NCHRP 12-68

FY 2004

Rotational Limits for Elastomeric Bearings

Final Report

APPENDIX G

John F. Stanton

Charles W. Roeder

Peter Mackenzie-Helnwein

Department of Civil and Environmental Engineering

University of Washington

Seattle, WA 98195-2700

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX G Proposed Design Specifications

G.1 Basis

The overall objective of this approach is to create a comprehensive specification that is consistent with the results of the research conducted here, with the performance of existing bearings in the US, and with specifications world-wide.

As in previous editions of the AASHTO LRFD Design Specifications, two design methods are provided. Method B includes axial force, rotation and shear, whereas Method A represents a simplification of the Method B approach that allows engineers to design bearings without having to consider rotations in detail. Method A was created by estimating the largest rotations likely to occur in practice, and determining the corresponding axial stress that would be allowed under Method B. The two methods are thus consistent with each other to the greatest extent possible. Some restrictions on the use of Method A are imposed to prevent its use outside the domain of validity of the simplifications on which it is based.

The Method B specification is written using the shear strains caused by axial force, rotation and shear displacement. This approach obviates the need for different equations to address different combinations, such as compression and rotation with or without shear, and is thus conceptually simpler than the existing version. Limiting the total shear strain is also the principle that underlies the existing specifications. The intent of the proposed design provisions is thus more transparent than that of the 2004 AASHTO LRFD Design Specifications without changing their conceptual basis. Furthermore, future changes can be made relatively easily, should they be needed.

The total allowable strain is slightly higher than the one implicit in the 2004 LRFD Specifications, but that fact is partially offset by the presence of a constant amplification factor that is applied to cyclic strains arising from traffic loading. Section G.2 provides design rules for bearings that:

- are readily satisfied by bearings in common use today, thus meeting a minimum but necessary criterion of reasonability,
- are consistent with the debonding trends observed in the tests,
- penalize cyclic loads, in accordance with the findings of the testing program, which showed that cyclic loading led to much more debonding than did monotonic loading of the same magnitude,
- remove the previous restrictions on lift-off, for bearings that have no external plates, and from which the girder can readily separate over part of the bearing surface,
- introduce a new check for hydrostatic tension stress, to guard against internal rupture of the elastomer in bearings that have external plates and are subjected to light axial load and large rotations,
- remove the absolute compressive stress limits (of 1.60 and1.75 ksi) and replace them with an implicit limit related to *GS*, to encourage the use of bearings with

higher shape factors for high load applications. Such bearings performed extremely well in the testing program.

An amplification factor of 2.0 is proposed for cyclic loading. This is higher, and therefore more conservative, than the European value of 1.0 or 1.5 (value to be chosen by the bridge's owner). The European Specification (EN 1337) uses the same total strain capacity of 5.0 that is proposed here, so the existence of a higher cyclic amplification factor makes these proposals inherently more conservative than those of EN 1337. Despite that, they are still simpler, more versatile and more liberal than those in the 2004 AASHTO LRFD Specifications.

A change in testing requirements is also advocated. In previous editions of the AASHTO Design Specifications, design by Method B was linked to the requirement for additional, more rigorous testing, and in particular, a long-term test. This testing is relatively expensive and time consuming, and designers were therefore reluctant to use Method B. However, that long-term test has been recently eliminated by the AASHTO T-2 Committee during part of a major re-consolidation of testing requirements from the AASHTO Construction Specifications into the M-251 Material Specifications. The present status is that the materials in the bearing are to satisfy the physical property tests defined in Section 4 of M-251, and the finished bearings are to be sampled on a lot basis and the sample is to be subjected to the tests defined in Section 8. At the owner's discretion, bearings designed by Method A may instead be subjected to the less rigorous tests of Appendix X1.

The researchers appreciate the desire to consolidate all testing requirements in a single document. However, linking the testing requirements to the design method has several drawbacks, and a change is therefore suggested. The primary reasons are:

- The shear strains in a Method A bearing are not necessarily smaller than those in a Method B bearing. Appendix F shows how Method A was derived as a special case of Method B, with the motivation of simplification, rather than ensuring lower stresses. In fact, an increase of 25% for the allowable stresses under Method A is recommended. In many cases, the shear strain due to rotation in a Method A bearing will indeed be smaller than the design value implicit in method A, so the total shear strain will be less than the maximum allowed. But that is true only of some, and not all, Method A bearings.
- Bearing manufacturers apply the same procedures and standard of care to the fabrication of every bearing. To maintain several different ones would invite errors. Furthermore, the manufacturers are usually unaware of the design method that has been used. The consequence is that they do not deliberately manufacture Method B bearings to a higher (or lower) standard than Method A bearings.
- Fabrication problems are most likely to occur in large bearings, for several reasons. First the curing becomes more difficult, because the center of the bearing takes longer to heat up and the outer regions risk over-cure before the middle has fully cured. Second, a bearing with many shims has a greater probability of a shim being left out during the lay-up, or shim movement in the mold during curing under high temperature and pressure, than is the case with a small number of shims.

The uncertainties in fabrication operations for large bearings are thus greater those associated with the design method. It is therefore proposed that the additional testing should be applied not to bearings designed by Method B, but rather to large bearings, which are the ones more likely to experience difficulties during fabrication. This will encourage design by Method B and, by implication, the use of higher shape factors.

The format of the proposed Method B provisions is simpler than the existing one and therefore reduces the number of sub-sections required in Article 14.7.5.3. The inevitable change in numbering of the sub-sections offers the opportunity to rationalize their sequence as well. Table G-1 shows the existing and proposed sequences. The primary objective is to present the design information in the order in which it will be used. Shear deformations usually control the thickness, for which a trial value is selected first. Then strength requirements (combined axial, rotation and shear) are used to determine plan dimensions and individual layer thicknesses. Reinforcement selection, compressive deflection calculations and seismic requirements can typically be conducted without affecting the bearing properties selected in previous steps, and so are placed last.

Table G-1 Summary of Proposed Section Changes in AASHTO Method B Specifications.

Section	Old Title	New Title
14.7.5.3.1	Scope	Scope
14.7.5.3.2	Compressive Stress	Shear Deformations
14.7.5.3.3	Compressive Deflection	Combined Compression, Rotation and Shear
14.7.5.3.4	Shear Deformations	Stability
14.7.5.3.5	Combined Compression and Rotation	Reinforcement
14.7.5.3.6	Stability	Compressive Deflection
14.7.5.3.7	Reinforcement	Seismic Requirements
14.7.5.3.8	Seismic Requirements	

The proposed Method A Specifications maintain the format of the existing ones. Because that article also addresses cotton duck pads (CDP), plain elastomeric pads (PEP) and fiberglass reinforced pads (FGP), a decision was needed over the use of a cyclic amplification factor. Such a factor is not used for the present Method A, but it does form a part of the proposed Method B. If the proposed new Method A for steel-reinforced bearings were to include cyclic amplification, it would be inconsistent with the procedures for the other pad types in Method A. If it were to be based on non-amplified stresses, then it would be inconsistent with the proposed Method B. Thus it is not possible to be consistent with both procedures. The latter course (no amplification, thereby maintaining consistency with other Method A bearings) was eventually chosen, but a change to the opposite approach would be relatively simple if Committee T-2 sees fit to do so.

It should be noted that the researchers see several problems with the testing regime presently defined in M-251. They have also heard complaints from manufacturers along similar lines. They are willing to meet with the T-2 Committee members and a representative group of manufacturers to discuss those testing requirements with the goal of improving them.

G.2 Proposed Specification Provisions

This section contains wording of the proposed Design Provisions.

Wording in italics indicates comments or operational suggestions, such as new locations for existing text.

~~Strikeouts~~ indicate existing wording to be deleted.

<u>Underlines</u> indicate new wording to be added.

G.2.1 AASHTO 14.4 Movements and Loads

G.2.1.1 AASHTO 14.4.1 General

The commentary (paragraph 1) states:

"If the bridge deck is cast-in-place concrete, the bearings at a single support should permit transverse expansion and contraction".

This statement should be changed to include precast concrete decks as well.

The commentary (fourth paragraph) contains the statement:

"The location of bearings off the neutral axes of the girders can create horizontal forces due to elastic shortening of the girders when subjected to vertical loads".

The meaning of the statement is not clear. The girders do not shorten under vertical loads. If the statement is intended to refer to the fact that rotation at the girder end causes horizontal movement at the bottom flange, and that those movements induces shear force in the bearing, then that fact is addressed by the previous sentence, and there is no need to repeat the information.

G.2.1.2 AASHTO 14.4.2 Design Requirements.

The Commentary (paragraph 1) states:

"Live load rotations are typically less than 0.005 radians, but the total rotation due to fabrication and setting tolerances may be significantly larger than this".

This statement is not consistent with the fact that the rotation allowance for fabrication and placement is 0.005 radians. Either the statement or the allowance should be changed. Note that 0.005 radians is a very small angle, and corresponds to a movement on a carpenter's level of only about one tenth of a bubble length. Bearings are therefore likely to be installed to an accuracy better than this only if an instrument more sophisticated than a carpenter's level is used. That appears unlikely with current construction methods.

The Commentary (paragraph 2) states:

"As a result, such bearings are permitted temporary overstress during construction. If this was not so, temporary local uplift, caused by light load and large rotation might unreasonably govern the design".

Delete these two sentences. The construction condition is now addressed properly by Method B.

G.2.2 AASHTO 14.7.5 Steel-Reinforced Elastomeric Bearings – Method B

G.2.2.1 AASHTO 14.7.5.1 General

After the third paragraph ("tapered elastomer layers shall not be used…") add a new sentence:

Plan dimensions used for computing the properties of the bearing shall be taken as the average of the gross bearing dimensions and the shim dimensions. The shape factor of a layer of an elastomeric bearing…

Change the definitions of L and W to:

L = plan dimension of the bearing perpendicular to the axis of rotation under consideration

W = plan dimension of the bearing parallel to the axis of rotation under consideration

These definitions are used in the proposed 14.7.5.3.3 (Combined stress) and 14.7.5.3.4 (Stability). They should also be changed in the list of notation at the start of Chapter 14.

COMMENTARY

Make changes as shown. Strike-throughs signify deletions. Underlines signify new wording.

~~The stress limits associated with Method A usually result in a bearing with lower capacity than a bearing designed using method B. This increased capacity resulting from the use of Method B requires additional testing and quality control.~~

Steel-reinforced elastomeric bearings are treated separately from other elastomeric bearings because of their greater strength and superior performance in practice (Roeder et al. 1987, Roeder and Stanton 1991). The critical parameter in their design is the shear strain in the elastomer at its interface with the steel plates. Axial load, rotation and shear deformations all cause such shear strains. The design method (Method B) described in this section accounts directly for those shear strains, and provides a versatile means of allowing for different combinations of loading. ~~allows higher compressive stresses and more slender bearings than are permitted for other bearing types of elastomeric bearings, both of which can lead to lower horizontal forces on the substructure. To qualify for the more liberal design, the bearings should be subjected to more rigorous testing.~~

Tapered layers cause larger shear strains and bearings made with them fail prematurely due to delamination or rupture of the reinforcement. All internal layers should be the same thickness, because the strength and stiffness of the bearing in resisting compressive load are controlled by the thickest layer.

Large steel-reinforced elastomeric bearings are more difficult to fabricate than small ones. The consequences of failure are also likely to be more severe in a large bearing. Therefore the provisions of the AASHTO M-251 materials specification impose additional test requirements on large bearings.

The shape factor, S_i, of layer *i* is defined in terms of its ~~the gross~~ plan dimensions, which are defined as the average of the shim and the gross dimensions. Finite element studies have shown that the critical responses of laminated bearings can best be approximated by the simpler calculation methods on which the equations of Article 14.7.5.3 are based if the properties are based on the average of the gross bearing dimensions and the shim dimensions. (Stanton et al. 2007). Use of the average rather than the gross dimensions will make the greatest difference in small bearings, since the cover is usually the same in all bearings. ~~Refinements to account for the difference between the gross dimensions and the dimensions of the reinforcement are not warranted because quality control on elastomer thickness has a more dominant influence on bearing behavior~~.

Holes are strongly discouraged in steel-reinforced bearings. However, if holes are used, their effects should be accounted for when calculating the shape factor because they reduce the loaded area and increase the area free to bulge. Suitable shape factor formulae are:…"

G.2.2.2 AASHTO 14.7.5.2 Material Properties

No change

G.2.2.3 AASHTO 14.7.5.3 Design Requirements

G.2.2.3.1 AASHTO 14.7.5.3.1 Scope

Delete this article and its Commentary.

G.2.2.3.2 AASHTO 14.7.5.3.2

Present Title "Compressive Stress".

Delete existing section 14.7.5.3.2. "Compressive Stress".

Replace it with the material from the present 14.7.5.3.4 "Shear deformations". Renumber to 14.7.5.3.2.

G.2.2.3.3 AASHTO 14.7.5.3.3

Present Title: "Compressive Deflection".

Retain this material (Compressive Deflection), but move and renumber it to new 14.7.5.3.6. Also, in Commentary, add reference to Stanton and Lund (2004), directly after "…. Stanton and Roeder 1982".

Replace with new Code and Commentary on combined Compression, Rotation and Shear, as follows.

Combined Compression, Rotation and Shear.

Combinations of axial load, rotation and shear at the service limit state shall satisfy:

$$\left(\gamma_{a,st} + \gamma_{r,st} + \gamma_{s,st}\right) + 2.0\left(\gamma_{a,cy} + \gamma_{r,cy} + \gamma_{s,cy}\right) \le 5.0 \qquad \text{(G-1)}$$

The static component of γ_a shall also satisfy

$$\gamma_{a,st} \le 3.0 \qquad \text{(G-2)}$$

where

γ_a = shear strain caused by axial load

γ_r = shear strain caused by rotation

γ_s = shear strain caused by shear displacement

Subscripts "*st*" and "*cy*" indicate static and cyclic loading respectively. Cyclic loading shall consist of loads induced by traffic. All other loads may be considered static. In rectangular bearings, the shear strains shall be evaluated separately for rotation about the strong and weak axes of the bearing. In circular bearings the rotations about different axes shall be added vectorially, and the shear strains shall be evaluated using the largest sum.

The shear strains γ_a, γ_r and γ_s, shall be established by rational analysis, in lieu of which the following approximations are acceptable. The shear strain due to axial load may be taken as

$$\gamma_a = D_a \frac{\sigma_s}{GS} \qquad \text{(G-3)}$$

where, for a rectangular bearing,

$$D_a \approx \max\left\{d_{a1}, \left(d_{a2} + d_{a3} * L / W\right)\right\} \qquad \text{(G-4)}$$

and

$$d_{a1} = 1.06 + 0.210\lambda + 0.413\lambda^2$$

$$d_{a2} = 1.506 - 0.071\lambda + 0.406\lambda^2$$

$$d_{a3} = -0.315 + 0.195\lambda - 0.047\lambda^2$$

and for a circular bearing

$$D_a = 1.0 \qquad \text{(G-5)}$$

For a rectangular bearing the shear strain due to rotation may be taken as

$$\gamma_r = D_r \left(\frac{L}{h_{ri}} \right)^2 \theta_i \qquad \text{(G-6)}$$

where, ,

$$D_r = \frac{1.552 - 0.627\lambda}{2.233 + 0.156\lambda + L/W} \leq 0.5 \qquad \text{(G-7)}$$

For a circular bearing the shear strain due to rotation may be taken as

$$\gamma_r = D_r \left(\frac{D}{h_{ri}} \right)^2 \theta_i \qquad \text{(G-8)}$$

where

$$D_r = 0.375 \qquad \text{(G-9)}$$

The shear strain due to shear deformation of any bearing may be taken as

$$\gamma_s = \frac{\Delta_s}{h_{rt}} \qquad \text{(G-10)}$$

In the above

D = Diameter of the bearing

D_a = dimensionless coefficient used to determine shear strain due to axial load

D_r = dimensionless coefficient used to determine shear strain due to rotation

h_{ri} = thickness of the i^{th} internal layer of elastomer

h_{rt} = total elastomer thickness.

L = plan dimension of the bearing perpendicular to the axis of rotation under consideration

W = plan dimension of the bearing parallel to the axis of rotation under consideration

Δ_s = maximum shear deformation of the bearing at the service limit state.

θ_i = rotation of the i^{th} layer of elastomer (radians)

λ = Compressibility Index = $S\sqrt{\frac{3G}{K}}$

σ_s = average axial stress on the bearing at the service limit state

In each case, the static and cyclic components of the shear strain shall be considered separately and then combined using Equation (G-1).

In bearings with externally bonded steel plates on both top and bottom, the hydrostatic stress shall satisfy:

$$\sigma_{hyd} \le 2.25G \qquad \text{(G-11)}$$

where σ_{hyd} is the peak hydrostatic tension, computed by

$$\sigma_{hyd} = 3GS^3\theta_i f(\alpha) \qquad \text{(G-12)}$$

$$f(\alpha) = \frac{4}{3}\left\{\left(\alpha^2 + \frac{1}{3}\right)^{1.5} - \alpha\left(1-\alpha^2\right)\right\} \qquad \text{(G-13)}$$

and

$$\alpha = \frac{\varepsilon_a}{S\theta_i} \qquad \text{(G-14)}$$

In Equation (G-14), the average axial strain, ε_a, shall be computed as

$$\varepsilon_a = \frac{\sigma_s}{3B_a GS^2} \qquad \text{(G-15)}$$

and shall be taken as positive for compression. Constant B_a is given, for a rectangular bearing, by

$$B_a \approx (2.31 - 1.86\lambda) + (-0.90 + 0.96\lambda)\left(1 - \min\left\{\frac{L}{W}, \frac{W}{L}\right\}\right)^2 \qquad \text{(G-16)}$$

And, for a circular bearing, by

Error! Objects cannot be created from editing field codes. (G-17)

For values of α greater than 1/3, the hydrostatic stress is compressive, so Equation (G-11) is satisfied automatically and no further evaluation is necessary. The values of ε_a and θ_i used in Equation (G-14) shall consist of the static components plus 2.0 times the cyclic components of the strain and rotation relevant to the loadcase under consideration.

COMMENTARY

Elastomers are almost incompressible, so when a steel-laminated bearing is loaded in compression, the elastomer expands laterally due to the Poisson effect. That expansion is partially restrained by the steel plates to which the elastomer layers are bonded, and the restraint results in bulging of the layers between the plates. The bulging creates shear stresses at the bonded interface between the elastomer and steel. If they become large enough they can cause shear failure of the bond or the elastomer adjacent to it. This is the most common form of damage in steel-laminated elastomeric bearings, and is the reason why limitations on the shear strain in the elastomer dominate the design requirements.

The material properties needed for the elastomer include both *G* (shear modulus) and *K* (bulk modulus). The value of *G* varies considerably among rubber compounds, and can be loosely related to hardness (see Table 14.7.5.2-1). The value of *K* varies little with hardness. In the absence of better information, it may be taken as 450 ksi for all elastomers permissible under this specification for use in steel-reinforced elastomeric bearings.

The cyclic components of the loading are multiplied by an amplification factor of 2.0 in Equation (G-1). This reflects the results of tests that showed that cyclic shear strain causes more debonding damage than a static shear strain of the same amplitude. This approach, of using an explicit summation of the shear strain components coupled with an amplification factor on cyclic components, is found in other specifications, such as the European EN 1337.

In some cases, the rotations due to dead and live load will have opposite signs, in which case use of the amplification factor of 2.0 could lead to an amplified rotation that is artificially low. This is clearly not consistent with the intent of the amplification factor. A plausible interpretation would be to treat the static part of the load as consisting of the abs(DL) minus abs(LL), and then to treat the cyclic component as abs(LL). This will lead to the amplified load being equal to abs(DL) + abs(LL). A similar interpretation may be used for other components of loading, such as thermal camber. In cases where the sense of the loading components in the critical combination is unclear, the sum of the absolute value should be used.

For skew bridges, the girder ends will rotate in both bending and torsion. The magnitudes and orientations of the rotations may not be known precisely unless a 3-D analysis of the bridge is conducted. In particular, the torsional rotations of skew steel girder bridges that occur during construction may depend on the way that the members are detailed and erected. If rectangular bearings are used, they should be oriented so that their long edges are parallel to the support line unless 3-D analysis shows that some other orientation is preferable. Bearings in the shape of parallelograms are not recommended.

While they may fit well beneath the girder, they are more difficult to fabricate, and the region in the acute angle corner resists little load and provides little benefit. Circular bearings offer a good alternative.

To minimize possible confusion over the value S of *W* and *L*, a convention is needed. The one used here is that *W* is always the length of the side parallel to the axis of rotation under consideration. This holds true for computing both stiffness and shear strain coefficients. Usually, the bearing will experience rotation about its weak axis, so *W* will be the length of the long side and *L*, the length of the short side. Thus, for a 10 in. x 20 in. bearing, L = 10 in. and W = 20 in. for bending about the weak axis, but L = 20 in. and W = 10 in. for bending about the strong axis. The coefficients D_a and D_r given in Equations (G-4) and (G-7) compute the shear strain on the side of the bearing, of length *W*, that is parallel to the axis of rotation. Because both strains occur in the same place, they are additive.

Note that, under axial load alone, the largest shear strain occurs on the long side of the bearing. For the common case of rotation about the weak axis, the largest shear strains due to both axial and rotation loading individually occur in the same place, so shear strains need only be calculated there. If the primary loading is about the strong axis, the largest total shear strain may occur either at the long side (due to axial load alone) or at the short side (due to axial plus rotation effects). Both must be calculated, and the larger controls.

In a rectangular bearing, shear strains due to axial force and rotation diminish towards to the corner. Thus separate evaluations should be made about each axis, and it is neither necessary nor appropriate to take the vector sum at the corner.

The compressibility Index, λ, represents the effect of finite bulk stiffness of the rubber. For conventional bearings it makes little difference, but in high shape factor bearings it reduces the stiffness below the value that would be computed using an incompressible model (i.e. with $\lambda = 0$).

Previous editions of the Specifications contained provisions to prevent net upward movement of any point on the bearing. Recent research (Stanton et al., 2007) has shown that, if the bearing is not equipped with bonded external plates, the sole plate can lift away from the bearing without causing any tension in the elastomer. Furthermore, the compression effects are slightly less severe than in a bearing that is identical except for the presence of bonded external plates, and is subjected to the same loading combination. Thus the “no-lift-off” provisions have been removed.

However, in a bearing equipped with external plates, upward movement of part of the plate can cause internal rupture due to hydrostatic tension. Provisions have been added to address this case. It is expected to control only rarely, and when it does, it is likely to do so during under construction conditions, when the axial load is light and the rotation, due to pre-camber, is large. For the construction load case, the cyclic components of the loading will be zero. For bearings with external plates, Equations (G-1) and (G-11) should be checked under all critical loading conditions, including construction, and about both strong and weak axes of rectangular bearings.

Tests have shown that sharp edges on the internal steel shims cause stress concentrations in the elastomer and promote the onset of debonding. The internal shims should be de-burred or otherwise rounded prior to molding the bearing. The design values in Equation (G-1) are consistent with that procedure.

G.2.2.3.4 AASHTO 14.7.5.3.4.

Present Title: "Shear Deformations"

Retain the material on Shear Deformations. Move and renumber to new 14.7.5.3.2.

Replace with material from present 14.7.5.3.6 "Stability". Renumber accordingly. Revise the definitions of L and W in the Stability requirements to be the same as in the proposed 14.7.5.3.3.

G.2.2.3.5 AASHTO 14.7.5.3.5

Present title "Combined Compression and Rotation".

Delete this section. Replace it with the material from the present 14.7.5.3.7 "Reinforcement".

G.2.2.3.6 AASHTO 14.7.5.3.6

Present title. "Stability"

Retain the material on Stability. Move it to the new 14.7.5.3.4. Replace it with material from existing 14.7.5.3.3 "Compressive Deflection".

G.2.2.3.7 AASHTO 14.7.5.3.7

Present title. "Reinforcement".

Retain the existing material on Reinforcement. Move it to the new 14.7.5.3.4. Replace it with the existing material from 14.7.5.3.8 "Seismic requirements".

G.2.2.3.8 AASHTO 14.7.5.3.8

Present title. "Seismic Requirements".

Retain the existing material on Seismic requirements. Move it to the new 14.7.5.3.7. Then delete this section (14.7.5.3.8).

G.2.2.3.9 AASHTO 14.7.6.4 Anchorage

New article. (Anchorage requirements are specified in Method A, but not Method B. Since Method B allows greater rotation than Method A, the absence of anchorage requirements in Method B is not rational).

For bearings without bonded external plates, a restraint system shall be used to secure the bearing against horizontal movement if either

$$\theta_i \geq \frac{3\varepsilon_a}{S} \qquad \text{(G-18)}$$

or the factored shear force sustained by the deformed bearing at the strength limit state exceeds one fifth of the minimum vertical force, P_{sd}, due to permanent loads,

COMMENTARY

If the rotation is large enough to cause lift-off, the bearing may be susceptible to slipping out of place, and a restraint system is required to prevent this from occurring. Such a restraint system is also desirable for smaller rotations. The need for it depends on the magnitude of the rotation and the coefficient of friction available between the bearing and the surfaces with which it is in contact.

G.3 AASHTO 14.7.6 Steel Reinforced Elastomeric Bearings - METHOD A

G.3.1 AASHTO 14.7.6.1 General

Make the following changes, indicated by underline:

The provisions of this article shall be taken to apply to the design of:

- Plain elastomeric pads, PEP;
- Pads reinforced with discrete layers of fiberglass, FGP;
- Steel reinforced elastomeric bearings in which $S^2/n < 16$, without bonded external plates, and for which the primary rotation is about the weak axis;
- Cotton duck pads (CDP) with closely spaced layers of cotton duck and manufactured and tested under compression in accordance with Military Specification MIL-C-882.

Otherwise, this article remains unchanged.

G.3.2 AASHTO 14.7.6.2 Material Properties and 14.7.6.3.1 Scope

Both of these articles appear to address material properties, and the information is in some cases conflicting. For example, 14.7.6.2 says that hardness shall lie between 50 and 70, but 14.7.6.3.1 says that "for these bearings" (FGP and Steel-reinforced bearings? It is not clear), the hardness shall be 50 ± 10.

It is suggested that the T-2 Committee may wish to consider

- *Combining and rationalizing these two articles.*
- *Changing the limits on hardness for "these bearings". At present 40 durometer (i.e. 50 – 10 = 40) is permitted, but that is very low in the absolute and leads to very low allowable average compressive stresses, and is lower than allowed*

under 14.7.5.2. Furthermore, Table 14.7.5.2-1 gives no shear modulus equivalent to 40 durometer. It would also be worth clarifying whether these target hardness values are for design (in which case a couple of points over or under may be permissible in practice) or whether they are absolute limits, exceedence of which would be cause for rejection in the field.

G.3.3 AASHTO 14.7.6.3.2 Compressive Stress

"… at the top and bottom of the elastomer layer.

For steel-reinforced bearings designed in accordance with the provisions of this article:

σ_s < ~~1.0~~ <u>1.25</u> ksi and σ_s < ~~1.0~~ <u>1.25</u> *GS* *(14.7.6.3.2-4)*

where the value of *S* used shall be for the thickest layer of the bearing."

The T-2 Committee may wish to consider imposing an additional limit on compressive stress on PEP that is related to shape factor, to bring PEP into line with other pad types. At present is permissible to use a plain pad with shape factor 1.0 under a stress of 800 psi. Such a pad would perform very poorly. The absolute limit of 800 psi is also too high compared with the (present) 1000 psi allowed for steel reinforced bearings.

G.3.4 AASHTO 14.7.6.3.3 Compressive Deflection

Leave unchanged.

G.3.5 AASHTO 14.7.6.3.4 Shear

Leave unchanged except for a change in article number 14.7.5.3.4 referring to Method B (if those changes are accepted).

G.3.6 AASHTO 14.7.6.3.5 Rotation

Leave unchanged.

G.3.7 AASHTO 14.7.6.3.6 Reinforcement

Leave unchanged.

G.3.8 AASHTO 14.7.6.3.7 Seismic provisions

Leave unchanged.

G.3.9 AASHTO 14.7.6.4 Anchorage

Leave unchanged.

G.4 AASHTO M-251 Materials Specification.

<u>Change Section 3.5 as follows:</u>

At the owner's discretion, bearings ~~specified by hardness and designed in accordance with Method A of the AASHTO LRFD Bridge design Specifications or the Standard Specifications for Highway Bridges~~ with a total rubber thickness, h_{rt}, less than 8 inches, and with a plan area smaller than 1000 in^2, may be tested and accepted in accordance with Appendix X1 in lieu of Section 8.

The above modification represents a change in philosophy for testing. It is also recommended that M251-06 be carefully reviewed by a group that includes representation from at least the T-2 Committee, manufacturers, and the 12-68 research team. The present version of the specification contains a number of inconsistencies and potentially serious flaws.

G.5 Notes.

1. The symbol σ_s is used in Article 14.7.5.3.3 to mean "service average compressive stress due to total load from applicable service load combinations in Table 3.4.1-1 (ksi)". The word "service" is here understood to mean when the bridge is complete.

   This definition implies that only service loadcases are to be investigated. However, the intent is that the engineer should investigate several different loadcases, including construction conditions. In bearings that have bonded external plates, large rotations and light axial loads during construction may cause internal rupture due to hydrostatic tension.

   Thus it is necessary to ask whether a new symbol for stress should be used, the definition of σ_s should be changed, or some other solution adopted. The symbol σ_a was used to indicate average axial stress during the research, and corresponding quantities (ε_a, B_a, etc.) have the same subscript for consistency. Thus, defining a new symbol σ_a is a possibility. However consistency with other articles in the Specifications is important. The researchers seek the advice of the Project Panel, and the T-2 Committee, on how best to handle this matter. Wording has already been placed in the Commentary to alert the designer to the need to check construction conditions for such bearings.

2. The anchorage requirements of the existing Method A are expressed in terms of the factored shear force, whereas all other bearing design requirements pertain to the service load limit state. It is recommended that the anchorage requirements be changed to the service limit state.

3. We recommend that the requirement for more rigorous testing be changed to apply to large bearings rather than those designed under Method B. However, a problem with testing remains: large bearings are the ones most in need of testing, but how can they best be tested if the required loads are too large for the available testing equipment? It is suggested that this is a matter that should be determined by joint discussions between the T-2 Committee, a group of the major manufacturers and the research team.

   The most likely potential problems in the bearing include shim movement during manufacture (but this can usually be detected in the short-term test to 150% of design load), and improper cure. Both of these are most strongly related to bearing thickness. Possible approaches to effective testing are outlined in Section 3.3 of the main report.