Design of Laminated Elastomeric Bridge Bearings

CHARLES W. ROEDER AND JOHN F. STANTON

Elastomeric bearings have been used for many years. They are economical and require minimual maintenance, however, the historic AASHTO design provisions have limited the range of applications of these bearings. Recent research has resulted in recommendations which can increase the versatility of elastomeric bearings, but the recommendations require increased design calculations. A simple method of satisfying these more complex design equations is presented. The method uses a standard spread sheet computer program, and it automates and simplifies the design equations. These proposed design equations increase the load, movement and rotational capacity of many elastomeric bearings over those permitted with existing AASHTO design provisions, but the recommendations require greater care in design and quality control in manufacture of the bearings.

INTRODUCTION

Elastomeric bridge bearings have been used and have provided economical and maintenance free service for many years. Provisions for them were first included in the 1961 American Association of State Highway Officials (AASHO) Bridge Design Specifications (1), based on experimental research performed on unreinforced elastomeric pads (2). This first specification limited the average compressive stress on the bearings to 800 psi and the average compressive strain to 15%. The maximum thickness of the pad could be no more than 20% of its smallest plan dimension to assure stability, and the minimum thickness was controlled by the expected movement of the bridge.

This specification was simple, and it was used with only minor changes for nearly 25 years. Most bearings design to it performed well, but over time some problems and limitations came to light. First, the specification was unduly restrictive, because the stress and strain limits combined with the geometric constraints meant that elastomeric bearings could only be used for relatively small bridges with light loads and short movements. In fact, the original specification restricted elastomeric bearings to bridges shorter than 80 ft. Second, quality control problems occurred in some states, and a few bridge engineers became disenchanted with elastomeric bearings. These problems were usually caused by shoddy manufacturing, but the early specification contained only material tests, and required no load tests on finished bearings with which to separate well and badly made bearings. Finally, bearing use changed over the years, partly through the influence of practice in other countries, and reinforced elastomeric bearings started to be used more widely in place of the unreinforced pads for which the early specification was developed. However the specification did not permit the designer to take advantage of the superior properties of reinforced bearings.

The NCHRP 10-20 Research Project was initiated to overcome these difficulties. In 1985, a new specification was approved and now forms part of the 1989 AASHTO Specification (3) as a result of a state of the art study (4,5) performed as part of the 10-20 Project. Since then, considerable research (6,7) has been completed within the NCHRP 10-20 project, and new design recommendations (7) have been developed.

These latest design recommendations (7) have not yet been adopted by AASHTO, but they are based on extensive experimental and theoretical studies (4-11) of the behavior and modes of failure of elastomeric bearings. They differentiate between plain pads and reinforced bearings, and allow engineers to choose between two levels of design. The first restricts the load to relatively low levels but requires only modest design effort and quality control, while the second takes advantage of the better performance obtainable from reinforced elastomeric bearings at the expense of more complicated design procedures and more stringent quality control.

The purpose of this paper is to outline some of these advantages, and to show that highest level design procedures may be executed quickly and easily using a spreadsheet. The paper provides a brief overview of the behavior of and recommended provisions for steel laminated elastomeric bearings. It does not deal with plain pads, fiberglass or fabric reinforced pads, since the stresses allowed on them have not changed significantly. The benefits of the changes are illustrated, and it is shown that steel laminated elastomeric bearings can support larger loads and accommodate larger movements and rotations than were possible under earlier specifications (1,3), often allowing good quality elastomeric bearings to be used in place of other more troublesome and expensive bearing systems.

FUNDAMENTALS OF BEARING BEHAVIOR

Steel reinforced elastomeric bearings are built as illustrated in Fig. 1. Alternate layers of elastomer (typically 1/4 to 3/4" or 6 to 18 mm thick) and steel (typically 1/16" to 3/16" or 1.5 to 4.5 mm thick) are hot bonded together during vulcanization. The elastomer may either be natural rubber or polychloroprene (Neoprene). Cover layers of elastomer are placed around the

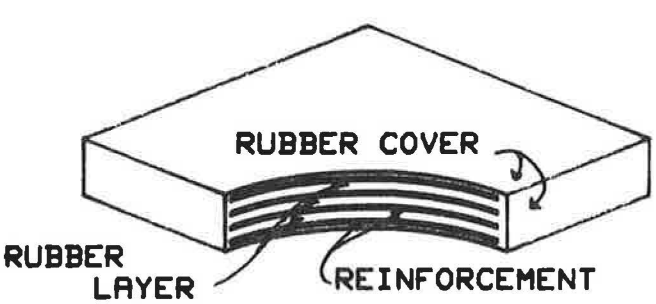


FIGURE 1 Typical steel reinforced elastomeric bearing

Department of Civil Engineering, University of Washington, Seattle, WA 98195

edges of the reinforcement to protect it from corrosion, and they may also be placed above and below the top and bottom reinforcement layers as shown in the figure. Top and bottom cover layers are are typically about one half the thickness of the internal rubber layers, but are sometimes left off to simplify attachment of the top and bottom steel plates to the structure.

The geometry of the complete bearing and the individual layers dominates the performance of the bearing. The shear strain at the edge of the steel-rubber interface proves to be the critical response quantity in an elastomeric bearing layer, and Figure 2a shows the shear strain caused by compressive load. The reinforcement restrains the lateral displacement of the elastomer and so stiffens the bearing against compressive load, but the resulting bulge pattern causes the shear strains illustrated in the figure. The shape factor, S, is the characteristic used to describe the influence of the layer geometry on the compressive stiffness and the induced shear strains. For a single rubber layer it is defined as the plan area divided by the area free to bulge.

Bridge bearings must accommodate rotations and lateral movements due to dead, live and seismic load, creep and shrinkage and thermal effects. They do so by deformation of the elastomer as shown in Figs. 2b and 2c. The lateral stiffness of a bearing is dominated by shear effects and so is controlled by the plan area and total rubber thickness, and it is not sensitive to the individual layer thicknesses or shape factor. It is given approximately by $K_t = GA/h_{rt}$, where A is the plan area, G is the shear modulus of the elastomer and h_{rt} is the total rubber thickness. The rotational stiffness is also strongly dependent upon the geometry of the bearing (and in particular, the shape factor) and the stiffness of the elastomer. Both lateral movement and rotation cause shear strains in the elastomer as illustrated in Figs. 2b and 2c.

PROPOSED DESIGN PROVISIONS

Bearing design consists largely of selecting appropriate material properties and bearing geometry.

The most important material property for design is the shear modulus, G, which can vary significantly with temperature and to a lesser extent with test method and rate of loading. However durometer hardness has historically been used because it is so easily measured. Hardness is approximately related to shear stiffness, but the relationship between them is not always reliable, particularly at low temperatures. Thus, the use of elastomer hardness has tended to mislead or confuse engineers in the design of elastomeric bearings and their expectations of bearing performance. The proposed recommendations overcome these difficulties by basing design on the shear modulus and defining an appropriate test procedure for measuring it.

For designers who wish to continue using hardness, the range of shear modulus which corresponds to a particular hardness is given in the proposed specification, but each aspect of the design is to be based on the most disadvantageous shear modulus from the range. This is done to allow for the uncertainty in the true G value when the hardness alone is specified, and the penalty it imposes provides an incentive to measure and use the true shear modulus. The proposed specification also deals with the variation in elastomer stiffness with temperature (11) through appropriate material property and testing requirements.

The design of a laminated elastomeric bearing requires an appropriate balance between the compressive, shear, and rotational characteristics. The bearing must have an appropriate height, plan area, layer thickness, and elastomer stiffness to accommodate lateral movement and rotation without developing excessive force or moment or allowing

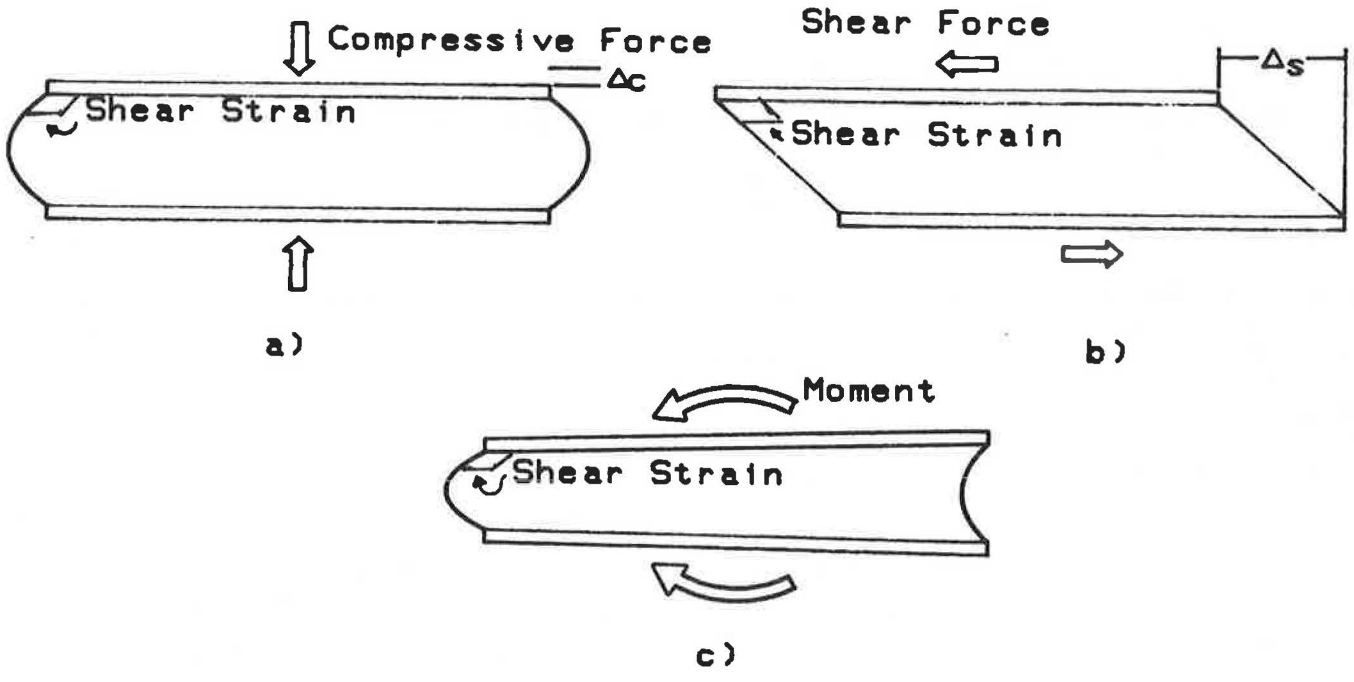


FIGURE 2 Strains in elastomeric bearings

excessive vertical deflections. In addition, the stresses and strains in the bearing materials must be restricted to tolerable levels. The total shear strains in the elastomer must be small enough to prevent fatigue (8) and delamination (4,9) of the elastomer from the reinforcement. The compressive stress on the bearing is further limited by stability (10), and the tensile strength of the reinforcement must also be adequate (4). These design considerations have been investigated in great detail (3-11) and design equations have been proposed (6-7) to control each mode of failure. The design equations are discussed in detail elsewhere (6-7), but they are briefly summarized in Fig. 3.

APPLICATION OF THE DESIGN EQUATIONS

The recommended design constraints of Fig. 3 appear to be complicated and must be simultaneously satisfied, but this process becomes simple with the aid of a personal computer and a spreadsheet. The equations and inequalities of Fig. 3 were programmed into an EXCEL spreadsheet on a Macintosh computer and Fig. 4 shows a typical printout. The row and column identifiers are retained in this figure to help identify terms, but they would normally be excluded. Five groups of numbers must be input, and they are highlighted by enclosing them in boxes. The upper left hand box (cells C5-9) contains the material properties. Allowance is made for a maximum and minimum shear modulus, in case the designer chooses to define the elastomer by its hardness. The program then selects the most disadvantageous G value at each step.

The upper right hand box (cells E5-9) contains the load, movement and rotation data. The remaining three smaller boxes contain the geometric properties of the bearing, such as the plan dimensions (L and W), the rubber layer thickness (h_{ri}), the steel laminate thickness (h_s) and the number of rubber layers (N), which should be entered in the order shown. Cells C13-28 contain the maximum and minimum permissible values for each quantity if the constraints of Fig. 3 are to be satisfied. As each dimension is chosen and entered in column E, the constraints on the next one appear in column C and some additional quantities (such as the shape factor corresponding to the chosen dimensions) appear in column E outside the boxes. In some cases, such as in cells C23 and 24, two or more criteria exist for one quantity, and the value chosen must satisfy both.

Figure 4 therefore represents an illustrative example

Definitions

Shape Factor : $S = \frac{\text{Plan Area}}{\text{Perimeter Area Free to Bulge}}$

Compressive Stiffness :

$$E_c = 3G[1+2\,kS^2] \text{ (psi)}$$

Shear Stiffness : $H = GA\frac{\Delta_s}{h_{rt}}$

Deformation Limits

Shear: $h_{rt} > 2\,\Delta_s$

Rotation : $\Theta_{TL,x} < 2\,\Delta_c / L$

Compressive Stress Limits

Delamination : $\sigma_{s,TL} < 1{,}600$ psi

Stability (sidesway prevented) :

$$\sigma_{c,TL} = \frac{G}{\left(\frac{1.92(h_{rt}/L)}{S\sqrt{1+2L/W}} - \frac{2.67}{S(S+2)(1+L/4W)}\right)}$$

Stability (sidesway permittted) :

$$\sigma_{c,TL} = \frac{G}{\left(\frac{3.84(h_{rt}/L)}{S\sqrt{1+2L/W}} - \frac{2.67}{S(S+2)(1+L/4W)}\right)}$$

Combined Stress Limits

Fatigue (with shear deformation) :

$$\sigma_{c,TL} \le \frac{1.66\ G\ S}{\left(1 + \frac{L\ \Theta_{TL,x}}{4\ \Delta_c}\right)}$$

and

$\sigma_{c,LL} \le 0.66\ G\ S$

Fatigue (no shear deformation) :

$$\sigma_{c,TL} \le \frac{2.0\ G\ S}{\left(1 + \frac{L\ \Theta_{TL,x}}{4\ \Delta_c}\right)}$$

and

$\sigma_{c,LL} \le 1.0\ G\ S$

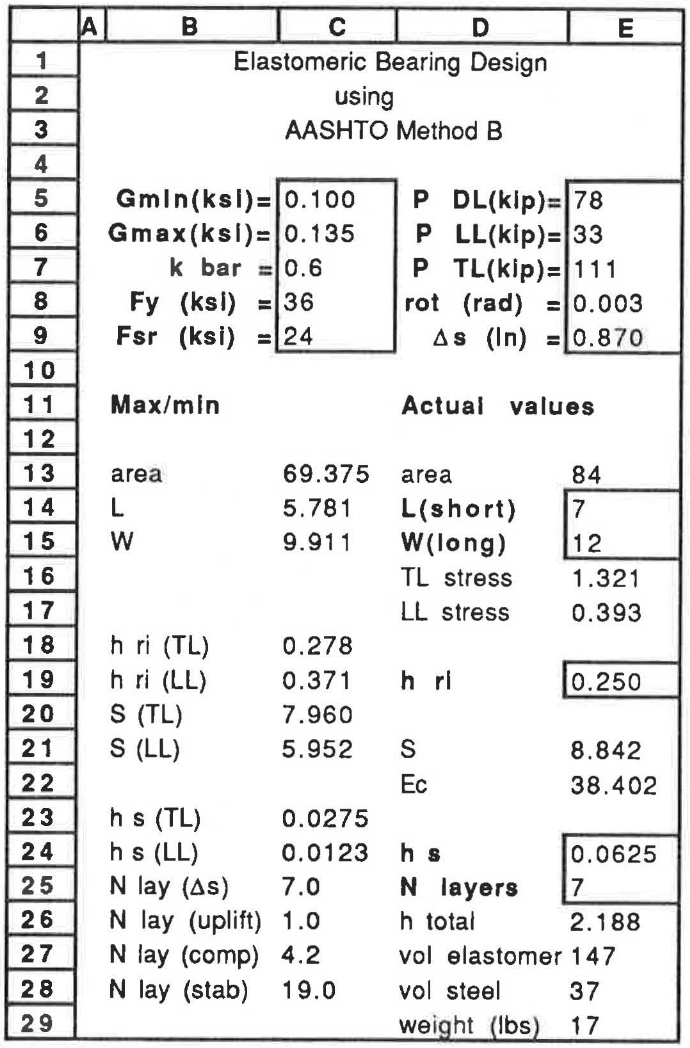
Reinforcement Thickness

$$h_s \ge \frac{1.5\ (h_{r1} + h_{r2})\ \sigma_{c,TL}}{F_y}$$

and

$$h_s \ge \frac{1.5\ (h_{r1} + h_{r2})\ \sigma_{c,LL}}{F_{sr}}$$

FIGURE 3 Proposed design equations for reinforced elastomeric bearings of the use of the design procedure with the spreadsheet program. In this example, the bearing is designed for a dead load of 78 kips, a live load of 33 kips, a translational movement of .87", and a rotation of .003 radians. The resulting bearing is 7" x 12" with 0.25" layers. It is clear that this 111 kip load is quite large for a bearing of this size compared to the stress level historically permitted for elastomeric bearings by the AASHTO Specification. It clearly illustrates the benefits of the proposed provisions because this increased load capacity allows broader use of elastomeric bearings.



	A	B	C	D	E
1		Elastomeric Bearing Design			
2		using			
3		AASHTO Method B			
4					
5		Gmin(ksi)=	0.100	P DL(kip)=	78
6		Gmax(ksi)=	0.135	P LL(kip)=	33
7		k bar =	0.6	P TL(kip)=	111
8		Fy (ksi) =	36	rot (rad) =	0.003
9		Fsr (ksi) =	24	Δs (in) =	0.870
10					
11		Max/min		Actual values	
12					
13		area	69.375	area	84
14		L	5.781	L(short)	7
15		W	9.911	W(long)	12
16				TL stress	1.321
17				LL stress	0.393
18		h ri (TL)	0.278		
19		h ri (LL)	0.371	h ri	0.250
20		S (TL)	7.960		
21		S (LL)	5.952	S	8.842
22				Ec	38.402
23		h s (TL)	0.0275		
24		h s (LL)	0.0123	h s	0.0625
25		N lay (Δs)	7.0	N layers	7
26		N lay (uplift)	1.0	h total	2.188
27		N lay (comp)	4.2	vol elastomer	147
28		N lay (stab)	19.0	vol steel	37
29				weight (lbs)	17

FIGURE 4 Sample output of spreadsheet program

The program is simple to execute and designs can be completed very rapidly. However, the program does not automatically choose the geometry of the bearing The designer must select a value for each input quantity, ensuring that it falls between the minimum and maximum permissible values calculated by the program. The example shown in Fig. 4 satisfies the design equations, because all of the dimensions lie between the minimum and maximum permissible values. Design with the spreadsheet is very quick and can be illuminating, since it illustrates how changes in the bearing dimensions and material properties affect the design.

The calculations in the lower right hand corner (cells E27-29) give the weight and volume of the selected bearing. These quantities are not required by the design provisions, but they provide useful information for the engineer. The weight and size of the bearing provide a direct measure of the ease with which it can be handled and installed and a basis for estimating its approximate cost.

Fig. 5 shows the formulas used in the spreadsheet of Fig. 4. All the design constraints of Fig. 3 are included, and the calculations are for bearings which are subject to shear displacements. Bearings fixed against translation lead to higher load capacity due to improved fatigue and buckling behavior and a separate spreadsheet could be written for that case. Other changes, such as some level of automatic redesign, could be incorporated if desired.

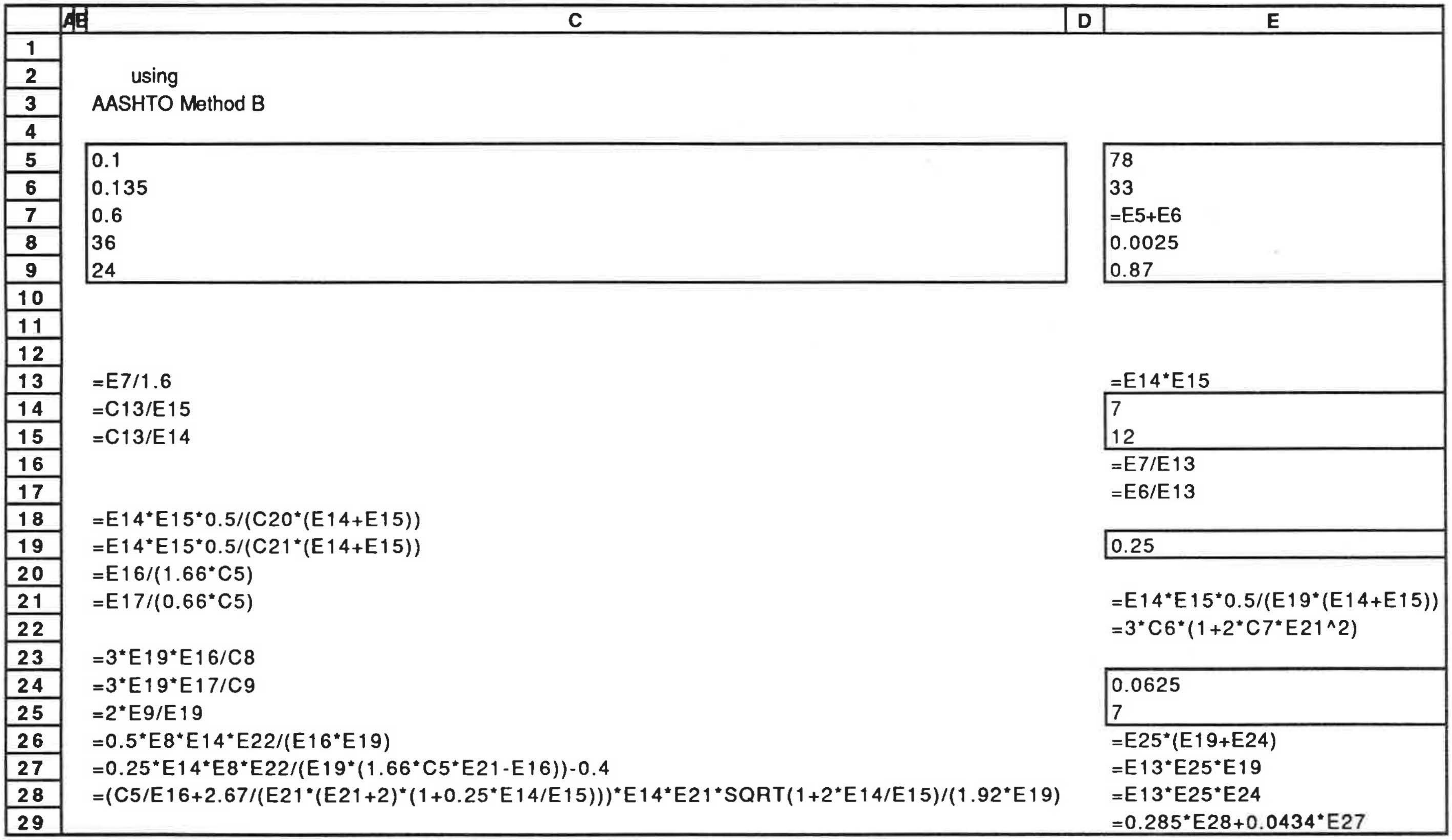
EFFECT OF PROPOSED PROVISIONS

The spreadsheet can be used to evaluate the effect of the proposed provisions on elastomeric bearing design and to compare the recommended provisions to the 1961 AASHO (1) and the 1989 AASHTO (3) Specifications. The comparisons are made using an elastomer with a nominal hardness of 55 on the Shore 'A' scale, which corresponds approximately to nominal, minimum and maximum shear moduli of 110, 95 and 125 psi (.76, .66 and .86 MPa). The comparisons are all based on rectangular bearings with W/L=2.0 and dead load/live load =1.5. These values were chosen because they fall within the practical range and because the rectangular shape allows more rotation than does a square.

The effect of the proposed provisions is illustrated in Fig. 6, which shows old and new load ratings for bearings with 0.25" and 0.75" thick rubber layers. Bearings with plan dimensions between 5" by 10" and 15" by 30" are represented in the graph. The proposed provisions confer a higher load rating than do the old ones on bearings with thin layers and high shape factors. Any bearing larger than 6" by 12" has a high enough shape factor that the load is governed by the 1600 psi limit. Load on the bearings with 3/4" layers is governed by the fatigue limit (a multiple of GS) which, for the shape factors in question, is less than 1600 psi, and the change from the old provisions is less pronounced. In fact, when the maximum rotation occurs, the allowable load is very similar to the value under the old provisions. Thus it can be seen that the proposed provisions offer the greatest advantage if a high shape factor is used.

The upper limit on load size of an elastomeric bearing is controlled by manufacturing techniques. The elastomer in a very large bearing cannot be cured uniformly, reliably and economically because the heat takes time to penetrate through the bulk of the material. There is no precise limit because each manufacturer has different processing equipment but, under the proposed provisions, 600 kips represents an approximate upper bound. The proposed provisions thus extend the load range for which elastomeric bearings are feasible, and offer the possibility of using them in situations where other more trouble-prone and potentially more expensive bearings have been used in the past.

The graph also shows that, for the bearings with 3/4" layers, application of the maximum rotation reduces the allowable load considerably. Rotation appears from the graph to have a larger effect on bearings with thicker layers, which



	A	B	C	D	E
1					
2			using		
3			AASHTO Method B		
4					
5			0.1		78
6			0.135		33
7			0.6		=E5+E6
8			36		0.0025
9			24		0.87
10					
11					
12					
13			=E7/1.6		=E14*E15
14			=C13/E15		7
15			=C13/E14		12
16					=E7/E13
17					=E6/E13
18			=E14*E15*0.5/(C20*(E14+E15))		
19			=E14*E15*0.5/(C21*(E14+E15))		0.25
20			=E16/(1.66*C5)		
21			=E17/(0.66*C5)		=E14*E15*0.5/(E19*(E14+E15))
22					=3*C6*(1+2*C7*E21^2)
23			=3*E19*E16/C8		
24			=3*E19*E17/C9		0.0625
25			=2*E9/E19		7
26			=0.5*E8*E14*E22/(E16*E19)		=E25*(E19+E24)
27			=0.25*E14*E8*E22/(E19*(1.66*C5*E21-E16))-0.4		=E13*E25*E19
28			=(C5/E16+2.67/(E21*(E21+2)*(1+0.25*E14/E15)))*E14*E21*SQRT(1+2*E14/E15)/(1.92*E19)		=E13*E25*E24
29					=0.285*E28+0.0434*E27

FIGURE 5 Formulae used in Spreadsheet

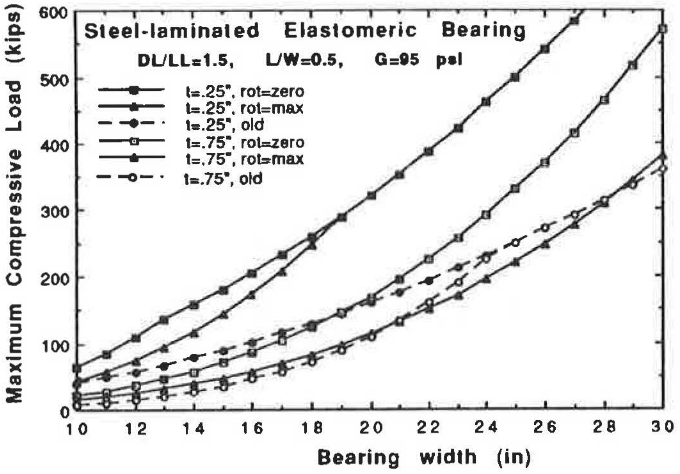


FIGURE 6 Compressive load capacity of a rectangular elastomeric bearing as a function of bearing width

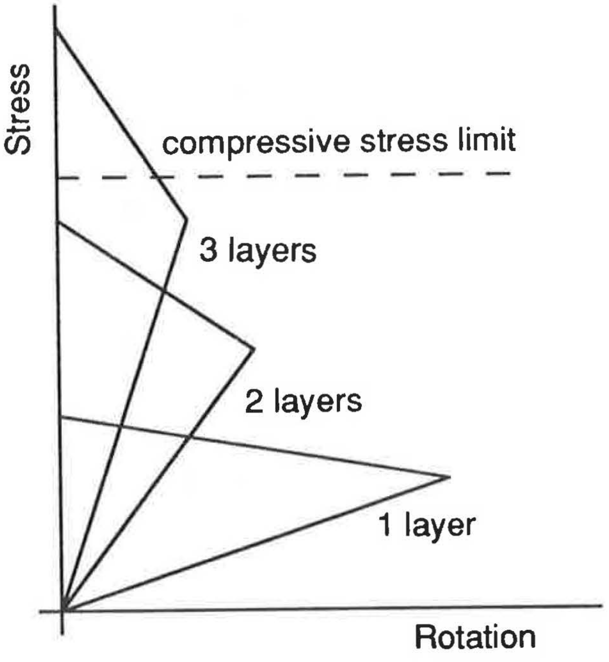


FIGURE 7 Interaction of rotation and compressive load

seems contradictory but the explanation lies in the fact that θ_{max} for the 3/4" layer bearings is much larger than θ_{max} for the 1/4" layer bearings. Rotation had no influence on load rating under the old specifications because it was not included explicitly.

The relationship between compressive stress and rotation is further illustrated in Fig. 7 in which stress is plotted against rotation capacity for a bearing with given plan dimensions and total rubber thickness. The three different curves represent different numbers of layers (and different layer thicknesses). The individual interaction curves resemble the axial force - bending moment interaction curves used in reinforced concrete design. The upper line represents 'tension-controlled' designs, in which rotation is limited by the requirement of no uplift, and the lower line represents 'compression-controlled' designs in which the fatigue or delamination limit is active. In most cases the maximum rotation capacity occurs at 2/3 the maximum stress allowed by the fatigue limit. If the bearing load is high but the rotation is large, the best design strategy may be to choose a shape factor which causes this 2/3 maximum fatigue stress to be equal to the 1600 psi delamination stress. For a 55 durometer elastomer, this would require a shape factor of about 11, which is higher than is commonly used today in the USA, but is typical in Europe and Australia. Such an approach makes use of the highest possible compressive stress yet optimizes the rotation capacity for that stress. If the rotation capacity is too small, a smaller number of thicker layers will be needed, but the allowable stress then decreases and so the bearing must be larger.

With hand design calculations, it is difficult and tedious to achieve these optimum conditions, but the spreadsheet speeds up the calculations so much that optimum or near-optimum bearings can be designed very rapidly.

Rotations are important under the proposed provisions whereas they have been ignored in previous specifications. This has two main consequences. First, the largest component of rotation comes from inaccuracies in levelling the bearing and in fabrication of the girders which rest on it. Thus better quality control in these operations would reduce the rotation demand on the bearing and allow a greater proportion of its capacity to be used in resisting compressive load. Second, a greater total rubber thickness leads to a larger rotation capacity, so rotation should be taken into account when selecting the bearing height.

The relationship between rotation capacity and height is illustrated in Fig. 8. The bearing properties are those used in Fig. 6, and in addition shear displacement is assumed to be

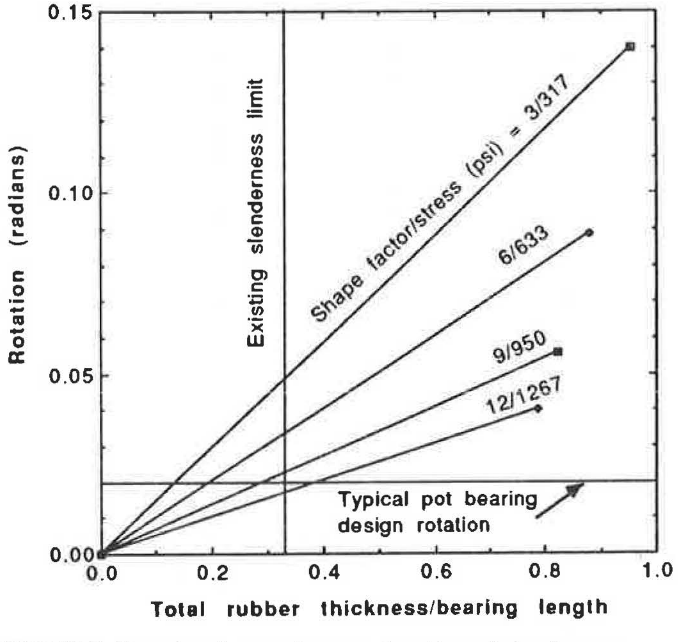


FIGURE 8 Rotational capacity as a function of slenderness

the maximum possible, but, for buckling calculations, sway is assumed to be prevented. These conditions correspond to those at the free end of a bridge in which the other end is fixed. For each shape factor, the compressive stress which allows the maximum rotation is used, and the curve stops at the stability limit. The figure shows that taller bearings are now possible with the improved buckling models (10) used in the recommended provisions. It also shows that the maximum rotation increases significantly with increasing slenderness or bearing height and with decreasing shape factor. The common pot bearing design rotation of 0.02 radians is marked on the figure, and many elastomeric bearings can be seen to have a larger rotation capacity than it. This is an interesting observation, because pot bearings are usually regarded as high rotation bearing systems whereas elastomeric bearings are not.

The footprint of a pot bearing is usually controlled by the allowable stress on the concrete seat, which is typically 1000 to 1500 psi. Since the proposed provisions permit compressive stresses on laminated elastomeric bearings of this order of magnitude, the space required for both bearings will be comparable. Fig. 8 shows that an elastomeric bearing could provide greater rotation capacity and could be a viable alternative.

QUALITY CONTROL

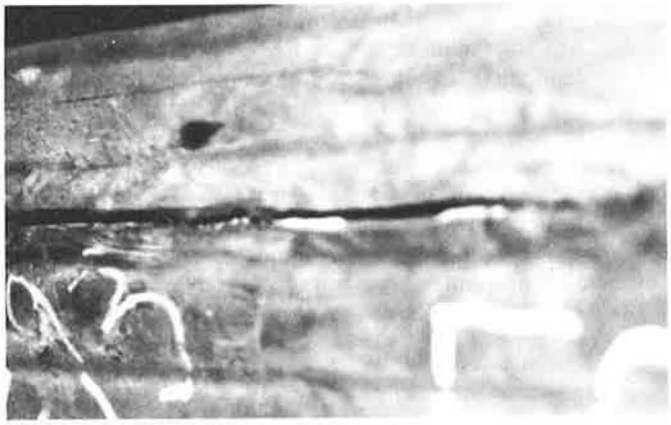
The proposed provisions offer some real benefits but require some additional effort in the engineering design. However this paper has shown that the design calculations can be greatly simplified with the aid of a simple spreadsheet. The increased capacities also require tighter quality control during bearing manufacture and installation.

Problems associated with elastomeric bearings can generally classified as: poor design or choice of materials, poor quality materials, poor quality fabrication and improper installation. The first and last are controlled by the designer and installer and are not considered further here. The quality of the materials used is assured by ASTM material property tests, and most of those previously required by AASHTO (such as tensile strength and elongation at break) are retained with largely unchanged limiting values. Material stiffness tests are required in place of the former hardness test, since stiffness is a more direct and reliable indicator of bearing behavior. In addition, low temperature stiffness tests (7,11) are required for colder climates to assure that the elastomer has appropriate low temperature characteristics. The low temperature brittleness test is retained but the target values are modified to reflect more accurately the regional climate. These improved material property tests are a necessary complement to the proposed higher design stresses but they should add little or no cost to most bearings.

Fabrication quality is addressed by load testing. It is not foolproof, but it represents a good compromise among simplicity, reliability and cost. Previous specifications did not require load tests. Under the proposed provisions every steel-laminated elastomeric bearing would be subjected to a short duration load test to 150% of its maximum service load. Bearings which exhibit cracking of the elastomer or unusual bulging patterns such as shown in Fig. 9a or 9b would be rejected. These flaws typically indicate a poor quality elastomer, excessive strain in the bearing due to poor geometry control, or partial delamination of the steel from the elastomer. This test requires 10 minutes or less to complete and can be performed with equipment available to all elastomeric bearing manufacturers.

The short duration load test will show most fabrication flaws, but some appear only under long duration loading so a long duration load test is also proposed. Unusual or unacceptable bulge patterns or cracks or flaws in the elastomer as shown in Fig. 9a or 9b will again be the basis for rejection. The long duration load test is an effective but more expensive and time consuming quality control test. It requires that a load which is 150% of the maximum service load be applied and maintained for 15 hours. As a result, the long duration load test is required only for a sample of the bearings which have already passed the short duration load test. Failure

a)



b)

FIGURE 9 Potential problems in the manufacture of elastomeric bearings of a single bearing is cause for either rejecting the entire lot of bearings or additional testing of the entire lot.

Improved quality control during installation is also required (7) to assure that the bearing performs as expected. For example, the bearings must sustain rotations caused by out of level pier caps or excessive camber or twist in bridge girders. It is essential that tolerances be controlled on the construction site if the bearing is to perform properly. This can be done by requiring levelling shims or a grout bed to ensure that the bearing is properly positioned and levelled. Installation tolerances are more important than ever, because the recommended provisions have less inherent conservatism built in to them. The recommended provisions are safe, but they will not protect the bridge against careless workmanship. The good judgement of the bridge engineer combined with adherence to the required tolerances are needed for this last element of quality control.

PRACTICAL IMPLICATIONS

The proposed bearing design provisions offer substantial advantages, but require more detailed calculations and tighter quality control. This paper has reviewed all three elements. The major practical implications are -

1. Laminated elastomeric bearings can be designed for compressive stress levels well above the upper limit of 800 psi which has historically been used for elastomeric pads. As a result, smaller and more economical bearings can now be used, and more important, laminated elastomeric bearings can sometimes be used in place of other more expensive and often more trouble prone bearing systems.
2. Improved stability models have been developed. As a result taller laminated elastomeric bearings can be designed which can accommodate larger translational movements and larger rotations. This again indicates that elastomeric bearings can sometimes be used in place of other large movement or high rotation bearing systems.
3. Smaller and taller bearings will result in smaller forces and moments transferred between the substructure and the superstructure. This can lead to increased economy and greater reliability of the structural design.
4. The benefits are achieved at the cost of increased effort in the design calculations. However, the design calculations can be completed quickly, economically, and systematically with the aid of the simple spreadsheet described in this paper.
5. The benefits also require improved quality control in the manufacture and installation of the bearing. Suitable quality control measures are briefly reviewed in the paper. They will add slightly to the cost of an individual bearing, but the increased cost will be small compared to the potential overall savings.

CONCLUSIONS

This paper presents a brief overview of recent proposed provisions for the design of laminated elastomeric bridge bearings. It summarizes the design calculations, and shows how they can be easily executed with the aid of a computer spreadsheet. It illustrates the effect of the recommendations on bearing design, and clearly shows that there can be a very beneficial effect on the total bridge design.

ACKNOWLEDGMENTS

This research was funded by the National Cooperative Highway Research Program (NCHRP) through NCHRP Project 10-20. Mr. Ian Friedland is the Project Engineer for this project, and Mr. Charles Purkiss is the chairman of the Project Panel. The authors are grateful for the financial support and the advice and support of the Project Engineer and the Project Panel. The opinions expressed in this paper are the opinions of the authors and are not necessarily the opinions of AASHTO, NCHRP, the National Research Council or the National Academy of Science.

REFERENCES

1. *Standard Specification for Highway Bridges*, AASHTO, 7th Edition, Washington, D.C., 1961.
2. E.I. DuPont de Nemours Co, *Design of Neoprene Bearing Pads*, Wilmington, Delaware, 1959.
3. *Standard Specification for Highway Bridges*, AASHTO, 14th Edition, Washington, D.C., 1989.
4. Stanton, J.F., and Roeder, C. W., "Elastomeric Bearings Design, Construction, and Materials", *NCHRP Report 248*, TRB, National Research Council, Washington, D. C., August 1982.
5. Roeder, C. W., and Stanton, J. F., "Elastomeric Bearings : A State of the Art", ASCE, *Journal of the Structural Division*, No. 12, Vol 109, December 1983.
6. Roeder, C. W., Stanton, J. F., and Taylor, A.W., "Performance of Elastomeric Bearings", *NCHRP Report 298*, TRB, National Research Council, Washington, D. C., October 1987.
7. Roeder, C. W., Stanton, J. F., and Feller, T., "Low Temperature Behavior and Acceptance Criteria for Elastomeric Bridge Bearings", *NCHRP Report 325*, TRB, National Research Council, Washington, DC 1989.
8. Roeder, C. W., Stanton, J. F. and Taylor, A. W., "Fatigue of Steel-Reinforced Elastomeric Bearings," ASCE, *Journal of Structural Division*, Vol. 116, No. 2, 1990.
9. Roeder, C.W. and Stanton, J.F., "Failure Modes of Elastomeric Bearings and Influence of Manufacturing Methods," Proceedings of 2nd World Congress on Bearings and Sealants, *ACI Publication SP-94*, Vol. I, ACI, San Antonio, Texas, 1986.
10. Stanton, J. F., Scroggins, G., Taylor, A. W. and Roeder, C. W., "Stability of Laminated Elastomeric Bearings," ASCE, *Journal of Engineering Mechanics*, No. 6, Vol. 116 1990.
11. Roeder, C. W., Stanton, J. F., and Feller, T., "Low Temperature Performance of Elastomers," ASCE, *Journal of Cold Regions*, No. 3, Vol. 4, 1990.