

# LRFD Design Criteria for Cotton Duck Pad Bridge Bearing

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## **Introduction**

Cotton duck pads (CDP) are preformed elastomeric pads consisting of thin layers of elastomer interlayered with layers of cotton duck fabric. Manufactured under Military Specification MIL-C-882-E,<sup>3</sup> CDP are known to be quite stiff and to have large compressive load capacity. Because of this great stiffness, the translational movement and rotational capacity of CDP have been severely limited. Very few tests have been performed on these pads to examine their behavior, and, as a consequence, the design limits for these pads have been based historically on models for plain unreinforced elastomeric bearing pads (PEP), with the additional constraint caused by the larger bearing stiffness added to the model. As a consequence, although CDP are permitted significant compressive load capacity in the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) and Standard Specifications, they are allowed virtually no translational movement or rotational capacity in these same specifications. The AASHTO limit on translational movement capacity is less serious than that on rotational capacity, because CDP are often used with polytetrafluoroethylene (PTFE) sliding surfaces, which can accommodate significant translation even though the CDP is very stiff. The AASHTO limitation on rotation is very severe, however, because it makes difficult the accommodation of construction tolerances with CDP applications. The severity of this rotational limit is the primary focus of this research study.

The present AASHTO design limits for CDP were established in the absence of significant experimental data. Although recent tests have been completed on CDP, these tests were completed by or funded by bearing manufacturers. Nonetheless, CDP have been used successfully for many years with relatively few problems reported, and there is evidence<sup>7</sup> that they have been used at higher loads and with larger deformations than permitted in the AASHTO Specifications. This study was intended to evaluate existing

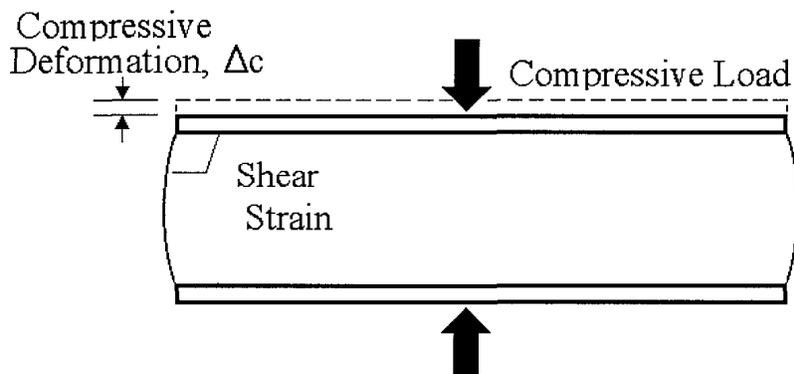
proprietary data and to develop improved recommendations for the AASHTO Specifications within this available body of information. The primary concern in this evaluation was the present restrictive rotational limits, but the scope was intended to consider the whole range of CDP behavior. The main goal of this work was to evaluate the validity of existing tests that claim to represent the true behavior expected in bridge bearings.

### **Initial Evaluation**

In the evaluation of elastomeric bearings, there is a classical procedure used to establish the resistance and deformation limits of all types of elastomeric bearings. Basic models are established for reinforced elastomeric bearings, which are then adapted to a range of different elastomeric pads based on differences in behavior. Elastomeric pads and bearings must accommodate movements and rotations while supporting large gravity loads. Elastomers are a very flexible material that permits translational deformation and rotation, but the flexibility of the elastomer clearly does not provide the stiffness needed to support the gravity loads. Resistance of gravity loads is achieved by adding reinforcement to the rubber layer, as shown in Figure 1. All materials deform outward when subjected to a compressive load. In structural mechanics, this phenomenon is known as the Poisson effect. Because the elastomer is flexible, elastomeric materials would ordinarily deform outward a great deal. However, the reinforcement layer is extremely stiff compared with the rubber, and it prevents this outward movement and causes the rubber instead to assume the bulged pattern in compression, as illustrated in Figure 1. This restraint and the resulting bulge pattern of the rubber dramatically stiffen the bearing in compression. The increase in compressive stiffness may be many orders of magnitude. The shape factor (S) of the bearing represents an approximate measure of the bulging effect:

$$S = \frac{\text{Plan Area}}{\text{Perimeter Area of Layer}} = \frac{L W}{2 (L+W) t} \quad \text{Equation 1}$$

where L and W represent the length and width in plan dimensions of a rectangular bearing and t represents the thickness of the elastomer layer. The shear strain in the elastomer limits the bearing resistance, because excess strain will induce tearing or deterioration of the elastomer. This strain is also a function of the shape factor. Thus, the design of elastomeric bearings for compressive load calls for limiting the strain in the elastomer and controlling the shape factor to achieve the required strength and stiffness.



*Figure 1. Deformation of elastomeric bearing under gravity loads.*

Plain unreinforced elastomeric pads (PEP) do not have the direct layer reinforcement shown in Figure 1, and as a consequence they rely on friction between the elastomer and the load surface to control the stiffness and deformation. Friction is highly variable, and so PEP deform more and have larger shear strains under compressive load than do steel reinforced elastomeric bearings. Thus, AASHTO requires a significant reduction in load capacity for PEP over that permitted for reinforced elastomeric bearings.

Cotton duck pads have attributes of both PEP and reinforced elastomeric bearings. Friction at the load surface is still a major bulging restraint for CDP. However, CDP also have closely spaced layers of cotton duck fabric reinforcing the elastomer. The

shape factor becomes somewhat nebulous for CDP. One could argue that the thickness of the elastomer in the shape factor equation is the distance between fabric layers. This definition would result in shape factors of the order of one hundred or more. At these shape factors, the compressive stiffness of the bearing pad would be grossly overestimated, because the cotton duck is many orders of magnitude more flexible than the steel shims of reinforced elastomeric bearings are. Another model might base the nominal shape factor on the nominal pad thickness, but this model would have to recognize an increase in apparent elastomer stiffness because of the many more layers of the cotton duck than the two layers of steel used in a reinforced elastomeric bearing. Because CDP are much stiffer than PEP but more flexible than a steel reinforced bearing, the shape factor has a less clear meaning for CDP. In this report, the nominal shape factor will be employed as the more realistic indicator of bearing behavior. With this limited understanding of CDP behavior, AASHTO provides a limit for the compressive load of CDP (1,500 psi), and the issue of vertical deflection is not viewed as an issue of great concern as long as CDP is kept within that stress limit.

Translational movements in a bridge are accommodated by shear deformation of the elastomer, as illustrated in Figure 2. The steel reinforcement of a reinforced elastomeric bearing does not provide any significant stiffness to the elastomer with respect to this shear deformation. Therefore, the bearing and the elastomer deform easily, as shown in the figure. The deformation limits on the bearing in shear are controlled by the shear strain and by the concern that this deformation pattern might break down at very large strains. Local curling of the corners occurs. The differences between PEP and reinforced elastomeric bearings are insignificant for this translational movement, because the reinforcement has little effect on the behavior. For CDP, however, the reinforcement layers are much more closely spaced, and there are many more of them. Furthermore, the finished CDP is considerably harder (90 durometer, as opposed to 50 or 60) and stiffer than reinforced bearings or PEP. The actual elastomer for CDP is of a hardness similar to

that used for PEP and steel reinforced elastomeric bearings, but the closely spaced layers of CDP fabric reduce the indentation and increase the hardness and apparent stiffness of the finished pad. As a consequence, the translational movements that can be tolerated by CDP are significantly smaller than those of the other alternatives. The resulting small limit ( $h_{rt} > 10 \Delta_s$ ) does not normally cause a serious problem with CDP, because the hard rubber makes very suitable the attachment of a PTFE sliding surface, and this attachment readily accommodates large translational movements.

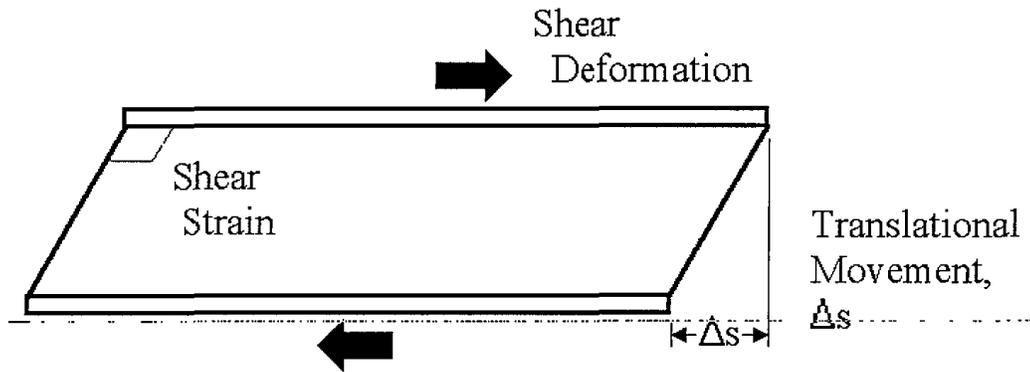


Figure 2. Deformation of elastomeric bearing under translational movement.

Rotation of reinforced elastomeric bearings again depends on the deformation of the rubber and on the shape factor, as illustrated in Figure 3. The limitation on the maximum rotation is controlled by the maximum shear strain in the elastomer, by the prevention of uplift of the superstructure from the bearing, and by the prevention of tensile stress in the elastomer. Uplift is a concern because it overloads the loaded portion of the bearing or bearing pad well beyond the normal permissible stress limits and because bearing serviceability problems are common when uplift occurs. Hydrostatic tensile stresses are extremely damaging to elastomers and may cause serious problems at very small strains. Unfortunately, both uplift and hydrostatic tensile stress are difficult to determine. As a consequence, the present procedure is very conservatively defined. Research work on this issue would be very beneficial for all elastomeric bearing types: However, within the present framework of the AASHTO provisions, elastomeric bearing

types are controlled by assuring that the compressive deformation per layer,  $\Delta_c$ , shown in Figure 1, is greater than the rotation per layer,  $\theta$ , times one half the base dimension. That is,

$$\theta \leq \frac{2 \Delta_c}{d} \quad \text{Equation 2}$$

The compressive stiffness of CDP has never been well defined because of the absence of reliable test data for these bearing pads, and so the application of this rotation limit to CDP has been difficult to rationally apply. As a result, rotations on CDP have been very conservatively limited in the AASHTO Specifications.

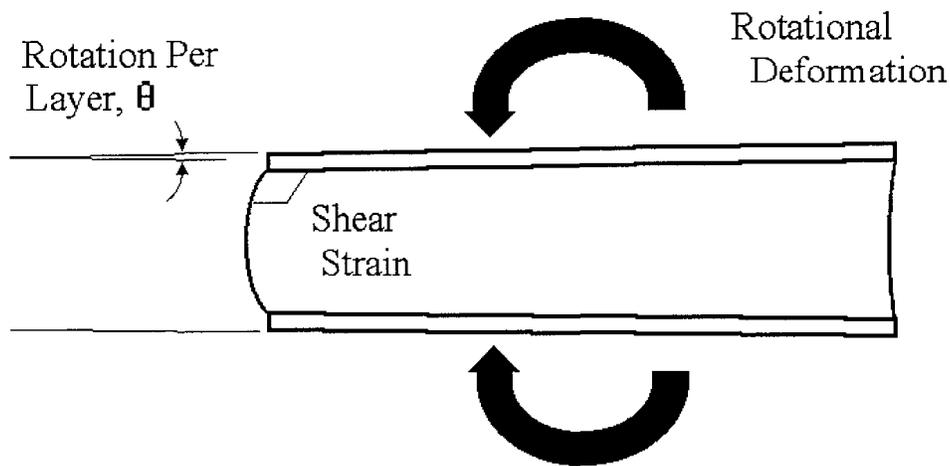


Figure 3. Deformation of an elastomeric bearing under rotation.

### Test Results on CDP as They Relate to the Bearing Pad Design Method

Relatively few tests on CDP are available, but the number of tests available today is large compared to the number available when the AASHTO LRFD provisions were developed. New data was examined and evaluated to determine possible revisions to the AASHTO Specifications. The reference list included later in this report includes all documents considered in this evaluation. Two series of tests<sup>1</sup> on CDP were performed by Wiss, Janey, Elstner Associates, Inc. on pads provided by a single manufacturer. A range of nominal shape factors varied from approximately 0.3 to 5.8 in these tests, and Figure 4

shows the compressive stress versus the compressive strain obtained from these compression tests. Figure 4 shows that specimens with higher shape factors generally have greater stiffness and smaller strains than specimens with smaller shape factors. The stiffness is directly related to the slope of these curves. However, the influence of shape factor is much less pronounced with CDP than with normal reinforced elastomeric bearings and PEP. This finding is illustrated in Figures 4, 5 and 6. Figures 5 and 6 show typical stress strain curves for steel reinforced bearings and PEP, respectively, with 50 Shore A durometer hardness elastomer. Figures 5 and 6 show a much wider variation of compressive stiffness with the variation of shape factors than that illustrated in Figure 4. Cotton duck pads have deflection and stiffness comparable to those achieved with a steel reinforced bearing with 50 durometer hardness elastomer and shape factors in the range of 5 to 10. Furthermore, PEP are much more flexible than CDP for all practical shape factors.

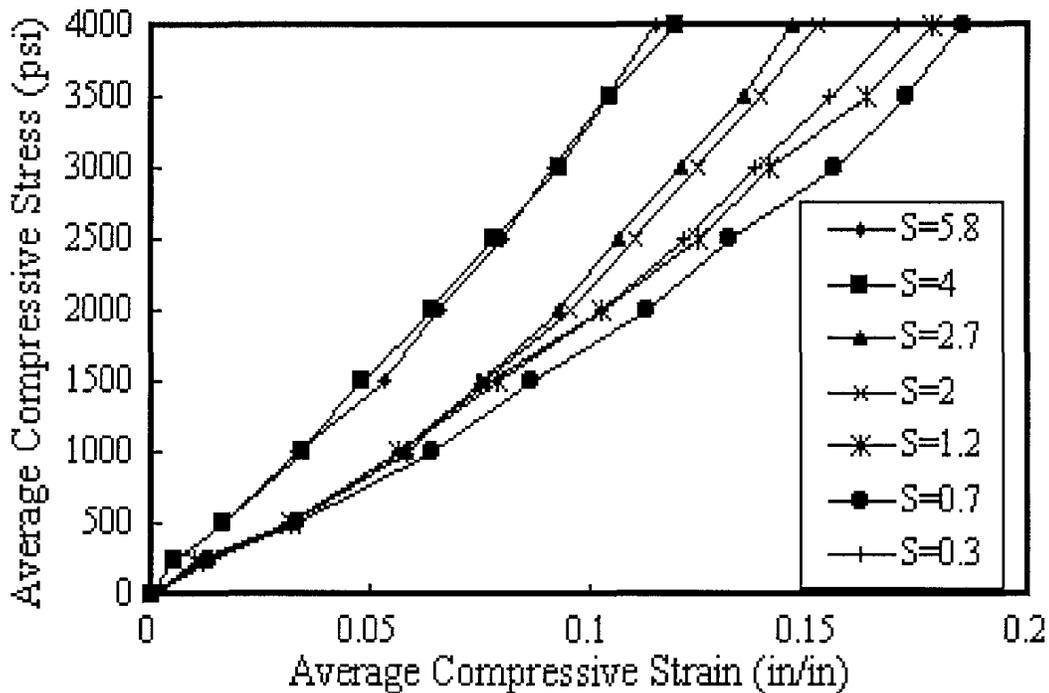


Figure 4. Compressive stress and strain of CDP with different shape factors.

The CDP specimens in Figure 4 were all manufactured by a single supplier. The tests were funded by that manufacturer, but they were performed by a reputable outside agency, and so the results have reasonable credibility for consideration of changes to AASHTO specifications. However, there are several manufacturers of CDP in the United States, and it is important to consider whether similar results will be achieved by all manufacturers. Figure 7 shows tests completed<sup>2</sup> on standard size CDP test specimens (2 in. x 2 in. x 1 in.) manufactured by three different manufacturers. The shape factor of these test specimens is 0.5, and so these three curves should be compared with the S=0.3 and S=0.7 curves of Figure 4. Comparison of Figure 4 with Figure 7 shows that the variation in behavior among different manufacturers and samples is of similar magnitude

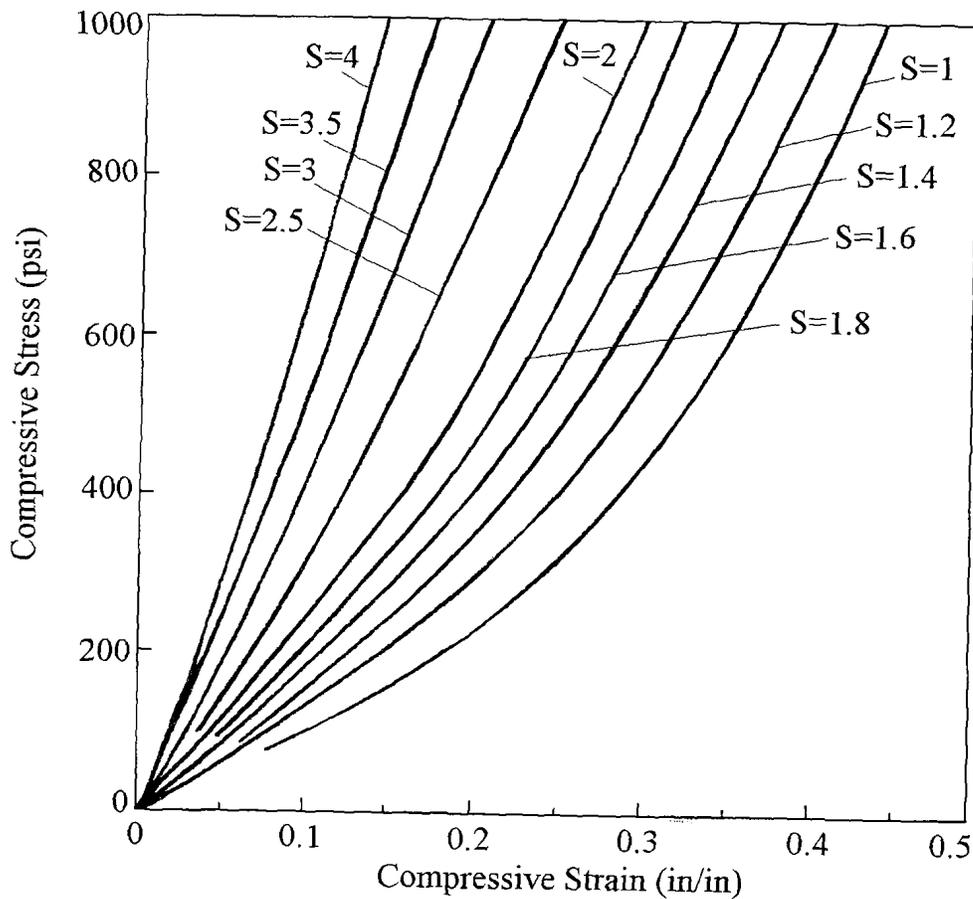


Figure 5. Compressive stress and strain of PEP with different shape factors.

to the variation caused by shape factor, as illustrated in Figure 4. The variation is not excessive in the lower stress ranges encountered in standard bridge design practice. It should be noted that the tests provided in Figure 7 were completed by one manufacturer.<sup>2</sup> The specimens were tested to loads well above the 10,000 psi stress limit, and the tests appear to be done to acceptable standards.

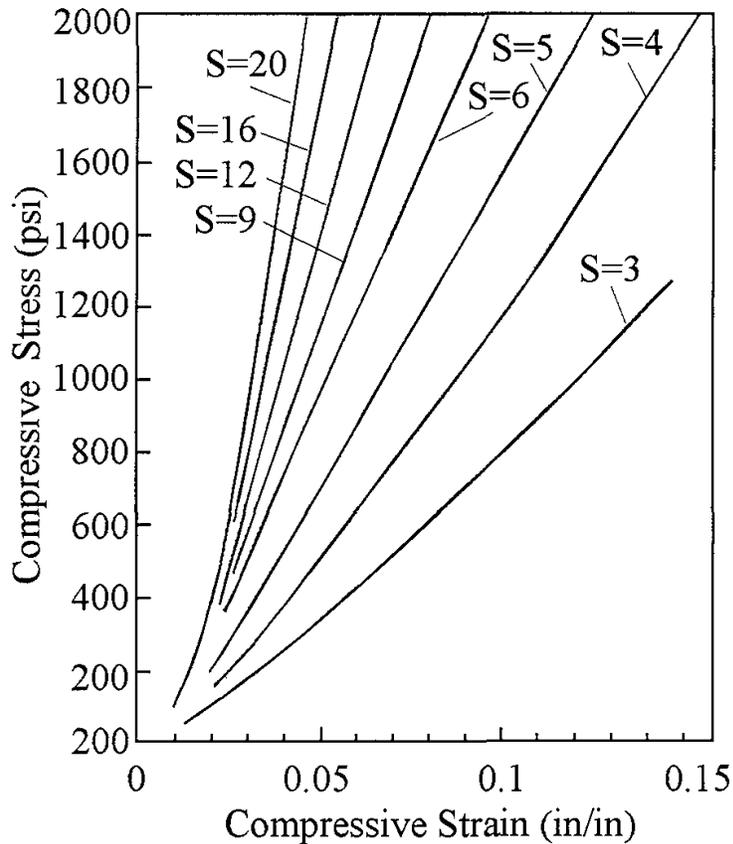


Figure 6. Compressive stress and strain of steel reinforced elastomeric bearings with different shape factors.

Figure 8 shows another set of compressive stress-strain data for CDP provided by another manufacturer from tests performed 10 to 15 years prior to those of Figures 4 and 7. The findings from this fifth manufacturer<sup>4,5</sup> are generally consistent with those of the other tests because they fall near the middle of the other data.

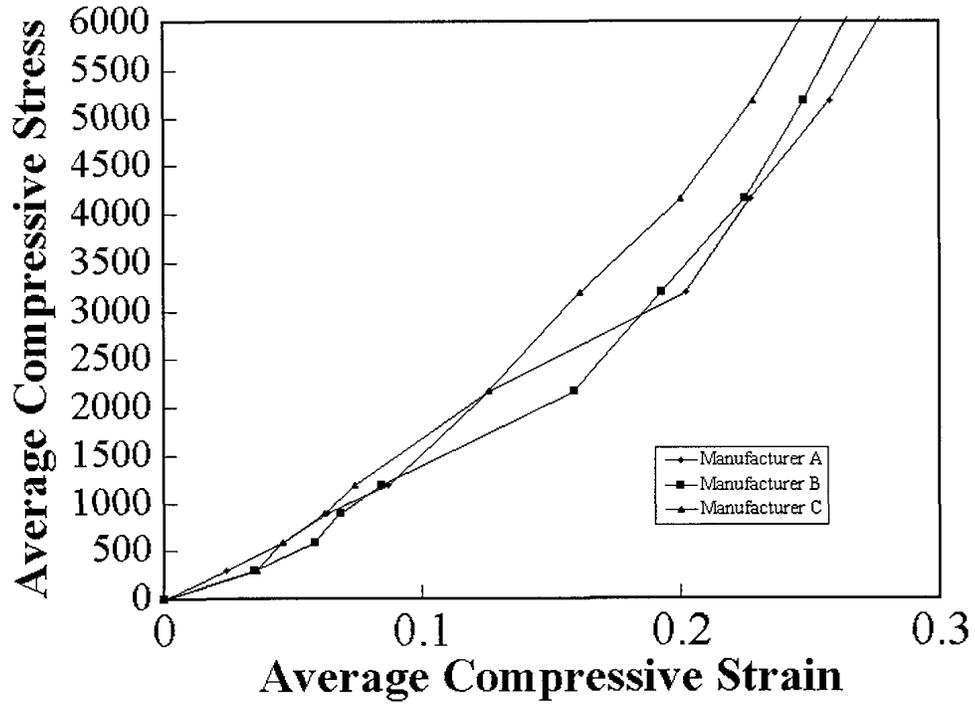


Figure 7. Compressive stress and strain of CDP from three different manufacturers.

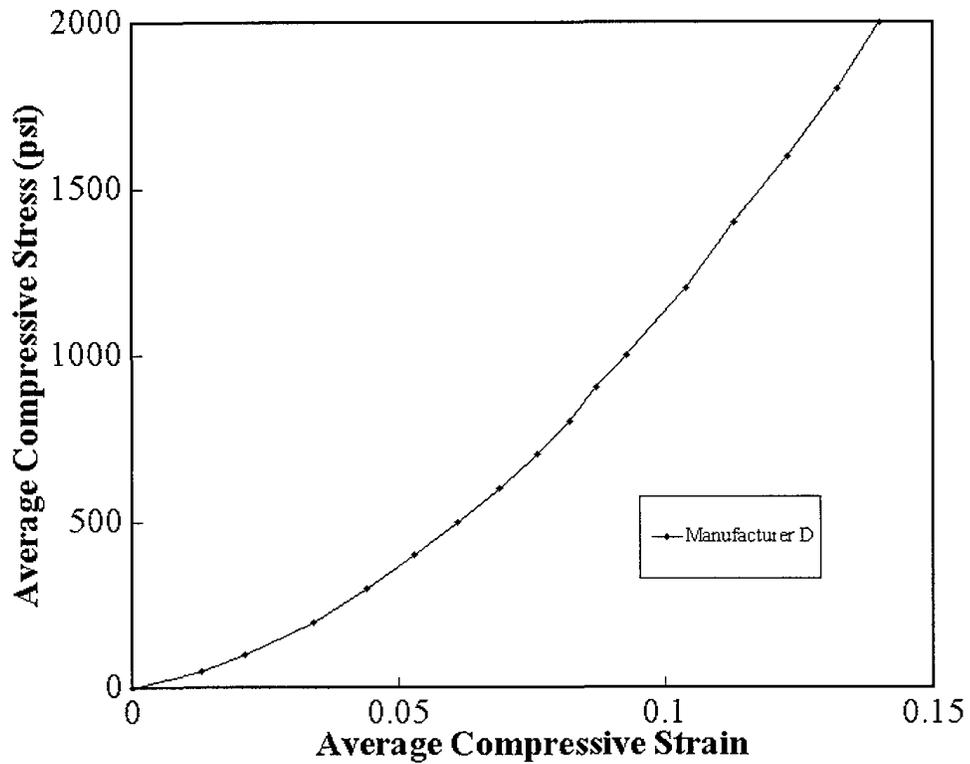


Figure 8. Compressive stress and strain recommendations for CDP from a fourth manufacturer.

CDP are manufactured under the guidance of a military specification, MIL-C-882E.<sup>3</sup> This specification was reviewed as part of this research. It is a very broad and somewhat vague document. The specification does not relate directly to CDP bridge bearing, and it also contradicts itself a number of times. For example, the document simultaneously requires the use of new elastomer and encourages the use of recycled elastomer. The document provides no recognition of natural rubber, even though CDP appear to have been manufactured with natural rubber for some past applications. Furthermore, continuous changes in the economic environment for bridge bearings suggest that natural rubber will probably be used again in the future. The specification provides a basis for rejecting many materials and practices through numbers of major or total defects, but it does not define major or minor defects. In general, the military specification is not well directed to CDP bridge bearing. One of the major sales claims made by CDP manufacturers is that these pads are manufactured under the military specification. Bridge engineers must be aware that this military specification is not as comprehensive as most AASHTO specifications used in bridge design. Nevertheless, CDP have performed well in bridge engineering practice despite the limitations of the manufacturing standards, and so it would be inappropriate to be overly concerned by the deficiencies of the military specification at this time.

The military specification provides deflection limits for CDP as well as minimum guidance for producing and manufacturing these pads. Figure 9 shows approximate upper and lower stress strain curve limits provided by this specification. These strain limits vary slightly with the thickness of the pad. The figure is an approximate average of these variable limits. Furthermore, the limits are to be applied to a standard 2 in. x 2 in. test specimen that may have nominal shape factors as large as 2 and as small as 0.5. Comparison of these limits with the test data of Figures 4, 7, and 8 shows that the test data from specimens with shape factors of 3 or less generally fall within these limits. Data points for specimens with nominal shape factors of 4 or more fall outside of these

limits, however, and so these limits are not absolute as far as the manufacture of CDP is concerned. A nominal shape factor of 3 is fairly large for CDP practical bearing. Nevertheless, deformations for CDP are not highly sensitive to shape factor, and it is reasonable to treat these limits as limits within which a statistically significant percent of CDP should fall. This concept will be used later in the establishment of deformation limits for CDP in the AASHTO specifications.

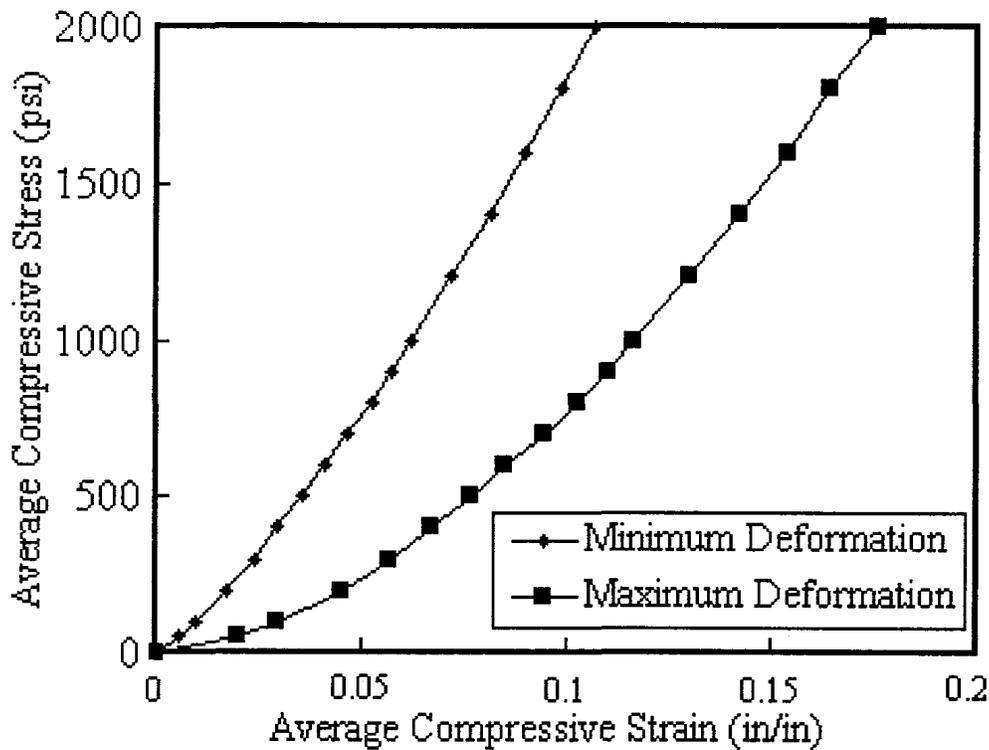


Figure 9. Upper and lower deformation limits prescribed by military specification.

The compressive load capacity of CDP is large, and failure under compressive load is normally not expected until the average compressive stress exceeds 10,000 psi. The tests reviewed in this study achieved this minimum strength level. Strengths at ultimate failure were commonly in the order of 14,000 psi. AASHTO specifications currently limit CDP to 1,500 psi, which is well below this maximum resistance. However,

Figures 4, 7, 8, and 9 show that stressing CDP to anything approaching their maximum resistance leads to very large bearing pad strains that are not normally permitted in bridge bearing applications. Comparison of these figures shows that CDP have average compressive strains between 0.08 and 0.15 at the 1,500 psi stress limit. The strain is more frequently near .15 because the shape factor of CDP is usually small. Figures 5 and 6 show that the compressive strain for CDP at the maximum permissible stress level is 2 to 3 times the maximum compressive strain for steel reinforced elastomeric bearings at their maximum permissible stress levels. The strains in PEP at their maximum permissible stress are more similar to those noted in CDP. Thus, this comparison shows that the 1,500 psi stress level is appropriate and possibly generous, because this stress level causes strains that are large compared to those permitted for other bearing types.

There is no reliable test data on shear deformation of CDP. The Wiss, Janey, and Elstner study<sup>1</sup> included some data on shear deformation, but this study did not separate slip from shear deformation. Slip between the elastomer and the sub- or super-structure is not permitted in AASHTO, because slip leads to abrasion, long-term wear, and deterioration of the pad. Because of the close spacing of the cotton duck layers, evidence suggests that CDP are stiffer than PEP or steel reinforced bearings of comparable thickness. Allowing large deformations in these pads is likely to cause deterioration of the pad and overly large forces in the bridge structure. In the absence of better data, there is no basis for changing the AASHTO specifications beyond the values presently provided.

There have been no true rotational tests on CDP, either. However, recent tests have applied combined compression and rotation<sup>1</sup> through a beveled load plate. The beveled load plate tests do not provide a clear picture of CDP behavior under rotation, however, because stiffness is not determined and the sequential load-deformation behavior is not accurately simulated. However, beveled load plate tests provide some important information that suggests that CDP can tolerate the increased shear strains

induced by combined compression and rotation. In light of this observed behavior, it appears appropriate to treat CDP in a way that is similar to how other elastomeric bearing types are treated. This treatment should result in a more calculable rotational resistance.

### **Design Recommendations**

The previous discussion has provided some insight into the behavior of CDP and the relationship of this behavior to the AASHTO specifications. The CDP provisions are relatively vague because of the shortage of reliable information available to engineers for evaluating the behavior of CDP. This report has shown that although there is still a shortage of data, there is considerably more data available today than when the LRFD provisions were written. As a result, improvements can be made to the AASHTO specifications, and the recommended improvements in LRFD format are included in Appendices A and B. Appendix A is a proposal for the LRFD specifications in SI units, and Appendix B is a proposal for English units. This section will provide a brief overview of the recommendations. Although the researcher has reviewed recommendations provided by manufacturers,<sup>5,6</sup> the recommendations here are based on available evidence and experimental results rather than unsupported opinions.

The results examined here show that CDP are affected by shape factor, but the shape factor influence is less than that of many other factors. As a result, past design concepts such as using a very large shape factor for CDP are irrational. In fact, shape factor appears to be a secondary consideration in the design of CDP, and so it is not recommended in the provisions.

The maximum compressive stress limit for CDP has historically been 1,500 psi, or 10.5 MPa. This stress limit has always been based on intuitive judgments of behavior and the observation that the maximum capacity of CDP is normally well above the maximum compressive load capacity at failure, which exceeds 10,000 psi. However, the

maximum load capacity for steel reinforced elastomeric bearings is in the range of 14,000 to 20,000 psi. Stresses and strains in steel reinforced bearings are reduced to lower levels in AASHTO specifications to ensure durability and long-term serviceability. Similar thinking is needed with CDP, although the foundation of limited experimental data leaves room for debate as to what the limit should be. Manufacturers' recommendations regarding compressive stress limits vary. Some companies have suggested the 1,500 psi stress limit, but others<sup>6</sup> would prefer to increase this stress limit significantly.

The researcher limited the compressive stress to be consistent with past practice and with other bearing types. Ordinarily, the upper stress limit would depend on the shear strain, as shown in Figure 1. However, this shear strain is lost, since the shape factor is not included in the evaluation. Therefore, a modified procedure was employed. The average compressive strain, rather than the elastomer shear strain, was used to establish the strain limits. In the past, similar reasoning has been used for PEP and steel reinforced elastomeric bearings. The average compressive strain at the maximum stress limits were determined for steel reinforced bearings of Figure 6, and this limit is plotted as a dashed line in Figure 10. It can be seen from this figure that most steel reinforced elastomeric bearings have a maximum compressive strain in the order of 0.05 to 0.07, and they never get strains larger than 0.10. If the 0.10 strain limit were imposed on CDP, Figure 9 shows that the maximum compressive stress would be limited to approximately 800 psi, well below the 1,500 psi stress limit. Bearings have a long and demanding service life with millions of cycles of loading, and CDP should not be used at levels far beyond that permitted for other bearing systems. Furthermore, the test data for CDP are limited, and the tests that have been done do not fully reflect the demands on bridge bearings. As a result, there is little reason to increase this stress limit above 1,500 psi until a database of fatigue and dynamic testing is available. At the same time, CDP have been designed at 1,500 psi in recent years with few reported problems. As a consequence, it is recommended that CDP continue to be designed to the 1,500 psi (10.5

MPa) stress limit until more data and information is available to evaluate CDP under cyclic loading and long duration load effects. Figure 9 shows that this recommendation will produce maximum compressive strains in the order of 0.14 to 0.15, strains 2 to 2.5 times those permitted for steel reinforced bearings. Figure 4 shows that CDP bearing of practical size and shape will have maximum compressive strains of 0.1 or less at this stress limit. The 1,500 psi stress limit seems very generous in view of the available information on these pads.

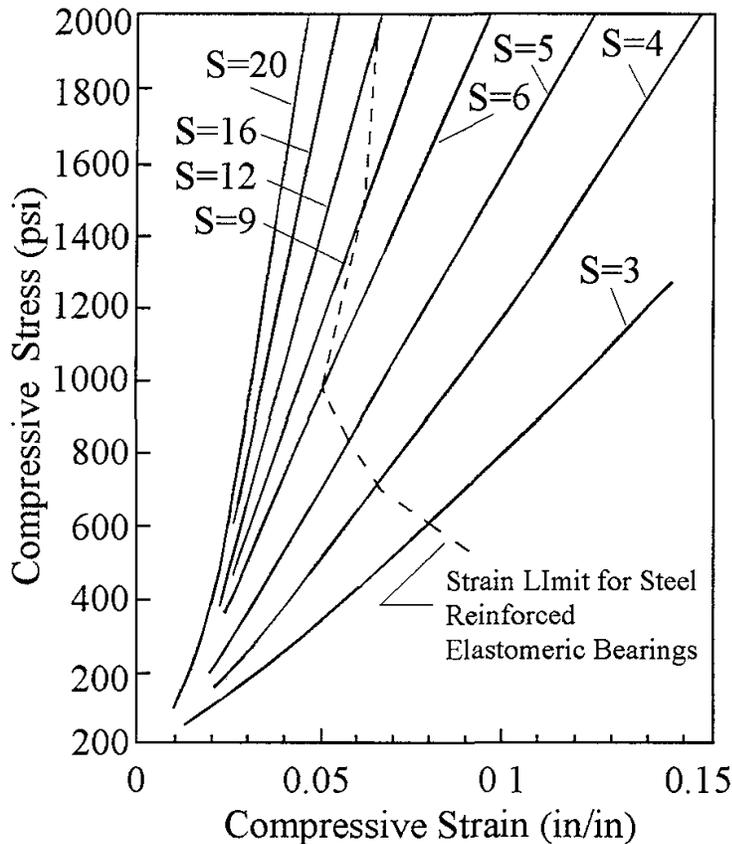


Figure 10. Maximum compressive strain limits for steel reinforced elastomeric bearings.

Experimental data is also lacking for shear deformation of CDP. As a result, it is recommended that the present shear limit,  $h_{rt} > 10$  s, be retained until experimental data is available to justify a rational revision. This strain limit will result in transmission of maximum forces through CDP similar to those that would occur in PEP or steel reinforced bearings in the same application.

Experimental data for rotation of CDP bearing is also limited. However, the limits expressed in Equation 2 and the shear strain limits control the rotational capacity of all elastomeric bearing types. The shear strains are dependent upon shape factor, and this work has shown that shape factor is not the best indicator of CDP behavior. Therefore, a modified procedure was also used for rotation. First, Equation 2 provided the present requirements for uplift and prevention of tensile stress. This equation provided a greater restriction on bearings that are stiff in compression. Therefore, the maximum stiffness limit of Figure 9 (or the least flexible limit or limit with smallest deflections) was used to establish this rotation limit. Figure 11 shows a least squares curve fit that was applied to this limit. The application of this limit to Equation 2 indicates that

$$\theta \leq \frac{t_p \sigma_c}{d 10000} \quad (\text{in English Units}) \quad \text{Equation 3a}$$

where  $t_p$  represents the pad thickness,  $\sigma_c$  represents the average compressive stress in psi, (P/A), and  $d$  represents the dimension of the bearing pad in the plane of the rotation as shown in Figure 12. Equation 3a has some conservatism in the uplift limit because of roundoff and simplifications used to develop the equation. As suggested in Figure 4, the resulting CDP bearing with nominal shape factor of 3 or less will be conservatively designed by this limit. Comparison of the limit in Equation 3a with Figure 4 also shows that pads with large shape factors may be liberally designed by this approach. Cotton duck pads with large shape factors are rare, but a 17-percent reduction in this rotation limit was used to assure acceptable behavior throughout the range of practical bearing behavior. Therefore, the proposed design limit is

$$\theta \leq \frac{t_p \sigma_c}{d 12000} \quad (\text{in English Units}) \quad \text{Equation 3b}$$

Equation 3b conservatively prevents uplift, but it provides no limit on the shear strain in the elastomer. Arguments similar to those used for compressive stress can be

used to establish strain limits for combined compression and rotation. The limit for massive compressive strains ensures that the maximum strains in rotation are not too much larger than the maximum strains permitted in compression of CDP. Similar limits are employed with PEP and steel reinforced bearings. These conditions are met if the compressive stress under combined rotation and compression fits the following equation:

$$\sigma_{\text{allowable}} \leq 1,500 - 500 \frac{\theta}{\theta_{\text{max}}} \quad (\text{in English units}) \quad \text{Equation 4}$$

where  $\theta_{\text{max}}$  is the rotation at the intercept of the uplift and strain limit curves. This intercept will occur at a compressive stress of 1,000 psi, and so

$$\theta_{\text{max}} = \frac{t_p}{d} 12 \quad (\text{in English Units}) \quad \text{Equation 4b}$$

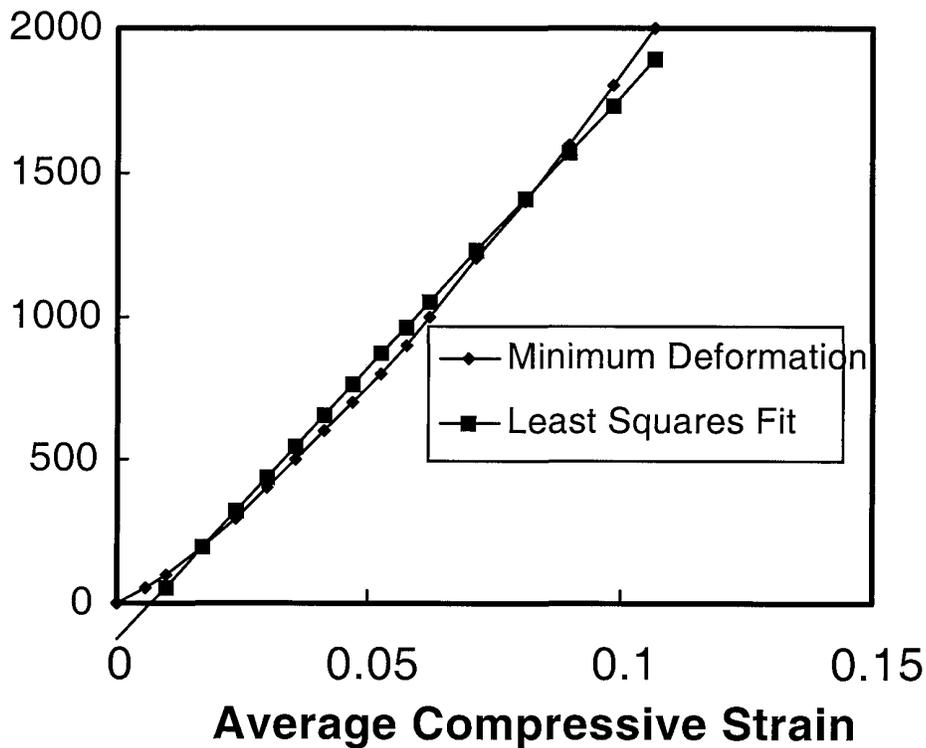
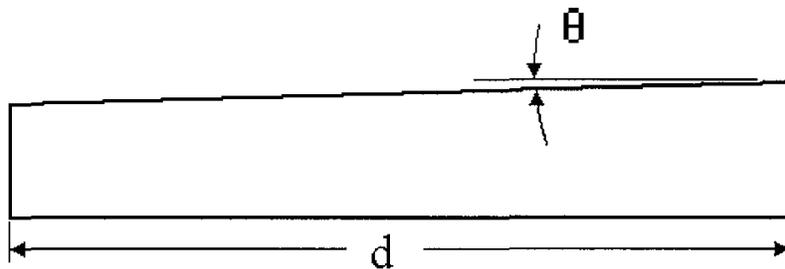


Figure 11. Least squares fit to lower strain limit.



*Figure 12. Rotation geometry.*

The maximum strains in CDP resulting from this equation are 2 to 4 times those permitted with steel reinforced elastomeric bearings. Nothing larger can be permitted until better test data on CDP are available. The use of this large strain depends heavily on the generally good performance of CDP in past bridge applications and on the observation that CDP take compressive stress levels in excess of 10,000 psi without failing. However, bridge engineers cannot be assured of the same level of performance from CDP as that which can be expected from the steel reinforced bearing provisions at these design limits. At the same time, the combined limits of Equations 3b and 4a permit significant rotation. For example, a 1.5-in. CDP with a base dimension of 8 in. would have a rotational capacity of approximately 0.0156 radians. At this load and rotation, a maximum compressive strain of approximately 0.18 should occur. Since this results in maximum strains for CDP which are in the order of 3 times those permitted for steel reinforced elastomeric bearings, bridge engineers must recognize that performance of CDP may be less long term than other bearing types. Testing of CDP under cyclic repeated loading would be beneficial in evaluating these concerns.

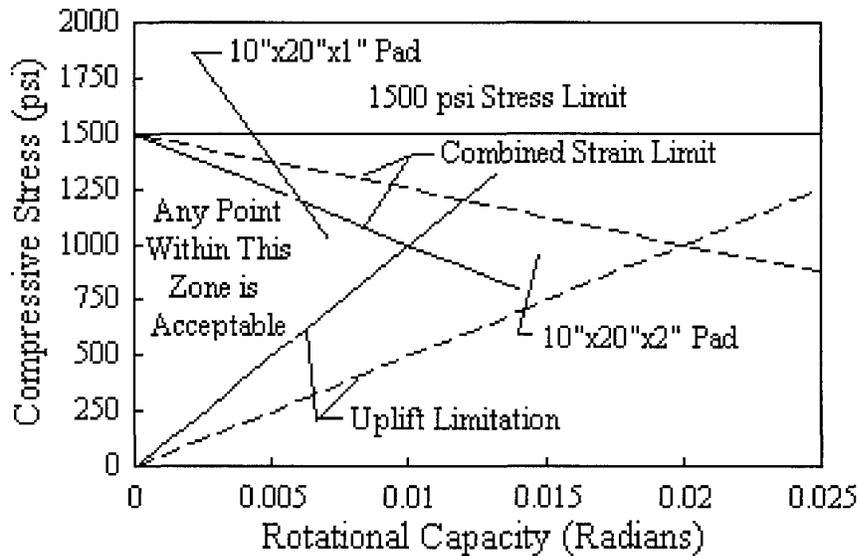


Figure 13. Illustration of the proposed rotation and stress limits for typical CDP.

Figure 13 shows how the combined effects of the 1,500 psi compressive stress limit, the uplift limitation of Equation 3, and the combined strain limitation of Equation 4a affect the capacity of typical CDP applications. The rotation permitted by the existing AASHTO LRFD provisions would result in maximum permissible rotations that are approximately 10 percent of the maximums shown in these figures. This connection indicates that the proposed provisions lead to a significant increase in the rated capacity of CDP bearing.

When Equation 3b is translated into SI units, then

$$\theta \leq \frac{t_p \sigma_c}{d 83} \quad (\text{in SI units}) \quad \text{Equation 5}$$

where  $t_p$  and  $d$  are measured in mm, and  $\sigma_c$  is measured in MPa. Equation 4 can be translated into SI units by

$$\sigma_{\text{allowable}} \leq 10.5 - 3.5 \frac{\theta}{\theta_{\text{max}}} \quad (\text{in SI units - MPa}) \quad \text{Equation 6a}$$

where

$$\theta_{\text{max}} = \frac{t_p}{d 12} \quad (\text{in SI units}) \quad \text{Equation 6b}$$

The above discussion outlines the proposed limits. It should be again noted that CDP is manufactured under a relatively vague military standard. If the strain levels in CDP are to be fully utilized, new wording needs to be added to the AASHTO specifications to ensure that the production of CDP meets the understanding and expectations of bridge engineers. At the same time, CDP are a limited application, and the AASHTO specifications are very long and often very detailed. Therefore, this new wording to be added should be minimized to relate basic requirements without adding excessive detail.

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## **Appendix A**

# **Proposed AASHTO LRFD Criteria for Cotton Duck Pads (CDP) in SI Units**

## 14.7.6 Elastomeric Pads

### 14.7.6.1 GENERAL

The provisions of this article apply to the design of;

- plain elastomeric pads, PEP,
- pads reinforced with discrete layers of fiberglass, FGP, and
- 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.

Layer thicknesses in FGP may be different from one another. The shape factor for FGP and PEP is determined as specified in Article 14.7.5.1.

### 14.7.6.2 MATERIAL PROPERTIES

The materials shall satisfy the requirements of Article 14.7.5.2 except that the shear modulus shall be between 0.60 and 1.70 MPa and the nominal hardness between 50 and 70 on the Shore A scale, and shall conform to the requirements of Section 18.2 of Division II.

The shear force on the structure induced by deformation of the elastomer in PEP and FGP shall be based on a G value not less than that of the elastomer at 23 C. Effects of relaxation shall be ignored.

The finished CDP shall have a nominal hardness between 85 and 95 on the Shore A scale. The cotton duck reinforcement shall be either a two ply cotton yarn or a single ply 50-50 blend cotton-polyester. The fabric shall be have a minimum tensile strength of 26.3 N/mm width when tested by the grab method. The fill shall be 40±2 threads per inch, and the warp shall be 50±1 threads per inch.

### C14.7.6.1

Elastomeric pads have characteristics which are different from those of steel reinforced elastomeric bearings. PEP is weaker and more flexible because the pad is restrained from bulging by friction alone, Stanton and Roeder (1986) and (1983). Slip inevitably occurs, especially under dynamic loads, causing larger compressive deflections and higher internal strains in the elastomer.

FGP is reinforced with layers of fiberglass, and the reinforcement inhibits the deformations found in plain pads. However, elastomers bond less well to fiberglass, and the fiberglass is weaker than steel, so the fiberglass pad is unable to carry the same loads as a steel reinforced bearing, Crosier, et al, (1979). FGP have the advantage that they can be cut to size from a large sheet of vulcanized material.

CDP is reinforced with closely spaced layers of cotton duck and typically displays high compressive stiffness and strength, obtained by the use of very thin elastomeric layers. However, the thin layers also give rise to high shear and rotational stiffness. These increased stiffnesses lead to higher moments and forces in the bridge and reduced movement and rotational capacity of the bearing pad. As a consequence CDP is often used with a PTFE slider on top of the elastomer pad, Nordlin, Boss and Trimble (1970).

### C14.7.6.2

The elastomer requirements for PEP and FGP are the same as those required for steel reinforced elastomeric bearings.

CDP is made of elastomers with hardness and properties similar to that used for PEP and FGP. However, the closely space layers of duck fabric reduce the indentation and increase the hardness of the finished pad to the 85 to 95 durometer range. The cotton duck requirements are restated from the military specification

## 14.7.6.3 DESIGN REQUIREMENTS

### 14.7.6.3.1 Scope

Steel reinforce elastomeric bearings may be designed in accordance with this article, in which case they qualify for the test requirements appropriate for elastomeric pads. For this purpose, they shall be treated as FGP.

The provisions for FGP apply only to pads where the fiberglass is placed in double layers 3.0 mm apart.

The physical properties of neoprene and natural rubber used in these bearings shall conform to the following ASTM or AASHTO requirements, with modifications as noted:

	<u>ASTM</u>	<u>AASHTO</u>
<u>Compound</u>	<u>Requirement</u>	<u>Requirement</u>
Neoprene	D2000, Line Call Out M2BC520A14B14	AASHTO M251
Natural Rubber	D2000, Line Call Out MA44520A13B33	AASHTO M251

### 14.7.6.3.2 Compressive Stress

At the service limit state, the average compressive stress,  $\sigma_s$ , in any layer shall satisfy:

- for PEP
 
$$\sigma_s \leq 0.55 G S \leq 5.5 \text{ MPa} \quad (14.7.6.3.2-1)$$
- for FGP
 
$$\sigma_s \leq 1.0 G S \leq 5.5 \text{ MPa} \quad (14.7.6.3.2-1)$$
- for CDP
 
$$\sigma_s \leq 10.5 \text{ MPa} \quad (14.7.6.3.2-1)$$

because the reinforcement is essential to the good performance of these pads

#### C14 7.6.3.1

The use of Section 14.7.6 for the design of steel reinforced elastomeric bearings results in reduced stress, strain and movement capability on the steel reinforced elastomeric bearing. It permits simpler design calculations for steel reinforced elastomeric bearings and use of the less stringent test methods than those defined in Article 14.7.5. However, the resulting bearing is a less capable bearing than that designed by article 14.7.5. This provision continues the use of "Method A" which was allowed in earlier specifications.

The three types of pad, PEP, FGP, and CDP behave differently, so information relevant to the particular type of pad should be used for design. For example, in PEP, slip at the interface between the elastomer and the material on which it is seated or loaded is dependent on the friction coefficient, and this will be different for pads seated on concrete, steel, grout, epoxy and etc.

#### C14.7.6.3.2

In PEP and FGP, the compressive stress is limited to  $G$  times the effective shape factor. The effective shape factor for a plain pad is approximately 0.55 times the nominal  $S$ , and this is reflected in formula 14.7.6.3.2-1. Both PEP and FGP are also limited to 5.5 MPa for all circumstances, but this upperbound stress limit can be achieved with a thicker rubber layer with FGP than the total rubber thickness of PEP.

In CDP, the pad stiffness and behavior is less sensitive to shape factor. The 10.5 MPa stress limit is approximately 15% of the maximum compressive load that can be consistently achieved with these pads. However, the average compressive strain at this allowable stress limit is in the range of 0.08 to 0.15 in/in. These compressive strains are

For FGP, the value of  $S$  used shall be that for the greatest distance between the midpoint of the double reinforcement layers at the top and bottom of the elastomer layer.

#### 14.7.6.3.3 Compressive Deflection

The provisions of Article 14.7.5.3.3 shall apply.

#### 14.7.6.3.4 Shear

The horizontal bridge movement shall be computed in accordance with Article 14.4. The maximum shear deformation of the pad,  $s$ , shall be taken as the horizontal bridge movement, reduced to account for the pier flexibility and modified for construction procedures. If a low friction sliding surface is used,  $s$ , need not be taken larger than the deformation corresponding to first slip.

somewhat larger than those tolerated with steel reinforced elastomeric bearings, and the strain limit provides a rational reason for limiting stress to this level. Larger compressive strains would result in increased damage to the bridge and the bearing pad and reduced serviceability of the CDP.

#### C14.7.6.3.3

The compressive deflection with PEP, FGP, and CDP will be larger and more variable than those of steel reinforced elastomeric bearings. Appropriate data for these pad types may be used to estimate their deflections. In the absence of such data, the compressive deflection of a PEP and FGP may be estimated at 3 and 1.5 times the deflection estimated for a steel reinforced elastomeric bearing of the same shape factor in C14.7.5.3.3 and Figure C14.7.5.3.3-1, respectively.

CDP is typically very stiff in compression. The shape factor may be computed but it has a different meaning and less significance to the compressive deflection than it does for FGP and PEP. As a result, the maximum compressive deflection for CDP can be estimated based upon an average compressive strain of  $(\sigma_c/1.6)$  in MPa and mm/mm units.

#### C14.7.6.3.4

The deformation in PEP and FGP are limited because these movements are the maximum tolerable for repeated and long term strains in the elastomer. They insure serviceable bearings with no deterioration of performance and they limit the forces that the pad transmits to the structure.

In CDP, the shear deflection is limited to only 1/10 of the total elastomer thickness. There are several reasons for this limitation. First, there is only limited available experimental evidence regarding shear deformation of CDP. Second, the information that is available shows

The provisions of Article 14.7.5.3.4 shall apply, except that the pad shall be designed as follows:

- for PEP and FGP:

$$h_{rt} > 2 \Delta_s \quad (14.7.6.3.4-1)$$

- for CDP:

$$h_{rt} > 10 \Delta_s \quad (14.7.6.3.4-2)$$

#### 14.7.6.3.5 Rotation

The provisions of this section shall apply at the service limit state. Rotations shall be taken as the maximum sum of the effects of initial lack-of-parallelism and subsequent girder end rotation due to imposed loads and movements. Stress shall be the maximum stress associated with the load conditions inducing the maximum rotation.

##### 14.7.6.3.5.1 Rotation of PEP and FGP

Rectangular pads shall satisfy:

$$\sigma_s \leq 0.5 G S \left( \frac{L}{h_{rt}} \right)^2 \theta_{s,x} \quad (14.7.6.3.5.1-1)$$

$$\sigma_s \leq 0.5 G S \left( \frac{W}{h_{rt}} \right)^2 \theta_{s,z} \quad (14.7.6.3.5.1-2)$$

Circular pads shall satisfy:

$$\sigma_s \leq 0.375 G S \left( \frac{D}{h_{rt}} \right)^2 \theta_s \quad (14.7.6.3.5.1-3)$$

where

$\sigma_s$  = service average compressive stress due to total load associated with the maximum rotation (MPa)

that CDP has much larger shear stiffness than that noted with PEP and FGP, and so the strain limit assures that CDP pads do not cause dramatically larger bearing forces to the structure than do PEP and FGP. Third, the greater shear stiffness means that relative slip between and CDP pad and the bridge girders is likely if the deformation required of the bearing is too large, and the slip may lead to abrasion and deterioration of the pad as well as other serviceability concerns. Slip may also lead to increased costs because of anchorage and other requirements. Finally, CDP pads are harder than PEP and FGP, and so they are very suitable for the addition of PTFE sliding surfaces to accommodate the required bridge movements.

#### C14.7.6.3.5

Rotation of steel reinforced elastomeric bearings and elastomeric pads is controlled by preventing uplift between the bearing and the structure and by limiting the shear strains in the elastomer.

##### C14.7.6.3.5.1

PEP and FGP are quite flexible in compressive loading, and as a consequence very large strains are tolerated but stresses are kept quite low in article 14.7.6.3.2. As a consequence, PEP and FGP are checked for uplift only, and the equations provided in this article provide a lower bound stress limit to assure that uplift conditions are met.

- G = shear modulus of the elastomer (MPa)
- S = shape factor of thickest layer of an elastomeric bearing
- L = length of a rectangular elastomeric bearing (parallel to longitudinal bridge axis) (mm)
- $h_{rt}$  = total elastomer thickness in an elastomeric bearing (mm)
- W = width of the bearing in the transverse direction (mm)
- D = diameter of pad (mm)
- $\dot{\epsilon}_s$  = rotation about any axis of the pad (RAD)
- $\dot{\epsilon}_{s,x}$  = service rotation about the transverse axis (RAD)
- $\dot{\epsilon}_{s,z}$  = service rotation about the longitudinal axis (RAD)

##### 14.7.6.3.5.2 Rotation of CDP

The compressive stress in CDP shall satisfy:

$$\sigma_s \geq \left( \frac{L}{t_p} \cdot 69. \right) \theta_s \quad (14.7.6.3.5.2-1)$$

and

$$\sigma_s \leq 10.5 - 3.5 \frac{\theta_s}{\theta_{max}} \quad (14.7.6.3.5.2-2)$$

where

$$\theta_{max} = \frac{t_p}{L \cdot 12.}$$

$\bar{\sigma}_s =$  service average compressive stress due to total load associated with the maximum rotation (MPa)

#### C14.7.6.3.5.2

CDP is significantly stiffer than PEP and FGP. As a result, significantly larger compressive stress values are permitted for CDP in article 14.7.6.3.2 and as a consequence both the strains and uplift must be kept under control for CDP. However, shear strains of the elastomer are a less meaningful measure for CDP than for steel reinforced elastomeric bearings, because shape factor has a different meaning for CDP than for other elastomeric bearing types. CDP is known to have relatively large compressive load capacity, and it is generally accepted that it can tolerate the relatively large compressive strains associated with these loads. It should be noted that these compressive strains in CDP are significantly larger than those tolerated in steel reinforced bearings, but they have been employed for many years without excessive problems. Therefore, two compressive stress limits are included in this article. A

$L$  = length of a CDP bearing pad in the plane of the rotation (mm)

$t_p$  = total thickness in CDP pad (mm)

$\epsilon_s$  = maximum rotation of the CDP pad (RAD)

#### 14.7.6.3.6 Stability

To ensure stability, the total thickness of the pad shall not exceed the least of  $L/3$ ,  $W/3$ , or  $D/4$ .

#### 14.7.6.3.7 Reinforcement

The reinforcement in FGP shall be fiberglass with a strength in each plan direction of at least  $15.2 h_{ri}$  in N/mm. For the purpose of this article, if the layers of elastomer are of different thickness,  $h_{ri}$  shall be taken as the mean thickness of the two layers of the elastomer bonded to the same reinforcement. If the fiberglass reinforcement contains holes, its strength shall be increased over the minimum value specified herein by twice the gross width divided by the net width.

#### 14.7.6.4 ANCHORAGE

If the factored shear force sustained by the deformed pad at the strength limit state exceeds one-fifth of the compressive force,  $P_{sd}$ , due to permanent loads, the pad shall be secured against horizontal movement.

minimum compressive stress in Eq. 14.7.6.3.5.2-1 is assuring that uplift does not occur. Equation 14.7.6.3.5.2-2 assures that the maximum compressive strain for CDP under rotation does not exceed the maximum strains commonly expected under compression by an excessive amount.

#### C14.7.6.3.6

The stability provisions in this article are unlikely to have a significant impact upon the design of PEP, since a plain pad which had this geometry would have such a low allowable stress limit that the design would be uneconomical.

The buckling behavior of FGP and CDP is complicated because the mechanics of their behavior is not well understood. The reinforcement layers lack the stiffness of the reinforcement layers in steel reinforced bearings and so stability theories developed for steel reinforced bearings do not apply to CDP or FGP. The geometric limits included here are simple and conservative.

#### C14.7.6.3.7

The reinforcement should be strong enough to sustain the stresses induced in it when the bearing is loaded in compression. For a given compression, thicker elastomer layers lead to higher tension stresses in the reinforcement. It should be possible to relate minimum reinforcement strength to the compressive stress which is allowed in the bearing in Article 14.7.6.3.2. The relationship has been quantified for FGP. For PEP and CDP, successful past experience is the only guide currently available.

## **Appendix B**

# **Proposed AASHTO LRFD Criteria for Cotton Duck Pads (CDP) in English Units**

## 14.7.6 Elastomeric Pads

### C14.7.6.1

#### 14.7.6.1 GENERAL

The provisions of this article apply to the design of;

- plain elastomeric pads, PEP,
- pads reinforced with discrete layers of fiberglass, FGP, and
- 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.

Layer thicknesses in FGP may be different from one another. The shape factor for FGP and PEP is determined as specified in Article 14.7.5.1.

#### 14.7.6.2 MATERIAL PROPERTIES

The materials shall satisfy the requirements of Article 14.7.5.2 except that the shear modulus shall be between 80 and 250 psi and the nominal hardness between 50 and 70 on the Shore A scale, and shall conform to the requirements of Section 18.2 of Division II.

The shear force on the structure induced by deformation of the elastomer in PEP and FGP shall be based on a G value not less than that of the elastomer at 73°F. Effects of relaxation shall be ignored.

The finished CDP shall have a nominal hardness between 85 and 95 on the Shore A scale. The cotton duck reinforcement shall be either a two ply cotton yarn or a single ply 50-50 blend cotton-polyester. The fabric shall be have a minimum tensile strength of 150 lb/inch width when tested by the grab method. The fill shall be 40±2 threads per inch, and the warp shall be 50±1 threads per inch.

Elastomeric pads have characteristics which are different from those of steel reinforced elastomeric bearings. PEP is weaker and more flexible because the pad is restrained from bulging by friction alone, Stanton and Roeder (1986) and (1983). Slip inevitably occurs, especially under dynamic loads, causing larger compressive deflections and higher internal strains in the elastomer.

FGP is reinforced with layers of fiberglass, and the reinforcement inhibits the deformations found in plain pads. However, elastomers bond less well to fiberglass, and the fiberglass is weaker than steel, so the fiberglass pad is unable to carry the same loads as a steel reinforced bearing, Crosier, et al, (1979). FGP have the advantage that they can be cut to size from a large sheet of vulcanized material.

CDP is reinforced with closely spaced layers of cotton duck and typically displays high compressive stiffness and strength, obtained by the use of very thin elastomeric layers. However, the thin layers also give rise to high shear and rotational stiffness. These increased stiffnesses lead to higher moments and forces in the bridge and reduced movement and rotational capacity of the bearing pad. As a consequence CDP is often used with a PTFE slider on top of the elastomer pad, Nordlin, Boss and Trimble (1970).

### C14.7.6.2

The elastomer requirements for PEP and FGP are the same as those required for steel reinforced elastomeric bearings.

CDP is made of elastomers with hardness and properties similar to that used for PEP and FGP. However, the closely space layers of duck fabric reduce the indentation and increase the hardness of the finished pad to the 85 to 95 durometer range. The cotton duck requirements are restated from the military specification

English Units Version

14.7.6.3 DESIGN REQUIREMENTS

14.7.6.3.1 Scope

Steel reinforced elastomeric bearings may be designed in accordance with this article, in which case they qualify for the test requirements appropriate for elastomeric pads. For this purpose, they shall be treated as FGP.

The provisions for FGP apply only to pads where the fiberglass is placed in double layers 1/8 inch apart.

The physical properties of neoprene and natural rubber used in these bearings shall conform to the following ASTM or AASHTO requirements, with modifications as noted:

	<u>ASTM</u>	<u>AASHTO</u>
<u>Compound</u>	<u>Requirement</u>	<u>Requirement</u>
Neoprene	D2000, Line Call Out M2BC520A14B14	AASHTO M251
Natural Rubber	D2000, Line Call Out MA44520A13B33	AASHTO M251

14.7.6.3.2 Compressive Stress

At the service limit state, the average compressive stress,  $\sigma_s$ , in any layer shall satisfy:

- for PEP

$$\sigma_s \leq 0.55 G S \leq 800 \text{ psi} \quad (14.7.6.3.2-1)$$

- for FGP

$$\sigma_s \leq 1.0 G S \leq 800 \text{ psi} \quad (14.7.6.3.2-1)$$

- for CDP

$$\sigma_s \leq 1500 \text{ psi} \quad (14.7.6.3.2-3)$$

to assure that bridge engineers verify these minimum requirements since the reinforcement is essential to the good performance of these pads.

C14 7.6.3.1

The use of Section 14.7.6 for the design of steel reinforced elastomeric bearings results in reduced stress, strain and movement capability on the steel reinforced elastomeric bearing. It permits simpler design calculations for steel reinforced elastomeric bearings and use of the less stringent test methods than those defined in Article 14.7.5. However, the resulting bearing is a less capable bearing than that designed by article 14.7.5. This provision continues the use of "Method A" which was allowed in earlier specifications.

The three types of pad, PEP, FGP, and CDP behave differently, so information relevant to the particular type of pad should be used for design. For example, in PEP, slip at the interface between the elastomer and the material on which it is seated or loaded is dependent on the friction coefficient, and this will be different for pads seated on concrete, steel, grout, epoxy and etc.

C14.7.6.3.2

In PEP and FGP, the compressive stress is limited to G times the effective shape factor. The effective shape factor for a plain pad is approximately 0.55 times the nominal S, and this is reflected in formula 14.7.6.3.2-1. Both PEP and FGP are also limited to 800 psi for all circumstances, but this upperbound stress limit can be achieved with a thicker rubber layer with FGP than the total rubber thickness of PEP.

In CDP, the pad stiffness and behavior is less sensitive to shape factor. The 1500 psi stress limit is approximately 15% of the maximum compressive load that can be consistently achieved with these pads. However, the average compressive strain at this allowable

## English Units Version

stress limit is in the range of 0.08 to 0.15 in/in.  
These compressive strains are

For FGP, the value of S used shall be that for the greatest distance between the midpoint of the double reinforcement layers at the top and bottom of the elastomer layer.

### 14.7.6.3.3 Compressive Deflection

The provisions of Article 14.7.5.3.3 shall apply.

### 14.7.6.3.4 Shear

The horizontal bridge movement shall be computed in accordance with Article 14.4. The maximum shear deformation of the pad,  $A_s$ , shall be taken as the horizontal bridge movement, reduced to account for the pier flexibility and modified for construction procedures. If a low friction sliding surface is used,  $A_s$  need not be taken larger than the deformation corresponding to first slip.

## English Units Version

somewhat larger than those tolerated with steel reinforced elastomeric bearings, and the strain limit provides a rational reason for limiting stress to the level. Larger compressive strains would result in increased damage to the bridge and the bearing pad and reduced serviceability of the CDP.

### C14.7.6.3.3

The compressive deflection with PEP, FGP, and CDP will be larger and more variable than those of steel reinforced elastomeric bearings. Appropriate data for these pad types may be used to estimate their deflections. In the absence of such data, the compressive deflection of a PEP and FGP may be estimated at 3 and 1.5 times the deflection estimated for a steel reinforced elastomeric bearing of the same shape factor in C14.7.5.3.3 and Figure C14.7.5.3.3-1, respectively.

CDP is typically very stiff in compression. The shape factor may be computed but it has a different meaning and less significance to the compressive deflection than it does for FGP and PEP. As a result, the maximum compressive deflection for CDP can be estimated based upon an average compressive strain of  $(\sigma_c/1000)$  in psi and in/in units.

### C14.7.6.3.4

The deformation in PEP and FGP are limited because these movements are the maximum tolerable for repeated and long term strains in the elastomer. They insure serviceable bearings with no deterioration of performance and they limit the forces that the pad transmits to the structure.

In CDP, the shear deflection is limited to only 1/10 of the total elastomer thickness. There are several reasons for this limitation. First, there is only limited available experimental evidence regarding shear deformation of CDP. Second, the information that is available shows

The Provisions of Article 14.7.5.3.4 shall apply, except that the pads' all be designed as follows:

- for PEP and FGP:

$$h_{rt} > 2 \Delta_s \quad (14.7.6.3.4-1)$$

- for CDP:

$$h_{rt} > 10 \Delta_s \quad (14.7.6.3.4-2)$$

### 14.7.6.3.5 Rotation

The provisions of this section shall apply at the service limit state. Rotations shall be taken as the maximum sum of the effects of initial lack-of-parallelism and subsequent girder end rotation due to imposed loads and movements. Stress shall be the maximum stress associated with the load conditions inducing the maximum rotation.

#### 14.7.6.3.5.1 Rotation of PEP and FGP

Rectangular pads shall satisfy:

$$\sigma_s \leq 0.5 G S \left( \frac{L}{h_{rt}} \right)^2 \theta_{s,x} \quad (14.7.6.3.5.1-1)$$

$$\sigma_s \leq 0.5 G S \left( \frac{W}{h_{rt}} \right)^2 \theta_{s,z} \quad (14.7.6.3.5.1-2)$$

Circular pads shall satisfy:

$$\sigma_s \leq 0.375 G S \left( \frac{D}{h_{rt}} \right)^2 \theta_s \quad (14.7.6.3.5.1-3)$$

where

## English Units Version

$\sigma_s$  = service average compressive stress due to total load associated with the maximum rotation (psi)

that CDP has much larger shear stiffness than that noted with PEP and FGP, and so the strain limit assures that CDP pads do not cause dramatically larger bearing forces to the structure than do PEP and FGP. Third, the greater shear stiffness means that relative slip between and CDP pad and the bridge girders is likely, and the slip may lead to abrasion and deterioration of the pad as well as other serviceability concerns. Slip may also lead to increased costs because of anchorage and other requirements. Finally, CDP pads are harder than PEP and FGP, and so they are very suitable for the addition of PTFE sliding surfaces to accommodate the required bridge movements.

### C14.7.6.3.5

Rotation of steel reinforced elastomeric bearings and elastomeric pads is controlled by preventing uplift between the bearing and the structure and by limiting the shear strains in the elastomer.

#### C14.7.6.3.5.1

PEP and FGP are quite flexible in compressive loading, and as a consequence very large strains are tolerated but stresses are kept quite low in article 14.7.6.3.2. As a consequence, PEP and FGP are checked for uplift only, and the equations provided in this article provide a lower bound stress limit to assure that uplift conditions are met.

English Units Version

- G = shear modulus of the elastomer (psi)
- S = shape factor of thickest layer of an elastomeric bearing
- L = length of a rectangular elastomeric bearing (parallel to longitudinal bridge axis) (inch)
- $h_{rt}$  = total elastomer thickness in an elastomeric bearing (inch)
- W = width of the bearing in the transverse direction (inch)
- D = diameter of pad (inch)
- $\dot{\epsilon}_s$  = rotation about any axis of the pad (RAD)
- $\dot{\epsilon}_{s,x}$  = service rotation about the transverse axis (RAD)
- $\dot{\epsilon}_{s,z}$  = service rotation about the longitudinal axis (RAD)

C14.7.6.3.5.2

14.7.6.3.5.2 Rotation of CDP

The compressive stress in CDP shall satisfy:

$$\sigma_s \geq \left( \frac{L}{t_p} \frac{10000}{t_p} \right) \theta_s \quad (14.7.6.3.5.2-1)$$

and

$$\sigma_s \leq 1500 - 500 \frac{\theta}{\theta_{max}} \quad (14.7.6.3.5.2-2)$$

where

$$\theta_{max} = \frac{t_p}{d} \frac{1}{12}$$

$\dot{\sigma}_s$  = service average compressive stress due to total load associated with the maximum rotation (psi)

CDP is significantly stiffer than PEP and FGP. As a result, significantly larger compressive stress values are permitted for CDP in article 14.7.6.3.2 and as a consequence both the strains and uplift must be kept under control for CDP. However, shear strains of the elastomer are a less meaningful measure for CDP than for steel reinforced elastomeric bearings, because shape factor has a different meaning for CDP than for other elastomeric bearing types. CDP is known to have relatively large compressive load capacity, and it is generally accepted that it can tolerate that relatively large compressive strains associated with these loads. It should be noted that these compressive strains in CDP are significantly larger than those tolerated in steel reinforced bearings, but they have been employed for many years without excessive problems. Therefore, two compressive stress limits are used in included in this article.

## English Units Version

$L$  = length of a CDP bearing pad in the plane of the rotation (inch)

$t_p$  = total thickness in CDP pad (inch)

$\epsilon_s$  = maximum rotation of the CDP pad (RAD)

### 14.7.6.3.6 Stability

To ensure stability, the total thickness of the pad shall not exceed the least of  $L/3$ ,  $W/3$ , or  $D/4$ .

### 14.7.6.3.7 Reinforcement

The reinforcement in FGP shall be fiberglass with a strength in each plan direction of at least  $1700 h_{ri}$  in lbs/inch. For the purpose of this article, if the layers of elastomer are of different thickness,  $h_{ri}$  shall be taken as the mean thickness of the two layers of the elastomer bonded to the same reinforcement. If the fiberglass reinforcement contains holes, its strength shall be increased over the minimum value specified herein by twice the gross width divided by the net width.

### 14.7.6.4 ANCHORAGE

If the factored shear force sustained by the deformed pad at the strength limit state exceeds one-fifth of the compressive force,  $P_{sd}$ , due to permanent loads, the pad shall be secured against horizontal movement.

A minimum compressive stress in Eq. 14.7.6.3.5.2-1 is assuring that uplift does not occur. Equation 14.7.6.3.5.2-2 assures that the maximum compressive strain for CDP under rotation does not exceed the maximum strains commonly expected under compression by an excessive amount.

#### C14.7.6.3.6

The stability provisions in this article are unlikely to have a significant impact upon the design of PEP, since a plain pad which had this geometry would have such a low allowable stress limit that the design would be uneconomical.

The buckling behavior of FGP and CDP is complicated because the mechanics of their behavior is not well understood. The reinforcement layers lack the stiffness of the reinforcement layers in steel reinforced bearings and so stability theories developed for steel reinforced bearings do not apply to CDP or FGP. The geometric limits included here are simple and conservative.

#### C14.7.6.3.7

The reinforcement should be strong enough to sustain the stresses induced in it when the bearing is loaded in compression. For a given compression, thicker elastomer layers lead to higher tension stresses in the reinforcement. It should be possible to relate minimum reinforcement strength to the compressive stress which is allowed in the bearing in Article 14.7.6.3.2. The relationship has been quantified for FGP. For PEP and CDP, successful past experience is the only guide currently available.