TEXAS' USE OF PRECAST CONCRETE STAY-IN-PLACE FORMS FOR BRIDGE DECKS

Brian D. Merrill, P.E. Texas Department of Transportation

ABSTRACT

In 1963, TxDOT developed a bridge deck construction method that allows approximately half of the deck to be precast. Precast, prestressed concrete panels span concrete or steel girders, supporting the weight of the cast-in-place top half of the deck. This method generated little interest until the early 1980's; however, standard details and specifications have greatly increased its use, and today, approximately 85% of all bridges built in Texas use this forming method. The method speeds up bridge deck construction while lowering costs and improving safety during construction. This paper addresses the following aspects of the use of this method: design, fabrication, construction, research, advantages and limitations on its use.

Keywords: Bridge decks, Stay-in-place forms, Forming systems.

INTRODUCTION

Beginning in 1963, Texas developed a bridge deck construction method where about half of the deck could be precast. Precast, prestressed concrete panels (PCP's) were designed to span girders, supporting the weight of the cast-in-place (CIP) top half of the deck. However, early attempts to cantilever the panels across the outside beam to support the overhang generated too many construction problems, and the concept was abandoned. Use of PCP's between girders on prestressed concrete girder bridges gained popularity slowly. During this time, bridge decks were paid for by the cubic yard of concrete, and reinforcing steel was a separate pay item.

In 1983, a revision to TxDOT's specifications changed the bid item for reinforced concrete slabs from cubic yards to square feet of bridge deck area with the specification allowing either removable forms, stay-in-place metal deck forms, or precast prestressed concrete panels at the contractor's option. Standard details developed by TxDOT's Bridge Division unified the requirements for PCP use across the entire state. The use of panels escalated.

PCP's used as stay-in-place forms for bridge decks have become the main forming system for most girder-type bridges built in Texas. TxDOT developed the standard details and specifications for PCP use and refined them in response to construction difficulties, research, and changes in materials. The system is so popular among Texas contractors that a small "cottage" industry has developed solely for the purpose of fabricating these panels. Bridge decks have been built using PCP's in virtually every area of the state, including areas where high concentrations of deicing chemicals are applied to bridge decks.

HOW THE SYSTEM WORKS

In Texas, the bridge deck thickness for most girder-type bridges is 8 inches. Design details and specifications typically show reinforcing details for a full-depth CIP slab and then give options for forming systems: conventional plywood forming, PCP, or stay-in-place metal forms with full-depth CIP concrete. The contractor can choose any of these forming methods although in certain cases one or more of these options may be restricted (refer to "Limitations" section below). PCP standard details indicate all of the necessary adjustments to the reinforcing details required for the use of the system.

PCP's used as stay-in-place forms are fabricated 4 inches thick, leaving 4 inches of CIP concrete with a single layer of reinforcing steel. The precast panels are normally prestressed at one of several fabrication plants although some contractors have elected to cast their own panels. The panels are placed on bedding strips set on top of the girder flanges. Girder elevations must be carefully checked prior to and after placing panels to ensure that the minimum deck thickness and reinforcing steel cover are maintained and that the panel support requirements are met (see Fig 1). In the overhangs, the deck must be conventionally formed using plywood, but at the ends of the spans, both plywood and metal decking are used to provide a thickened-slab end diaphragm.

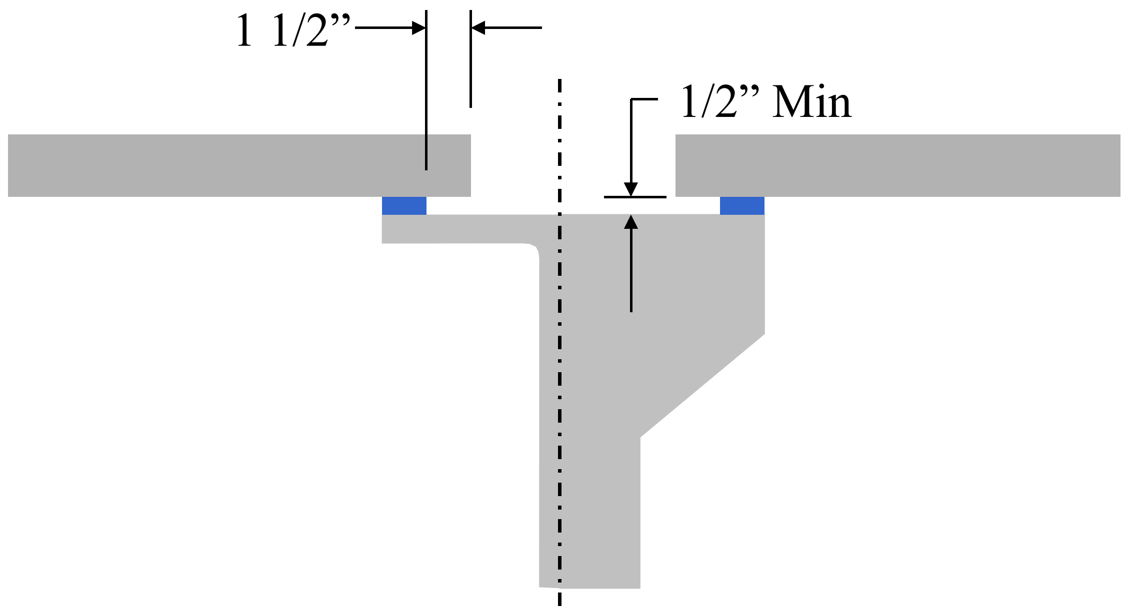

Fig. 1 Typical Installation of PCP on Steel or Prestressed Concrete Girders

Designers adjust the bearing seat elevations for all prestressed concrete girder bridges to allow for the panel support requirements in anticipation of the use of this system.

ADVANTAGES OF THE SYSTEM

The PCP system offers several significant advantages to the contractor: speed, cost savings, and safety.

SPEED

Use of PCP’s greatly accelerates the construction of a given bridge deck and can also reduce construction time for the entire project.

An experienced contractor can often set the panels for an entire typical bridge deck in a few days. Of course, the contractor has to perform some preliminary work before the panels are set. The girders must be profiled so that the top of girder elevations can be compared to the desired finished slab elevations. This information will be used to determine the height of the panel bedding strips. Conventional forming using plywood decking or use of stay-in-place metal decking can often take several days or weeks to set and grade. The time required to tie the reinforcing steel is also cut almost in half because only one mat of steel is required with the PCP system while two mats are needed for full-depth placement using conventional forms or metal decking.

Use of PCP's also allows for larger bridge decks to be placed in one casting operation, which can save time for the entire project. A typical three-span overpass might be 40 feet wide and 300 feet long. The concrete volume for an 8-inch thick bridge deck is 298 cubic yards. Assuming that concrete can be delivered and placed in 8-cubic yard loads every 15 minutes, the time required to place 298 cubic yards of concrete is more than 9 hours. Depending on labor and equipment availability and ready-mix plant production capability, the contractor may have to place the spans in separate operations. Using PCP's, the CIP volume is just over half of the full-depth volume – approximately 165 cubic yards for this example. The time required for this pour at the same concrete delivery rate is now about 5 hours. Using a single pour for the entire bridge means the bridge may be completed and opened to traffic much sooner.

COST SAVINGS

Contractors who use PCP's realize significant cost savings over the other forming systems. The time required to set and grade panels is much less than that required for plywood or metal deck forms, resulting in reduced labor and equipment rental costs. This shortened form setting time can also reduce the time lanes must be closed when working over traffic, a cost savings not only to the contractor but also to the traveling public. Labor costs for placing reinforcing steel are cut in half with the PCP option, but this savings is often offset by the panel fabrication cost. Equipment rental costs for concrete pumps can be lower using PCP's because of the reduced volume of CIP concrete. Because PCP's are a stay-in-place forming system, form removal costs are limited to the overhangs resulting again in time, labor, and lane closure savings.

Contractors have also indicated that their insurance premiums are lower when they use PCP's, even lower than for metal deck stay-in-place forms due to the inherent safety of the system. This helps explain why Texas' average bridge deck prices are some of the lowest in the nation.

SAFETY

PCP's have an excellent safety record in Texas. The panels typically weigh approximately 3000 pounds and cannot be blown off the girders in high winds as plywood or metal decking can. They provide a stable and safe working platform for laborers tying the reinforcing steel and placing the concrete. Unlike plywood or metal decking, which spans to the edge of the girder flanges, PCP's are wider than the gap between the adjacent girder flanges so it is unlikely that they can fall between the girders as plywood or metal decking can.

Safety is obviously increased with respect to form removal when compared to plywood decking, especially when working over or near traffic.

Metal deck forms have failed and collapsed during concrete placement in several incidents in Texas. Many metal deck manufacturers tried to lower the cost of using these systems by providing the thinnest sheet metal possible. When analyzed, the sheet metal decking was found to be able to carry the required concrete load as long as the decking was undamaged. In many cases, the steel banding used to ship the decking caused small dents in the ribs of the metal panels. Additional dents were caused by laborers tying the reinforcing steel or by the welder's cart as it bounced across the metal decking. These dents reduced the stiffness of the metal decking, causing it to buckle under the weight of the wet concrete. As a result, TxDOT now requires that metal decking be no thinner than 20-gauge.

ADVANTAGES FOR TEXAS

Use of the PCP system also has significant advantages for TxDOT in addition to those previously mentioned. The panel system gives us the ability to incorporate prestressed steel in the positive moment area of the deck. This produces a definite improvement in long term durability of our decks. Another advantage for TxDOT is the high quality of the prefabricated panels. The panel fabricators are located in areas of the State with very high quality coarse and fine aggregates. Hence, high quality materials are incorporated into decks for areas of the State that may have marginal materials. The result is a definite increase in deck durability. Finally, use of the PCP system also lowers the initial cost of bridge decks.

DESIGN

For typical bridges in Texas, a "design" is not required for decks. Deck thickness, reinforcing and forming requirements are standardized across the state.

CIP SLABS

Plan details for all typical bridge decks indicate the required thickness and reinforcing steel spacing for a full-depth slab. The decks are almost always 8 inches thick with transverse reinforcing in two layers. The required concrete strength is 4000 psi with Grade 60 reinforcing steel. Transverse deck reinforcing consists of straight #5 bars at 6 inches on center in the top and bottom layers. The clear cover over the top layer is 2 inches while the bottom layer has a clear cover of 1-1/4 inches. Longitudinal temperature and distribution steel are also provided using #4 bars at 9 inches in the top layer and #5 bars at 9 inches in the bottom layer.

During development of the PCP system, deck slabs were designed as a beam in flexure supported by the girders using the AASHTO Service Load design provisions with HS 20 loads for conservatism. TxDOT's bridge deck design requirements limited the calculated stress in the reinforcing steel (f_s) to 24,000 psi and the concrete stress (f_c) to 1,600 psi using a modular ratio (n) of 8. Design calculations are not required for standard 8-inch thick decks where the clear span between flanges of prestressed concrete beams or the span between quarter points of steel girder flanges does not exceed 8.7 feet. The panels can actually span farther than this distance, but the design is controlled by the negative moment reinforcing in the CIP portion over the girders.

PRECAST PANEL DESIGN

TxDOT has standard detail sheets for precast concrete panels on prestressed concrete beams and structural steel beams. These standard details can be inserted into the bridge plans when the PCP option can be allowed, which is more often than not (refer to "Limitations" section). The panels have been designed to match the span limits for the fully CIP deck mentioned above. These details can be viewed online at:
http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/bridge-e.htm

PCP designs are highly standardized, and they are intended to follow the AASHTO Bridge Design Specifications. Service Load design is used but ultimate strength is checked at mid-span. The panels alone support the dead load. The composite PCP/CIP cross section resists slab live load moments. Transverse reinforcing in the CIP portion, #5 bars at 6 inches, is designed for the negative live load slab moment. Distribution reinforcing is not required, based on the results of load testing mentioned later in this report. The panels use 5000 psi concrete and 3/8-inch diameter Grade 270 strands at 6 inches on center. The panels are generally not long enough to develop larger strands, so the design is based on the amount that can be developed rather than full development. The strands are located at mid-depth in the 4-inch thick panel and are prestressed to 16.1 kips. The tensile stress at the bottom of the panel (f_t) is limited to the value determined by Equation 1.

$f_t = 6\sqrt{f'c}$ (Eq. 1)
Where $f'c$ = 5,000 psi, f_t = 424 psi

The midspan ultimate flexural capacity of the PCP/CIP composite slab is based on f^*_{su} which is calculated using Equation 2. [Eq. 9-19 in the AASHTO Standard Specifications for Highway Bridges, 17th Ed, 2002]

$f^*_{su} = \text{(Panel Length)}/2D + 2f_{se}/3$ (Eq. 2)
Where D is the strand diameter and $f_{se} = (0.7)(270) - 45$ ksi = 144 ksi

For short panels, usually 5 feet or less in span, #4 Grade 60 reinforcing steel can be substituted for the strands. Reinforcing steel instead of prestressing strands is required in panels shorter than 3.5 feet to prevent splitting. The panel length (span) can be adjusted in each panel to accommodate flaring beams but this requires diligence on the contractor's part to ensure that the panels are set in the correct location.

The PCP deck system has been evaluated using the new LRFD criteria and no changes were required. It is interesting to note that the PCP deck system always fails in punching shear in laboratory tests at levels much greater than the HS20 design load.

TxDOT traditionally provided cast-in-place diaphragms at slabs ends to provide additional stiffness for fully cast-in-place decks. When the PCP system became popular, forming and casting these conventional beam-type diaphragms became more difficult. In response to contractor's requests for an easier-to-build system, TxDOT developed a thickened slab "diaphragm" (see Fig. 2). This detail became the standard for both conventional fully CIP decks and decks using the PCP system. The detail uses #3 rebar extending out of the end panels into the CIP diaphragm. The new diaphragm detail still requires either conventional plywood or stay-in-place metal forms for the thickened slab portion.

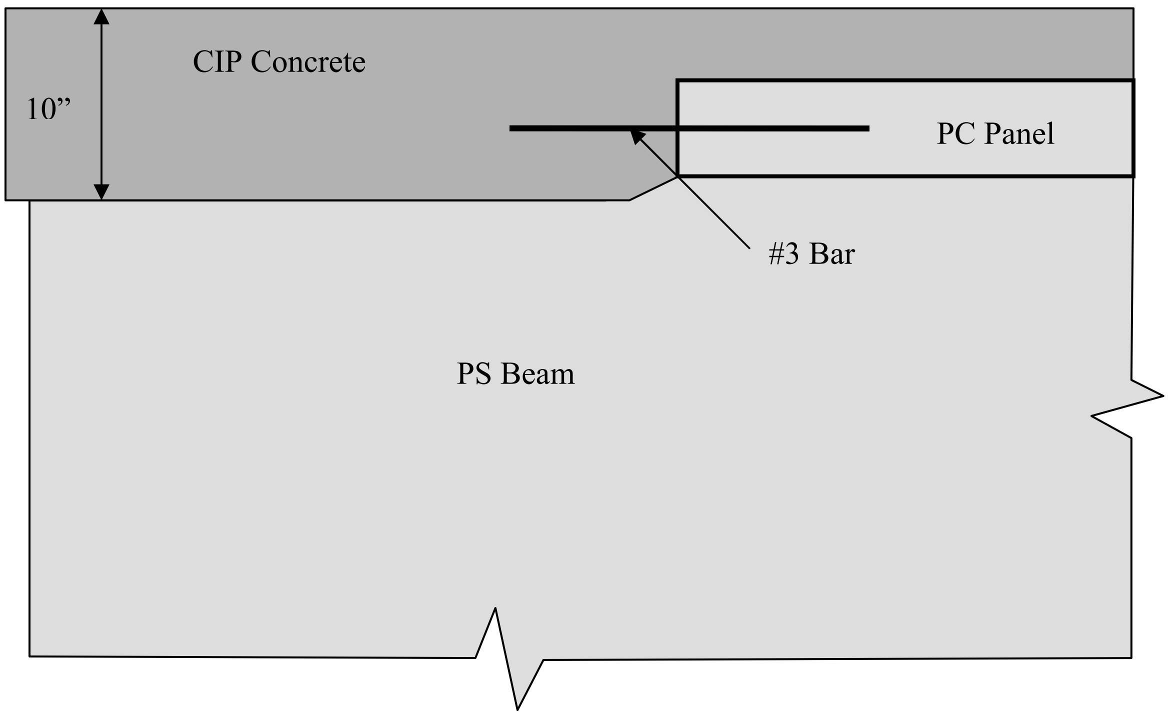

Fig. 2 Typical Section at Thickened Slab Diaphragm – Current Details

The standard details allow the panels to be staggered for use on skewed structures. Panels at the end of the spans have #3 reinforcing bars that extend into the CIP portion to stiffen this connection (see Fig. 3).

Fig. 3 Staggered Panels on 45^{o} Skew. Note Extension of Reinforcing Steel From Panels; Dashed line indicates centerline of bent

LIMITATIONS

TxDOT does prohibit the use of PCP's for certain applications:

- Curved steel girder bridges. TxDOT's Bridge Design Engineer prefers to have a monolithic deck on these units because of the complicated interaction between the deck, the curved girders, and the diaphragms. PCP fabricators can actually fabricate a pie-shaped panel for use on curved girders, but TxDOT has elected not to use them for this application.
- Bridge widenings. PCP's are not allowed in the bay adjacent to the existing structure because it is usually not possible to set the panels properly on the existing structure. PCP's can be used on the other girders when the widening involves multiple girders.
- Phased construction. PCP's were not often allowed in the bay adjacent to the previously placed deck because it was difficult to install a header form that leaves enough room for the panels to be set properly on the girders from the earlier stages (see Fig. 4). The latest version of the standards moves the location of the staged construction joint to allow use of PCP's in all bays (see Fig. 5).
- Steel girders with narrow flanges. Girders with flanges less than 12 inches wide make PCP use difficult because the shear studs conflict with the panels. Standard details allow shear studs to be skewed across the flange width to facilitate use of PCP's where sufficient flange width is available.

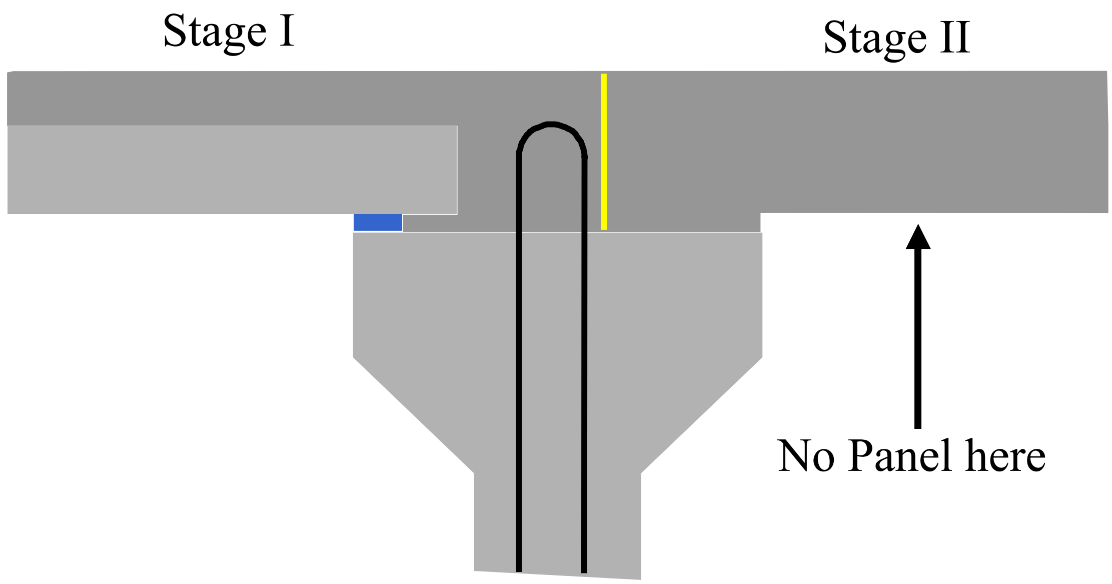

Fig. 4 Original PCP Installation for Phased Construction

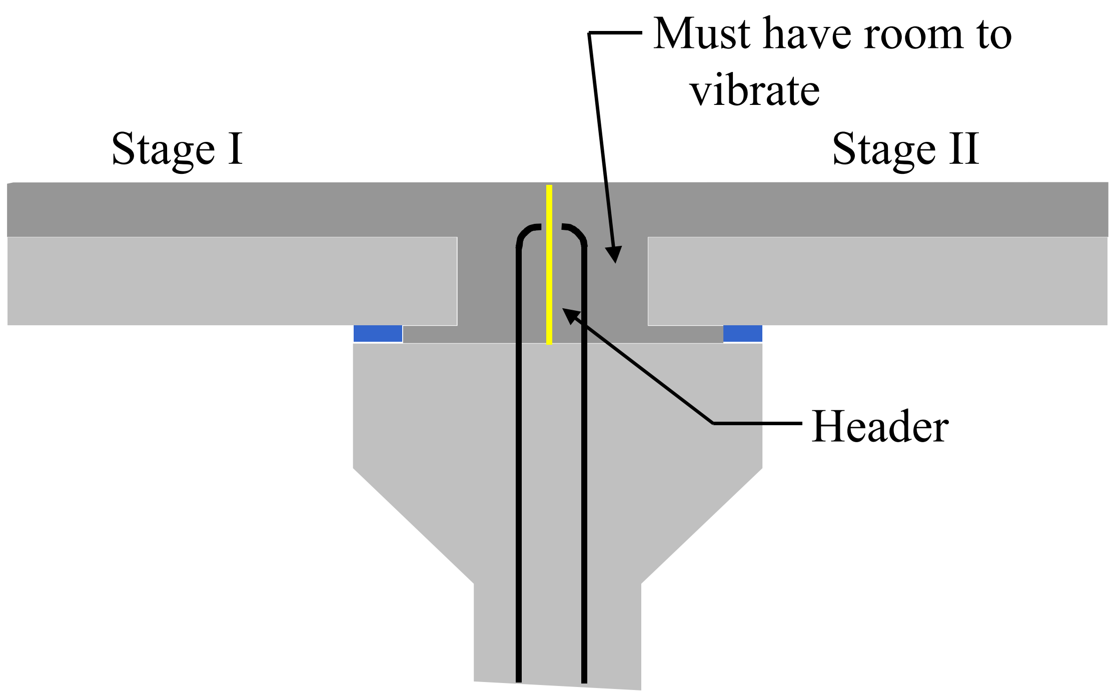

Fig. 5 Revised Construction Joint to Allow PCP Use for Phased Construction

CONSTRUCTION

PCP use greatly simplifies and speeds bridge deck forming and grading because almost half of the deck is precast. Several critical factors affect performance of the completed bridge deck: fabrication, setting of panels, and concrete placement. The operation most critical to the successful use of PCP's is the setting and grading of panels.

FABRICATION

Panels are typically precast in a prestressing plant although a few contractors have elected to fabricate their own panels. Fixed plant fabrication results in a cost benefit due to mass production but also results in better quality control as the fabricators' personnel and the TxDOT inspectors become familiar with the standard details and specifications.

Panels are cast in 8-foot wide casting beds that range from 350 to 500 feet in length. Fixed bulkheads or self-stressing forms are used to pretension the strands prior to concrete placement. Shop drawings are prepared by the fabricator to ensure that the panels are cast to the proper length. Each panel is marked with the project identification information and its cast date. The panels are typically formed with a short gap, usually 6 inches, between panels (see Fig. 6). This gap allows for slight panel movement when the strands are released and also provides a short extension of the strands into the CIP portion of the deck (see Fig. 7).

The required concrete strength is 5000 psi, but most fabricators use a high-range water reducer along with Type III cement so that the concrete reaches 4000 psi in about 14 hours for strand release. This allows panels to be cast in a given bed every other day. On a typical day, the largest PCP fabricator in Texas can produce up to 500 panels (approx. 23,300 sf). In comparison, a smaller fabricator may produce only 50 panels per day. The panels are given a broom finish to aid in the development of bond between the panel and the CIP concrete. Panels are stacked for storage and shipped when the contractor is ready to place them. TxDOT specifications are explicit with regard to panel quality and damage to panels during storage and handling, and TxDOT plant inspectors monitor all stages of panel production.

Fig. 6 Forming of End Panel Showing Gap in Forms and #3 Reinforcing Steel

Fig. 7 Completed Panels in Storage – Note 3” Strand extension

SETTING PANELS

Prior to setting panels, the contractor must ensure that the girders are plumb and properly braced. Standard bracing details for prestressed concrete girders are included in all plans. Bracing is required because no positive connection occurs between the panels and the girders until the CIP concrete has set up. TxDOT does not typically use intermediate diaphragms on prestressed girders. The outside girders are especially susceptible to twisting due to torsional loads applied by the screed on the deck overhang brackets.

Once the girders have been erected and braced, the contractor needs to profile the top flange of the girders at selected intervals. The elevation difference between the proposed slab elevations and the elevations along the top flange, with adjustments made for anticipated girder deflection, will be used to determine the height of the panel bedding strips. The standard details and specifications explicitly require panels to be supported at least 1/2 inch above the girder as indicated in Fig. 1 so that mortar can flow under the panels to provide bearing for live loads. If the 1/2-inch dimension cannot be achieved, the profile grade of the deck must be adjusted. Notes on the standards and in the specifications allow the deck to be poured up to 2 inches thicker at midspan to accommodate these grade adjustments and to allow for differential camber between adjacent girders.

The contractor uses bedding dimensions determined above to precut bedding strips. For many years, bedding strips were made from asphalt-impregnated fiberboard. In recent years, TxDOT noted that the fiberboard crushed over time if the panels were set too far in advance. This meant that panels initially set to meet the 1/2-inch minimum dimension might not have the required gap when the concrete was placed. A decade ago high-density extruded polystyrene foam was found that works well as a bedding strip for the panels. It does not deflect under the weight of the panels, does not absorb water, and can be glued to the girders for additional stability. The foam, because it is very stiff, can be used up to 4 inches high while the fiberboard is limited to 1.5 inches. Texas contractors initially had difficulty finding the foam, so its use was limited; however, the foam is now readily available and is popular with contractors because of its dimensional stability and ease of use. The latest version of the PCP standards allows only foam to be used for panel bedding. Bedding strips must be placed at the edge of the girder flange as shown in Fig. 1. The length of the panels is set such that the panels overhang the bedding strips by a minimum of 1.5 inches as shown in Fig. 1. Additional panel length (transverse) is provided to account for girder sweep tolerances and to ensure a sufficient mortar bearing for the panels for live loads.

Once the panels have been set, the contractor should re-profile the top flanges of the girders. These elevations can be compared to the initial elevations to determine the deflection under the weight of the panels. TxDOT plans give estimated girder deflections based on the original design criteria for the prestressed concrete girders, but the actual dead load deflections often differ from these values. The total dead load deflection can be assumed to be slightly more than twice the deflection due to the panels. These deflection values are then used to set the grades for the screed and to determine the required chair heights for the reinforcing steel.

Use of the PCP option requires a little more thought on the contractor’s part when it comes to placing the reinforcing steel and checking the clear cover and CIP depth against the screed during the dry runs. The contractor (and inspectors) must be aware that the outside girders, upon which the transverse screed rides, are not carrying the same load due to the panels as the interior girders (see Fig. 8). The screed must be set artificially high to account for the fact that the outside girders will deflect more than the interior girders due to the CIP concrete.

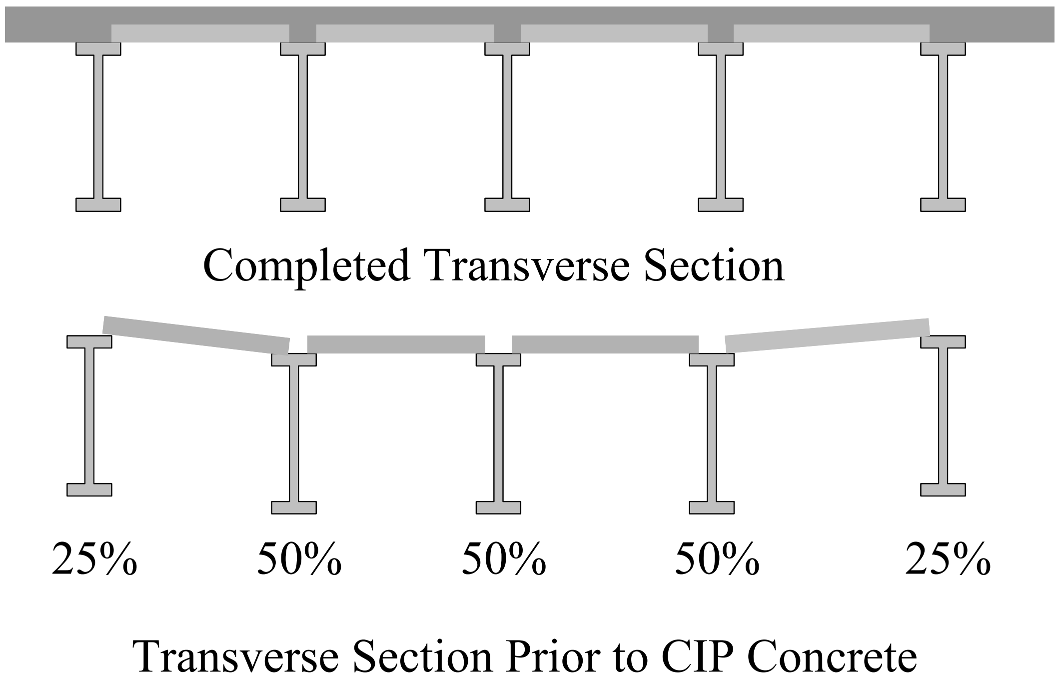

Fig. 8 Partial deflection of girders due to panels and completed section.

Placement of the CIP concrete on PCP's requires careful attention as well. The panels must be wetted down prior to placement but should not have any standing water on them. If the panels are dry when the concrete is placed, the panels will draw moisture out of the CIP concrete, resulting in drying shrinkage cracking. Careful vibration of the concrete is also required, especially in the gap between panels over the girders, to allow mortar to flow under the panels to provide live load bearing. All other aspects of concrete placement for PCP use are the same as the other forming methods.

RESEARCH

Texas invested considerable time and money for research related to prestressed concrete panels. The following is a summary of each project conducted to date:

- "Test of Precast Prestressed Concrete Bridge Deck Panels," Texas Highway Department, Bridge Division, undated. This in-house full-scale study was conducted on the first three bridges to use the PCP's built in 1963. The study was concerned with the bond between the CIP concrete and the panels and the load transfer between panels. The study concluded that monolithic action was achieved and that bond should be a concern.
- "Study of In-Service Bridges Constructed with Prestressed Panel Sub-Decks," TxDOT Research Report 145-2, Jones & Furr, Texas Transportation Institute, 1970. This project used full-scale testing to verify that load transfer to adjacent girders using PCP's was

identical to that for a monolithic slab of equal thickness. It also determined the condition of the bond between the CIP concrete and the panels.

- "Development Length of Strands in Prestressed Panel Subdecks," TxDOT Research Report 145-2, Furr & Jones, Texas Transportation Institute, 1970. Studies were made regarding development length of various strand sizes. The strand size and reinforcing steel required for short panels in the current PCP standards were determined using this research.
- "Evaluation of a Prestressed Panel, Cast-In-Place Concrete Bridge," TxDOT Research Report 145-3, Buth, Furr & Jones, Texas Transportation Institute, 1972. This report was a continuation of the 145-1 project, which focused on the ability of the CIP/PCP deck to act compositely with the prestressed girders. Using theoretical models and full-scale testing, it concluded that the CIP/PCP combination worked as well as monolithic deck acting compositely with the prestressed girders. The report indicated the presence of small transverse cracks in the CIP concrete over the joints between adjacent panels but concluded that these cracks do not affect the structural performance of the deck/girder composite system. Several changes in the standards were made as a result of this project.
- "Cyclic Load Tests of Composite Prestressed-Reinforced Concrete Panels," TxDOT Research Report 145-4F, Furr & Ingram, Texas Transportation Institute, 1972. This study concluded TxDOT's 2-5-70-145 Research Project by evaluating several proposed modifications to the standard details.
- "The Effect of Transfer Strand Extensions on the Behavior of Precast Prestressed Panel Bridges," TxDOT Research Report 303-1F, Bieschke and Klingner, Center for Transportation Research, 1982. Early designs for PCP's required the strands to extend out of the panels to provide positive moment resistance for load transfer over the girders. One proposed detail change, in an attempt to make fabrication easier, allowed the strands to be cut flush with the panel edge. This study used side-by-side full-scale static and fatigue tests and concluded that PCP's performed equally well with and without the strand extensions. Despite this finding, TxDOT decided to continue to require the strands to extend out of the panels by 3 inches. The report recommended that bridge deck capacity under concentrated loads be investigated using yield-line models as well as punching shear models, especially in the overhang areas. A significant finding in this report concerned the placement of the panel bedding strips. The authors noted that mortar must be able to flow under the panels to provide live load support. If this does not occur, the panels bear primarily on the flexible bedding strips, causing very significant longitudinal cracking. The authors concluded the report by stating: "Overall, the experimental program showed that the precast, prestressed panel deck was stronger, stiffer and more crack-resistant than the cast-in-place deck."
- "Bridge Slab Behavior at Expansion Joints: Overview," TxDOT Research Project 4418. This report evaluated slab ends at expansion joints for 8' and 10' girder spacing with no skew. The PCP deck panels were placed flush with the end of the slab and topped with a 4" thick cast-in-place deck. The purpose was to determine if the thickened slab diaphragm typically used by TxDOT could be eliminated. The results were uniformly excellent: first cracking occurred between 1.8 and 2.8 times the LRFD design tandem load and failure in shear occurred between 5.3 and 7.2 times the LRFD design tandem

load. When steel armor joints were included in the test, the load capacity increased by almost 25%.

- "Use of Innovative Materials to Control Restrained Shrinkage Cracking in Concrete Bridge Decks," TXDOT Research Project 4098. This project studied various materials in an attempt to reduce or eliminate cracking due to drying shrinkage – the main cause of cracking with the PCP system. The studied concluded that Shrinkage-Compensating Admixtures, fibers, high-volume flyash, and certain special cements all controlled cracking to degree in the laboratory specimens. The next step will be field trials to determine the cost/benefit ratio for each method as well as any field issues related to handling, placement, and curing.

Several studies conducted elsewhere relating to the use of precast panels for bridge decks have not been mentioned in this article.

PROBLEMS

As with any construction method, attention to detail and compliance with all plan notes and specifications are required for the successful use of PCP's for bridge deck construction. The system is not perfect, and a few notable problems have been associated with the use of the panels.

LONGITUDINAL CRACKING

Longitudinal cracking is probably the most significant problem associated with the use of PCP's because it can result in a reduction in deck stiffness over the girders that could compromise the deck's load-transfer mechanism. In many cases, early users of the system experienced significant longitudinal cracking along the panel edges over the girders. These cracks can usually be attributed to insufficient bearing under the panels for live load. In the middle 1970's, design and construction engineers from another state visited Texas to determine why their decks were exhibiting significant longitudinal cracking when panels were used. It was their practice to specify the bedding strips at the panel edge. This prevented mortar from flowing beneath the panel to provide a firm bearing for live load.

A similar situation arose in Texas but for a different reason. Contractors found that it was difficult to glue the fiberboard bedding strips to the girders to keep them from dislodging. To alleviate this, contractors began to place the fiberboard bedding strip away from the edge of the flange approximately 1 inch, knowing that the panels had sufficient length to provide the 1.5-inch overhang distance. The extra room kept the bedding strips from falling off as the workers walked the tops of the girders. Unfortunately, this method failed to account for the fact that prestressed girders are not always perfectly straight, nor are they always placed with the exact spacing shown on the plans. This results in insufficient bearing for the panels, just as if the bedding strips had been intentionally placed at the panel edge (see Fig's. 9, 10 and 11)

Fig. 9 Large Longitudinal Crack at Panel Edge

Fig. 10 Close-up of Crack from Fig. 9

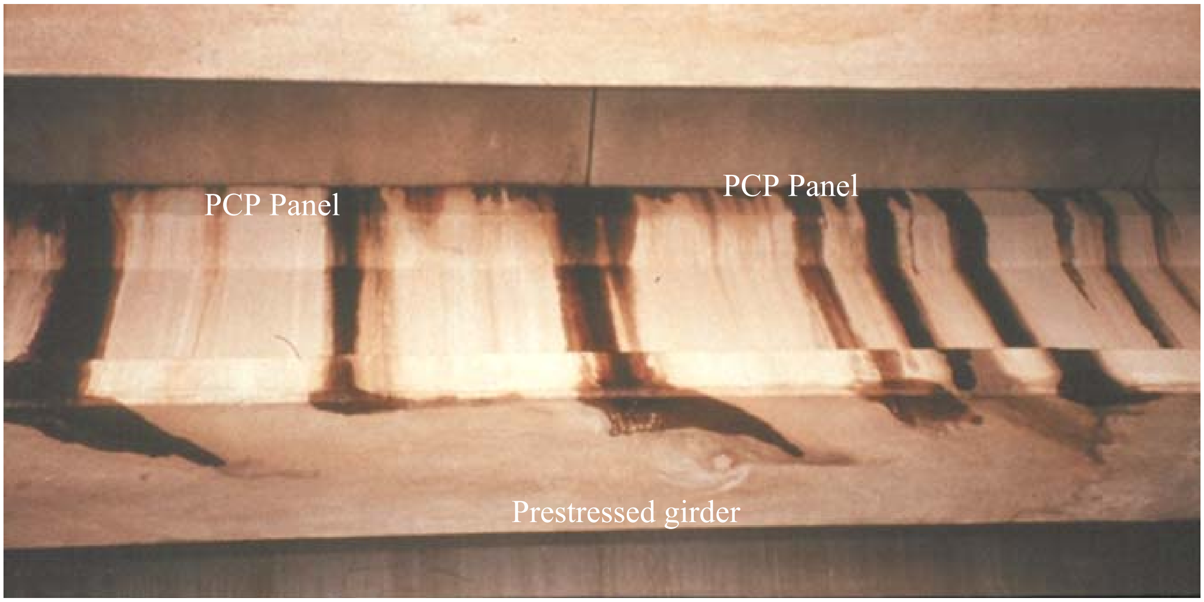

Fig. 11 Water Penetration at Crack from Fig's. 9 and 10

A similar problem can occur with fiberboard bedding if strips are placed too far in advance of the concrete placement. The fiberboard crushes over time, especially if it gets wet, and the panels may end up resting partially on the girders and partially on the bedding strips, once again preventing the mortar from flowing under the panels. Both of these problems have been alleviated using the high-density foam. The foam can be glued in place at the edge of the flange, and it will not crush over time so the panels stay in the proper position until placement of the concrete (see Fig. 12).

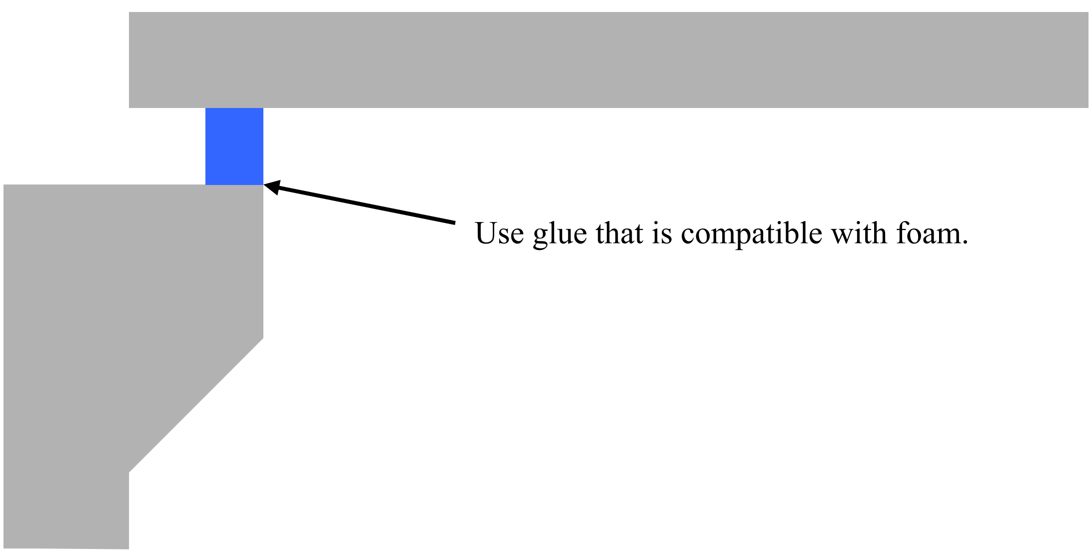

Fig. 12 Foam Supports for Panels

Longitudinal cracking can occur even with proper execution of the details. Cracks can develop at the re-entrant corners of the panels due to drying shrinkage of the concrete and the restraint provided by the girders and panels (see Fig. 12). These cracks are typically small, and TxDOT has not experienced significant problems associated with these cracks. The cracks do seem to be more prevalent where the concrete was not designed or placed properly. Many projects are under tremendous pressure to speed construction, and in many cases the concrete mix is designed with extra cement to provide higher early strengths. This extra cement increases the water demand of the mix and the potential for shrinkage. Curing may also be shortened in the interest of opening a bridge to traffic. TxDOT recently completed a research project that looked for ways to minimize the shrinkage cracking in deck concrete through the use of supplementary cementing materials, fibers, admixtures, or modifications to the details. Research has shown that longitudinal cracks do not significantly affect the capacity of the slab.

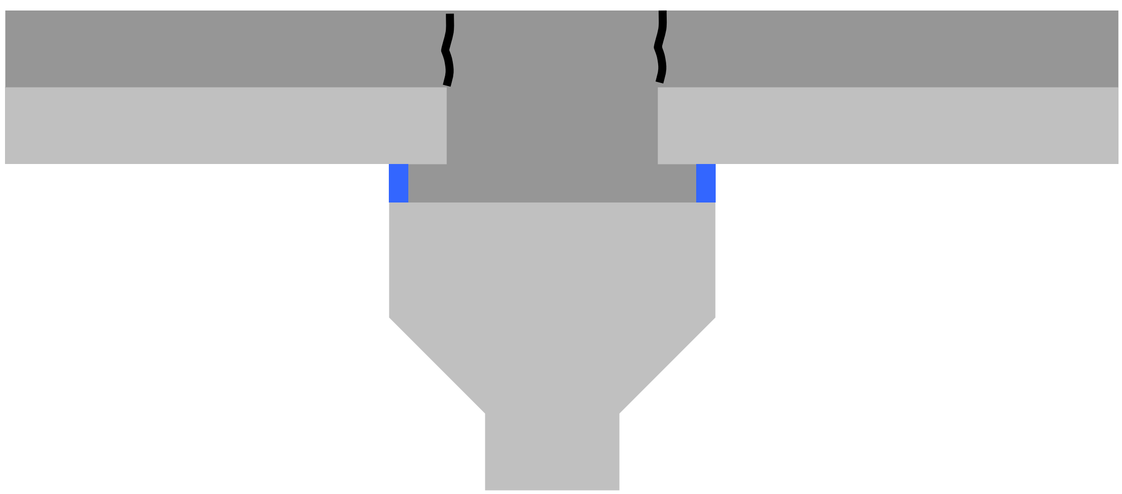

Fig. 12 Longitudinal Cracks over Girders

TRANSVERSE CRACKING

Several of the research reports mentioned above noted transverse cracking as a common occurrence with panel usage. The causes are shrinkage of the concrete, restraint provided by the panels, and the gap between adjacent panels (see Fig. 13). Research concluded that these cracks do not affect the structural performance of the composite deck. TxDOT has not experienced any problems that can be attributed to the formation of these cracks but did decide several years ago to reduce the spacing of the longitudinal reinforcing in the CIP portion from 12 inches to 9 inches.

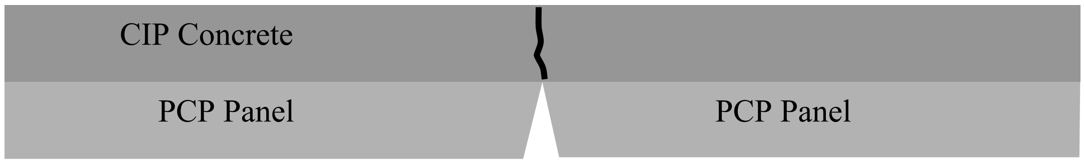

Fig. 13 Transverse Cracks between Panels

GRADING AND YIELD

Grading and yield are problems that primarily affect the contractors' operations and costs. The panels can be difficult to grade especially if the girder cambers vary widely, as is often the case. Many decks require adjustment of the final grade to ensure that the required deck thickness, the required reinforcing steel clear cover, and an acceptable ride quality are maintained. Grading issues are little concern to a contractor experienced in the use of panels but can pose problems for those new to the method. Yield is defined as the volume of CIP concrete divided by the square foot of bridge deck area. TxDOT pays for bridge decks by the square foot, but the contractor still has to order concrete by the cubic yard. Grade adjustments mean that more concrete volume must be ordered to cover the same area of deck. This results in a cost increase to the contractor that is not apparent at bidding time.

Skewed bridges also increase the level of difficulty in that more conventional forming must be used at the end of the spans. Flared beams can also pose problems. Both of these issues have been addressed with revisions to the standard drawings.

NEW DEVELOPMENTS

TxDOT routinely reviews and modifies standards for bridge construction in an attempt to improve speed of construction, reduce costs, improve safety, or provide increased service life. These goals are not always inclusive and we must weigh any positive changes against any possible negative consequences. Industry is also included in discussions involving these changes to properly determine the impact of proposed changes. We are considering several changes to the PCP system that could affect many of the mentioned goals.

- Elimination of the thickened slab diaphragm. This concept, studied in TxDOT research project 4418 mentioned above, could greatly simplify deck construction by eliminating the formwork necessary at slab ends. The effect of skewed ends has yet to be resolved but we have already implemented the square-end detail on several high-profile projects.
- Using PCP's in the slab overhang regions. Contractors currently use standard bridge deck overhang brackets and plywood or steel forms for the overhang regions. Setting, grading, and removing the overhang brackets takes significant time and can be a safety hazard. This concept would cantilever the PC panels in the exterior bay to form

the deck overhang. The details are being developed and it is likely that some research will be needed to evaluate the rail/overhang performance as well as other issues identified in the review process.

- Reducing the top mat of reinforcing steel. This concept seeks to speed deck construction by reducing the amount of top slab steel to the point where a light gauge welded wire fabric may be used. It takes significant time to tie and grade the top mat of deck reinforcing steel and rolling out WWF would greatly speed deck construction. There are several issues to be considered with this concept and additional research is also going to be necessary for proper validation.

CONCLUSIONS

The PCP bridge deck forming system is by far the most popular system used by contractors in Texas. Speed of construction is the primary advantage of its use as well as its simplicity because it is derived from standard details and specifications.

There are limitations to the use of this forming system, and there have been some negative consequences in the form of deck cracking. The speed and cost savings resulting from its use easily offset these drawbacks, and TxDOT has had few significant problems with the use of this system.