Eliminating Expansion Joints in Bridges

by Dr. Maher K. Tadros, PE,
e.construct.USA LLC

Traditional bridges use expansion joints in conjunction with expansion (sliding) bearing devices to accommodate superstructure movement due to volume change effects. These effects are primarily due to creep and shrinkage of concrete and both daily and seasonal temperature variations. However, use of expansion joints, especially above the abutment and pier supports, may require significant maintenance expenses and may shorten bridge life. Leakage of contaminated water and freeze-thaw cycles can cause staining and cracking of the concrete surface and locking of the expansion bearings, which would further exacerbate concrete deterioration.

Bridges with structurally continuous beams over the piers offer a number of advantages. Continuity for superimposed dead loads and live loads allows for relatively long spans. Such bridges also have better resistance to wind and seismic forces. They have significantly less deflection and vibration than simple-span bridges, and thus improved durability. Ride quality is also improved if the "bump" at the piers caused by the expansion joint is eliminated.

A number of owners have adopted measures to eliminate expansion joints on bridges, and limit their use to locations in the approach slabs only, as illustrated in Fig. 1. In addition, some owners have developed details that allow for use of simple elastomeric pads for erection purposes, or just wood blocking until the diaphragm concrete is placed. Bridges that utilize these features are sometimes called *jointless* or *integral* bridges.

There are no requirements in the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* (AASHTO LRFD specifications) for maximum bridge length allowed without expansion joints. Many state highway agencies allow eliminating expansions joints for bridges that are less than 350 ft long with steel beams and 650 ft long with concrete beams. However, there are a number of examples where bridges over 1000 ft long have performed well without expansion joints.

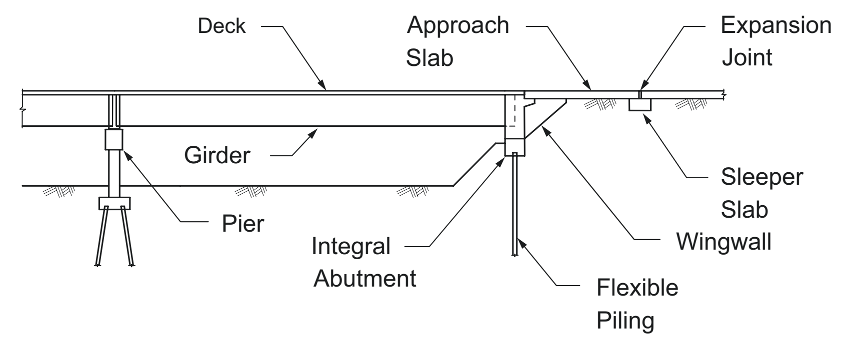

Figure 1. Elevation of a typical jointless bridge. Figure: e.construct.USA.

The discussion below presents several options available to eliminate expansion joints and provide jointless bridge superstructures. More details are available in the PCI publication *The State-of-the-Art of Precast/Prestressed Integral Bridges,* authored by the PCI Subcommittee on Integral Bridges of the Committee on Bridges.[1]

Details at Abutments

A bridge abutment has the dual purpose of resisting the loading transmitted from the supported superstructure and the pressure from the soil retained in transitioning from soil-supported roadway to "point"-supported bridge. Creating a totally integral abutment detail requires that the abutment carry the vertical loads from the end span as well as the lateral soil pressure from the adjacent soil.

A simple integral abutment detail employed by Midwest states, including Nebraska, is to directly support the concrete beams on steel cross channels that are directly welded to steel HP piles at the required seat elevations (Fig. 2). The beams are secured in position on the channels until the abutment wall concrete is placed and cured. No bearing pads are used.

If the expansion of an integral bridge due to thermal effects, for example, creates excessive stresses on the abutment or excessive deformation of the supporting piles, another option may be used (Fig. 3). The detail is called a *semi-integral* or *turn-down* abutment. In this situation, the pile cap (or abutment wall) is separated from the abutment diaphragm by compressible filler, such as extruded

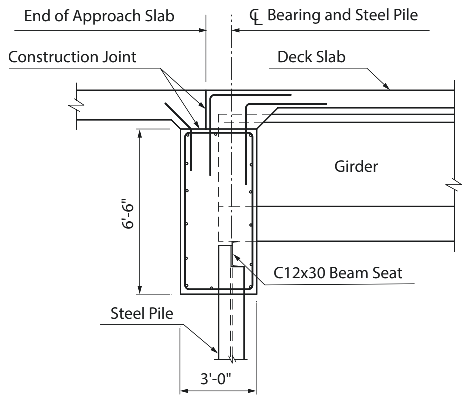

Figure 2. Example of integral abutment detail. Figure: Reference 2.

polystyrene (XPS), except at the beam bearings. The beams are set on "expansion bearing" devices that allow the beam ends to move longitudinally due to volume change effects, which is similar to the conventional abutment except that no expansion joint is provided at the end of the deck.

Similar to an integral abutment, a semi-integral abutment has an abutment diaphragm that is integrally connected to the superstructure. But a semi-integral abutment differs from an integral abutment by providing some sort of moment relief detail (hinge) between the superstructure/abutment diaphragm and the abutment. Semi-integral abutments are also recommended by some owners, regardless of bridge length, when the bridge is square or up to a 45 degree skew.

Bearing Details

Similar to abutments, integral bridge details may involve continuous concrete diaphragms from the deck slab to the piling. Washington State Department of Transportation has a detail in which the beams are temporarily supported on wooden blocking until the diaphragm concrete is placed. Other owners use bearing devices to set the beams. Diaphragms are then constructed to complete what may be considered a semi-integral system. Examples of fixed and expansion bearings, from Nebraska Department of Roads[2] details at continuity diaphragms, are given in Figs. 4 and 5. The same details may also be used for abutment locations to accompany the detail shown in Fig. 3. Similar details may be used for simply supported girders.

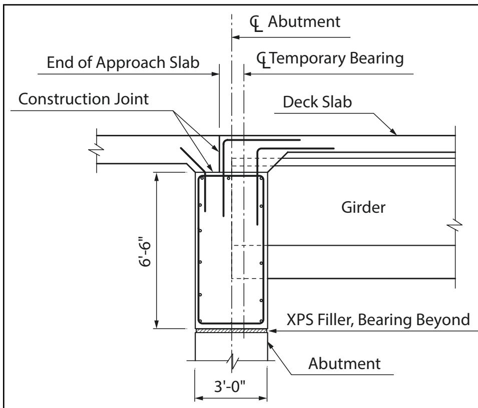

Figure 3. Example of semi-integral (turn-down) abutment detail. Figure: e.construct.USA.

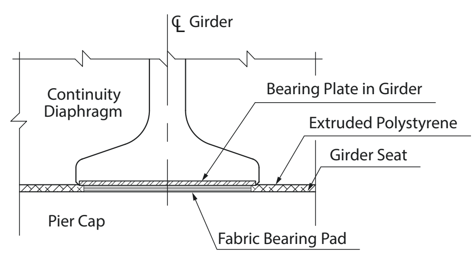

Figure 4. Example of fixed bearing details. Figure: Reference 2.

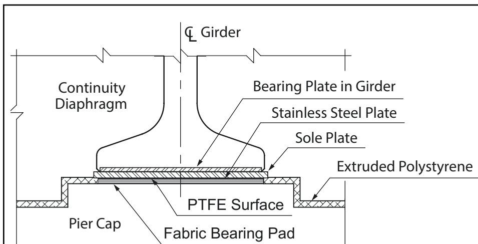

Figure 5. Example of expansion. Figure: Reference 2.

Details at Piers

Simple Span Beams with Continuous Deck Slabs

Most of the concrete beam bridges in Florida and Texas are currently built using a detail where the deck is continuous over the joint between girders at a pier. A typical detail is shown in Fig. 6. Their details do not include beam end diaphragms or debonding between the deck and beam. The absence of end diaphragms in these details significantly simplifies construction, but may not be feasible in states subjected to significant seismic activities. Some of the details include a saw-cut or tooled crack control joint in the deck over the pier that may be filled with sealant.

Simple Span Beams with Link Slabs

In this approach, the slab is continuous across the joint between girders at a pier, but a length of the slab is debonded from the girders on both sides of the joint. This detail reduces cracking in the continuous deck slab by distributing the deformations it experiences over a greater distance. This method is considered a cost-effective way of providing a jointless deck in several states. It has some advantage over details that provide full continuity, such as simple construction and small cast-in-place concrete volume. Because the deck is mildly reinforced and not prestressed, the tensile stress in the deck is not usually limited. To control cracking, a groove is typically formed or cut in the deck at the centerline of the pier that may be filled with a sealant.

The link slab system is common, but not limited, to states in the South and Southwest. Considerable research in the 1990s by Paul Zia and his students[3,4] produced recommendations for design and construction of link slabs. They recommend debonding the end 5% of the slab from the end of the beam to help control cracking in the link slab region. Recommended analysis is to impose the end rotations of the beams on the slab. The resulting stress in the deck reinforcement should be limited to 40 ksi and cracking should be checked with current AASHTO LRFD specifications crack control provisions.

An example of a link slab system used to remove expansion joints when rehabilitating bridges in Virginia[5] is shown in Fig. 7. In this detail, which is used for relatively short spans, the debonded length is a constant 2 ft.[5]

Continuous-for-Live-Load Beams

A common system to provide deck continuity over the piers is the so-called continuous-for-live-load system for prestressed concrete beams. The beams are first set on bearings as simple spans. The diaphragm concrete may be placed partial height (Fig. 8). The deck concrete is then placed, still on simple-span beams. Longitudinal reinforcement placed in the deck over the pier region is designed to resist all subsequent loads as a continuous span composite superstructure. This system is quite popular, especially in the Midwest, where deicing chemicals can create significant deterioration of bridges with expansion joints. It has performed well for more than 40 years. It is also quite common in other countries, such as Canada, Spain, United Kingdom, France, Italy, Belgium, and Brazil.

The behavior of this system is complicated by the interacting effects of creep and shrinkage of concrete, thermal gradient, moment redistribution due to cracking, and soil-structure interaction. AASHTO LRFD specifications Article 5.14.1.4 allows designers to use one of four methods of design. Due to the complexity of applying the theoretical method in the specifications, the simplest and most conservative empirical method is often employed. It involves two requirements:

(a) The beams must be 90 days old before they are allowed to be connected with the cast-in-place diaphragm.
(b) Positive moment reinforcement must provide a flexural strength of 120% of the cracking moment.

The most restrictive requirement is the one that requires the girders to be 90 days old. It appears to conflict with the philosophy of accelerated bridge construction (ABC), especially for damaged-beam replacement. (Additional detailed discussion was included in the Summer 2014 issue of *ASPIRE* by Dr. Richard Miller, the lead author of NCHRP Report 519,[6] regarding the analysis options and code requirements.[7]) The second requirement results, in the author's opinion, in an excessive amount of positive moment (bottom) reinforcement. The cracking moment is a theoretical value that is no longer valid once the beam cracks at the face of the diaphragm. Crack-control reinforcement would be a more appropriate approach.

A number of states, including Nebraska, Iowa, Tennessee, and Minnesota, have sponsored research, including field trials on actual bridges, to develop semi-empirical design and detailing guidelines that have proven their validity over several decades of service. For example, Nebraska Department of Roads typically allows use of the following guidelines:

- The beams must be 30 days old before placement of the diaphragm concrete can begin.
- The positive moment connection between girders is made by extending a minimum of eight strands from each girder that overlap in the diaphragm.

Figures 8 and 9 show details at the pier and an example of a bridge recently constructed in Nebraska using the simplified approach.

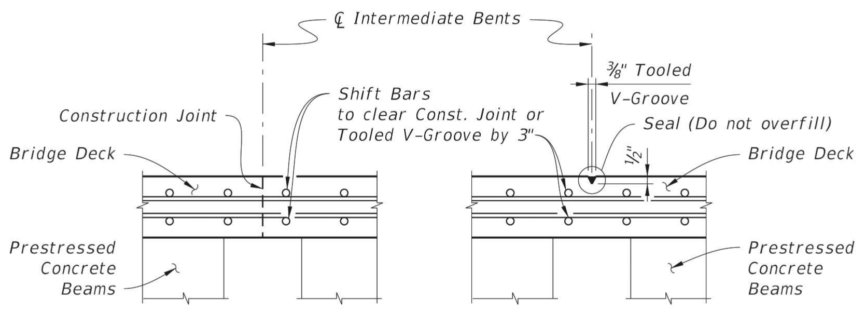

Figure 6. Florida Department of Transportation details for continuous slab over joint between simple spans. Figure: Florida Department of Transportation Structures Detailing Manual.

Threaded Rod Continuity System

A recently developed method called *threaded rod continuity* was reported by Sun et al.[8] In this method, beams are made continuous with high-strength threaded rods placed on top of the beams in the negative moment zone over the pier region. The rods are embedded in a concrete placement on the top flange of the beam that is constructed at the same time as the continuity diaphragm, as shown in Fig. 10. The result is a continuous beam for deck weight as well as all subsequent loads. This system, while slightly more complicated than the continuous-for-live-load system, allows for further optimization of the capacity of the beams. Also, as an additional benefit, the negative moment due to deck weight generally offsets the long-term positive restraint moment at the pier, eliminating the need for bars or strands extending from girders to provide a positive moment connection.

Concluding Remarks

- Elimination of expansion joints in bridge decks has been an effective method of constructing bridges. It results in reduced maintenance and improved life expectancy.
- Current consensus seems to allow elimination of expansion joints on concrete beam bridges as long as 650 ft. Much longer bridges have occasionally been constructed without reported distress.
- It is possible to replace elaborate bearing devices with simple elastomeric pads, or to make the superstructure integral with the supports without any bearings.[1] For this latter option, careful analysis would be needed.
- Workshops and webinars (such as a Florida International University ABC Center webinar by Russo in October 2012[9]) have started to demystify the phenomena that are included in many of the research papers on this topic.
- Lastly, there is a need for simple and practical national guidelines for design and detailing of the popular continuous-for-live-load connection system.

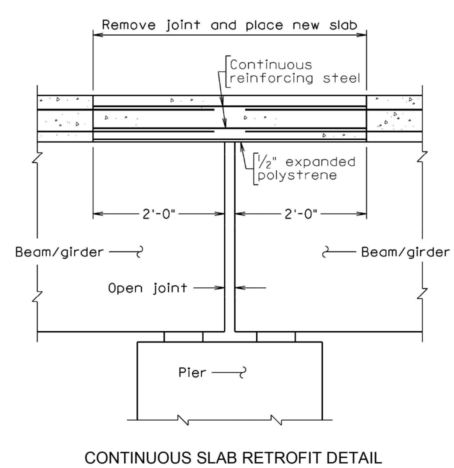

Figure 7. Link slab detail used by Virginia Department of Transportation to eliminate expansion joint in rehabilitation projects. Figure: Virginia Department of Transportation Structure Design Manual.

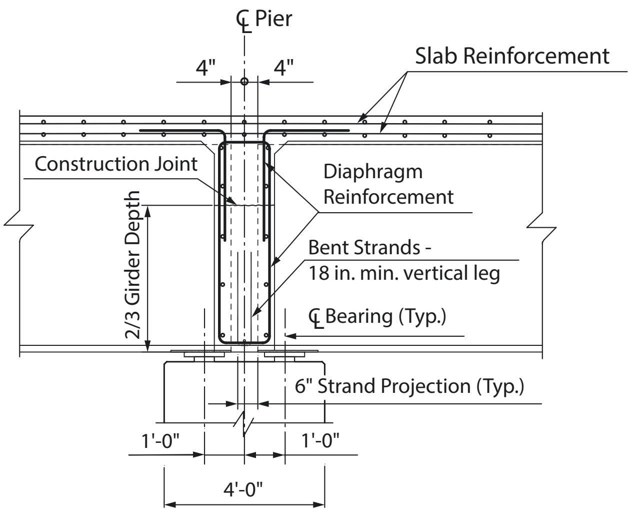

Figure 8. Example of pier diaphragm details with either fixed or expansion bearings. Figure: e.construct.USA.

Figure 9. Fairview Road Bridge over Interstate 80, near Omaha, Neb., utilizing continuous-for-live load details. Photo: e.construct.USA.

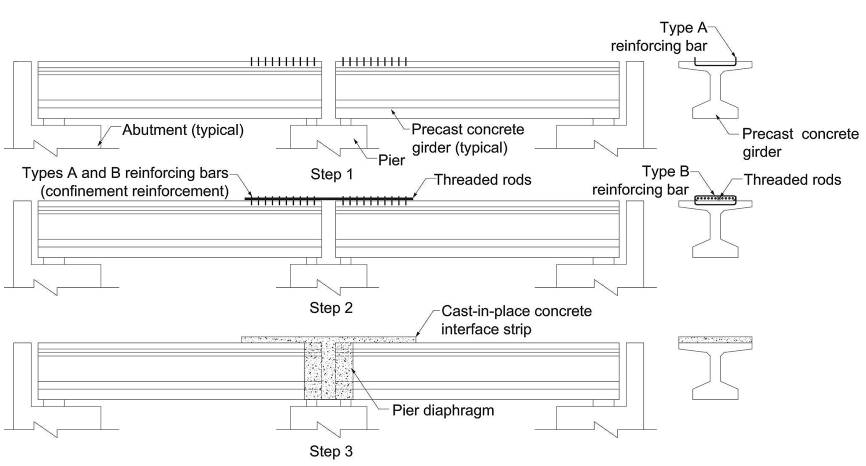

Figure 10. Construction steps of implementing threaded rod continuity system prior to deck placement. Figure: Reference 8.

References

1. PCI Subcommittee on Integral Bridges. 2001. *The State-of-the-Art of Precast/Prestressed Integral Bridges*. Precast/Prestressed Concrete Institute, Chicago, IL.
2. Nebraska Department of Roads. 2014. *Bridge Office Policies and Procedures (BOPP) Manual*. Nebraska Department of Roads, Lincoln, NE.
3. Canter, A., and P. Zia. 1998. "Behavior and Design of Link Slabs for Jointless Bridge Decks." *PCI Journal*, Precast/Prestressed Concrete Institute, Chicago, IL. V. 43, No. 3, (May-June), pp. 68-78.
4. El-Safty, A. K. 1994. "Analysis of Jointless Bridge Decks with Partially Debonded Simple Span Beams." Ph.D. diss., North Carolina State University, Raleigh, NC.
5. Matteo, A. 2015. "VDOT's Use of Concrete Closure Pours to Eliminate Bridge Deck Expansion Joints." *Concrete Bridge Views*, No. 79, http://www.concretebridgeviews.com/i79/Article1.php.
6. Miller, R. A., R. Castrodale, A. Mirmiran, et al. 2004. *Connection of Simple-Span Precast Concrete Girders for Continuity*. National Cooperative Highway Research Program Report 519. Transportation Research Board, National Research Council, Washington, DC.
7. Miller, R. A. 2014. "Special Notice: Bridges Composed of Simple-Span, Precast Concrete Girders Made Continuous." *ASPIRE*, Precast/Prestressed Concrete Institute, Chicago, IL, V. 8, No. 3 (Summer), pp 47-48.
8. Sun, C., N. Wang, M. K. Tadros, et al. 2016. "Threaded Rod Continuity for Bridge Deck Weight." *PCI Journal*, Precast/Prestressed Concrete Institute, Chicago, IL. V. 61, No. 3, pp. 47-67.
9. Russo, Francesco. "Economical Details over Piers Using Simple-for-Dead-Load and Continuous-for-Live-Load Design—Part 1: ABC Concrete Girder Bridges." Florida International University ABC Center Webinar, October 18, 2012.

Dr. Maher K. Tadros is a PCI Titan and principal of e.construct.USA LLC in Omaha, Neb.