Steel Bridge Design Handbook

CHAPTER 15

Bearing Design

February 2022

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Foreword

The Steel Bridge Design Handbook covers a full range of topics and design examples to provide bridge engineers with the information needed to make knowledgeable decisions regarding the selection, design, fabrication, and construction of steel bridges. The Handbook has a long history, dating back to the 1970s in various forms and publications. The more recent editions of the Handbook were developed and maintained by the Federal Highway Administration (FHWA) Office of Bridges and Structures as FHWA Report No. FHWA-IF-12-052 published in November 2012, and FHWA Report No. FHWA-HIF-16-002 published in December 2015. The previous development and maintenance of the Handbook by the FHWA, their consultants, and their technical reviewers is gratefully appreciated and acknowledged.

This current edition of the Handbook is maintained by the National Steel Bridge Alliance (NSBA), a division of the American Institute of Steel Construction (AISC). This Handbook, published in 2021, has been updated and revised to be consistent with the 9th edition of the AASHTO LRFD Bridge Design Specifications which was released in 2020. The updates and revisions to various chapters and design examples have been performed, as noted, by HDR, M.A. Grubb & Associates, Don White, Ph.D., and NSBA. Furthermore, the updates and revisions have been reviewed independently by Francesco Russo, Ph.D., P.E., Brandon Chavel, Ph.D., P.E., and NSBA.

The Handbook consists of 19 chapters and 6 design examples. The chapters and design examples of the Handbook are published separately for ease of use, and available for free download at the NSBA website, www.aisc.org/nsba.

The users of the Steel Bridge Design Handbook are encouraged to submit ideas and suggestions for enhancements that can be implemented in future editions to the NSBA and AISC at solutions@aisc.org.

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8. Abstract Steel bridge bearings may be divided into three general types: elastomeric bearings, high-load multi-rotational bearings, and mechanical bearings. The designer must determine which bearing type is best suited to cost effectively accommodate the design requirements. This chapter of the Handbook provides practical information for efficient bearing design and detailing.	
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Steel Bridge Design Handbook: Bearing Design

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1.0 INTRODUCTION

Steel bridge bearings may be divided into three general types: elastomeric bearings, high-load multi-rotational bearings, and mechanical bearings. The designer must determine which bearing type is best suited to cost effectively accommodate the design requirements. This volume of the Handbook provides practical information for efficient bearing design and detailing.

2.0 BEARING TYPES

Steel bridge bearings may be divided into three general types: elastomeric bearings, high-load multi-rotational bearings, and mechanical bearings. The designer must determine which bearing type is best suited to cost effectively accommodate the design requirements. Design of elastomeric bearings is typically the responsibility of the design engineer whereas for most high-load multi-rotational (HLMR) bearings the designer only performs a preliminary sizing for the purpose of providing sufficient space to accommodate the overall height of the bearing system and the footprint of the anchor bolts, masonry plate, and sole plate/upper plate while the manufacturer performs the detailed design of the bearing assemblies.

2.1 Elastomeric Bearings

Plain, steel reinforced, and cotton duck elastomeric bearing pads are the three predominant elastomeric bearing styles designed and supplied in the USA.

Glass fiber reinforced elastomeric bearings are similar to steel reinforced elastomeric bearings, but due to the sudden failure characteristics of the fiberglass, their compressive stresses are limited. Glass fiber reinforced bearings have not demonstrated economic advantages over steel reinforced bearings and are not widely used.

2.1.1 Plain Pads

Plain elastomeric bearing pads (PEP) rely upon friction at the contact surfaces to resist bulging. Local slip resulting from friction loss leads to increased strain, thus limiting the load carrying capacity of the bearing. The permissible compressive stress is a function of the shape factor (i.e., the bearing plan area divided by the area of perimeter free to bulge), so plain pads must be relatively thin to carry any reasonable compressive load, and therefore can accommodate only small horizontal translations and rotations.

2.1.2 Steel Reinforced Elastomeric Bearings

Steel reinforced elastomeric bearings rely upon both contact surface friction and restraint of the bonded internal steel shims to resist elastomer bulging (see Figure 1). The use of several thin, uniformly spaced elastomer layers allow for both higher design compressive stresses and higher translation and rotation capacity than PEPs.

The shape factor, which varies with modifications to plan dimensions and layer thickness, affects compressive and rotational stiffness that controls the stress in the steel shims and elastomer strain. It does not affect the translational stiffness or the deformation capacity.

Steel reinforced elastomeric bearings can handle larger rotations and translations than other elastomeric bearings by employing multiple elastomer layers, but the design must satisfy stability requirements.

Figure 1 Elastomeric Bearing (courtesy R. J. Watson)

2.1.3 Cotton Duck Bearings

Cotton duck reinforced Pads (CDP), or fabric-reinforced bearings, are fabricated by vulcanizing very thin layers of elastomer with cotton fabric weave. They have an overall Shore ‘A’ durometer hardness in excess of 90, which is stiff against shear and rotation and can accommodate high compressive loads. Because of their resistance to translation, they are commonly used with a PTFE sliding surface and do not require a metallic substrate between the PTFE and the CDP.

2.2 High-Load Multi-Rotational (HLMR) Bearings

Pot, disc and spherical bearings currently make up the readily available variety of HLMR bearings that sustain high loads and are able to rotate in any direction. They can be fixed or, when fabricated with sliding surfaces, they can accommodate translation for use as expansion bearings. In that scenario, the bearing can be configured to allow translation in all directions, or guide bars can be used to restrict movement to one direction. Information, including design recommendations, figures and standard design tables, are readily available for the more common types of HLMR bearings in literature from manufacturers as well as their websites.

2.2.1 Pot Bearings

Pot bearings subject a confined elastomeric element (disc) to high pressures, effectively causing the disc to behave as a fluid (see Figure 2). The neoprene or natural rubber elastomeric disc is confined within the machined pot plate. The vertical force is transmitted to the elastomeric disc via the piston, which seats within the pot. Tight fitting brass sealing rings prevent the elastomer from escaping in the gap between the piston and the pot. Horizontal forces are resisted by contact of the piston face width against the pot wall. The vertical and horizontal loads are transmitted from the piston and pot to the sole and masonry plates through bearing and by mechanical connections. Several Owner-agencies still specify the use of pot bearings to fill their HLMR bearing needs, but many others allow disc bearing alternates or have abandoned pot bearings all together due to durability/maintenance issues with the various mechanical parts associated with the piston, the machined pot plate, and the sealing rings.

Figure 2 Pot Bearing (courtesy HDR)

2.2.2 Disc Bearings

Disc bearings subject an unconfined elastomeric disc to high pressures (see Figure 3). The polyether urethane disc is stiff against compression and rotation but is free to bulge. Horizontal forces are transmitted from an upper load plate to either a shear pin at the center of the disc, or to a restricting ring. The latter is similar in detail to the pot bearing, except that the disc is unconfined with no requirement for sealing rings. If a restricting ring configuration is used, a positive locator device is supplied. The shear pin serves this purpose when it is used to resist the horizontal loads. Disc bearings represent a simpler alternative to pot bearings and spherical bearings and have become more popular due to their relatively low cost, durability, and reduced maintenance demands.

Figure 3 Disc Bearings (courtesy R. J. Watson)

2.2.3 Spherical Bearings

Spherical bearings transmit all loads, both vertical and horizontal, through the spherical coupling of a convex and concave plate. This interface is typically a mating of low coefficient of friction PTFE and stainless steel. All vertical loads are assumed to be transmitted radially through the interface and all horizontal loads are resisted by the spherical geometry of the plates. Spherical bearings are often more expensive than other HLMR bearing options due to their complicated fabrication requirements.

2.3 Mechanical Bearings

Mechanical bearings (incorporation of bronze plates is included) or steel bearings distribute forces, both vertical and horizontal, through metal-to-metal contact. Most fixed bearings rely upon a pin or knuckle to allow rotation while restricting translational movement (see Figure 4). Rockers, rollers, and sliding types are common expansion styles historically used and under certain circumstances are still used today.

The metal-to-metal contact typically results in corrosion and eventual "freezing" of the bearing components. Lubricants have been used to mitigate corrosion, but trap debris, which in turn holds moisture and promotes corrosion. Mechanical bearings should not be specified for new designs except under special circumstances. For example, this bearing type might be used in bridge widening projects where existing bearing styles must be matched. Steel rocker and roller bearings are also still used in some railroad bridges.

Figure 4 Fixed Mechanical Bearing (courtesy HDR)

3.0 BEARING DESIGN REQUIREMENTS

3.1 Loads, Rotation and Translation

Compressive loads include structure dead loads and traffic live loads. Impact does not need to be considered for many bearing types. Elastomeric bearings are designed for unfactored service loads in accordance with the *AASHTO LRFD Bridge Design Specifications, 9th Edition (2020)* (referred to herein as AASHTO LRFD BDS) [1]. HLMR bearings designed in accordance with the AASHTO *Standard Specifications for Highway Bridges, 17th Edition* [2] require unfactored load combinations from Section 3, and those designed in accordance with the AASHTO LRFD BDS require factored service vertical loads in addition to applicable strength and extreme horizontal forces. Steel bearings should be designed for the same loads as HLMR bearings, but the vertical loads should also include impact. In the case of multirotational bearings, the minimum load on the bearing cannot be less than 20% of the vertical design capacity.

Horizontal loads to the bearing resulting from wind loads, braking forces, centrifugal forces, restraint of deformations or translations (due to temperature changes or other displacement-driven loading effects), or Extreme Event I (Seismic) loading should be determined by analysis of the structure. Elastomeric bearings are to be checked for resistance to shear deformation (in both directions in the case of rectangular pads, and in the direction of the resultant of horizontal forces in the case of circular bearings) where the deformation is determined based on the magnitude of the calculated horizontal force and the shear stiffness of the bearing. If the horizontal loads exceed the shear resistance of the bearing then consideration should be given to a method (internal or external to the bearing) that will resist the additional force.

In the case of HLMR and mechanical bearings, the strength limit-states horizontal loads specified for bearing design are determined as the larger of the calculated design forces at the strength and extreme event limit-states or 15% of the maximum vertical design load at the service limit state. The commentary in the AASHTO LRFD BDS explains that the 15% factor applied to the service limit state vertical load is meant to approximate a strength limit state load factor.

Bearings are required to accommodate rotational and translational demands. The sources of these movements include secondary effects of gravity loading which result from bridge skew and curvature and also include initial camber, beam grade, temporary construction loads and movements, misalignment, construction tolerances, support settlement, and deformation-driven loading effects such as thermal expansion and contraction. AASHTO LRFD BDS provide direct requirements for the determination of some of these effects, such as temperature ranges and bearing rotational construction tolerances, and provide indirect requirements for determination of other effects, such as provisions for gravity loads like dead load and live load effects, the effects of which on rotations and translations must then be determined by the engineer by analysis of the behavior of the structure.

Whether or not the bearing is intended to resist movement, the bearing, connections and substructure units should be designed to transfer the forces imparted by the bearings' resistance to movement. Elastomeric bearings resist movement by shear stiffness. Additionally, the frictional forces of steel bearings and bearings utilizing PTFE/stainless steel sliding surfaces should be considered. The design coefficients of friction should be examined at all compressive load levels and the expected low temperature.

3.2 Design Requirements

This section discusses the application of AASHTO LRFD BDS and recommends considerations for design.

3.2.1 Elastomeric Bearings

Steel reinforced elastomeric bearings can be designed by either the AASHTO LRFD BDS Method 'A' (Article 14.7.6) or Method 'B' (Article 14.7.5). The stress limits associated with Method A usually result in a bearing with a lower capacity than a bearing designed using Method B. This increased capacity resulting from the use of Method B requires additional testing and quality control (Article C14.7.5.1). Designers need to specify which method is used in the bearing design to verify fabrication and quality control complies with the appropriate requirements.

Other elastomeric bearings [plain elastomeric pads (PEP), fiberglass-reinforced pads (FGP), and cotton duck fabric pads (CDP)] must be designed in accordance with AASHTO LRFD BDS Method 'A'.

Shear modulus (G) is a critically important material property in the design and performance of elastomeric bearings. The designer should use the minimum and maximum values of G for various durometer hardness as shown in AASHTO LRFD BDS. Fabricators have compounds for different durometer hardness, which in turn have average shear moduli. Although it is possible to specify the elastomer by a shear modulus, check with fabricators to obtain their shear modulus limits. If the elastomer is specified by its shear modulus, AASHTO LRFD BDS allows the fabricator to provide a measured shear modulus within 15% of the value specified. Instead, elastomers are typically specified by durometer hardness only. Therefore, no reference to a required shear modulus should be stated if specifying durometer hardness, and vice versa. If specifying the elastomer based on durometer, designers must consider that a range of shear modulus can be expected (as shown in AASHTO LRFD BDS Table 14.7.6.2-1) and must consider the least favorable value (maximum or minimum) for each step in the bearing design.

Elastomeric bearings cannot be set with an initial offset to account for varying temperatures at the time of installation. When an initial offset is necessary, the designer should make provisions by multiplying the design translation by a minimum factor of safety of 1.5 or verify that the contractor is required to reset the bearing. For bearings that must be reset, the contract documents should include a note similar to that found in the Ohio Department of Transportation Construction and Material Specifications [3], "If the steel is erected at an ambient temperature higher than 80 °F or lower than 40 °F and the bearing shear deflection exceeds one-sixth of the bearing height at 60 °F ± 10 °F, raise the beams or girders to allow the elastomeric bearings to return to their undeformed shape at 60 °F ± 10 °F." If the elastomeric bearing includes a sliding surface, the designer should indicate, in the contract plans, the initial offset from centerline to use during erection/installation depending on temperature.

Some states require elastomeric bearings to be designed for one-way translation equal to the movement expected through the entire high-low temperature range. This is very conservative, but allows the bearing to be set at any temperature without requiring it to be reset at a given mid-range temperature.

AASHTO LRFD BDS C14.4.2 requires the design rotation for elastomeric bearings to be the sum of the rotations due to all unfactored loads and an allowance for uncertainties, taken as 0.005 radians (unless an approved quality control plan justifies the use of a smaller value). AASHTO LRFD BDS also requires that sole plates be beveled to produce a level-bearing surface at the top of the elastomeric bearing when the underside of the girder, under the full dead load and at the mean annual temperature, is out of level by more than 0.01 radians (1%). This implies that beveled sole plates are not required if the out of plane rotation is less than 1%. If the designer elects not to use beveled sole plates (see discussion on sole plates later in this volume) at slopes less than or equal to 1.0%, then the additional permanent rotation induced by the out of plane condition must be added into the required design rotation sum, including the 0.005 radian allowance for uncertainties.

Elastomeric bearings have also been used in the design of seismic isolation systems. Refer to AASHTO *Guide Specifications for Seismic Isolation Design* [4] for design, fabrication and quality control tests supplementary to the Standard Specifications.

3.2.2 HLMR Bearings

AASHTO LRFD BDS Article 14.7.4 has detailed design requirements for pot bearings. The code also allows for the design of internal pot components following accepted engineering principles. These include but are not limited to using failure theories (Von Mises Theory, Mohr's Theory, etc.) for the calculation of pot wall thickness for square pots.

Flat brass sealing rings used with pot bearings are available in 0.125 in. increment widths but the available thickness is less diversified; therefore the fabricator may use more than the minimum required number of rings to achieve the required overall thickness. Brass sealing rings shall conform to ASTM B36 (half hard) for rings of rectangular cross-section and Federal Specification QQB626, Composition 2 for rings of circular cross-section in accordance with AASHTO LRFD BDS.

Less guidance is provided in AASHTO LRFD BDS for the design of spherical bearings. For a complete description of PTFE/Spherical bearing design theory and a design example, the reader is directed to the California Department of Transportation (Caltrans) "Memo to Designers 7-1" [5]. This Caltrans document cautions that the maximum radius of the mating convex and concave plates should not exceed 36 inches due to manufacturing limitations. However, some manufacturers are able to achieve radii in excess of this limitation.

The memo also states that for horizontally restrained bearings, the ratio of the maximum horizontal force to the minimum vertical force should not exceed 0.40 to avoid overstressing the PTFE fabric at the spherical interface. If this criterion cannot be met, alternate means to transfer the horizontal forces should be employed. As the spherical cap of the concave plate approaches hemispherical, it becomes increasingly difficult to fabricate and bond the woven fabric PTFE from a single piece. If the ratio of the arc length of the cap to the base diameter of the cap exceeds 1.15, it may be necessary to fabricate the woven fabric PTFE from multiple pieces. FHWA Structural Committee for Economical Fabrication (SCEF) *Standard 106, High Load Multi-Rotational Bearings* [6], offers assistance to bridge design engineers specifying disc bearings and other HLMR bearings, and includes a number of design equations for the elastomeric disc.

In addition to the design rotation determined by the engineer, AASHTO LRFD BDS requires that both disc and pot bearings are designed with a rotational tolerance for construction. A second rotational tolerance for pot bearings is also required to account for installation and fabrication as the pot bearings are more likely to experience hard contact between metal components because there are numerous metal components surrounding the load element and they are in close proximity to each other. AASHTO LRFD BDS recognizes the efficiency of disc bearings in resisting vertical load and accommodating rotational demands and, although they are not subject to the additional rotational tolerance for fabrication and installation like pot bearings, requires that they be proportioned to avoid hard contact between metal components under the least favorable combination of displacements and rotations at the strength limit state. This provision is intended to avoid designs with such low profile that the metal components might make contact and prevent further rotation or displacement under certain conditions.

SCEF requires that the shear restriction mechanism be designed to withstand the design horizontal forces without exceeding the shear, bending, and bearing capacities, excluding the shear resistance of the disc. AASHTO LRFD BDS similarly requires that the shear resisting mechanism transmit horizontal forces between the upper and lower steel plates. The shear resistance of the urethane elastomeric element cannot be included to resist horizontal forces because the resistance from the disc is reduced as the vertical load decreases.

3.2.3 Mechanical Bearings

Limited design information is also provided in AASHTO LRFD BDS for mechanical (steel) bearing design (Article 14.7.1). Mechanical bearings such as metal bolsters, metal rockers, and roller bearing assemblies are viewed by many as an outdated system with high initial costs and costly long term maintenance requirements.

4.0 BEARING STYLE SELECTION GUIDELINES

In this section, requirements and appropriateness of bearing styles are discussed with respect to design and fabrication.

4.1 Design Limitations

Each bearing style has practical limitations that make it more or less suitable for a particular design situation than another style. The practical limitations discussed below are not absolute and the designer must verify compliance with AASHTO LRFD BDS as the limitations are often adjusted with updates and revisions to the Specifications.

Compressive forces in plain elastomeric pads (PEP) will generally be limited to approximately 100 kips for practical bearing sizes. Practical limitations for rotation and translation are very small, on the order of 0.01 radians and 0.5" respectively.

For cotton duck pads, design compressive forces should generally be limited to approximately 315 kips for practical bearing sizes. Reasonably, rotation is limited to approximately 0.003 radians, and movement without PTFE bonded to the upper surface, is limited to approximately 0.2". Currently, the use of CDP is limited by the low rotational capacity due to relatively large compressive strains at the service limit stress.

Steel reinforced elastomeric bearings designed in accordance with the AASHTO LRFD BDS Method 'A' are treated as plain elastomeric pads under Method 'A'. Steel reinforced elastomeric bearings designed using Method 'B' often result in bearings with a higher capacity than those designed with Method 'A'. Steel reinforced elastomeric bearings with practical proportions are typically limited to compressive forces in the range of approximately 50 – 800 kips when designed using Method 'B.' A practical limitation for translation, based on stability and economics, is in the order of 4 inches without the addition of a sliding element, and rotation is generally limited to 0.04 radians.

Typically, steel reinforced elastomeric bearings are designed for conditions in which the direction of movement and live load rotation is along the same axis and therefore, rectangular shapes are suitable. For horizontally curved structures and short span highly skewed structures, these directions may not coincide, or their directions may not be easily defined. In these instances, circular bearings may be considered since they easily accommodate translation and rotation in any direction although rectangular pads work fine.

For any style of elastomeric bearing, if a sliding element is provided, the bearing must be designed to accommodate the expected bearing translation as the result of frictional forces that build up prior to sliding. Friction is greatest at low temperatures and low compressive stresses. Therefore, the shear deformation resistance of the bearing must be greater than the translation expected from the frictional forces generated at the coldest expected temperature and the minimum vertical load condition. The engineer should confirm that for the expected highest friction coefficients that the bearing will, in fact, slide. Otherwise the bearing will be subjected to greater than permitted deformations and transmit higher forces than intended.

HLMR bearings designed for expansion with a PTFE/stainless steel sliding surface can nearly accommodate horizontal movements to whatever the requirement may be (see additional discussion later in this volume). Because of the stiffness of the elastomeric element, HLMR bearings should be limited to a rotation of 0.02 radians and are typically limited to a compressive force in the range of approximately 200 – 10,000 kips. If the anticipated minimum vertical load is 20% or less than the vertical design capacity of the bearing, HLMR bearings should not be used, in accordance with AASHTO LRFD BDS Article 14.6.1.

Given the higher bearing pressures passing through the HLMR bearing components, it is necessary to check the imposed concrete bearing pressures. AASHTO LRFD BDS permits the concrete bearing stress capacity to be increased by $(A_2/A_1)^{1/2}$, but not more than 2.0 (see Article 5.6.5).

4.2 Fabrication and Testing Limitations

Perhaps the single most limiting factor to contribute to a bearing style selection is the feasibility of the bearing to be fabricated and tested. Consideration should be given to the design compressive force and the testing force required, since the availability of domestic presses for testing may be limited.

Steel reinforced elastomeric bearings are molded in the presence of heat and pressure. The pressure required during the molding process is on the same order as that to which the bearing is designed. AASHTO *LRFD Bridge Construction Specifications, 4th Edition* (2017) [7] requires load testing to 150% of the maximum design stress, and often, the same press that was used to mold the bearing can be used to test it. The compressive stress controls the press that is required for testing, so if a press other than the one used to mold the bearing is required, free height available must be considered. Total bearing height must include vulcanized plates if required. Equipment available to mold and test bearings varies among fabricators. Designs that approach the recommended maximum compressive forces and translation limits should be verified with fabricators at an early stage in design.

HLMR bearings can often be stripped of upper and lower load plates to test the rotational elements and therefore, for testing purposes, are not necessarily subjected to the same bearing height issues as elastomeric bearings.

Very large bearings typically require large or thick plates, which can be machined to specified tolerances by a limited number of facilities. Plate availability varies depending on the thickness required. In general, plate material less than six inches in thickness is usually available. Required plate thicknesses in excess of six inches may require a special order, which adds significantly to the manufacturing time. ASTM A709, Grade 50 [A709M, Grade 345] is available only up to a purchase thickness of four inches. If greater than four-inch purchase thickness is required at the same strength, then ASTM A588/A588M should be specified or permitted. (In accordance with

Specification ASTM A709/A709M, Grade 50W [345W] is also included in Specification ASTM A588/A588M).

The convex plate of a spherical bearing is typically machined from a piece of solid stainless steel. A stainless steel surface may also be obtained by welding a specified thickness stainless steel overlay to a carbon steel plate. The surface is then machined to the desired finish. The typical and recommended specification for solid stainless steel is ASTM A240, Type 304. Solid stainless steel plate in excess of six inches may be difficult to procure in ASTM A240, Type 304 material. If it is required that the plate be solid stainless steel, other material specifications or the option of purchasing non-domestic material should be written into the specifications. Due to unavailability of solid stainless steel or long lead times to purchase foreign or alternate stainless steel material, allowing a stainless steel welded overlay should be considered as an option. Fabricators should be consulted to determine the manufacturing feasibility of large or unusual bearings.

5.0 COST EFFECTIVE DETAILING RECOMMENDATIONS

This section draws attention to commentary and details provided in AASHTO/NSBA G9.1-2022 *Steel Bridge Bearing Guidelines* [8] that should be considered during the design phase. All bearings should be considered replaceable. Provisions should be made during the design stage to verify that the superstructure and substructure can structurally and physically accommodate jacking and removal of each bearing element. Likewise, for HLMR bearings, the entire bearing, or internal elements of the bearing assembly (i.e. – pot, disc, concave and convex plates, etc.), should be designed for removal and replacement.

5.1 Anchorage to Structure

5.1.1 Sole Plates

A sole plate is a steel plate located on top of a bearing and attached to the bottom surface of the superstructure (for example, to the bottom side of the bottom flange of a girder). Sole plates serve many purposes, including distributing the reaction of the bearing to the superstructure element, accommodating construction tolerances between the location of the bearing and the location of the superstructure through a field-welded connection, providing a way to accommodate beam grades and cambers without introducing excessive rotational demand on bearings, and providing a convenient way to connect anchor bolts to the superstructure. Sole plates are not necessarily required when elastomeric bearings are used, but are often used to fulfil one or more of the above-listed functions.

Beveled sole plates should be used to produce a level bearing surface at the top of the elastomeric bearing when the underside of the girder, under the full dead load and at the mean annual temperature, is out of level by more than 0.01 radians (1%). In situations where girders may also be subject to layover (i.e., out-of-plumb) the use of sole plates beveled in two directions may be warranted. When a beveled sole plate is used, the change in thickness along the length of the sole plate should be at least 0.125 in. Fabricators have the resources to machine nearly any bevel requirement, but if the difference in plate thickness due to the bevel is as little as 0.125 in., it may be difficult for the contractor to differentiate the proper orientation of the plate. For these cases, the fabricator shall be required to mark the plate in some way to delineate the thick and thin ends. It is suggested that the designer include the bevel information in the contract documents.

Refer to AASHTO/NSBA G9.1-2022 for sole plate thickness requirements [8]. The minimum thickness of a beveled sole plate should not be less than 0.75 in. and the sole plate thickness should be determined such that it provides sufficient resistance to bending if the width of the elastomeric bearing extends significantly beyond the edges of the girder flange.

Sole plates are connected to the girders by welding or bolting. Welding is preferred because it allows for greater adjustment during installation or erection and is more economical. If bolted, it is desirable to use standard or oversized holes with a bolt and nut combination (as shown on AASHTO/NSBA G9.1-2022, Drawing Number E1.2, Option ‘A’) or tap through holes in the sole plate. If the sole plate is drilled and tapped for bolts within the imprint of the bearing components (as shown on Drawing Number E1.2, Option 'B'), the sole plate thickness should be designed to allow for an appropriate length of thread engagement per the recommendations of the Industrial Fasteners Institute (IFI) Technical Bulletin on Calculating Thread Strength [9]. Standard bolt lengths are in 0.25 in. increments. When the required bolt lengths vary, threaded studs with double nuts are another option (as shown on the right side of Option 'B' in the AASHTO/NSBA document). Additional plate thickness is required to account for the bottom portion of the hole unable to be tapped (generally 0.313 in. to 0.438 in. depending on the diameter) and the plate thickness to remain intact (usually 0.25 in. to 0.375 in.).

Vulcanizing to bond the sole plate to the elastomeric bearing is recommended when the design requires a positive connection between the sole plate and the bearing to prevent the bearing from "walking" (i.e., to prevent the bearing from slipping out of position under load).

For additional sole plate connection requirements and details unique to HLMR bearings, refer to AASHTO/NSBA G9.1-2022 [8]. For welded connections between the girder and sole plate, weld current shall not be permitted to pass between the sole plate and masonry plate to prevent fusion of metal-to-metal contact surfaces. Expansion bearings utilize a low coefficient of friction material sliding surface to accommodate longitudinal and transverse translations. To verify the bearing sole plate is either centered or offset at the proper location during installation/erection, the fabricator should mark the transverse (and longitudinal if required) centerlines of the upper and lower bearing assembly components.

5.1.2 Masonry Plates and Anchor Rods

A masonry plate is a steel plate located between the bottom of the bearing and the top of the substructure supporting the bridge. Masonry plates serve to distribute bearing reactions to the substructure concrete and to accommodate anchor bolts which attach the bearing to the substructure. Refer to AASHTO/NSBA G9.1-2004, Sections 1.4.5 and 2.4.6 for recommended design and detailing considerations [8]. Note that in all cases, the figures in AASHTO/NSBA G9.1-2004 show the bearings without a masonry plate.

In cases where the horizontal load in the bearing exceeds one-fifth the minimum vertical load due to permanent loads, the bearing should be secured against slippage. One way this can be achieved is by specifying that the bearing be shop vulcanized to bond the bearing to the masonry plate, which in turn is then anchored to the substructure. Although field epoxy bonding the bearing to the concrete surface would satisfy this requirement, bearings should never be epoxy bonded or adhesively bonded to the concrete bearing surface unless the elastomeric bearing has also been vulcanized to a sole plate. If the bearing is not vulcanized to a sole plate, and the epoxy bond between the bearing and the concrete fails, the bearing would be in a condition where only extremely low friction surfaces remain to prevent the bearing from "walking" (i.e., to prevent the bearing from slipping out of position under load).

AASHTO/NSBA G9.1-2022, Detail Sheets E1.1-E4.2 and H1.4-H1.9 provide anchor rod details and connections between the bearing and the substructure [8]. Anchor rods for HLMR bearings should generally be located beyond the imprint of the sole plate to facilitate installation and avoid interference with bearing components during movement and rotation. For HLMR bearings whose components are welded (as opposed to tightly fit within a machined recess) to the sole and masonry plates to allow for future bearing removal, the use of a headed "anchor" bolt, coupler and anchor rod is suggested. If the anchor assemblies are under the sole plate or other bearing component plates, provide sufficient clearance to install and remove the bolts . An example of this removable detail is presented in Figure 5. Heavy hex coupler nuts (DH or 2H) compatible with ASTM A563 or A194 nuts of the same grade are used to develop the full tensile capacity of the heavy hex bolt. If the headed "anchor" bolt is subject to tension, the entire anchor assembly and substructure should be designed to resist this tension.

Due to the large cost difference between heavy hex and standard grade coupler nuts, the contract documents must clearly state that the heavy hex grade is required. Otherwise, it is customary for fabricators to purchase the standard grade when the bearing resists only horizontal shear forces.

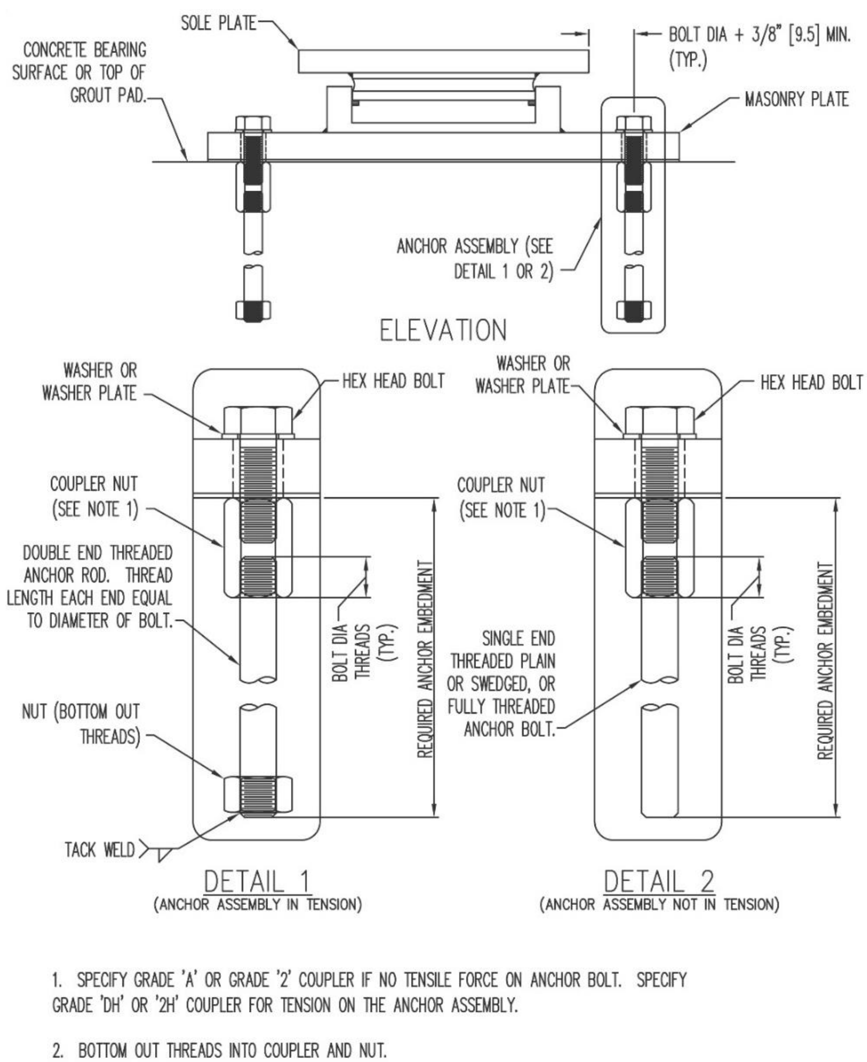


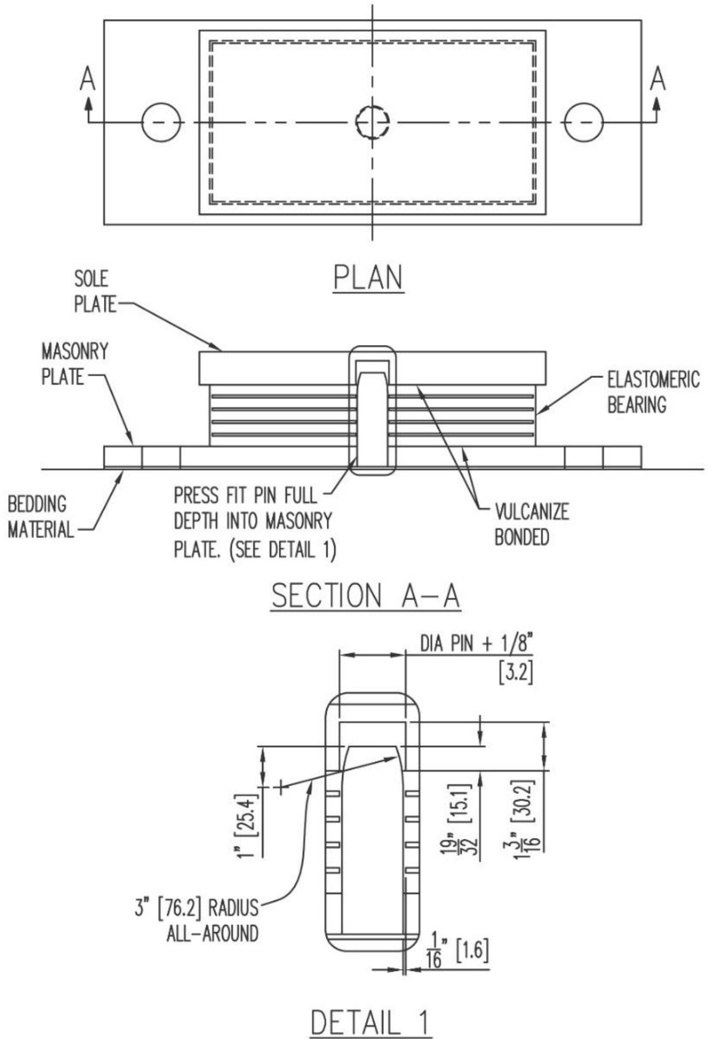
Figure 5 Sketch of a removable bearing detail.

5.2 Lateral Restraint

AASHTO/NSBA G9.1-2022, Detail Sheets [8] provide examples of approaches for laterally restraining elastomeric bearings. For expansion elastomeric bearings, if the restraint system is external to the bearing and stainless steel is required on the guiding system, there should be a corresponding low coefficient of friction material for it to mate. The stainless steel should completely cover the material in all movement extremes, and consideration must be given to vertical displacement due to construction and application of the dead loads.

Some states have incorporated a pin, internal to the bearing, to provide restraint in the horizontal direction. The anchor pin diameter is designed to resist the applied horizontal force, as should all other elements in the load path. The shear resistance of the elastomer can be included if the bearing is vulcanize bonded to the upper and lower plates. Generally, a 1.5 in. minimum anchor pin diameter is specified. As shown in Figure 6 (based on New York State Department of Transportation, Bridge Detail Sheet BD-BG2 R1) [10], the pin should be tapered at the top and should be received by an opening in the underside of the sole plate.

Longitudinally guided expansion bearings on structures with a horizontally curved alignment and structures with non-parallel girders should be guided in the same direction with respect to the centerline of the substructure where the line of bearings is installed. Guiding at differing directions will cause the bearings to bind. This effect is magnified by increased amounts of required movement. It is generally accepted for design purposes that the direction of movement for structures on a horizontally curved alignment is along the chord from the location of the center of no thermal movement to the expansion point. In continuous steel superstructure units with only one fixed pier, the center of no thermal movement can often be assumed to be located at that fixed pier; in structures with multiple fixed piers or other complicated longitudinal restraint conditions, a more refined analysis of the relative stiffness of the supports may be needed to determine the location of the center of no thermal movement. When warranted in unusual situations, the structure can be forced to move in any direction the designer chooses by careful arrangement of fixed, guided, and free bearings; however, the resulting forces must be accounted for in the design of the bearings, their anchorage, and the substructures.



1. THE DIAMETER OF THE PIN SHALL BE CHECKED FOR SHEAR DUE TO HORIZONTAL LOADS. THE MINIMUM PIN DIAMETER SHALL BE 1.5" [38.1 mm].

2. TOTAL RESISTANCE = ELASTOMER RESISTANCE + ANCHOR PIN RESISTANCE.

Figure 6 Sketch of a lateral restraint detail.

5.3 Uplift Restraint

Uplift due to service loads should be avoided, ideally by designing the bridge with a well-balanced span arrangement that avoids uplift at any supports. When such a span balance cannot be achieved, the strategic placement of additional dead load (ballast) may be the next preferred means of avoiding uplift. If uplift due to service loads cannot be averted, special bearings designed for uplift resistance (which are not addressed in the AASHTO LRFD BDS nor in this volume of the Handbook), are required.

Uplift forces due to construction loads should be offset either by revising the deck pouring sequence or restrained by means other than the bearing. The uplift restraint system for elastomeric bearings should be external to the bearing. This can be accomplished through the use of tie-down anchor rods from the superstructure to the substructure. Relatively low uplift forces due to construction loads or seismic events can often be economically accommodated in the design of HLMR bearings. For HLMR bearings, methods similar to those used with elastomeric bearings can be applied, or the bearing can be designed with attachments.

5.4 Miscellaneous

If a PTFE sliding element is required for an elastomeric bearing and the PTFE is the same plan dimensions as the elastomeric bearing, theoretically, a load plate between the PTFE and the elastomeric bearing is not required. However, the elastomeric bearing must also be stiff enough to provide a relatively rigid backing to support the PTFE material without significant deformation. AASHTO LRFD BDS requires that a load plate be used when the hardness of the elastomer is less than 90 durometer.

Generally, a protective coating of some kind is provided for the load plate. If the design load plate for this situation is thin (0.375 in. or less), it becomes impractical to apply a protective coating to the plate edges and depending on the size of the plate, using the galvanization process could significantly warp the plate. Consideration should be given to using stainless steel or uncoated weathering steel for this plate. Because of the importance of keeping sliding surfaces free of debris and damage, and the complexity of HLMR bearings with sliding surfaces, it is recommended that the protective coating system be applied in its entirety in the shop prior to field installation. Minimal field protective coating application is required and generally limited to faying surfaces that were shop primed only or bare.

A polished stainless steel surface is typically provided to interface with the PTFE material. The sliding required to accommodate thermal expansion and contraction or other movements of the superstructure occurs between the PTFE and the polished stainless steel surface. The polished stainless steel surface usually takes the form of a very thin stainless steel plate welded to a larger, thicker steel sole plate or upper plate. The stainless steel plate and sole/upper plate are sized to accommodate the anticipated movement range of the bearing; the length should be set generously to allow for uncertainty in the magnitude of the movements in either direction.

The AASHTO LRFD Bridge Construction Specifications, 4th Edition, (2017) Article 18.2.6, prohibits welding on exterior plates of elastomeric bearings unless 1.5 in. of steel exists between the elastomer and the weld, and also restricts the temperature of the steel adjacent to the elastomer to 400 °F while welding on the exterior plates [7]. During the molding process, the core temperature of the elastomer reaches approximately 240 °F and is held there for roughly 60 minutes. Therefore, for practical purposes the temperature of the steel adjacent to the elastomer should never exceed 200 °F, which is significantly less than the 400 °F limit allowed for welding in the AASHTO LRFD Bridge Construction Specifications. The temperature of the steel adjacent to the elastomer should be monitored by the use of pyrometric sticks or other suitable means.

AASHTO LRFD BDS requires that woven PTFE be attached to the metallic substrate by mechanical interlocking. The term “mechanical interlocking” refers to woven PTFE fabric without a reinforced interwoven backing being bonded to the metallic substrate, which has been machined to a grid-like surface. The code offers no guidance on the pattern or depth of the grid or other machining requirements. The purpose of the “mechanical interlocking” is to control creep in the same manner that recessing sheet PTFE controls creep and cold flow. Recessing woven PTFE serves no purpose. Woven PTFE is more commonly fabricated with strands of fiber reinforcing agents (e.g. Kevlar) interlocked into the strands of the PTFE to control creep. The fiber reinforcing serves as a means to mechanically interlock the PTFE to the metallic substrate. The strands should not come to the surface, nor should the epoxy adhesive used to bond the fabric to the steel.

When HLMR bearings are designed to accommodate translation with a sliding surface, the bearing manufacturer must assume that the girder has been stiffened sufficiently to resist bending and local buckling as the girder transitions through the full range of movement. In cases of very large movements, the use of “auxiliary” bearing stiffeners may be warranted. An auxiliary bearing stiffener is an additional bearing stiffener (or series of stiffeners) adjacent to the primary bearing stiffeners, located so that when a large movement occurs, there will still be a stiffener located above the bearing to strengthen the web of the girder and provide sufficient resistance to the bearing reaction.

6.0 INSPECTION AND MAINTENANCE

Elastomeric bearings and disc bearings are relatively low maintenance devices. Pot bearings and mechanical bearings tend to have more maintenance requirements. However, all bearings should be inspected in accordance with the most recent procedures set forth by FHWA's National Bridge Inspection Program or a more stringent state or local government policy.

Elastomeric bearings should be checked for over-translation. Because the total sum thickness of internal steel shims may be unknown at the time of inspection, if the translation (deviation from vertical) is half the total height of the bearing, the bearing should be considered past the allowable one way movement. For situations where the beam can slip infrequently to reach translation equilibrium on the bearing pad and not move the bearing pad off of the substructure support, lateral translation of up to half the thickness of the pad should not be a reason for concern.

Elastomeric bearings should also be checked for evidence that the bearing has "walked out" from under the beam or girder. Steel reinforced elastomeric bearings should be checked for any splitting or tearing. A small amount of bulging, splitting, or tearing in steel reinforced elastomeric bearings will not necessarily reduce the serviceability of the bearing pad unless the reinforcing becomes subjected to an excessively corrosive environment. Check the area where the pad is bonded to the sole and masonry plates, if applicable. Check for thickness variations that cannot be attributed to normal rotation of the bearing. Older elastomeric bearings may have been designed before the shape factor was included in the design. Therefore, check for excessive bulging (vertical faces of plain pads and vertical face of layers between steel laminates is near semicircular which may lead to splitting) and/or rolling of the bearing on the bridge seat or beam.

Any bearing with PTFE/stainless steel-sliding elements should be inspected for fragments of PTFE on the surrounding surface, which would indicate damage to the stainless steel, or encroachment of the stainless steel edge onto the PTFE surface. The stainless steel should be examined for scratching, weld spatter, grout, paint, and any other type of debris, which could cause damage to the PTFE and prevent proper function of the bearing. Examine the position of the stainless steel surface on the bearing to determine remaining movement capacity.

Pot bearings should be checked for failure of the sealing rings and leakage of elastomer from within the pot.

The elastomeric element of disc bearings should be checked for splitting, cracking, and excessive bulging.

Other elements (fasteners, anchors, bearing support, welds, etc.) of elastomeric and HLMR bearings should be examined as outlined in the governing bridge inspection manual.

7.0 REFERENCES

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