Feng, J., Chen, H. “Bearings.”
Bridge Engineering Handbook.
Ed. Wai-Fah Chen and Lian Duan
Boca Raton: CRC Press, 2000

Section III
Substructure Design

26

Bearings

Johnny Feng
J. Muller International, Inc.

Hong Chen
J. Muller International, Inc.

26.1 Introduction

Bearings are structural devices positioned between the bridge superstructure and the substructure. Their principal functions are as follows:

1. To transmit loads from the superstructure to the substructure, and
2. To accommodate relative movements between the superstructure and the substructure.

The forces applied to a bridge bearing mainly include superstructure self-weight, traffic loads, wind loads, and earthquake loads.

Movements in bearings include translations and rotations. Creep, shrinkage, and temperature effects are the most common causes of the translational movements, which can occur in both transverse and longitudinal directions. Traffic loading, construction tolerances, and uneven settlement of the foundation are the common causes of the rotations.

Usually a bearing is connected to the superstructure through the use of a steel sole plate and rests on the substructure through a steel masonry plate. The sole plate distributes the concentrated bearing reactions to the superstructure. The masonry plate distributes the reactions to the substructure. The connections between the sole plate and the superstructure, for steel girders, are by bolting or welding. For concrete girders, the sole plate is embedded into the concrete with anchor studs. The masonry plate is typically connected to the substructure with anchor bolts.

26.2 Types of Bearings

Bearings may be classified as fixed bearings and expansion bearings. Fixed bearings allow rotations but restrict translational movements. Expansion bearings allow both rotational and translational movements. There are numerous types of bearings available. The following are the principal types of bearings currently in use.

26.2.1 Sliding Bearings

A sliding bearing utilizes one plane metal plate sliding against another to accommodate translations. The sliding bearing surface produces a frictional force that is applied to the superstructure, the substructure, and the bearing itself. To reduce this friction force, PTFE (polytetrafluoroethylene) is often used as a sliding lubricating material. PTFE is sometimes referred to as Teflon, named after a widely used brand of PTFE, or TFE as appeared in AASHTO [1] and other design standards. In its common application, one steel plate coated with PTFE slides against another plate, which is usually of stainless steel.

Sliding bearings can be used alone or more often used as a component in other types of bearings. Pure sliding bearings can only be used when the rotations caused by the deflection at the supports are negligible. They are therefore limited to a span length of 15 m or less by ASHTTO [1].

A guiding system may be added to a sliding bearing to control the direction of the movement. It may also be fixed by passing anchor bolts through the plates.

26.2.2 Rocker and Pin Bearings

A rocker bearing is a type of expansion bearing that comes in a great variety. It typically consists of a pin at top that facilitates rotations, and a curved surface at the bottom that accommodates the translational movements (Figure 26.1a). The pin at the top is composed of upper and lower semicircularly recessed surfaces with a solid circular pin placed between. Usually, there are caps at both ends of the pin to keep the pin from sliding off the seats and to resist uplift loads if required. The upper plate is connected to the sole plate by either bolting or welding. The lower curved plate sits on the masonry plate. To prevent the rocker from walking, keys are used to keep the rocker in place. A key can be a pintal which is a small trapezoidal steel bar tightly fitted into the masonry plate on one end and loosely inserted into the recessed rocker bottom plate on the other end. Or it can be an anchor bolt passing through a slotted hole in the bottom rocker plate.

A pin bearing is a type of fixed bearings that accommodates rotations through the use of a steel pin. The typical configuration of the bearing is virtually the same as the rocker described above except that the bottom curved rocker plate is now flat and directly anchored to the concrete pier (Figure 26.1b).

Rocker and pin bearings are primarily used in steel bridges. They are only suitable for the applications where the direction of the displacement is well defined since they can only accommodate translations and/or rotations in one direction. They can be designed to support relatively large loads but a high vertical clearance is usually required when the load or displacement is large. The practical limits of the load and displacement are about 1800 kN and ±100 mm, respectively, and rotations of several degrees are achievable [3].

Normally, the moment and lateral forces induced from the movement of these bearings are very small and negligible. However, metal bearings are susceptible to corrosion and deterioration. A corroded joint may induce much larger forces. Regular inspection and maintenance are, therefore, required.

26.2.3 Roller Bearings

Roller bearings are composed of one or more rollers between two parallel steel plates. Single roller bearings can facilitate both rotations and translations in the longitudinal direction, while a group of rollers would only accommodate longitudinal translations. In the latter case, the rotations are provided by combining rollers with a pin bearing (Figure 26.1c).

Roller bearings have been used in both steel and concrete bridges. Single roller bearings are relatively cheap to manufacture, but they only have a very limited vertical load capacity. Multiple roller bearings, on the other hand, may be able to support very large loads, but they are much more expensive.

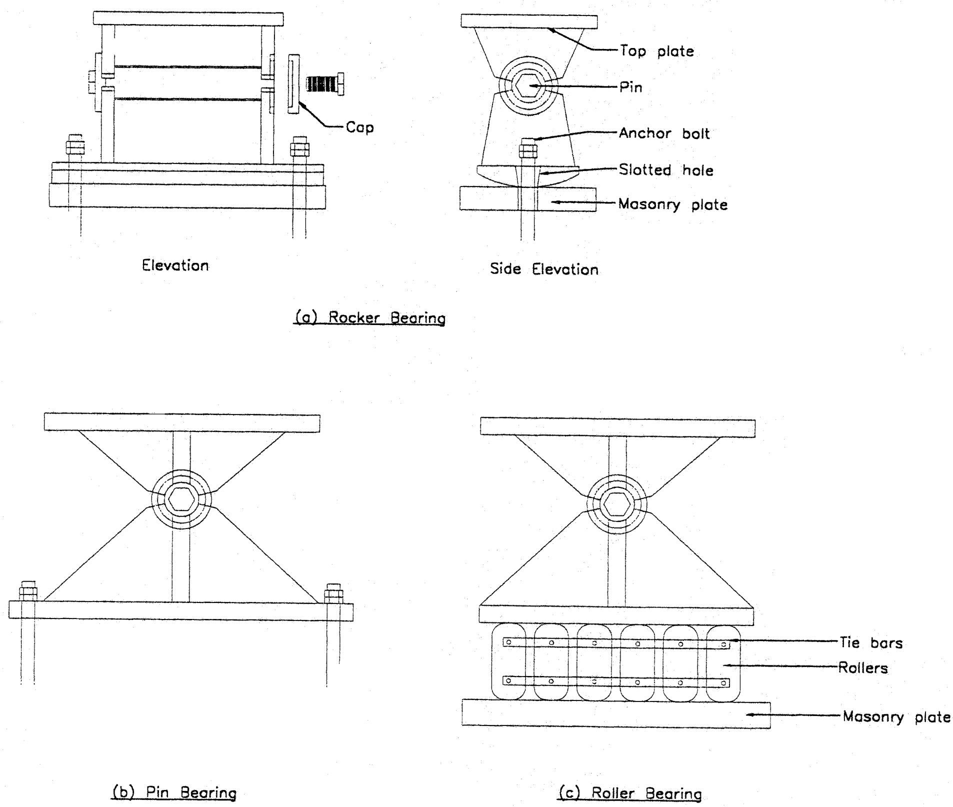

FIGURE 26.1 Typical rocker (a), pin (b), and roller bearings (c).

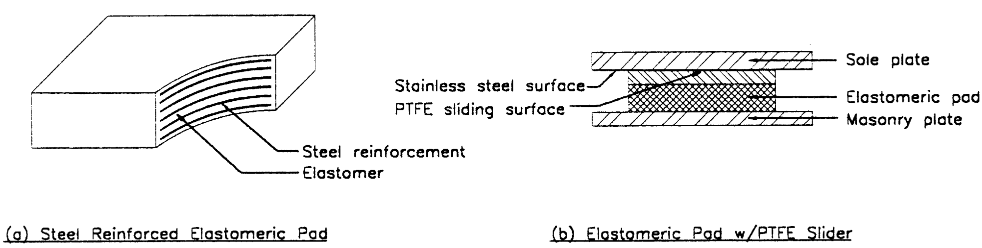

FIGURE 26.2 Elastomeric bearings. (a) Steel-reinforced elastomeric pad; (b) elastomeric pad with PTFE slider.

Like rocker and pin bearings, roller bearings are also susceptible to corrosion and deterioration. Regular inspection and maintenance are essential.

26.2.4 Elastomeric Bearings

An elastomeric bearing is made of elastomer (either natural or synthetic rubber). It accommodates both translational and rotational movements through the deformation of the elastomer.

Elastomer is flexible in shear but very stiff against volumetric change. Under compressive load, the elastomer expands laterally. To sustain large load without excessive deflection, reinforcement is used to restrain lateral bulging of the elastomer. This leads to the development of several types of elastomeric bearing pads — plain, fiberglass-reinforced, cotton duck–reinforced, and steel-reinforced elastomeric pads. Figure 26.2a shows a steel-reinforced elastomeric pad.

Plain elastomeric pads are the weakest and most flexible because they are only restrained from bulging by friction forces alone. They are typically used in short- to medium-span bridges, where bearing stress is low. Fiberglass-reinforced elastomeric pads consist of alternate layers of elastomer and fiberglass reinforcement. Fiberglass inhibits the lateral deformation of the pads under compressive loads so that larger load capacity can be achieved. Cotton-reinforced pads are elastomeric pads reinforced with closely spaced layers of cotton duck. They display high compressive stiffness and strength but have very limited rotational capacities. The thin layers also lead to high shear stiffness, which results in large forces in the bridge. So sometimes they are combined with a PTFE slider on top of the pad to accommodate translations (Figure 26.2b). Steel-reinforced elastomeric pads are constructed by vulcanizing elastomer to thin steel plates. They have the highest load capacity among the different types of elastomeric pads, which is only limited by the manufacturer's ability to vulcanize a large volume of elastomer uniformly.

All above-mentioned pads except steel-reinforced pads can be produced in a large sheet and cut to size for any particular application. Steel-reinforced pads, however, have to be custom-made for each application due to the edge cover requirement for the protection of the steel from corrosion. The steel-reinforced pads are the most expensive while the cost of the plain elastomeric pads is the lowest.

Elastomeric bearings are generally considered the preferred type of bearings because they are low cost and almost maintenance free. In addition, elastomeric bearings are extremely forgiving of loads and movements exceeding the design values.

26.2.4 Curved Bearings

A curved bearing consists of two matching curved plates with one sliding against the other to accommodate rotations. The curved surface can be either cylindrical which allows the rotation about only one axis or spherical which allows the bearing to rotate about any axis.

Lateral movements are restrained in a pure curved bearing and a limited lateral resistance may be developed through a combination of the curved geometry and the gravity loads. To accommodate lateral movements, a PTFE slider must be attached to the bearings. Keeper plates are often used to keep the superstructure moving in one direction. Large load and rotational capacities can be designed for curved bearings. The vertical capacity is only limited by its size, which depends largely on machining capabilities. Similarly, rotational capacities are only limited by the clearances between the components.

Figure 26.3a shows a typical expansion curved bearing. The lower convex steel plate that has a stainless steel mating surface is recessed in the masonry plate. The upper concave plate with a matching PTFE sliding surface sits on top of the lower convex plate for rotations. Between the sole plate and the upper concave plate there is a flat PTFE sliding surface that will accommodate lateral movements.

26.2.5 Pot Bearings

A pot bearing comprises a plain elastomeric disk that is confined in a shallow steel ring, or pot (Figure 26.3b). Vertical loads are transmitted through a steel piston that fits closely to the steel ring (pot wall). Flat sealing rings are used to contain the elastomer inside the pot. The elastomer behaves like a viscous fluid within the pot as the bearing rotates. Because the elastomeric pad is confined, much larger load can be carried this way than through conventional elastomeric pads.

Translational movements are restrained in a pure pot bearing, and the lateral loads are transmitted through the steel piston moving against the pot wall. To accommodate translational movement, a PTFE sliding surface must be used. Keeper plates are often used to keep the superstructure moving in one direction.

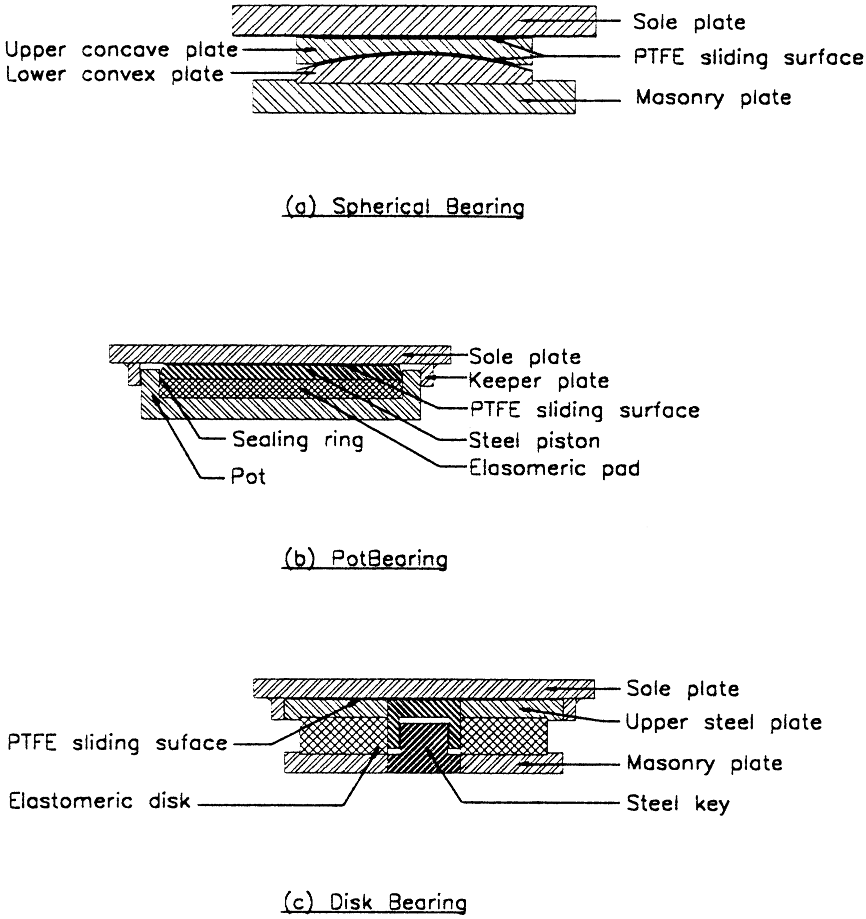

FIGURE 26.3 Typical spherical (a), pot (b), and disk (c) bearings

26.2.6 Disk Bearings

A disk bearing, as illustrated in Figure 26.3c, utilizes a hard elastomeric (polyether urethane) disk to support the vertical loads and a metal key in the center of the bearing to resist horizontal loads. The rotational movements are accommodated through the deformation of the elastomer. To accommodate translational movements, however, a PTFE slider is required. In this kind of bearings, the polyether urethane disk must be hard enough to resist large vertical load without excessive deformation and yet flexible enough to accommodate rotations easily.

26.3 Selection of Bearings

Generally the objective of bearing selection is to choose a bearing system that suits the needs with a minimum overall cost. The following procedures may be used for the selection of the bearings.

26.3.1 Determination of Functional Requirements

First, the vertical and horizontal loads, the rotational and translational movements from all sources including dead and live loads, wind loads, earthquake loads, creep and shrinkage, prestress, thermal and construction tolerances need to be calculated. Table 26.1 may be used to tabulate these requirements.

TABLE 26.1 Typical Bridge Bearing Schedule

Bridge Name of Reference					
Bearing Identification mark					
Number of bearings required					
Seating Material		Upper Surface			
		Lower Surface			
Allowable average contact pressure (PSI)		Upper Surface	Serviceability		
			Strength		
		Lower Surface	Serviceability		
			Strength		
Design Load effects (KIP)	Service limit state		Vertical	max.	
				perm	
				min.	
			Transverse		
			Longitudinal		
	Strength limit state		Vertical		
			Transverse		
			Longitudinal		
Translation	Service limit state	Irreversible	Transverse		
			Longitudinal		
		Reversible	Transverse		
			Longitudinal		
	Strength limit state	Irreversible	Transverse		
			Longitudinal		
		Reversible	Transverse		
			Longitudinal		
Rotation (RAD)	Service limit state	Irreversible	Transverse		
			Longitudinal		
		Reversible	Transverse		
			Longitudinal		
	Strength limit state	Irreversible	Transverse		
			Longitudinal		
		Reversible	Transverse		
			Longitudinal		
Maximum bearing dimensions (IN)	Upper surface		Transverse		
			Longitudinal		
	Lower surface		Transverse		
			Longitudinal		
	Overall height				
Tolerable movement of bearing under transient loads (IN)			Vertical		
			Transverse		
			Longitudinal		
Allowable resistance to translation under service limit state (KIP)			Transverse		
			Longitudinal		
Allowable resistance to rotation under service limit state (K/FT)			Transverse		
			Longitudinal		
Type of attachment to structure and substructure			Transverse		
			Longitudinal		

Source: AASHTO, *LRFD Bridge Design Scecifications,* American Association of State Highway and Transportation Officials, Washington, D.C.

TABLE 26.2 Summery of Bearing Capacities [3,5]

Bearing Type	Load Min. (KN)	Load Max. (KN)	Translation Min. (mm)	Translation Max. (mm)	Rotation Max. (rad)	Costs Initial	Costs Maintenance
Elastomeric pads							
Plain	0	450	0	15	0.01	Low	Low
Cotton duck reinforced	0	1,400	0	5	0.003	Low	Low
Fiberglass reinforced	0	600	0	25	0.015	Low	Low
Steel reinforced	225	3,500	0	100	0.04	Low	Low
Flat PTFE slider	0	>10,000	25	>100	0	Low	Moderate
Disk bearing	1,200	10,000	0	0	0.02	Moderate	Moderate
Pot bearing	1,200	10,000	0	0	0.02	Moderate	High
Pin bearing	1,200	4,500	0	0	>0.04	Moderate	High
Rocker bearing	0	1,800	0	100	>0.04	Moderate	High
Single roller	0	450	25	>100	>0.04	Moderate	High
Curved PTFE bearing	1,200	7,000	0	0	>0.04	High	Moderate
Multiple rollers	500	10,000	100	>100	>0.04	High	High

26.3.2 Evaluation of Bearings

The second step is to determine the suitable bearing types based on the above bridge functional requirements, and other factors including available clearance, environment, maintenance, cost, availability, and client's preferences. Table 26.2 summarizes the load, movement capacities, and relative costs for each bearing type and may be used for the selection of the bearings.

It should be noted that the capacity values in Table 26.2 are approximate. They are the practical limits of the most economical application for each bearing type. The costs are also relative, since the true price can only be determined by the market. At the end of this step, several qualified bearing systems with close cost ratings may be selected [5].

26.3 Preliminary Bearing Design

For the various qualified bearing alternatives, preliminary designs are performed to determine the approximate geometry and material properties in accordance with design specifications. It is likely that one or more of the previously acceptable alternatives will be eliminated in this step because of an undesirable attribute such as excessive height, oversize footprint, resistance at low temperature, sensitivity to installation tolerances, etc. [3].

At the end of this step, one or more bearing types may still be feasible and they will be included in the bid package as the final choices of the bearing types.

26.4 Design of Elastomeric Bearings

26.4.1 Design Procedure

The design procedure is according to AASHTO-LRFD [1] and is as follows:

1. Determine girder temperature movement (Art. 5.4.2.2).
2. Determine girder shortenings due to post-tensioning, concrete shrinkage, etc.
3. Select a bearing thickness based on the bearing total movement requirements (Art. 14.7.5.3.4).
4. Compute the bearing size based on bearing compressive stress (Art. 14.7.5.3.2).
5. Compute instantaneous compressive deflection (Art. 14.7.5.3.3).
6. Combine bearing maximum rotation.
7. Check bearing compression and rotation (Art. 14.7.5.3.5).
8. Check bearing stability (Art. 14.7.5.3.6).
9. Check bearing steel reinforcement (Art. 14.7.5.3.7).

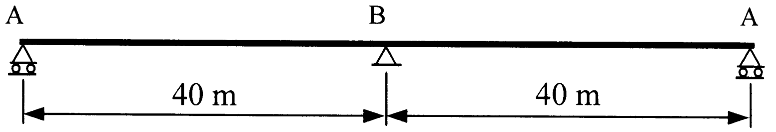

FIGURE 26.4 Bridge layout

26.4.2 Design Example (Figure 26.4)

Given

L	= expandable span length	= 40 m
R_{DL}	= DL reaction/girder	= 690 kN
R_{LL}	= LL reaction (without impact)/girder	= 220 kN
θ_s	= bearing design rotation at service limit state	= 0.025 rad
ΔT	= maximum temperature change	= 21°C
Δ_{PT}	= girder shortening due to post tensioning	= 21 mm
Δ_{SH}	= girder shortening due to concrete shrinkage	= 2 mm
G	= shear modulus of elastomer	= 0.9 ~ 1.38 MPa
γ	= load factor for uniform temperature, etc.	= 1.2
ΔF_{TH}	= constant amplitude fatigue threshold for Category A	= 165 MPa

Using 60 durometer reinforced bearing:

F_y	= yield strength of steel reinforcement	= 350 MPa

Sliding bearing used:

1. **Temperature Movement**
From Art. 5.4.2.2, for normal density concrete, the thermal coefficient α is

$$\alpha = 10.8 \times 10^{-6}/^\circ\text{C}$$

$$\Delta_{TEMP} = (\alpha)(\Delta T)(L) = (10.8 \times 10^{-6}/^\circ\text{C})(21^\circ\text{C})(40{,}000\ \text{mm}) = 9\ \text{mm}$$

2. **Girder Shortenings**

$$\Delta_{PT} = 21\ \text{mm and } \Delta_{SH} = 2\ \text{mm}$$

3. **Bearing Thickness**
h_{rt} = total elastomer thickness
h_{ri} = thickness of ith elastomeric layer
n = number of interior layers of elastomeric layer
Δ_S = bearing maximum longitudinal movement = $\gamma \cdot (\Delta_{TEMP} + \Delta_{PT} + \Delta_{SH})$
Δ_S = 1.2 × (9 mm + 21 mm + 2 mm) = 38.4 mm
h_{rt} = bearing thickness $\geq 2\Delta_S$ (AASHTO Eq. 14.7.5.3.4-1)
h_{rt} = 2 × (38.4 mm) = 76.8

Try h_{rt} = 120 mm, h_{ri} = 20 mm and n = 5

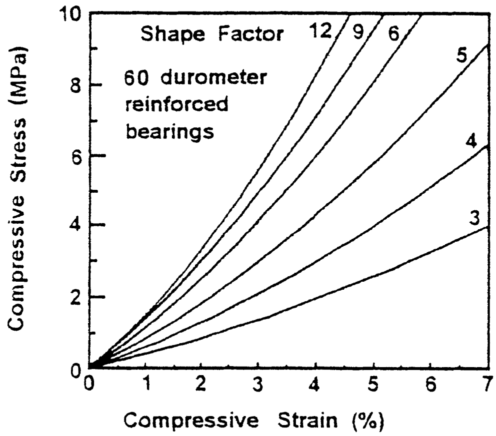

FIGURE 26.5 Stress–strain curves. (From AASHTO, Figure C14.7.5.3.3.1.)

4. **Bearing Size**

   L = length of bearing

   W = width of bearing

   S_i = shape factor of thickness layer of the bearing = $\dfrac{LW}{2h_{ri}(L+W)}$

   For a bearing subject to shear deformation, the compressive stresses should satisfy:

σ_S = average compressive stress due to the total load ≤ $1.66GS \le 11$ (AASHTO Eq. 14.7.5.3.2-1)

σ_L = average compressive stress due to the live load ≤ $0.66\,GS$ (AASHTO Eq. 14.7.5.3.2-1)

$$\acute{o}_S = \frac{R}{LW} = \frac{1.66GLW}{2\,h_{ri}(L+W)}$$

Assuming σ_S is critical, solve for L and W by error and trial.

$$L = 300 \text{ mm and } W = 460 \text{ mm}$$

$$S = \frac{LW}{2h_{ri}(L+W)} = \frac{(300\text{ mm})(460\text{ mm})}{2(20\text{ mm})(300\text{ mm}+460\text{ mm})} = 4.54$$

$$\acute{o}_L = \frac{R_L}{LW} = \frac{(200,000\text{ N})}{(300\text{ mm})(460\text{ mm})} = 1.6\text{ MPa}$$

OK

$$\le 0.66\,GS = 0.66\,(1.0\text{ MPa})(4.54) = 3.0\text{ MPa}$$

5. **Instantaneous Compressive Deflection**

   For σ_S = 6.59 MPa and S = 4.54, one can determine the value of ε_i from Figure 26.5:

$$\varepsilon_i = 0.062$$

$$\ddot{a} = \sum \mathring{a}_i h_{ri} \qquad \text{(AASHTO Eq. 14.7.5.3.3-1)}$$

$$= 6\,(0.062)(20\text{ mm}) = 7.44\text{ mm}$$

6. **Bearing Maximum Rotation**

The bearing rotational capacity can be calculated as

$$\acute{a}_{\text{capacity}} = \frac{2\delta}{L} = \frac{2\,(7.44\,\text{mm})}{300\,\text{mm}} = 0.05\,\text{rad} < \acute{a}_{\text{design}} = 0.025\,\text{rad} \qquad \text{OK}$$

7. **Combined Bearing Compression and Rotation**

a. *Uplift requirement* (AASHTO Eq. 14.7.5.3.5-1):

$$\acute{o}_{\text{s,uplift}} = 1.0GS\left(\frac{\acute{a}_{\text{design}}}{n}\right)\left(\frac{L}{h_{\text{ri}}}\right)^2$$

$$= 1.0\,(1.2)\,(4.54)\left(\frac{0.025}{5}\right)\left(\frac{300}{20}\right)^2 = 6.13\text{ MPa} < \acute{o}_s = 6.59\text{ MPa} \qquad \text{OK}$$

b. *Shear deformation requirement* (AASHTO Eq. 14.7.5.3.5-2):

$$\acute{o}_{s\text{,shear}} = 1.875GS\left(1 - 0.20\left(\frac{\acute{a}_{\text{design}}}{n}\right)\left(\frac{L}{h_{\text{ri}}}\right)^2\right)$$

$$= 1.875\,(1.0)\,(4.54)\left(1 - 0.20\left(\frac{0.025}{5}\right)\left(\frac{300}{20}\right)^2\right) = 6.60\text{ MPa} > \acute{o}_s = 6.59\text{ MPa} \qquad \text{OK}$$

8. **Bearing Stability**

Bearings shall be designed to prevent instability at the service limit state load combinations. The average compressive stress on the bearing is limited to half the predicted buckling stress. For this example, the bridge deck, if free to translate horizontally, the average compressive stress due to dead and live load, σ_s, must satisfy:

$$\sigma_s \le \frac{G}{2A - B} \qquad \text{(AASHTO Eq. 14.7.5.3.6-1)}$$

where

$$A = \frac{1.92\dfrac{h_{\text{rt}}}{L}}{S\sqrt{1 + \dfrac{2.0\,L}{W}}} \qquad \text{(AASHTO Eq. 14.7.5.3.6-3)}$$

$$= \frac{1.92\dfrac{(120\text{ mm})}{(300\text{ mm})}}{(4.54)\sqrt{1 + \dfrac{2.0(300\text{ mm})}{(460\text{ mm})}}} = 0.11$$

$$B = \frac{2.67}{S(S+2.0)\sqrt{1+\frac{L}{4.0W}}}$$

(AASHTO Eq. 14.7.5.3.6-4)

$$= \frac{2.67}{(4.54)(4.54+2.0)\sqrt{1+\frac{(300\text{ mm})}{4.0(460\text{ mm})}}} = 0.08$$

$$\frac{G}{2A-B} = \frac{(1.0\text{ MPa})}{2(0.11)-(0.08)} = 6.87 > ó_s$$ OK

9. Bearing Steel Reinforcement

The bearing steel reinforcement must be designed to sustain the tensile stresses induced by compression of the bearing. The thickness of steel reinforcement, h_s, should satisfy:

a. *At the service limit state*:

$$h_s \geq \frac{3h_{max}ó_s}{F_y}$$ (AASHTO Eq. 14.7.5.3.7-1)

$$= \frac{3(20\text{ mm})(6.59\text{ MPa})}{(350\text{ MPa})} = 1.13\text{ mm}$$ (governs)

b. *At the fatigue limit state*:

$$h_s \geq \frac{2h_{max}ó_L}{\ddot{A}F_y}$$ (AASHTO Eq. 14.7.5.3.7-2)

$$= \frac{2(20\text{ mm})(1.6\text{ MPa})}{(165\text{ MPa})} = 0.39\text{ mm}$$

where h_{max} = thickness of thickest elastomeric layer in elastomeric bearing = h_{ri}.

Elastomeric Bearings Details

Five interior lays with 20 mm thickness each layer
Two exterior lays with 10 mm thickness each layer
Six steel reinforcements with 1.2 mm each
Total thickness of bearing is 127.2 mm
Bearing size: 300 mm (longitudinal) × 460 mm (transverse)

References

1. AASHTO, *LRFD Bridge Design Specifications,* American Association of State Highway and Transportation Officials, Washington, D.C., 1994.
2. AASHTO, *Standard Specifications for the Design of Highway Bridges,* 16th ed. American Association of State Highway and Transportation Officials, Washington, D.C., 1996.
3. Stanton, J. F., Roeder, C. W., and Campbell, T. I., High Load Multi-Rotational Bridge Bearings, NCHRP Report 10-20A, Transportation Research Board, National Research Council, Washington, D.C., 1993.
4. Caltrans, Memo to Designers, California Department of Transportation, Sacramento, 1994.
5. AISI, Steel bridge bearing selection and design guide, *Highway Structures Design Handbook,* Vol. II, American Iron and Steel Institute, Washington, D.C., 1996, chap. 4.