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UTILIZATION OF FULL-DEPTH PRECAST CONCRETE DECK PANELS IN BRIDGE, PAST AND FUTURE

By

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ABSTRACT:

Use of full-depth precast concrete deck panels in highway bridges in the United States started as early as 1965. The motive behind using this construction system has been to increase the speed of construction of the deck for rehabilitation projects especially in areas with high traffic volume where traffic closures have high cost and cause a lot of inconvenience to the public. Over the years, the design engineers have started to see that this construction system is advantageous not only for rehabilitation projects but also for new construction projects. This is because of the higher quality of the deck that minimizes future maintenance cost and increases the service life of the deck.

This paper presents the results collected from the literature review and the survey conducted in the on going NCHRP 12-65 project, "Full-Depth, Precast-Concrete Bridge Deck Panel Systems." The survey was sent to the highway state agencies in the United States, Canada and Mexico. This paper gives a summary of the system details that have been used in bridges in the United States from the early 1970s until present.

KEYWORDS:

Full-depth, Precast, Deck panels, Bridges, Composite, Superstructure

INTRODUCTION

Public inconvenience and loss of income during bridge construction have been the driving motives to explore rapid construction methods[1]. Precast concrete bridge elements can be used to effectively reduce construction time. A cast-in-place (CIP) concrete bridge deck slab represents a significant part of the time required to complete a superstructure of a bridge. It includes a time-consuming process of forming, reinforcing bar placement, concrete placement, and an extended period of moist curing. As a result, use of full depth precast deck panels has the potential of replacing CIP decks as a natural extension to the use of prefabricated girders in bridges.

Full depth precast concrete deck panels can be fabricated to cover full or partial width of a bridge. They can be transversely pretensioned or conventionally reinforced. Also, they can be made composite with the supporting girders by extending the shear connectors of the girders into the panels through prefabricated pockets. The panels are installed next to each other separated with a relatively small gap of 1 to 2 in. (25 to 50 mm). The shear connector pockets and the transverse gaps between panels are filled with flowable and early strength concrete mix or grout. In some cases, the design engineer opts to post-tension the panels in the longitudinal direction to put the transverse gap between panels under compression and eliminate possible cracking under traffic loads.

The following sections give a summary of some of the connection details that have been used in bridges built in the United States during the past 30 years. These- results were collected from the literature review and the survey conducted in the on going NCHRP 12-65 project, "Full-Depth, Precast-Concrete Bridge Deck Panel Systems." The survey was sent to the highway state agencies in the United States, Canada and Mexico. The goal of this summary is not to report all of the bridges built with full depth precast panels, but to show the diversity of the connection details between panels and between the panels and the superstructure.

BRIDGES BUILT WITH FULL-DEPTH PRECAST PANELS BEFORE 1973

Several bridges were constructed using full depth precast panels[2]. Among them were the Pintala Creek Bridge, Montgomery County, Alabama, the Kosciuszko Bridge, Brooklyn-Queens Expressway, New York, the Big Blue River Bridge, Kingstown, Indiana, and the Bean Blossom Creek Bridge, Bloomington, Indiana. Biswas[2] reported in his paper that these structures had, in general, performed well. However, some structures had partial failure of panel-to-panel joints. Follow-up phone interviews, that were conducted between the authors of this paper and the designers in the highway agencies where some of these bridges were built, have shown that this type of failure was locally and was a result of lack of longitudinal post-tensioning and/or overlay.

Features of these bridges can be summarized in the following points: (1) the deck girder systems were primarily noncomposite, (2) the spans did not have any skews, or superelevations, (3) more projects involved new construction than rehabilitation, (4) fewer geometric fit-up problems were experienced with new construction than with replacement deck, and (5) full depth precast panel deck system was used for both temporary and permanent bridges.

BRIDGES BUILT WITH FULL-DEPTH PRECAST PANELS BETWEEN 1973 AND PRESENT

Since 1974, significant advances in the construction of full depth precast concrete deck panels have been made any many major bridges were built with precast concrete panels. Most of them were made composite with the superstructure. The following sections give a summary of some of the connection details that were used in these bridges. More information of these bridges can be found in references 2 to 13.

PANEL/SUPERSTRUCTURE CONNECTION

The majority of the bridges built during this period were made composite with the superstructure. This was achieved by extending steel shear studs or structural steel channels into the precast deck through prefabricated pockets in the deck slab.

The spacing between the pockets ranged from 18 in. to 24 in. and the number of studs per pocket ranged from 4 to 12 studs. In some cases, one stud per row was used as in the case of the three-span bridge over the Delaware River between Sullivan County, New York, and Wayne County, Pennsylvania, (see Fig. 1), and in some other cases, as much as four studs were used per row as in case of the I-80 overpass project, in Oakland, California (see Fig. 2).

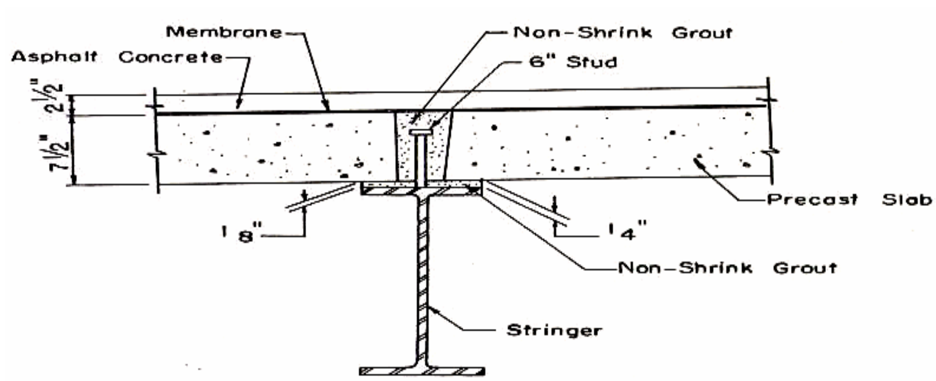


Fig. 1 Deck/Superstructure connection details of the Delaware River Bridge

In addition to steel shear studs, standard channel sections welded to the top flange were used in some bridges, such as the experimental bridge at Amsterdam, New York[6], see Fig. 3. Although the experimental study had shown that the channel welded sections performed well, their use was very limited in bridges because of the relatively long time required for welding compared to shear studs. On the same experimental bridge, a bolted connection was used as shown in Fig. 4. In the bolted connection, the panels were placed using steel shims for leveling. After the holes of the bolts were drilled in the top flange of the steel girder through the sleeves in the panels, high strength bolts were fastened. Achievement of full tension in the bolts could not be ascertained because breaking of the precast slab due to excessive tensioning was expected. This connection detail was not used in any subsequent projects.

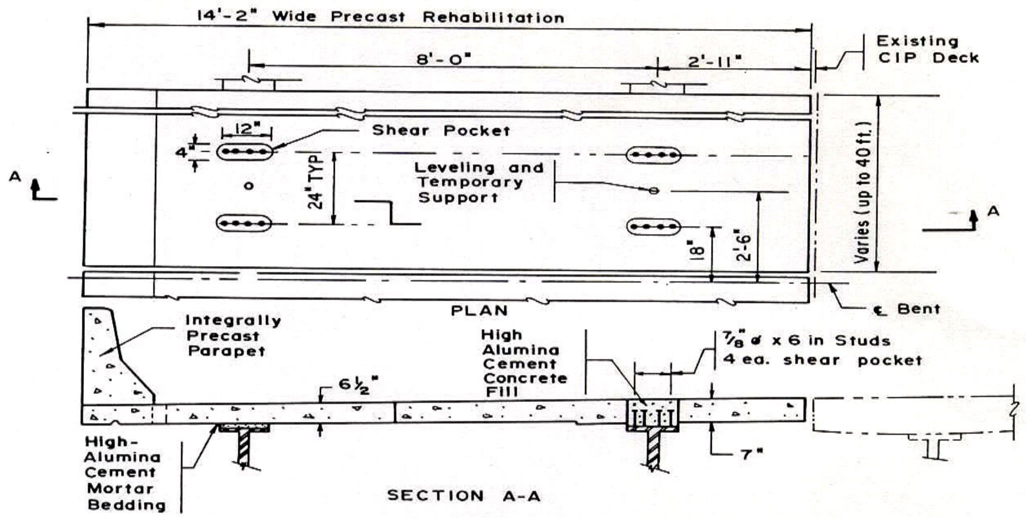


Fig. 2 Panel dimensions and cross section of the I-80 Overpass project, Oakland, California

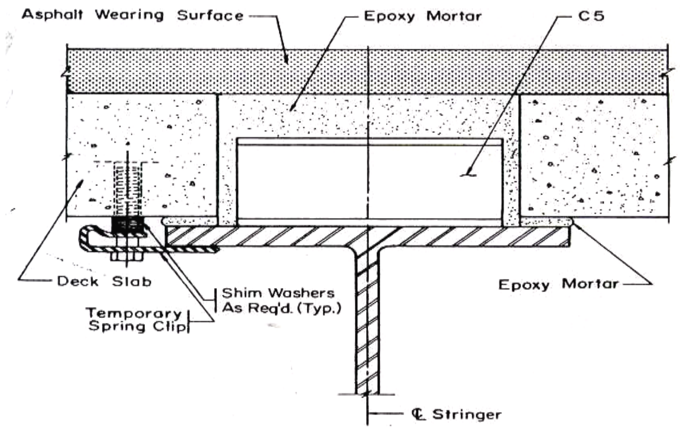


Fig. 3 Welded channel section detail used in the New York Thruway Experimental Bridge

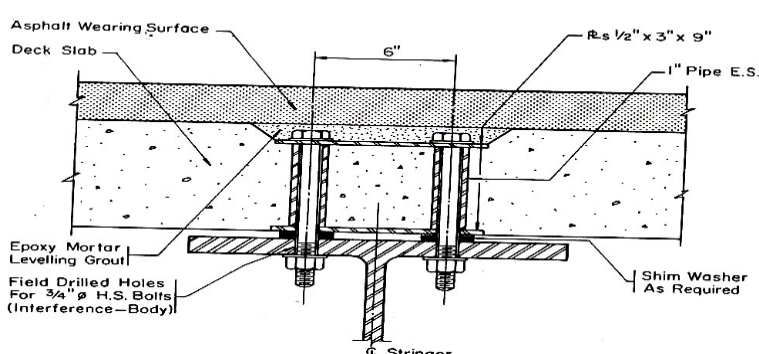


Fig. 4 Bolted detail used in the New York Thruway Experimental Bridge

In most of the projects built during this period, the panels were supported on the girders using steel shims and a 1 to 2 in. high haunch was provided between the precast panel and the girders. The grout filling the haunch after gaining strength guaranteed full bearing of the precast panels on the supporting girders eliminating any possible stress concentrations in the panels. Many details were used to build dams for the grout, such as the light-gauge side forms bolted using ¼ in. diameter tie rods that were used on Queen Elizabeth Way-Welland River Bridge, Ontario, Canada, (see Fig. 5) and the elastomeric strips used on the Clark's Summit Bridge on the Pennsylvania Turnpike (see Fig. 6). In both cases, bridge tie anchors, bolted on the bottom surface of the panels, were used to secure the grout dam against leakage.

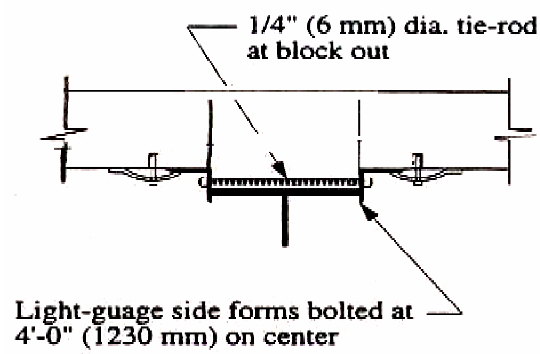


Fig. 5 Grout dam built using light-gauge side forms
(Queen Elizabeth Way-Welland River Bridge, Ontario, Canada)

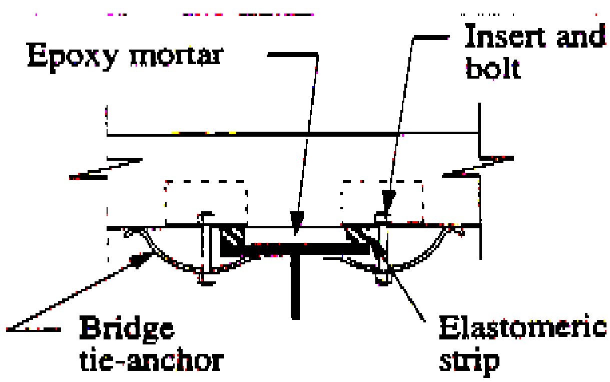


Fig. 6 Grout dam built using elastomeric strips
(Clark's Summit Bridge, Pennsylvania Turnpike)

In order to adjust the panel elevation, leveling screws were used as shown in Fig. 7. Typically, two screws per every girder line were used per panel. These screws were designed to support the panel weight and expected construction loads. After the grout filling the haunches and pockets gained strength, the screws were removed or torch cut.

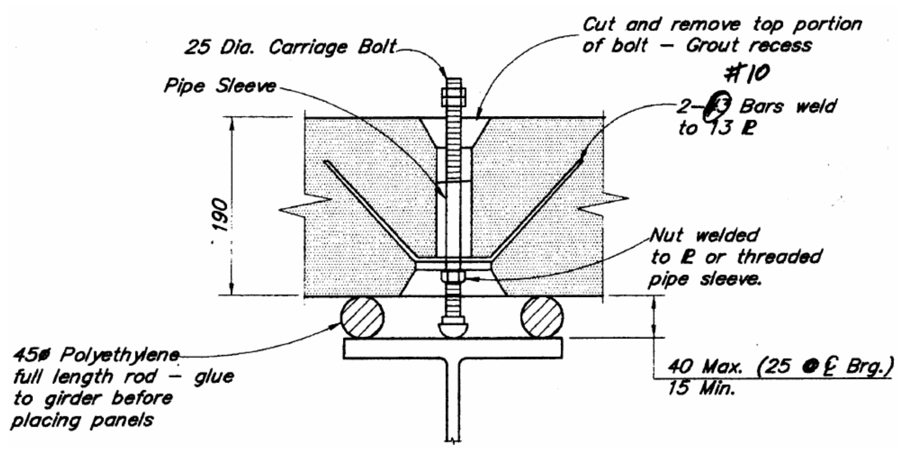


Fig. 7 Leveling screw detail

Transverse Panel-to-panel connection

The transverse edges of the precast panels were usually provided with shear keys. Typically, the shear key that extends along the transverse edges of a precast panel plays an important role in the service performance of the finished deck. The shear key has to be designed to protect adjacent panels form relative vertical movement and transfer the traffic load from one panel to the next panel without failure at the panel-to-panel joint.

Under traffic load, a panel-to-panel joint experiences two types of straining actions: (1) a vertical shear force that tries to break the pond between the panel and the grout filling the joint, and (2) a bending moment that puts the top half of the joint in compression and the bottom half of the joint in tension. Two types of shear keys have been used with full-depth precast concrete panels. These are:

(1) Non-grouted match-cast shear key (as shown in Fig. 8): this type was used on Bloomington Bridge, Indiana. Although match casting could be achieved in a controlled fabrication environment, i.e. in a precast concrete plant, it was found that it was very difficult to achieve a perfect match in the field after installing the panels due to construction tolerances and elevation adjustment of the panels. This detail was used in conjunction with longitudinal post-tensioning. Also, thin neoprene sheets were installed between adjacent panels to avoid high stress concentrations. Cracking and spalling of concrete at the panel joints were observed after five years of service[10], which eventually lead to a leakage problem at the joints.

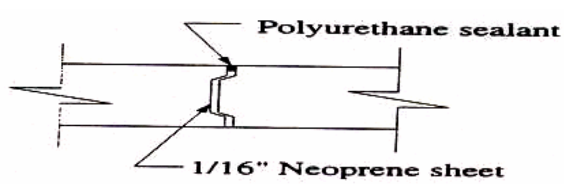
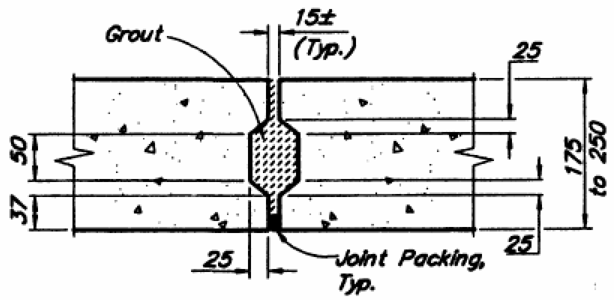
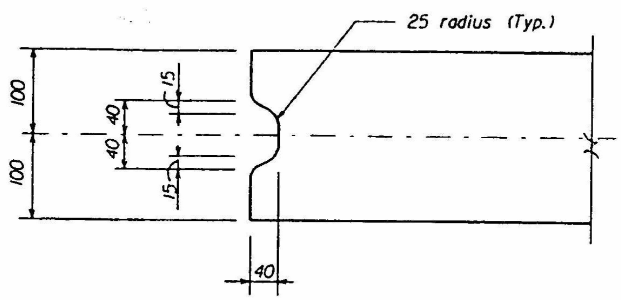


Fig. 8 Non-grouted match-cast joint

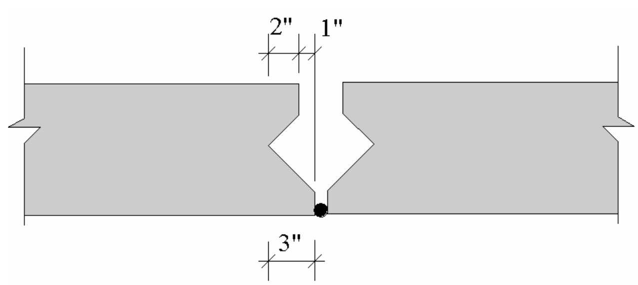
(2) Grouted Female-to-Female Joints: In this group of joints, grout was used to fill the joint between adjacent panels. Inclined surfaces were provided in the shear key detail to enhance the vertical shear strength capacity of the joint. Therefore, vertical shear forces applied at the joint were resisted by bearing and by bond between the grout and the panel. The shear key was recessed at the top to create a relatively wide gap that allows casting the grout in the joint. Fig. 9 gives some of these details that were used in bridges between 1973 and present.



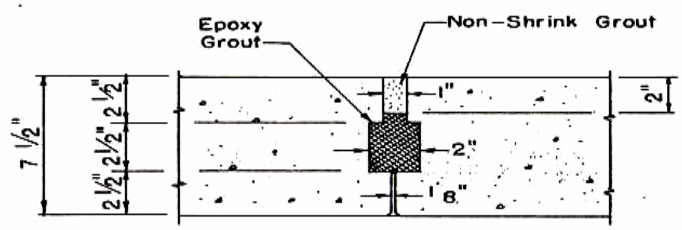
(a) Trapezoidal-shape shear key detail used in the Pedro Creek Bridge, Alaska



(b) Semi-circle shear key detail used in the George Washington Memorial Parkway Bridges, Washington DC



(c) V-Shape shear key detail used in the Skyline Drive Bridge, Omaha, Nebraska



(d) Rectangular shear key detail used in the Delaware River Bridge, New York

Fig. 9 Various grouted female-to-female joint details

With grouted joints, a form has to be provided at the bottom surface of the panels to protect the grout from leaking during casting. Two methods of forming have been used:

(a) Polyethylene backer rods in the tight space between panels at the bottom of joint (see Fig. 10): This detail has been used for a very long time by many highway authorities. Although, this detail does not require any construction work to be done form under a bridge, it has been reported[14,15,16] that due to fabrication and construction tolerances the joint may end up partially full, i.e. the grout does not fill the full height of the joint, as shown in Fig. 10. Partially-filled grouted joints cause high stress concentrations at the panel edges, especially if longitudinal post-tensioning is applied, and initiate cracking close to the bottom surface of the panels.

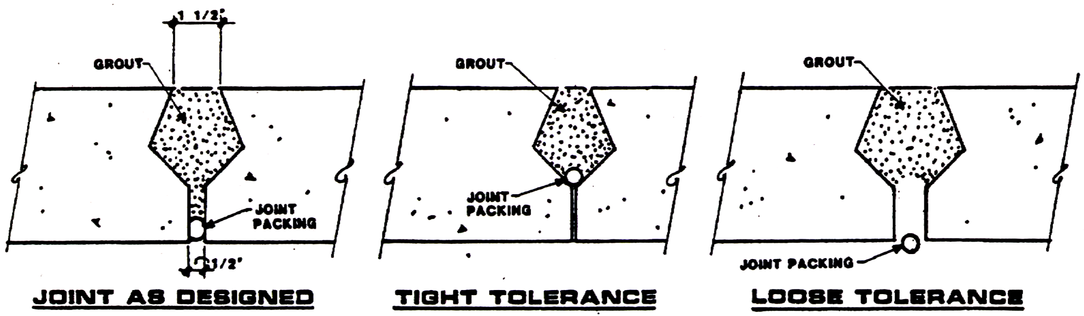


Fig. 10 Effect of tight and loose tolerances on panel-to-panel joints

(b) Wood forming from under the panel (as shown in Fig. 11): In this detail, a gap of 1 to 3 in. (25 to 76 mm) is maintained between adjacent panels and wood forms are installed from under the panel. The forms are hanged from the top surface of the precast panels using threaded rods and nuts. Using this detail usually results in a full-height grouted joint with excellent service performance[14,15].

Fig. 11 Wood forming of the panel-to-panel joint used in the Arch Tied Bridges, Texas

The bond between the grout and the shear key surface can be significantly enhanced by roughening the shear key surface[16]. This has been found extremely important in connecting precast panels when no longitudinal post-tensioning is used and the joint is not pre-compressed. Roughening can be achieved by sand blasting the shear key surface that is followed by a thoroughly washing procedure. This operation can be done in the precast plant before shipping the panels or on the bridge site before installing the panels on the bridge. Also, roughening can be achieved during fabrication of the panels by painting the side forms with a retarding agent. After removing the side forms, the shear key is washed with water under high pressure, so that the aggregate of the concrete will be exposed and a uniformly roughened surface is created. This concept was used by Texas Department of Transportation in the precast concrete panels used for the Arch Tied Bridges, as shown Fig. 12.

Fig. 12 Exposed aggregate roughened surface used in the Arch Tied Bridges, Texas

LONGITUDINAL REINFORCEMENT

Longitudinal reinforcement in deck slabs is used to distribute the concentrated live load in the longitudinal direction. Also, it is used to resist the negative bending moment due to live loads at the intermediate supports for continuous span bridges. For deck slabs made with full depth precast panels, splicing this reinforcement at the transverse joint between panels is a challenge for design engineers because:

(1) The panel has relatively short length (from 8 to 10 ft), therefore, a long concrete closure joint (2 to 3 ft) has to be used to lap splice the longitudinal reinforcement. This requires wood forming from under the panels and extended period of time for curing
(2) The longitudinal reinforcement is spliced at the transverse grouted-joint between panels that is considered the weakest joint in the system. Therefore, great care has to be taken in detailing the splice connection to maintain the construction feasibility and avoid leakage at the joint during the service life of the deck.
(3) Splicing the longitudinal reinforcement requires high quality control during fabrication of the panel to guarantee that the spliced bars will match with very small or zero tolerance.
(4) Splicing the longitudinal reinforcement requires creating pockets and/or modifying the side form of the panel, which increase the cost of fabrication of the panels.

As a result, few highway agencies such as Alaska Department of Transportation (ADOT) and New Hampshire Department of Transportation (NHDOT) have opted not to splice the longitudinal reinforcement for simply supported span bridges. Fig. 13 shows the transverse joint of the precast deck system that has recently been used on Dalton and Pedro Creek Bridges on Route FAP 65 in Alaska. Although, ADOT design engineers have reported that there is neither significant cracking nor leakage at the joints, the reader should note that the average daily traffic on these bridges is very low compared to bridges built in metropolitan cites.

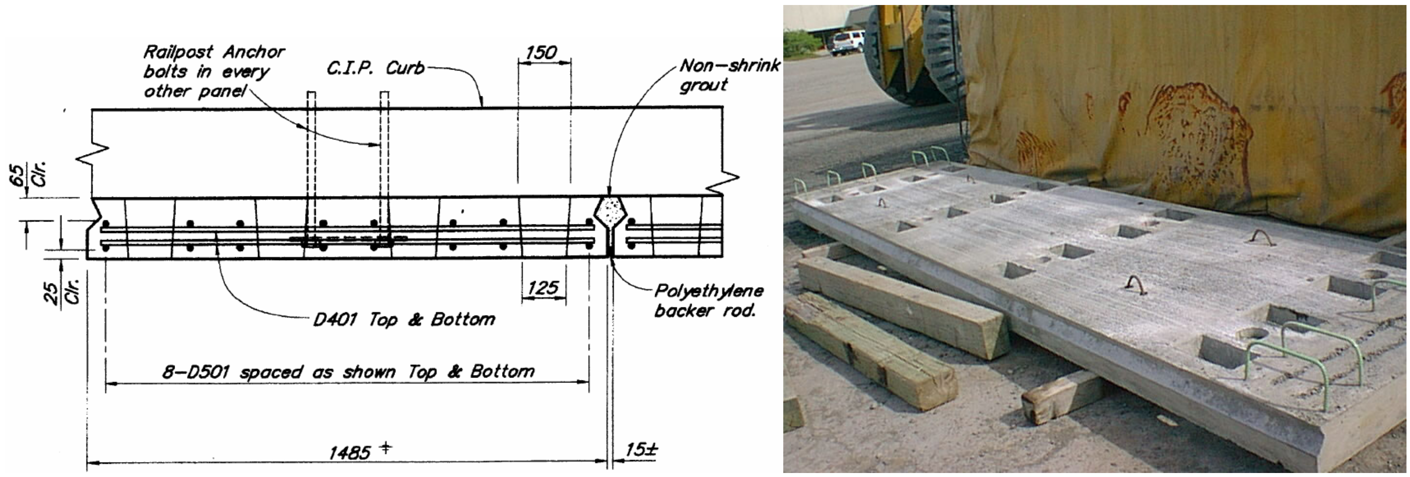


Fig. 13 Non-reinforced panel-to-panel connection used on bridges by ADOT

The majority of highway agencies prefer to provide some type of reinforcement across the transverse joints. Various methods have been used in the past to provide and splice the longitudinal reinforcement. These are:

(1) Using lap splice: this detail was used in the full depth precast concrete deck panel system for the rehabilitation project of the deck of the C-437 of the County Road over I-80 to Wanship, Utah, as shown in Fig. 14. Please, note that the design engineer allows the use of threaded coupler at the face of the transverse joints to simplify the side forms used in fabrication.

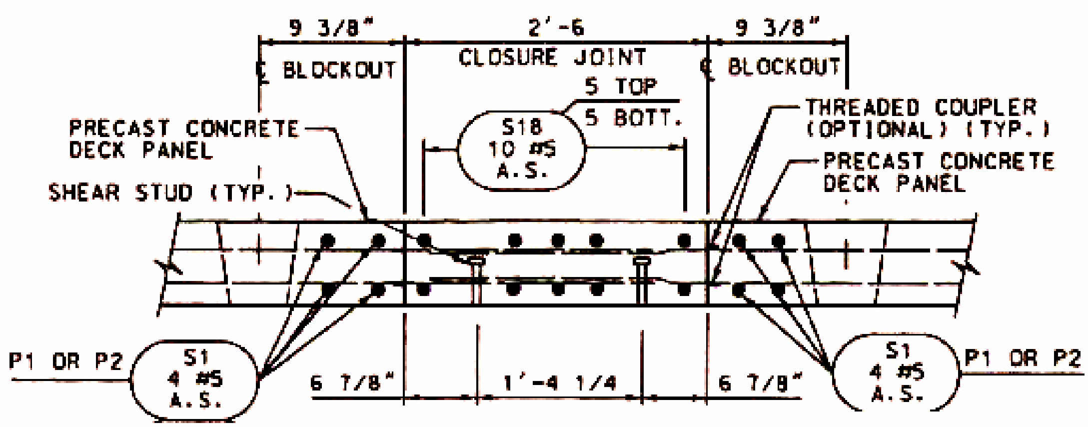


Fig. 14 Lap splicing of longitudinal reinforcement used on Structure C-437, Wanship, Utah

(2) Using U-shape pin bars: this detail was used on Castlewood Canyon Bridge, Colorado. The section shown in Fig. 15 shows the U-shape pins bars are overlapped and confined with rectangular stirrups.

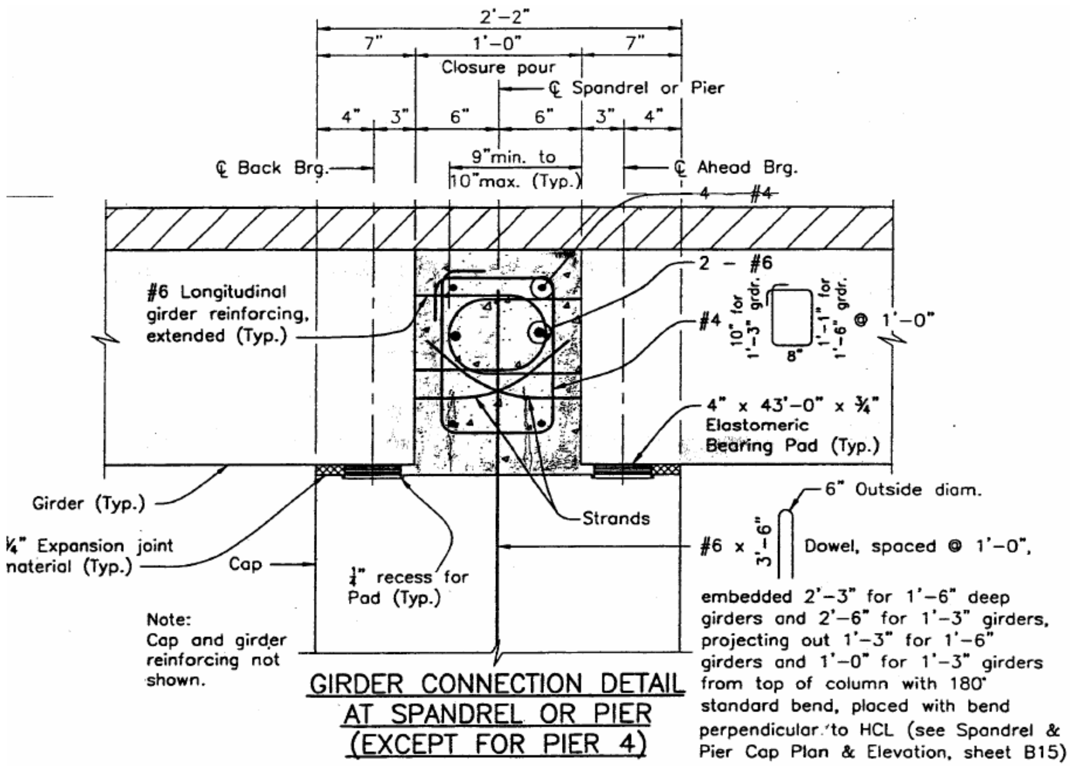


Fig. 15 Continuity detail over the cross piers used on Castlewood Canyon Bridge, Colorado

(3) Using spiral confinement: this detail has been developed to reduce the lap splice length and give higher construction flexibility of the splice connection[4]. Fig. 16 shows the splice connection where a lose bar confined with high strength spiral is used. Using this detail reduces the lap splice length by about 40 to 50 percent and helps in simplifying the fabrication of the panel because no bars extend outside the transverse edges of the panel.

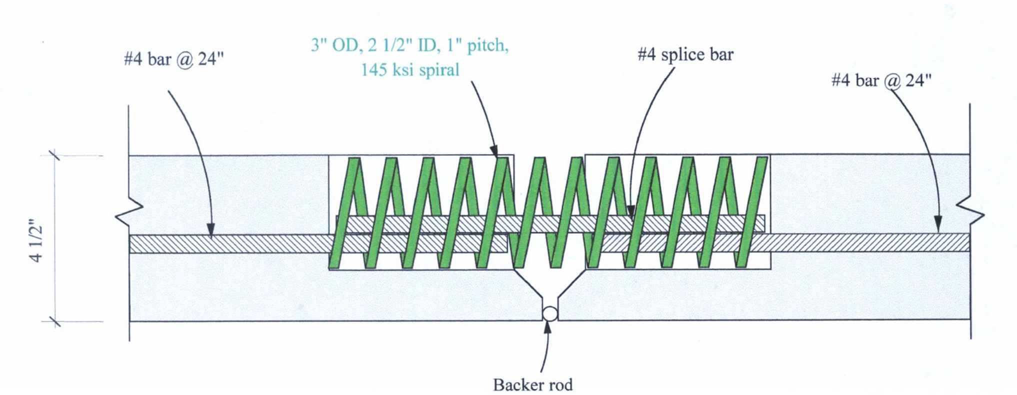


Fig. 16 Panel-to-panel connection using spiral confinement

(4) Using longitudinal post-tensioning: Longitudinal post-tensioning has been used on the majority of bridges built with full-depth precast panels during the last 30 years. It puts the transverse panel-to-panel joints under compression that eliminates tensile stresses resulted from live load. The authors of this paper have found that the amount of the post-tensioning stress after seating losses used in bridges ranges from 150 ksi to 250 ksi. Longitudinal post-tensioning is typically conducted after the transverse panel-to-panel joints are grouted and cured, and before the deck/girder connection is locked. This procedure guarantees that all of the post-tensioning force will be applied on the precast deck.

In most of the cases, high strength threaded rods uniformly distributed between girder-lines are used. The threaded rods are fed inside ducts that are provided in the panel during fabrication. Fig. 17 shows the post-tensioning details that were used on Bridge-4 constructed on Route 75, Sangamon County, Illinois. Longitudinal post-tensioning can be provided in stages and coupled as shown in Fig. 17. After the threaded rods are post-tensioned and secured, the ducts are grouted with non-shrink grout to protect the threaded rods from corrosion.

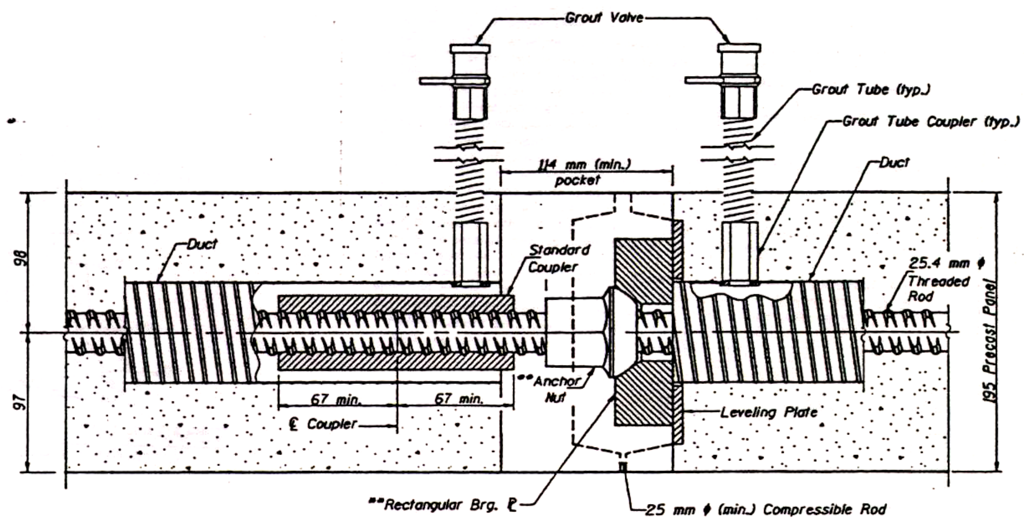


Fig. 17 Post-tensioning detail used on Bridge-4 constructed on Route 75, Sangamon County, Illinois

Recently, longitudinal post-tensioning reinforcement concentrated at girder lines has been used on the Skyline Drive Bridge in Omaha, Nebraska. Fig. 18 shows cross section of the bridge at a girder line. The post-tensioning reinforcement is made of 16- ½ in., 270 ksi, Low relaxation strands. The strands are fed in open channels created over girder lines and a special end panel that houses the anchorage device is used as shown in Fig. 18.

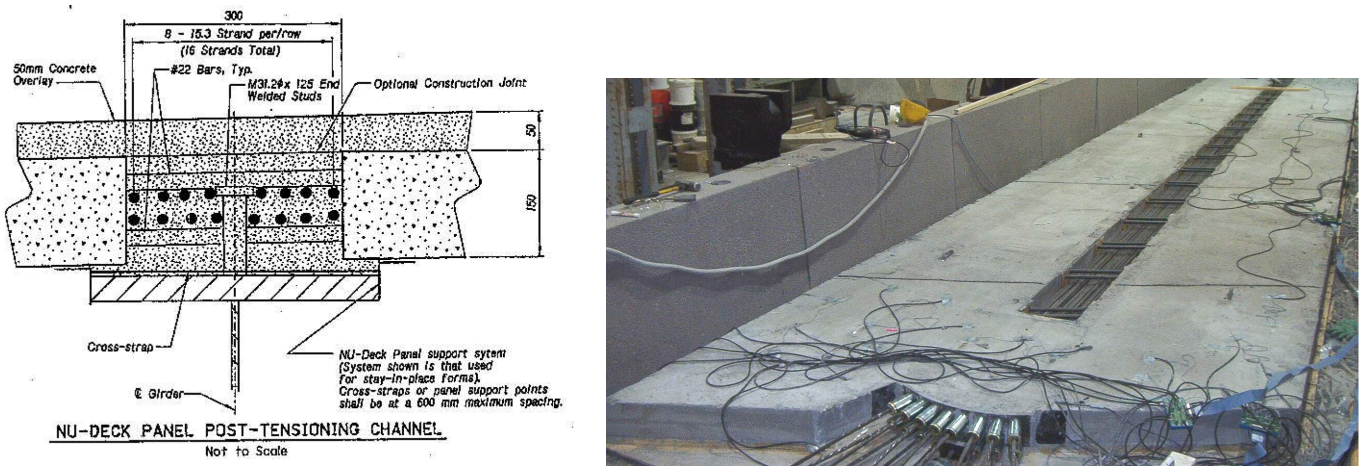


Fig. 18 Longitudinal post-tensioning concentrated at girder lines used on the Skyline Drive Bridge, Omaha, Nebraska

CONCLUSION

Full-depth precast panel has been used in the United States for more than 30 years. This type of construction is considered one of the most effective strategies to enhance speed of deck replacement. This is because no cast-in-place concrete is needed except for small and local joints between the prefabricated pieces where the use of rapid set concrete mixes would not require concrete placing, finishing and curing workers to be at the site. Also, the prefabricated pieces are produced under high quality control and tight tolerances in precast yards, which results in highly durable products with no shrinkage cracks, minimum permeability, and long expected service life.

Various systems of full depth precast panels with a wide variety of connection details have been developed and used. Although all of these systems share the same concept (i.e. prefabricated pieces connected together after being installed on the bridge), each system is considered unique in the way the panels are connected transversely and/or longitudinally, adjustment of Transverse Profile of the Bridge, connection between the deck and the barrier, handling of composite action with the supporting girders (composite or non-composite system).

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