

Integral Bridges

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In the United States and Canada, integrated bridge construction is becoming one of the bridge engineer's primary responses to joint-related bridge damage caused by the use of deicing chemicals and the restrained growth of rigid pavements. The relative success that has been experienced with integral bridges—bridges without deck joints—is now being reflected not only in the increasing number of longer integral bridges, but also in the integral conversion of existing jointed bridges. It appears that the initial success of such techniques would be an accelerated use of integrated conversion as an effective alternative to bridge joint rehabilitation.

Integral bridge construction may be defined as the practice of constructing bridges without deck joints. When such construction is used to eliminate intermediate joints in multiple-span bridges, it is accepted that the continuity achieved by such construction will subject superstructures to secondary stresses. These stresses are caused by the response of continuous superstructures to thermal and moisture changes and gradients, settlement of substructures, posttensioning, and so on. When such construction is used to eliminate deck joints at abutments, it is likewise accepted that such structures will, in addition, be subjected to secondary stresses due to restraint provided by abutment foundations and backfill against the cyclic movement of bridge superstructures. The justification for such construction is based on the recognition that for short- and medium-span bridges of moderate lengths, significantly more damage and distress has been caused by the use of deck joints than by the secondary stresses these joints were intended to prevent. In addition, elimination of costly joints and bearings and the details and procedures necessary to permit their use generally results in more economical bridges. Consequently, more bridge engineers are now willing to relinquish some of their control of secondary stresses primarily to achieve simpler and less expensive bridges with greater overall integrity and durability.

CONTINUOUS SUPERSTRUCTURES

Current design trends received their primary impetus and direction almost six decades ago. In May 1930, a brief 10-page paper (1) published in the *Proceedings of the American Society of Civil Engineers* generated considerable discussion in academia. It also created a minor revolution in the design and construction of short- and medium-span bridges. In this paper, Cross presented a simple and quick method for the analysis of integral-type structures such as continuous beams and frames. The method was quickly adopted by bridge engineers, and the bridge practices of many transportation depart-

ments began to change. Before Cross' "moment distribution," multiple-span bridges were generally constructed as a series of simple spans. Following the introduction of moment distribution, bridge engineers began eliminating troublesome deck joints at piers by providing continuous superstructures.

On the basis of a recent mail survey (2), it appears that the Ohio Department of Transportation was one of the first agencies to initiate the routine use of continuous construction (Figure 1). Its experience provides an informative background for this movement toward the use of fully integrated continuous construction. At first, riveted field splices were used to integrate adjacent spans and achieve full continuity for steel stringer bridges. By 1934, the department had devised its first butt-welded field splice. Following this first tentative application, the welded field splice was continuously improved and used almost exclusively for more than 30 years for the erection of steel stringer bridges. In the late 1950s, high-strength bolted field splices were adopted for the Patterson-Riverside Bridge at Dayton, Ohio, one of the first bridge applications for high-strength bolting in the United States. By 1963, high-strength bolting replaced field butt welding in Ohio as the method of choice for integrating multiple-span steel bridges to achieve full continuity. Consequently, by riveting, field welding, and high-strength bolting, Ohio has employed continuous construction almost exclusively on multiple-span steel bridges for close to 50 years. Because continuity can be achieved more readily with cast-in-place concrete, Ohio has been building continuous concrete bridges for close to 60 years.

Figure 1 shows the beginning of the routine use of continuous construction in the United States and Canada and the per-decade increase in the number of transportation departments that have adopted the use of continuous construction. As shown in Figure 1, 26 of 30 departments responding to the recent mail survey (2), or 87 percent of responding departments, now routinely use continuous construction for short- and medium-span bridges.

Currently the state of Tennessee appears to be leading the way in constructing long continuous bridges. For example, the Long Island Bridge at Kingsport was constructed in 1980 by using 29 continuous spans without a single intermediate joint. The total length of this bridge is about 2,700 ft center to center of abutment bearings. Deck joints and movable bearings have been furnished, but only at the two abutments. It has been aptly named "The Champ."

INTEGRAL BRIDGES

During the past two to three decades, many bridge engineers have become acutely aware of the relative performance of bridges built with deck joints at abutments and those built without them. In most respects, bridges without joints—inte-

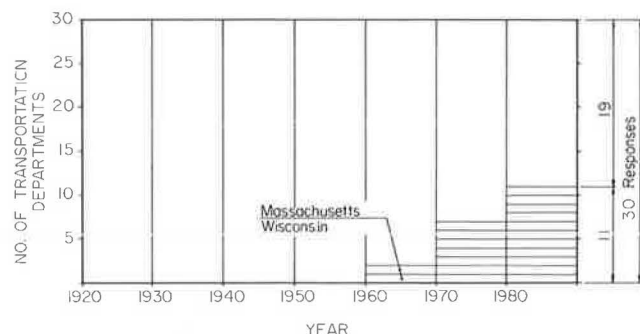


FIGURE 1 Design trends for continuous bridges: early conversion of simple spans to continuous spans.

gral 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.

Because of the growth and pressure generated by jointed rigid pavement, many bridges built with deck joints at abutments have been and are being severely damaged. After deck joints are closed by pavement growth, bridge decks are squeezed by the generation of pavement pressures. These pavement pressures can easily exceed 1,000 psi or cumulatively the total force due to such pressures can exceed 650 tons per lane of approach pavement (3). When the design of abutments for nonintegral-type bridges—bridges with deck joints at abutments—is considered, the forces of these magnitudes are irresistible. Many abutment backwalls have been fractured. Other abutments have been split from top to bottom. In longer bridges with intermediate deck joints, piers have been cracked and fractured as well.

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

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

Costs of various types of bridges showed marked differences. For two bridges built essentially the same except that one was provided with separate abutments and deck joints and the other was provided with integral abutments, the jointed bridge was usually more expensive. In addition, bridges with integral abutments suffered only minor damage from pavement pressure, were essentially unaffected by deicing chemicals, and functioned for extended periods without appreciable maintenance or repair. Consequently, more bridge engineers began to appreciate the merits of integral bridges for short to moderate bridge lengths. Gradually, design changes were made and longer integral bridges were built and evaluated. In 1946 Ohio's initial length limitation for its standard continuous concrete slab bridges was 175 ft. In a 1973 study of integral construction (4), 4 states responded that they were using steel bridges and 15 states that they were using concrete bridges in the 201- to 300-ft range. In a 1982 study (5), even longer bridges were reported:

Continuous steel bridges with integral abutments have performed successfully for years in the 300-foot range in such states as North Dakota, South Dakota, and Tennessee. Continuous concrete structures, 500 to 600 ft long with integral abutments have been constructed in Kansas, California, Colorado, and Tennessee.

Currently, 11 states are building continuous bridges with integral abutments in the 300-ft range. Missouri and Tennessee report even longer lengths. Missouri reports steel and concrete bridges in lengths of 500 and 600 ft, respectively, and Tennessee reports lengths of 400 and 800 ft for similar bridges. Finally, Figure 2 shows that 20 of 30 transportation departments, or 60 percent of those responding to the survey, are now using integral construction for continuous bridges.

The attributes of integral bridges have not been achieved without cost. Parts of these bridges operate at very high stresses, stresses 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 vulnerability to destructive pavement pressures and deicing chemical deterioration. In 1985, Loveall, then Engineering Director for the Tennessee

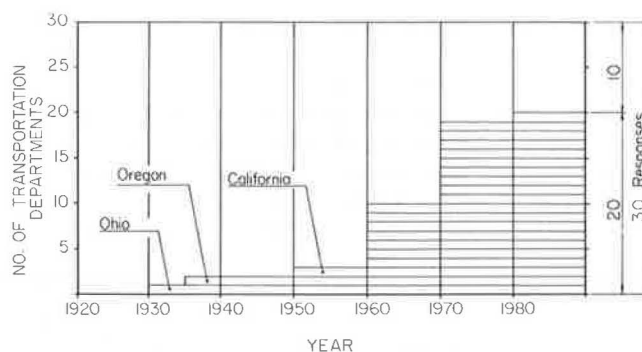


FIGURE 2 Design trends for continuous bridges: early use of integral abutments.

Department of Transportation, reflected this attitude when he wrote (6):

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 20 years) highway bridges up to several hundred ft have been designed with no joints, even at the abutments. If the structure is exceptionally long, we include joints at the abutment 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.

Even though 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 structural distress and structural fracture.

STRUCTURAL DISTRESS

Responses to an early survey about construction of continuous bridges with integral abutments indicated a rather widespread concern by bridge engineers for the potentially high stresses that would be present in longer bridges (4). This concern, more than any other, appeared to be responsible for the early lack of enthusiasm for using integral abutments for longer continuous bridges. Although the majority of bridges with integral abutments 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 longitudinal thermal cycling of the superstructure and 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 (5,7). Occasionally, a combination of circumstances results in visible distress.

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

In a recent article in *Concrete International*, Gamble (8) emphasizes the importance of considering restraint stresses in cast-in-place construction. He discusses cracking that occurred in a continuous concrete frame bridge. Even though concrete in 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 the bridge deck. Failures of this type emphasize the necessity of achieving flexibility in substructure design and conservative reinforcement to withstand secondary stresses induced by foundation restraint and superstructure shortening.

Currently, precast concrete or prefabricated steel superstructures are generally replacing small cast-in-place bridges in many states and provinces. Consequently, problems associated with initial shrinkage are gradually being eliminated.

However, where cast-in-place construction continues to be used, flexibility of substructures remains a critical part of bridge design. For example, Loveall said (6):

Structural analysis of our no joint bridges indicates that we should have encountered problems, but we almost never have. Once we tied the stub abutment of a bridge 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.

Development of new forms of construction will be accompanied by instances of structural distress, and this has certainly been true for continuous bridges with integral abutments. However, as shown in Figure 2, the increased use of integral abutments suggests that 60 percent of transportation departments are satisfied with the performance of integral construction and are using such construction in one form or another for longer and longer bridges. With continued care and consideration, the trend shown in Figure 2 will no doubt continue.

INTEGRAL BRIDGE DETAILS

Figures 3–8 show integral abutment details used by six transportation departments. It is probably not accidental that a fair amount of similarity is evident in these designs, because structural details from early successful designs are adapted by other bridge engineers for use by their departments. Even though there are similarities, there are also differences, which reflect the types of bridges being built and the care and concern being given to the choice and development of specific details. It should also be realized that these sketches are “bare bones” presentations. They do not reflect other important design aspects such as skew and construction procedures, which are considered in the application of these details for specific bridges. These aspects cannot be illustrated and properly described in a paper as brief as this one. Nevertheless, because these aspects can have a considerable effect on the performance, integrity, and durability of integral designs, it is appropriate to mention at least passive pressure and pile stresses for those engineers considering such designs for the first time.

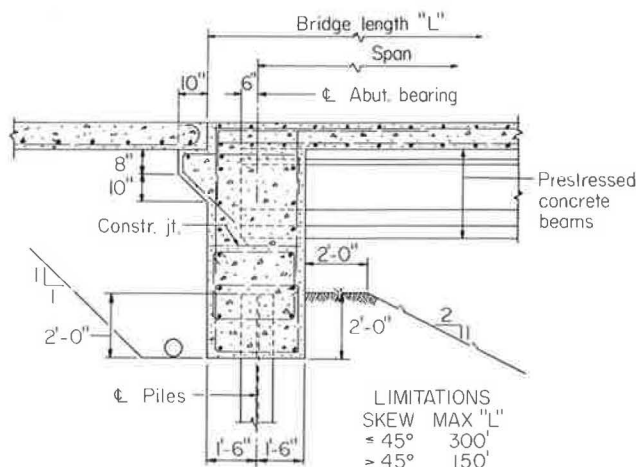


FIGURE 3 Integral abutments: Iowa.

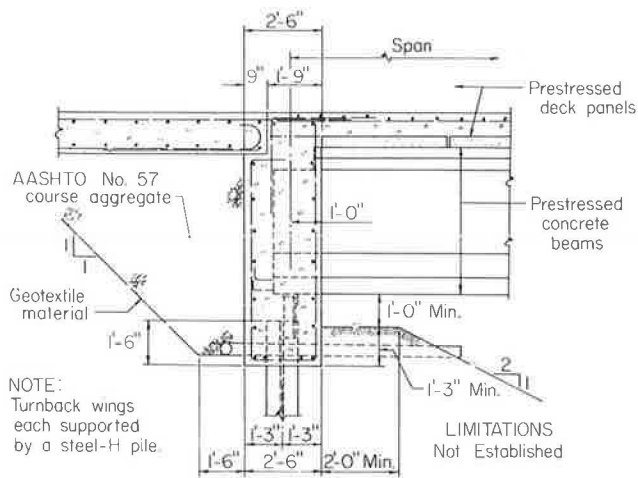


FIGURE 4 Integral abutments: Pennsylvania.

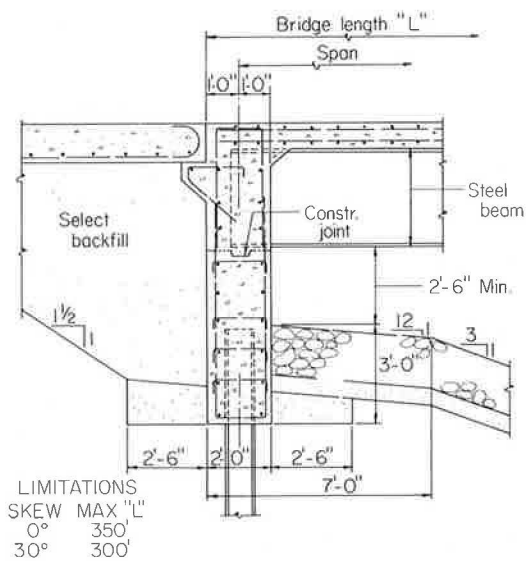


FIGURE 5 Integral abutments: North Dakota.

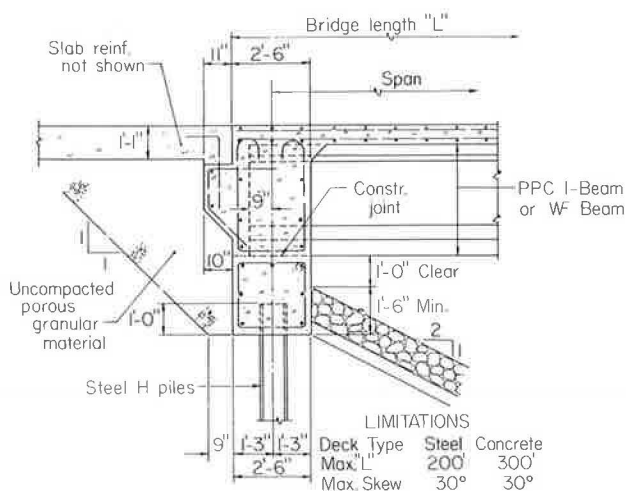


FIGURE 6 Integral abutments: Illinois.

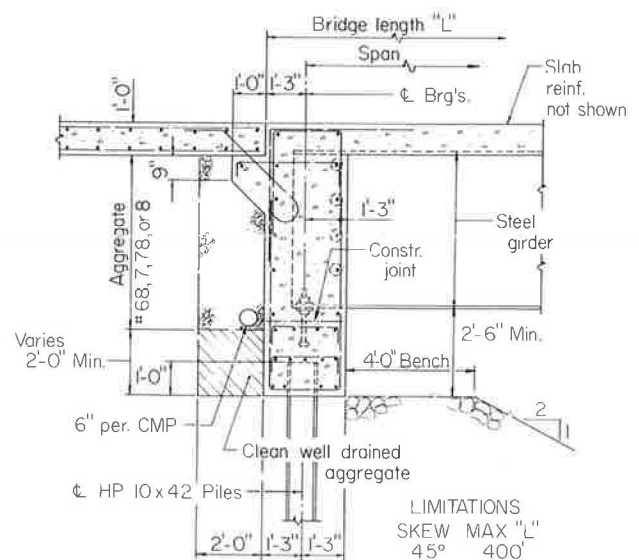


FIGURE 7 Integral abutments: Tennessee.

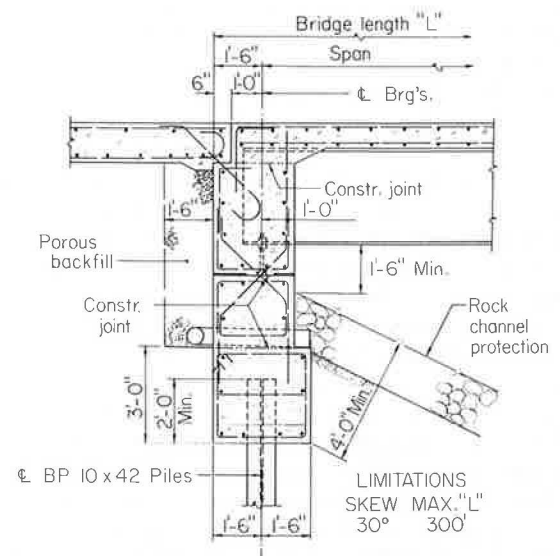


FIGURE 8 Integral abutments: Ohio.

Passive Pressure

To minimize the passive pressure developed in abutment backfill by an expanding integral bridge, design engineers have used a number of controls, devices, and procedures. Including but not limited to the following, they have (a) limited bridge length, structure skew, and the vertical penetration of abutments into embankments; (b) used select granular backfill and uncompact backfill; (c) provided approach slabs to prevent vehicular compaction of backfill or to permit the use of backfill voids behind abutments; (d) used embankment benches to shorten wingwalls and used suspended turn-back wingwalls; and (e) used semiintegral abutment designs (Figure 4) to eliminate passive pressure below bridge seats.

Pile Stresses

Knowing that longitudinal forces in superstructures are somewhat directly related to the resistance of abutment pile foundations to longitudinal movement, design engineers have (a) limited the foundation of integral bridges to a single row of slender vertical piles, (b) limited the pile types, (c) oriented the weak axis of H-piles normal to the direction of movement, (d) used prebored holes filled with fine granular material for piles, (e) provided an abutment hinge to control pile flexure, (f) limited structure skew, and (g) used semiintegral abutment designs for longer bridges (Figure 9) to minimize foundation restraint to longitudinal movement.

Surveys

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 those attitudes and opinions have changed during the last decade. In 1973, Emanuel et al. (4) received responses about their current design practices from 43 transportation departments. In 1982, Wolde-Tinsae et al. (5) used a questionnaire as part of an investigation into nonlinear pile behavior. Responses from 29 transportation departments were presented in tabular form. In 1983, Greimann et al. (9) elicited responses from 30 transportation departments on their pile orientation practices for skewed integral bridges. In 1987, Wolde-Tinsae and Klinger (10) solicited responses from selected transportation departments in the United States, Canada, Australia, and New Zealand. (The reports by Wolde-Tinsae et al., Greimann et al., and Wolde-Tinsae and Klinger also contain valuable bibliographies for those interested in a more in-depth study of current research on behavior of integral bridges and performance of abutment pilings.) Last, in 1987 the author received responses from 30 transportation departments describing the limitations that these departments use

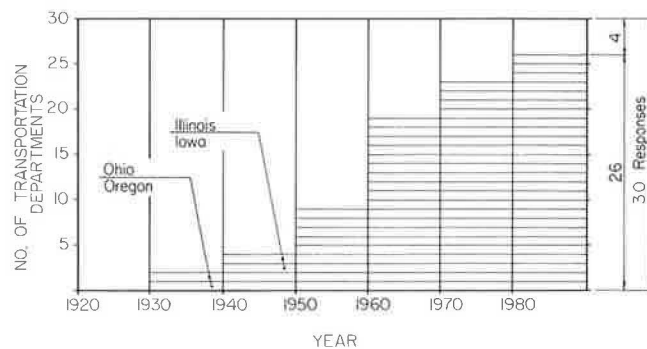


FIGURE 10 Design trends for continuous bridges: routine use of continuous construction.

to control the behavior and performance of integral bridges (2).

INTEGRAL CONVERSIONS (RETROFITTING)

Following the trend toward the use of continuous construction and the use of integral abutments, as shown in Figures 1 and 2, transportation departments are also beginning to convert existing multiple-span bridges from simple to continuous spans. Figure 10 shows that this effort began with Wisconsin and Massachusetts in the 1960s and has gathered strength in the past two decades. Currently 11 of 30 departments, or about 30 percent of the transportation departments, have converted one or more bridges from multiple simple spans to continuous spans.

Although the chart in Figure 10 suggests considerable activity, it actually shows only the relative number of departments that have made such conversions. It is not indicative of the number of bridges that have been converted. For example, positive responses were received from only two departments in response to the following question (2): "In recent years, have you converted any bridges from multiple simple spans to continuous spans to eliminate intermediate deck joints?" The Ontario Ministry of Transportation and Communications responded:

We are modifying a few structures from simple spans to continuous spans, eliminating the intermediate deck joints in the process. . . .

The Texas Department of Highways and Public Transportation 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 bents. On a few occasions, we have removed only the joint and surrounding deck area, added reinforcing, and replaced that portion of the deck thus tying the adjacent spans together.

The Tennessee Department of Transportation also has been actively converting simple span bridges to continuous spans. In a recent paper, Wasserman, Engineering Director of Structures at the Tennessee Department of Transportation describes and illustrates a number of such conversions (11).

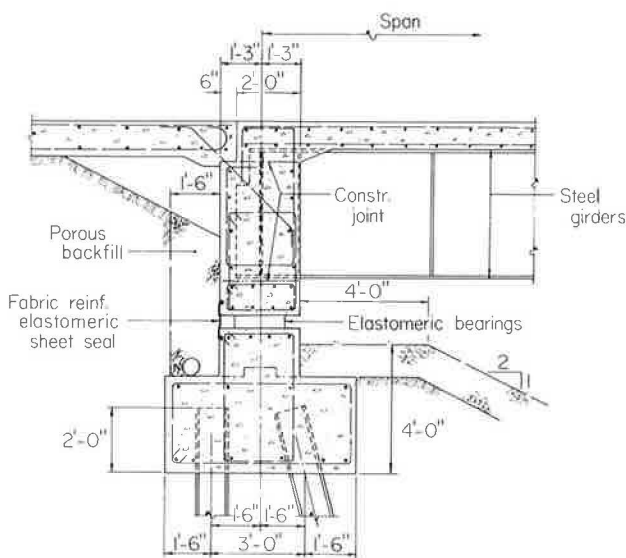


FIGURE 9 Semiintegral abutment details: Ohio.

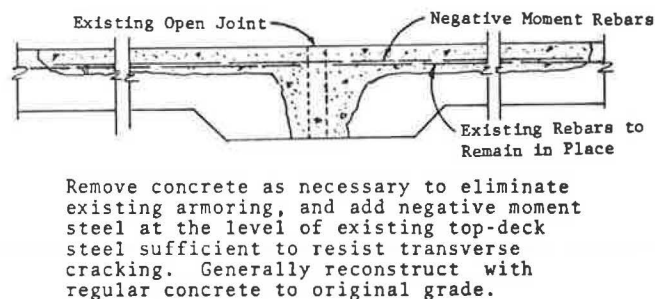


FIGURE 11 Integral conversions at piers: Texas.

To give this movement some direction, the Federal Highway Administration has issued a Technical Advisory on the subject (12). That advisory in part recommends that a study of the bridge layout and existing 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. . . ." For unrestrained abutments,

a fixed integral condition can be developed full length of the 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 [Figure 11].

The detail shown in Figure 11 reflects the procedure described by Texas. Note that the detail shows that only the slab portion of the deck is being 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 horizontal movement. Providing for such movement will prevent horizontal forces from being imposed on bearings from rotation of the beams and slab continuity.

The state of Utah also has converted some simple span bridges to continuous ones by using a design similar to the one shown in Figure 12. For deck slabs with a bituminous overlay, a membrane can be used to waterproof the new slab section over piers. With a design like this, it is understood that the deck slab would be exposed to longitudinal flexure from rotation of the beam ends responding to the movement

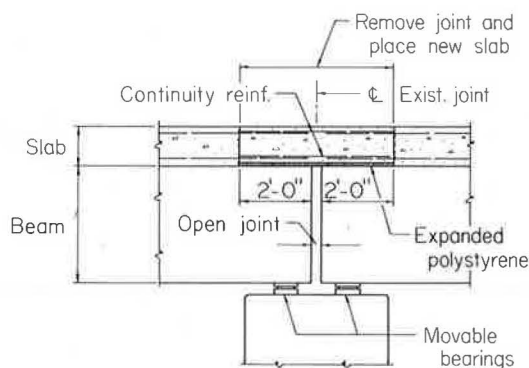


FIGURE 12 Integral conversions at piers: Utah.

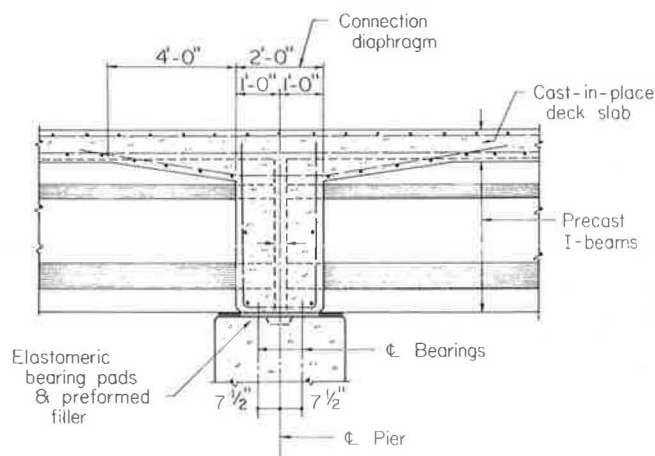


FIGURE 13 Integral conversions at piers: Wisconsin.

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 an open joint or a poorly executed sealed joint.

In new construction, conversion of simple spans to continuous spans is rather commonplace. Figure 13 shows the design detail used in Wisconsin for prestressed I-beam bridges. A substantial concrete diaphragm is placed at piers between the ends of simply supported prestressed beams of adjacent spans. It extends transversely between parallel beam lines. Then a reinforced concrete deck slab is placed to integrate the beams and deck slab, thereby providing a fully composite continuous structure. This type of prestressed I-beam construction appears to be standard for many transportation departments.

Figure 14 shows the standard design detail used by the state of Ohio to achieve continuity for simply supported prestressed box beams. These box beams are placed side by side and then transversely bolted together. Finally, continuity reinforcement is placed and the concrete closure placement is made.

In a 1969 paper, Freyermuth (13) gives a rather complete description of the considerations necessary to achieve continuity in a bridge composed of a continuously reinforced concrete deck slab on simply supported precast prestressed beams.

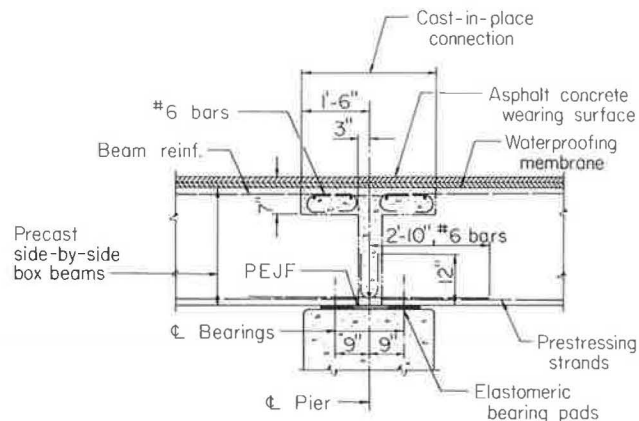


FIGURE 14 Integral conversions at piers: Ohio.

Conversion of existing bridges either by replacing the deck completely or by replacing portions of the deck adjacent to deck joints over piers can be accomplished by following the procedures developed 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 deck joints, the continuity achieved also results in a slightly higher bridge load capacity because pos-

itive moments due to live load are reduced by continuous rather than simple beam behavior.

Although too recent to consider in terms of a design trend, conversion of nonintegral to integral or semiintegral abutments for both single- and multiple-span bridges has begun. Figures 15 and 16 give design details used for a number of recent conversions by the Ohio Department of Transportation. Reconstruction of these abutments was made necessary by the substantial damage induced by pavement growth and

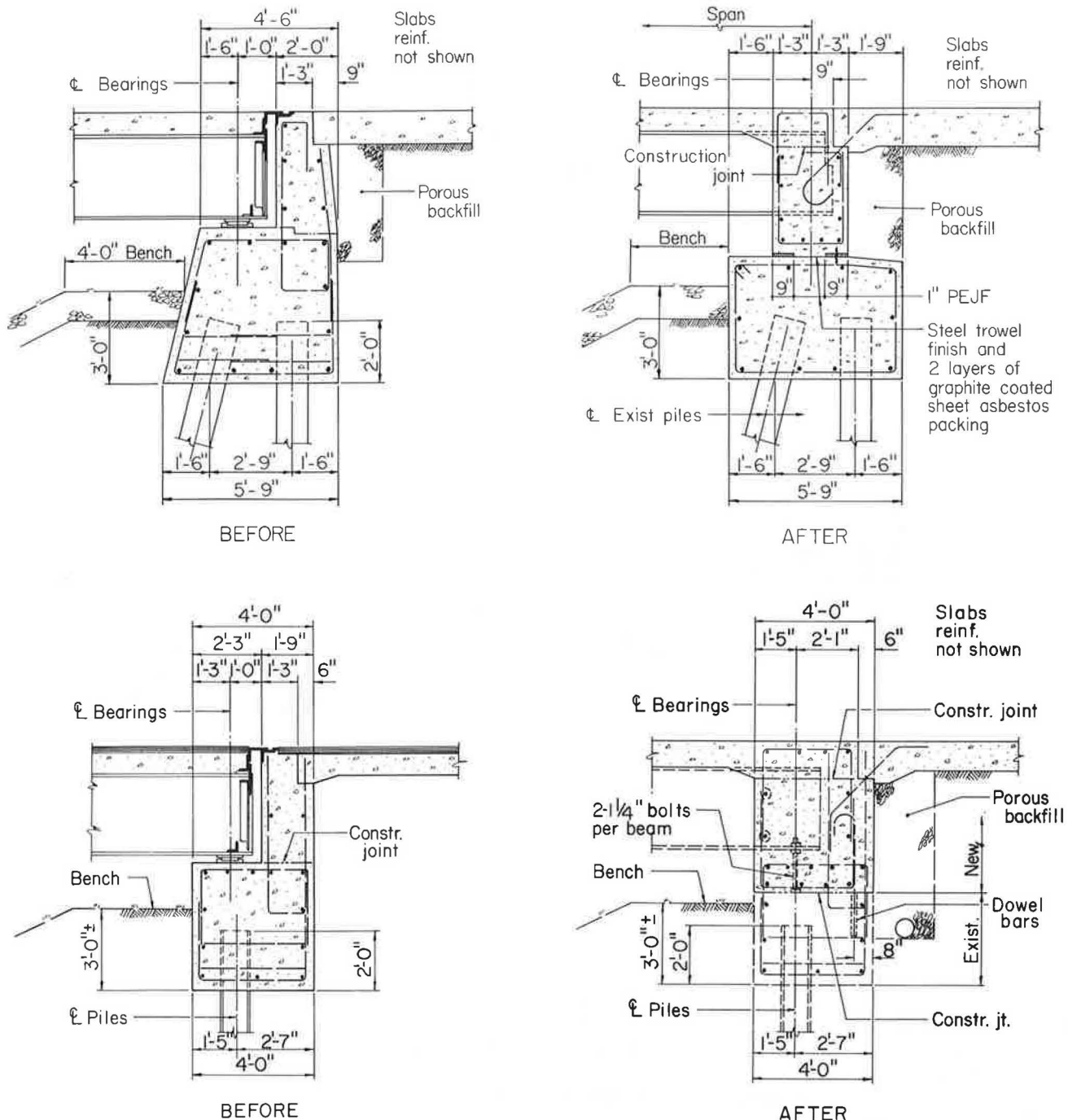


FIGURE 15 Integral conversions at stub-type abutments.

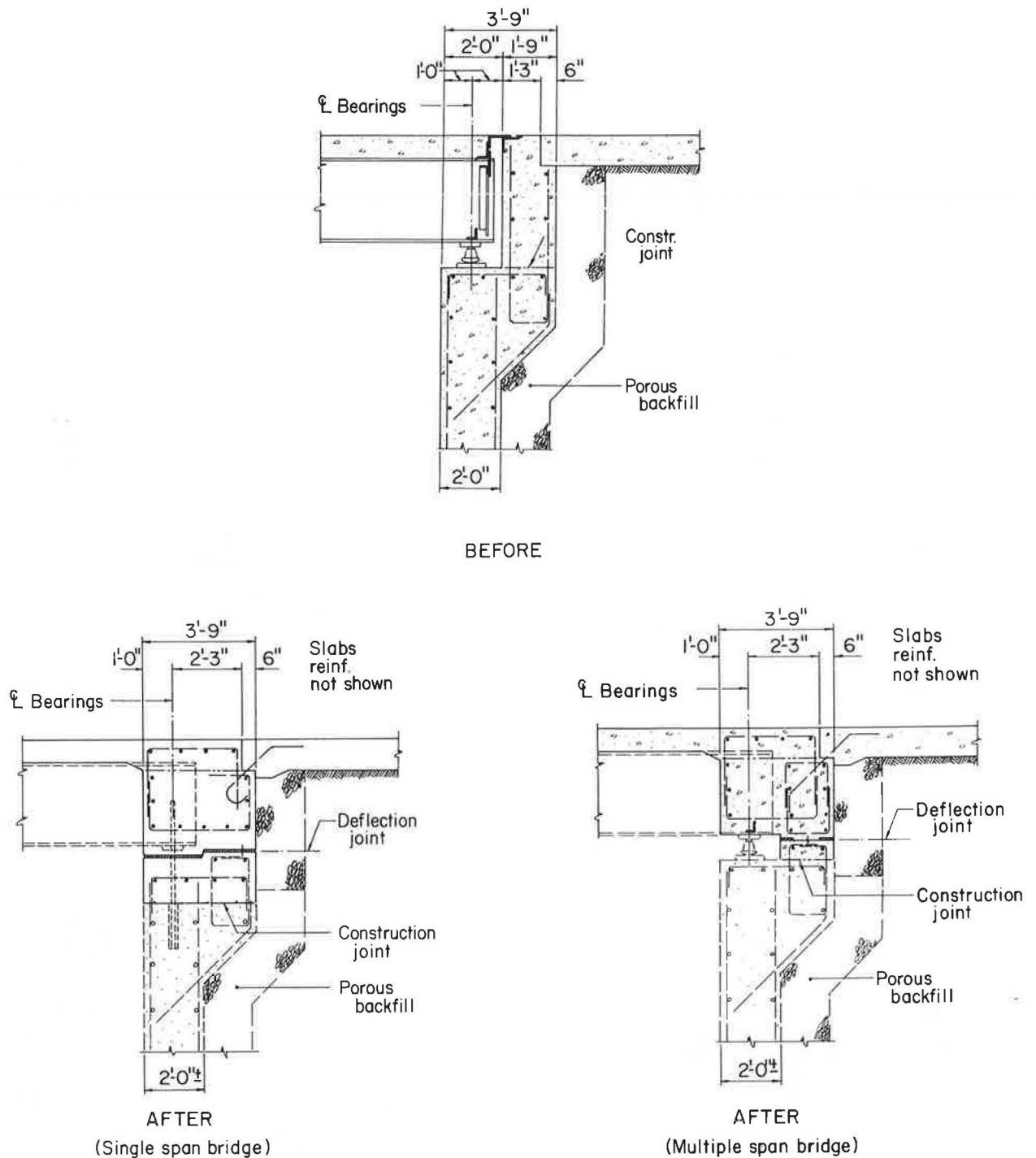


FIGURE 16 Integral conversions at wall-type abutments.

pressure, by deicing chemical deterioration, or by both. Instead of replacing backwalls and joints, and in some cases bearings and bridge seats as well, it was decided to pattern the reconstruction after the design details used by the department for its new integral bridges. In this way, subsequent concern about the effects of pavement pressure and deicing chemical deterioration has been minimized.

SUMMARY

As the trend shown in Figure 1 continues, 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 bridges (Figure 2) 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.

Because design and construction of fully continuous bridges have become routine and continuous conversion of simple spans in new construction is becoming more commonplace, it is surprising that similar conversion techniques are not used more often to convert existing jointed bridges to continuous bridges. Presumably, the next decade or two will see a burgeoning in retrofitting simple multiple-span bridges to continuous bridges (Figure 10) and from nonintegral to integral abutments. When more information on the operating stress levels of integral bridges has been developed and when more fully described design details and procedures for integral conversions have become available, bridge engineers will be able to more fully justify their consideration of such construction. Until then, much intuition and prudent judgment will continue to be used to ensure that integral construction and conversion techniques will provide the service life needed to justify their adoption and continued use.

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