Full-Depth Precast Concrete Bridge Deck Construction

John R. Fowler, P.Eng., President
Canadian Precast/Prestressed Concrete Institute

Paper prepared for presentation

at the Bridges – Links to a Sustainable Future Session

of the 2088 Annual Conference of the

Transportation Association of Canada

Toronto, Ontario

ABSTRACT

An alternate to cast-in-place bridge decks are prefabricated, full-depth precast concrete deck panels. These panels can be constructed off-site under controlled conditions in a precast plant and brought to the bridge site ready to be installed and connected. This requires significantly less on-site construction work and ensures minimum traffic interference. In many urban situations, a bridge can be rebuilt using night or weekend closures or staged construction to maintain traffic in both directions. The benefits of precast full-depth bridge deck panels include: durable high quality materials; minimal on-site construction and traffic disruption; increased safety for construction crews and the public; and minimal adverse economic impact due to road closures.

This paper summarizes many of the findings in a "State-of-the-Art Report on Full Depth Precast Concrete Bridge Deck Panels" [1]. *This report will be published by the Precast / Prestressed Concrete Institute (PCI) later this year.*

INTRODUCTION

Some regulatory authorities are willing to pay a premium to minimize interference with traffic during construction. Traffic holdups also have an adverse impact on the environment. Many bridge deck replacement projects using full-depth precast bridge decks have demonstrated significant reductions in construction time, reduced impacts on traffic flow, as well as good performance. The use of precast bridge decks dates back to the early 1960's.

Precast deck systems have been used successfully in most provinces; however, precast decks still remain a small percentage of all bridge decks constructed when compared to cast-in-place (CIP) deck construction. Some reasons for using CIP construction over precast construction are initial costs, lack of knowledge by designers, variable detailing, project specific details, small deck areas, and concerns about long-term bridge deck performance, unlimited construction time, contractor familiarity with CIP construction and a lack of familiarity with post-tensioning systems and installation. Panels can be designed for composite or non-composite action with the supporting girders. *This paper will consider only composite deck systems*.

ADVANTAGES

Reduced Construction Time and Impact on Traffic

Many projects constructed using full-depth precast deck panels have demonstrated a significant reduction in construction time, that has been documented to be from 50 to 75 % of the time required for cast-in-place bridge deck construction. These savings in construction time can meet the public's demands for faster construction and fewer traffic delays. The reduced construction time also reduces safety hazards to motorists and workers by minimizing the total time they are exposed to the bridge construction. This time saving provides greater flexibility in establishing the project schedule and allows the contractor to concentrate on other critical path items.

Full-depth precast deck systems have also alleviated construction restrictions on peak-traffic flows for projects in high-traffic urban locations. Precast deck systems allow replacement of bridge decks during non-peak traffic, leaving the full roadway open for peak traffic. Precast deck replacement can be accomplished with night-only construction, weekend-only construction, or other non-peak traffic period construction.

Quality

The quality of precast deck systems is superior to CIP bridge decks because production occurs in a controlled precast plant environment. The variability of construction due to environmental conditions is eliminated in a plant that uses consistent casting operations and curing techniques. Furthermore, panels of questionable quality, should they occur, can be culled and recast. Some owners and engineers find that with CIP decks, they sometimes have to accept decks with less than desirable concrete because of a lack of practical remedies. This is avoided with precast decks because less than desirable concrete never makes it to the field.

CIP decks are more susceptible to cracking than precast decks. When concrete is placed over relatively stiff girders it becomes part of the girder/deck composite system as soon as it begins to harden after placement when its tensile capacity is small. Shrinkage in the first few hours after setting causes a reduction in concrete volume that is restrained by the supporting girders. This often results in cracking, especially in the transverse direction. Shrinkage cracking can be reduced or eliminated by using well cured precast deck panels as most of the shrinkage and creep occurs in the first 60 days after casting.

High performance concrete (HPC) is recommended for all bridge decks due to its superior durability in severe environmental conditions. Production in CPCI Certified plants provide greater assurance that the performance characteristics of HPC will be achieved. For example, plant-produced 60 MPa concrete panels are as easily produced as 30 MPa panels, while it is difficult to consistently produce a conventional CIP concrete deck on site at strengths higher than 35 MPa. Shrinkage and the associated cracking are better controlled in a precast plant. A two-way prestressed concrete bridge deck is expected to be crack-free for the service life of the bridge, an advantage that is not practical to achieve with CIP decks.

Weight Reduction

The dead load of the bridge deck is a significant portion of the design load for a bridge, especially for longer span structures. Reducing the weight of the full-depth precast concrete deck panels can be accomplished by reducing deck thickness by using a higher concrete strength and/or prestressing and by the tighter control of construction tolerances.

Reducing the deck weight can be beneficial by:

- Improving the structural efficiency for new designs, such as increased span lengths or increased girder spacing
- Improving the bridge load ratings when used for deck replacement on an existing structure
- Increasing the traffic capacity on an existing structure by increasing the number or width of lanes when the deck is replaced without requiring significant structural improvements to the superstructure or substructure
- Reducing the seismic loads,
- Reducing the substructure and foundation loads.

Cost

The initial cost of a bridge deck using precast full-depth concrete panels is typically higher than for a CIP deck. This difference is due to the current limited use and popularity of precast full-depth decks. This cost should be lower with greater use, consistent details, and uniform designs.

The total cost of the full-depth precast deck system can be significantly below a CIP deck system when the road user and traffic maintenance costs are considered in the evaluation of viable systems. It has been reported that traffic maintenance costs are approximately 30 to 50% of the project construction cost [88]. Past and recent projects demonstrate the benefits to the contractor of precast deck systems for projects that include incentive and penalty clauses or time constraints.

The cost of a precast deck varies widely based on geographic location due to materials cost, transportation and labor. For example, a typical precast deck system in one US state (Virginia) costs $560 per sq m, while a typical precast deck system in another US state (Nebraska) costs $300 per sq m. The average cost of a conventional CIP bridge deck in Nebraska of $215 per sq m. The initial cost premium is outweighed by bridge deck quality, deck life, traffic control, and maintenance costs.

SYSTEM DESCRIPTION

Full-depth precast decks use a series of precast concrete panels that are full-depth in thickness with the length and width determined by specific bridge geometry. The length of the panel along the roadway is usually 2.4 to 3.6 m. The width of the panels is typically equal to the full width of the bridge. Both the length and width are determined by handling and transportation limits.

Generally, speed and economy are achieved when using the least number of panels. For bridges wider than 15 m, panels may be designed for half the bridge by providing a joint over the supporting girder but it will be difficult to meet the empirical deck slab design requirements of CSA S6 [2], Clause 8.18.4. Partial panel widths are used for bridge replacement projects with construction phasing requirements.

Panels span between the supporting girders can be designed as reinforced or prestressed concrete using pretensioning or post-tensioning. The general preference is to use prestressed concrete to eliminate possible cracking from handling, shipping, construction and service loads.

Full-depth precast bridge deck systems:
(1) Use precast panels with pockets or block-outs to accommodate shear connections to the supporting girders,
(2) Contain grout between the supporting girders and the precast panels,
(3) Have temporary support and forms along the girder to retain the grout,
(4) Contain transverse joints between the precast panels and grout to fill these joints,
(5) Have some type of overlay to improve pavement rideability.

Longitudinal post-tensioning is typically included in the system to tie the panels together.

DESIGN ISSUES

Introduction

The proper design and specifications for a full-depth precast, prestressed concrete bridge deck system are important for its successful construction.

The system must be based on detailed evaluations of:

- System components, particularly the joints between adjacent precast panels,
- Connection between the slab and the supporting system,
- Adequacy of the prestressing force provided to secure the integrity of the transverse joints when post-tensioning is used.

A well designed system can provide a very effective and economical design that can be implemented for the rehabilitation of existing highway bridges, as well as new bridge construction, to shorten construction time, the duration of bridge closures and to minimize the interference to traffic flow.

Prestressing and high performance concrete can produce durable deck panels that are effective in aggressive environments. Panels are connected to the steel stringers or precast prestressed concrete girders through shear pockets to provide composite action.

Transverse Joints

The transverse keyway joint (Figures 11 and 12) is the structural element that connects the edges of the panels together. When the wheel load of a vehicle crosses the transverse joint, the joint is subjected primarily to flexure and vertical shear. These loads can generate cracks that allow the infiltration of water and chloride ions that can corrode the steel reinforcement.

Some of the materials that can be used to fill the joints are:

- Non-shrink cementitious grout
- Magnesium phosphate grout
- Polymer concrete

Joints will crack if the grouting material is not strong enough to resist the applied shear and flexural effects. An investigation of various non post-tensioned joints in bridges revealed that many of the transverse joints exhibited leakage and vertical misalignment [5]. These leaking joints allow penetration of foreign materials and gradually make the joint vulnerable and expensive to repair.

Design Parameters

The major parameters to be defined in the design and construction of full-depth precast panels are:

1. Precast panel dimensions and configuration (straight vs. skew)
2. Shear pocket dimensions, spacing, and number and size of shear connectors that are required to achieve full composite action between the precast panels and the supporting system
3. Type and configuration of the joint between adjacent precast slabs (female-to-female joint vs. male-to-female match-cast)
4. Type of grout materials within the joint and the shear pockets (cementitious or epoxy materials)
5. Mild reinforcement design and details
6. Amount of prestressing force needed longitudinally to secure the integrity of the joints, and transversely to account for handling and erection stresses
7. Type of overlay materials, if used
8. Parapets and parapet connections
9. Concrete materials

Critical factors contributing to the reduced performance of bridge decks:

1. Debonding and leakage through the panel-to-panel joints leading to severe corrosion due to lack of post-tensioning in the longitudinal direction
2. Inadequate material in the joint, inadequate configuration of the joint, and inadequate surface preparation of the joint
3. Loss of full composite action between precast slabs and the supporting system due to lack of haunch, inadequate design and distribution of shear connectors, and inadequate materials in shear pockets
4. Failure of the overlay system

Measures taken to rectify these problems include improving the performance of the transverse joints in the maximum negative and positive moment regions, post-tensioning the transverse joints longitudinally and ensuring full composite action between the precast panels and the supporting system using a formed haunch and sufficient shear connectors.

Precast Deck Panels

Panels are designed for transverse flexure with mild reinforcement, prestressing strands, bonded post-tensioning strands, or a combination. Many precast panels can be designed with sufficient transverse prestress to avoid cracking during handling and erection of the slab units. The panels should be furnished with longitudinal reinforcement for load distribution. The design of the distribution reinforcement should be in accordance with S6 specifications based on a slab with mild reinforcement.

Slab Thickness

S6-06, Clause 8.18.2 requires a minimum slab thickness of 175 mm excluding any provision for grinding, grooving, and sacrificial surface. Minimum concrete cover must comply with Table 8.5 and the clear distance between the top and bottom transverse reinforcement must be at least 55 mm. Post-tensioning may require an increase in the minimum slab thickness depending on the type of post-tensioning system used. For typical girder spacings the minimum deck thickness is structurally sufficient. Handling, shipping and construction loads may dictate slab thickness and reinforcement requirements.

Deck Slab Concrete

Bridge owners may have their own concrete design/performance requirements, or CSA A23.1-04 high performance concretes (HPC) can be used:

- **C-1** - Structurally reinforced concrete exposed to chlorides with or without freezing and thawing conditions (bridge decks, parking decks and ramps, portions of marine structures located within tidal and splash zones, concrete exposed to seawater spray and salt water pools).
- **C-XL** - Structurally reinforced concrete exposed to chlorides or other severe environments with or without freezing and thawing conditions, with higher durability performance expectations than the C-1, A-1 or S-1 classes.

Class of exposure	**C-1**	**C-XL**
Maximum water-to-cementing materials ratio	0.40	0.37
Minimum specified compressive strength	35 MPa at 28d	50 MPa within 56d
Air content category (a) Exposed to freezing and thawing (b) Not exposed	 1 2	 1 2
Chloride ion penetrability - ASTM 1202	< 1500 coulombs within 56 d	< 1000 coulombs within 56 d

Allowable curing regimes – CSA A23.1

Curing Type	Name	Description
1 N	Basic	3 d at ≥ 10^0C or for a time necessary to attain 40% of the specified strength.
2 N with HVSCM C-1	Additional	7 d at ≥ 10^0C **and** for a time necessary to attain 70% of the specified strength. When using silica fume concrete, additional curing procedures shall be used.
3 C-XL C-1 with HVSCM	Extended	A wet curing period of 7 d. The curing types allowed are ponding, continuous sprinkling, absorptive mat, or fabric kept continuously wet.
	Note:	***In accordance with Clause 1.2, curing of plant production of precast concrete shall be as set out in CAN/CSA A23.4.***

Configuration of Precast Deck Slabs

The size and configuration of precast deck slabs depend on the geometric layout of the bridge (Figure 1). Many bridges impose irregular geometrical constraints on the type of construction.

Precast panels may be cast as skewed or rectangular panels (Figures 2 and 3) depending on the aspect ratio of the bridge slab and the designer's preference. If rectangular panels are used on a skewed bridge, then special end panels will have to be made to account for the skew. For a skewed panel, setting the transverse reinforcement parallel to the transverse edge of the panel (at a skew angle to the girders) allows the precaster to cut all transverse reinforcement at equal lengths, that increases production efficiency.

Handling

The loads and forces on a precast deck slabs during fabrication, transportation, and erection require separate analyses because the support points and orientation are usually different than when the panel is in its final position. Panels may also need to be analyzed if they will be required to support cranes and other construction loads.

Panel Sizes

<u>Factors to be considered when selecting the most feasible size and orientation of precast concrete full-depth deck panels for a project are:</u>

1. Stability and stresses on the concrete element during handling
2. Transportation size, weight regulations, and equipment restrictions
3. Available crane capacity and rigging at both the plant and the project site (position of the crane must be considered, as capacity is a function of reach)

Panel to Girder Connectors

For new bridge deck construction on steel girders, shear studs may be installed on the girder before delivery to the construction site. If pockets are provided in the precast panels, shear studs may also be welded to the steel girders on site after the panels are in place.

For new bridge deck construction on precast concrete girders, it is common to use the girders' shear reinforcement that is extended up from the web through the top flange as L-bars or hairpin bars, for the horizontal shear reinforcement. The wide top flange of bulb-Tee girders can reduce the effective deck span between girders.

On rehabilitated bridges, the existing shear reinforcement is typically cut off prior to panel installation. Shear reinforcement is then field installed on the existing girders in the location of the panels' shear pockets. Issa [6] reports that shear stud bolts can be attached to concrete girder flanges by drilling holes in the existing girders, then anchoring the bolts in the holes with approved adhesive.

Shear connectors should be capable of resisting both horizontal and vertical movement between the concrete and the supporting system. In making the slab units and the supporting system fully composite, the maximum spacing of shear connectors has usually been limited to 600 mm. However, recent research has resulted in bridge deck construction utilizing a shear connector spacing of 1200 mm. Additionally, NCHRP Project 12-65 research has also verified the adequacy of a 1200 mm shear connector spacing [4]. Conventional procedures are followed to obtain the number of shear connectors needed for composite design. The design for variable horizontal shear can be accommodated by changing the number of shear connectors per shear pocket. The shear pockets (Figure 4) should have rounded corners and should be wider at the top than at the bottom.

Large diameter shear studs have been extensively researched in recent years including the work performed under NCHRP Project 12-65 [4]. A 1¼" (31.8 mm) diameter stud replaces two 7/8" (20.3 mm) diameter studs. Larger diameter shear studs reduce congestion in the pockets and produce adequate structural capacity.

Precast Slabs on Steel Girders

Shear connector studs should conform to S6 requirements for fatigue and nominal resistance design on steel girders, as in conventional construction. It is recommended that the minimum distance between the centers of the studs be 2½ in (60 mm). [6]; while the distance between the edge of the girder flange and the center of the stud should be not less than 1½ in (40 mm). [6]. Details of shear studs and shear pockets for precast slabs on steel stringers are shown in Figure 4.

Precast Slabs on Precast Concrete Girders

Interface shear resistance design should conform to the S6 code requirements as in conventional construction. Reinforcement for interface shear between the concrete slab and the concrete girders may consist of single bars, multiple leg stirrups or multiple threaded bars, that are concentrated in shear pockets spaced at 600 mm (Figure 8). Horizontal shear reinforcement should be anchored to develop the specified yield strength on both sides of the shear plane by embedment or hooks. The bars should be anchored in both the concrete girder and the precast slab. Details of shear connectors and shear pockets for precast slabs on concrete girders are shown in Figure 10.

Longitudinal Post-Tensioning

Research studies of past bridge rehabilitation projects [5] indicate that the most common cause for deterioration of precast bridge deck panels is concrete cracking across the joints. Post-tensioning through the precast panel joints provides a residual compressive force that imparts excellent crack control and water tightness.

Longitudinal post-tensioning provides continuity between precast panels (Figure 7). The post-tensioning should be located at mid-depth in the slab units and run the entire length of the bridge or between closure pours. The post-tensioning should transmit a minimum prestress level of 250 psi (1.7 MPa) [3] after all losses for simply supported spans. Additional prestress is needed to overcome the tensile stress due to negative composite dead and live load moments in continuous spans. A prestress level of 300-850 psi (2.0 to 6.0 MPa) may be required for these continuous spans depending on the magnitude of the maximum negative moment.

There are three types of longitudinal post-tensioning that can be used; high strength threaded rods, mono-strand, or flat multi-strand tendons. In all types, the post-tensioning reinforcement will be provided in straight ducts that are installed during fabrication of the panels and later grouted after the reinforcement is inserted and tensioned.

An important aspect of a design is ensuring that the precast panels are in compression in the longitudinal direction under all applied loads, taking into full consideration the long-term effects of concrete creep and shrinkage.

Creep and shrinkage cause a reduction of post-tensioning compression in the deck and load shedding to the supporting system. Panels are typically cast two to three months prior to erection so a significant amount of the shrinkage will have occurred before deck placement. Some designers use 100-200 psi (0.7 to 1.4 MPa) residual stress in negative moment sections to account for shrinkage and creep.

DECK PANEL FABRICATION AND INSTALLATION

Requirements for Production

Quality control checks that must be performed during the production of full-depth precast panels include:

(1) Location and alignment of post-tensioning ducts
(2) Deck thickness to satisfy cover requirements
(3) Positioning and rigidity of the transverse shear key
(4) Uniformity of the surface finish
(5) Influence of shrinkage, creep, and camber on the final alignment
(6) Location of attachments of traffic barriers
(7) Location and coordination of the shear pocket positioning with respect to the existing or proposed girder alignment
(8) Accurate location of lifting hardware for handling and placement of the panels
(9) Conflicts between reinforcing, ducts, anchorages, and local reinforcing around pockets as well as the main transverse and longitudinal reinforcing

Clearances, dimensions, and tolerances must be addressed in the development of shop drawings and form work, and routinely verified in the pre-pour inspection as well as during the post-pour inspection. The placement of ducts, anchorages, and all other materials in the slabs should be inspected and approved before pouring the concrete.

The precaster should communicate with the design engineer when special handling reinforcement is needed that is not shown on the project drawings. The precaster may identify special reinforcing that should be placed in the panels to facilitate handling and/or erection. Additional reinforcing may be required near lifting inserts.

Methods for lifting the deck panels should be shown on the shop drawings. Any steel lifting embedments cast in the panel should be recessed at least 50 mm and grouted flush with the deck surface at the jobsite. Alternative lifting methods should be submitted for approval prior to use.

Tolerances

Tolerances for casting the slabs should be included especially in the location of longitudinal post-tensioning ducts when duct splices are needed between panels. The ducts should be oversized to accommodate the specified tolerances. The precast concrete deck slabs should be fabricated to the tolerances given in CSA A23.4 Precast concrete – Materials and construction.

Precast deck panels should be produced and placed such that there is no more than 5 mm difference in elevation between the top surfaces of adjacent slabs. The cumulative length along the span should be checked throughout erection, and joint spaces adjusted so that the proper span length is achieved.

Panel Installation

The use of continuous structural angles as supports between the top of new or existing steel girders and the underside of the new precast deck panels is one method of elevation control that addresses support and leveling requirements.

These structural angles also provide the formwork needed for the CIP haunches and pockets after the panels have been set (Figure 9).

Leveling bolts are another proven method of elevation control for precast deck panels (Figure 5). One major advantage of using leveling bolts for elevation control is that fine elevation adjustments are possible at any time during construction until the grout material is placed in the haunch area. The use of leveling bolts requires access under the bridge to install and remove the formwork for the grout material.

Girder deflection issues must be carefully considered. When the construction allows complete spans of deck panels to be erected, post-tensioned, and grouted in a continuous operation, the deflection accommodation is relatively simple. The top of girder elevations are determined and all of the support angles for that span are set and checked prior to the setting of any deck panels. If leveling bolts are used the procedure is the same except that dimensions are marked on the girders for the amount of support height required for each panel corner. All of the top-of-girder elevations are determined prior to setting any panels.

In a rapid deck replacement project, where long spans may not be completely replaced in a continuous operation, and traffic is to be maintained during non-working periods, the deflection accommodation is more difficult. The deflection calculation becomes a “balancing act” between the dead load of the portion of the existing deck that remains, the dead load that has been removed because of the partial existing deck demolition, and the anticipated deflection due to the installation of the new deck panels.

Wearing and Protection Systems

Full-depth precast bridge deck systems require a smooth riding, skid resistant surface and enhanced protection against the intrusion of chlorides.

The use of low permeability HPC in the precast deck panels is by far the most practical and economical of the wearing and protection systems for deck panels that are prestressed transversely and longitudinally. The use of HPC is projected to provide a service life of more than 150 years.

For precast panels where a sacrificial concrete overlay is desired, the monolithic concrete wearing and protection system is by far the most practical and economical. The panel thickness is increased to provide a top sacrificial layer. After the top surface layer becomes contaminated with chlorides, this sacrificial surface can be milled off and replaced.

Where an impermeable layer on the deck surface is desired, the thin epoxy overlay wearing and protection system is the next most practical. The low cost and ease of maintenance and replacement make it ideal for precast deck panels.

A thin bonded hydraulic cement concrete overlay and a waterproof membrane overlaid with asphalt concrete can be used when the owner requires that the deck panel system have an overlay for corrosion protection and the desired ride quality. These protection systems are the most complicated and expensive and may require future maintenance, repairs and replacement and should be used when the lower cost alternatives are not acceptable.

RECOMMENDATIONS

- Keep the geometry simple.
- Strive for maximum repetition of panels by minimizing the number of different panels.
- Avoid horizontal curves, and flares.
- Take advantage of the transverse deck span capacity to increase girder spacing and reduce the number of girder lines in new construction.
- Use a deck system [7] that allows a reasonable exterior precast concrete overhang that does not need to be CIP or propped.

REFERENCES

1. *State-of-the-Art Report on Full Depth Precast Concrete Bridge Deck Panels* - Draft report to be published by the Precast/Prestressed Concrete Institute (PCI) later in 2008.
2. *CSA S6-06, Canadian highway bridge design code*, Canadian Standards Association.
3. *AASHTO LRFD Bridge Design Specifications*, American Association of State Highway and Transportation Officials, Washington, D.C., Third Edition 2004, with 2005 interim.
4. Badie, S.S., Tadros, M.K., and Girgis, A.F., *Full-Depth, Precast-Concrete Bridge Deck Panel System*, NCHRP 12-65, National Cooperative Highway Research Program, Final Report Draft, July 31, 2006 (submitted).
5. Issa, M.A., Yousif, A.A., Kaspar, I.I., and Khayyat, S.Y., *Field Performance of Full Depth Precast Panels in Bridge Deck Reconstruction*, *PCI Journal*, Vol. 40, No. 3, May-June 1995d, pp. 82-108.
6. Issa, M. A., Salas, J. S., Shabila, H. I., and Alrousan, R.Z. *Composite Behavior of Full-Depth Precast Slabs Installed on Precast Prestressed Girders*, Accepted for publication in the PCI Journal, 2006.
7. Fallaha, S., Sun, C., Lafferty, M.D., and Tadros, M.K., *High Performance Precast Concrete NUDECK Panel System for Nebraska's Skyline Bridge*, *PCI Journal*, Vol. 49, No. 5, Sep-Oct 2004, pp. 40-50.
8. Badie, S.S., Baishya, M.C., and Tadros, M.K., *NUDECK – An Efficient and Economical Precast, Prestressed Bridge Deck System*, *PCI Journal*, Vol. 43, No. 5, Sep-Oct 1998, pp. 56-74.
9. Tadros, M.K., Baishya, M.C., Rossback, P.E., and Pietrok, G.A., *Rapid Replacement of Bridge Decks*, Concrete International, Vol. 21, No. 2, February 1999, pp 52-55.

10. Issa, M.A., Idriss, A.T., Kaspar, I.I., and Khayyat, S.Y., *Full Depth Precast, Prestressed Concrete Bridge Deck Panels*, *PCI Journal*, Vol. 40, No. 1, Jan-Feb 1995, pp. 59-80.

FIGURES

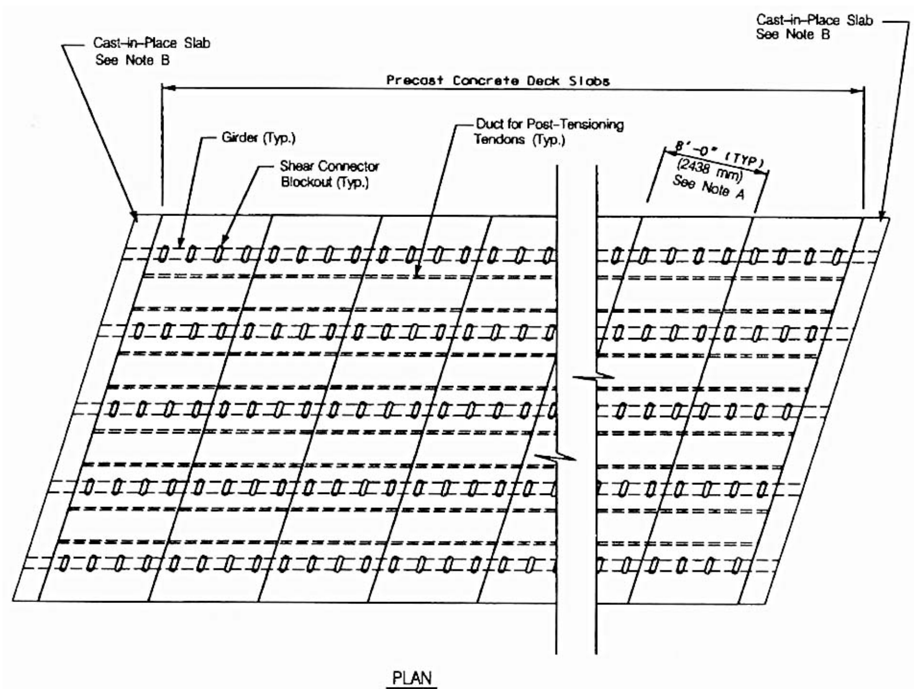

Figure 1 – Plan view of typical deck panel layout

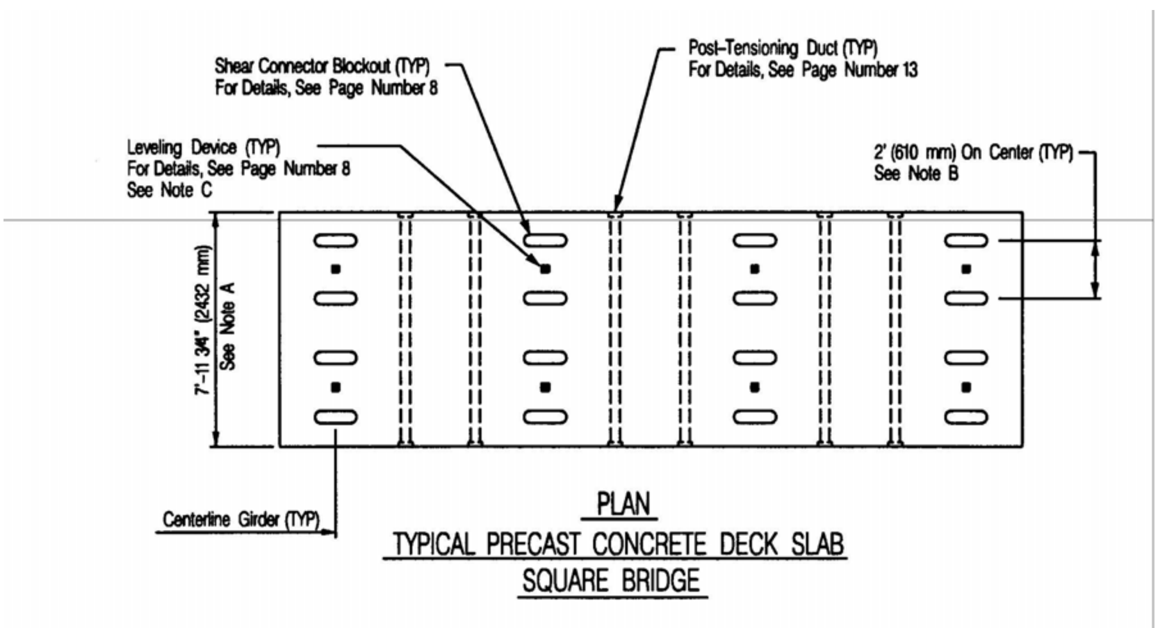

Figure 2 – Typical plan for square panel

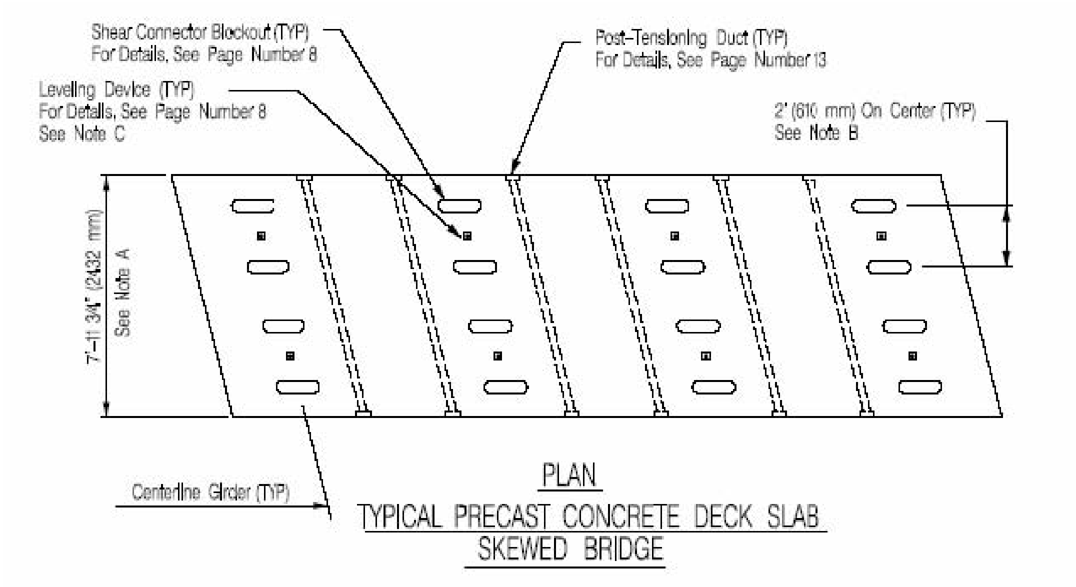

Figure 3 – Typical plan for skewed panel

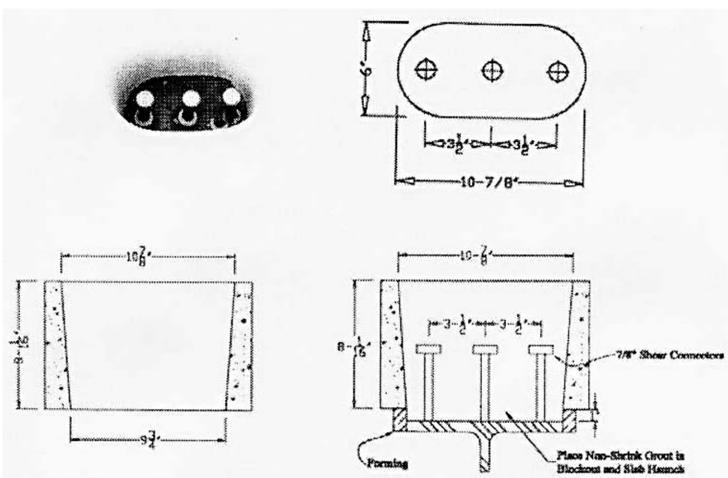

Figure 4 – Shear stud and pocket detail

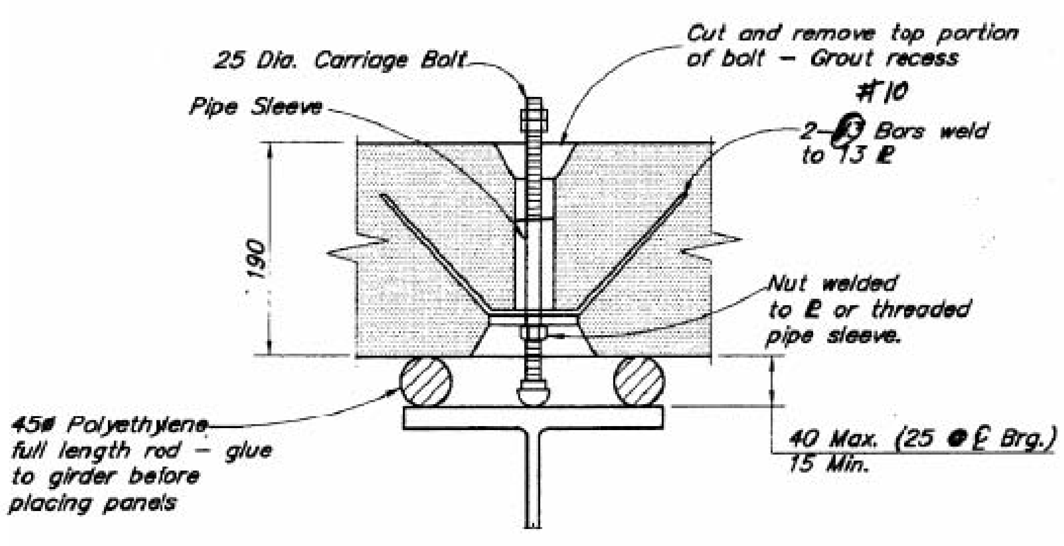

Figure 5 – Leveling bolt detail

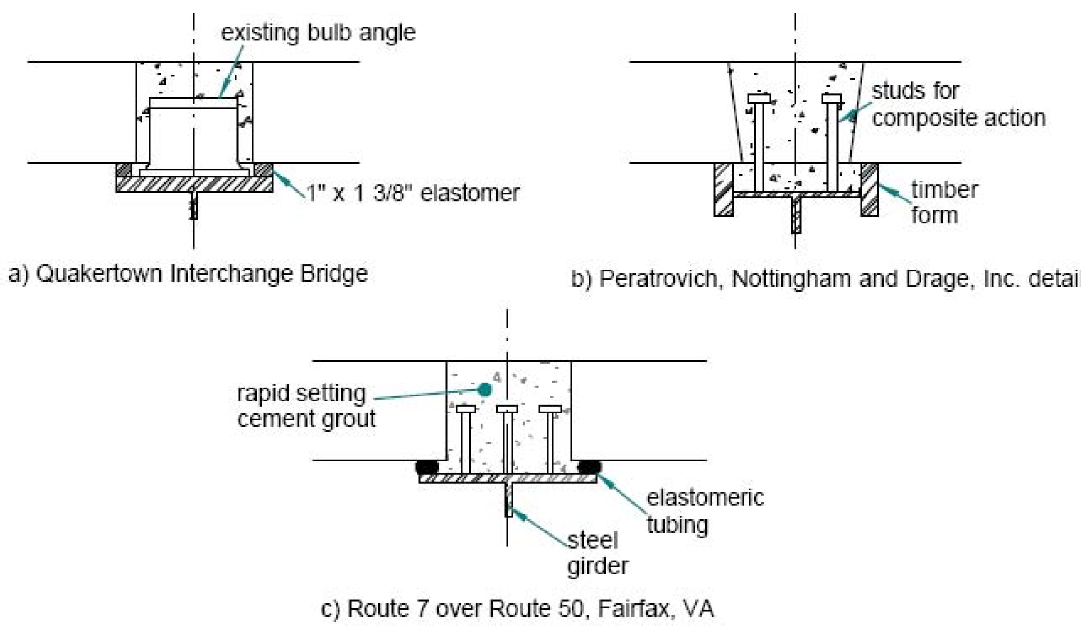

Figure 6 – Haunch forming details used on various bridges

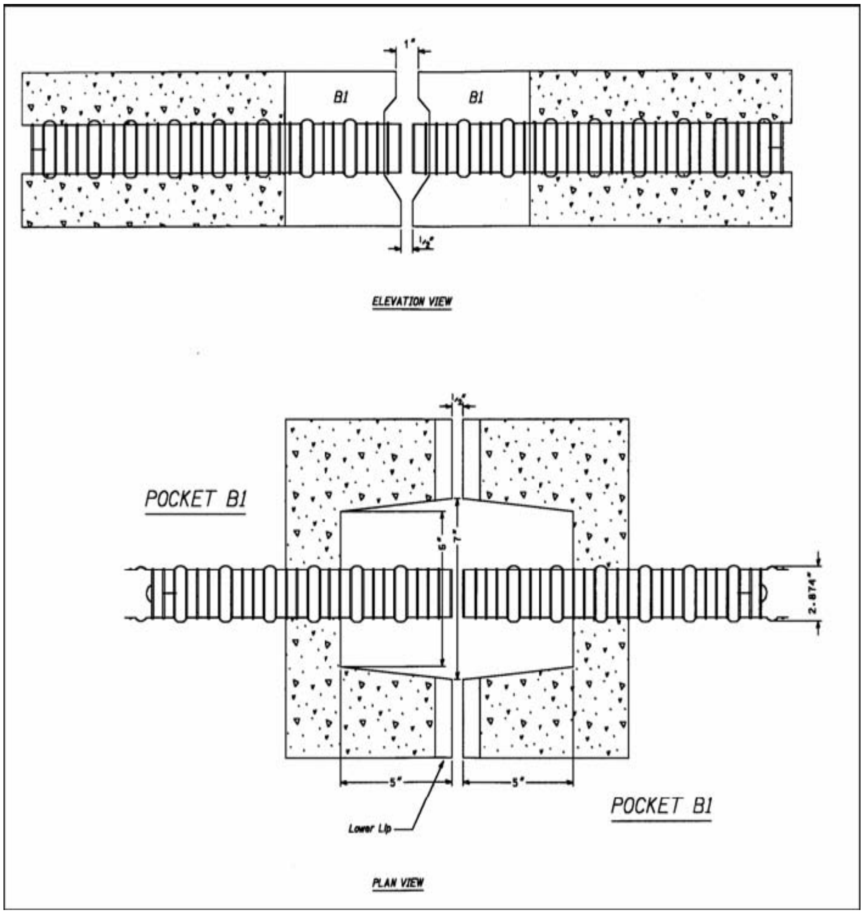

Figure 7 – Typical layout of sheath ducts across a transverse joint

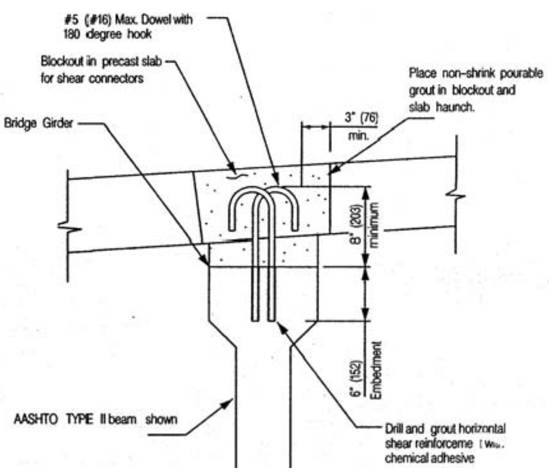

Figure 8 – Section view of shear connector for precast concrete girders

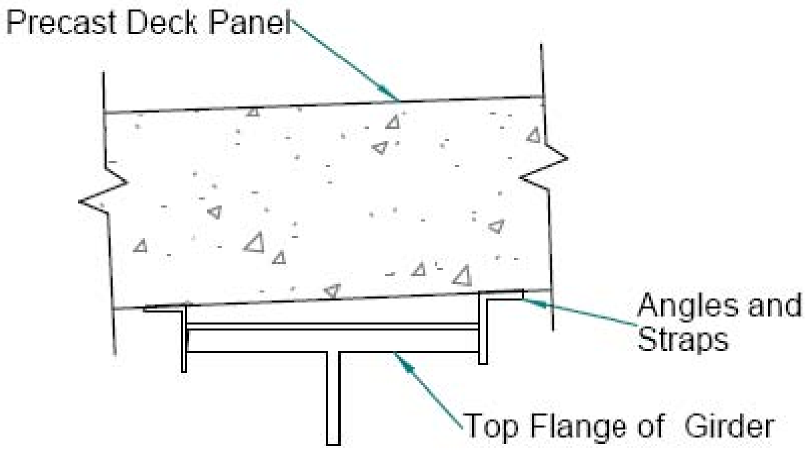

Figure 9 – Levelling and haunch forming system on steel girders

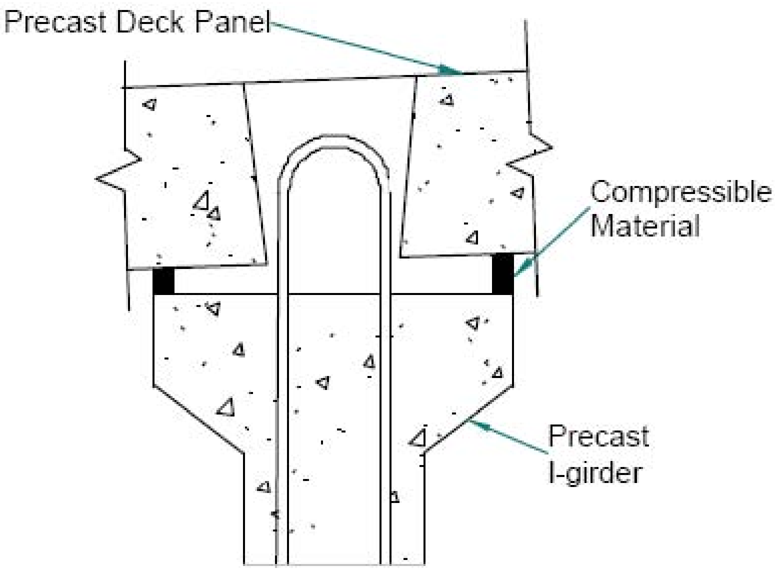

Figure 10 - Levelling and haunch forming system on precast concrete girders

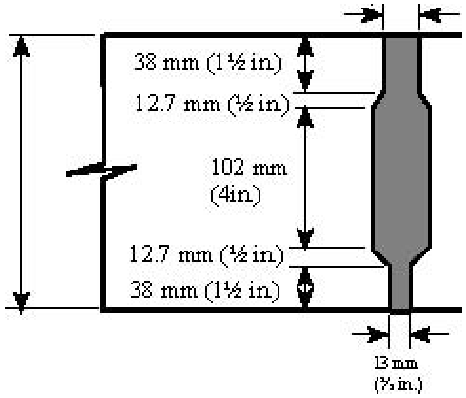

Figure 11 – Typical female-to-female transverse joint

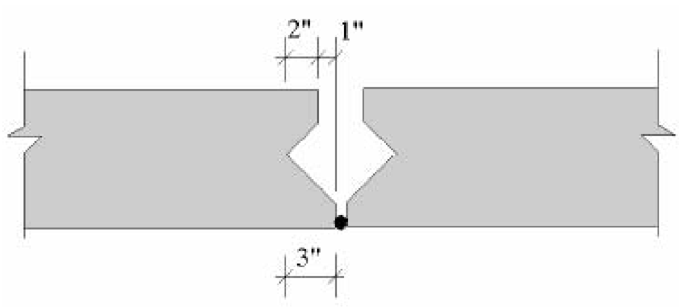

Figure 12 – V-shaped shear key used in Nebraska