Dornsife, R.J. "Expansion Joints."
Bridge Engineering Handbook.
Ed. Wai-Fah Chen and Lian Duan
Boca Raton: CRC Press, 2000

25

Expansion Joints

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25.1 Introduction

Expansion joint systems are integral, yet often overlooked, components designed to accommodate cyclic movements. Properly functioning bridge expansion joint systems accommodate these movements without imposing significant secondary stresses on the superstructure. Sealed expansion joint systems provide barriers preventing runoff water and deicing chemicals from passing through the joint onto bearing and substructure elements below the bridge deck. Water and deicing chemicals have a detrimental impact on overall structural performance by accelerating degradation of bridge deck, bearing, and substructure elements. In extreme cases, this degradation has resulted in premature, catastrophic structural failure. In fulfilling their functions, expansion joints must provide a reasonably smooth ride for motorists.

Perhaps because expansion joints are generally designed and installed last, they are often relegated to peripheral status by designers, builders, and inspectors. As a result of their geometric configuration and the presence of multiple-axle vehicles, expansion joint elements are generally subjected to a significantly larger number of loadings than other structural members. Impact, a consequence of bridge discontinuity inherent at a joint, exacerbates loading. Unfortunately, specific expansion joint systems are often selected based upon their initial cost with minimal consideration for long-term performance, durability, and maintainability. Consequently, a plethora of bridge maintenance problems plague them.

In striving to improve existing and develop new expansion joint systems, manufacturers present engineers with a multitudinous array of options. In selecting a particular system, the designer must carefully assess specific requirements. Magnitude and direction of movement, type of structure, traffic volumes, climatic conditions, skew angles, initial and life cycle costs, and past performance of alternative systems must all be considered. For classification in the ensuing discussion, expansion joint systems will be grouped into three broad categories depending upon the total movement range accommodated. Small movement range joints encompass all systems capable of accommodating total motion ranges of up to about 45 mm. Medium movement range joints include systems accommodating total motion ranges between about 45 mm and about 130 mm. Large movement range joints accommodate total motion ranges in excess of about 130 mm. These delineated ranges are somewhat arbitrary in that some systems can accommodate movement ranges overlapping these broad categories.

25.2 General Design Criteria

Expansion joints must accommodate movements produced by concrete shrinkage and creep, post-tensioning shortening, thermal variations, dead and live loads, wind and seismic loads, and structure settlements. Concrete shrinkage, post-tensioning shortening, and thermal variations are generally taken into account explicitly in design calculations. Because of uncertainties in predicting, and the increased costs associated with accommodating large displacements, seismic movements are usually not explicitly included in calculations.

Expansion joints should be designed to accommodate all shrinkage occurring after their installation. For unrestrained concrete, ultimate shrinkage strain after installation, β, may be estimated as 0.0002 [1]. More-detailed estimations can be used which include the effect of ambient relative humidity and volume-to-surface ratios [2]. Shrinkage shortening of the bridge deck, Δ_{shrink}, in mm, is calculated as

$$\Delta_{\text{shrink}} = (\beta)\cdot(\mu)\cdot(L_{\text{trib}})\cdot(1000\ \text{mm/m}) \tag{25.1}$$

where

L_{trib} =tributary length of structure subject to shrinkage; m

β = ultimate shrinkage strain after expansion joint installation; estimated as 0.0002 in lieu of more-refined calculations

μ = factor accounting for restraining effect imposed by structural elements installed before slab is cast [1]

= 0.0 for steel girders, 0.5 for precast prestressed concrete girders, 0.8 for concrete box girders and T-beams, 1.0 for flat slabs

Thermal displacements are calculated using the maximum and minimum anticipated bridge deck temperatures. These extreme values are functions of the geographic location of the structure and the bridge type. Thermal movement, in mm, is calculated as

$$\Delta_{\text{temp}} = (\alpha)\cdot(L_{\text{trib}})\cdot(\delta T)\cdot(1000\ \text{mm/m}) \tag{25.2}$$

where

α = coefficient of thermal expansion; 0.000011 m/m/°C for concrete and 0.000012 m/m/°C for steel

L_{trib} = tributary length of structure subject to thermal variation; m

δT = temperature variation; °C

Any other predictable movements following expansion joint installation, such as concrete post-tensioning shortening and creep, should also be included in the design calculations.

25.3 Jointless Bridges

Bridge designers have used superstructure continuity in an effort to avoid some of the maintenance problems associated with expansion joints [3]. This evolution from simple-span construction was facilitated by the development of the moment distribution procedure published by Hardy Cross [4] in 1930.

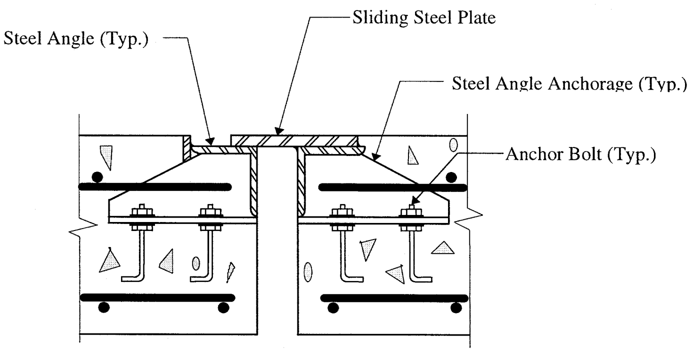

FIGURE 25.1 Sliding plate joint (cross section).

In recent years, some transportation agencies have extended this strategy by developing jointless bridge designs. Jointless bridges are characterized by continuous spans built integrally with their abutments. In many instances, approach slabs are tied to the superstructure slab or to the abutments. The resulting designs are termed *integral* or *semi-integral* depending upon the degree of continuity developed among superstructure, substructure, and approach slab elements. Design methods and details for jointless bridges vary considerably [3,5]. Many transportation agencies have empirically established maximum lengths for jointless bridges [5].

Jointless bridges should not be considered a panacea for addressing expansion jointmaintenance problems. As superstructure movements are restrained in jointless bridges, secondary stresses are induced in superstructure and substructure elements. Stresses may also be induced in approach slabs. If inadequately addressed during design, these stresses can damage structural elements and adjacent asphalt pavements. Damaged structural elements, slabs, and pavements are accompanied by increased probability of moisture infiltration, further exacerbating deterioration. Most jointless bridges have been built relatively recently [5]. Their long-term performance and durability will determine how extensively the jointless bridge concept is applied to future construction.

25.4 Small Movement Range Joints

Many different systems exist for accommodating movement ranges under about 45 mm. These include, but are not limited to, steel sliding plates, elastomeric compression seals, preformed closed cell foam, epoxy-bonded elastomeric glands, asphaltic plug joints, bolt-down elastomeric panels, and poured sealants. In this section, several of these systems will be discussed with an emphasis on design procedures and past performance.

25.4.1 Sliding Plate Joints

Steel sliding plates, shown in Figure 25.1, have been used extensively in the past for expansion joints in both concrete and timber bridge decks. Two overlapping steel plates are attached to the bridge deck, one on each side of the expansion joint opening. They are generally installed so that the top surfaces of the plates are flush with the top of the bridge deck. The plates are generally bolted to timber deck panels or embedded with steel anchorages into a concrete deck. Steel plate widths are sized to accommodate anticipated total movements. Plate thicknesses are determined by structural requirements.

Standard steel sliding plates do not generally provide an effective seal against intrusion of water and deicing chemicals into the joint and onto substructure elements. As a result of plate corrosion and debris collection, the steel sliding plates often bind up, impeding free movement of the superstructure. Repeated impact and weathering tend to loosen or break anchorages to the bridge deck.

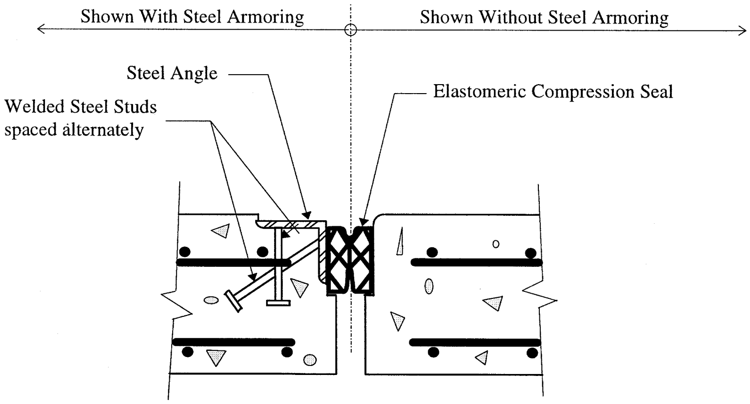

FIGURE 25.2 Compression seal joint (cross section).

Consequently, sliding plate systems are rarely specified for new bridge construction today. Nevertheless, sliding plate systems still exist on many older structures. These systems can be replaced with newer systems providing increased resistance against water and debris infiltration. In situations where the integrity of the deck anchorage has not been compromised, sliding plates can be retrofitted with poured sealants or elastomeric strip seals.

25.4.2 Compression Seal Joints

Compression seals, shown in Figure 25.2, are continuous elastomeric sections, typically with extruded internal web systems, installed within an expansion joint gap to seal the joint effectively against water and debris infiltration. Compression seals are held in place by mobilizing friction against adjacent vertical joint faces. Hence, design philosophy requires that they be sized and installed to be always in a state of compression. Compression seals may be installed against smooth concrete faces or against steel armoring. When installed directly against concrete, polymer concrete nosing material is often used to provide added impact resistance. Combination lubricant/adhesive is typically used to install the seal in its compressed state.

Because compression seals are held in place by friction, their performance is extremely dependent upon the close correlation of constructed joint width and design joint width. If the joint opening is constructed too wide, friction force will be insufficient to prevent the compression seal from slipping out of the joint at wider expansion gap widths. Relaxation of the elastomer and debris accumulation atop the seal contribute to seal slippage. To minimize slippage and maximize compression seal performance, a joint may be formed narrower than the design width, then sawcut immediately prior to compression seal installation. The sawcut width is calculated based upon ambient bridge deck temperature and the degree of slab shrinkage which has already occurred. As an alternative to sawcutting, block outs can be formed on each side of the joint during bridge deck casting. Prior to compression seal installation, concrete is cast into the block outs, often with steel armoring, to form an expansion gap width compatible with ambient conditions.

In design calculations, the maximum and minimum compressed widths of the seal are generally set at 85 and 40% of the uncompressed width [1]. These widths are measured perpendicular to the axis of the joint. It is also generally assumed that the width of the seal at about 20°C is 60% of its uncompressed width. For skewed joints, bridge deck movement must be separated into components perpendicular to and parallel to the joint axis. Shear displacement of the compression seal should be limited to a specified percentage of its uncompressed width, usually set at about 22% [1]. Additionally, the expansion gap width should be set so that the compression seal can be installed over a reasonably wide range of construction temperatures. Manufacturers' catalogues generally specify the minimum expansion gap widths into which specific size compression seals can be installed. The expansion gap width should be specified on the contract drawings as a function of the bridge deck temperature.

Design relationships can be stated as follows:

$$\Delta_{\text{temp-normal}} = \Delta_{\text{temp}} \cdot \cos\theta \qquad \text{[thermal movement normal to joint]} \tag{25.3}$$

$$\Delta_{\text{temp-parallel}} = \Delta_{\text{temp}} \cdot \sin\theta \qquad \text{[thermal movement parallel to joint]} \tag{25.4}$$

$$\Delta_{\text{shrink-normal}} = \Delta_{\text{shrink}} \cdot \cos\theta \qquad \text{[shrinkage movement normal to joint]} \tag{25.5}$$

$$\Delta_{\text{shrink-parallel}} = \Delta_{\text{shrink}} \cdot \sin\theta \qquad \text{[shrinkage movement parallel to joint]} \tag{25.6}$$

$$W_{\text{min}} = W_{\text{install}} - [(T_{\text{max}} - T_{\text{install}})/(T_{\text{max}} - T_{\text{min}})]\ \Delta_{\text{temp-normal}} > 0.40\text{W} \tag{25.7}$$

$$W_{\text{max}} = W_{\text{install}} + [(T_{\text{install}} - T_{\text{min}})/(T_{\text{max}} - T_{\text{min}})]\ \Delta_{\text{temp-normal}} + \Delta_{\text{shrink-normal}} < 0.85\text{W} \tag{25.8}$$

where

θ = skew angle of expansion joint, measured with respect to a line perpendicular to the bridge longitudinal axis; degrees
W = uncompressed width of compression seal; mm
W_{install} = expansion gap width at installation
T_{install} = bridge deck temperature at time of installation; °C
W_{min}, W_{max} = minimum and maximum expansion gap widths; mm
T_{min}, T_{max} = minimum and maximum bridge deck temperatures; °C

Multiplying Eq. (25.7) by –1.0, adding to Eq. (25.8), and rearranging yields:

$$W > (\Delta_{\text{temp-normal}} + \Delta_{\text{shrink-normal}})/0.45 \tag{25.9}$$

Similarly,

$$W > (\Delta_{\text{temp-parallel}} + \Delta_{\text{shrink-parallel}})/0.22 \tag{25.10}$$

Now, assuming $W_{\text{install}} = 0.6$ W,

$$W_{\text{max}} = 0.6W + [(T_{\text{install}} - T_{\text{min}})/(T_{\text{max}} - T_{\text{min}})]\ \Delta_{\text{temp-normal}} + \Delta_{\text{shrink-normal}} < 0.85W \tag{25.11}$$

which, upon rearranging, yields:

$$W > 4\ [(T_{\text{install}} - \text{T}_{\text{min}})/(\text{T}_{\text{max}} - \text{T}_{\text{min}})\ \cdot(\Delta_{\text{temp-normal}}) + \Delta_{\text{shrink-normal}}] \tag{25.12}$$

Equations (25.9), (25.10), and (25.12) are used to calculate the required compression seal size. Next, expansion gap widths at various construction temperatures can be evaluated.

25.4.3 Asphaltic Plug Joints

Asphaltic plug joints comprise liquid polymer binder and graded aggregates compacted in preformed block outs as shown in Figure 25.3. The compacted composite material is referred to as polymer modified asphalt (PMA). These joints have been used to accommodate movement ranges up to 50 mm. This expansion joint system was developed in Europe and can be adapted for use with concrete or asphalt bridge deck surfaces. The PMA is installed continuously within a block out centered over the expansion joint opening with the top of the PMA flush with the roadway surface. A steel plate retains the PMA at the bottom of the block out during installation. The polymer

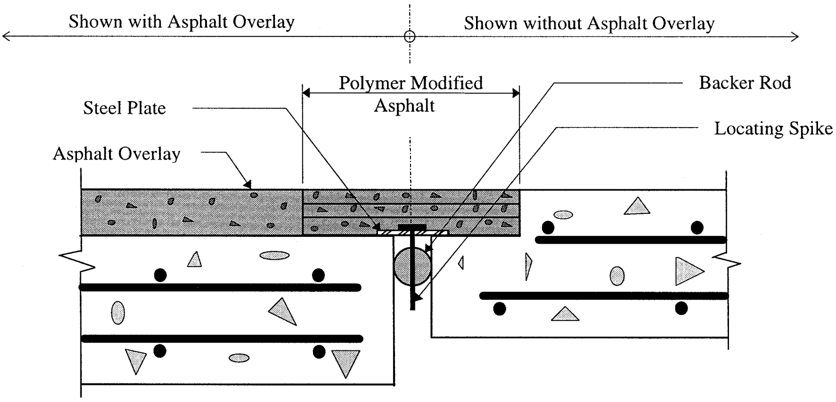

FIGURE 25.3 Asphaltic plug joint (cross section).

binder material is generally installed in heated form. Aggregate gradation, binder properties, and construction quality are critical to asphaltic plug joint performance.

The asphaltic plug joint is designed to provide a smooth, seamless roadway surface. It is relatively easy to repair, is not as susceptible to snowplow damage as other expansion joint systems, and can be cold-milled and/or built up for roadway resurfacing. The performance of asphaltic plug joints in the United States has been somewhat erratic [6]. The material properties of PMA vary with temperature. Asphaltic plug joints have demonstrated a proclivity to soften and creep at warmer temperatures, exhibiting wheel rutting and eventual migration of PMA out of the block outs. In very cold temperatures, the PMA can become brittle and crack at the plug joint-to-pavement interface, making the joint susceptible to water infiltration. Ongoing research is investigating these issues and developing comprehensive design guidelines, material specifications, and installation procedures to improve their performance [6].

As with all expansion joint systems, designers must understand the limitations of asphaltic plug joints. These joints were not designed for, and should not be used to, accommodate differential vertical displacements, as may occur at longitudinal joints. Because of PMA creep susceptibility, asphaltic plug joints should not be used where the roadway is subject to significant traffic acceleration and braking. Examples include freeway off-ramps and roadway sections in the vicinity of traffic signals. Asphaltic plug joints have also performed poorly in highly skewed applications and in applications subjected to large rotations. Maintaining the minimum block-out depth specified by the manufacturer is particularly critical to successful performance. In spite of these limitations, asphaltic plug joints do offer advantages not inherent in other expansion joint systems.

25.4.4 Poured Sealant Joints

Durable low-modulus sealants, poured cold to provide watertight expansion joint seals as shown in Figure 25.4, have been used in new construction and in rehabilitation projects. Properties and application procedures vary between products. Most silicone sealants possess good elastic performance over a wide range of temperatures while demonstrating high levels of resistance to ultraviolet and ozone degradation. Rapid-curing sealants are ideal candidates for rehabilitation in situations where significant traffic disruption from extended traffic lane closure is unacceptable. Other desirable properties include self-leveling and self-bonding capabilities. Installation procedures vary among different products, with some products requiring specialized equipment for mixing individual components. Designers must assess the design and construction requirements, weighing desirable properties against material costs for alternative sealants.

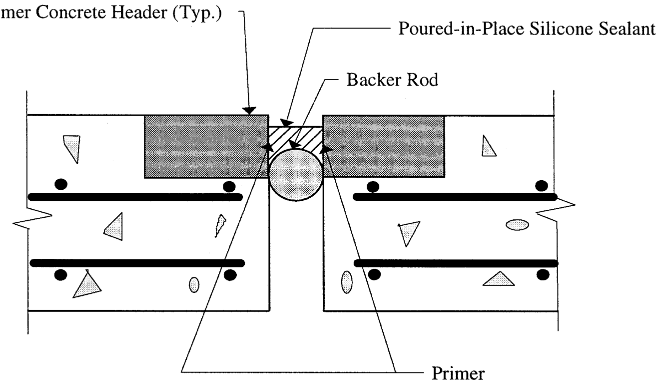

FIGURE 25.4 Poured sealant joint (cross section).

Most sealants can be installed against either concrete or steel. Particularly in rehabilitation projects, it is extremely critical that the concrete or steel substrates be thoroughly cleaned before the sealant is placed. Some manufacturers require application of specific primers onto substrate surfaces prior to sealant placement to enhance bonding. Debonding of sealant from substrate concrete or steel, compromising the integrity of the watertight seal, has previously plagued poured sealant joints. The latest products are relatively new, but have demonstrated good short-term performance and versatility of use in bridge rehabilitation. Their long-term durability will determine the extent of their future application.

Poured sealant joints should be designed based upon manufacturers' recommendations. Maximum and minimum working widths of the poured sealant joint are generally recommended as a percentage of the sealant joint width at installation. A minimum recess is typically required between the top of the roadway surface and the top of the sealant. This recess is critical in preventing tires from contacting and debonding the sealant from its substrate material.

25.4.5 Design Example 1

Given

A reinforced-concrete box-girder bridge has an overall length of 70 m. A compression seal expansion joint at each abutment will accommodate half of the total bridge movement. These expansion joints are skewed 20°. Bridge deck temperatures are expected to range between –15°C and 40°C during the life of the structure.

Find

Compression seal sizes and construction gap widths at 5, 20, and 30°C.

Solution

Step 1: Calculate temperature and shrinkage movement.

$$\text{Temperature: } \Delta_{temp} = (\tfrac{1}{2})(0.000011 \text{ m/m/°C})(55\text{°C})(70 \text{ m})(1000 \text{ mm/m}) = 21 \text{ mm}$$

$$\text{Shrinkage: } \Delta_{shrink} = (\tfrac{1}{2})(0.0002 \text{ m/m})(0.8)(70 \text{ m})(1000 \text{ mm/m}) = \underline{\ 6 \text{ mm}}$$

$$\text{Total deck movement at the joint:} \quad 27 \text{ mm}$$

$$\Delta_{temp\text{-}normal} + \Delta_{shrink\text{-}normal} = (27 \text{ mm})(\cos 20°) = 25 \text{ mm}$$

$$\Delta_{temp\text{-}parallel} + \Delta_{shrink\text{-}parallel} = (27 \text{ mm})(\sin 20°) = 9.2 \text{ mm}$$

Step 2: Determine compression seal width required from Eqs. (25.9), (25.10), and (25.12).

$$W > 25\text{ mm}/0.45 = 56\text{ mm}$$

$$W > 9.2\text{ mm}/0.22 = 42\text{ mm}$$

$$W > 4 \cdot [(20°\text{C} + 15°\text{C})/(40°\text{C} + 15°\text{C}) \cdot (21\text{ mm}) + 6\text{ mm}] \cdot \cos 20° = 73\text{ mm}$$

Use 75 mm compression seal.

Step 3: Evaluate construction gap widths for various temperatures for a 75 mm compression seal.

$$\text{Construction width at } 20°\text{C} = 0.6 \cdot (75\text{ mm}) = 45\text{ mm}$$

$$\text{Construction width at } 5°\text{C} = 45\text{ mm} + [(20°\text{C} - 5°\text{C})/(40°\text{C} + 15°\text{C})] \cdot (21\text{ mm}) \cdot (\cos 20°) = 50\text{ mm}$$

$$\text{Construction width at } 30°\text{C} = 45\text{ mm} - [(30°\text{C} - 20°\text{C})/(40°\text{C} + 15°\text{C})] \cdot (21\text{ mm}) \cdot (\cos 20°) = 41\text{ mm}$$

Conclusion

Use a 75-mm compression seal. Construction gap widths for installation temperatures of 5, 20, and 30°C are 50, 45, and 41 mm, respectively.

25.5 Medium Movement Range Joints

Medium movement range expansion joints accommodate movement ranges from about 45 mm to about 130 mm and include sliding plate systems, bolt-down panel joints (elastomeric expansion dams), strip seals, and steel finger joints. Sliding plate systems were previously discussed under small motion range joints.

25.5.1 Bolt-Down Panel Joints

Bolt-down panel joints, also referred to as elastomeric expansion dams, consist of monolithically molded elastomeric panels reinforced with steel plates as shown in Figure 25.5. They are bolted into block outs formed in the concrete bridge deck on each side of an expansion joint gap. Manufacturers fabricate bolt-down panels in varying widths roughly proportional to the total allowable movement range. Expansion is accompanied by uniform stress and strain across the width of the panel joint between anchor bolt rows. Unfortunately, the bolts and nuts connecting bolt-down panels to bridge decks are prone to loosening and breaking under high-speed traffic. The resulting loose panels and hardware in the roadway present hazards to vehicular traffic, particularly motorcycles. Consequently, to mitigate liability, some transportation agencies avoid using bolt-down panel joints.

25.5.2 Strip Seal Joints

An elastomeric strip seal expansion joint system, shown in Figure 25.6, consists of a preformed elastomeric gland mechanically locked into metallic edge rails embedded into concrete on each side of an expansion joint gap. Movement is accommodated by unfolding of the elastomeric gland. Steel studs or reinforcing bars are generally welded to the edge rails to facilitate bonding with the concrete in formed block outs. In some instances the edge rails are bolted in place. Edge rails also furnish armoring for the adjacent bridge deck concrete. Properly installed strip seals have demonstrated relatively good performance. Damaged or worn glands can be replaced with minimal traffic disruptions.

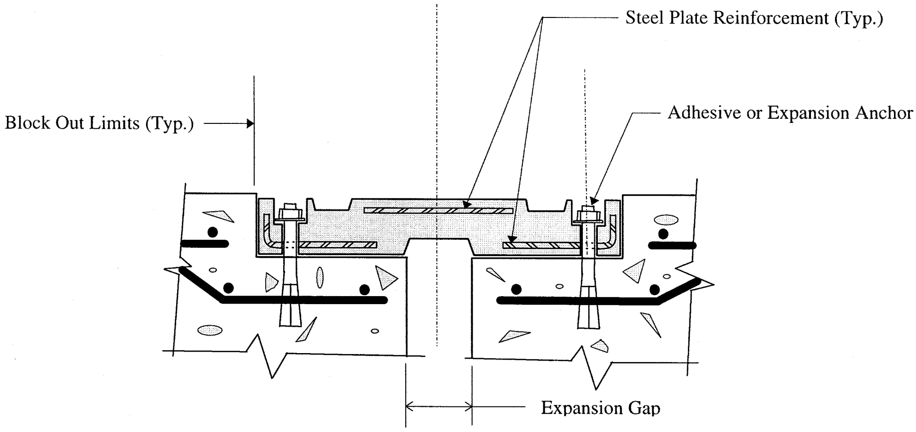

FIGURE 25.5 Bolt-down panel joint (cross section).

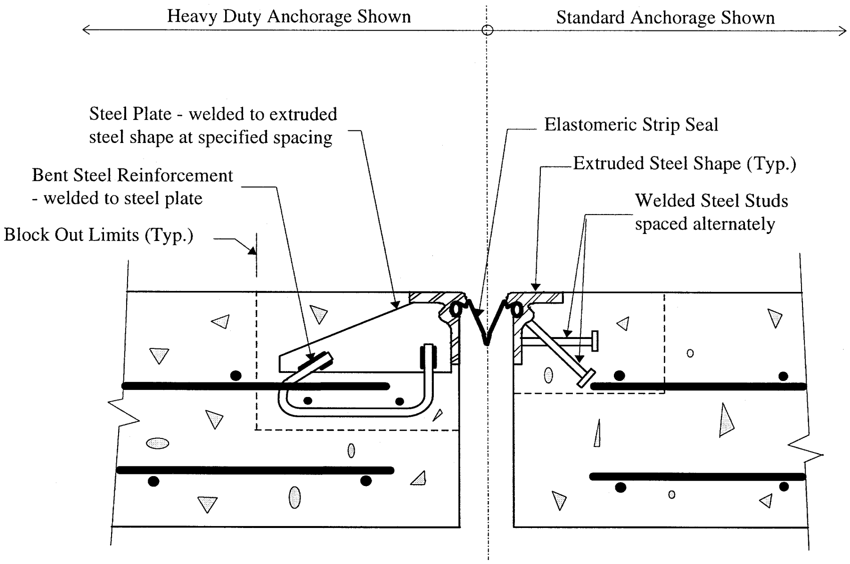

FIGURE 25.6 Elastomeric strip seal joint (cross section).

The elastomeric glands exhibit a proclivity for accumulating debris. In some instances, this debris can resist joint movement and result in premature gland failure.

25.5.3 Steel Finger Joints

Steel finger joints, shown in Figure 25.7, have been used to accommodate medium and large movement ranges. These joints are generally fabricated from steel plate and are installed in cantilever or prop cantilever configurations. The steel fingers must be designed to support traffic loads with sufficient stiffness to preclude excessive vibration. In addition to longitudinal movement, they must also accommodate any rotation or differential vertical deflection across the joint. To minimize the potential for damage from snowplow blade impact, steel fingers may be fabricated with a slight downward taper toward the joint centerline. Generally, steel finger joints do not provide a seal against water intrusion to substructure elements. Elastomeric or metallic troughs can be installed beneath the steel finger joint assembly to catch and redirect water and debris runoff. However, unless regularly maintained, these troughs clog and become ineffective [3].

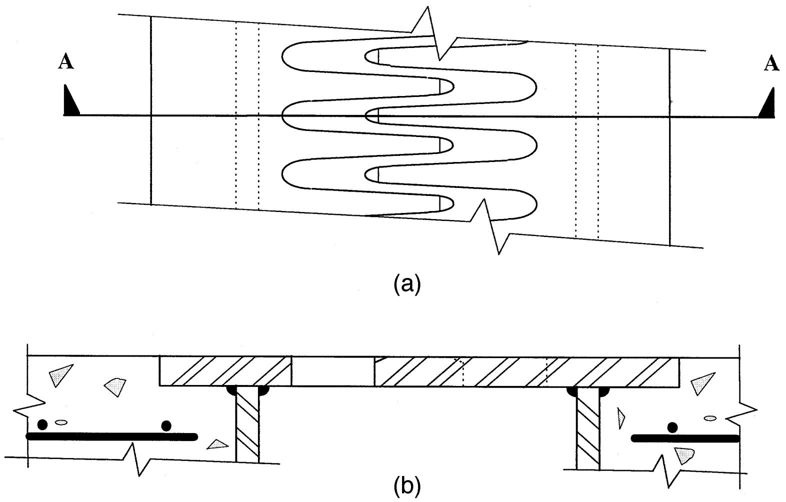

FIGURE 25.7 Steel finger joint. (a) Plan view; (b) section A–A.

25.5.4 Design Example 2

Given
A steel-plate girder bridge has a total length of 180 m. It is symmetrical and has a strip seal expansion joint at each end. These expansion joints are skewed 15°. Bridge deck temperatures are expected to range between –35°C and 50°C during the life of the structure. Assume an approximate installation temperature of 20°C.

Find
Type A and Type B strip seal sizes and construction gap widths at 5, 20, and 30°C. Type A strip seals have a 15 mm gap at full closure. Type B strip seals are able to fully close, leaving no gap.

Solution
Step 1: Calculate temperature and shrinkage movement.

Temperature: $\Delta_{\text{temp}} = (½)(0.000012 \text{ m/m/°C})(85°\text{C})(180 \text{ m})(1000 \text{ mm/m}) = 92 \text{ mm}$

Shrinkage: $\Delta_{\text{shrink}} = 0.0$ (no shrinkage, $\mu = 0.0$ for steel bridge) ______

Total deck movement at the joint: 92 mm

$\Delta_{\text{temp-normal-closing}} = (50°\text{C} - 20°\text{C})/(50°\text{C} + 35°\text{C})(92 \text{ mm})(\cos 15°) =$ 31 mm

$\Delta_{\text{temp-normal-opening}} = (20°\text{C} + 35°\text{C})/(50°\text{C} + 35°\text{C})(92 \text{ mm})(\cos 15°) =$ 58 mm

Step 2: Determine strip seal size required. Assume a minimum construction gap width of 40 mm at 20°C.

Type A: Construction gap width of 40 mm at 20°C will not accommodate 31 mm closing and still allow a 15 mm gap at full closure. Therefore, minimum construction gap width at 20°C must be 31 mm + 15 mm = 46 mm.

Size required = 46 mm + 58 mm = 104 mm → Use 100 mm strip seal

Type B: Construction width of 40 mm at 20°C is adequate.

$$\text{Size required} = 40\text{ mm} + 58\text{ mm} = 98\text{ mm} \rightarrow \underline{\text{Use 100 mm strip seal}}$$

Step 3: Evaluate construction gap widths for various temperatures for a 100 mm strip seal.
Type A: Required construction gap width at 20°C = 15 mm + 31 mm = 46 mm

$$\begin{aligned}\text{Construction gap width at 5°C} &= 46\text{ mm} + (20°\text{C} - 5°\text{C})/(20°\text{C} + 35°\text{C})(58\text{ mm})\\ &= 62\text{ mm}\end{aligned}$$

$$\begin{aligned}\text{Construction gap width at 30°C} &= 46\text{ mm} - (30°\text{C} - 20°\text{C})/(50°\text{C} - 20°\text{C})(31\text{ mm})\\ &= 36\text{ mm}\end{aligned}$$

Type B: Construction width of 40 mm at 20°C is adequate.

$$\begin{aligned}\text{Construction gap width at 5°F} &= 40\text{ mm} + (20°\text{C} - 5°\text{C})/(20°\text{C} + 35°\text{C})(58\text{ mm})\\ &= 56\text{ mm}\end{aligned}$$

$$\begin{aligned}\text{Construction gap width at 30°F} &= 40\text{ mm} - (30°\text{C} - 20°\text{C})/(50°\text{C} - 20°\text{C})(31\text{ mm})\\ &= 30\text{ mm}\end{aligned}$$

Conclusion
Use a 100 mm strip seal. Construction gap widths for Type A strip seals at installation temperatures of 5, 20, and 30°C are 62, 46, and 36 mm, respectively. Construction gap widths for Type B strip seals at installation temperatures of 5, 20, and 30°C are 56, 40, and 30 mm, respectively.

25.6 Large Movement Range Joints

Large movement range joints accommodate more than 130 mm of total movement and include bolt-down panel joints (elastomeric expansion dams), steel finger joints, and modular expansion joints. Bolt-down panel and steel finger joints were previously discussed as medium movement range joints.

25.6.1 Modular Bridge Expansion Joints

Modular bridge expansion joints (MBEJ), shown in Figure 25.8, are complex, expensive, structural systems designed to provide watertight wheel load transfer across wide expansion joint openings. These systems were developed in Europe and introduced in the United States in the 1960s [7]. They are generally shipped to the construction site for installation in a completely assembled configuration. MBEJs comprise a series of center beams supported atop support bars. The center beams are oriented parallel to the joint axis while the support bars span parallel to the primary direction of movement. MBEJs can be classified as either single-support bar systems or multiple-support bar systems. In multiple-support bar systems, each center beam is supported by a separate support bar at each support location. Figure 25.8 depicts a multiple-support bar system. In the more complex single-support bar system, one support bar supports all center beams at each support location. This design concept requires that each center beam be free to translate along the longitudinal axis of the support bar as the joint opens and closes. This is accomplished by attaching steel yokes to the underside of the center beams. The support bar passes through the openings in the yokes. Elastomeric springs between the underside of each center beam and the top of the support bar and between the bottom of the support bar and the bottom of the yoke support each center beam and permit it to translate along the longitudinal axis of the support bar.

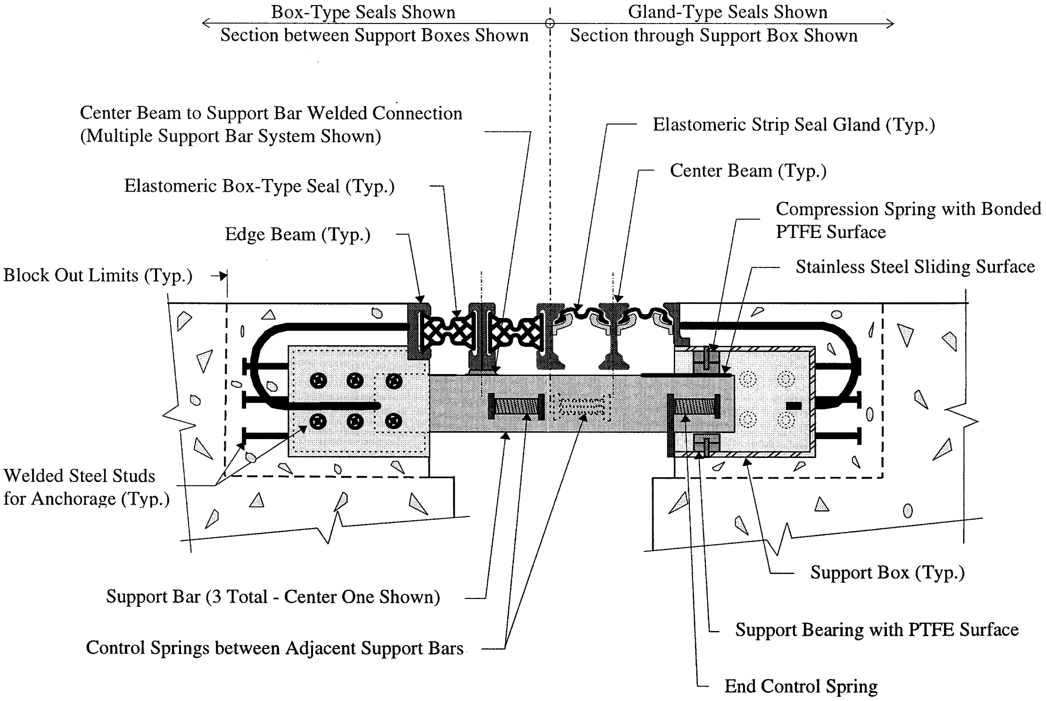

FIGURE 25.8 Modular bridge expansion joint (multiple support bar system), cross section.

The support bars are, in turn, supported on sliding bearings mounted within support boxes. Polytetrafluorethylene (PTFE)-to-stainless-steel interfaces between elastomeric support bearings and support bars facilitate unimpeded translation of the support bars as the expansion gap varies. Control springs between adjacent support bars and between support bars and support boxes of multiple-support bar MBEJs are designed to maintain equal distances between center beams as the expansion gap varies. The support boxes are embedded in bridge deck concrete on each side of the expansion joint. Elastomeric strip seals or elastomeric box-type seals attach to adjacent center beams, providing resistance to water and debris intrusion.

The highly repetitive nature of axle loads predisposes MBEJ components and connections to high fatigue susceptibility, particularly at connections of center beam to support bar. Bolted connections have, generally, performed poorly. Welded connections are preferred, but must be carefully designed, fatigue-tested, fabricated, and inspected to assure satisfactory performance and durability. Field-welded center beam splices are also highly fatigue susceptible, requiring careful detailing, welding, and inspection. A lack of understanding of the dynamic response of these systems, connection detail complexity, and the competitive nature of the marketplace have exacerbated fatigue susceptibility. Fortunately, current research is developing fatigue-resistant structural design specifications in addition to focusing on developing minimum performance standards, performance and acceptance test methods, and installation guidelines for MBEJs [7,8].

Calculated total movements establish MBEJ size. Often, an allowance is made to provide a nominal factor of safety on the calculated movements. Currently available systems permit 75 mm of movement per strip seal element; hence, the total movement rating provided will be a multiple of 75 mm. To minimize impact and wear on bearing elements, the maximum gap between adjacent center beams is limited, typically to about 90 mm [9]. To facilitate installation within concrete block outs, contract drawings should specify the face-to-face distance of edge beams as a function of temperature at the time of installation.

Design relationships can be expressed as:

$$n = \mathrm{MR}/\mathrm{mr} \tag{25.13}$$

$$G_{\min} = (n - 1) \cdot (w) + (n) \cdot (g) \tag{25.14}$$

$$G_{\max} = G_{\min} + \mathrm{MR} \tag{25.15}$$

where
MR = total movement rating of the MBEJ system; mm
mr = movement rating per strip seal element; mm
n = number of seals
$n - 1$ = number of center beams
w = width of each center beam; mm
g = minimum gap per strip seal element at full closure; mm
$G_{\min}$ = minimum face-to-face distance of edge beams; mm
$G_{\max}$ = maximum face-to-face distance of edge beams; mm

Structural design of MBEJs is generally performed by the manufacturer. Project specifications should require that the manufacturer submit structural calculations, detailed fabrication drawings, and applicable fatigue tests for approval. All elements and connections must be designed and detailed to resist fatigue stresses imposed by repetitive vertical and horizontal wheel loadings. Additionally, MBEJs should be detailed to provide access for inspection and periodic maintenance, including replacement of seals, control springs, and bearing components.

25.6.2 Design Example 3

Given
Two cast-in-place post-tensioned concrete box-girder bridge frames meet at an intermediate pier where they are free to translate longitudinally. Skew angle is 0° and bridge deck ambient temperatures range from –15 to 50°C. A MBEJ will be installed 60 days after post-tensioning operations have been completed. Specified creep is 150% of elastic shortening. Assume that 50% of shrinkage has already occurred at installation time. The following longitudinal movements were calculated for each of the two frames:

	Frame A	Frame B
Shrinkage	30 mm	15 mm
Elastic shortening	36 mm	20 mm
Creep (1.5 × elastic shortening)	54 mm	30 mm
Temperature fall (20 to –15°C)	76 mm	38 mm
Temperature rise (20 to 50°C)	66 mm	33 mm

Find
MBEJ size required to accommodate the total calculated movements and the installation gaps measured face to face of edge beams, "G_{install}," at 5, 20, and 30°C.

Solution
Step 1: Determine MBEJ size.

Total opening movement (Frame A) = (0.5)(30 mm) + 54 mm + 76 mm = 145 mm
Total opening movement (Frame B) = (0.5)(15 mm) + 30 mm + 38 mm = 76 mm
Total opening movement (both frames) = 145 mm + 76 mm = 221 mm
Total closing movement (both frames) = 66 mm + 33 mm = 99 mm

Determine size of modular joint, including a 15% allowance:

$$1.15(221\text{ mm} + 99\text{ mm}) = 368\text{ mm} \rightarrow \underline{\text{Use 375 mm movement rating MBEJ}}.$$

Step 2: Evaluate installation gaps measured face to face of edge beams at 5, 20, and 30°C.

$\text{MR} = 375\text{ mm}$ (MBEJ movement range)
$\text{mr} = 75\text{ mm}$ (maximum movement rating per strip seal element)
$n = 375\text{ mm}/75\text{ mm} = 5$ strip seal elements
$n - 1 = 4$ center beams
$w = 65\text{ mm}$ (center beam top flange width)
$g = 0\text{ mm}$
$G_{min} = (4)(65\text{ mm}) + (4)(0\text{ mm}) = 260\text{ mm}$
$G_{max} = 260\text{ mm} + 375\text{ mm} = 635\text{ mm}$
$G_{20C} = G_{min}$ + Total closing movement from temperature rise
$= 260\text{ mm} + 1.15(99\text{ mm}) = 374\text{ mm} \rightarrow \underline{\text{Use 375 mm}}$.
$G_{5C} = 375\text{ mm} + [(20°\text{C} - 5°\text{C})/(20°\text{C} + 15°\text{C})] \cdot (76\text{ mm} + 38\text{ mm}) = 424\text{ mm}$
$G_{30C} = 375\text{ mm} - [(30°\text{C} - 20°\text{C})/(50°\text{C} - 20°\text{C})] \cdot (66\text{ mm} + 33\text{ mm}) = 342\text{ mm}$

Check spacing between center beams at minimum temperature:

$$G_{-15C} = 375\text{ mm} + 221\text{ mm} = 596\text{ mm}$$

$$\text{Maximum spacing} = [596\text{ mm} - (4) \cdot (65\text{ mm})]/5 = 67\text{ mm} < 90\text{ mm} \qquad \text{OK}$$

Check spacing between center beams at 20°C for seal replacement:

$$\text{Spacing} = [375\text{ mm} - 4(65\text{ mm})]/5 = 23\text{ mm} < 40\text{ mm}$$

Therefore, center beams must be mechanically jacked in order to replace strip seal elements.

Conclusion
Use a MBEJ with a 375 mm movement rating. Installation gaps measured face to face of edge beams at installation temperatures of 5, 20, and 30°C are 424, 375, and 342 mm, respectively.

25.7 Construction and Maintenance

In conjunction with appropriate design procedures, the long-term performance and durability of expansion joint systems require the synergistic application of high-quality fabrication, competent construction practices, assiduous inspection, and routine maintenance. Expansion joint components and connections experience severe loading under harsh environmental conditions. An adequately designed system must be properly manufactured, installed, and maintained to assure adequate performance under these conditions. The importance of quality control must be emphasized. Contract drawings and specifications must explicitly state design, material, fabrication, installation, and quality control requirements. Structural calculations and detailed fabrication drawings should be submitted to the bridge designer for careful review and approval prior to fabrication.

Experience and research will continue to improve expansion joint system technology [10,11]. It is vitally important that design engineers keep abreast of new technological developments. Interdisciplinary and interagency communication facilitates exchange of important information. Maintenance personnel can furnish valuable feedback to designers for implementation in future designs. Designers can provide valuable guidance to maintenance personnel with the goal of increasing service life. Manufacturers furnish designers and maintenance crews with guidelines and limitations for successfully designing and maintaining their products. In turn, designers and maintenance personnel provide feedback to manufacturers on the performance of their products and how they might be improved. Communication among disciplines is key to improving long-term performance and durability.

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