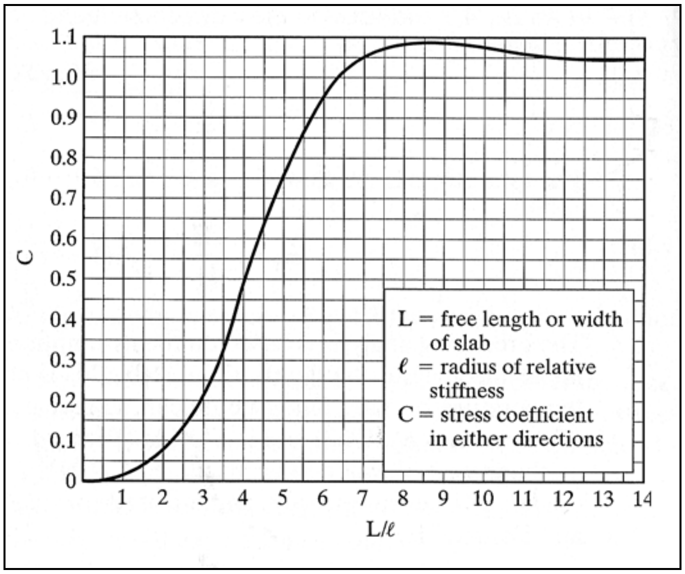


Figure 4-1 Stress Coefficient at the Center of Slab for the Curling Ratio L / ℓ (*28*).

Radius of Relative Stiffness

Radius of relative stiffness (RRS, ℓ-value), which is defined in equation 1, is the stiffness relationship between the concrete slab and subgrade support (*29*). It represents the degree of resistance to slab deflection relative to the magnitude of subgrade reacting pressure. The ℓ-value increases as slab thickness or the elastic modulus of the concrete increases but decreases as the subgrade k-value increases.

$$\ell = \sqrt[4]{\frac{Eh^3}{12(1-\nu^2)k}} \qquad [1]$$

Where, ℓ = radius of relative stiffness (in.),
E = elastic modulus of the PCC layer (psi),
h = thickness of PCC slab (in.),
ν = Poisson's ratio, and
k = modulus of subgrade reaction (pci).

Modulus of Subgrade Reaction

Modulus of subgrade reaction k can be determined by the circular plate loading test *(30)*. The test procedure involves measuring the plate deflection relative to the reaction of subgrade during the loading of the plate. However, joint spacing factors relative to the stress behavior, illustrated in Figure 4-1, is related to the effect of the slab support immediately below the slab, particularly where stabilized base is involved. Therefore, joint spacing is a function of the slab thickness and the "effective" k-value immediately below the slab. The effective k-value depends on the subgrade k-value, and thickness and stiffness of the subbase layer supporting the concrete slab. Unfortunately, there is no established method to determine the "effective" k-values other than to perhaps adopt adjustments to the subgrade k-value indicated by data published by portland cement association (PCA) *(31)*. Table 4-1 shows adjustment of k-value for treated subbases that could be construed for determining an effective k-value for curling purposes. It is well accepted that cement-treated subbases significantly increase the effective k-value over a subgrade k-value or that is caused by use of untreated subbases. Note that the employment of the adjusted values to the subgrade k-value as recommended by PCA was intended for load effects (which the authors advise against) rather than for use in compensating for curling effects. Although the recommended use of this tabular data is somewhat unusual, a beneficial result is gained.

Table 4-1 Design k-Values for Untreated and Cement-Treated Subbases *(31)*.

Subgrade k-value, pci	Untreated subbase k-value, pci				Cement-treated subbase k-value, pci			
	4 in.	6 in.	9 in.	12 in.	4 in.	6 in.	8 in.	10 in.
50	65	75	85	110	170	230	310	390
100	130	140	160	190	280	400	520	640
200	220	230	270	320	470	640	830	-

LOAD INDUCED PAVEMENT DEFORMATION

Slab transition thickness is an important aspect of pavement design not only because it serves as a starting point for other factors related to the design but also because it significantly affects the amount of deflection induced in a concrete pavement. If slab thickness is insufficient to achieve adequate stiffness or bending resistance for the given design load and deflection criteria, a pavement transition may suffer from premature deterioration with serious cracking in a short period of time. When slab thickness is adequate for the design load but lacking relative to deflection criteria, load transfer devices could be used to solve this problem. Load transfer improves joint stiffness, and the stiffness of the joint is an element in the LTE between adjacent slabs that serves to reduce deflection. Stiffness consists of two components, one due to aggregate interlocking and the other due to the reinforcing steel bar or dowel. When joint stiffness is insufficient and does not satisfy the deflection criteria, a jointed pavement transition may suffer from faulting or corner cracking. Again, the amount of deformation of a concrete pavement at a joint under load depends upon the resistance of the joint to load deformation.

Slab Thickness

A thickness design criteria for pavement transition should be deflection-based rather than fatigue-based, since traffic effects in many instances are accounted for in the original pavement design. Therefore, a check on the design thickness based on the maximum allowable deflection is in order. If the design thickness does not meet the allowable slab deformation criteria, load transfer devices such as dowel bars or sleeper slab elements should be considered (*32*). However, in the cases where load transfer requirements cannot be met, the design slab thickness may need to be adjusted if subgrade and subbase conditions cannot be modified.

As a general concept, the 'effective' slab thickness is an equivalent single slab thickness varying as a function of the degree of bonding between the concrete slab and the base layer. Figure 4-2 shows the effective thickness (by equation 2) for unbonded concrete slabs and bases, which often serves as a good assumption for concrete pavement systems incorporating a bond breaker. Accordingly, increasing the elastic modulus of base increases (how be it slightly) the effective thickness.

$$h_e = \sqrt[3]{h_c^{\ 3} + \frac{E_b}{E_c} h_b^{\ 3}} \qquad [2]$$

Where, h_e = effective thickness of combined slab (in.)
h_c = thickness of concrete slab (in.)
h_b = thickness of base (in.)
E_c = elastic modulus of concrete (lb/in.^{2}, psi)
E_b = elastic modulus of base (psi)

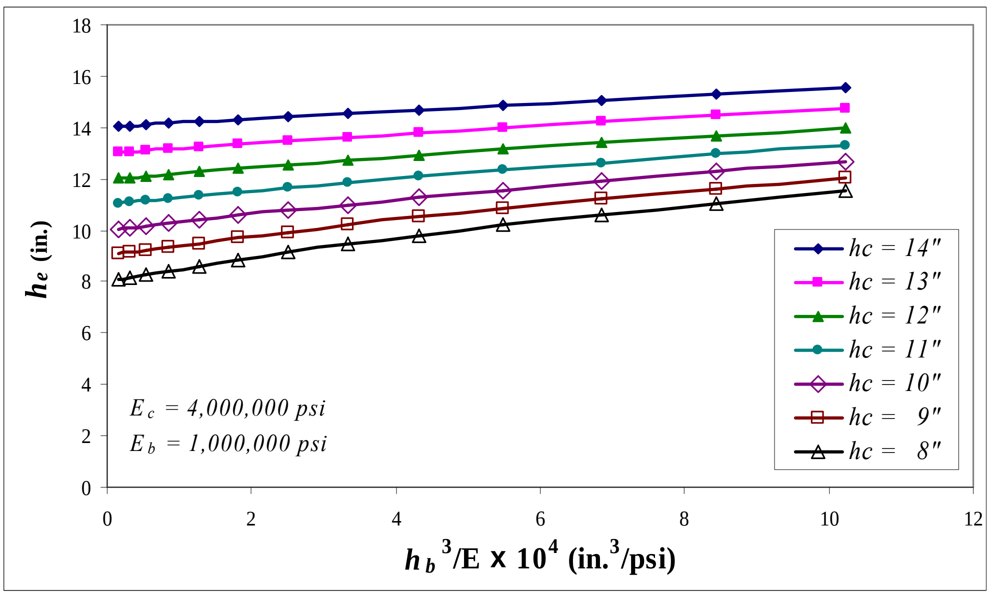


Figure 4-2 Effective Slab Thickness.

Again as a point of clarification, slab thickness relative to curling analysis refers to the thickness of the concrete slab only, but relative to load deformation analysis, the effective slab thickness which includes the thickness of the base (equation 2) is used. Conversely, the modulus of subgrade reaction in the curling analysis is an effective k-value above the subbase while for load analysis the k-value of subgrade is below the base.

Corner Deflection based on Westergaard's Equation

Corner deflection of Westergaard in equation 3 decreases when the concrete slab thickness or k-value increases. The maximum deflection allowed is based on the subgrade type, strength, and its elastic characteristics relative to the maximum strain. In like manner, the maximum allowable stress that the native subgrade can tolerate is based on the elastic-plastic characteristics. Figure 1-2 illustrates these concepts, which is a typical, generic plot of stress vs. strain under monotonic loading for a soil. Based on this approach, the pavement structure is designed so that stresses induced in the subgrade under traffic loading do not exceed 50 percent of the UCCS in order to maintain elastic behavior.

$$\delta = \frac{P}{k\ell^2}\left[1.1 - 0.88\left(\frac{a\sqrt{2}}{\ell}\right)\right] \qquad [3]$$

Where, δ = corner deflection (in.),
P = wheel load (lb),
k = foundation modulus (pci),
ℓ = radius of relative stiffness (in.), and
a = radius of circular load (in.).

Dimensionless Deflection

For design purposes, it is useful to refer to slab deflection in a dimensionless format to gain the widest possible application in design. Figure 4-3 shows the examples of dimensionless deflection using equation 4 for various concrete slab thickness and subbase modulus. The UCCS of subgrade is assumed to be 20 psi; therefore, the dimensionless deflection should be less than 10 psi to stay within the elastic behavior of the subgrade. If dimensionless deflection is more than one-half UCCS, support of the pavement would be subject to the development of permanent deformation possibly leading to slab cracking or faulting of the transition joint.

$$d^* = \frac{\delta k \ell^2}{P} \quad \Rightarrow \quad \delta \cdot k = \frac{P \cdot d^*}{\ell^2} \leq 10 \text{ psi limit } (\approx \frac{1}{2}\text{UCCS}) \qquad [4]$$

Where, d^* = dimensionless deflection,
δ = Westergaard corner deflection (in.),

k = foundation modulus (pci),
ℓ = radius of relative stiffness (in.), and
P = wheel load (lb).

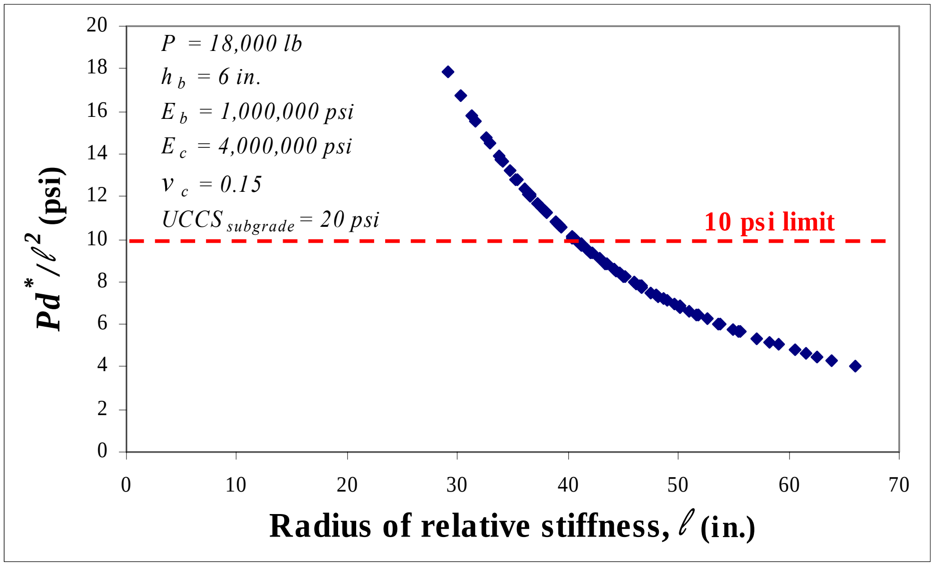


Figure 4-3 Deflection Limit.

Joint Stiffness

When design thickness is not sufficient to restrict deflection to the maximum allowable level, improvement of the load transfer may be in order. LTE mainly depends on slab thickness and dowel bar size and spacing. Therefore, dowel bar size and spacing could be selected according to the relationship between joint stiffness, slab thickness, and minimum or the desirable level of LTE. As previously mentioned, joint spacing, slab thickness, and load transfer are the key design factors for a good performing pavement transition, especially in terms of the joint stiffness that along with LTE is the core of the transition design.

Joint stiffness (J) is made up of stiffness due to aggregate interlock and dowel or steel bars. Loss of stiffness in a joint may lead to faulting in jointed pavements or punchouts in CRC pavements. To achieve a greater load transfer, aggregate interlock is very important, and it can be achieved through small joint/crack openings even though dowels make a significant contribution to the load transfer *(33)*. The joint stiffness could convert to the degree of load transfer, and joint stiffness can be calculated using equation 5. The stiffness of the supporting, slab thickness, and joint stiffness decide the amount of deflection of joint area, and dowel bar size can be decided by the required joint stiffness. Equations from 5 to 13 show the LTE is a function of the opening of the joint or the crack *(34)*.

$$J = J_D + J_{AI} \quad [5]$$

Where, J = total joint stiffness,

J_D = joint stiffness of dowel bars, and

J_{AI} = joint stiffness of aggregate interlock.

$$J_D = \frac{D}{sk\ell} \qquad [6]$$

$$D = \frac{1}{\frac{1}{DCI} + \frac{1}{12C}} \qquad [7]$$

$$DCI = \frac{4\beta^3 E_d I_d}{(2+\beta w)} \qquad [8]$$

$$\beta = \sqrt[4]{\frac{Kd}{4E_d I_d}} \qquad [9]$$

Where, K = modulus of dowel support, 1,500,000 (pci),

d = diameter of dowel (in.),

E_d = Young's modulus of dowel, 30,000,000 (psi),

I_d = moment of inertia of dowel bar cross-section (in^4) = $\frac{\pi d^4}{64}$, and

w = joint or crack opening (in.).

$$C = \frac{E_d I_d}{w^3(1+\phi)} \qquad [10]$$

$$\phi = \frac{12E_d I_d}{G_d A_z w^2} \qquad [11]$$

Where, G_d = shear modulus of dowel bar (psi) = $\frac{E_d{}^4}{2(1+v_d)}$,

v_d = Poisson's ratio of dowel, 0.3, and

A_z = effective cross-section area of dowel (in.^{2}) = $0.9 \times \frac{\pi d^2}{4}$.

$$J_{AI} = \frac{Agg}{k\ell} \qquad [12]$$

$$\log\left(\frac{Agg}{k\ell}\right) = ae^{-e^{\frac{-(x-b)}{c}}} + de^{-e^{\frac{-(s-e)}{f}}} + ge^{-e^{\frac{-(x-b)}{c}}} \times e^{-e^{\frac{-(s-e)}{f}}} \qquad [13]$$

Where, a = -4,

x = 0.039,

b = -11.26,

c = 7.56,

d = -28.56,

$s = 0.0312\, h_e^{1.4578} \cdot e^{-0.039\ cw}$,

h_e = effective thickness of combined slab (in.),

cw = crack width (mils = in.×10^3),

e = 0.35,

f = 0.382, and

g = 56.26.

Load Transfer Efficiency

LTE can be calculated by equation 14 using joint stiffness and the relationship between the joint stiffness and the LTE as represented in Figure 4-4 *(11)*. LTE increases rapidly up to approximately 85 percent. However, LTE gradually approaches 100 percent as joint stiffness increases from a J value of 10 to 1000. For the example, LTE across a transverse joint could be supplied by aggregate interlocking alone or in combination with dowel bars. Figure 4-5 shows that aggregate interlock drops rapidly at openings greater than 30 mils but that steel dowel can only provide a certain amount of stiffness (i.e., about 85 percent LTE). Consequently, only a certain level of LTE can be achieved by the joint stiffness contribution of a steel dowel. However, since joint openings vary seasonally and daily, LTE due to aggregate interlocking will vary accordingly; therefore, maintaining a high level of LTE is best achieved with using dowels, particularly in a jointed system *(35)*.

$$LTE = \frac{1}{1 + Log^{-1}\left[\dfrac{0.214 - 0.183\left(\dfrac{a}{\ell}\right) - Log(J)}{1.180}\right]} \qquad [14]$$

Where, J = total joint stiffness and
a = loaded radius.

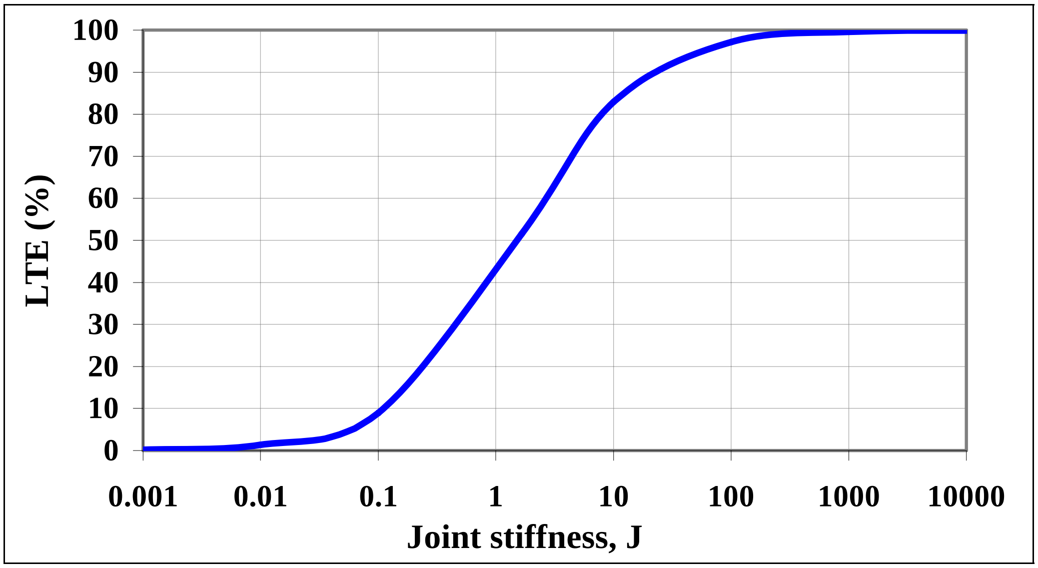


Figure 4-4 Relationship between the Joint Stiffness and the LTE *(35)*.

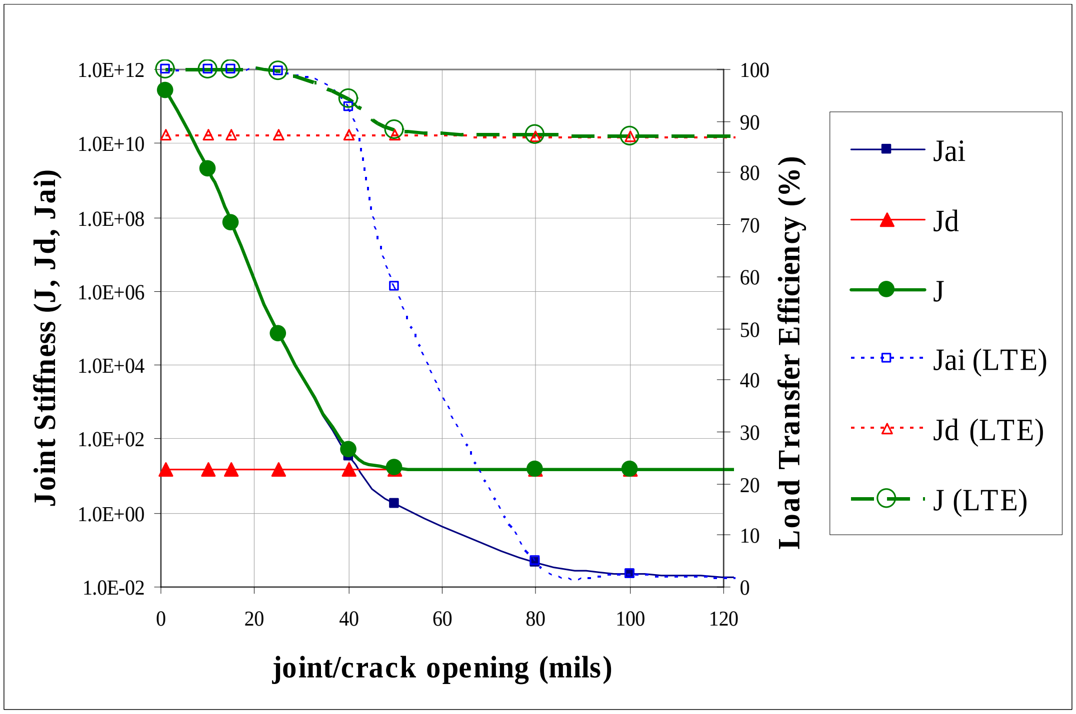


Figure 4-5 Relationship of the Joint/Crack Opening, Joint Stiffness, and the LTE *(33)*.

Corner Deflection with LTE

Corner loading induces the largest deflection among the various loading positions on a slab because two sides of the slab are free to move unless otherwise restricted. If the corner is tied to an adjacent slab, the free end condition begins to convert to edge or interior loaded condition. The provision of load transfer (up to 100 percent LTE) free edge at the corner can reduce the corner deflection with LTE up to 50 percent of the deflection with no LTE by equation 15. Figure 4-6 shows the variation of the corner deflection with LTE according to equation 15 for various concrete slab thicknesses.

$$\delta_{LTE} = \frac{\delta_{FE}}{1 + LTE} \qquad [15]$$

Where, δ_{LTE} = corner deflection with load transfer (in.),
δ_{FE} = corner deflection by corner loading at the free end of slab (in.), and
LTE = load transfer efficiency (%).

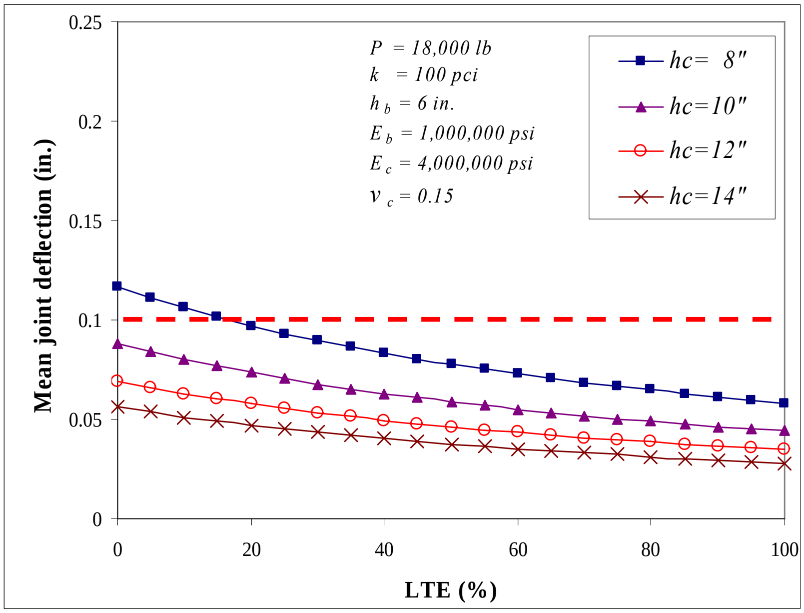


Figure 4-6 Mean Joint Deflection with LTE.

Reliability Based Design Approach

Reliability concepts are applied to the design process because of the many factors that can cause variability in performance. In terms of deflection, many factors such as modulus of elasticity, k-value, interlayer friction, and LTE can vary to affect the resulting movement. By considering the variability of these factors, the necessary LTE for limiting deflection to allowable levels can be calculated with a given level of confidence.

The deflection variance (*Var[δ]*) allows for the determination of a measured level of reliability against permanent subgrade deformation through equation 16. The deviations of all the factors related to slab deflection are assumed to be normally distributed; Z_R is selected relative to a target level of reliability from a normal distribution table (i.e., Z_R for a 95 percent confidence level is 1.645) for use in:

$$\delta_{CI} = \bar{\delta} + Z_R(SD_\delta) \qquad [16]$$

Where, δ_{CI} = design corner deflection with confidence interval (in.),

δ = mean corner deflection by corner loading (in.),

Z_R = reliability factor of normal distribution, and

SD_δ = deflection standard deviation (in.) = $\sqrt{VAR[\delta]}$.

Figure 4-7 shows an example analysis for an 11 in. thick concrete slab showing a mean deflection less than 0.1 in. (the design deflection limit) without the aid of LTE. However, after considering the variation of design factors at a level of 95 percent reliability, the deflection limit can be met with 80 percent LTE (*36*). This example shows how the variation of the design factors affect design of the joint system to meet the deflection criteria. To prevent permanent deformation, proper doweling should be employed at the joint to achieve at least 80 percent LTE if joint openings are too much to allow for a contribution from aggregate interlocking.

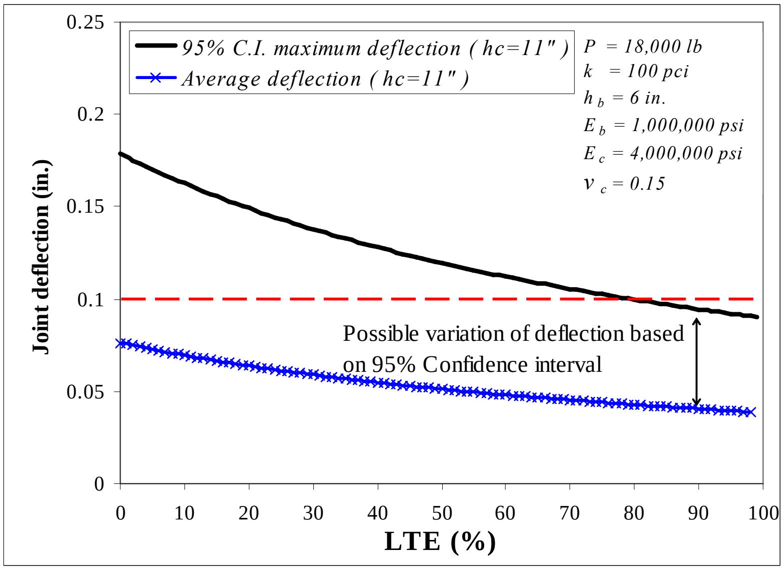


Figure 4-7 Design Deflection Variation with LTE at 95 Percent Confidence Interval.

EXAMPLE OF TRANSITION BEHAVIOR ANALYSIS

Figure 4-8 shows a conceptual view of the analysis conditions and the joint configuration of an AC/PCC transition. Table 4-2 lists details of the analysis conditions. Since joint stiffness and LTE concept is not applicable to this type of joint, for deflection estimation, a finite element method of analysis is used. Unbonded conditions are assumed between the layers of the transition from an AC to a PCC pavement. The followings are considered for AC/PCC transition analysis:

- traffic loading at different locations of the concrete transition slab (loading at the tips and middle of the tapered slab, and near the expansion joint);
- variation of the concrete transition slab size, the taper size, and slab thickness; and
- variation in subgrade type: cement treated base (CTB) or asphalt treated base (ATB).

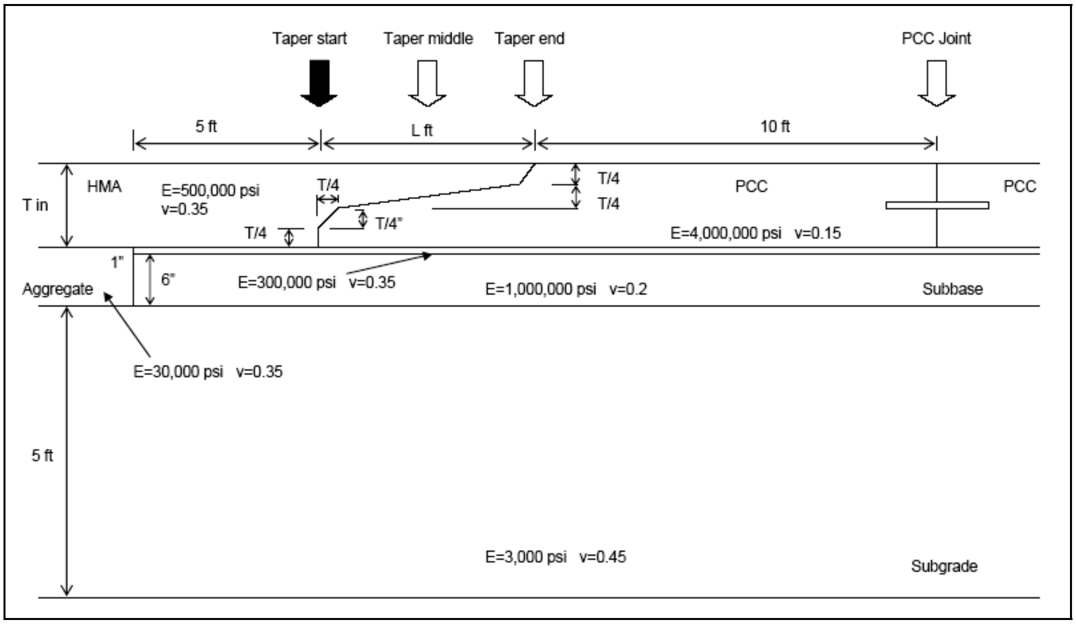


Figure 4-8 Conceptual AC/PCC Transition Analysis Conditions.

Table 4-2 AC/PCC Transition Analysis Case Conditions.

Loading location	Taper start, Taper middle, Taper end, and PCC joint
Joint Taper slab length	3, 4, 5, 6, and 7 ft
AC/PCC slab thickness	8, 9, 10, 11, and 12 in.
Base support type	CTB: 1 in. AC bond breaker + 6 in. CTB and ATB: 4 in. Asphalt Treated Base

A 10 in. thick slab is used for the taper slab length analysis and a 15 ft long PCC slab is used for slab thickness analysis. Two base types are compared for each loading location. Figure 4-9 shows an analysis program output for loading at the taper start location. Plotted deflections are exaggerated by 300 times to help with visualization of the results.

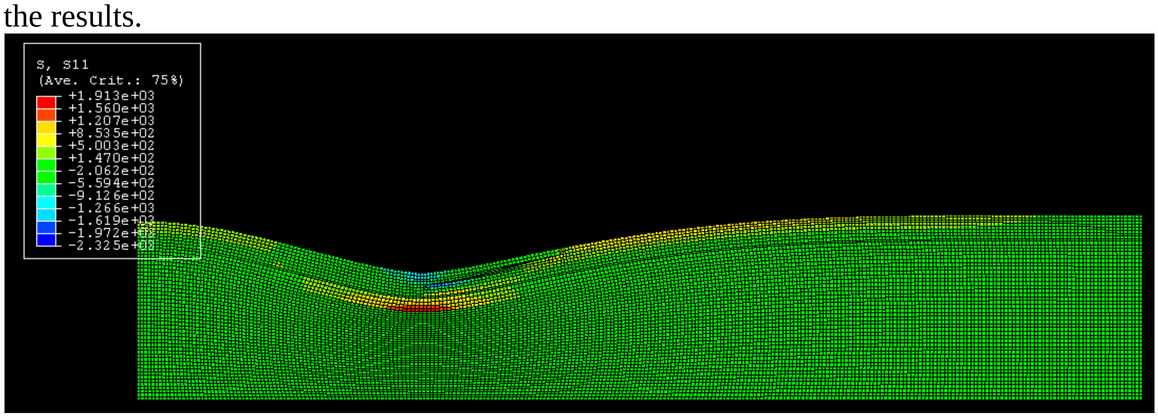


Figure 4-9 Stress and Deflection with the Loading at the Taper Start on CTB.

Taper Section Slab Length

Figures 4-10 and 4-11 show the results of the deflection analysis for various taper slab lengths relative to the four loading locations. The maximum deflection occurs when the loading location is at the taper slab start position because the slab behavior at this location is similar to a corner loading condition with no LTE since there is no load transfer device for AC/PCC transition except treated base. Moreover, PCC layer thickness is smallest along with a discontinuity in material types. Maximum deflection is nearly independent of the taper slab length.

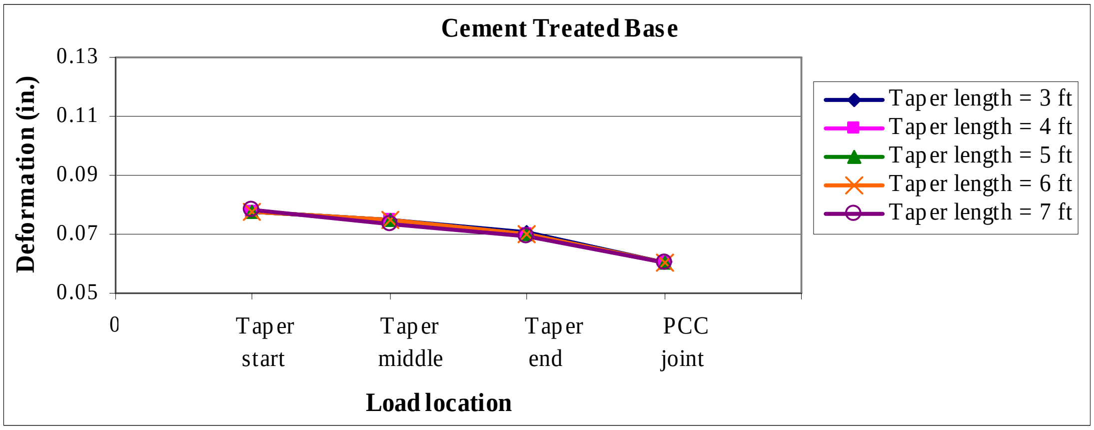


Figure 4-10 Maximum Deflection vs. Loading Location for Various Taper Lengths (CTB).

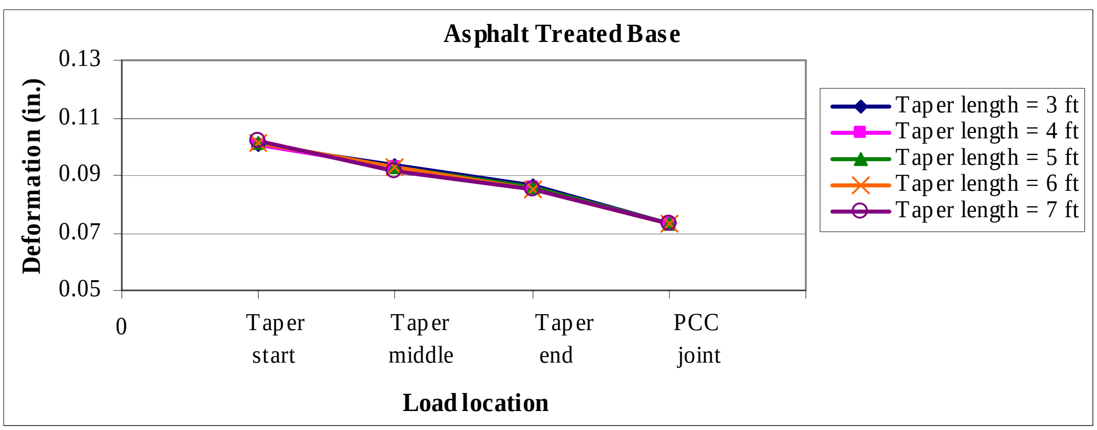


Figure 4-11 Maximum Deflection vs. Loading Location for Various Taper Lengths (ATB).

AC/PCC Slab Thickness

The analysis results for the deflections for various slab thickness are represented by the response at four loading locations shown in Figures 4-12 and 4-13. Among the loading locations, maximum deflection occurs at the PCC slab taper start loading location for both base types. When concrete slab thickness increases, the radius of relative stiffness increases; load dispersion through the AC pavement increases as deflection decreases. Moreover, changing the subbase from an ATB to a CTB, the maximum deflection decreases about 30 percent at the taper slab start location because the subbase restricts the difference of vertical movement between AC and PCC pavement. However, a tendency for crack reflection to occur through the AC layer may still exist due to stiffness differences, but could be reduced by increasing of stiffness of the AC pavement.

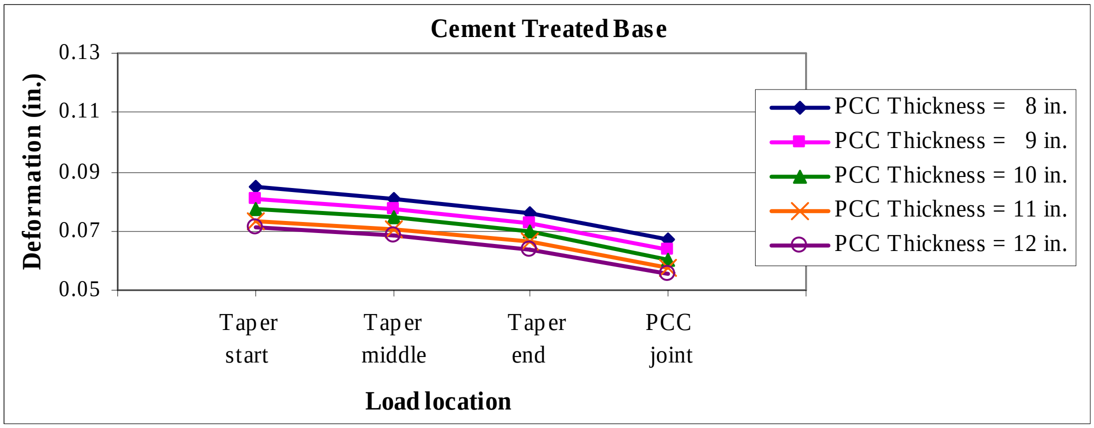


Figure 4-12 Maximum Deflection vs. Loading Location for Various Slab Thicknesses (CTB).

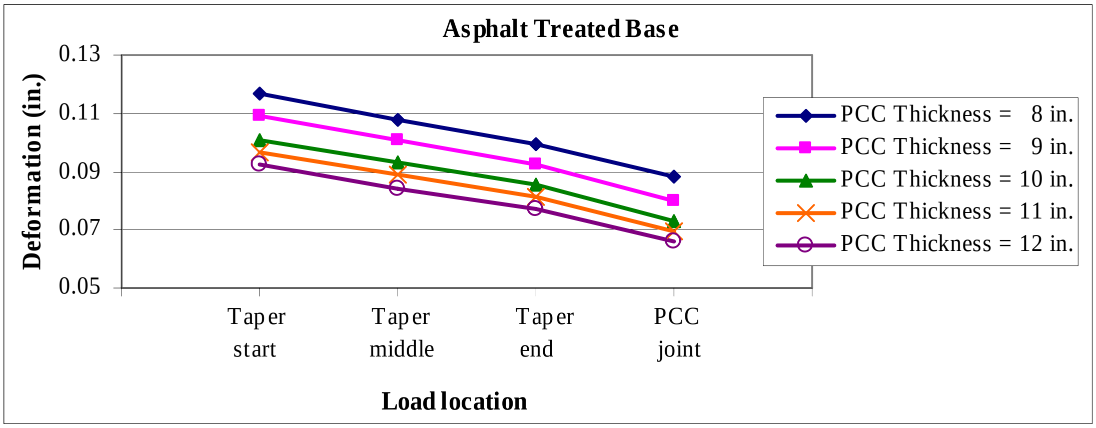


Figure 4-13 Maximum Deflection vs. Loading Location for Various Slab Thicknesses (ATB).

The loading at the PCC taper slab start location is the maximum deflection among the four loading locations and, as before, the taper length does not affect AC/PCC transition behavior, but slab thickness does. CTB would reduce the subgrade deflection about 30 percent in comparison with ATB, and greater modulus AC with a babbled edge at the end of the PCC slab would help reduce deflection and reflection cracking in the AC pavement over the joint.

CHAPTER 5
TRANSITION DESIGN IMPROVEMENTS AND PROMISING CONCEPTS

This chapter is focused on the measures to improve current transition design in terms of three general categories: transverse construction joints, longitudinal construction joints, and thickness transitions. The general features such as joint details, tie bars, and dowels are addressed within the context of each transition type as well as limitations and optimized configurations relative to deflection criteria are identified. Table 5-1 lays out the classification and notations of the joint types detailed in this chapter. Joint types for contraction joint, construction joint, and isolation joint are defined as Type A, B, and C, respectively. These basic joint types are associated with modifiers that further detail them with respect to the design of the joint. Deformed bars tie the slabs together as well as provide transfer load, but smooth dowels provide transfer load without restraining the opening of the joint. Thickened edge, wide flange, and sleeper slabs are used in cases where wide opening joints are expected such as at transitions between CRC pavement and bridge approach slabs to insure a minimum level of load transfer. As an example of these designations, a longitudinal contraction joint with deformed bars would be designated as *Longitudinal Type A (DB)*, a transverse construction joint with dowels would be *Transverse Type B (SD),* and a transverse isolation joint with a wide flange would be *Transverse Type C (WF)*.

Table 5-1 Classification and Notations of Joint Types.

Type	Joint Description	Modifier	Abbreviation
A	Contraction joint	With smooth dowel	SD
B	Construction joint	With deformed bar	DB
C	Isolation joint	Thickened edge	TE
		Wide flange	WF
		Sleeper slab	SS

TRANSVERSE CONSTRUCTION JOINT CATEGORY

The transitions of CRC to CRC pavement and CRC to JC pavement are similar but different in the amount of joint opening that occurs when a CRC pavement meets existing JC or JRC pavement. The transition of CRC to AC and JC to AC pavement are partially the same as between two PCC pavements since in both cases the detail incorporates a jointed transition segment in order to minimize the joint openings between PCC and AC pavements. Generally speaking, the incorporation of a slab segment in the transition allows two joint transitions: one for CRC to JC or JC to JC pavement transition and the other for PCC slab and the AC pavement transition to be sealed and movement kept to a minimum. The bridge approach and terminal transitions are unique in that designs typically include an expansion joint that can be combined with a sleeper slab element, but opening should be minimized to the extent possible.

Transition between CRC Pavement and CRC Pavement

The objective of the transition between CRC pavement segments is to maintain uniformity of both support and cracking across the transition area. Performance-wise, the reinforcing steel maintains the stiffness of the transverse joint included in this transition, but typically the transverse cracks manifest little aggregate interlocking behavior and need to derive sufficient load transfer capability from the reinforcing steel or dowels if included in the transition. In order to supplement the load transfer capability of the reinforcing steel, a certain amount of doweling may provide a sufficient level of load transfer in a CRC to CRC pavement transition.

Figures 5-1 and 5-2 show the reinforcing associated with a CRC pavement to CRC pavement construction joint. The wheel path can be assumed to be a 3-ft wide area positioned 1 ft from the longitudinal edge. As a minimum, three 36-in. deformed bars should be drilled and epoxied in each wheel path to provide for additional load transfer. If more than six months transpire before placing the adjacent CRC pavement, joint type should be the transverse isolation joint with deformed bar (Type C [DB]) that includes an expansion joint filler material (such as preformed bituminous fiber) to minimize damage due to differential thermal movement (aggravated by difference in set temperatures). Design analysis entails determination of additional load transfer bar size, spacing, and length. The amount of additional doweling is based on traffic level and the size and spacing of the existing reinforcement. Additionally, the supplemental doweling may adversely impact the spacing requirements between the steel bars and the dowels, possibly causing consolidation problems of the concrete during paving. Consequently, doweling in this instance should be limited to the wheel path area of the slab along the transverse joints. Similar considerations are applicable when the wheel path is located on or near the longitudinal joint.

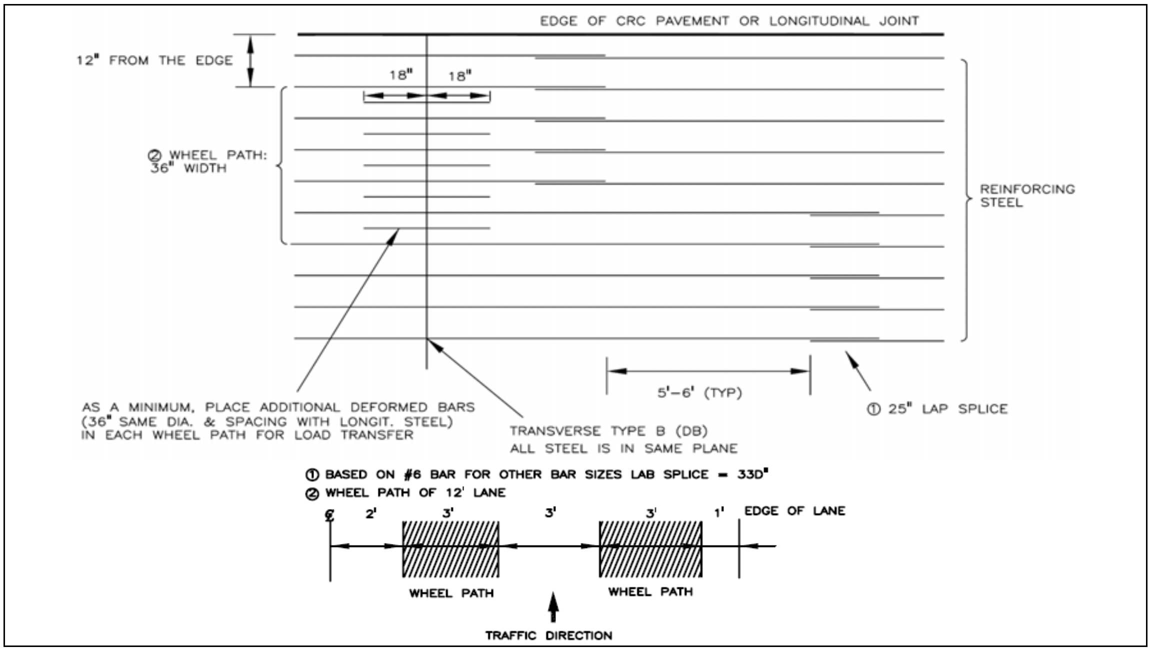


Figure 5-1 Improvement Concept of CRC Pavement to CRC Pavement Transition.

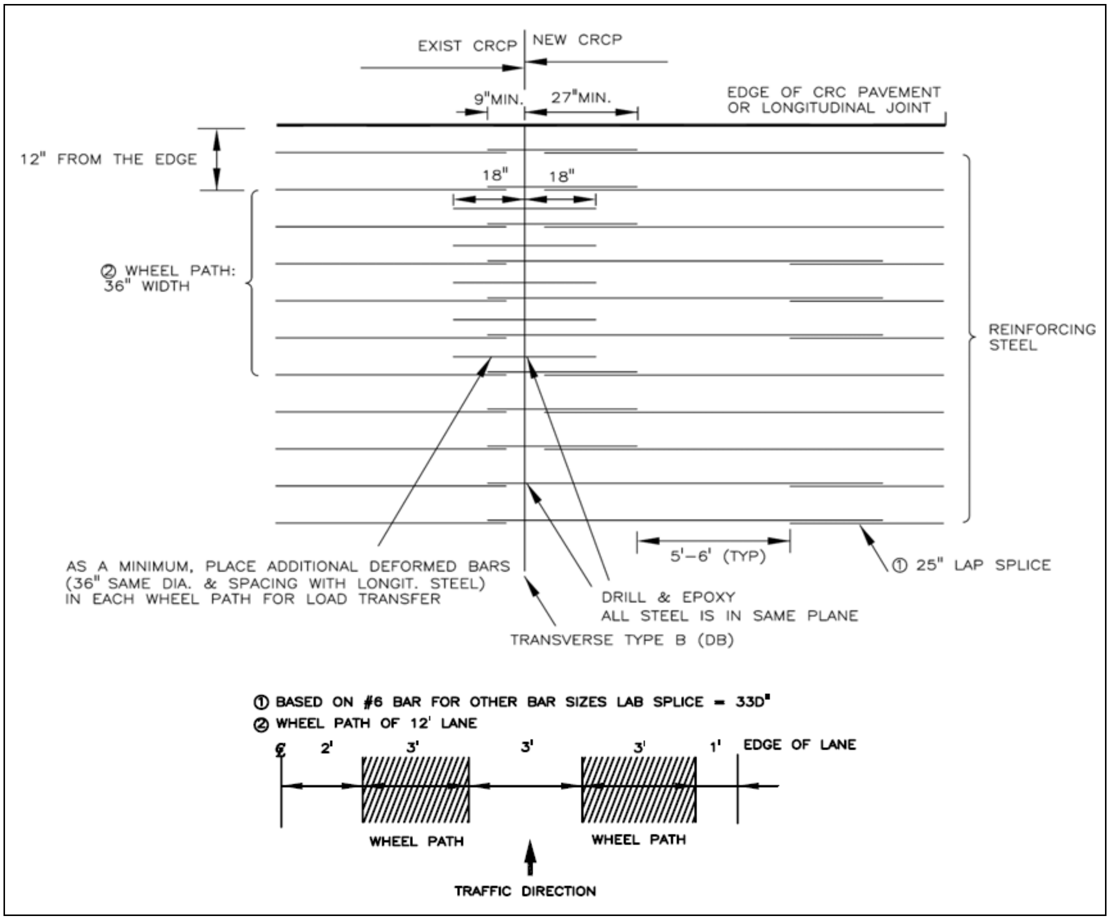
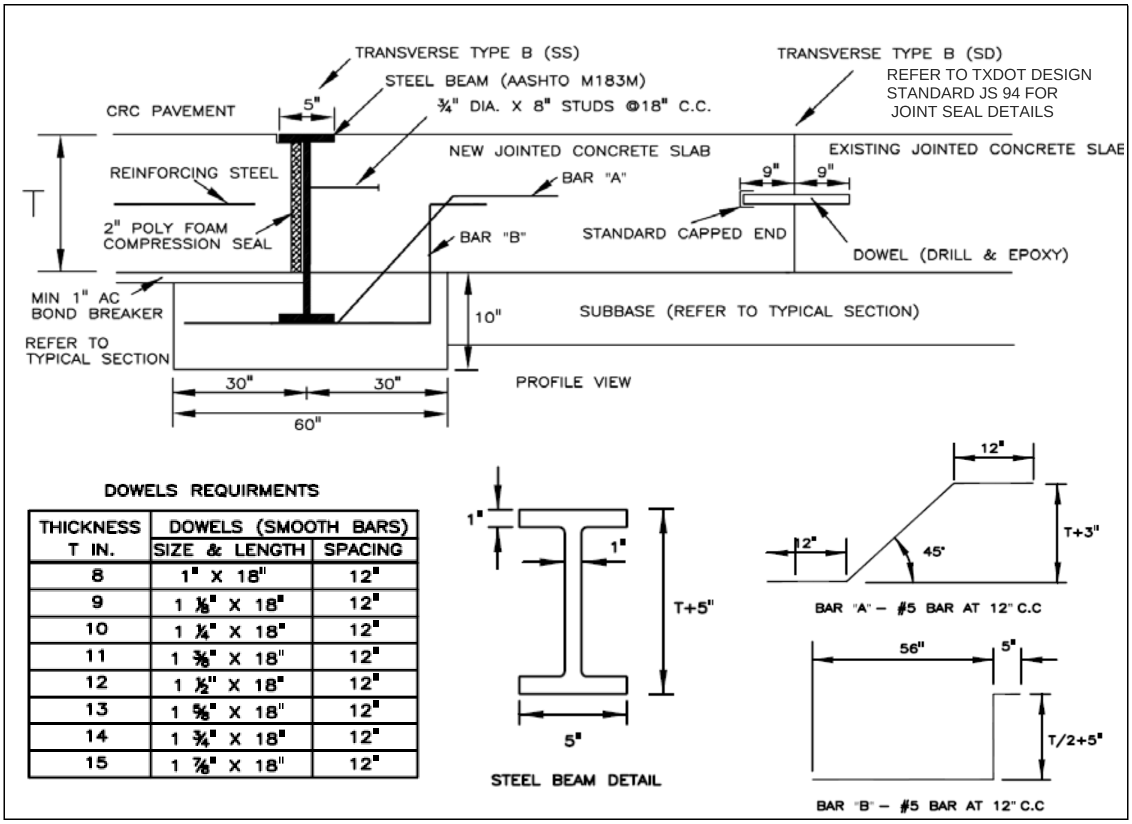


Figure 5-2 Improvement Concept of CRC Pavement to CRC Pavement Transition for Intervallic Construction Joint.

Transition between CRC Pavement and JC Pavement

The objective of a transition of this nature is to allow the action of the joint reinforcement in the joint to isolate the movements of the CRC from the JC slab. Performance of this transition is keyed on keeping the joint area clear of incompressible debris and maintaining the opening to less than 1.5 in., but special consideration may need to be given for deflection or support continuity at this joint requiring the use of a sleeper slab element. The expansion joint typically includes a filler material that is 1.5 in. wide. The placement of the dowelling is often interspersed in the pattern of the reinforced steel.

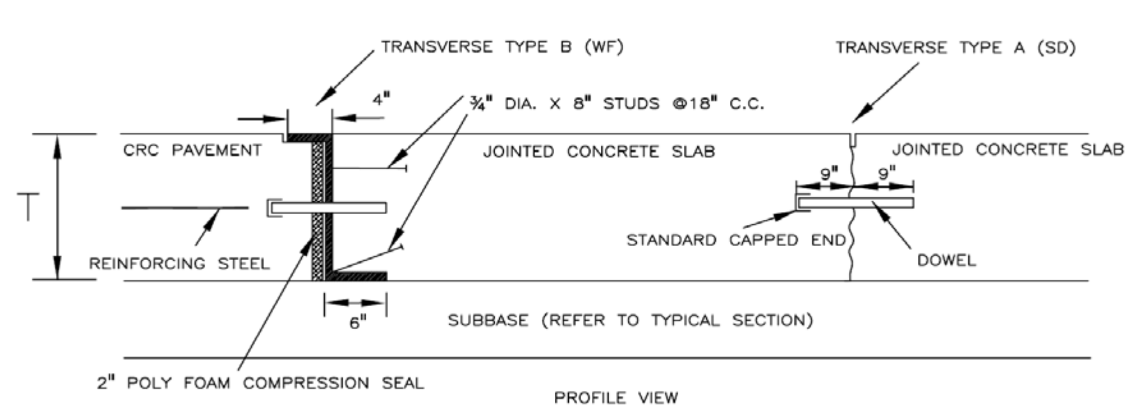
For the transition between CRC pavements and JC pavement, three options are recommended. The first option in Figure 5-3 details a sleeper slab with an embedded I-beam. A 2 in. poly foam compression seal is inserted at the end of the CRC pavement based on an expected end movement. A 6 in. wide I-beam is tied to the jointed concrete slab by 0.75 in. diameter, 8 in. studs at 18 in. centers. Sleeper slab length is 60 in. with various thicknesses that may depend on the subgrade conditions. This detail is applicable in case where movement is restricted to only one side of the joint.



THICKNESS T IN.	DOWELS (SMOOTH BARS) SIZE & LENGTH	SPACING
8	1" x 18"	12"
9	1 ⅛" x 18"	12"
10	1 ¼" x 18"	12"
11	1 ⅜" x 18"	12"
12	1 ½" x 18"	12"
13	1 ⅝" x 18"	12"
14	1 ¾" x 18"	12"
15	1 ⅞" x 18"	12"

Figure 5-3 Improvement Concept of CRC Pavements to JC Pavement Transition Using Sleeper Slab.

The second option in Figure 5-4 is using a wide flange with dowels instead of an I-beam and sleeper slab. This design option can be applied effectively between previously placed CRC pavement and new jointed concrete slab since a sleeper slab is not involved. This design is applicable in case where movement is expected to occur on both sides of the joint. It uses the same type of compression seal as with option 1 to allow CRC pavement movement. Wide flange width is recommended to be 4 in., but it can be varied based on field conditions. The same size and spacing studs with option 1 are used to tie into the concrete slab. Dowel size and spacing would be determined by design to achieve appropriate LTE between CRC pavement and JC pavement. Specific wide flange and reinforcing steel transition design details are tentative until sufficient experience using this option has been gained.



DOWELS REQUIRMENTS

THICKNESS T IN.	DOWELS (SMOOTH BARS) SIZE & LENGTH	SPACING
8	1" X 18"	12"
9	1 ⅛" X 18"	12"
10	1 ¼" X 18"	12"
11	1 ⅜" X 18"	12"
12	1 ½" X 18"	12"
13	1 ⅝" X 18"	12"
14	1 ¾" X 18"	12"
15	1 ⅞" X 18"	12"

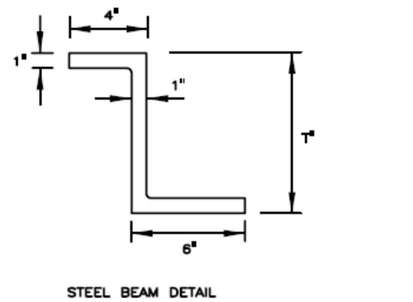


Figure 5-4 Improvement Concept of CRC Pavement to JC Pavement Transition Using Wide Flange.

The third option in Figure 5-5 uses a 240-ft long gradually reduced reinforced CRC end segment. The first 120 ft section that includes the terminal end is reinforced at 30 percent of the design steel content and the next 120 ft at 60 percent of the design steel content. Twelve foot space sawcuts are employed in the 30 percent reinforced zone with the option of providing dowels to compensate for the expected wider openings. Sixty percent of the design steel content section is sawcut at 6 ft (or the designed) intervals to induce a uniform crack pattern. Sawcuts are made soon after initial setting of the CRC pavement concrete. The second and third options should be considered experimental until further experience is gained from constructing them.

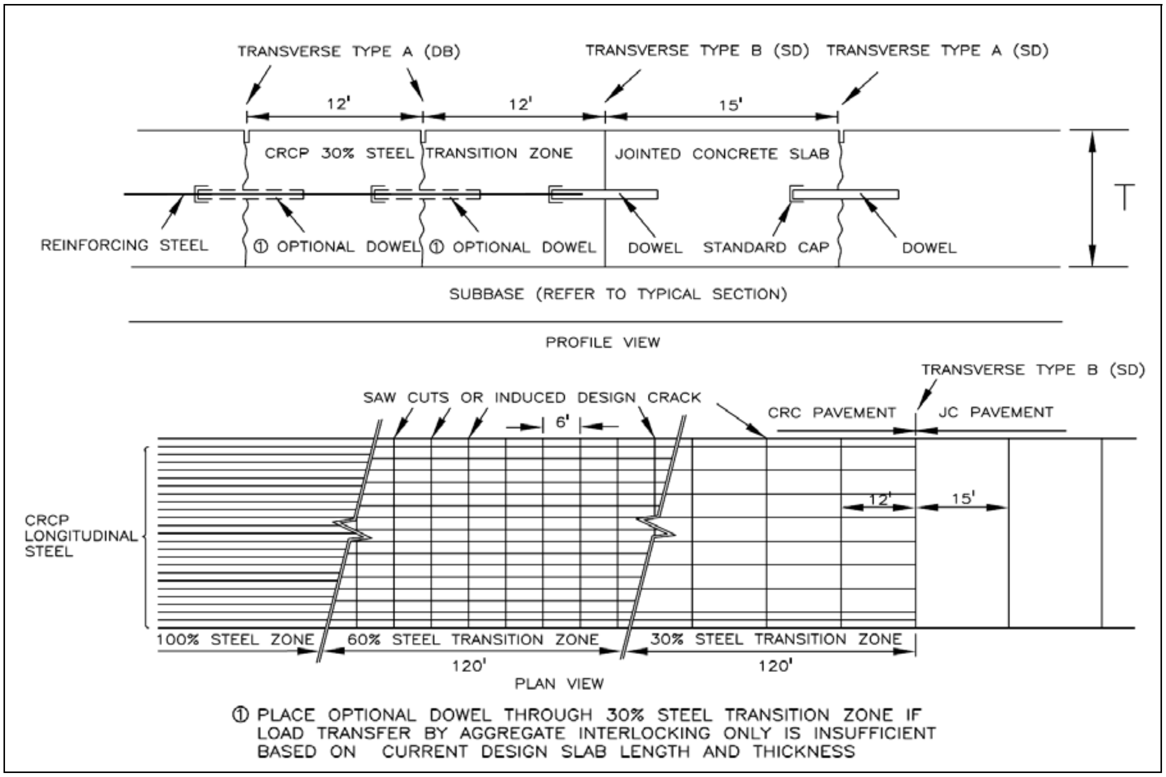


Figure 5-5 Improvement Concept of CRC Pavements to JC Pavement Transition Using Steel Transition.

Transitions between CRC Pavement and AC Pavement

The objective of a CRC to AC pavement transition is to reduce the free edge deflection to those deflections developing at an interior slab location with a concomitant reduction in subgrade stress. A PCC slab should be employed as a buffer between the different two material types. The desirable features of the transverse joint between PCC slab and AC pavement include continuous behavior while the joint between the CRC and the JC slab would also include similar behavior while being subjected to wider openings. Load transfer with isolation between CRC pavement and JC pavement may be addressed through the use of a sleeper slab or, in some instances, a wide flange or elastomeric concrete joint.

Figure 5-6 shows an option that uses a tapered slab between JC pavement and AC pavement. As previously noted, a beveled edge should be placed at the end of the tapered section to minimize crack reflection in the AC pavement; a treated subbase needs to be extended into the AC pavement section for a distance of at least 5 ft. TxDOT typically uses a 6 in. thick CTB with a 1 in. thick AC bond breaker for the treated subbase layer in both CRC and JC pavement; 4 in. hot mixed asphalt concrete (HMAC) or asphalt stabilized base (ASB) is also commonly used. The following are recommended construction practices:

* Compaction of hot mixed asphalt and subgrade materials to 100 percent and 95 percent density, respectively.
* Subgrade may be either cement or lime stabilized.
* The tapered section should be rough finished with a beveled edge.

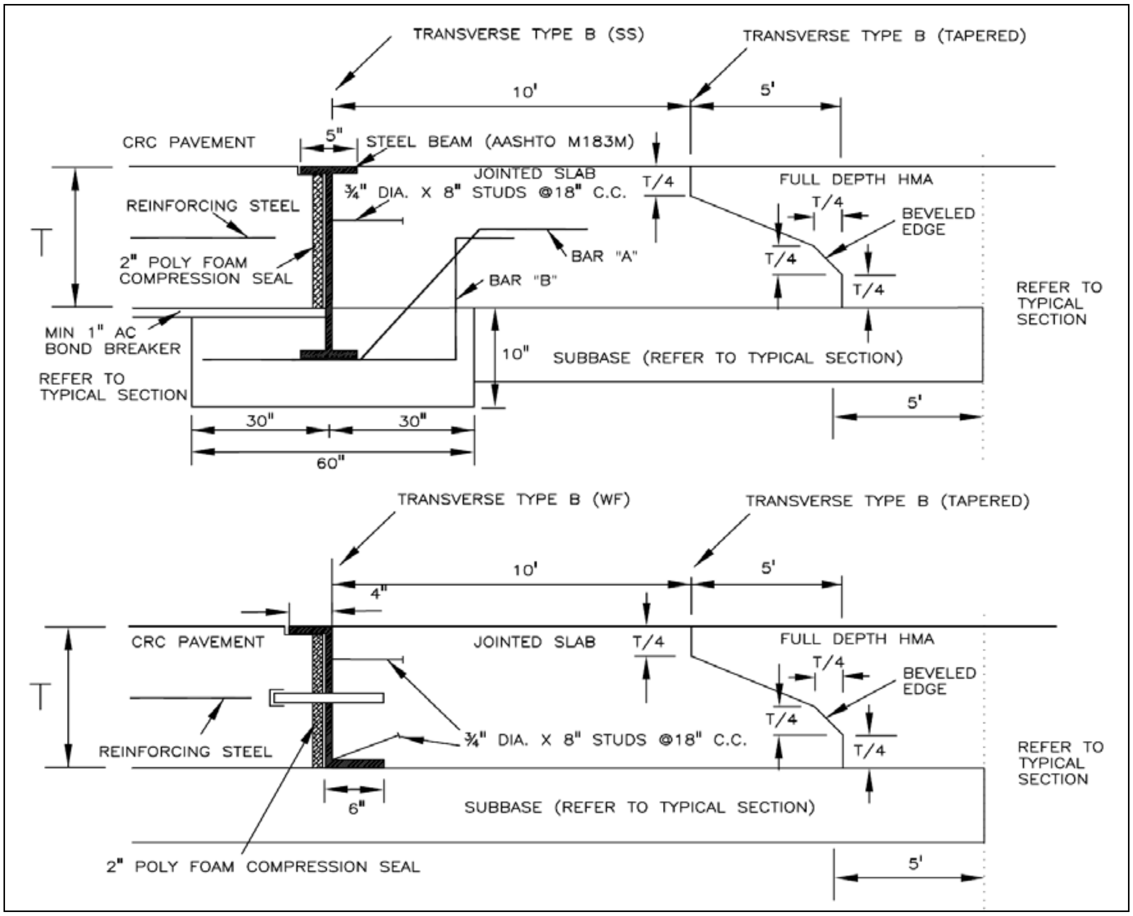


Figure 5-6 Improvement Concept of CRC Pavement to AC Pavement Using Transition-Tapered Slab.

Figure 5-7 shows the other option that uses an elastomeric concrete joint to transition the vertical movement between the jointed concrete slab and the AC pavement section. This option also needs a treated subbase extension into the AC pavement section at least 5 ft, and a sleeper slab or wide flange joint type should be constructed between the CRC pavement and jointed concrete slab. Dowel size and spacing for wide flange joint design would be determined by design to achieve the appropriate LTE between CRC and JC pavement. Table 5-2 shows the guidelines for the elastic modulus of elastomeric concrete. The order of placement in the construction is the portland cement concrete first, the AC material next, and finally cutting a slot for placing the elastomeric concrete.

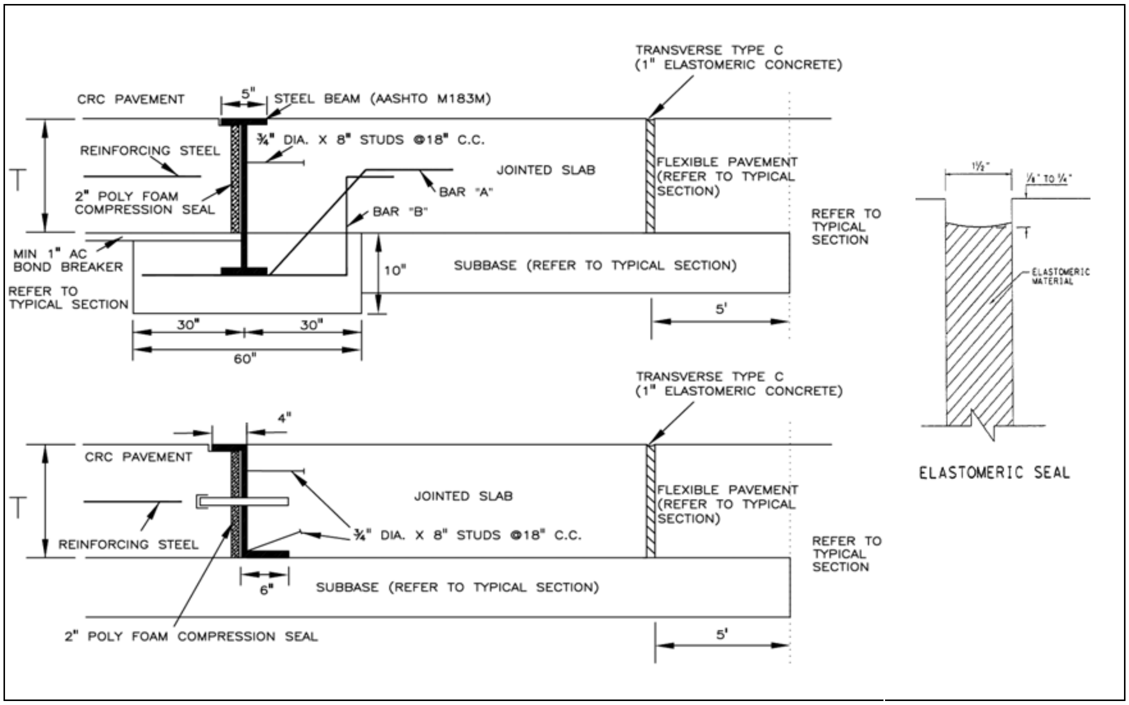


Figure 5-7 Improvement Concept of CRC Pavement to AC Pavement Transition-Elastomeric Concrete.

Table 5-2 Properties of Elastomeric Concrete.

Brand Name Manufacturer	Compressive Strength	Tensile Strength	Elastic Modulus
Pro-Crete Capital Services	2800 psi	900 psi	3.02×10^6 psi
Delcrete™ D.S. Brown	800 psi	600 psi	1.61×10^6 psi
Pro-Crete NH Capital Services	4200 psi	2250 psi	3.69×10^6 psi

Transitions between JC Pavement and AC Pavement

The objective and related performance factors for asphalt pavement transitions in jointed concrete systems are similar to those previously stated for CRC pavement. Such transitions need special measures to ensure deflection or support continuity across the joint which may, under circumstances of traffic and subgrade strength combinations, pose no performance issues. Elaborating further, this transition need to promote continuous deflection between JC and AC pavement sections to maintain the riding quality and life of the transition.

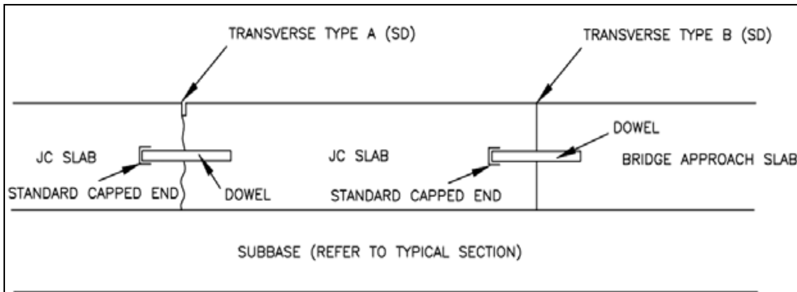
The improvement of the transition from JC pavement to AC pavement is basically identical to the transition of CRC to AC pavement. However, the concrete pavement joint type is the construction joint type and not the isolation joint type because the joint opening between JC pavement segments would be less than the joint opening between CRC and a JC slab.

Terminals at Bridge Abutments

The objective of bridge terminal transitions is to facilitate change from one pavement type or structure to another pavement type or structure while maintaining a smooth vertical profile. Performance of the transition can often focus on the opening and closing of the transition joints and their ability to maintain proper stiffness throughout these opening and closings. However, differential settlements cannot be allowed to occur under the approach slab in order to protect the integrity of the transition.

An improvement in this design is a modification of Figures 5-3, 5-4, and 5-5 involving joints between CRC pavement and the approach slab. This joint may have a sleeper slab or wide flange with dowels. As a previous related note indicated, the sleeper slab length is 60 in. with various thicknesses based on the subgrade condition. Additionally, a treated subbase is used throughout the transition area to reduce the potential for faulting. Steel transition design in Figure 5-5 can be considered also as an improved experimental design for the transition between the CRC pavement and the bridge approach slab.

The sleeper slab elements may only be necessary for CRC pavement but often depend on the expected opening at the transition joint. Figure 5-8 shows the transition between JC pavement and a bridge approach slab. A doweled construction joint with subbase is used at the end of the JC pavement to provide load transfer at the joint between the JC slab and the bridge approach slab. The bridge approach slab thickness transition may be needed when the bridge approach slab thickness is thicker than the jointed concrete slab thickness.



DOWELS REQUIRMENTS

THICKNESS T IN.	DOWELS (SMOOTH BARS) SIZE & LENGTH	SPACING
8	1" X 18"	12"
9	1 1/8" X 18"	12"
10	1 1/4" X 18"	12"
11	1 3/8" X 18"	12"
12	1 1/2" X 18"	12"
13	1 5/8" X 18"	12"
14	1 3/4" X 18"	12"
15	1 7/8" X 18"	12"

Figure 5-8 JC Pavements to Bridge Approach Slab Transition.

Partial Restraining/Inclusion Type Joints

The main objective of partial restraining (i.e., drop inlets) transitions is to isolate movement between a structure and the surrounding pavement. To this end, drainage structures need to be isolated from pavement using an isolation joint. Construction involving an integral curb should be discontinued at the isolation joint. When pavement areas have drainage structures, joints should be aligned with the corners of the structure configuration where joint corner angles are not less than 60 degrees. Since uncontrolled cracking often occurs on the corner of a drainage structure, transverse contraction joints could be placed matching with the transverse edge to prevent uncontrolled cracking.

Figure 5-9 shows the drop inlet design. Drop inlet structures should be isolated from the pavement structure because they are relatively fixed. A doweled transverse construction joint is used between the structure and the pavement. The transverse contraction joint should match inlet corners to prevent diagonal random cracking in the pavement.

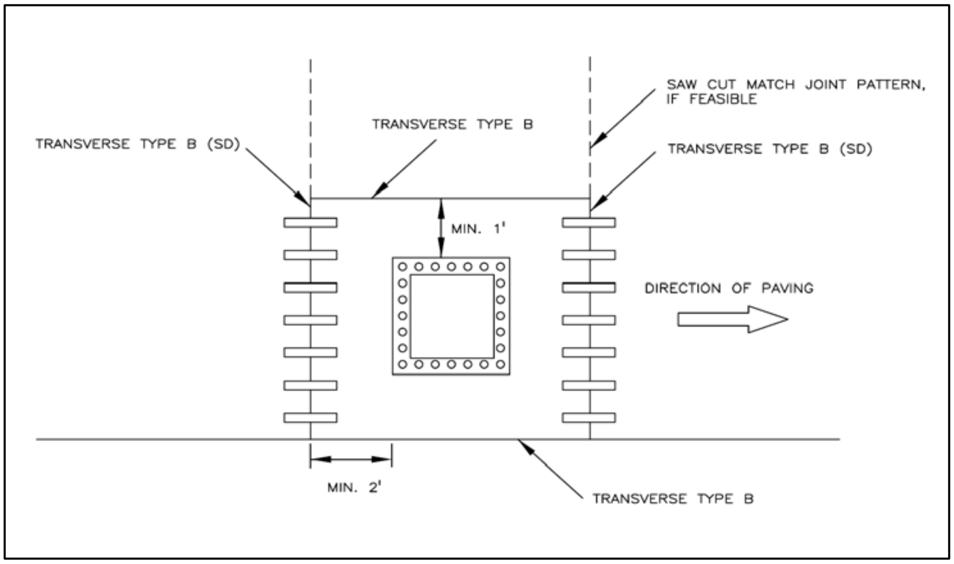


Figure 5-9 Improvement Concept of Drop Inlet/Drainage Box.

LONGITUDINAL CONSTRUCTION JOINT CATEGORY

The objective of longitudinal transition is to maintain integrity and to prevent excess widening of the longitudinal joint between adjoining lanes. Joint patterns that delineate adjacent lanes should be as continuous as possible to maintain uniformity of movement between longitudinal lanes. Ramp and main lane segments create longitudinal construction joints that possibly develop some shear stress in them if they are not properly jointed together. The same is true of pavement segments through intersections.

Ramps/Gore Area Transition

The objective of ramp transition is to tie the movements of the ramps with the movements of the main lanes. Figure 5-10 shows the design improvement concept for ramp gore area transition. Gore area termination may need to be at least 2 ft wide to allow for construction. A transverse contraction or construction joint should be matched at the end of the gore area to prevent diagonal random crack propagation into the ramp pavement. Thickness transition, if needed, should be completed before this transverse contraction and transition over a distance of 20 ft.

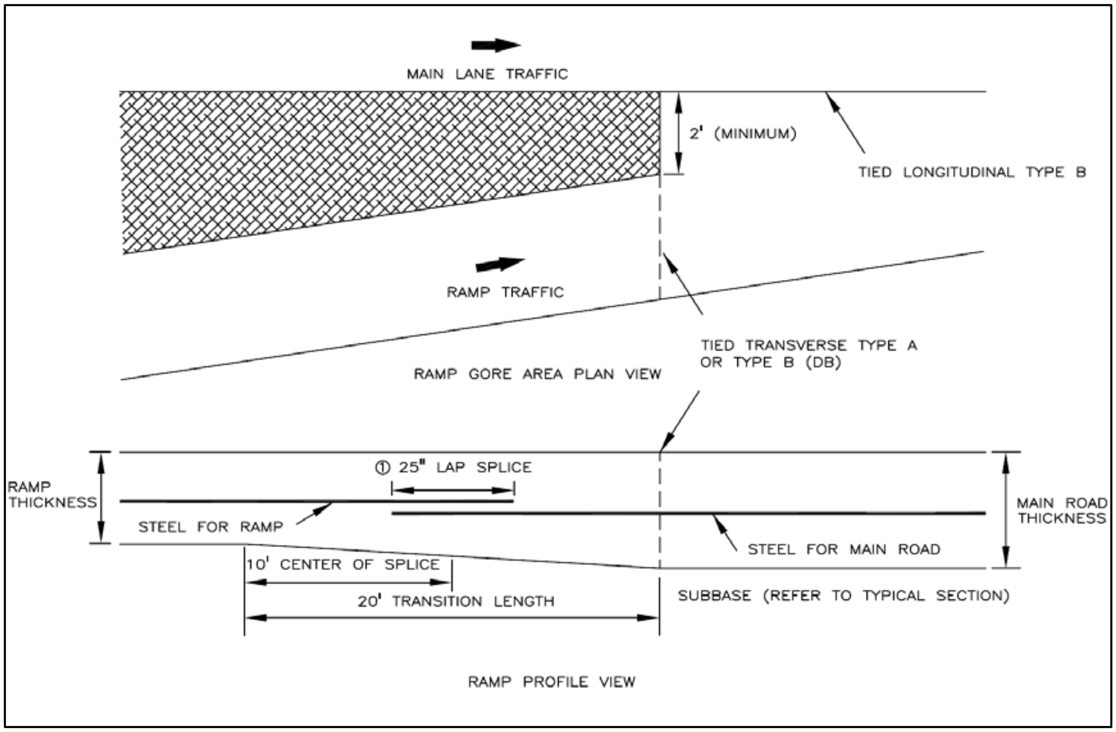


Figure 5-10 Improvement Concept of Ramp Transition.

Intersections

Intersections encompass the pavement areas of two orthogonally arranged pavement segments. This type of arrangement can be mutually restricting, and if there is no proper isolation from each other, restraint cracking may occur. Therefore, the objective of a transition for intersections is to promote compatibility of the movements between orthogonally arranged pavement segments included in the intersection.

Figures 5-11 and 5-12 are suggestions to reduce the level of restraint relative to the orientation of the continuously paved lanes. Figure 5-11 is appropriate when the frontage road would be paved continuously through the intersection and the cross road isolated from the frontage road in the intersection. When the length between the frontage road longitudinal joints is less than 500 ft, the contraction design using JC pavement should be used instead of CRC pavement since proper development of CRC cracking patterns cannot be assured. Figure 5-12 is for continuous paving of the cross road and isolation of the frontage road. A wide flange, sleeper slab, or thickened edge joint type may be applicable for the isolation sections. In the special area where the two directional pavement segments overlap, a transverse contraction joint with reinforcing steel bar (header joint) is employed if the paving is interrupted. The longitudinal construction joint between CRC pavement and the turning radius will be tied with deformed bars. The thickened edge isolation joint type is used on the other directional edge of the turning radius to avoid restriction of the CRC pavement end movement while reducing deflection. The 2 ft supplementary slab is doweled at the corner of the turning radius to prevent corner cracking. The continuously paved pavement segment and the orthogonal pavement segment should be isolated to avoid lateral restraint caused by differential directional movement using a wide flange, sleeper slab, or thickened edge. Traffic routing during paving should facilitate construction of the jointing plan, but avoid additional transverse (i.e., header) joints in this region, if possible.

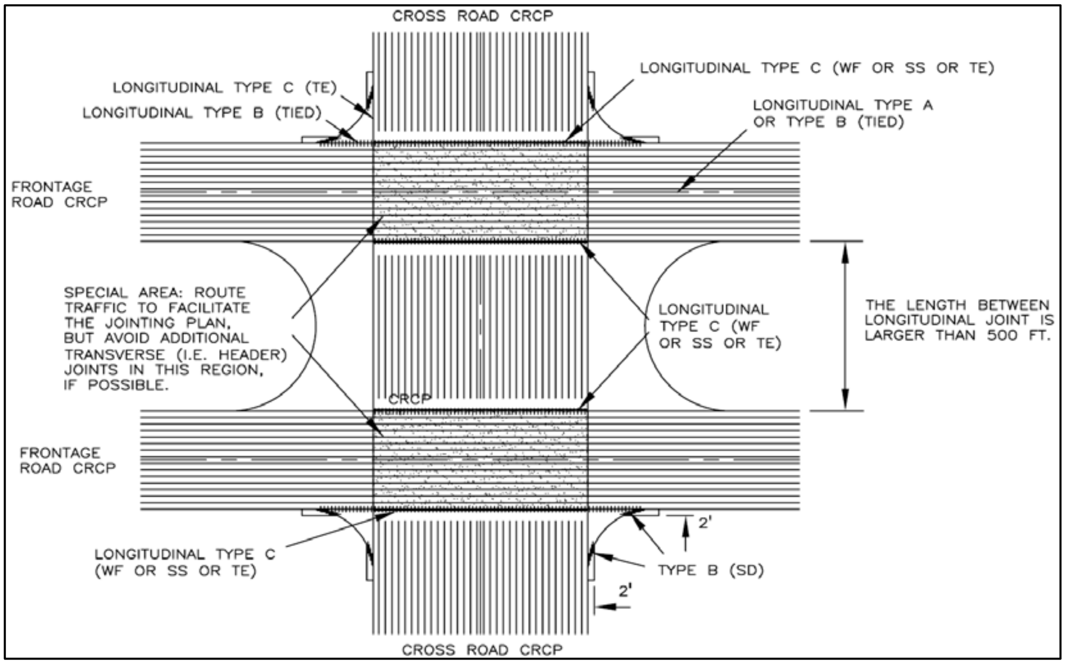


Figure 5-11 Improvement Concept of Intersection Transition for Continuous Frontage Road Paving.

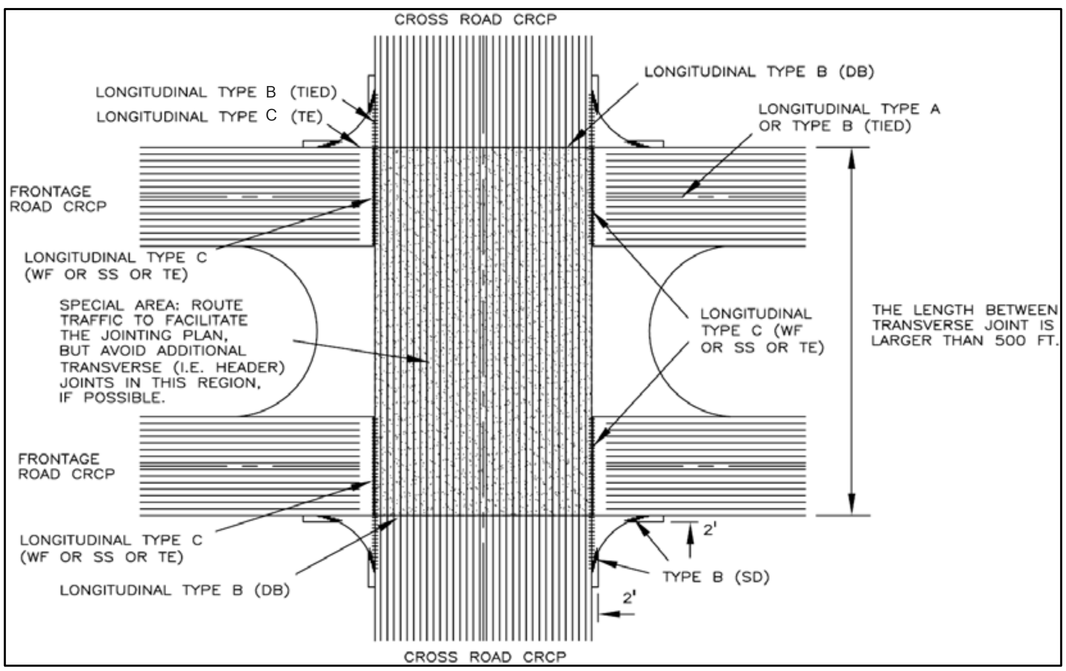


Figure 5-12 Improvement Concept of Intersection Transition for Continuous Cross Road Paving.

THICKNESS TRANSITION CATEGORY

Since the dimensions between two slabs would be different whether the same pavement type or material, stiffness cannot be the same and subsequently deflections are also uneven. Making gradual changes between two slabs or employing load transfer equipment could reduce this discontinuous transition problem and achieve better performance such as less faulting, longer joint life, and better rideability.

PCC Pavement Thickness Transition

The key word of PCC pavement thickness transition is continuity: continuity of support and continuity of deflection. When thickness transition occurs abruptly as a butt type at a construction joint, it may promote a blockage to subbase drainage paths and create support problems and, if load transfer is insufficient, deflection between two slabs would be different. The use of a graduated thickness transition or load transfer implements between the two slabs with dowels would help promote this continuity.

Figure 5-13 shows the CRC pavement to CRC pavement thickness transition. This is a transition of two continuously reinforced concrete pavement segments that have different thicknesses. Dowels/tie bars are drilled and epoxied into the existing pavement to transition to the new pavement. The tapered transition area should be at least 20 ft, and lap splice length of the steel bars should be 33 times the steel bar diameter. The reinforcing steel splice is made in the thickness transition area if one is present. It is important to achieve proper consolidation of the concrete between existing and new slabs during construction.

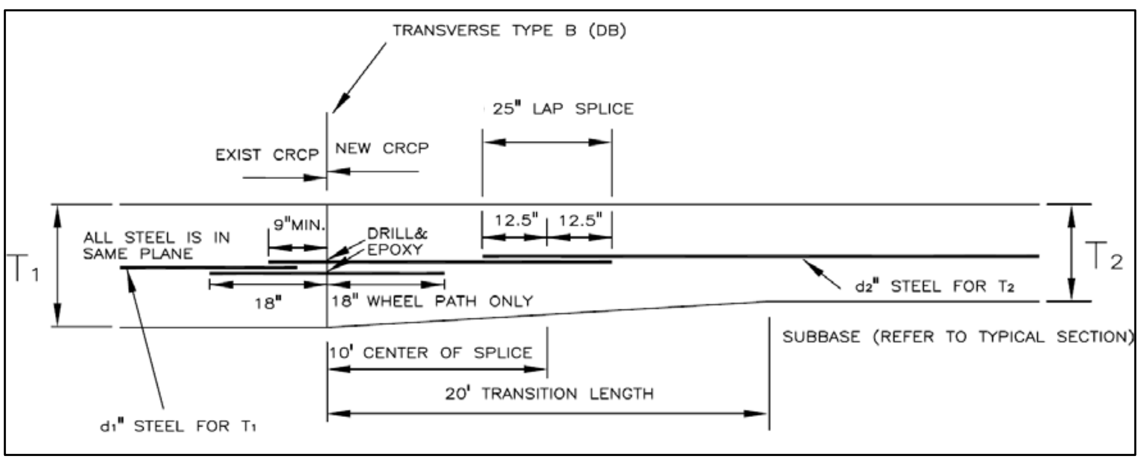


Figure 5-13 Improvement Concept of CRC Pavement to CRC Pavement Thickness Transition.

Figure 5-14 shows the transition between two jointed concrete pavements that have different thickness involving a tapered section. The tapered slab is approximately 15 ft in length but should be less than 4.44ℓ to prevent random cracking occurrences. Transverse Type B (SD) is used at the end of the tapered transition to facilitate matching the transition at the ends of the construction.

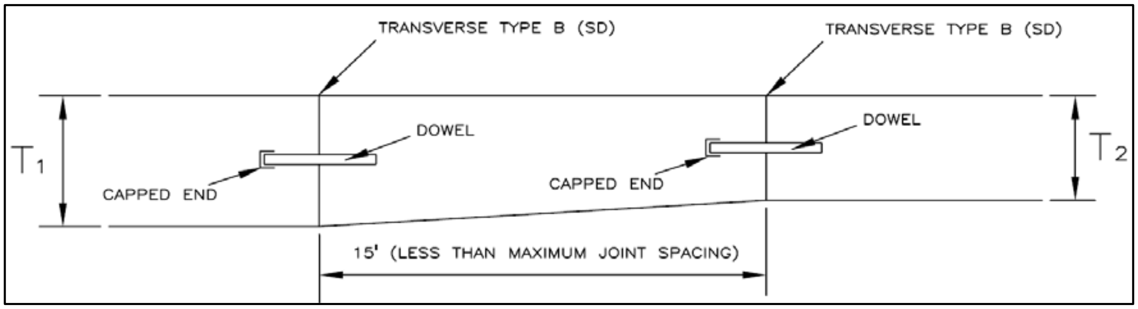
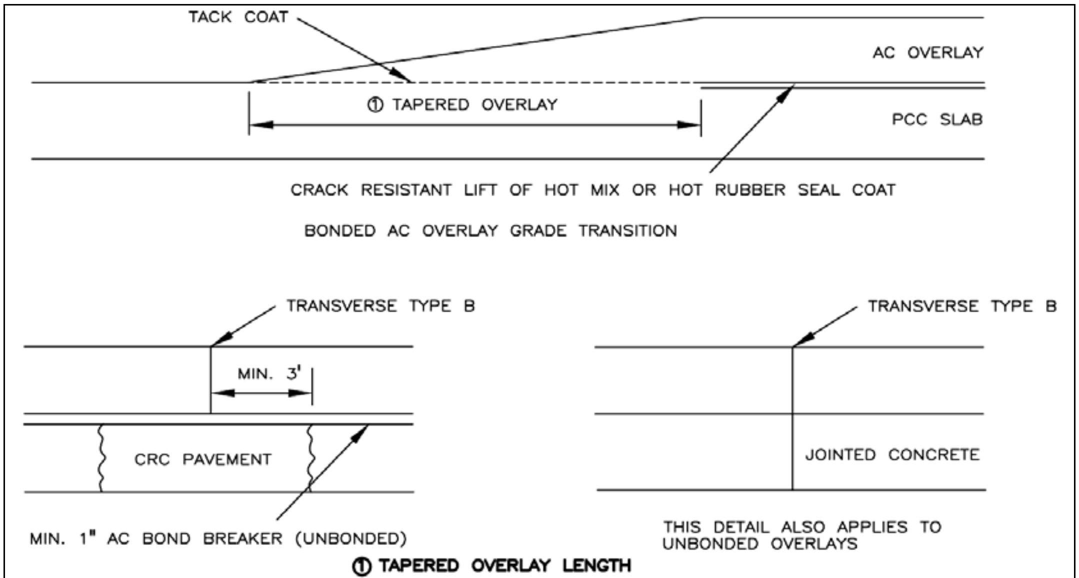


Figure 5-14 Improvement Concept of JC Pavements and JC Pavement Transition.

Overlays – Unbonded, Bonded, AC Transitions

The primary objective of this type of transition is to promote a smooth ride through the transition between pavement segments. Recommended rates of taper for overlay are introduced in the section.

Figure 5-15 shows other overlay transition concepts. A tapered overlay is used to transition an AC overlay to a concrete slab where the length of the transition depends on the overlay thickness. A tack coat application is made before the overlay to promote bonding between the AC overlay and the PCC slab. A stress-absorbing membrane interlayer can help the reflection cracking in the AC overlay. Transverse construction joints in bonded overlays should be matched with transverse joints in the existing pavement.



① TAPERED OVERLAY LENGTH

OVERLAY THICKNESS	TAPER MINIMUM LENGTH
1 "	50 '
2 "	100 '
3 "	150 '
4 "	200 '
5 "	250 '
6 "	300 '

Figure 5-15 AC or PCC Overlay over PCC Pavement Transition.

Figure 5-16 shows a CRC bonded overlay to CRC pavement transition. The transition involves a double layer of steel when the thickness is more than 13 in. based on TxDOT's CRC pavement design standard. Additional reinforcing bars are used between the bonded overlay and the new CRC pavement if LTE is not sufficient. The minimum lap splice length of steel bars should be 33 times the largest steel bar diameter. A CRC pavement to CRC pavement thickness transition slab can be used when the bonded overlay thickness is different with new CRC pavement.

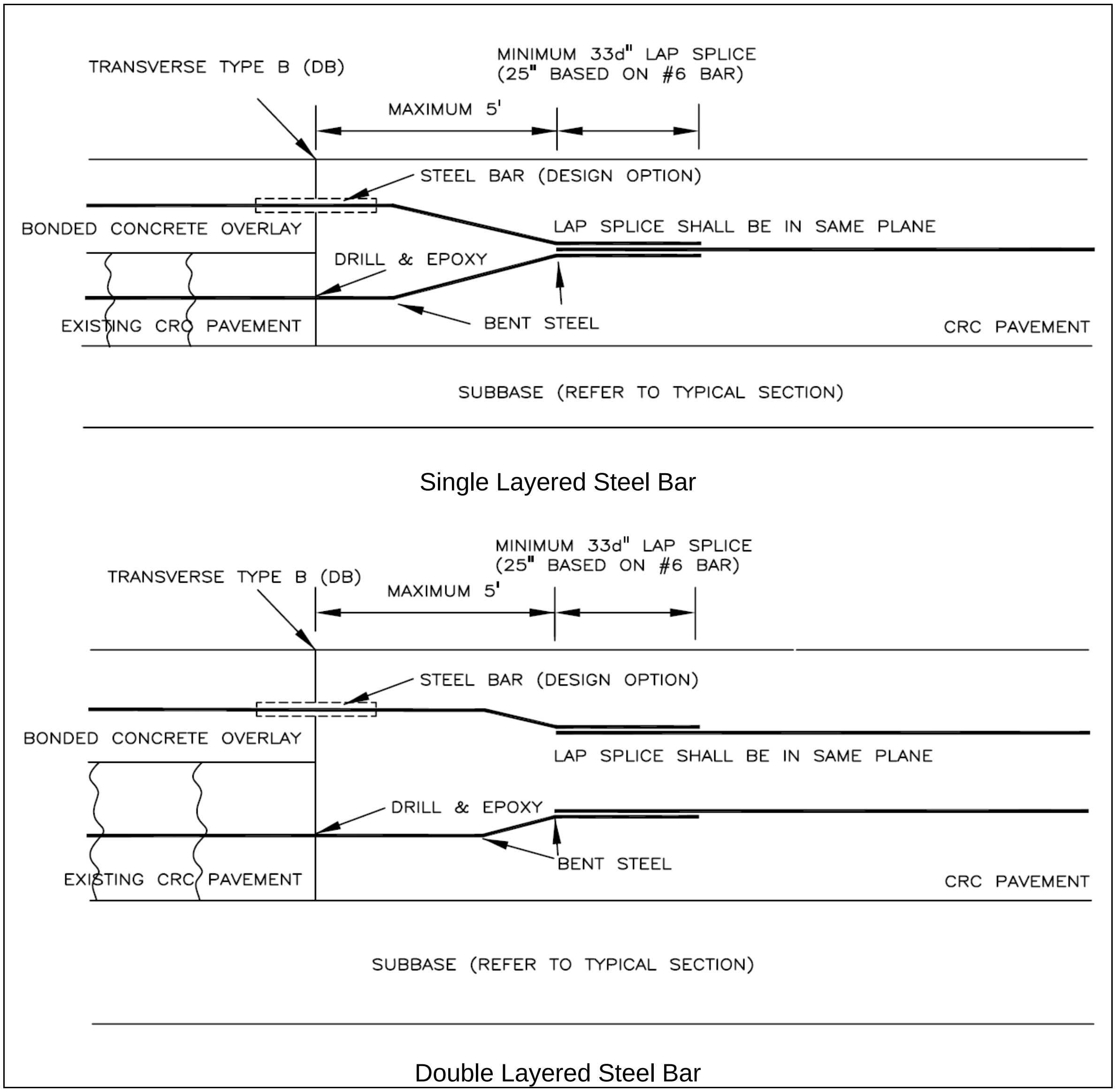


Figure 5-16 Improvement Concept of CRC Pavement Overlay Transition.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

Pavement transitions are key and common elements of pavement design. Transition details that are necessary for joining pavement sections that incorporate different design elements may include pavement type and pavement structure. Transition elements are necessary to ensure a smooth transition between two different pavement sections and to minimize future pavement performance issues. In this research, field visits were conducted in selected districts to survey conditions of concrete pavement transitions relative to slab cracking and associated distresses that may be related to improperly restrained segments due to inappropriate jointing practices or other design-related factors. In many districts, various forms of cracking were witnessed, providing a means to ascertain the causes and concepts for design improvements to prevent such cracking in future construction. Proper jointing of concrete pavements is essential to ensure good performance since it is the primary key to avoiding random cracking and irregular joint movements. Environmental factors such as temperature and moisture difference between top and bottom of a slab generate curling stress; this stress can cause cracks on the pavement with traffic load. Subgrade volume changes by non-uniform settlement or expansion also impose stresses to pavement, but it is controllable by treated base relative to climatic factors. As another source of stress, traffic loadings over pavement generate deformation, especially on the corner. The major factors relating with transition behavior such as radius of relative stiffness, modulus of subgrade reaction, combined slab thickness and elastic modulus, joint stiffness, and load transfer efficiency are discussed with reliability concepts.

Joint spacing, slab thickness, and joint stiffness are the prime factors in the performance of concrete pavement transition. Joint spacing is highly related with environmental factors such as temperature and moisture. When joint spacing is short, curling stresses are low, and joint openings between two adjoining slabs are small minimizing the possibility of premature cracking. However, the more sawcut joints, the greater the impact on rideability. The advantage of longer joint spacing is improved rideability; however, the slab has greater vulnerability to cracking due to traffic and climatic combinations and decreased joint LTE by greater joint openings. Dowelled joints can compensate for the lack of aggregate interlock; therefore, proper joint spacing needs to be balanced with the need for doweling for economical and good performance design. Slab thickness design is important as a starting point in transition design and is a key in affecting the amount of deflection of a transition pavement. Failure to meet the established deflection criteria may shorten service life. A load transfer device can be used to satisfy deflection criteria and stiffen the joint against load deformation. Joint stiffness is an element of LTE between adjacent slabs and reduction of deflection. It consists of stiffness due to aggregate interlock and dowel bars.

This report focuses on the measures to improve current transition design in terms of three general categories: transverse construction joints, longitudinal construction joints, and thickness transitions. The general features such as joint details, tie bars, and dowels are addressed for each transition type; limitations are identified, and then optimized configurations relative to deflection criteria are discussed. The objective of the transition between CRC pavements is to maintain uniformity of both support and cracking across the transition area while the transition of CRC and JC pavement is to allow the action of the joint reinforcement in the joint to isolate the movements of the CRC from the JC slab. The goal of CRC to AC pavement transition is to reduce the free edge deflection to those developing at an interior slab location with a concomitant reduction in subgrade stress. A bridge terminal transition facilitates change from one pavement type to structure while maintaining a smooth vertical profile. Performance of the transition can often focus on the opening and closing of the transition joints and their ability to maintain proper stiffness throughout these opening and closings. Otherwise, the seamless design considered as a continuum structure rather than individual elements can be an improvement to remove transition joints that are often the source of maintenance issues.

Longitudinal transitions are to maintain integrity and to prevent excess widening of the longitudinal joint between adjoining lanes. Joint patterns that delineate adjacent lanes should be as continuous as possible to maintain uniformity of movement between longitudinal lanes. The objective of ramps transition is to tie the movements of the ramps with the movements of the main lanes, but a transition for intersections is to promote compatibility of the movements between orthogonally arranged pavement segments included in the intersection. Transitions between new pavement and existing pavement, main highway lane and ramp, and overlay induce thickness change transversally or longitudinally. Making gradual changes between two slabs or employing load transfer equipment could reduce this discontinuous transition problem and improve performances.

To fully benefit from the findings from this project, it is recommended that implementation efforts be undertaken to further advance key transition details outlined in this report. Candidate transitions could be those at terminal bridge connections and placement intersection.

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