11.4 Shear resistance of elastomeric bearings

For elastomeric bearings where shear movements are accommodated by shear in the elastomer, the shear force (H) due to a movement δ_s shall be calculated as follows:

$$H = K_s \delta_s \qquad \ldots 11.4$$

where

K_s = shear stiffness of an elastomeric bearing

δ_s = maximum resultant vector shear displacement tangential to the bearing surface

12 ELASTOMERIC BEARINGS

12.1 General

This Clause sets out the minimum requirements for the design of single unbonded layer (plain pads and strips) and laminated elastomeric bearings.

NOTE: Wherever possible, elastomeric bearings should be selected from standard sizes as given in Appendix A, and checked to meet all the criteria contained in this Standard.

12.2 Physical properties of elastomer

The elastomer used in the manufacture of bridge bearings shall comply with Appendix B. Values of the shear modulus (G) and the bulk modulus (B) relevant to the elastomer hardnesses detailed in Appendix B are given in Table 12.2.

For plain pads and strips, the durometer hardness shall be IRHD 60 or above.

Appropriate values of G and B shall be adopted for alternative elastomer formulations based on appropriate test results.

The physical properties of natural rubber vary significantly at temperatures below −10°C. For areas where the lowest one-day mean ambient temperatures fall below −10°C, variations in the value of G of the elastomer shall be assessed or the use of alternative formulations considered, or both.

TABLE 12.2

ELASTOMER PROPERTIES

Durometer hardness IRHD ±5	Shear modulus, G MPa	Bulk modulus, B MPa
53	0.69	2 000
60	0.90	2 000

12.3 General requirements

Laminated elastomeric bearings shall have a side cover of elastomer with a minimum design thickness of 6 mm to protect the edges of the steel plates.

Tolerances for the manufacture of laminated elastomeric bearings shall be as given in Appendix C.

The steel plates shall be bonded to the elastomer during vulcanizing and the edges of all plates shall be lightly rounded and the corners chamfered. For non-standard bearings having thicker layers of elastomer under high compression, plate thickness shall be checked to ensure that the plate does not fail in tension (see Clause 12.6.6).

Contact surfaces of a bearing shall be dimensioned to allow an edge clearance of at least 25 mm all round. This allows tolerance when positioning bearings and ensures adequate edge support.

Relatively large tolerances shall be provided to meet the specified stiffness properties of elastomeric bearings and also inherent variations of stiffness that occur in elastomers with variations of strain. Where it is significant, the effects of these tolerances and variations shall be considered in the design of the structure. They may be assumed to be of the total order of ±20%.

12.4 Design principles

12.4.1 *General*

Elastomeric bearings shall be designed to resist serviceability limit state loads and movements.

12.4.2 *Bearing rotations*

The structural elements of the bridge shall be detailed with the objective that, at completion of construction, the loaded faces of the elastomeric bearing are parallel.

The elastomeric bearing shall then be designed to accommodate rotations due to traffic loading and other transient effects, thermal effects and long-term permanent effects in combination with an initial lack-of-parallelism due to construction tolerances.

Where superstructure members are erected directly on to previously prepared bearings, pre-existing rotations in the superstructure members shall be determined by calculation or measurement and increased by a rotation of not less than 0.005 radians, to permit for construction tolerances. The rotation to account for initial lack of parallelism may be taken as zero where either—

(a) the superstructure members are initially supported above the bearings and the remaining spaces are then fully grouted; or

(b) the superstructure is cast directly on to the installed bearing.

12.5 Basis of design

12.5.1 *General*

Elastomeric bearings accommodate translation and rotation by elastic deformation. The deflection of the elastomer under compressive load is influenced by its shape and where reinforcing plates are bonded to the elastomer, the design shall be based on the assumption that there is no relative movement at the steel and elastomer interface.

The design of elastomeric bearings shall be in accordance with Clause 12.6. Pads, strips and laminated elastomeric bearings with shape factors outside the limits specified in Clause 12.5.2 require special consideration in the design.

12.5.2 *Shape factor*

The shape factor (S) of a layer of elastomer shall be the area under compression divided by the area free to bulge, and shall be calculated for layers without holes as follows:

(a) *For laminated elastomeric bearings*:

$$S = \frac{A_b}{P t_e} \quad \ldots 12.5.2(1)$$

where

A_b = bonded surface area

P = surface perimeter

t_e = effective thickness of the individual elastomer layer in compression (due to vertical load or rotation)

= t_i for an inner layer ... 12.5.2(2)

= $1.4t_c$ for a cover layer ... 12.5.2(3)

t_i = thickness of the individual inner layer of elastomer in laminated elastomeric bearing

t_c = thickness of a cover layer of laminated elastomeric bearing

(b) *For plain pad bearings*:

$$S = \frac{A_r}{Pt_e} \quad \text{... 12.5.2(4)}$$

where

A_r = total rubber plan area

t_e = $1.8t$ ... 12.5.2(5)

t = total thickness of elastomer in laminated elastomeric bearing or thickness of plain pad or strip bearing

(c) *For strip bearings*:

$$S = \frac{w}{2t_e} \quad \text{... 12.5.2(6)}$$

where

w = width of strip

t_e = $1.8t$ ... 12.5.2(7)

Where dowel holes are to be provided, a special assessment of the shape factor (S) shall be made allowing for the holes and the restraint to bulge provided by the dowels.

For the design criteria specified in Clause 12, the shape factor (S) shall be as follows:

(i) For plain pads and strips .... $1 \leq S \leq 4$.

(ii) For internal layers of laminated elastomeric bearings................................ $4 \leq S \leq 12$.

12.6 Design requirements

12.6.1 *Maximum shear strain in laminated elastomeric bearings*

To ensure that the total shear strain developed in the elastomer is not excessive, the following requirement at the edge of the bonded surface shall be satisfied:

$$\varepsilon_{sc} + \varepsilon_{sr} + \varepsilon_{sh} \leq \frac{2.6}{\sqrt{G}} \quad \text{... 12.6.1(1)}$$

where

ε_{sc} = shear strain at edge of bonded surface due to loads normal to bearing surfaces

ε_{sr} = shear strain at edge of bonded surface due to relative rotation of bearing surfaces

ε_{sh} = shear strain at edge of bonded surface due to forces tangential to the bearing surface or movement of the structure, or both

The values of shear strains shall be calculated as follows:

$$\varepsilon_{sc} = 6S\varepsilon_{c} \qquad \ldots\ 12.6.1(2)$$

where

ε_c = compressive strain due to loads normal to the bearing surfaces (based on the effective plan area A_{eff})

$$= \frac{N}{3A_{eff}\,G\left(1+2S^2\right)} \quad \text{for internal layers only} \qquad \ldots\ 12.6.1(3)$$

N = compressive load on a bearing, serviceability limit state

A_{eff} = effective loaded plan area nominally equal to the projected area common to top and bottom when a bearing is distorted tangentially

$$= A_b\left(1-\frac{\delta_a}{a}-\frac{\delta_b}{b}\right) \quad \text{for rectangular bearings} \qquad \ldots\ 12.6.1(4)$$

$$= A_b-\delta_s d \quad \text{for circular bearings} \qquad \ldots\ 12.6.1(5)$$

δ_a = maximum shear displacement tangential to bearing surface in the direction of dimension a due to movements of the structure and tangential forces

a = plan dimension of the edge of the bonded surface of rectangular bearings parallel to the span of the bridge

δ_b = maximum shear displacement tangential to bearing surface in the direction of dimension b due to movements of the structure and tangential forces

b = plan dimension of the edge of the bonded surface of the rectangular bearing transverse to the span of the bridge

δ_s = maximum resultant vector shear displacement tangential to the bearing surface, e.g., temperature effects and the like, and tangential force effects, e.g., braking forces and the like in the directions of the dimensions a and b

d = plan diameter of circular bearing at edge of bonded surface

$$\varepsilon_{sr} = \frac{\alpha_a a^2+\alpha_b b^2}{2t_i t} \quad \text{for rectangular bearings} \qquad \ldots\ 12.6.1(6)$$

$$= \frac{\alpha d^2}{2t_i t} \quad \text{for circular bearings} \qquad \ldots\ 12.6.1(7)$$

$$\varepsilon_{sh} = \frac{\delta_s}{t} \quad \text{for all bearings} \qquad \ldots\ 12.6.1(8)$$

α_a = angle of rotation parallel to the span of the bridge

α_b = angle of rotation transverse to the span of the bridge

α = maximum angle of rotation, i.e., change in angle between top and bottom surfaces of bearing in critical direction

To limit the effect of fatigue, which is likely to be significant only in short spans, anchor spans and lightweight structures, the following shall also be satisfied:

$$\varepsilon_{scl} \leq 1.4\sqrt{\frac{0.69}{G}} \qquad \ldots 12.6.1(9)$$

where

ε_{scl} = shear strain at edge of bonded surface due to live load and impact only

$= 6S\varepsilon_{cl}$ ... 12.6.1(10)

NOTE: In the calculations for total shear strain, bulk modulus is not included.

12.6.2 *Compressive stress on elastomeric bearings*

The mean compressive stress on elastomeric bearings shall be determined as follows:

(a) The mean compressive stress (N/A_b) on laminated elastomeric bearings shall not be greater than 15 MPa.

(b) The mean compressive stress (N/A_r) on plain pad and strip bearings shall not be greater than the lesser of $2GS$ or 5 MPa.

12.6.3 *Shear strain due to tangential movements and forces*

To limit tangential distortion and to minimize rolling of the edges of the bearings or tendency of the steel plates to bend, the following shall be satisfied:

$\varepsilon_{sh} \leq 0.5$

The tangential movements and forces shall not reduce the projected plan area common to the top and bottom faces of a bearing by more than 20%, i.e.—

(a) $A_{eff} \geq 0.8A_b$ for laminated elastomeric bearings; and

(b) $A_{eff} \geq 0.8A_r$ for plain pads and bearing strips.

12.6.4 *Rotational limitation*

For plain pads and laminated elastomeric bearings, the total compressive deflection (d_c) shall satisfy the following:

(a) *For rectangular bearings*:

$$d_c \geq \frac{\alpha_a a + \alpha_b b}{3} \qquad \ldots 12.6.4(1)$$

(b) *For circular bearings*:

$$d_c \geq \frac{\alpha d}{3} \qquad \ldots 12.6.4(2)$$

(c) *For plain strip bearings*:

$$d_c \geq \frac{\alpha_a w}{3} \qquad \ldots 12.6.4(3)$$

12.6.5 *Stability of bearings*

The stability of bearings shall be determined as follows:

(a) *Plain pad and strip bearings* For plain pad and strip bearings, the thickness shall not be greater than one quarter of the least lateral dimension.

(b) *Laminated elastomeric bearings* For laminated elastomeric bearings, the stability shall satisfy the following:

$$N \leq \frac{2b_e GSA_{eff}}{3t} \qquad \text{... 12.6.5}$$

where

b_e = lesser of a and b for rectangular bearings

= diameter (d) for circular bearings

S = shape factor of the thickest inner layer

12.6.6 *Thickness of steel plates*

The minimum thickness of steel plates in elastomeric bearings shall conform to the following:

(a) $t_s > \frac{3Nt_i}{A_b f_y}$; and ... 12.6.6(1)

(b) $t_s \geq 5$ mm ... 12.6.6(2)

where

f_y = yield strength of the steel plate

For steel plates with dowel holes, f_y shall be factored by 0.5.

12.6.7 *Fixing of bearings*

Under the provision of Clause 10.2, bearings may be restrained by friction only, provided that under all serviceability limit state load combinations—

$$N_{min} \geq 10H - 2f_o A_{eff} \qquad \text{... 12.6.7(1)}$$

where N_{min} is the minimum compressive load normal to the bearing anchorage interface concurrent with H,

and under permanent loads only—

$$N_{min\ PE} \geq 3f_o A_{eff} \qquad \text{... 12.6.7(2)}$$

where

$N_{min\ PE}$ = minimum permanent compressive load normal to the bearing anchorage interface concurrent with H, serviceability limit state

f_o = stress used in calculation of anchorage of laminated elastomeric bearing

= 1.0 MPa

To provide for earthquake loads, suitable retaining devices shall be provided at the bearing in accordance with Clause 10.2, or by separate devices in accordance with Clause 10.3.

NOTE: Where mechanical devices are used to restrain the bearing, these devices may limit the depth of elastomer available to accommodate shear deformation.

12.6.8 *Compressive deflection*

The total compressive deflection (d_c) of the bearing shall be determined as follows:

$$d_c = \Sigma(t_n \varepsilon_c) \qquad \text{... 12.6.8(1)}$$

The value of the compressive strain (ε_c) in a layer of a laminated elastomeric bearing to be used in deriving the compressive deflection (d_c) shall be determined as follows:

$$\varepsilon_c = \frac{N}{EA_b} \qquad \text{... 12.6.8(2)}$$

where

E = effective compression and rotation modulus for elastomer

$$= E_h + \left[\frac{C_1 G S^2}{1 + \left(\frac{C_1 G S^2}{0.75 B} \right)} \right] \qquad \text{... 12.6.8(3)}$$

C_1 = a constant dependent on the bearing shape

E_h = homogeneous compression modulus calculated as follows:

(a) *For rectangular bearings*:

$$E_h = 4G \left[1 - \left(\frac{q}{1 + q^2} \right)^2 \right] \qquad \text{... 12.6.8(4)}$$

$$C_1 = 4 + q\,(6 - 3.3q) \qquad \text{... 12.6.8(5)}$$

where

q = ratio

= a/b; or ... 12.6.8(6)

= b/a, whichever is the lesser ... 12.6.8(7)

(b) *For circular bearings*:

E_h = $3G$ ... 12.6.8(8)

C_1 = 6

(c) *For plain pads and strips*:

$$\varepsilon_c = \frac{N}{A_r \left[16GS + 2\left(\frac{N}{A_r} \right) \right]} \qquad \text{... 12.6.8(9)}$$

12.7 Bearing stiffnesses

12.7.1 *Compressive stiffness*

The compressive stiffness (K_c) shall be determined as follows:

$$K_c = \frac{1}{\Sigma \left(\frac{1}{K_{cn}} \right)} \qquad \text{... 12.7.1(1)}$$

where

K_{cn} = compressive stiffness of layer n

$$= \frac{EA_b}{t_n} \qquad \text{... 12.7.1(2)}$$

E = see Clause 12.7.3

t_n = thickness of a typical layer n of elastomer

12.7.2 *Shear stiffness*

The shear stiffness (K_s) shall be determined as follows:

$$K_s = \frac{A_r G}{t} \qquad \text{... 12.7.2}$$

The value of t shall be adjusted to allow for any layers of rubber not free to shear.

The value of the shear stiffness (K_s) of a bearing under varying compressive or shear stresses, or both, may be calculated from Equation 12.7.2 using G as defined in Clause 12.2.

12.7.3 *Rotational stiffness*

The rotational stiffness (K_r) of a bearing shall be the rotational moment (M) to produce unit rotation and determined as follows:

(a) Rotational stiffness (K_{rn}) of a layer n a laminated elastomeric bearing:

$$K_{rn} = \frac{M}{\alpha} = \frac{EI}{t_n} \qquad \text{... 12.7.3(1)}$$

where

M = rotational moment

I = second moment of area of the plan area of the bonded elastomer about its axis of rotation

(i) For individual layers of laminated elastomeric bearings:

$$E = E_h + \left[\frac{C_2 G S^2}{1 + \left(\frac{C_2 G S^2}{0.75B}\right)}\right] \qquad \text{... 12.7.3(2)}$$

C_2 = constant dependent on the bearing shape

(ii) For rectangular bearings:

$$E_h = 4G\left[1 - \left(\frac{m}{(m^2+1)}\right)^2\right] \qquad \text{... 12.7.3(3)}$$

$$C_2 = 4 - \left[\frac{32}{10 + m(4 + 3m + m^2)}\right] \qquad \text{... 12.7.3(4)}$$

m = ratio of the sides of a rectangular laminated elastomeric bearing

= a/b ... 12.7.3(5)

(iii) For circular bearings:

$$E_h = 3G \qquad \text{... 12.7.3(6)}$$

$$C_2 = 2$$

(b) Total rotational stiffness (K_r):

$$K_r = \frac{1}{\Sigma\left(\frac{1}{K_{rn}}\right)} \qquad \ldots 12.7.3(7)$$

(c) Rotational stiffness of a plain pad or strip:

$$K_r = \frac{M}{\alpha} = \frac{EI}{t} \qquad \ldots 12.7.3(8)$$

where

E = effective compression and rotation modulus for elastomer (see Clause 12.6.8)

I = as specified in Item (a) for gross plan area of the elastomer about its axis of rotation

12.7.4 *Inclined elastomeric bearings*

Inclined elastomeric bearings shall be used only in opposed pairs of identical bearings to permit an increased transverse shear stiffness of the pair of bearings without increasing the longitudinal shear stiffness or vice versa. First principles shall be used to determine the combined effects.

The effective lateral horizontal stiffness (K_h) of a pair of identical bearings of shear stiffness (K_s) and compressive stiffness (K_c), if at oppositely opposed each at an angle of θ to the horizontal, shall be calculated as follows:

$$K_h = 2K_c \sin^2\theta + 2K_s \cos^2\theta \qquad \ldots 12.7.4(1)$$

where θ is the angle of inclination of the opposing bearings.

Similarly, the effective compression stiffness (K_v) shall be calculated as follows:

$$K_v = 2K_c \cos^2\theta + 2K_s \sin^2\theta \qquad \ldots 12.7.4(2)$$

To prevent lift-off in one of the pair of bearings, it shall be ensured that—

$$\frac{N}{H} > \frac{K_c \tan\theta}{K_c \tan^2\theta + K_s} \qquad \ldots 12.7.4(3)$$

provided $\theta < 5°$.

Where significant transverse rotation of the superstructure occurs at the bearings due to eccentric load effects, the effective value of K_h shall be reduced as follows:

$$K_h = \frac{2K_c K_s}{K_c \cos^2\theta + K_s \sin^2\theta} \qquad \ldots 12.7.4(4)$$

Excessive tensions, however, may develop in the bearings due to superstructure rotations, especially if the compressive deflections are not sufficient. In this case, overall performance of the bearing assembly shall be assessed from first principles.

12.8 Creep

Long duration loads introduce time-dependent effects in elastomers through creep and stress relaxation.

For most applications, the effects of creep and stress relaxation need not be considered; however, when considering new formulations and synthetic rubber, creep tests shall be required.

NOTES:

1 For natural rubber, maximum compressive creep values of about 25% of the instantaneous deformation may be used.

2 Creep effects are logarithmic functions of time and are also dependent on temperature, stress history and elastomer formulation.

12.9 Load testing of elastomeric bearings

All laminated bearings shall be load tested in compression to 1.5 times the rated load at zero shear and zero rotation.

Compressive and shear stiffness testing shall be on representative samples of bearings. The actual number of bearings checked for stiffness shall be determined by quality control procedures and previous test data.

When acceptance tests for shear stiffness are required or when determining effective values of G, bearings shall be subjected to a mean compressive stress of 2 MPa, and the shear stiffness or value of G derived from the mean shear stiffness, measured between 5% and 25% shear strain.

Methods of testing laminated elastomeric bearings shall be in accordance with Appendix D.

Representative samples of plain pad and strip bearings shall be subjected to compressive load tests to 1.5 times the design vertical load.

13 POT BEARINGS

13.1 Design

The components of pot bearings, including associated sliding contact surfaces, shall be designed for ultimate limit state effects.

The following primary design parameters and fabrication details of pot bearings shall be adopted:

(a) The maximum mean compressive stress on the elastomer shall be 50 MPa.

(b) The thickness and formulation of the elastomer shall depend on the required rotational capacity and the smoothness of the inner surface of the pot; however, in no case shall the total pad thickness be less than the larger of one fifteenth of the diameter of the elastomeric pad or 10 mm.

(c) The maximum displacement due to the ultimate limit state rotation at the perimeter of the elastomeric pad shall not be greater than 20% of the total pad thickness, including sealing ring.

(d) Shifts (e) in the centre of pressure due to rotation shall not be greater than $d_1/6$, where d_1 is the diameter of the elastomeric pad within the pot bearing. The value of e shall be calculated by dividing the rotational moment by the concurrent vertical force.

NOTE: An expression for determining the rotational moment of pot bearings is provided in AS 5100.4 Supp 1, the Commentary to this Standard.

(e) To prevent extrusion of the elastomer from the pot, the elastomer shall have a seal, typically a set of split metal rings, vulcanized or recessed into the top of the elastomeric disc. The total clearance between the inside walls of the pot and the piston shall not be greater than 1.0 mm.

(f) Pot bearings shall be anchored in accordance with Clause 10.1 and movement restraints shall be provided, where required, in accordance with Clause 8.

(g) Provision for horizontal movements, if required, shall be provided by a PTFE sliding surface in accordance with Clause 14.