

Chapter 1

Integral Bridges

We are suspicious of new ideas, however good, if they threaten old ideas however bad.

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Introduction

The first integral bridge in the United States was the Teens Run Bridge. It was built in 1938 near Eureka in Gallia County, Ohio. It consists of five continuous reinforced concrete slab spans supported by capped pile piers and abutments. Since that time construction of integral bridges has spread throughout the United States and abroad. The United Kingdom recently adopted them for routine applications. Japan completed its first two in 1996. South Korea completed its first such bridge in 2002.

Integral bridges may be briefly defined as single-span or continuous multiple-span bridges constructed without movable transverse deck joints (movable deck joints) at piers or abutments, or as more generally described in Chapter 10 and Appendix 2, integral bridges may be conceived of as components of composite structure movement systems, systems generally composed of:

- Jointless superstructures constructed integrally with capped pile abutments
- Abutments supported by embankments and single rows of vertically driven piles
- Rigid piers with movable bearings, or flexible piers constructed integrally with the superstructure
- Attached approach slabs that bear on abutments and abutment backfill
- Cycle control joints, of some sort, for the longer bridges, located between approach slabs and approach pavements.

When multiple-span bridges are constructed without movable deck joints at piers, it is accepted that the continuity achieved by such construction will subject superstructures to secondary stresses, stresses that are induced by the response of continuous superstructures to settlements of substructures, post-tensioning, etc. When continuous bridges are constructed without such joints at the superstructure/abutment interface, it is likewise accepted that they will, in addition, be subjected to secondary stresses due to superstructure/abutment continuity, and to the resistance of abutment foundations and backfill to cyclic longitudinal superstructure movements. The justification for such construction is based on the growing awareness that, for single- and multiple-span bridges of moderate lengths, significantly more damage and distress have been caused by the use of movable deck joints at piers and abutments than the secondary stresses that these joints were intended to prevent. In addition, elimination of costly joints and bearings and the labor-intensive details and construction procedures necessary to permit their use have generally resulted in more cost-effective bridges. Consequently, more and more bridge engineers are now willing to relinquish some of their control of secondary stresses primarily to achieve simpler and more cost-effective bridges and bridges with greater overall integrity and durability.

Before continuing this discussion about integral bridges, a pause should be taken here to comment on the use of the unfortunate phrase “integral abutment bridges.” It is this author’s contention that the use of this phrase by members of the bridge engineering profession leaves novice engineers with the incorrect impression that it would be proper and acceptable to provide integral abutments for all bridges including multiple-span *non-continuous* bridges. Obviously, such construction is totally inappropriate, and especially for those projects that are built in conjunction with jointed concrete approach pavement (see Chapter 2). It therefore should be understood that in this and other chapters of this book, the designations “integral bridges” and “semi-integral bridges” will be used exclusively. The first designation refers to single- or multiple-span *continuous* bridges without movable deck joints at the superstructure/abutment interface. These are generally supported by embankments with stub-type abutments on flexible piles. The second designation refers to single- or multiple-span *continuous* bridges without movable deck joints in their superstructures but with movable longitudinal joints between their superstructures and rigidly supported abutments. The piers for such structures may be semi-rigid self-supporting structures generally surmounted by movable bearings, or flexible substructures constructed integrally with superstructures. Approach slabs that span across and are partially supported by structure backfill should be attached to the superstructures of such bridges. Cycle-control joints (see Appendix

2) in some form should be provided between their approach slabs and approach pavements.

Continuous superstructures

Current design trends (about 1990) received their primary impetus and direction almost six decades ago. In May 1930, a brief 10-page paper on the “Analysis of Continuous Frames by Distributing Fixed End Moments” [1], published in the *Proceedings of the American Society of Civil Engineers*, generated considerable discussion in academia. Its publication was followed shortly by what could be considered a minor revolution in the design and construction of short- and moderate-span bridges. In that paper, Professor Hardy Cross presented a simple and quick method for the analysis of integral-type structures such as continuous beams and frames. His moment distribution method was quickly adopted by bridge design engineers, and the bridge design and construction practices of many transportation departments began to change. Before Cross’s “Moment Distribution” [1], most multiple-span bridges were generally constructed as a series of simple spans. Following the introduction of moment distribution, bridge design engineers began adopting continuous construction primarily to eliminate troublesome movable deck joints at piers.

On the basis of a nation-wide mail survey of state and province transportation departments [2], it appears that the Ohio Highway Department (now the Ohio Department of Transportation, or Ohio DOT) was one of the first agencies to initiate the routine use of continuous construction for the design and construction of multiple-span bridges. Its experience provides an informative background for this movement toward the use of fully integrated construction.

To minimize the use of movable deck joints at piers and thus prevent deleterious deck drainage from reaching and saturating the surfaces of vulnerable primary superstructure and pier components, beginning in the late 1920s and early 1930s, Ohio DOT adopted the *routine use* of continuous construction for multiple-span highway bridges. To make such a practice possible at a time when continuous construction was a rarity, Ohio DOT had to develop and perfect various field-splicing procedures for the bridging materials then available. For the shortest multiple-span bridges and those bridges with spans less than 50 ft. (15 m), continuous reinforced concrete slab bridges were developed and adopted. At first, rolled steel beams were made continuous by the use of riveted field splices at piers (Figure 1.1). To achieve continuous steel girders, field-riveted plate and angle splices were provided at counter flexure points. At about the same time, welding procedures and welder pre-qualification tests were developed for field welding of steel bridge members, and some of the shortest rolled beam bridges were provided with field-welded splices at piers. These initial welded splices consisted of partially butt-welded beam webs supplemented with fillet-welded moment plates. Field-welded splices were constantly being improved by Ohio DOT and, by the mid-1950s, all rolled beam bridges were being made continuous by field butt welding of beam webs and flanges, and by fillet welding of flange moment plates.

From the late 1920s to the mid-1950s, steel girder fabrication and girder field splices were of riveted construction. However, in 1954, high-strength bolts were used



Figure 1.1 USR 52, Isaacs Creek Bridge, Adams County, Ohio, 1931. This was one of first steel beam bridges in Ohio where riveted field splices at piers were used to achieve superstructure continuity.

in lieu of field-driven rivets for the field splices of the Patterson-Riverside, Great Miami River Bridge of Dayton, Ohio (Figure 1.2). This was one of the first applications of high-strength bolting for highway bridges in the United States. By 1963, high-strength bolting replaced field butt welding in Ohio as the method of choice for integrating multiple-span bridges to achieve full continuity. Consequently, by riveting, field butt welding, and high-strength bolting, Ohio DOT has employed continuous construction for more than 70 years.

In conjunction with the development and adoption of continuous construction for all moderate-length highway bridges, Ohio DOT was also the first state to routinely eliminate deck joints at abutments. This was accomplished in the case of continuous reinforced concrete slab bridges by providing embankments and stub-type integral abutments supported by flexible piles in lieu of movable deck joints and wall-type abutments (see Chapter 5). This new abutment type is now designated as an integral abutment and Ohio DOT was the first state transportation department to adopt such construction as a standard practice. A version of this integral abutment design has been used in Ohio for many hundreds of bridges ever since. However, it was not until the early 1960s that the integral concept was first used by Ohio DOT for a steel beam bridge (see Appendix 3, photograph). Since that time, most steel beam and girder bridges with skews 30° or less, and lengths not longer than about 300 ft. (91.44 m), were of integral construction (if site geological characteristics and/or embankment heights allowed the use of flexible piles for abutment support).

In 1951, Ohio DOT was one of the first transportation organizations in the United States to pioneer the use of prestressed concrete for highway bridges. In fact,



Figure 1.2 The Patterson-Riverside, Great Miami River Bridge, Dayton, Ohio, 1954.

Ohio DOT set up its own plant for casting and prestressing concrete T-beams. More than a dozen single-span bridges were constructed using these state-manufactured, prestressed concrete beams. But it was not until the early 1960s that commercially produced, prestressed box beams were adapted to continuous construction. These first continuous, prestressed box beam bridges were also provided with embankments and stub-type abutments on flexible piles but they were not entirely jointless because rotation joints were provided at abutments. Recently, however, some fully integral, continuous, prestressed box beam bridges were built by Ohio DOT.

Two design examples serve to illustrate just how strongly Ohio DOT bridge engineers favored the use of integral bridges, and the unusual means that they were willing to consider just to avoid the use of movable deck joints in highway bridges. For instance, at some sites where the depth of overburden was not considered sufficient to provide flexible piles for integral abutment construction, bedrock has been prebored and backfilled to a suitable depth to permit the driving of end-bearing flexible piles for the abutments. At other sites, stream channel alignments have been modified so that integral bridges could be used that would not exceed the 30° skew limitation that had been established for such structures. As can be surmised by these examples, and the other practices that have been developed and adopted by Ohio DOT, Ohio bridge design engineers' primary bridge design goal has always been the avoidance of deck joints whenever practicable.

Somewhat paralleling Ohio DOT's implementation of continuous construction, other state and province transportation departments were also showing interest in similar construction. By 1987, 26 out of 30 mail responses [2, p. 20], or 87 percent of responding transportation departments, indicated that they were using continuous construction for short- and moderate-length bridges.



Figure 1.3 Long Island Bridge, Kingsport, Tennessee, 1980.

The Tennessee Department of Transportation (Tennessee DOT) now appears to be leading the way in the construction of continuous bridges. For example, the Long Island Bridge of Kingsport, Tennessee (Figure 1.3) was constructed in 1980 using 29 continuous spans without a single intermediate movable deck joint. The total length of this bridge is about 2,700 ft. (823 m) center to center of abutment bearings. Movable deck joints and movable bearings were furnished, but only at the two abutments. It has aptly been named the “Champ.”

Integral bridges

During the last half-century, many bridge engineers have become acutely aware of the relative performance of bridges built with and without movable deck joints. In this respect, bridges without such joints (integral bridges) have performed more effectively because they remain in service for longer periods of time with only moderate maintenance and occasional repairs. Some of this experience was forced upon bridge engineers by circumstances beyond their control.

As a result of the growth and pressure generated by jointed rigid pavement (see Chapter 2 and Appendix 1), many bridges built with movable deck joints have been and are being severely damaged. After these joints are closed by pavement growth, the effectively jointless bridge restrains the pavement from further growth, resulting in the generation of longitudinal pavement pressures (compressive forces) against and within the bridge. Over time, these pavement pressures can easily exceed

1000 psi (6.89 MPa) or cumulatively the total force due to such pressures can exceed 650 tons (716 tonnes) per lane of approach pavement [3]. When the design of abutments of non-integral-type bridges – bridges with movable deck joints at the superstructure/abutments interface – is considered, forces of these magnitudes are irresistible. Stub abutments subjected to such pressures have routinely been moved, joints closed, and ultimately joints and wingwalls fractured. Wall-type abutments have been split from top to bottom. In longer bridges with intermediate movable deck joints, piers have been cracked and fractured as well (see Chapter 2).

In geographical regions of the country that experience low seasonal temperatures and an abundance of snow and freezing rain, the use of de-icing chemicals to maintain dry pavements throughout the winter season has also had a significantly adverse affect on the durability and integrity of bridges built with movable deck joints. Open joints and sliding plate joints of shorter bridges and open finger joints of longer bridges have allowed roadway drainage, contaminated with de-icing chemicals, to penetrate below roadway surfaces and wash over supported beams, bearings, and bridge seats. The resulting corrosion and deterioration have been so serious that some bridges have collapsed while others have had to be closed to traffic to prevent their collapse. Many jointed bridges have required extensive repair. Most of the jointed bridges that have remained in service have required almost continuous maintenance to counteract the adverse effects of contaminated deck drainage. To help minimize or eliminate these maintenance efforts, a whole new industry was born.

Beginning in the early 1960s, the first elastomeric compression seals were installed in bridges in the United States to seal movable deck joints. Since these first installations, numerous types of elastomeric joint seals have been developed and improved in an attempt to achieve joint seal designs that would both effective and durable. Most designs have been disappointing. Many leaked. Some required more maintenance than the original bridge built without them. By and large, the many disappointments associated with various types of joint seals have caused bridge engineers to consider other options.

Costs of various types of bridges show marked differences. For two bridges built in essentially the same way, except where that one was provided with movable deck joints at the superstructure/abutment interface and the other with integral abutments, the jointed bridge was usually the more expensive. In addition, abutments of integral bridges suffered only minor damage from pavement pressure, were essentially unaffected by de-icing chemicals, and functioned for extended periods of time without appreciable maintenance or repair, whereas jointed bridges suffered major damage from de-icing chemicals and pavement pressure. Consequently, more bridge engineers began to appreciate the merits of integral bridges for short- or moderate-length bridges. Gradually, design changes were made and longer integral bridges were built and evaluated. In 1946, Ohio's initial length limitation for its continuous concrete slab bridge was 175 ft. (53.3 m). In a 1973 study of integral construction [4], four states reported that they were using integral steel bridges and 15 states were using integral concrete bridges in the 201–300 ft. (61–90.4 m) range. In a 1982 study, even longer bridges were reported.

Continuous integral bridges with steel main members have performed successfully for years in the 300-ft. [91.4-m] range in such states as North Dakota, South Dakota

and Tennessee. Continuous integral bridges with concrete main members, 500 to 800 ft. (152.4 to 243.8 m) long have been constructed in Kansas, California, Colorado, and Tennessee. [5]

As of 1987, 11 states reported building continuous integral bridges in the 300 ft. (91.4 m) range. Missouri and Tennessee reported even longer lengths. Missouri reported steel and concrete bridges in lengths of 500 and 600 ft. (152.4 and 182.9 m), respectively. Tennessee reported lengths of 400 and 800 ft. (121.9 and 243.8 m) for similar bridges. Actually, 20 of 30 transportation departments, or 60 percent of those departments responding to the 1987 survey, were *using* integral construction for continuous bridges.

The attributes of integral bridges have not been achieved without some concerns about high unit stresses. Parts of these bridges operate at very high stresses levels, levels that cannot easily be quantified. These stresses are significantly above those permitted by current design specifications. In this respect, bridge engineers have become rather pragmatic. They would rather build cheaper integral bridges and tolerate these higher stresses than build the more expensive jointed bridges with their lower stresses and concomitant vulnerability to destructive pressures and deicing-chemical deterioration. This attitude was expressed by Clelland Loveall, then Engineering Director for the Tennessee DOT. At the time he wrote:

In Tennessee DOT, a structural engineer can measure his ability by seeing how long a bridge he can design without inserting an expansion joint. ... Nearly all our newer (last twenty years) highway bridges up to several hundred ft. have been designed with no joints, even at abutments. If the structure is exceptionally long, we include joints at the abutments but only there. ... Joints and bearings are costly to buy and install. Eventually, they are likely to allow water and salt to leak down onto the superstructure and pier caps below. Many of our most costly maintenance problems originated with leaky joints. So we go to great lengths to minimize them. [6]

Tennessee DOT is still leading the bridge engineering profession in the construction of longer and longer integral bridges. Under their present Engineering Director, Edward Wasserman, Tennessee DOT recently completed the Happy Hollow Creek Bridge, a seven-span prestressed concrete curved integral bridge with a total length of over 1,175 ft. (358 m) (see the photograph at start of this chapter). As shown in this photograph, tall flexible twin circular column piers support the superstructure of this outstanding structure. A single row of steel H-piles is used to support each abutment. Although, to some engineers, the length of this structure may seem extreme, it is well within Tennessee DOT's Bridge Design Policy Statement regarding the length of integral bridges. With respect to expansion joint selection, the policy statement stipulates:

When the total anticipated movement at an abutment is less than two (2) inches [50 mm] and the abutment is not restrained against movement, no joint will be required and the superstructure and abutment beam will be constructed integrally. [7]

In 1997, six bridge engineers from the United Kingdom participated in a study tour of integral bridges in North America. This task group visited Ohio, Tennessee,

Missouri, Washington State, California, and Ontario. They also visited Construction Technology Laboratories of Skokie, Illinois, where comprehensive integral bridge research was under way. In their report of the study tour, they generalized their opinions about the performance of integral bridges inspected by the task group as follows:

Integral bridges were inspected in five States in the USA, and in Ontario, Canada. In all cases these were found to be performing well. It is important to note that, in contrast, the non-integral bridges that were seen all had leaking expansion joints, and several were deteriorating badly. The few minor problems in integral bridges that were found were all considered to be due to poor detailing. Integral construction transfers possible problems from the abutment to the approach slab and pavement.

No integral bridges were seen on the tour where the integral concept was considered to have been inappropriate. [8]

Although bridge engineers have conditioned themselves to tolerate higher stress levels in integral bridges, occasionally their design control is not sufficient to prevent these high stresses from resulting in relatively minor structural distress. In this respect, consider some of the responses to survey questions about noticeable structure distress.

Structural distress

Responses to an early survey about continuous integral bridges indicated a rather widespread concern by bridge engineers for the potentially high stresses that would be present in longer integral bridges [4]. This concern, more than any other, appeared to be responsible for the early lack of enthusiasm for using integral construction for the longer continuous bridges. Although most integral bridges perform adequately, many of them operate at high stress levels. For instance, an abutment supported on a single row of piles is considered flexible enough to accommodate thermal cycling of the superstructure and the dynamic end rotations induced by the movement of vehicular traffic. Nevertheless, the steel piles of such an abutment are routinely subjected to axial and flexural stresses approaching, equaling, or exceeding yield stresses [5, 9]. Occasionally, a combination of circumstances results in visible distress.

Responding to a 1973 survey, a number of bridge engineers said that some integral bridge abutment wingwalls had minor cracks [4]. This problem was corrected by the use of more generous wingwall reinforcement. Other engineers reported pile cap cracking, cracking that appears to have been eliminated by providing more substantial pile cap connection reinforcement and by rotating steel H-piles to place the weak axis normal to the direction of bridge movement.

In a 1984 article in *Concrete International*, Gamble [10] emphasizes the importance of considering restraint stresses in cast-in-place construction. He discusses cracking that occurred in a continuous concrete frame bridge with footings that were founded *in* bedrock. Even though the concrete of this structure was considerably below the specified cylinder strength, and shear reinforcement did not meet current requirements, failure of the structure was attributed to its stiffness and

resistance to shrinkage and contraction of its bridge deck. Failures of this type emphasize the necessity of achieving suitable flexibility in supporting substructures and conservative reinforcement to withstand the secondary stresses induced by foundation restraint and superstructure shortening.

Currently, precast prestressed concrete and prefabricated steel superstructures are generally replacing small cast-in-place bridges in many states and provinces. Consequently, problems associated with initial shrinkage of superstructures are gradually being eliminated. However, where cast-in-place construction continues to be used for substructures, flexibility remains a critical part of bridge design. In this respect, Loveall of Tennessee DOT provides an example of the lack of flexibility in substructure design:

Structural analysis of our no joint bridges indicates that we should have encountered problems, but we almost never have. Once we tied the stub of an abutment into rock, and the structure cracked near its end, but we were able to repair the bridge and install [a] joint while the bridge was under traffic. The public never knew about it. That was one of few problems. [6]

Development of new forms of construction will be accompanied by instances of structural distress, and this has certainly been true with continuous integral bridges. However, as indicated by the 1987 mail survey, the application of integral bridges increased exponentially from its beginnings in the 1930s and was beginning to taper off in the 1980s when 20 of 30, or 60 percent, of responding transportation departments were using integral bridge construction in one form or another for longer and longer bridges. Presumably, with continued care and consideration, it appears that the use of integral bridges will continue to see a gradual increase in the numbers of transportation departments adopting the integral bridge concept for routine bridge applications.

Integral bridge details

Abutment details of integral bridges used by six transportation departments, as of 1989, when the text that serves as the basis of this chapter was originally prepared, are presented in Figures 1.4 and 1.5. Presumably, the details presently used by these same departments have remained essentially the same except for minor changes in dimensions and reinforcement. What has changed in the intervening years are the numbers of other departments that have adopted standard integral details for their routine bridges. It is probably not an accident that a fair amount of similarity is evident in these designs because structural details from early successful designs are adapted and improved by other bridge engineers for use by their departments. Even though there are similarities, there are also differences that reflect the various types of bridges being built, and the care and concern being given to the conception and development of specific details. It should also be realized that these sketches are mere “bare bones” presentations. They do not reflect other important design aspects and construction procedures that should be considered in the application of these details for specific applications. All of these aspects could not be illustrated and properly described in a chapter as brief as this one. Nevertheless, because these

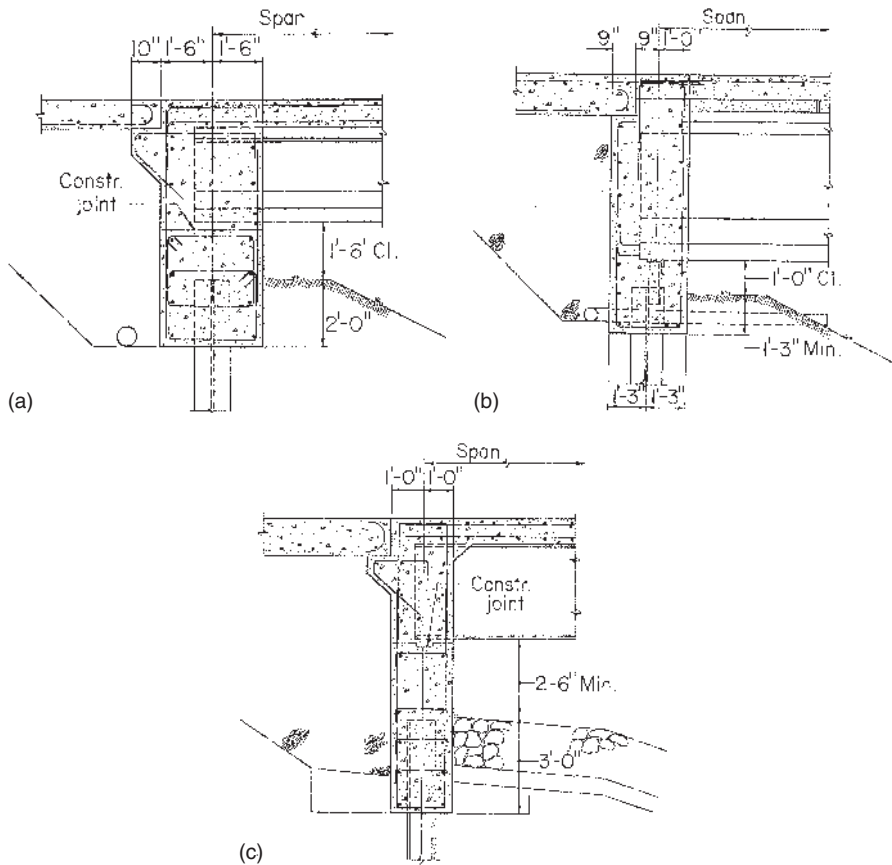


Figure 1.4 Integral abutment: (a) Iowa DOT; (b) Pennsylvania DOT; and (c) North Dakota DOT.

aspects can have a considerable effect on the performance, integrity, and durability of integral designs, it is appropriate to mention something about some of them, especially passive pressure and pile stresses, for those engineers who will be considering such designs for the very first time.

Passive pressure

To minimize passive pressure development in structure backfill by an elongating integral bridge, bridge design engineers have used a number of controls, devices and procedures. Including but not limited to the following practices, they have:

- limited bridge length
- limited bridge skew
- limited abutment type to embankment supported stubs
- provided embankment benches to minimize the length of transverse wingwalls
- limited the vertical penetration of abutments into the benches

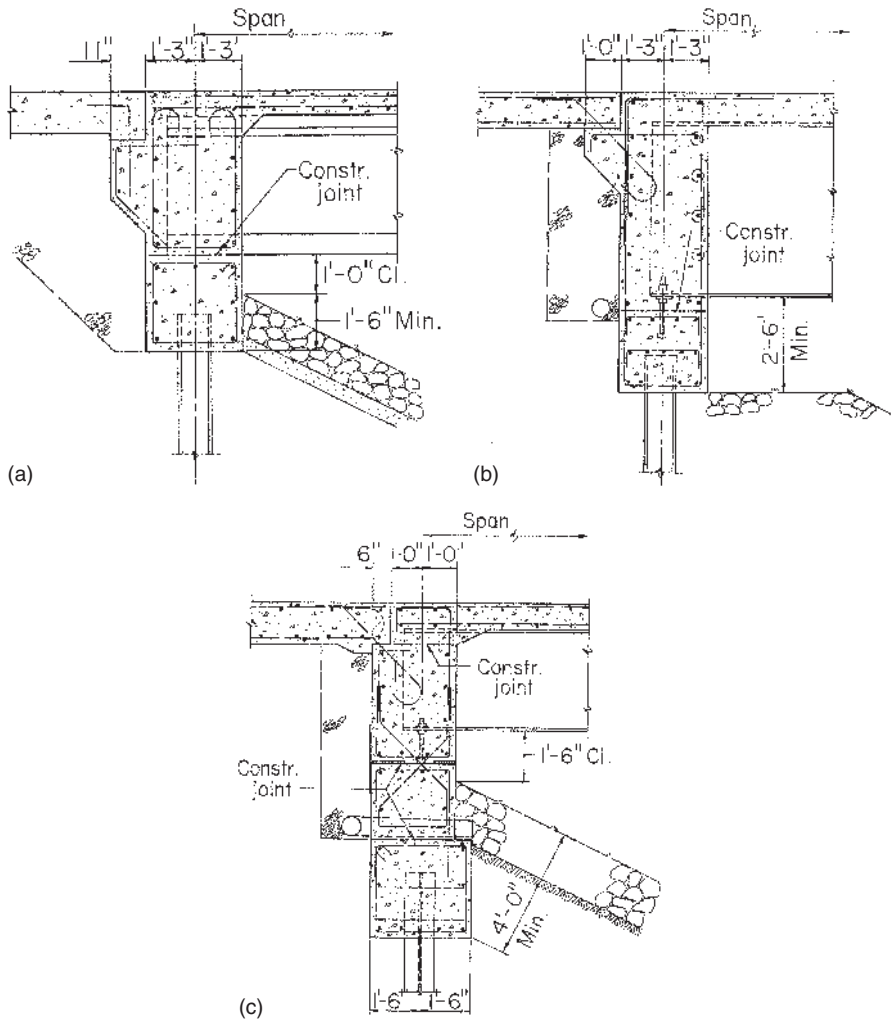


Figure 1.5 Integral abutment: (a) Illinois DOT; (b) Tennessee DOT; and (c) Ohio DOT.

- limited the clearance between the superstructure and embankment benches to make the abutment surfaces exposed to passive pressure as small as possible
- provided well-drained select granular backfill at abutments
- provided turn-back wingwalls to minimize total longitudinal pressure on the abutments
- provided approach slabs to prevent live load surcharging of backfill, and to minimize vehicular compaction of backfill.
- provided approach slabs with curbs adjacent to curbed bridges to protect backfill from erosion
- used a semi-integral abutment design to eliminate passive pressure below the bridge seat and permit the use of a semi-rigid foundation design (Figure 1.6).

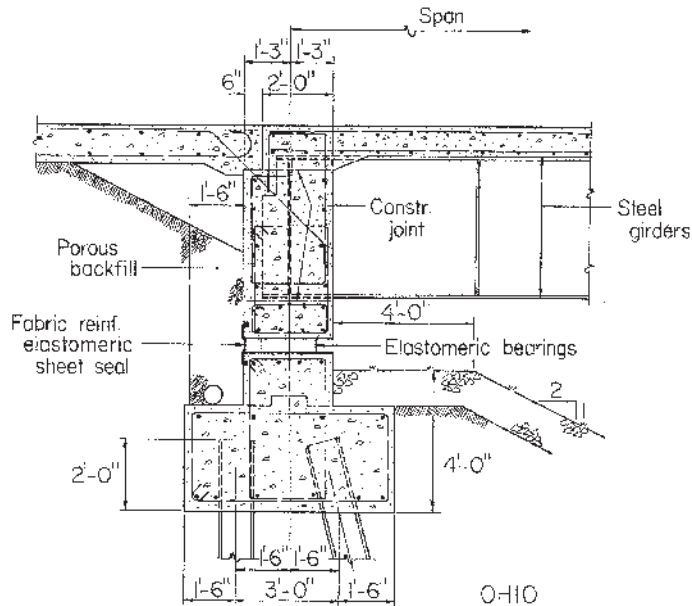


Figure 1.6 Ohio DOT's first semi-integral abutment (1979).

Pile stresses

Knowing that longitudinal forces on superstructures are somewhat directly related to the resistance of abutment pile foundations to longitudinal movement, design engineers have:

- provided each abutment foundation with a single row of slender vertical piles
- provided only those pile types that could tolerate a considerable amount of distortion without failure; in this respect, it has shown that steel H-piles are the most suitable pile type for longer integral bridge applications [11]
- oriented the weak axis of H-piles normal to the direction of pile flexure
- provided prebored holes filled with granular material
- provided an abutment hinge (see Figure 1.5c) to minimize pile flexure
- limited the length of the structure to minimize pile flexure
- limited structure skew angle
- provided semi-integral abutments to minimize restraint on superstructures due to longitudinal movement.

Questionnaires

A number of questionnaires about integral bridge practices have been circulated in recent years. The responses reflect the policies, attitudes, and opinions of those engineers responsible for bridge design policies. They also show how some of these attitudes and opinions have changed during the last couple of decades. In 1973, Emanuel *et al.* [4] received responses about the then current design practices from

43 transportation departments. In 1982, Wolde-Tinsae *et al.* [5] used a questionnaire as part of an investigation into non-linear pile behavior. They tabulated the responses that they received from 29 transportation departments. Greimann *et al.* [12] elicited responses from 30 transportation departments on their pile orientation practices for skewed integral bridges. In 1987, Wolde-Tinsae and Klinger [13] solicited responses from selected transportation departments in the United States, Canada, Australia, and New Zealand. (The reports by Wolde-Tinsae *et al.* [5], Greimann *et al.* [12], and Wolde-Tinsae and Klinger [13] also contain valuable bibliographies for those interested in a more in-depth study of available research on the behavior of integral bridges and the performance of abutment pilings.) In addition, In 1988, the author received responses from 30 transportation departments describing the limitations that these departments used to control the behavior and performance of the integral bridges designed and constructed by them [2].

Integral conversions

Following the trend toward the use of end-jointed continuous construction and the use of jointless continuous construction, transportation departments are also beginning to convert existing multiple-span bridges from simple to continuous spans. This effort began with Wisconsin and Massachusetts DOTs in the 1960s and has gathered strength in the last several decades. Currently, more than 30 percent of the transportation departments have converted one or more bridges from multiple simple spans to continuous spans. Although the 1988 mail survey suggested considerable activity, it was not indicative of the number of bridges that had been converted. For example, positive responses were received from only two departments to the following question: "In recent years, have you converted any bridges from multiple simple spans to continuous spans to eliminate deck joints?" The Ontario Ministry of Transportation and Communications responded:

We are modifying a few structures from simple spans to continuous spans, eliminating deck joints in the process. ...[2, p. 27]

The Texas Department of Public Transportation (DPT) responded:

In recent years, we have eliminated numerous intermediate joints. Generally, this is done while replacing the slab. We simply place the slab continuous across the beams. On a few occasions, we have removed only the joint and surrounding deck area, added reinforcement, and replaced that portion of the deck thus tying the adjacent spans together. [2, p. 27]

Tennessee DOT also has been actively converting simple-span bridges. In a paper on jointless bridges, Edward Wasserman, Engineering Director of Structures, described and illustrated a number of such conversions [14]. To give this movement some direction, in 1980, the Federal Highway Administration (FHWA) issued a technical advisory on the subject [15]. That advisory in part recommends that a study of the bridge layout and existing movable deck joints be made "to determine which joints can be eliminated and what modifications are necessary to

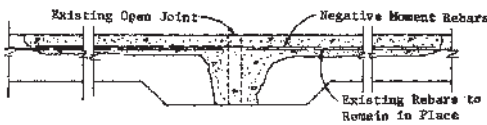
revamp those that remain to provide an adequate functional system. ...” Further, it recommends:

For unrestrained abutments, a fixed integral condition can be developed full length of shorter bridges. An unrestrained abutment is assumed to be one that is free to rotate, such as a stub abutment on one row of piles or an abutment hinged at the footing. ... [W]here feasible, develop continuity in the deck slab. Remove concrete as necessary to eliminate existing armoring, and add negative moment steel at the level of existing top-deck steel sufficient to resist transverse cracking. [15]

The detail in Figure 1.7a from the FHWA *Technical Advisory* mirrors the details used by the Texas Department of Public Transportation (Texas DPT) for its conversion of multiple simple spans to continuous spans. Note that Figure 1.7a shows that only the slab portion of the deck is made continuous. The simply supported beams remain simply supported. For such construction, it is important to ensure that one or both of adjacent bearings supporting the beams at a joint are capable of allowing

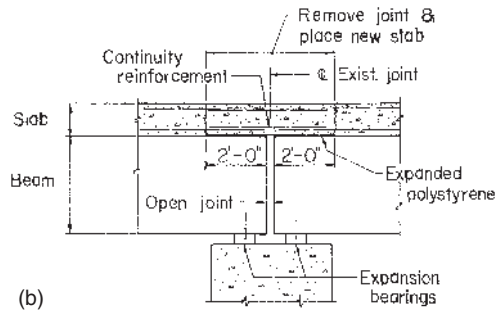
Conversion of Open Joints - When rehabilitation of an existing open joint is considered, the following suggestions should be evaluated.

Fixed Option - Where feasible, develop continuity in deck slab.

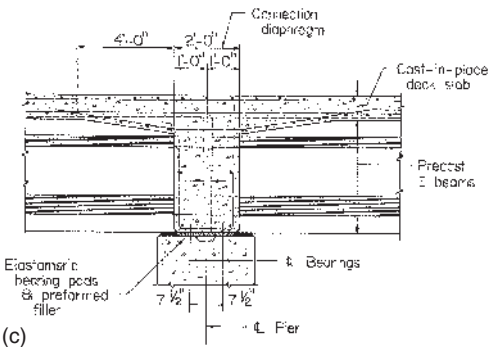


Remove concrete as necessary to eliminate existing armoring, and add negative moment steel at the level of existing top-deck steel sufficient to resist transverse cracking. Generally reconstruct with regular concrete to original grade.

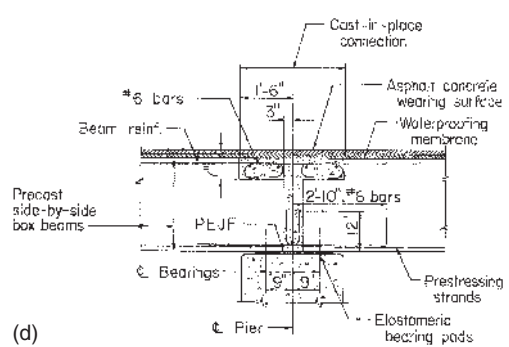
(a)



(b)



(c)



(d)

Figure 1.7 (a) Integral conversion at piers, Texas DPT (copied from the FHWA *Technical Advisory* [15]); (b) integral conversion of existing beams at piers, Utah DOT; (c) integral conversion of precast I-beams at piers during original construction, Wisconsin DOT; and (d) integral conversion of prestressed box beams at piers during original construction, Ohio DOT.

horizontal movement. Providing for such movement will prevent large horizontal forces from being imposed on bearings due to rotation of adjacent spans and continuity of the deck slab.

Utah DOT has also converted some simple span bridges to continuous spans by using a design similar to the one illustrated in Figure 1.7b. For deck slabs with a bituminous overlay, an elastomeric type of membrane can be used under the overlay to waterproof the new slab section over the piers. With a design like this, it is understood that the deck slab would be exposed to longitudinal flexure due to the rotation of beam ends responding to the movement of vehicular traffic. However, for short- and medium-span bridges, the deck cracking associated with such behavior is preferred by some over the long-term adverse consequences associated with open movable deck joints or a poorly executed joint seals.

In new construction, the conversion of simple spans to continuous spans is rather commonplace. Figure 1.7c shows the detail used by Wisconsin DOT for the construction of prestressed concrete I-beam bridges. A substantial concrete diaphragm is provided at piers between the ends of the simply supported beams of adjacent spans. The diaphragm extends transversely for the width of the superstructure. Then a continuous reinforced concrete deck slab is placed to integrate the beams, diaphragms, and slab, thereby providing a fully composite continuous superstructure. This type of prestressed concrete I-beam construction now appears to be standard for many transportation departments.

Figure 1.7d illustrates the standard detail used by Ohio DOT to achieve continuous bridges by using simply supported, prestressed concrete box beams with continuity connections at the piers. Boxes are placed side by side and then transversely bolted together. Finally, continuity reinforcement is placed and reinforced concrete closure placements are made.

In a 1969 paper, Freyermuth [16] gives a rather complete description of the analysis procedures that can be used to achieve continuity in a bridge composed of a continuously reinforced concrete deck slab on simply supported, precast, prestressed beams. Conversion of existing bridges, by replacing either the deck completely or only portions of the deck adjacent to movable deck joints at piers, can be accomplished by following the procedures developed by Freyermuth for new structures. Obviously, for existing bridges, creep effects will be negligible. Shrinkage effects for other than complete deck slab replacements should also be negligible. Not only does such continuous conversion eliminate troublesome joints, but the continuity achieved also results in a slightly higher bridge load capacity because positive moments due to live load are reduced by continuous rather than simple span behavior.

Although too recent to consider in terms of a design trend, conversion of non-integral abutments to achieve integral bridges or semi-integral bridges for both single- and multiple-span continuous bridges has begun. Figures 1.8–1.10 illustrate design details used for a number of conversions by Ohio DOT. Reconstruction of these abutments was made necessary by the substantial damage caused by pavement growth and pressure, by de-icing chemical deterioration, or both. Instead of replacing backwalls and joints, and in some cases bearings and bridge seats as well, it was decided to pattern reconstruction after the design details used by the department for its new integral and semi-integral bridges. In this way subsequent concern about

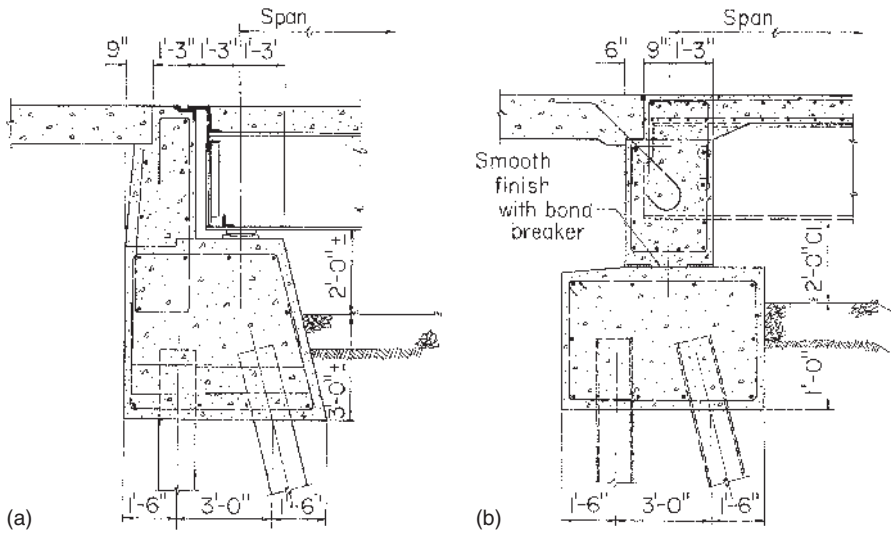


Figure 1.8 Conversion of a very short continuous bridge with movable deck joints at the superstructure/abutment interface (a), into a continuous bridge with integral abutments (b), Ohio DOT.

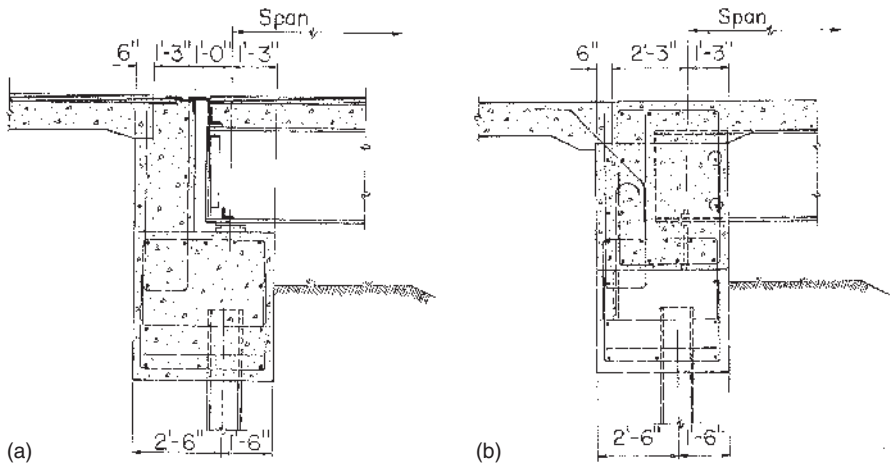


Figure 1.9 Conversion of a continuous bridge with movable deck joints at the superstructure/abutment interface (a), to a continuous bridge with integral abutments (b), Ohio DOT.

the adverse effects of pavement pressure and de-icing chemical deterioration were minimized.

When considering the design trends toward integral types of construction, it should not be surprising to learn that a number of transportation departments have also begun to retrofit steel beam and girder bridges constructed with intermediate movable deck joints with hinges into fully continuous structures. Conversion of

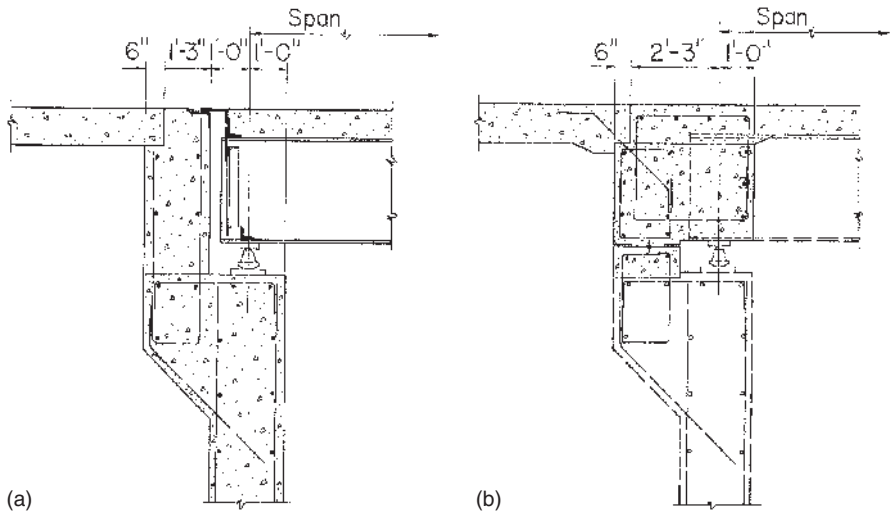


Figure 1.10 Conversion of single- or multiple-span continuous bridges with movable deck joints at the superstructure/wall-type abutment interface (a), into single- or multiple-span continuous semi-integral bridges (b), Ohio DOT.

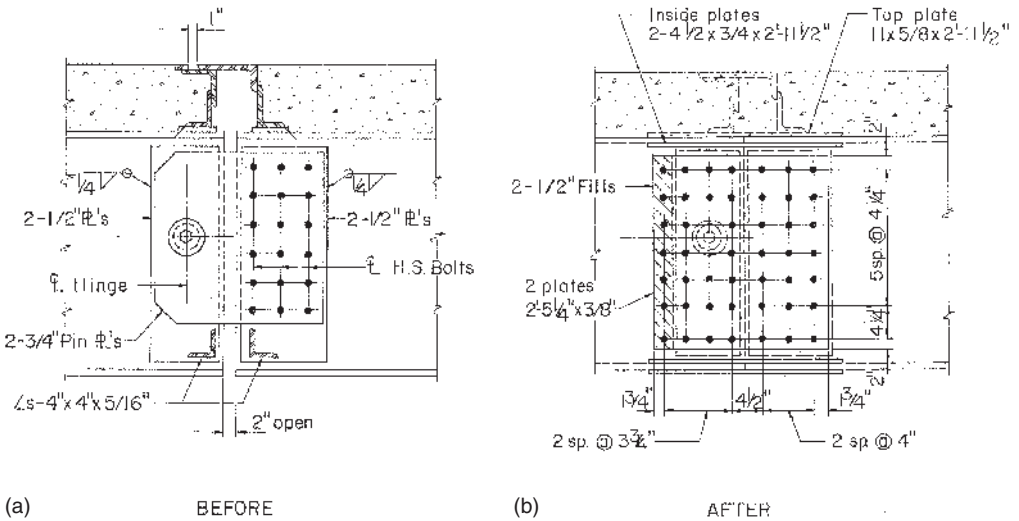


Figure 1.11 Conversion of multiple-span continuous bridges with intermediate deck joints and hinges (a), into continuous bridges with bolted splices (b), Ohio DOT.

these structures is being accomplished by replacing the hinges and leaking joints with bolted splices and continuous deck slabs (Figure 1.11). These joints and hinges were originally intended to accommodate long-term abutment settlement. But as these structures are now more than 20–30 years old, and as embankments are now essentially fully consolidated, the need for these movement systems no longer exists. However, where such labor-intensive conversions are not fully cost-effective, some

of these jointed superstructures are being completely replaced with fully continuous superstructures with integral abutments.

Finally, within the last two decades, Ohio DOT has converted many of its continuous bridges with movable deck joints at the superstructure/abutment interface by completely replacing independent semi-rigid stub abutments (see Figure 1.8a) with integrated flexible stub abutments (see Chapter 7, Figure 7.7). Presumably, this same rehabilitation technique is now being used by many other transportation departments throughout the United States. However, the number of such retrofitted structures is probably greater in Ohio because most of Ohio's old multiple-span bridges were originally constructed as continuous bridges. In fact, one would be hard pressed to find a multiple-span bridge in Ohio that was not of continuous construction. These are the bridges that are now being converted in record numbers to fully integrated construction.

Summary

As the trends noted above continue, it appears that the use of continuous construction for multiple-span bridges will become standard for all transportation departments in the very near future. It also appears that the use of integral abutments for single- and multiple-span continuous bridges will increase when comprehensive and conservative guidelines for their use become more readily available, and when their long-term performance has been more fully documented.

Presumably, the next decade or two will see a burgeoning in the retrofitting of simply supported multiple-span bridges to continuous bridges and from non-integral to integral bridges. When more information on the operating stress levels for these structures is developed and when more fully described design details and construction procedures for integral conversions become available, bridge engineers will be able to more fully justify their consideration. Until then, much intuition and prudent judgment will continue to be used to ensure that integral construction and conversion techniques will provide the structure service life needed to justify their adoption and continued use.

Epilogue

As a preliminary to the 2005 FHWA Conference on Integral Abutments and Jointless Bridges, a nation-wide survey was conducted of all major transportation departments of the United States. This survey posed various questions regarding the use of integral and semi-integral bridges. With respect to the number of these structures that have been employed, the following summary statement was made:

The survey responses indicate an increase in the number of integral [bridges] of over 200% in the last ten years. As in 1995, Tennessee continues to have over 2000 integral ... bridges, but Missouri reports having 4000 integral ... bridges, which represents the largest amount of integral bridges. An increase in the number of integral [bridges], since 1995, is most evident in the northern states where Illinois, Kansas and Washington all reported having

over 1000 in service. In addition, Michigan, Minnesota, New Hampshire, North Dakota, South Dakota, Oregon, Wyoming and Wisconsin, reported having between 100–500 integral bridges in service. Unlike the northern states, the southern states like Florida, Alabama and Texas do not use integral [bridges] and reported having one or [no] integral [bridges]. [17]

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