

Bridge Bearings: Types, Inspection and Replacement

Bearings are small, cheap compared with the girders they carry, and easy to ignore until one stops working. A frozen rocker, a pad that has walked off its seat or a pot bearing leaking elastomer can push forces into a substructure that was never designed for them. This course covers the three families of steel bridge bearings, how the AASHTO LRFD design requirements shape them, how to detail bearings so they can be replaced, how to inspect and code them using the AASHTO element definitions, and how to plan jacking and replacement. It draws mainly on the Steel Bridge Design Handbook, Chapter 15, Bearing Design (NSBA/AISC B915-22, February 2022, updated to the AASHTO LRFD 9th Edition from FHWA-HIF-16-002 Vol. 15), and on the AASHTO element definitions as reproduced in the Alabama DOT Bridge Element Inspection handbook (rev. 08/2014). Section numbers are given so you can check each point. Numbers in worked examples that do not come from these documents are labeled illustrative.

Learning objectives

- Identify bearing types
- Recognize bearing problems
- Understand elastomeric bearing design concepts
- Plan jacking and replacement

What a bearing has to do

A bridge bearing is the interface between the superstructure and the substructure. It has two jobs that pull in opposite directions. It must transfer forces, vertical reactions from dead and live load and horizontal forces from wind, braking, centrifugal action, restraint of thermal movement and earthquakes, into the pier or abutment. At the same time it must let the superstructure move where the design assumes it moves, rotating at the girder ends as load comes on and off, and translating as the deck expands and contracts with temperature.

The Steel Bridge Design Handbook, Chapter 15 (referred to here as SBDH Ch. 15), Section 3.1 lists the sources of rotation and translation a bearing must accommodate. They include the obvious ones, thermal expansion and contraction and live load end rotation, and several that designers sometimes forget: secondary effects of gravity loading caused by skew and curvature, initial camber, beam grade, temporary construction loads and movements, misalignment, construction tolerances and support settlement. AASHTO gives direct requirements for some of these, such as temperature ranges and rotational construction tolerances. For others, such as the rotations due to dead and live load, the engineer must find the effect by analyzing the structure.

A key principle from Section 3.1 applies whether or not a bearing is supposed to move: the bearing, its connections and the substructure should be designed to carry the forces created by the bearing's resistance to movement. An elastomeric pad resists translation through its shear stiffness. A steel sliding bearing or a PTFE (polytetrafluoroethylene) and stainless steel sliding surface resists through friction. SBDH Ch. 15 says the design coefficients of friction should be examined at all compressive load levels and at the expected low temperature, because that is where friction is highest.

This principle is also the key to inspection. A bearing that has stopped moving has not stopped the structure from trying to move. The thermal force that the bearing used to release now goes somewhere else: into anchor bolts, into a cracked bridge

seat, into a pier column bending about its base, or into the girder web over the support. Many of the bearing defects you will see in the field are evidence of that redirected force.

Fixed, expansion and guided

Every bearing is described by what it restrains. A **fixed** bearing allows rotation but no translation. An **expansion** bearing allows rotation and translation. An expansion bearing may be **guided**, restricted to movement in one direction by guide bars, or **non-guided** (floating), free to slide in any direction. SBDH Ch. 15 Section 2.2 describes exactly these configurations for high-load multi-rotational bearings: they can be fixed or, with sliding surfaces, used as expansion bearings that translate in all directions or, with guide bars, in one direction only. The AASHTO element definitions use the same vocabulary. Element 314, Pot Bearing, and Element 315, Disc Bearing, are defined as bearings that may be fixed against horizontal movement, guided to allow sliding in one direction, or floating to allow sliding in any direction.

The layout of fixed and expansion bearings along a bridge is a design decision that sets where thermal movement accumulates and which substructure units take longitudinal force. Before evaluating a bearing in the field, check the plans to learn which it is supposed to be. A rocker standing perfectly vertical on a hot afternoon is a problem at an expansion pier but means nothing at a fixed pier.

Elastomeric bearings

SBDH Ch. 15 Section 2 divides steel bridge bearings into three general types: elastomeric bearings, high-load multi-rotational (HLMR) bearings and mechanical bearings. It says the designer must decide which type best suits the design requirements at the lowest cost. Elastomeric bearings come first because they are by far the most common on short and medium spans.

Plain pads

Section 2.1.1 explains that plain elastomeric pads (PEP) rely on friction at their top and bottom contact surfaces to resist bulging. When the friction is lost locally, the pad slips and the strain increases, which limits the load the pad can carry. The permissible compressive stress depends on the **shape factor**, which the Handbook defines as the bearing plan area divided by the area of perimeter free to bulge. A thick pad has a large perimeter free to bulge and therefore a low shape factor, so plain pads must be relatively thin to carry any reasonable compressive load. Because they are thin, they can accommodate only small translations and rotations.

Steel reinforced elastomeric bearings

Section 2.1.2 describes steel reinforced elastomeric bearings as relying on both contact friction and the restraint of bonded internal steel shims to resist bulging. Splitting the elastomer into several thin, uniformly spaced layers raises the shape factor of each layer. The result is higher allowable compressive stress and, because the total elastomer thickness can be larger, higher translation and rotation capacity than a plain pad. The shape factor changes with the plan dimensions and the layer thickness. It controls compressive and rotational stiffness, and therefore the stress in the steel shims and the strain in the elastomer. The Handbook notes that it does not affect the translational stiffness or the deformation capacity, which depend on the total elastomer thickness. Using multiple layers lets these bearings take larger rotations and translations, but the design must then satisfy stability requirements, because a tall, narrow pad can become unstable.

Cotton duck and fiberglass pads

Section 2.1.3 describes cotton duck reinforced pads (CDP), also called fabric-reinforced bearings, made by vulcanizing very thin layers of elastomer with cotton fabric. Their overall Shore A durometer hardness exceeds 90, so they are stiff against

shear and rotation and can carry high compressive loads. Because they resist translation, they are commonly used with a PTFE sliding surface on top, and they do not need a metal plate between the PTFE and the pad. Glass fiber reinforced bearings resemble steel reinforced ones, but the Handbook says that because fiberglass fails suddenly, their compressive stresses are limited, they have not shown an economic advantage and they are not widely used.

Practical limits

SBDH Ch. 15 Section 4.1 gives practical limits, while warning that they are not absolute and must be checked against the current AASHTO specification:

- **Plain pads:** compressive force generally limited to about 100 kips for practical sizes; rotation and translation on the order of 0.01 radians and 0.5 inch.
- **Cotton duck pads:** compressive force generally limited to about 315 kips; rotation about 0.003 radians; movement without bonded PTFE about 0.2 inch. Their use is limited by low rotational capacity, caused by relatively large compressive strains at the service limit stress.
- **Steel reinforced (Method B):** compressive force roughly 50 to 800 kips for practical proportions; translation on the order of 4 inches without a sliding element, based on stability and economics; rotation generally limited to 0.04 radians.

Section 4.1 adds that rectangular pads suit bridges where movement and live load rotation are along the same axis. On horizontally curved structures and short, highly skewed spans, those directions may not coincide or may be hard to define, and circular bearings may be considered because they accommodate translation and rotation in any direction, although the Handbook notes rectangular pads also work.

Designing elastomeric bearings: Methods A and B

SBDH Ch. 15 Section 3.2.1 explains that steel reinforced elastomeric bearings can be designed by AASHTO LRFD Method A (Article 14.7.6) or Method B (Article 14.7.5). Method A's stress limits usually give a bearing with lower capacity. Method B gives higher capacity but requires additional testing and quality control (Article C14.7.5.1). The designer must state on the plans which method was used, so that fabrication and quality control can be checked against the right requirements. Plain pads, fiberglass reinforced pads and cotton duck pads must be designed by Method A. Section 4.1 adds that steel reinforced bearings designed by Method A are treated as plain pads under that method.

Section 3.1 notes that elastomeric bearings are designed for unfactored service loads under the AASHTO LRFD 9th Edition, and that impact does not need to be considered for many bearing types. Horizontal forces from wind, braking, centrifugal action, restraint of thermal movement or Extreme Event I should be found by analysis. Elastomeric bearings are checked for shear deformation in both directions for rectangular pads and in the direction of the resultant horizontal force for circular ones. If horizontal loads exceed the shear resistance of the bearing, a separate method, internal or external to the bearing, should be provided to resist the additional force.

Shear modulus and durometer

Section 3.2.1 calls the shear modulus G a critically important property. Designers should use the minimum and maximum G values for each durometer hardness shown in AASHTO (Table 14.7.6.2-1). Fabricators make compounds for different durometers, each with an average shear modulus. If the elastomer is specified by shear modulus, AASHTO allows the fabricator's measured value to be within 15% of the specified value. More commonly, the elastomer is specified by durometer hardness only. The Handbook's rule is to specify one or the other, never both. When specifying by durometer, the designer

must recognize that a range of G can be expected and must use the least favorable value, maximum or minimum, for each step of the design. For example, the minimum G gives the larger shear deformation under a given force, while the maximum G gives the larger force transmitted to the substructure for a given movement.

Rotation: the 0.005 radian allowance and beveled sole plates

Section 3.2.1 reports that AASHTO C14.4.2 requires the design rotation for elastomeric bearings to be the sum of rotations from all unfactored loads plus an allowance for uncertainties of 0.005 radians, unless an approved quality control plan justifies a smaller value. AASHTO also requires sole plates to be beveled to give a level bearing surface on top of the pad when the underside of the girder, under full dead load at the mean annual temperature, is out of level by more than 0.01 radians (1%). Beveled plates are therefore not required for slopes up to 1%. But if the designer skips the bevel at a slope of 1% or less, the permanent rotation from the out-of-level condition must be added to the design rotation, along with the 0.005 radian allowance.

Temperature at installation

An elastomeric bearing cannot be set with an initial offset to account for the temperature at installation. Section 3.2.1 gives two choices when an offset would be needed: multiply the design translation by a factor of safety of at least 1.5, or require the contractor to reset the bearing. For bearings that must be reset, the Handbook quotes a note from the Ohio DOT Construction and Material Specifications (Section 516.07): if the steel is erected at an ambient temperature above 80 °F or below 40 °F and the bearing shear deflection exceeds one-sixth of the bearing height at 60 °F $\pm$ 10 °F, raise the beams to let the bearings return to their undeformed shape at 60 °F $\pm$ 10 °F. Some states instead design elastomeric bearings for one-way translation equal to the movement over the entire high-to-low temperature range. The Handbook calls that very conservative but notes it lets the bearing be set at any temperature without a reset. If the elastomeric bearing includes a sliding surface, the plans should give the initial offset from centerline to use during erection for the installation temperature.

Sliding elements on elastomeric bearings

Section 4.1 warns that when a sliding element is added to any elastomeric bearing, the pad must accommodate the translation that develops from friction before sliding starts. Friction is greatest at low temperature and low compressive stress. The pad's shear deformation capacity must therefore exceed the translation produced by friction at the coldest expected temperature and the minimum vertical load. The engineer should also confirm that, at the highest expected friction coefficient, the bearing will actually slide. Otherwise the pad deforms beyond its limit and transmits more force than intended.

High-load multi-rotational bearings

When reactions grow beyond what elastomeric bearings can practically carry, or when rotations must be accommodated in any direction under high load, designers use high-load multi-rotational (HLMR) bearings. SBDH Ch. 15 Section 2.2 identifies three readily available types: pot, disc and spherical. All can be fixed, guided or non-guided.

Pot bearings

Section 2.2.1 explains that a pot bearing confines an elastomeric disc of neoprene or natural rubber inside a machined steel pot and loads it to high pressure, so that the disc behaves like a fluid. The vertical force passes to the disc through a piston that seats in the pot. Tight-fitting brass sealing rings keep the elastomer from escaping through the gap between piston and pot. Horizontal forces are resisted by contact between the piston face and the pot wall, and loads pass from piston and pot to the sole and masonry plates through bearing and mechanical connections.

The Handbook notes that several owners still specify pot bearings, but many now allow disc bearing alternates or have abandoned pots altogether because of durability and maintenance problems with the piston, the machined pot and the sealing rings. Section 3.2.2 adds design details: AASHTO Article 14.7.4 has detailed requirements for pot bearings, internal components may be designed with accepted engineering principles such as Von Mises or Mohr failure theories, flat brass rings are available in 0.125 inch width increments, and brass sealing rings must conform to ASTM B36 (half hard) for rectangular rings or Federal Specification QQ-B-626, Composition 2, for circular rings.

Disc bearings

Section 2.2.2 describes a disc bearing as an *unconfined* polyether urethane disc loaded to high pressure. The disc is stiff in compression and rotation but free to bulge. Horizontal force passes from the upper load plate either to a shear pin at the center of the disc or to a restricting ring. The restricting ring detail resembles a pot, but the disc is not confined and no sealing rings are needed; a positive locator device is supplied with it. The Handbook says disc bearings are simpler than pot and spherical bearings and have become more popular for their relatively low cost, durability and reduced maintenance.

Section 3.2.2 adds an important design rule: the shear-restricting mechanism must carry the design horizontal forces without counting on the shear resistance of the urethane disc, because the disc's resistance falls as vertical load falls. Both the FHWA Structural Committee for Economical Fabrication (SCEF) Standard 106 and AASHTO require this.

Spherical bearings

Section 2.2.3 explains that spherical bearings carry all loads through a convex and a concave plate that mate on a sphere, usually PTFE against stainless steel. Vertical loads are assumed to pass radially through the interface, and the spherical geometry resists horizontal load. They are often more expensive than other HLMR types because they are harder to fabricate. Section 3.2.2 notes AASHTO gives less guidance on spherical bearings and refers designers to Caltrans Memo to Designers 7-1. That memo cautions that the radius of the mating plates should not exceed 36 inches because of manufacturing limits, although some manufacturers exceed it. It also says that for horizontally restrained bearings, the ratio of maximum horizontal force to minimum vertical force should not exceed 0.40 to avoid overstressing the PTFE fabric at the spherical interface. If the arc length of the cap exceeds 1.15 times the cap's base diameter, the woven PTFE may need to be made from more than one piece.

Loads and limits for HLMR bearings

Section 3.1 states that HLMR bearings designed under AASHTO LRFD require factored service vertical loads plus the applicable strength and extreme event horizontal forces. The strength horizontal load for HLMR and mechanical bearings is the larger of the calculated strength and extreme event forces or 15% of the maximum service limit state vertical load. The AASHTO commentary explains that the 15% value approximates a strength load factor applied to the service load. For multi-rotational bearings, the minimum load on the bearing cannot be less than 20% of the vertical design capacity. Section 4.1 restates this: if the anticipated minimum vertical load is 20% or less of the bearing's vertical design capacity, HLMR bearings should not be used (AASHTO Article 14.6.1). The same section gives practical limits: HLMR bearings should be limited to a rotation of 0.02 radians because of the stiffness of the elastomeric element, and they typically carry compressive forces of about 200 to 10,000 kips. With a PTFE and stainless steel sliding surface, they can accommodate nearly any required horizontal movement.

Section 3.2.2 also notes that AASHTO requires both pot and disc bearings to include a rotational tolerance for construction, and pot bearings a second tolerance for installation and fabrication, because their many metal parts sit close together and are

more likely to make hard contact. Disc bearings do not carry the second tolerance but must be proportioned so that metal parts do not make hard contact under the least favorable combination of displacements and rotations at the strength limit state.

Mechanical bearings and why they freeze

SBDH Ch. 15 Section 2.3 defines mechanical, or steel, bearings, including those with bronze plates, as bearings that transfer vertical and horizontal forces through metal-to-metal contact. Most fixed mechanical bearings use a pin or knuckle to allow rotation while preventing translation. Expansion types historically included rockers, rollers and sliding plates, and some are still used under certain circumstances.

The Handbook is blunt about their weakness. Metal-to-metal contact typically leads to corrosion and eventual "freezing" of the bearing. Lubricants have been used to fight corrosion, but they trap debris, which holds moisture and promotes more corrosion. The Handbook concludes that mechanical bearings should not be specified for new designs except under special circumstances, for example a widening where the existing bearing style must be matched. Steel rocker and roller bearings are still used on some railroad bridges. Section 3.2.3 adds that AASHTO gives limited design information for mechanical bearings (Article 14.7.1) and that many view metal bolsters, rockers and roller assemblies as an outdated system with high first cost and costly long-term maintenance.

Section 3.1 notes that steel bearings should be designed for the same loads as HLMR bearings, but with vertical loads including impact.

What freezing does to the structure

Most bridge owners still have many mechanical bearings in service because they were standard on steel bridges for much of the twentieth century. When a rocker or roller freezes, the bearing becomes an unintended fixed point. As the superstructure tries to expand on a hot day, the frozen bearing either holds it, and the restraint force builds in the girder and the substructure, or it lets go suddenly and the rocker tips. Field signs include:

- A rocker tilted the wrong way for the air temperature, or tilted far beyond what the temperature explains.
- Pack rust between the rocker and its pintles or between rollers and the masonry plate.
- Bent, sheared or cracked anchor bolts and keeper plates.
- Cracked or spalled concrete at the bridge seat, especially at the front face and around anchor bolts.
- A pier column or bent that is out of plumb, or cracking at the base of a tall pier, suggesting it has been pushed longitudinally.
- Debris and corrosion products packed around the bearing.

Rocker tilt is the classic measurement. Recording the tilt and the air temperature at each inspection lets the engineer judge whether the bearing is following the temperature. A single reading tells you little; a series that shows the tilt staying constant from winter to summer shows the bearing is frozen. Under the AASHTO element definitions discussed later, restricted movement is coded under defect 2210, Movement, and tilt inconsistent with temperature under defect 2220, Alignment.

A tilted rocker is also a stability issue. A rocker has a limited range before it can tip off its bearing surface. If the tilt is approaching that limit, it is the kind of condition that may need prompt engineering review and possibly a critical finding under the owner's procedures; see *BR-I03, Critical Findings: Recognition, Reporting and Follow-Up*.

Choosing a bearing type

SBDH Ch. 15 Section 4 frames bearing selection around two kinds of limits: design limits, covered in the previous sections, and fabrication and testing limits, which the Handbook calls perhaps the single most limiting factor in selecting a bearing style.

Fabrication and testing limits

Section 4.2 explains that the designer must consider both the design compressive force and the force needed to test the bearing, because the availability of domestic test presses may be limited. Steel reinforced elastomeric bearings are molded under heat and pressure, and the molding pressure is of the same order as the design pressure. The AASHTO LRFD Bridge Construction Specifications, 4th Edition (2017), require load testing to 150% of the maximum design stress. Often the press that molded the bearing can test it. If a different press is needed, its free height must be checked, and the total bearing height must include any vulcanized plates. Equipment varies among fabricators, so designs that approach the recommended maximum force or translation should be checked with fabricators early.

HLMR bearings can often be stripped of their upper and lower plates so the rotational element can be tested alone, which eases the height problem. Very large bearings need large, thick plates that only a few shops can machine to tolerance. The Handbook notes plate under six inches thick is usually available, while thicker plate may be a special order that adds significantly to manufacturing time. ASTM A709 Grade 50 is available only up to a purchase thickness of four inches; for thicker plate at the same strength, ASTM A588 should be specified or permitted. The convex plate of a spherical bearing is usually machined from solid stainless steel, typically ASTM A240 Type 304, which may be hard to get over six inches thick. A stainless steel weld overlay on carbon steel, machined to finish, is an alternative the Handbook suggests allowing.

A practical selection sequence

Putting the Handbook's limits together gives a simple screening sequence for a new steel girder bridge. The numbers are the Handbook's practical ranges, not code limits, and must be checked against the AASHTO edition in use:

1. Find the service reactions (maximum and minimum), the design rotation including the uncertainty allowance and any out-of-level slope, and the design translation from the thermal range and other sources.
2. If the reaction is modest, rotation small and movement short, try a steel reinforced elastomeric bearing. Its practical range is roughly 50 to 800 kips (Method B), 0.04 radians and about 4 inches of translation without a slider.
3. If movement exceeds what the pad can take in shear, add a PTFE and stainless steel slider, and check the pad for the frictional translation that builds before sliding at the coldest temperature and minimum load.
4. If the reaction exceeds what an elastomeric bearing can practically carry, go to an HLMR bearing, with rotation under about 0.02 radians, and confirm the minimum load is more than 20% of the vertical capacity.
5. Among HLMR types, consider disc bearings for low cost and maintenance, pot bearings where the owner requires them, and spherical bearings for large rotations or special cases, accepting higher cost.
6. Avoid mechanical bearings on new work except where matching existing bearings on a widening.

Owner policy may override this sequence. Many DOTs have standard elastomeric bearing details and pre-approved HLMR suppliers, and some prohibit pot bearings. Always start with the owner's bridge design manual.

Detailing bearings so they can be replaced

SBDH Ch. 15 Section 5 opens with a principle every designer of new bridges should adopt: **all bearings should be considered replaceable**. During design, the engineer should verify that the superstructure and substructure can structurally and physically accommodate jacking and removal of each bearing. For HLMR bearings, either the whole bearing or its internal elements (the pot, disc, concave and convex plates and so on) should be designed for removal and replacement. The Handbook draws its detailing advice from the AASHTO/NSBA Steel Bridge Collaboration G9.1-2022, Steel Bridge Bearing Design and Detailing Guidelines.

Sole plates

Section 5.1.1 defines the sole plate as a steel plate on top of the bearing attached to the underside of the superstructure, typically the bottom flange. It distributes the bearing reaction to the girder, absorbs construction tolerances through a field-welded connection, accommodates beam grade and camber without adding rotation demand to the bearing, and gives a place to connect anchor bolts. Sole plates are not always needed on elastomeric bearings, but are often used for one of those purposes.

Beveled sole plates are used when the girder underside is out of level by more than 1% under full dead load at mean annual temperature. If the girder may also lean out of plumb (layover), a plate beveled in two directions may be warranted. The bevel should change the thickness by at least 0.125 inch along the plate; with a bevel that small it is hard to see which end is thick, so the fabricator must mark the thick and thin ends, and the bevel information should be in the contract documents. A beveled sole plate should be at least 0.75 inch thick, and thicker if the elastomeric bearing extends well beyond the edges of the flange and the plate must resist bending.

Sole plates are welded or bolted to the girder. The Handbook prefers welding because it allows more adjustment during erection and costs less. For bolted connections, it describes standard or oversized holes with bolt and nut, or tapped holes, with enough plate thickness for thread engagement per the Industrial Fasteners Institute guidance. Where a positive connection between sole plate and pad is needed to stop the bearing from walking, the Handbook recommends vulcanizing the sole plate to the bearing. When welding girder to sole plate, weld current must not pass between sole plate and masonry plate, to avoid fusing metal contact surfaces. On expansion bearings, the fabricator should mark the transverse (and if needed longitudinal) centerlines of upper and lower components so the sole plate can be set centered or at the correct offset.

Masonry plates and anchor rods

Section 5.1.2 defines the masonry plate as the plate between the bottom of the bearing and the top of the substructure. It spreads the reaction to the concrete and accommodates the anchor bolts. When the horizontal load on a bearing exceeds one-fifth of the minimum vertical load from permanent loads, the bearing should be secured against slipping, for example by shop vulcanizing the pad to a masonry plate that is anchored to the substructure. The Handbook warns that bearings should never be epoxy or adhesively bonded to the concrete unless the pad is also vulcanized to a sole plate. If the epoxy bond fails on a pad that is not vulcanized above, only very low friction surfaces remain to keep the bearing from walking.

For replaceability, anchor rods for HLMR bearings should generally sit outside the footprint of the sole plate, so they can be installed and do not interfere with bearing parts as the bearing moves and rotates. Where HLMR components are welded to the sole and masonry plates (rather than fit into a machined recess) to allow future removal, the Handbook suggests a headed "anchor" bolt, coupler and anchor rod (its Figure 5). If the anchor assembly lies under the sole plate or other plates, there must be clearance to install and remove the bolts. Heavy hex coupler nuts (DH or 2H) compatible with ASTM A563 or A194 nuts of the same grade develop the full tensile capacity of the heavy hex bolt. Because heavy hex couplers cost much more, the

contract documents must clearly require them; otherwise fabricators customarily buy standard grade when the bearing resists only horizontal shear.

Lateral restraint

Section 5.2 covers guiding. For expansion elastomeric bearings with external guides that use stainless steel, there should be a matching low-friction material, and the stainless should cover it at all movement extremes, allowing for vertical displacement as dead load is applied. Some states use a pin inside the bearing for horizontal restraint, designed for the applied horizontal force; the elastomer's shear resistance can be counted only if the bearing is vulcanized to upper and lower plates. A minimum pin diameter of 1.5 inches is generally specified, and the pin should be tapered at the top and received in an opening in the sole plate (its Figure 6, based on a NYSDOT detail).

On horizontally curved bridges and bridges with non-parallel girders, longitudinally guided bearings in a line should all be guided in the same direction relative to the substructure centerline. Guiding in different directions makes the bearings bind, and the effect grows with movement. For design, movement on a curved alignment is generally taken along the chord from the center of no thermal movement to the expansion point. In a continuous unit with one fixed pier, that center can often be assumed at the fixed pier; with several fixed piers a stiffness analysis may be needed. The designer can force movement in a chosen direction by arranging fixed, guided and free bearings, but must design the bearings, anchorage and substructure for the resulting forces.

Uplift

Section 5.3 says uplift under service loads should be avoided, ideally through a balanced span arrangement and, if that fails, by adding ballast. If service uplift cannot be avoided, special uplift bearings are needed, which neither AASHTO nor the Handbook addresses. Construction uplift should be handled by changing the deck pour sequence or by restraint outside the bearing. For elastomeric bearings the restraint should be external, such as tie-down anchor rods from superstructure to substructure. HLMR bearings can often take modest construction or seismic uplift economically through attachments.

PTFE sliding surfaces and field welding near elastomer

Many bearing problems found in the field start with the sliding surface or with heat during installation. SBDH Ch. 15 Section 5.4 covers both.

Sliding surfaces

The sliding that accommodates thermal movement happens between the PTFE and a polished stainless steel surface. The stainless is usually a very thin sheet welded to a thicker sole or upper plate. The Handbook says the stainless and the plate should be sized for the expected movement range, with length set generously to cover uncertainty in movement in both directions. Running the PTFE off the end of the stainless is one of the failure modes inspectors look for.

If a PTFE slider on an elastomeric bearing has the same plan size as the pad, a load plate between them is theoretically unnecessary, but the pad must be stiff enough to support the PTFE without significant deformation. AASHTO, as the Handbook reports, requires a load plate when the elastomer hardness is less than 90 durometer. Thin load plates (0.375 inch or less) are hard to coat at the edges and can warp if galvanized, so stainless steel or uncoated weathering steel may be considered. Because sliding surfaces must stay clean and undamaged, the Handbook recommends applying the complete protective coating in the shop, with minimal field coating limited to faying surfaces that were shop primed only or left bare.

Woven PTFE must be attached to its metal backing by mechanical interlocking. The Handbook explains that the purpose is to control creep and cold flow, the same reason sheet PTFE is recessed. Woven PTFE is more commonly made with reinforcing fibers such as Kevlar interlocked into the PTFE strands, and those fibers serve as the mechanical interlock. The strands and the bonding epoxy should not come to the surface.

For HLMR bearings with sliding surfaces, the manufacturer assumes the girder is stiffened to resist bending and local buckling as the reaction moves across the full range. For very large movements, the Handbook says auxiliary bearing stiffeners next to the primary stiffeners may be warranted, so that a stiffener is still over the bearing at the movement extreme.

Welding near elastomer

Bearing replacement often involves welding a new sole plate to an existing girder flange with the elastomeric bearing already in place. The Handbook reports that AASHTO LRFD Bridge Construction Specifications Article 18.2.6 prohibits welding on the exterior plates of elastomeric bearings unless there is 1.5 inches of steel between the elastomer and the weld, and limits the temperature of steel next to the elastomer to 400 °F. The Handbook then gives a more conservative practical limit. During molding, the elastomer core reaches about 240 °F for about 60 minutes. For practical purposes, the Handbook says, the steel next to the elastomer should never exceed 200 °F, much less than the 400 °F construction limit, and the temperature should be monitored with temperature-indicating crayons ("pyrometric sticks") or other suitable means. On a replacement project, write that limit and the monitoring method into the special provision.

Inspecting bearings: what to look for

SBDH Ch. 15 Section 6.0 states that elastomeric and disc bearings are relatively low maintenance devices, while pot bearings and mechanical bearings tend to need more maintenance. All bearings should be inspected under the current FHWA National Bridge Inspection Program procedures or more stringent state or local policy. The Handbook then gives specific checks by bearing type.

Elastomeric bearings

- **Over-translation.** Because the total thickness of internal steel shims is usually unknown in the field, the Handbook suggests that if the translation (the deviation of the pad's side from vertical) reaches half the total height of the bearing, the bearing should be considered past its allowable one-way movement. Where the beam slips infrequently to reach equilibrium on the pad without moving the pad off its support, lateral translation up to half the pad thickness should not be a reason for concern.
- **Walking.** Check for evidence that the pad has walked out from under the girder.
- **Splitting and tearing.** Check steel reinforced pads for splits or tears. The Handbook notes a small amount of bulging, splitting or tearing does not necessarily reduce serviceability unless the reinforcement is exposed to a very corrosive environment.
- **Bond to plates.** Check where the pad is bonded to sole and masonry plates.
- **Uneven thickness.** Look for thickness variations that normal rotation does not explain.
- **Older pads.** Some were designed before the shape factor was included in design. Look for excessive bulging, where the vertical faces of plain pads or of layers between shims are near semicircular and may split, and for rolling of the bearing on the seat or beam.

Sliding surfaces

Any bearing with PTFE and stainless steel should be checked for PTFE fragments on surrounding surfaces, which indicate damage to the stainless or the stainless edge running onto the PTFE. Examine the stainless for scratches, weld spatter, grout, paint and debris that can damage the PTFE and stop the bearing from working. Note where the stainless sits on the bearing to judge remaining movement capacity.

HLMR bearings

Check pot bearings for failed sealing rings and elastomer leaking from the pot. Check the elastomeric element of disc bearings for splitting, cracking and excessive bulging. Examine fasteners, anchors, bearing supports and welds of elastomeric and HLMR bearings as the governing inspection manual requires.

Mechanical bearings

Beyond the Handbook's general direction, the field signs of frozen or failing mechanical bearings covered earlier apply: corrosion and pack rust, tilt inconsistent with temperature, bent or broken anchor bolts and keepers, and cracked seats. The *BR-I07, Inspecting Steel Superstructures* and *BR-I08, Substructure Inspection* courses cover the girder end and bridge seat around the bearing, which is where much of the damage from a malfunctioning bearing shows up.

Always look past the bearing

A bearing defect is usually a symptom. A walked pad may point to an out-of-level seat, a missing bevel or a frozen bearing elsewhere in the line. A cracked bridge seat under a rocker may mean the rocker has been frozen for years. Leaking deck joints above are the most common source of the water, salt and debris that corrode bearings; see *BR-B02, Bridge Deck Joints: Performance and Replacement*. Record the air temperature, measure offsets and tilts, and photograph each bearing from the same position at each inspection so trends can be seen.

Coding bearings with AASHTO elements

Element-level inspection, introduced in *BR-I04, Element-Level Inspection Fundamentals (MBEI)*, treats each bearing as a counted element. The Alabama DOT Bridge Element Inspection handbook reproduces the AASHTO element and condition definitions used here. All bearing elements are National Bridge Elements (NBE), counted in units of EACH.

Element	Name	Definition (paraphrased)
310	Elastomeric Bearing	Bearings constructed primarily of elastomers, with or without fabric or metal reinforcement
311	Movable Bearing	Bearings that provide both rotation and longitudinal movement by rollers, rockers or sliding mechanisms
312	Enclosed / Concealed Bearing	Bearings enclosed so they are not open for detailed inspection; used for box girder hinges
313	Fixed Bearing	Bearings that provide for rotation only, with no longitudinal movement
314	Pot Bearing	High load bearings with confined elastomer; fixed, guided or floating
315	Disc Bearing	High load bearings with a hard plastic disk; fixed, guided or floating
316	Other Bearing	All other bearings regardless of translation or rotation constraints

For element 312, the commentary says that where the bearing material is not visible, the inspector should assess condition from alignment, grade across the joint, persistence of debris or other indirect indicators.

Bearing defects and condition states

The bearing condition state table uses these defects:

- **1000 Corrosion:** CS1 none; CS2 freckled rust, corrosion has initiated; CS3 section loss evident or pack rust present but not warranting structural review.
- **1020 Connection:** CS1 in place and functioning; CS2 loose fasteners or pack rust without distortion, still functioning; CS3 missing bolts or rivets, broken welds or fasteners, or pack rust with distortion, not warranting structural review.
- **2210 Movement:** CS1 free to move; CS2 minor restriction; CS3 restricted but not warranting structural review.
- **2220 Alignment:** CS1 lateral and vertical alignment as expected for the temperature; CS2 tolerable alignment that is inconsistent with the temperature; CS3 approaching the limits of lateral or vertical alignment for the bearing, not warranting structural review.
- **2230 Bulging, Splitting or Tearing:** CS1 none; CS2 bulging less than 15% of the thickness; CS3 bulging 15% or more of the thickness, splitting or tearing, or bearing surfaces not parallel, not warranting structural review.
- **2240 Loss of Bearing Area:** CS1 none; CS2 less than 10%; CS3 10% or more, not warranting structural review.
- **7000 Damage:** impact damage, with the specific damage captured under the appropriate material defect.

For every defect, CS4 (Severe) is the same: the condition warrants a structural review to determine its effect on strength or serviceability of the element or bridge, or a review has been done and found the defects do affect strength or serviceability.

Coding examples (illustrative)

These short examples show how the field observations map to defects. The bridges are hypothetical.

- A steel reinforced pad under a prestressed girder has walked so that about one-eighth of the girder's bearing length now overhangs the pad. That is roughly 12% loss of bearing area, so defect 2240 is CS3 unless the engineer decides a structural review is warranted.
- A rocker at an expansion pier is tilted toward the fixed pier on a cold morning, as expected, and the tilt is within the range shown on the plans for that temperature. Movement and alignment are CS1. The same rocker showing the same tilt on a hot afternoon months later would suggest restricted movement (2210) and alignment inconsistent with temperature (2220).
- A pot bearing shows a bead of extruded elastomer at the piston-pot gap. The element definitions do not have a defect named for elastomer leakage; agencies typically record it under the defect that best fits and describe it in the notes, and the Handbook identifies it as a sealing ring failure to check. Follow your agency's coding guidance.

Element data feed bridge management decisions; see *BR-S02, SNBI Condition, Inspection and Element Data*. Consistent coding of bearing movement and alignment over several cycles is what lets an owner program bearing work before the bearing damages the seat.

Worked example: is this pad over-translated? (illustrative)

This example uses illustrative numbers to show how the movement guidance fits together. It is not a design calculation.

Situation. A continuous steel girder unit has its fixed bearings at Pier 2. The expansion abutment is 200 feet from the fixed pier. The girders sit on steel reinforced elastomeric bearings with a total height of 3.5 inches. On an inspection at an air temperature of about 95 °F, the inspector measures the top of the pad offset 1.5 inches toward the abutment backwall relative to the bottom.

Expected thermal movement. Using an illustrative coefficient of thermal expansion for steel of 6.5×10^{-6} per °F and an illustrative design temperature range of 120 °F, the total movement at the abutment is about $6.5 \times 10^{-6} \times 200 \text{ ft} \times 12 \text{ in/ft} \times 120 \text{ °F} \approx 1.9$ inches over the full range. If the bearings had been set undeformed at a mid-range temperature, the one-way movement from that temperature would be about half of that, roughly 0.9 to 1.0 inch. An offset of 1.5 inches on a hot day is therefore more than temperature alone explains.

Compare with the guidance.

- The Handbook's inspection rule of thumb treats a pad as past its allowable one-way movement when the translation reaches half the total height. Half of 3.5 inches is 1.75 inches. The measured 1.5 inches is below that but close.
- The Ohio DOT reset note quoted in the Handbook uses one-sixth of the bearing height at $60 \text{ °F} \pm 10 \text{ °F}$ as the trigger for resetting bearings at installation. One-sixth of 3.5 inches is about 0.6 inch. That note governs construction, not inspection, but it shows the pad was probably not reset after erection, or that something else has pushed it.

What the engineer should do. The offset suggests the girders were erected at a high temperature without reset, or that the fixed point is not where the plans assume, for example because another bearing in the unit has frozen. The engineer should review the erection records, check the fixed pier bearings and other expansion bearings in the unit for restriction, and schedule a follow-up measurement on a cold day. If the winter reading shows the pad returning toward vertical, the bearing is working and was simply set off center. If not, the restraint is somewhere else in the unit. In element terms, the current observation is alignment inconsistent with the temperature (2220), coded CS2 or CS3 depending on how close the engineer judges it to the bearing's limits.

The lesson is that a single offset measurement is ambiguous. The temperature, the plan location of the fixed point, the bearing height and a second reading at a different temperature together make it meaningful.

Planning jacking and bearing replacement

Bearing replacement is one of the most common rehabilitation jobs on older steel bridges, usually replacing frozen rockers or rollers with elastomeric or HLMR bearings. The Handbook's principle that all bearings should be designed as replaceable, with structure and substructure able to accommodate jacking, describes what new bridges should provide. On older bridges, the engineer usually has to create that capacity. The steps below summarize common practice; jacking loads, stiffener design and lift limits must be determined for each bridge and are not given in the sources used for this course.

1. Establish why the bearing failed

Replacing a bearing without fixing the cause invites a repeat. Common causes are a leaking joint above, an out-of-level seat, a missing bevel, a fixed point in the wrong place or a frozen bearing elsewhere in the unit. If the joint above is leaking, replace or eliminate it in the same contract; see *BR-B02*. If the seat is cracked or spalled, plan the seat repair; see *BR-C02*, *Reinforced Concrete Bridge Repair Methods*.

2. Select the new bearing

Use the selection logic earlier in this course. On an existing bridge the available height between girder and seat often controls, because raising the girders permanently affects the deck profile, the joints and the approach. Elastomeric bearings with a sole plate are common replacements for rockers on moderate reactions. Check the new bearing for the restraint conditions it will impose: replacing a free rocker with a stiffer bearing changes the forces on the substructure and the anchorage.

3. Find jacking points and check the structure

The engineer must decide where the jacks go and check every element in the load path for the jacking condition. Typical options are jacking under the girder near the bearing with a temporary or added bearing stiffener, jacking under an end diaphragm or a jacking beam spanning between girders, or jacking from a temporary support tower when the seat cannot carry the jack. Checks usually include web crippling and local bearing at the jack, stiffener or diaphragm capacity, the jacking beam, the seat concrete bearing stress under the jack, and the effect of lifting one girder relative to its neighbors on the deck and cross frames. For concrete bearing under the jack and new masonry plates, the Handbook reports that AASHTO permits the concrete bearing resistance to be increased by the square root of A_2/A_1 , but not more than 2.0 (Article 5.6.5).

4. Specify the lift and its controls

The plans should state the maximum lift, the jacking load per point, whether adjacent girders are lifted together or one at a time, whether traffic is allowed on the span during jacking, and how the girder is supported if a jack fails, usually by stacked shims or lock-ring jacks that follow the lift. The deck and parapets act with the girders, so lifting one girder far beyond its neighbors can crack the deck. Many owners limit the lift and require that groups of girders be lifted together; follow the owner's standards for the actual values.

5. Remove and install

Removal of old rockers often means cutting anchor bolts and pintles and removing corroded keeper plates. Where the new sole plate is welded to the existing flange near an elastomeric bearing, apply the welding limits covered earlier: 1.5 inches of steel between weld and elastomer per the construction specification, and the Handbook's practical limit of 200 °F at the steel next to the elastomer, monitored with temperature-indicating crayons. Grout or shim the new masonry plate to the specified elevation, set expansion bearings at the offset the plans give for the installation temperature, and record the temperature and offset at completion as the baseline for future inspections.

6. Close out

Update the bridge file and the element inventory, since replacing a 311 movable bearing with a 310 elastomeric bearing changes the element record. Note the new bearing type, the installation temperature and offset, and the date. An inspector who later finds the pad offset will need those numbers to judge whether it is moving properly.

Summary checklist for owners and engineers

The following checklist pulls together the main points of this course. It is meant for review of designs, inspection reports and replacement plans.

New design

- Identify fixed, guided and non-guided bearings and the center of no thermal movement; on curved or splayed girders, guide all bearings in a line in the same direction.
- Include all sources of rotation and translation: thermal, live load, camber, grade, skew and curvature effects, tolerances and settlement.
- For elastomeric bearings: state Method A or B, specify durometer or shear modulus (not both), design with the least favorable G, include the 0.005 radian allowance, bevel the sole plate above a 1% slope, and address installation temperature by reset or the 1.5 factor.
- For HLMR bearings: confirm minimum load exceeds 20% of capacity, rotation within about 0.02 radians, horizontal design force at least 15% of service vertical load, and no reliance on disc shear resistance.
- Avoid mechanical bearings except to match existing work.
- Detail every bearing for replacement: jacking points, removable anchorage outside the sole plate footprint, heavy hex couplers where required, and generous stainless steel lengths.
- Check test press capacity and plate availability with fabricators early for very large bearings.

Inspection

- Record air temperature, offsets and rocker tilts every cycle, photographed from the same position.
- Elastomeric: over-translation (half the height as a rule of thumb), walking, splitting, bulging, bond to plates and uneven thickness.
- Sliding surfaces: PTFE fragments, contamination of the stainless and remaining travel.
- Pot: sealing ring failure and elastomer leakage. Disc: splitting, cracking and bulging of the disc.
- Mechanical: corrosion, pack rust, tilt inconsistent with temperature, anchor bolts and keepers, seat cracking.
- Code elements 310–316 with defects 1000, 1020, 2210, 2220, 2230, 2240 and 7000, and use CS4 when a structural review is warranted.

Replacement

- Fix the cause, especially leaking joints above, in the same contract.
- Check jacking load paths, seat bearing and differential lift effects.
- Control welding heat near elastomer and set expansion bearings for installation temperature.
- Update the element inventory and record baseline offsets.

Key takeaways

- A bearing must transfer forces and permit the movements the design assumes; when it stops moving, the force goes into anchor bolts, seats, piers and girders.
- SBDH Ch. 15 divides bearings into elastomeric, high-load multi-rotational (pot, disc, spherical) and mechanical types.
- Shape factor (plan area / perimeter area free to bulge) controls compressive and rotational stiffness of elastomeric layers, not their shear stiffness.
- Specify elastomer by durometer or by shear modulus, never both, and design with the least favorable G for each check.
- Elastomeric design rotation = unfactored load rotations + 0.005 rad; bevel the sole plate when the girder is out of level by more than 1%.
- HLMR bearings: limit rotation to about 0.02 rad and do not use them if minimum load is 20% or less of vertical capacity; horizontal design load is at least 15% of the service vertical load.

- Mechanical bearings corrode and freeze; they should not be used on new designs except special cases like matching an existing widening.
- Design every bearing to be replaceable, with jacking points and removable anchorage; code bearings with elements 310–316 and defects 2210–2240.

References

1. AASHTO, LRFD Bridge Design Specifications, 9th Edition, 2020
2. NCHRP Report 432, High-Load Multi-Rotational Bridge Bearings, 1999
3. FHWA, Bridge Inspector's Reference Manual (BIRM), FHWA-NHI-12-049, 2012 (as revised)
4. NSBA/AISC, Steel Bridge Design Handbook, Chapter 15: Bearing Design, Publication B915-22, February 2022 (update of FHWA-HIF-16-002 Vol. 15)
5. Alabama DOT Maintenance Bureau, Bridge Element Inspection (element and condition state definitions following the AASHTO Manual for Bridge Element Inspection), revised 08/2014

Study text only; the final quiz is taken online. Verify all references against the edition your agency has adopted.