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1 Bearings are Critical Element within overall Bridge Systems

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Introduction

Bearings are a critical element within overall bridge systems. Although they represent only a small part of the overall structure cost, they can potentially cause significant problems if they function improperly or if possible maintenance, retrofit, or replacement strategies are not envisioned and well planned at the design stage. Bridge superstructures exexperiences translational movements and end rotations caused by traffic loading, thermal effects, creep and shrinkage, wind and seismic forces, initial construction tolerances, and other factors. Bridge bearings are designed and built to accommodate these movements and rotations while supporting required gravity loads, transmitting those loads to the substructure, and providing necessary restraint for the superstructure. Proper functioning of bridge bearings is assumed in the analysis and design of overall bridge systems. Bearing failure or improper behavior can lead to significant changes in load distribution and overall structural behavior that are not accounted for in the design and can significantly affect the superstructure, substructure interaction.

This chapter describes various bearing types and provides information concerning factors affecting and increasing their service life. Methods for design for service life are discussed along with needs for future inspection, maintenance, and possible replacement. 1.2

Bearing types

Many bearing types have been developed, primarily to provide efficient, economical ways to accommodate various levels of load and movement. Each type has certain advantages and potential disadvantages. Table 1.1 identifies the commonly used bridge bearing types discussed in this chapter.

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Table 1.1. ***Bearing Types***

General Category	Bearing Type
Elastomeric bearings	Plain elastomeric pads
	Steel-reinforced elastomeric pads
	Cotton duck pads
Sliding bearings	Polytetrafluorethylene
	Alternative sliding materials
High-load multirotational bearings	Pot bearings
	Disc bearings
	Spherical bearings (cylindrical for unidirectional)
Fabricated steel mechanical bearings	Fixed pin
	Rocker or roller expansion

Elastomeric Bearings: Plain and Reinforced

Elastomeric bearings have become the most common type of bearing in recent years because of their desirable performance characteristics, durability, low maintenance requirements, and relative economy. Elastomeric bearings have no moveable parts. They accommodate movement and rotation by deformation of an elastomeric pad, which can be neoprene or natural rubber. Lateral and longitudinal movements are accommodated by the pad's ability to deform in shear. These bearings can accommodate combined movements in both longitudinal and transverse directions, and circular elastomeric bearings have been used to accommodate multirotation requirements. Existing bridges using elastomeric bearings with more than 50 years of very good service performance are reported.

Plain, unreinforced elastomeric pads are used for short spans on which loads and movements can be accommodated by a single layer of elastomer.

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As vertical load and movement requirements increase, thin reinforcing plates are combined with multiple layers of elastomer to form a laminated reinforced elastomeric assembly. Steel and fiberglass reinforcement layers have been used; however, fiberglass is weaker, more flexible, and does not bond as well to the elastomer as does steel reinforcement. As a result, the use of thin steel-plate reinforcement has become more common.

Neoprene is the most widely used elastomer, but some states also use natural rubber (Stanton et al. 2004), particularly in colder climates, to meet AASHTO low- temperature requirements. Natural rubber generally stiffens less than neoprene at low temperatures. Neoprene has greater resistance to ozone and a wide range of chemicals than natural rubber, making it more suitable for some harsh chemical environments.

The LRFD Bridge Design Specifications (LRFD specifications) (AASHTO 2012) currently provide two design methods for the design of elastomeric bearings: Method A, which is the simpler method and has fewer testing requirements; and Method B, which re¬quires greater design effort and more extensive testing.

Method A leads to viable designs for bridges up to 150 ft (Stanton et al. 2004), and Method B is generally used when a reasonable bearing cannot be designed using Method A. The majority of states use Method A (Stanton et al. 2004).

Cotton Duck Pads

Cotton duck bearing pads are another type of elastomeric bearings that are occasionally used in some states, typically for precast concrete I-girder bridges with span lengths up to the 150- to 180-ft range. Cotton duck pads (CDPs) are preformed elastomeric pads consisting of very thin layers of elastomer (less than 0.4 mm [1/60 in.]) interlaid with cotton or polyester fabric. They are stiff and strong in compression, giving them much larger com-pressive load capacities than plain elastomeric pads; however, CDP shear deflection capability is very limited. The CDP bearings provide a high stiffness in the direction of ap¬plied compressive force and are helpful in limiting problems encountered during construction of heavy girders because of rotational instability, generally observed with other elastomeric bearing types. For large shear strain, CDPs may split and crack or result in girder slip on the CDP. The limited shear deflection capacity is frequently overcome by the addition of a polytetrafluorethylene (PTFE) sliding surface to accommodate large movement. When PTFE surfaces are used, they are often combined with stainless steel sliding surfaces, similar to that shown in Figure 1.2. The overall capacities depend on the stiffness and deformation capacity of the CDP and vary from manufacturer to manufacturer. To assure adequate performance from CDP, quality control (QC) testing measures and design recommendations have been developed and incorporated into the LRFD speci-fica¬tions (Lehman et al. 2003).

Sliding Bearings

Polytetrafluorethylene

When horizontal movements become too large for elastomeric bearings to reasonably accommodate in shear, PTFE sliding surfaces can be used to provide additional capacity. They are commonly used to provide movement capability with CDPs, and they are also used to provide for horizontal movement in combination with other bearing systems that internally provide for compression and rotation, such as high-load multirotation (HLMR) pot and disc bearings. They are also used to accommodate large translations and rotations when combined with spherical or cylindrical bearings.

PTFE has low frictional characteristics, chemical inertness, and resistance to weathering and water absorption, making it an attractive material for bridge bearing applications.

The sliding movement is typically provided by a very smooth stainless steel-plate sliding on a PTFE surface. The stainless steel surface is larger than the PTFE surface so that the full movement can be achieved without exposing the PTFE. The stainless steel is typically placed on top of the PTFE to prevent contamination with dirt or debris. PTFE sliding bearings may be guided, allowing movement in only one direction, or nonguided, allowing multidirectional movement. When PTFE sliding surfaces are combined with elastomeric pads, the elastomeric pad must be designed to accommodate the shear force that is needed to overcome the PTFE friction resistance.

Sliding surfaces develop a frictional force that acts on the superstructure, substruc¬ture, and bearing. As a result, friction is an important design consideration, and the low frictional resistance of PTFE makes it very useful for this application. The coefficient of friction of PTFE increases with decreasing temperature and with decreasing contact pressure. It also increases if the mating surface is rough or contaminated with dust or dirt. Proper design, fabrication, and field installation are all essential for proper performance.

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Plain, unfilled PTFE is the most common material used for sliding bearings. Filled PTFE, with the addition of glass fibers, carbon fibers, or other chemically inert filler reinforcement, is sometimes used. Filled PTFE has significantly greater resistance to wear and creep, but it also has a higher friction coefficient by as much as 25% to 30%. Unfilled PTFE in the form of a woven fabric is occasionally used to provide higher bearing strength, longer wear, and increased creep resistance.

Lubrication significantly reduces the coefficient of friction, and dimpling of the PTFE surface has been used as a means to facilitate lubrication. Dimples are spherical indentations (0.32 in. maximum diameter by 0.08 in. minimum depth and covering 20% to 30% of the surface area) that are machined into the PTFE surface to act as reservoirs for storing lubrication. Silicone greases are specified because they are effective at low temperatures and do not attack the sliding material. Dimpled and lubricated PTFE has been used in Europe, but in the United States, it has been used only in special cases on large spherical bearings in which a very low coefficient of friction requirement is needed to reduce friction loads on substructures. Dimpled and lubricated PTFE demands a routine maintenance plan, as the coefficient of friction will significantly increase as the lubrication material is depleted. This increase in coefficient of friction can have an adverse effect on the service performance of other parts of the bridge system. 1.2.3.2

Alternatives to Plain PTFE

Maurer sliding material (MSM) is an alternative sliding material developed in Germany as a better-performing substitute for current PTFE-based sliding material, mainly for high-speed rail applications (Maurer Söhne 2003). The new material is an ultra high molecular weight polyethylene that has performed well in recent field applications and experimental testing in Europe, where it is one of the most popular sliding surfaces in use.

MSM was primarily developed to accommodate bridge movements and related wear caused by high-speed trains, which induce high rates of movement due to girder end rotations that result in large accumulated movement over time. Initial specifications required the bearing material to accommodate a rate of movement up to 15 mm/s and provide 80 years of service life.

Experimental testing in Europe with dimpled and lubricated specimens subjected to high loading rates has shown MSM to outperform PTFE in regard to compressive strength, coefficient of friction, and rate of wear. But because this material is relatively new, there are no long-term data available. More recently,

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research conducted under SHRP 2 Project R19A compared coefficient of friction and wear between lubricated and unlu¬bricated MSM and plain PTFE specimens at high movement rates. Unlubricated speci¬men tests showed MSM to have significantly greater wear resistance than plain PTFE, but with a greater coefficient of friction. Project R19A testing also compared coefficient of friction and wear of a glass reinforced PTFE, Fluorogold, with plain PTFE and MSM. Like MSM, the Fluorogold material had significantly greater wear resistance, but with a smaller increase in the coefficient of friction.

Service Life Design Method for Sliding Surfaces

Appendix G provides further information regarding a potential service life design method for sliding surfaces that considers a pressure–velocity factor in determining an effective wear rate for the surface material. The method requires test data to establish material wear characteristics; therefore, its application as a design method will be subject to the availability of sufficient existing test data to establish reliable wear rate curves for different sliding materials. The proposed design provisions are based on research conducted by SHRP 2 ProjectR19A (Ala et al., submitted for publication).

High-Load multirotation Bearings

When design loads and rotations exceed the reasonable limits for elastomeric bearings, HLMR bearings have typically been considered. HLMR situations often occur with longer spans, with curved or highly skewed bridges, or with complex framing, such as with straddle bents. In these cases the axis of rotation or the direction of movement, or both, are either not fixed or may be difficult to determine.

HLMR bearings include pot, disc, and spherical bearings, each of which is unique in how it accommodates large loads and rotations. All are fabricated in fixed and expansion versions. The expansion versions accommodate translational movement by means of PTFE sliding elements. Expansion versions may be guided, allowing movement in only one direction, or nonguided, allowing multidirectional movement. The following sections describe and compare each HLMR bearing type.

Pot Bearings

The pot bearing was first developed in Germany in the early 1960s, and its use began in the United States in the early 1970s (Fyfe et al. 2006). The main elements of these bearings include a shallow steel cylinder, or pot, which contains a tight-fitting elastomeric disc that is thinner than the depth of the

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cylinder. A machined steel piston fits inside the cylinder and bears directly on the elastomeric disc. Brass rings are used to seal the elastomer between the piston and pot components (see Figure 1.3).

Vertical load is carried through the piston of the bearing and is resisted by compres¬sive stress in the elastomeric pad. The pad is deformable but almost incompressible in its confined condition and is often idealized as behaving hydrostatically. In practice, the elas¬tomer has some shear stiffness and so this idealization is not completely justified. Rotation can occur about any axis and is accommodated by deformation of the elastomeric pad. Horizontal loads on a pot bearing are resisted by direct contact between the pot wall and the piston.

To achieve satisfactory performance, pot bearings require a high degree of QC in the fabrication and field installation process and an accurate determination of design loads and displacements. Through the years, they have been the most economical and most common HLMR bearing. They have been implemented on bridges throughout the country.

Disc Bearings

The disc bearing was developed and put into service in Canada in 1970 (Fyfe et al. 2006) and was a proprietary, patented device until recent times. It consists of a hard polyether urethane disc between upper and lower steel plates with a centre shear pin device to resist horizontal load. The discs are stiff enough to support compressive load, yet can deform to permit rotation. However, rotational stiffness for a disc bearing is several times that of a pot bearing.

Disc bearings are reasonably economical, but widespread use has been limited because of their originally patented and proprietary status, which made them available only from a single source. Now that there are additional bearing manufacturers that can supply disc bearings, their use has increased.

Spherical and Cylindrical Bearings

Spherical bearings are used primarily for accommodating large rotations about multiple or unknown axes. Sometimes referred to as curved sliding bearings, spherical bearings permit rotation about any axis; cylindrical bearings permit rotation about one axis. In these bearing types, rotation is developed by sliding a convex metal surface (lower element) against a concave PTFE surface (upper element). The rotation occurs about the center of the radius of the curved surface, and the maximum rotation is limited by the

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geometry and clearances of the bearing. Translational movement is accomplished by incorporating a flat PTFE sliding surface. Horizontal loads may be partially resisted by the curved geometry of the spherical head; however, large horizontal loads may require additional external restraint.

Spherical bearings require highly machined fabrication and are more sensitive to the qual¬ity of the initial manufacture and installation than other HLMR bearings. Although they are generally the most expensive HLMR type, their advantage is their ability to accommodate higher gravity loads and rotations.

Fabricated Steel Bearings

Fabricated steel mechanical bearings have been used for both fixed and expansion conditions and are the longest-used of any other bearing type. Many existing bridges have these types of bearings, and some states still use them for new construction. When functioning properly, mechanical steel bearings generally provide the closest representation of assumed structural end conditions of all bearing types and transmit loads through direct metal-to-metal contact. Most fixed bearings rely on a pin or knuckle to al-low rotation while restricting translational movement. Rockers, rollers, and sliding types are commonly used expansion bearings. Typically, steel bearings are expensive to fabricate, install, and maintain, which in part accounts for the popularity of elastomeric bearings. Further, steel bearings typically provide only unidirectional movement. These types of bearings are fully designed by the engineer to accommodate loads, movements, and ro-tations and can be developed to accommodate large requirements.

Bronze lubricated plate bearings have been used in conjunction with steel bearings to accommodate smaller amounts of movement at expansion ends, but they are not used much today. PTFE sliding surfaces have replaced bronze sliding plates because of a much lower coefficient of friction and lower cost.

Factors Influencing Service life of Bearings

This section discusses various factors influencing the service life of bearings by using a fault tree analysis approach that first identifies service life issues that generally pertain to all bearing types. This analysis is followed by specific discussions of service life issues pertaining to individual bearing types.

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