Adjacent precast concrete box-beam bridges: State of the practice

Henry G. Russell

Editor's quick points

- This paper provides information about the current practice for the design, construction, maintenance, repair, and inspection of adjacent precast concrete box-beam bridges.
- These bridges provide a popular and economical solution in many states because they can be constructed rapidly and deck forming is eliminated.
- This information was gathered primarily from a survey of state highway agencies through the AASHTO Highway Subcommittee on Bridges and Structures and a review of the *AASHTO LRFD Bridge Design Specifications*.

Bridges built with adjacent precast, prestressed concrete box beams are a popular and economical solution in many states because they can be constructed rapidly and deck forming is eliminated. The bridges may be single span (**Fig. 1**) or multiple spans (**Fig. 2**). They have also proved to be economical for major river crossings. Although the bridge in **Fig. 3** resembles an arch, the superstructure consists of adjacent precast, prestressed concrete box beams. According to recent National Bridge Inventory data, adjacent concrete box-beam bridges constitute about one-sixth of the bridges built annually on public roads.

The box beams are generally connected by grout placed in a keyway between each of the units and transverse ties. Partial- or full-depth keyways are typically used, incorporating grouts with various mixture proportions. Transverse ties, grouted or ungrouted, vary from a limited number of nontensioned threaded rods to several high-strength tendons post-tensioned in multiple stages. In some cases, no topping is applied to the structure, whereas other cases include a noncomposite topping or a composite structural slab.

Bridges constructed using box beams have been in service for many years and have generally performed well. However, a recurring problem is cracking in the grouted joints between adjacent units, resulting in reflective cracks forming in the wearing surface. In most cases, the cracking leads to leakage, which allows chloride-laden water to saturate the sides and bottoms of the beams. This eventually causes corrosion of the nonprestressed reinforcement, longitudinal prestressing strand, and transverse ties. In severe cases, the joints crack completely and load transfer is lost.

There is no design method for shear keys in the American Association of State Highway and Transportation Officials'

(AASHTO's) *Standard Specifications for Highway Bridges*[1] or the *AASHTO LRFD Bridge Design Specifications*.[2] Most shear-key details in use are regional standard details of uncertain origin with no information on the magnitude of forces induced in the shear keys nor the ability of a given detail to resist these forces.

State highway agencies were surveyed through the AASHTO Highway Subcommittee on Bridges and Structures, as were Canadian provinces through the Transportation Association of Canada, Class 1 railroads, U.S. counties through the National Association of County Engineers, and the industry through PCI, as part of a synthesis report for the National Cooperative Highway Research Program.[3]

Fifty-eight complete responses were received, including 21 from owners who do not use adjacent box-beam bridges. A follow-up survey was conducted with nonresponsive states to determine their use of box beams. **Figure 4** illustrates the use of box-beam bridges by all U.S. state highway agencies. This paper contains a summary of the survey responses, generally shown as state responses and total survey responses. In some cases, the percentage of responses

Figure 1. A single-span box-beam bridge was used for Schodack Island Road over Conrail tracks in New York state. Photo courtesy of the New York State Department of Transportation.

totals more than 100% because more than one answer was possible and some states use multiple practices.

Structural design and details

Span lengths

Survey respondents reported on the span lengths using adjacent box beams. **Figure 5** shows the results for the

Figure 2. A three-span box-beam bridge was used over a ravine in Illinois. Photo courtesy of the Illinois Department of Transportation.

Figure 3. An adjacent box-beam bridge with facade arches was used to replicate an arch bridge in Ohio.

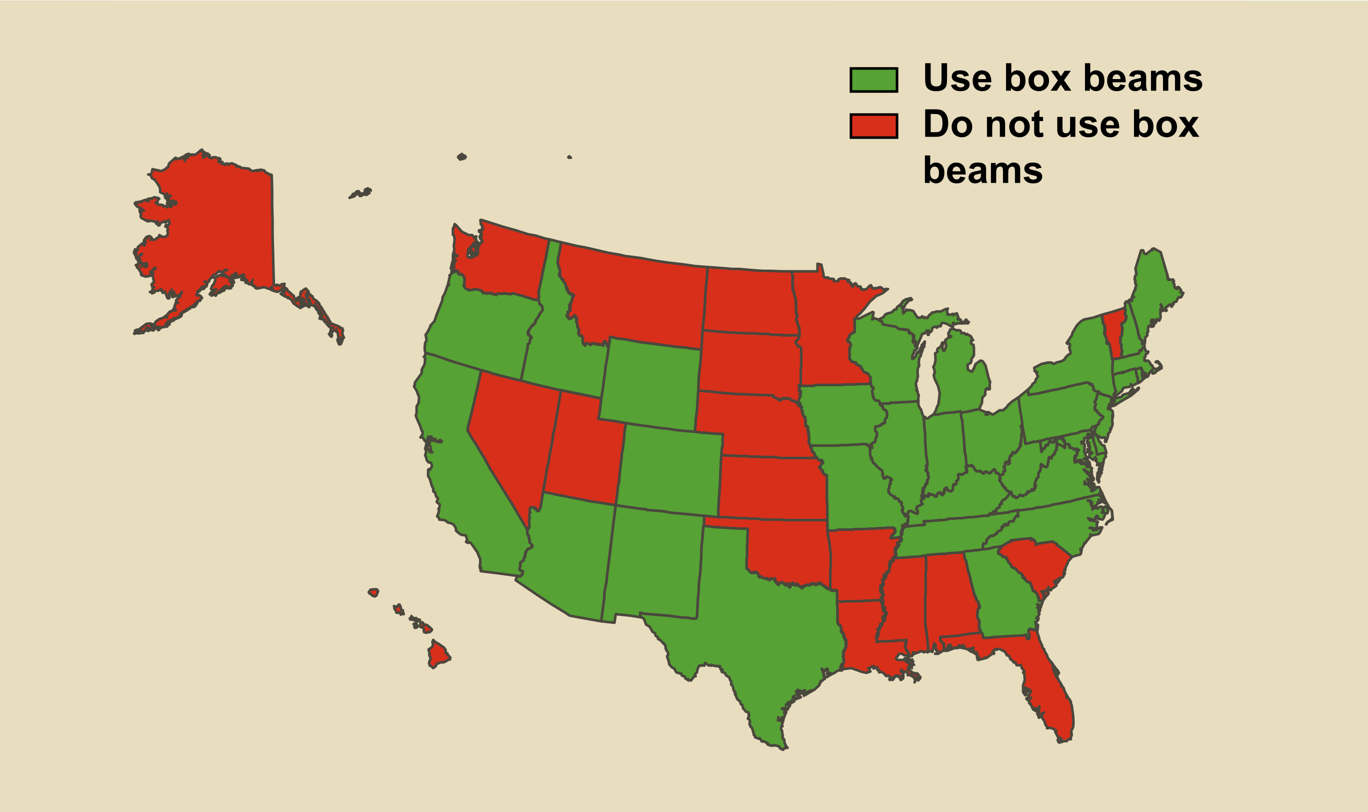

Figure 4. About two-thirds of the state departments of transportation use box-beam bridges.

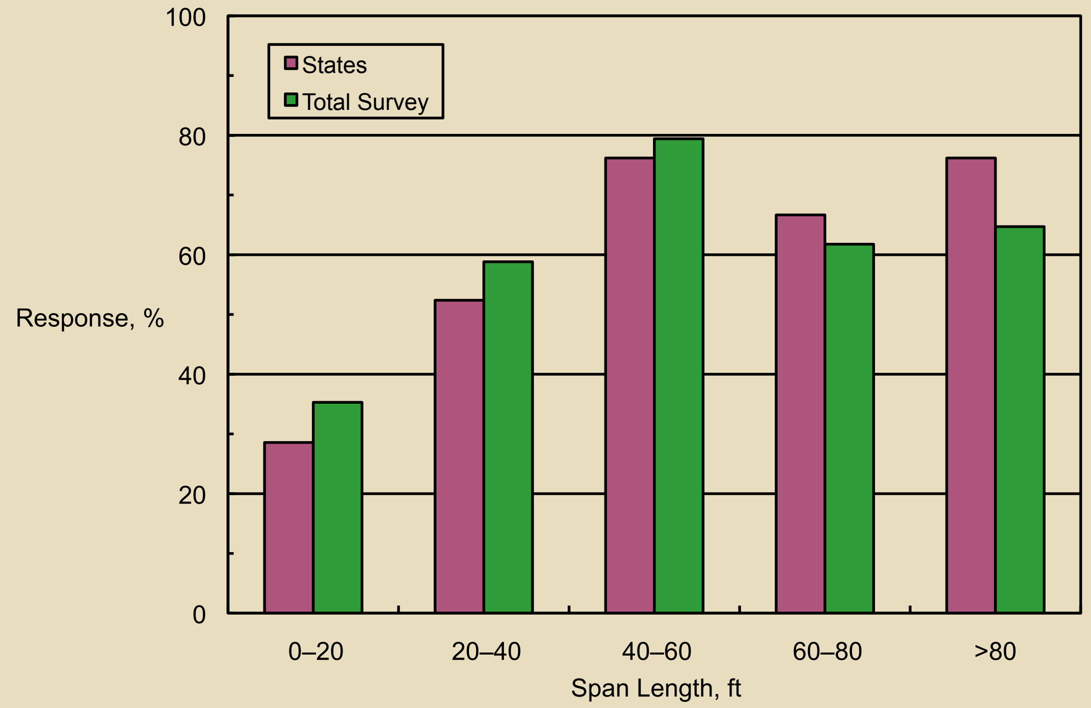

Figure 5. Box-beam bridges are used for a wide range of span lengths. Note: 1 ft = 0.305 m.

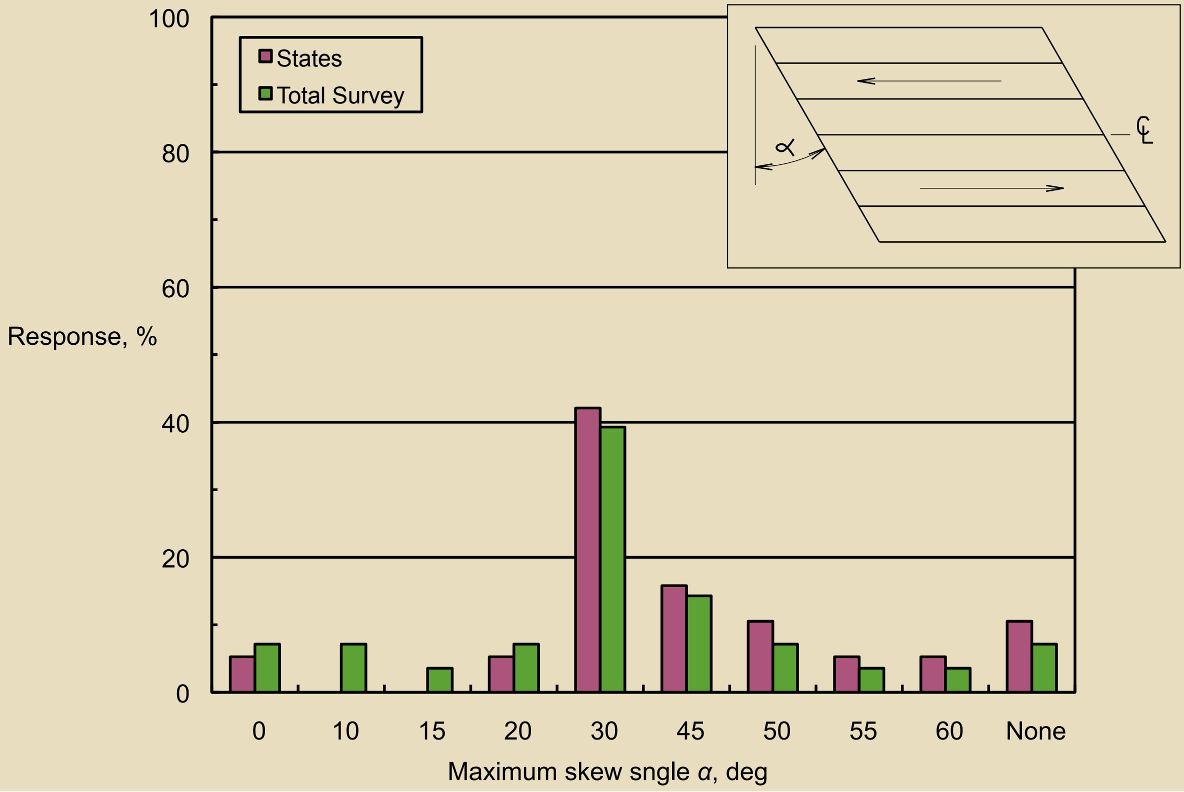

Figure 6. The most common maximum skew angle was 30 deg.

states only and the total survey and indicates that adjacent box beams are used for span lengths ranging from less than 20 ft (6 m) to more than 80 ft (24 m). The PCI *Precast Prestressed Concrete Bridge Design Manual*[4] includes pre-

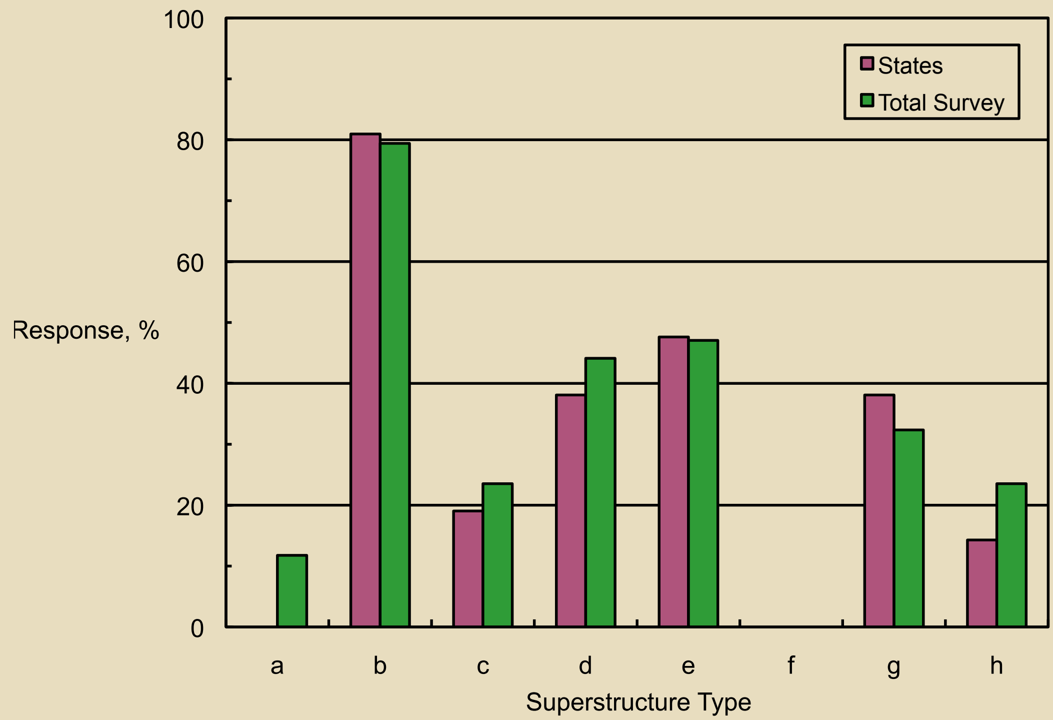

Figure 7. Simple spans with a cast-in-place concrete wearing surface were used by the majority of respondents for adjacent box-beam bridges. Note: a = simple spans with no cast-in-place concrete or bituminous wearing surface; b = simple spans with cast-in-place concrete wearing surface; c = simple spans with bituminous wearing surface only; d = simple spans with waterproofing membrane and bituminous wearing surface; e = continuous spans with composite cast-in-place concrete wearing surface; f = integral abutments with no cast-in-place concrete or bituminous wearing surface; g = integral abutments with composite cast-in-place concrete wearing surface; h = other.

liminary design charts for AASHTO box beams with span lengths ranging from 40 ft (12 m) to 140 ft (43 m).

Skew angles

The survey also asked about the maximum skew angle used for box-beam bridges. **Figure 6** summarizes the responses. The most common maximum skew angle between the abutment and the perpendicular to the bridge centerline is 30 deg. Some states indicated that they do allow exceptions to their normal maximum values.

Beam cross sections

According to the survey, 50% of the state respondents and 54% of the total respondents reported that they use AASHTO/PCI-shaped box beams. About 30% use state standards, and the remainder reported the use of PCI Northeast or Canadian PCI standards.

Composite versus noncomposite designs

Respondents identified the types of box-beam superstructures that they build. **Figure 7** shows that most respondents use simple spans with a cast-in-place concrete wearing surface. For all bridges with cast-in-place concrete wearing surfaces, the specified minimum thickness ranged from 4.5 in. (115 mm) to 6 in. (150 mm) for state agencies and 3 in. (75 mm) to 9 in. (230 mm) for the total survey. For owners that build continuous spans with a cast-in-place concrete deck, about 90% design the bridges for live-load continuity. The other superstructure type, listed in Fig. 7, was reported by Massachusetts, New Hampshire, and three Canadian provinces and consisted of a cast-in-place concrete topping with waterproofing membrane and asphalt wearing surface.

Keyway configurations

Keyway configurations, as shown in **Fig. 8**, are generally defined as partial depth or full depth. This terminology refers to the depth of the grout and not the depth of the box beam. Therefore, a full-depth keyway does not extend to the bottom of the beam because of the need to place a gasket near the bottom of the beam to prevent the grout from falling out. Figure 8 shows the typical keyway configurations and a new Illinois Department of Transportation (IDOT) detail.

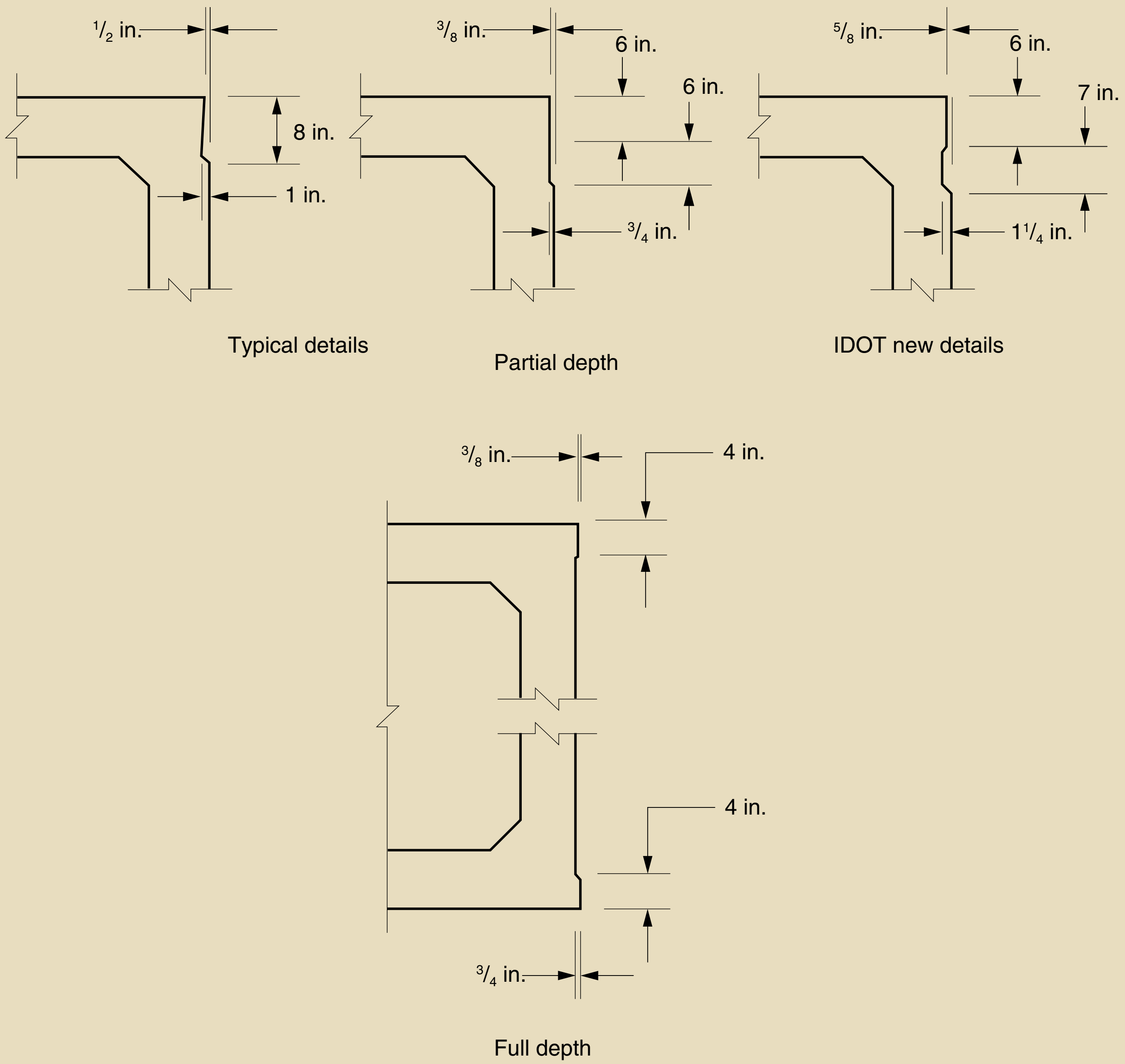

Figure 8. The figure shows examples of keyway configurations. Note: 1 in. = 25.4 mm.

In the survey, 82% of the state respondents and 73% of the total respondents reported that they use a partial-depth keyway. Most of the others reported using a full-depth keyway. In a separate survey, Connecticut and New York reported improved performance after they changed from partial-depth to full-depth keyways.[5]

Transverse tie details

Survey respondents identified the types of transverse ties used between the box beams (**Fig. 9**). Some respondents reported more than one type of tie. It may be concluded that the most commonly used types of transverse ties are unbonded post-tensioned strands or bars, with some owners using both types. Eighty-two percent of the respondents used either bonded or unbonded post-tensioning strands or bars.

The survey indicated a range of ways in which the post-tensioning force is defined, including force per bar or strand, force per duct, and torque on a threaded bar. The number of transverse tie locations varied from one to five per span, with a trend to use more ties for longer spans. The reported maximum tie spacings ranged from 10 ft (3.05 m) to 24 ft (7.32 m). No minimum spacings were reported.

Locations for the ties were at the ends, midspan, quarter points, and third points, depending on the number of ties. **Figure 10** schematically shows the different arrangements. About 70% of the respondents reported that the ties were

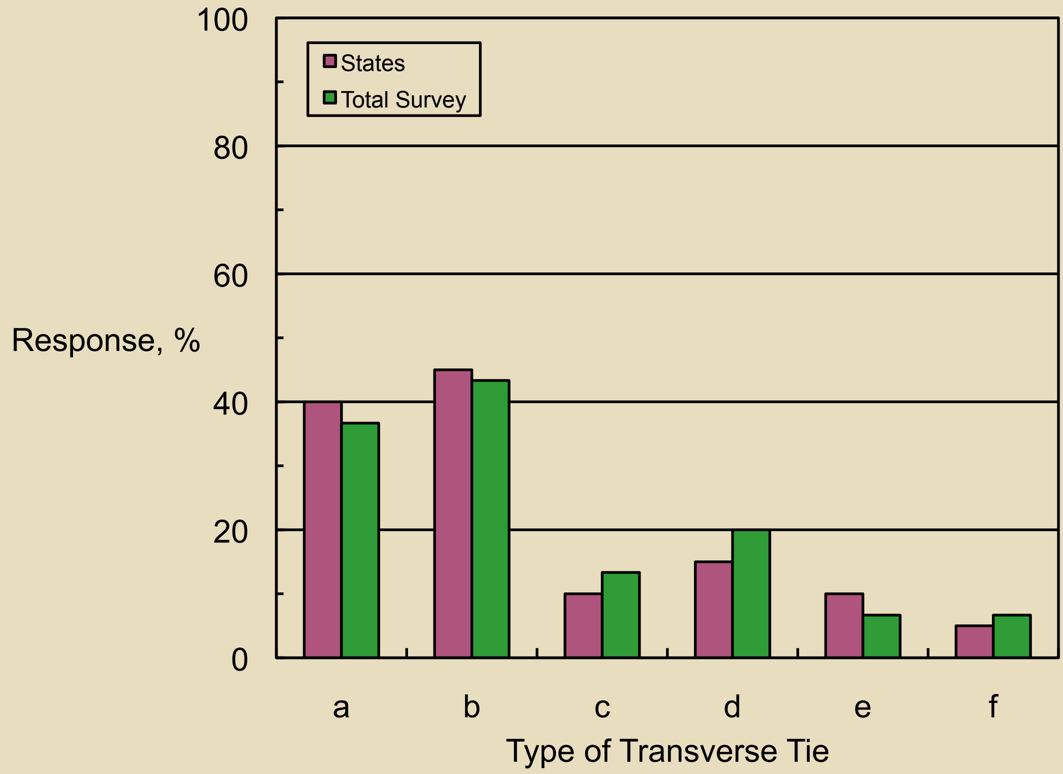

Figure 9. The most common types of transverse ties consist of unbonded post-tensioned strands or bars. Note: a = transverse unbonded post-tensioning strands; b = transverse unbonded post-tensioning bars; c = nonprestressed unbonded reinforcement; d = transverse bonded post-tensioning strands; e = transverse bonded post-tensioning bars; f = nonprestressed bonded reinforcement.

placed at mid-depth. If two strands or bars were used at one longitudinal location, they were placed at the third points in the depth. Other responses included specific location depths.

Design criteria for connections

Eighty-one percent of states and 89% of the respondents to the survey stated that they did not make any design calculations to determine the amount of transverse ties between box beams. Some respondents provided information about the post-tensioning force used for each transverse tie and the spacing of ties. Based on this information, the average transverse force per unit length along the span for various numbers of ties was calculated. **Figure 11** shows the results for 11 states. Where a single horizontal line is shown, it is based on the specified maximum spacing between ties. If the ties are closer than the minimum, the force will be higher than shown in the figure. Some states presented a range of forces as these states used a fixed number of ties for a range of span lengths. These are shown as a vertical band of color.

A design chart to determine the required effective transverse post-tensioning force is provided in the PCI bridge design manual[4]. This chart is based on the work of El-Remaily et al.[6] Values from the PCI bridge design manual are included in Fig. 11 for comparison.

Exterior beam details

According to the results from the survey, about two-thirds of the respondents use an exterior beam design that is the same as the interior beams. For the other third, the main reasons given for using different designs were the dead load of the parapet, curb, railing, and sidewalk and the live-load distribution.

Specifications and construction practices

AASHTO standard specifications

The majority of adjacent box-beam bridges in existence today were probably designed in accordance with the AASHTO standard specifications. Article 3.23.4.1 of the 17th edition[1] addresses load distribution in multibeam bridges constructed with prestressed concrete beams that are placed side by side on supports. It says, "The interaction between the beams is developed by continuous lon-

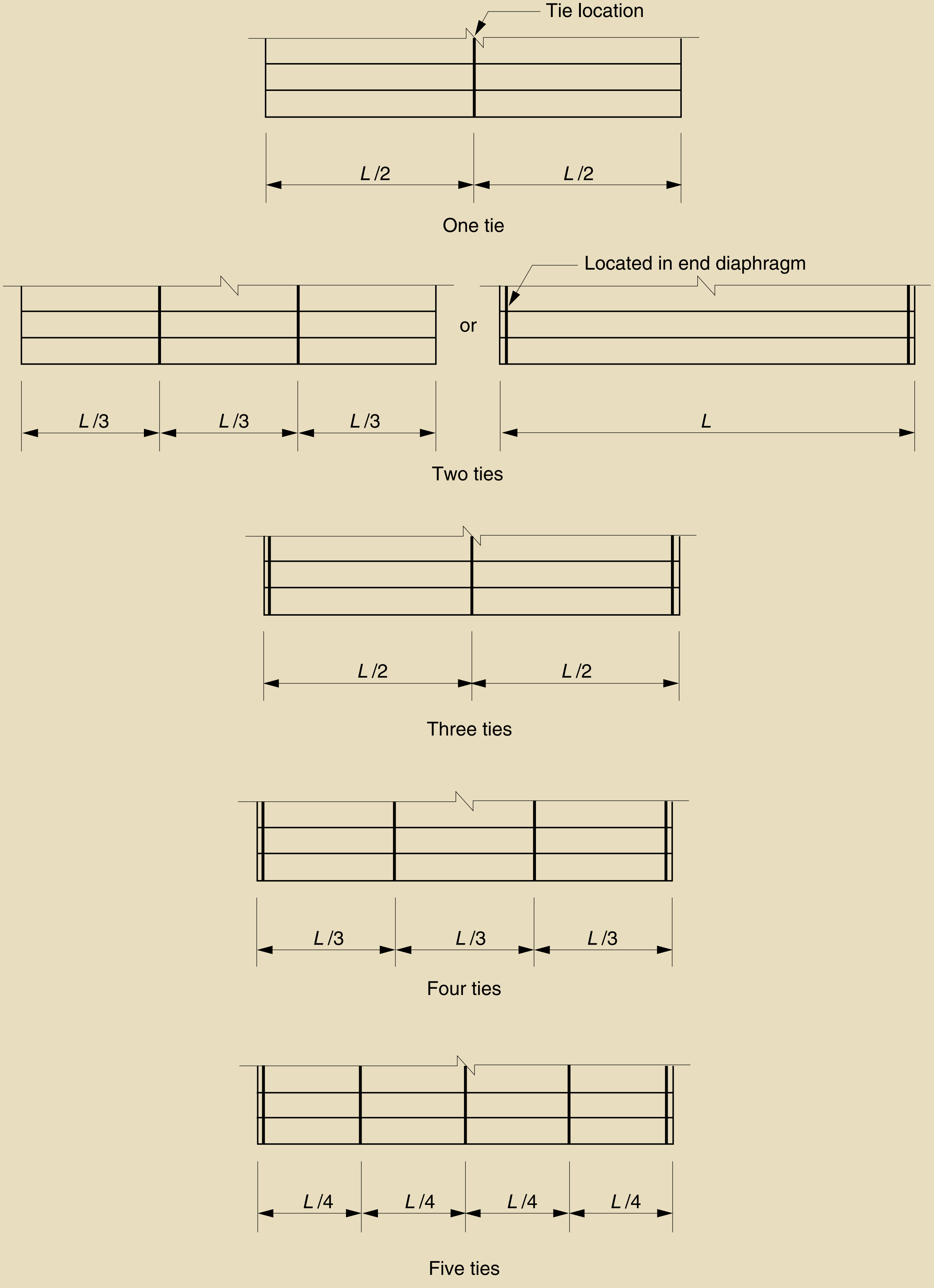

Figure 10. Various combinations of transverse tie locations are used. Note: L = length of member.

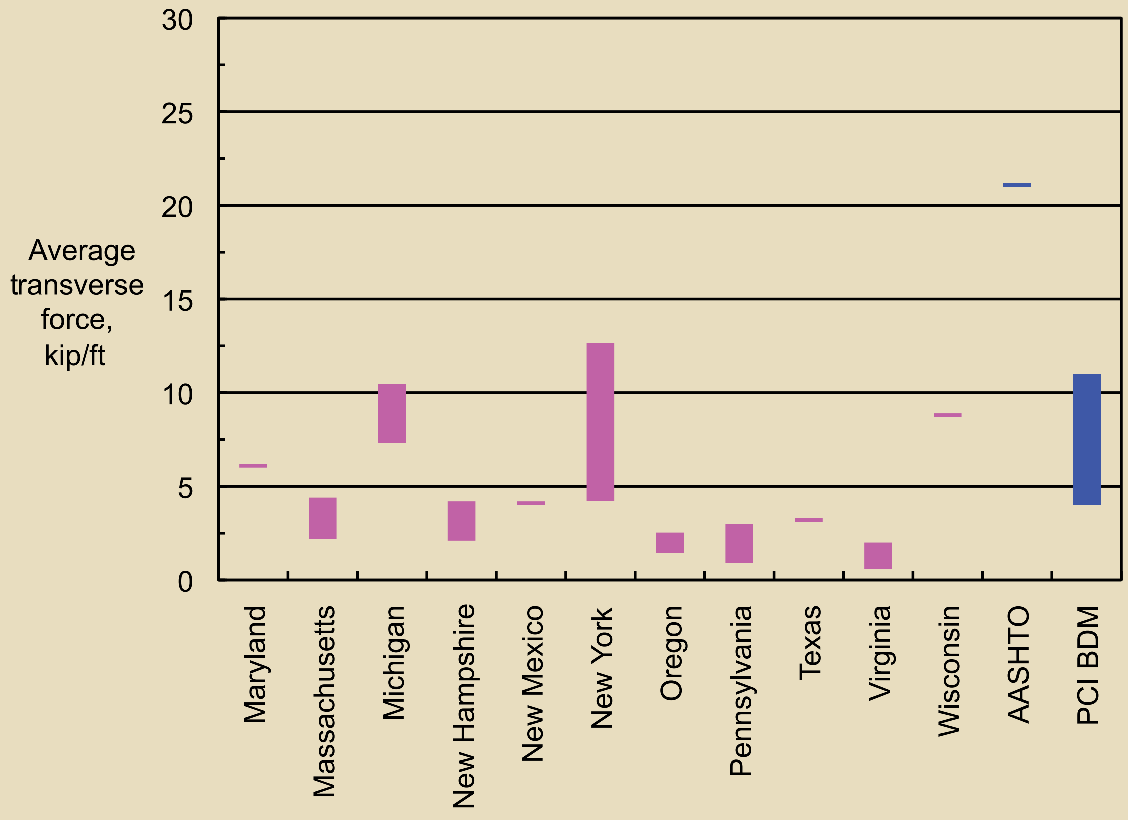

Figure 11. A wide range of average transverse post-tensioning forces per unit length along the span are used. Note: 1 kip/ft = 14.6 kN/m.

gitudinal shear keys used in combination with transverse tie assemblies which may, or may not, be prestressed, such as bolts, rods, or prestressing strands, or other mechanical means. Full-depth rigid end diaphragms are needed to ensure proper load distribution for channel, single- and multi-stemmed tee beams."

A procedure is then provided to calculate the distribution of wheel loads to each beam.

Section 9 addresses prestressed concrete analysis and design. Article 9.10.3.2 states that for precast concrete box multibeam bridges, diaphragms are required only if necessary for slab-end support or to contain or resist transverse tension ties.

Other than the articles cited above, the AASHTO standard specifications do not provide any guidance for the design or construction of the connection between adjacent box beams.

AASHTO LRFD specifications

Article 4.6.2.2 of the AASHTO LRFD specifications[2] addresses approximate methods of analysis of beam-slab bridges. The commentary of article 4.6.2.2.1 states that the transverse post-tensioning shown for some cross sections herein is intended to make the units act together. A minimum 0.25 ksi (1.7 MPa) prestress is recommended. The depth over which the 0.25 ksi is applied is not clearly defined in this article. However, an illustration in Table 4.6.2.2.1-1 shows the force applied at the level of the top flange in adjacent box-beam bridges without a concrete overlay. Precast concrete bridges with longitudinal joints act as a monolithic unit if sufficiently interconnected. The interconnection is enhanced by either transverse post-tensioning of the amount specified previously or by a reinforced structural overlay or both. The commentary cautions that the use of transverse mild steel rods secured by nuts is not sufficient to achieve full transverse flexural continuity unless demonstrated by testing or experience. Generally, post-tensioning is thought to be more effective than a structural overlay if the compressive stress specified previously is achieved.

Article 5.14.4.3 and its related commentary—denoted with a "C" preceding the article reference—contain the following provisions for precast concrete deck bridges made using solid, voided, tee, and double-tee cross sections.

5.14.4.3.2 Shear Transfer Joints

Precast longitudinal components may be joined together by a shear key not less than 7.0 in. in depth. For the purpose of analysis, the longitudinal shear transfer joints shall be modeled as hinges.

The joint shall be filled with nonshrinking grout with a minimum compressive strength of 5.0 ksi at 24 hours.

C5.14.4.3.2

Many bridges have indications of joint distress where load transfer among the components relies entirely on shear keys because the grout is subject to extensive cracking. Long-term performance of the key joint should be investigated for cracking and separation.

5.14.4.3.3 Shear-Flexure Transfer Joints

5.14.4.3.3a General

Precast longitudinal components may be joined together by transverse post-tensioning, cast-in-place closure joints, a structural overlay, or a combination thereof.

C5.14.4.3.3a

These joints are intended to provide full continuity and monolithic behavior of the deck.

5.14.4.3.3c Post-Tensioning

Transverse post-tensioning shall be uniformly distributed in the longitudinal direction. Block-outs may be used to facilitate splicing of the post-tensioning ducts. The compressed depth of the joint shall not be less than 7.0 in., and the prestress after all losses shall not be less than 0.25 ksi therein.

C5.14.4.3.3c

When tensioning narrow decks, losses due to anchorage setting should be kept to a minimum. Ducts should preferably be straight and grouted. The post-tensioning force is known to spread at an angle of 45 degrees or larger and to attain a uniform distribution within a short distance from the cable anchorage. The economy of prestressing is also known to increase with the spacing of ducts. For these reasons, the spacing of the ducts need not be smaller than about 4.0 ft. or the width of the component housing the anchorages, whichever is larger.

5.14.4.3.3d Longitudinal Construction Joints

Longitudinal construction joints between precast concrete flexural components shall consist of a key filled with a nonshrinkage mortar attaining a compressive strength of 5.0 ksi within 24 hours. The depth of the key should not be less than 5.0 in. If the components are post-tensioned together transversely, the top flanges may be assumed to act as a monolithic slab. However, the empirical slab design specified in Article 9.7.2 is not applicable.

The amount of transverse prestress may be determined by either the strip method or two-dimensional analysis. The transverse prestress, after all losses, shall not be less than 0.25 ksi through the key. In the last 3.0 ft. at a free end, the required transverse prestress shall be doubled.

C5.14.4.3.3d

This Article relates to deck systems composed entirely of precast beams of box, T- and double-T sections, laid side-by-side, and, preferably, joined together by transverse post-tensioning. The transverse post-tensioning tendons should be located at the centerline of the key.

Articles 5.14.4.3.3c and 5.14.4.3.3d clearly require a transverse prestress of at least 0.25 ksi (1.7 MPa) on a compressed depth of at least 7.0 in. (180 mm). This amounts to a transverse force of 21 kip/ft (300 kN/m). This requires 0.5-in.-diameter (13 mm) 270 ksi (1800 kPa) low-relaxation strands at 16.5 in. (420 mm) on center, stressed to 189 ksi (1300 MPa) after losses. If based on a 5 in. (130 mm) depth as stated in article C5.14.4.3.3d, the force would be 15 kip/ft (220 kN/m). Article C5.14.4.3.3d states that the post-tensioning tendons should be located at the centerline of the key, whereas 68% of the respondents to the survey reported that the ties were placed at mid-depth of the section.

Bearing types

Bearings are either plain elastomeric or laminated elastomeric. In the survey, about three-quarters of the respondents reported the use of plain elastomeric bearings. Forty-two percent of the states and 56% of the total respondents use one full-width support on each end, whereas two-point supports at each end are used by 42% of the states and 38% of the total respondents. The remainder, with one exception, use two-point supports at one end and a one-point support at the other. The exception reported the use of partial-width bearings with preformed asphalt joint filler under the remaining area. With two supports at one end, adjacent beams may be supported by the same bearing pad

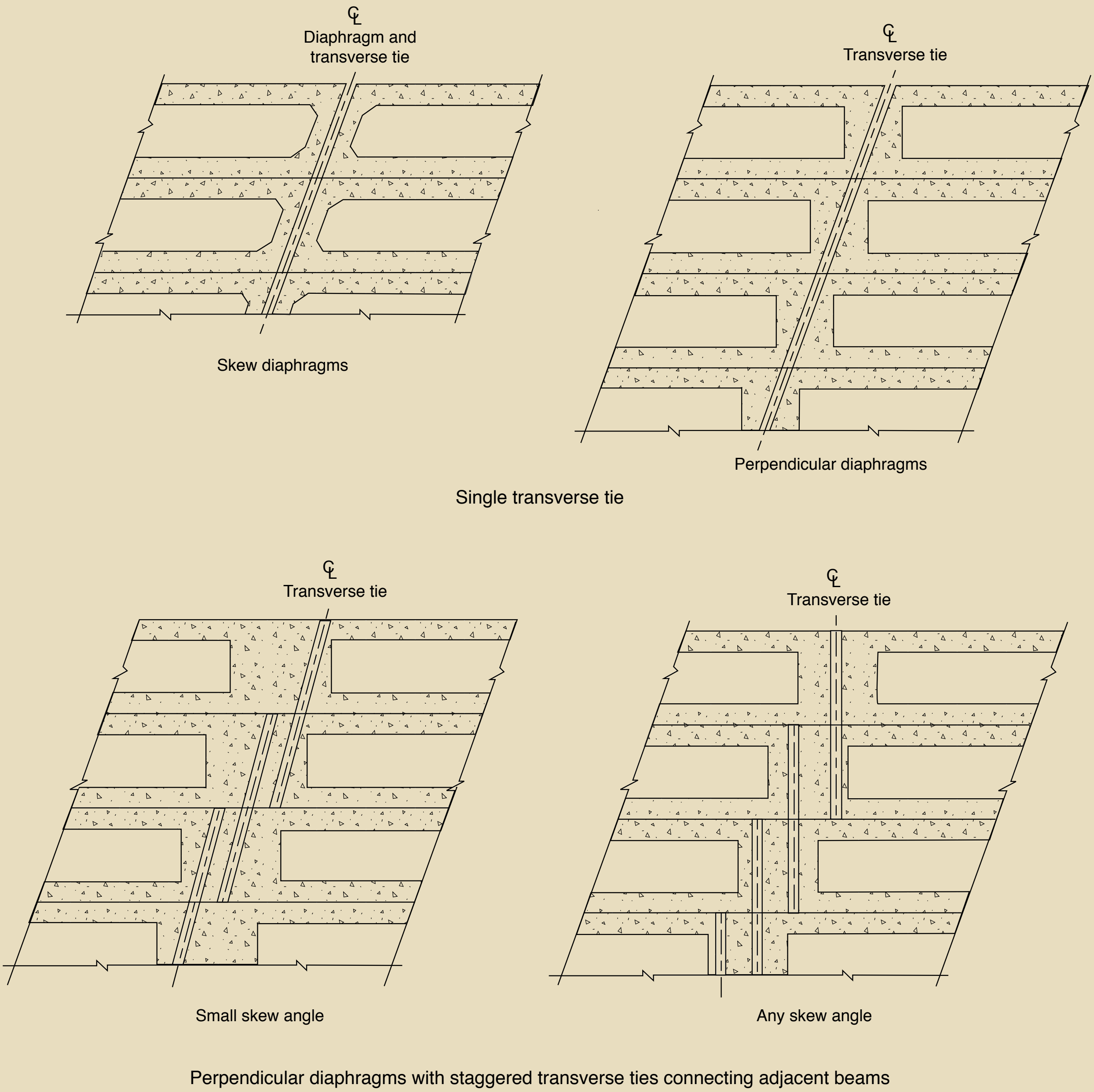

Figure 12. Various alternative transverse tie and diaphragm arrangements are used on skew bridges.

that extends under adjacent beams. Half of the respondents reported experiences with uneven seating. This was more prevalent in bridges that used a full-width support at each end.

Construction sequence

Results from the survey indicate that in single-stage construction, three-quarters of the respondents erect all beams and then connect them together at one time, as shown in **Fig. 12** as the single transverse tie. The other third erect and connect the first two beams, erect the third beam, and connect the third beam to the second beam, and so on, as in the perpendicular diaphragms with staggered transverse ties connecting adjacent beams in Fig. 12.

In two-stage construction, the respondents used one of the following sequences:

- Continue the sequence of erecting and connecting one beam at a time. The first beam of the second stage is erected and connected to the last beam of the first stage. The second beam of the second stage is then erected and connected to the first beam of the second stage and so on.

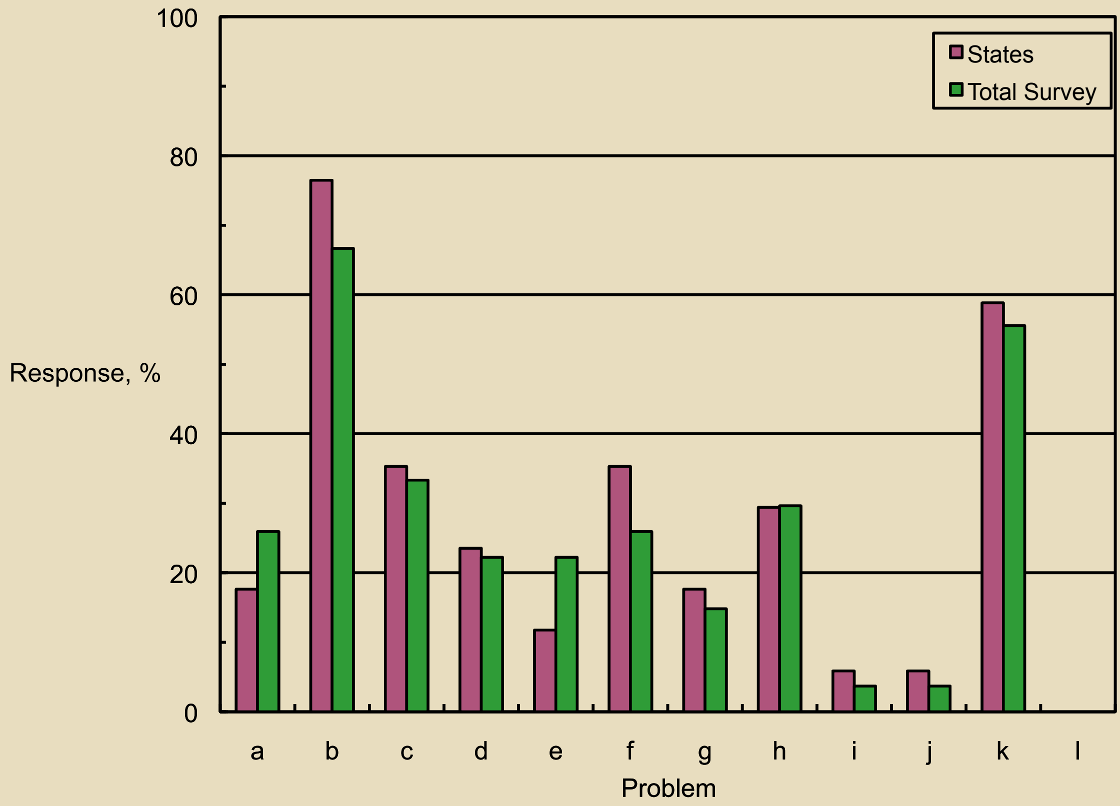

Figure 13. This figure shows responses regarding various types of distress observed along the joints between adjacent box beams. Note: a = none; b = longitudinal cracking along the grout–box beam interface; c = cracking within the grout; d = spalling of the grout; e = spalling of the corners of the boxes; f = differential vertical movement between adjacent beams; g = corrosion of the transverse ties; h = corrosion of the longitudinal prestressing strands; i = freeze-thaw damage to the grout; j = freeze-thaw damage to the concrete adjacent to the joint; k = water and salt leakage through the joint; l = other.

- All beams in the second stage are erected and then connected at one time with the second-stage transverse ties spliced to the ties of the first stage.

- All beams in the second stage are erected and then connected at one time with the second-stage transverse ties passing through the first-stage beams. This requires two sets of holes in the first-stage beams. Another variation is to connect all second-stage beams to the last beam of the first stage.

The construction sequence also depends on the skew of the bridge and the use of skewed or right-angled intermediate diaphragms. With a skewed bridge and perpendicular intermediate diaphragms, the beam-to-beam connection system is easier. With a skewed bridge and skewed diaphragms, either a beam-to-beam approach or all beams connected at one time is possible. About one-half of the respondents to the survey for this synthesis reported that the keyways were grouted before transverse post-tensioning and the other half reported after post-tensioning. Post-tensioning before grouting places a higher transverse stress in the beams at the contact locations because the bearing area is less. The grout then functions as a filler and may transfer some shear but will only transfer the compressive stress of any transverse bending moments. Post-tensioning after grouting puts a compressive stress in the grout and across the interface between the grout and the beams and provides a higher moment capacity before the precompression is overcome.

The decision to grout before or after post-tensioning appears to be related to the construction sequence. When all beams are post-tensioned at one time, the option exists to grout all keyways before or after post-tensioning without delaying construction. When beams are connected in pairs, it becomes necessary to allow the grout in the first keyway to gain strength before the first pair of beams can be post-tensioned and the next beam placed. This extends the construction time.

Differential camber

About one-third of the survey respondents reported that they had limitations on the differential camber between adjacent beams. One-half of those with limitations indicated that the maximum differential camber was 0.5 in. (13 mm). Other

Figure 14. Longitudinal cracking can occur in an asphalt riding surface.

Figure 15. Longitudinal cracking can occur in a composite concrete deck.

variations included 0.25 in. (6 mm) in 10 ft (3 m), 0.75 in. (19 mm) maximum, and 1 in. (25 mm) between the high and low beam in the same span. Methods to remove excessive camber included loading the high beam before grouting and post-tensioning, placing the barrier on the high beam, adjusting bearing seat elevations, accommodating the differential in the concrete or asphalt overlay, and preassembling the span before shipment to obtain the best fit.

Keyway preparation

Forty-five percent of the states responding to the survey stated that the keyways are sandblasted prior to beam installation. From all of the other respondents, only one—a county—reported using sandblasting. When sandblasting was used, it was always done before shipment. About one-third of the respondents reported that additional preparation other than sandblasting was performed for interior faces of beams. This generally involved cleaning with compressed air or water. One state reported applying a sealer to limit absorption from the grout. For the exterior face, only one-sixth of the respondents reported additional preparation.

Grouting materials and practices

Results from the survey showed that about 40% of the respondents use a nonshrink grout, about 25% use a mortar, and others use epoxy grout, epoxy resin, or concrete topping. The predominant method of placing grout is by hand. About 40% of the respondents provide no curing, 5% use curing compounds, and 45% use wet cure. The other respondents follow the manufacturers' recommendations.

Long-term performance, maintenance, and repairs

Types of distress

Survey respondents identified the types of distress that they observed at the joints between adjacent box beams. **Figure 13** shows the results. The most common types of observed distress are longitudinal cracking along the grout–to–box beam interface and water and salt leakage through the joint. **Figures 14** and **15** show that reflective cracks are often visible in the riding surface.

States reporting little or no observed distress

In the survey,[3] several states reported little or no observed distress. This section describes their practices.

In Massachusetts, the current standard is to use either simple or continuous spans with a 5-in.-thick (130 mm) cast-in-place concrete topping, a waterproofing membrane, and a 3.5-in.-thick (90 mm) bituminous wearing surface. The transverse ties are unbonded post-tensioning strands tensioned to 44 kip (200 kN). For spans less than 50 ft (15 m), the transverse ties are located at the ends and midspan. For spans greater than 50 ft (15 m), the ties are located at the ends, quarter points, and midspan. For a 50-ft-long (15 m) span, the average transverse force is 2.64 kip/ft (40 kN/m). For a 100-ft-long (31 m) span, the average force is 2.20 kip/ft (30 kN/m). The full-depth keyways are grouted before post-tensioning with a two-component polymer-modified cementitious fast-setting mortar. All beams are connected at one time.

Michigan reported that its only problem was spalling of the grout. Michigan's practice is to build simple and continuous spans with a composite concrete deck. Keyways are partial depth and filled by hand with a mortar after transversely post-tensioning. As Fig. 11 shows, Michigan uses the second highest amount of transverse post-tensioning of the 11 states that provided sufficient information to determine the transverse post-tensioning forces. The transverse ties are bonded post-tensioning bars tensioned to 104.5 kip (460 kN) for HS25 loading and 82.5 kip (370 kN) for HS20 loading. All beams are connected at one time.

Table 1. Factors influencing long-term performance

Factor	States, %		Total survey, %	
	Yes	No	Yes	No
Span length	25	75	20	80
Simple spans versus continuous spans	27	73	24	76
Skew	57	43	48	52
Bearing types	8	92	10	90
Topped versus untopped	80	20	72	28
Integral abutments	27	73	24	76
Phased construction	31	69	21	79
Waterproof membrane	45	55	47	53
Exterior beam details	0	100	7	93
Maintenance	36	64	48	52

Missouri reported that it recently started using box-beam bridges and found no major leakage through the joints. Missouri's practice is to build simple spans with a cast-in-place deck or an asphalt wearing surface with seal coat and to build continuous spans with a composite concrete deck. Keyways are partial depth and are filled by hand with a nonshrink grout. Adjacent box beams are connected in pairs using nontensioned unbonded reinforcement located at the mid-depth of the box.

New Mexico's practice is to use simple spans with a 5-in.-thick (130 mm) composite cast-in-place concrete deck. Transverse ties consist of two bonded post-tensioning bars stressed to 50 kip (220 kN) with five ties per span spaced not more than 25 ft (7.6 m) apart. This is equivalent to a force of at least 4 kip/ft (60 kN/m). The partial-depth keyways are grouted after post-tensioning using a mortar. Adjacent box beams are connected in pairs. The New Mexico response indicated that it does not build many of these types of bridges.

Although Oregon listed six types of distress, its response indicated that the types were not widespread. Oregon's practice is to build simple spans with a waterproofing membrane and bituminous wearing surface or to build continuous spans with a composite concrete deck. Keyways have a partial depth of 12 in. (300 mm) and are filled by hand with a nonshrink grout after post-tensioning. Adjacent box beams are connected in pairs with unbonded transverse post-tensioning located at mid-depth of the box. Transverse ties have a maximum spacing of 24 ft (7.3 m) and are tensioned to 39 kip (170 kN). This is equivalent to a force of at least 1.63 kip/ft (24 kN/m), which is relatively low according to the data in Fig. 11.

Maintenance procedures

Respondents of the survey suggested the following methods to maintain adjacent box-beam bridges:

- Seal the deck.
- Remove the asphalt topping.
- Seal the cracks.
- Wash the decks annually.

Repair procedures

Respondents listed the following methods as having been used to rehabilitate or retrofit adjacent box-beam bridges:

- Add a reinforced concrete deck.
- Add supplemental tie rods.
- Replace the asphalt wearing surface with a concrete deck.
- Use waterproofing membrane over the entire surface and reseal the deck.

When installing a new concrete deck, it is important to thoroughly clean the top surface of the beams and, if necessary, add reinforcement dowels into the webs to provide composite action between the deck and the beams. IDOT believes that replacing asphalt wearing surfaces with a thicker reinforced concrete wearing surface is effective in prolonging the life of beams if they are in good condition and have not experienced salt exposure from leaking keyways. The current practice in

Figure 16. Leakage can occur through longitudinal joints. Photo courtesy of the Pennsylvania Department of Transportation.

Figure 17. Efflorescence on the underside indicates leakage through the joints. Photo courtesy of the New York State Department of Transportation.

Illinois[7] is to use reinforced concrete overlays on new box-beam bridges.

Factors affecting long-term performance

In the survey conducted for the synthesis[3], respondents reported the methods of construction that they found most effective in preventing deterioration along the joints. The two methods most often identified were sufficient transverse post-tensioning and use of a concrete topping slab. Methods identified as being ineffective were asphalt wearing surface with or without a waterproofing membrane, phased construction, and lack of concrete overlay.

When asked to identify which factors appear to affect the long-term performance of adjacent box-beam bridges and which do not, the responses varied (**Table 1**).

The survey also asked about problems that have been observed with joints between adjacent units. The two major problems identified were longitudinal cracking along the grout–to–box beam interface and water and salt leakage through the joint. When a concrete topping was used, 65% of the responding states and 55% of the total respondents reported reflective cracking in the topping. Additional research is needed to identify cost-effective methods to prevent reflective cracking and subsequent leakage.

Inspection practices

Visual inspection

Visual inspection[7] is the current practice used to document the condition of beams. This is confirmed by the survey, which had 100% of the states and 90% of total respondents using only visual inspection for box-beam bridges.

The two other methods mentioned were chain dragging and full deck survey. Shear-key degradation is seen by visible evidence of water dripping from the joints between adjacent beams during a period of rain, icicles (**Fig. 16**), or staining caused by water wicking along the beam soffit (**Fig. 17**).

Identification of corrosion

The only means to visibly identify corrosion is from rust stains that appear on the surface or spalled concrete exposing corroded reinforcement. By the time either of these happens, active corrosion has occurred for some time.

Other practices

Forty-five percent of the respondents to the survey reported that they inspected drain holes for debris. Seventeen percent did not inspect, and 38% reported that inspection of drain holes was not applicable. Most clogged drain holes were cleaned by rodding them out in various ways.

Conclusion

Bridges built with adjacent precast, prestressed concrete box beams are used in about two-thirds of states. These bridges are economical and can be constructed quickly, and the deck forming is eliminated for most. Based on the survey, the current practice for box-beam bridges is summarized:

- About half of the states with box-beam bridges use AASHTO/PCI cross-sectional shapes.
- Span lengths range from less than 20 ft (6 m) to more than 80 ft (24 m).
- The most common maximum skew angle between the abutment and the perpendicular-to-the-bridge centerline is 30 deg.
- Most states use simple spans with cast-in-place concrete decks.

- Where a composite deck is used for continuous spans, the bridges are generally designed to be continuous for live load.
- Most longitudinal keyways between adjacent box beams are partial depth.
- The most common transverse tie consists of unbonded post-tensioned strands or bars.
- About half of the states grout the keyway before post-tensioning and about half after post-tensioning.
- There is no consensus about the number of transverse ties or the magnitude of post-tensioning force.
- Exterior and interior beams generally use the same design.
- Most bridges have either full-width support or two-point supports on each end.
- More states use plain elastomeric bearings than laminated elastomeric bearings.
- In single-stage construction, all beams are generally connected transversely at one time.
- In two-stage construction, a variety of sequences is used.
- About half of the states require sandblasting of the keyway before erection. The sandblasting is always done before shipment.
- The most common grout used for the keyways is a nonshrink grout.
- About half of the states require the use of wet curing or curing compounds for the grout.

Recommended practices

Based on the synthesis[3] and information presented in this paper, the following practices are recommended to eliminate or reduce the likelihood of longitudinal cracking and joint deterioration and, therefore, enhance the performance of adjacent box-beam bridges.

Design practices

- Require full-depth shear keys that can be grouted easily.
- Provide transverse post-tensioning so that tensile stresses do not occur across the joint.
- Require a cast-in-place, reinforced concrete, composite deck with a specified concrete compressive strength of 4000 psi (30 MPa) and minimum thickness of 5 in. (130 mm) to limit the potential for longitudinal deck cracking.

Construction practices

- Use stay-in-place expanded polystyrene to form the voids.
- Sandblast the longitudinal keyway surfaces of the box beams immediately before shipping to provide a better bonding surface for the grout.
- Clean the keyway surfaces with compressed air or water before erection of the beams to provide a better bonding surface for the grout.
- Grout the keyways before transversely post-tensioning to ensure compression in the grout.
- Use a prepackaged grout that provides a high bond strength to the box-beam keyway surfaces to limit cracking.
- Provide proper curing for the grout to reduce shrinkage stresses and ensure proper strength development.
- Provide wet curing of the concrete deck for at least seven days to reduce the potential for shrinkage cracking and to provide a durable surface.

Maintenance practices

- Seal longitudinal cracks as soon as they occur to prevent salt and water penetration.
- Wash the decks on an annual basis to remove chlorides.
- Clean drain holes on a regular basis to prevent water accumulation in the boxes.

Acknowledgments

The synthesis described in this paper was performed under the National Cooperative Highway Research Program project no. 20-5 and managed by Jon M. Williams, program director for the Transportation Research Board. The Topic Panel for the synthesis consisted of Donald W. Herbert of the Pennsylvania Department of Transportation; Ahmed Ibrahim of the California Department of Transportation; Stephen F. Maher of the Transportation Research Board; Barney Martin of Modjeski & Masters in Poughkeepsie, N.Y.; Basile Rabbat of the Portland Cement Association; Andrea Schokker of Pennsylvania State University; Michael B. Twiss of the New York State Department of Transportation; Julius F. J. Volgyi Jr. of the Virginia Department of Transportation; and Benjamin Graybeal and Gary Jakovich of the Federal Highway Administration. Their review of the report and technical input is greatly appreciated. Drawings for the synthesis report and this paper were prepared by the Virginia Department of Transportation.

References

1. American Association of State Highway and Transportation Officials (AASHTO). 2002. *AASHTO Standard Specifications for Highway Bridges*. 17th ed. Washington, DC: AASHTO.

2. AASHTO. 2007. *AASHTO LRFD Bridge Design Specifications, 4th Edition—2008 Interim Revisions*. Washington, DC: AASHTO.

3. Russell, H. G. 2009. *Adjacent Precast Concrete Box Beam Bridges: Connection Details*. National Cooperative Highway Research Program Synthesis 393. Washington, DC: National Research Council Transportation Research Board.

4. PCI Bridge Design Manual Steering Committee. 2004. *Precast Prestressed Concrete Bridge Design Manual*. MNL-133. Chicago, IL: PCI.

5. PCI Bridges Committee. Forthcoming. *State-of-the-Art of Precast/Prestressed Adjacent Member Bridges*. Chicago, IL: PCI.

6. El-Remaily, A., M. K. Tadros, T. Yamane, and G. Krause. 1996. Transverse Design of Adjacent Prestressed Concrete Box Girder Bridges. *PCI Journal*. V. 41, No. 4 (July–August): pp. 96–107.

7. Macioce, T. P., H. C. Rogers, R. Anderson, and D. C. Puzey. 2007. Prestressed Concrete Box Beam Bridges—Two DOTs' Experience. In *The PCI National Bridge Conference: Proceedings, October 22–24, 2007, Phoenix, Arizona*. CD-ROM.

About the authors

Henry G. Russell, FPCI, is an engineering consultant in Glenview, Ill.

Synopsis

The paper provides information about the current practice for the design, construction, maintenance, repair, and inspection of adjacent precast concrete box-beam bridges. These bridges provide a popular and economical solution in many states because they can be constructed rapidly and deck forming is eliminated. The bridges may be single or multiple spans. The box beams are generally connected by grout placed in a keyway between each of the units and usually with transverse ties. Partial- or full-depth keyways are typically used, incorporating grouts using various mixture proportions. Transverse ties, grouted or ungrouted, vary from a limited number of nontensioned threaded rods to several high-strength tendons, post-tensioned in multiple stages. In some cases, no topping is applied to the structure, while a noncomposite topping or a composite structural slab is added in other cases. Most shear-key details currently used are regional standard details of uncertain origin. This information was gathered primarily from a survey of state highway agencies through the AASHTO Highway Subcommittee on Bridges and Structures and a review of the *AASHTO LRFD Bridge Design Specifications*.

Keywords

Box beam, bridge, connection detail.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute's peer-review process.

Reader comments

Please address any reader comments to journal@pci.org or Precast/Prestressed Concrete Institute, c/o *PCI Journal*, 200 W. Adams St., Suite 2100, Chicago, IL 60606.