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Effects of shape factor on the behaviour of elastomeric roadway bridge bearings and benefits of circular bearing cross section

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ABSTRACT

Elastomeric bearings can support steel and concrete bridge girders. Layered bearings with steel plates are typical and they provide the lateral flexibility to accommodate longitudinal girder movement and the necessary vertical stiffness to vertical support reactions. Elastomeric bearings also replace existing roadway bridge girder supports. Mechanical behaviour of elastomeric bearings strongly relates to the incompressible character of the elastomer material. Incompressible character of elastomers, allows elastomer-bearing design through confining unbound surfaces and limiting surface deformations. A particular character of elastomeric bearings known as the shape factor (S) represents the difference in stiffness of two elastomeric bearings that have same cross sectional areas but different cross sectional shapes. Through an advanced finite element-modeling program, this study evaluates and compares the behaviours of rectangular and circular steel layered elastomeric bridge bearings under the application of vertical and lateral loads.

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1. Introduction

Elastomeric bridge bearings are in use since 1960's. Square, rectangular or circular bearings come in different cross-sectional areas, thicknesses and with different number of layers of steel or composite plates.

They accommodate the required longitudinal motion for bridge girders due to temperature dependent elongations and contractions. They also accommodate the necessary rotation at the supports due to bending and maintain the required bearing stress on the element supporting the girder. Therefore, correct positioning of the bearings with respect to the longitudinal axis of the girder is an important application issue. Curved girders and skewed bridge girders necessitate extra care in rectangular bearing positioning on the supporting pier for correctly aligning the principal bending axis of the bearings with the expected rotation and the expected longitudinal movement at the girder support. Unlike circular bearings that have the same rotational inertia around any central axis, the rotational inertia of square and rectangular bearing varies, being at their limits around their principal axis.

A conducted survey in 2001 among the transportation departments of the states in the USA, collected information about the use of elastomeric bridge bearing types and the experienced difficulties in the field with respect to the use of square and rectangular bearings. One of the stated problems was lateral movement of square and rectangular bearings in unexpected directions other than their principal axis. Another stated problem was delayering of the composite square and rectangular bearing. The final stated problem was crushing of elastomeric material due to bearing rotation around axis other than their principal axis. Table 1 shows responses from states that use circular elastomeric bearings. Fig. 1 shows an application case of circular elastomeric bearing.

Due to alignment difficulties of square and rectangular bearings on the piers in the field, use of circular bearings is increasing. This study analytically evaluates and compares the behaviours of bearings under vertical and lateral loads in terms of displacement and stress distributions.

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Table 1. States declaring circular elastomeric bridge bearing use in 2001 (Najm et al., 2002).

State	Diameter (cm)	Thickness (cm)	Type of elastomer	Type of bridge
Connecticut	60	5 – 7.5	Neoprene	Medium and high skew; 30 – 45 m span
Idaho	30 – 60	Not stated	Neoprene	High skew
Maine	30 – 60	2.5 – 10	Neoprene	High skew or curved, spans smaller than 30 m
Massachusetts	30 – 60	7.5 – 7.5	Polychloroprene	High skew or curved, spans smaller than 30 m
New Hampshire	30 – 90	5 – 10	Natural rubber	High skew or curved, spans smaller than 30 m
New York	30 – 60	Not stated	Neoprene and natural rubber	High skew or curved
Texas	30 – 60	2.5 – 7.5	Neoprene and polychloroprene	High skew or curved, bridges shorter than 45 m

Fig. 1. Use of circular elastomeric bridge bearing (Najm et al., 2002).

2. Elastomers

Elastomers are polymeric materials composed of carbon and hydrogen atoms and filler elements. Through a process known as vulcanization, bonds form between the polymeric chains through sulfur atoms thereby preventing relative slip between the polymeric chains and providing elasticity to the elastomeric element under loads.

Deformation characteristics of the polymeric material are dependent on ambient temperature. Ductility and the elasticity of the material diminish with reduced temperatures and the material becomes brittle. In order to categorize the polymeric material as an elastomer, the polymeric chains must preserve their ductility and elasticity.

Elastomers differ from other solid elements with their incompressible quality. In other words, the incompressible material cannot collapse onto itself under compression and always maintains its volumetric stability and density. Under the application of load, the elastomer body deforms through its unbound surfaces. Through its incompressible character, it is possible to change the stiffness of an elastomeric element by bounding and limiting its deformation through its free surfaces. On the other hand, elastomeric elements with the same cross sectional area but different cross sectional shapes have different unbound deformable surface areas. Because of this difference, a unique property known as the shape factor (S) develops, which affects the deformation value of the elastomeric bearing element under loads.

3. Shape Factor

Shape factor is the ratio of element cross section to the freely deformable surface area of the element. Fig. 2 shows a square elastomer with thickness (t) and side distance (a) under the application of a force (P). The cross section area effective in resisting this force is a^2 and the free surface area deforming because of this force is $4 \cdot a \cdot t$.The shape factor of this section is therefore $S = a^2/4at = a/4t$.

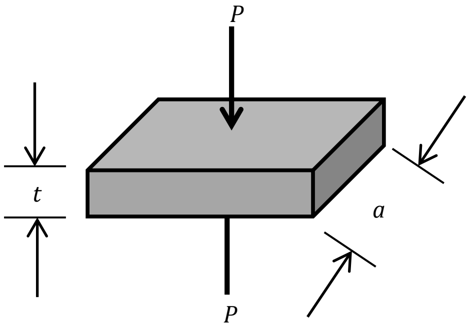

Fig. 2. A square elastomer bearing under load *P*.

Performing the same deduction for a circular elastomeric bearing with a diameter (D) and a thickness (t), one determines the shape factor as: $S = (\pi D^2/4) / (\pi D \cdot t) = D/4t$.

Effect of the geometric shape on the shape factor becomes apparent when the perimeters of a square and circular elastomeric bearing with the same cross section area (A) are compared. From Eqs. (1) and (2), the perimeter of a circle is 88.6% of the perimeter of a square with the same area. This finding agrees with the geometric definition of a circle, which states that a circle is the curve of a given length that encloses the greatest area (Falconer, 2013).

$$Area\ of\ a\ circle = Area\ of\ a\ square \rightarrow$$
$$a^2 = {\pi D^2}/{4} \ \rightarrow \ a = {D\sqrt{\pi}}/{2}, \tag{1}$$

$$Perimeter\ of\ a\ circle / Perimeter\ of\ a\ square =$$
$${\pi D}/{4a} = {\pi D}/{2D\sqrt{\pi}} = 0.886\,. \tag{2}$$

This geometric difference provides the shape factor of an elastomeric element. Eq. (3) qualitatively states the shape factor.

$$Shape\ factor = Loaded\ area / Deformable\ area =$$
$$Loaded\ area / Perimeter \times Thickness\,. \tag{3}$$

The thickness (t) term represents the smallest thickness representing the free deformable surface of the elastomeric bearing element. The thickness values of the unlayered and layered elastomeric bearing presented in Fig. 3 are different. Because of this difference, the shape factors of the two bearings are also different. Primary benefit of layering is to confine the freely deformable surfaces and limit the deformations to increase the stiffness. Theoretically, the stiffness of a fully confined elastomeric element would be infinite since the material is incompressible.

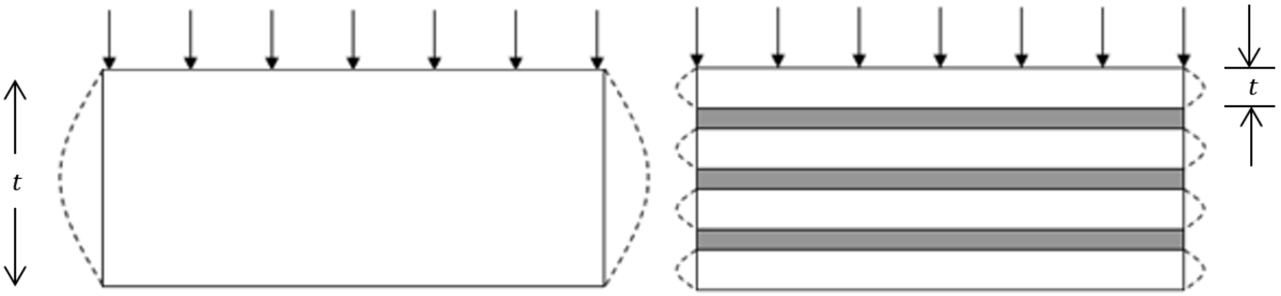

Fig. 3. Unlayered and layered elastomeric bearings with plates (Bezgin, 2002).

Eqs. (4), (5) and (6) develop and compare the shape factors of a square and circular bearing with the same cross sectional area. The perimeter of a circle relates to that of a square with the finding in Eq. (2).

$$S_{square} = \frac{Area\ of\ square}{Perimeter\ of\ square \times Thickness}, \tag{4}$$

$$S_{circular} = \frac{Area\ of\ circular}{0.886 \times Perimeter\ of\ square \times Thickness}, \tag{5}$$

$${S_{circular}}/{S_{square}} = {1}/{0.886} = 1.13\,. \tag{6}$$

The difference in the perimeters reflects on to the area of freely deformable surfaces and thus the shape factors of the two geometries.

The modulus of elasticity (E) of elastomers relates to the shear modulus (G), hardness (k) and the shape factor (S) as shown in Eq. (7) that has also been used by AASHTO (Bezgin, 2002; Fediuc et al., 2013).

$$E = 3 \cdot G \cdot (1 + 2 \cdot k \cdot S^2)\,. \tag{7}$$

Other such equations presented in literature (Bauman, 2008; Fediuc et al., 2013) show the direct relationship between elasticity modulus (E) and the shape factor (S). Thus, the shape factor is an influential parameter on the stiffness of an elastomeric bearing.

4. Layered Elastomers

In order to increase the stiffness of elastomeric bridge bearings and maintain the lateral flexibility, steel or composite plates strengthen bearings. Fig. 4 shows the variation of shear modulus of Shore-A 55 hardness neoprene elastomer with temperature used within the finite element models presented in this section. The finite element models developed for the steel-layered neoprene bearings have plates with 240 MPa yield strength. The analysis conditions are set at -10°C and the corresponding shear modulus of the elastomer at 1150 kPa.

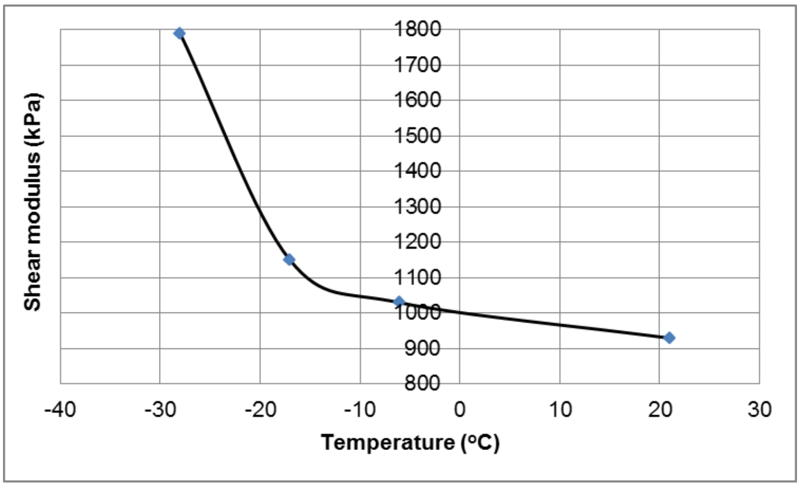

Fig. 4. Variation of shear modulus with temperature (Bezgin, 2002).

Thicknesses of the 3-layered, 5-layered and 7-layered square and circular bearings shown in Fig. 5 are 4.5 cm, 7.6 cm and 10.7 cm respectively. The length and the width of the square bearing is 40.6 cm and the diameter of the circular bearing is 45.8 cm. The bearings are analyzed under the action of 1150 kN vertical force through a rigid plate, generating 7 MPa compressive stress in the bearings.

The elastomeric layer thicknesses are 13.5 mm. Table 2 and Fig. 6 present the shortening values of the analyzed bearings. Eqs. (8) and (9) show the shape factors of the square and circular bearings.

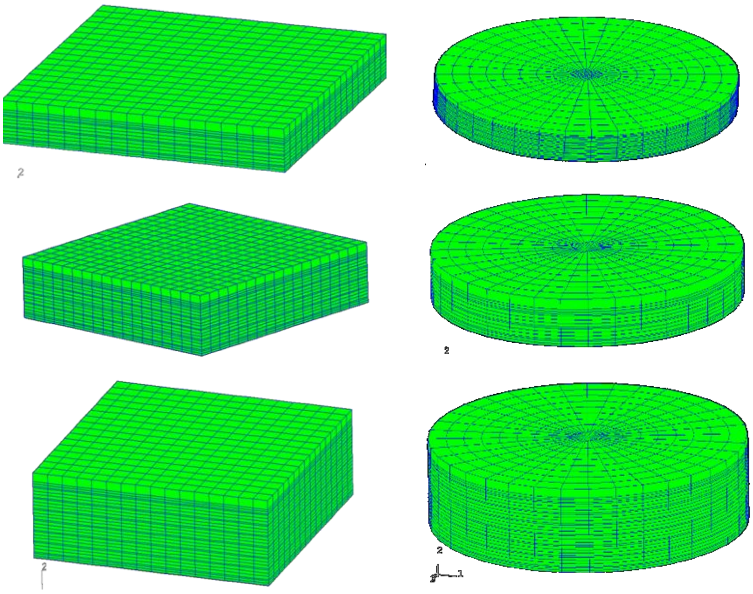

Fig. 5. Layered elastomeric bearings with 3, 5 and 7 layers (Bezgin, 2002).

$$S_{square} = {}^{40.6^2}\!/_{4 \cdot 40.6 \cdot 1.35} = 7.5\,, \qquad (8)$$

$$S_{circular} = {}^{\pi \cdot 45.8^2/4}\!/_{\pi \cdot 45.8 \cdot 1.35} = 8.5\,. \qquad (9)$$

Due to higher shape factor of the circular bearing, the contraction values are approximately 10% lower than the values obtained for the square bearing.

5. Elastomer Behaviour under Lateral Loads

Bridge girders longitudinally move to accommodate the elongations and contractions due to temperature differences. The bearings are also bent by the rotations at the ends of the girders they support. Determination of the direction and the axis of these movements and proper alignment of the bearings with respect to the expected movements is an important on-site matter due to its effects on the internal stress values and internal stress distributions within the elastomer. The primary rotational axis of a circular section is any axis that passes through its geometric center. However, rotational inertia values of square and rectangular shapes depend on the particular axis that pass through the geometric centers of the square and rectangular shapes. Therefore, if the square and rectangular shapes are so placed that they are bent under the deflecting girder they support around an axis that is not primary, unexpected stress values and distributions may arise. On the other hand, if the expected lateral movement is not aligned perpendicular to the primary rotational axis, the resulting stress distribution pattern can also have discontinuities of concentrations.

Table 2. Shortening values determined under the application of 7 MPa compressive stress (Bezgin, 2002).

Number of layers	Bearing thickness (cm)	Shortening (mm)	
		Square	Circular
3	4.6	0.34	0.31
5	7.6	0.65	0.59
7	10.7	0.86	0.80

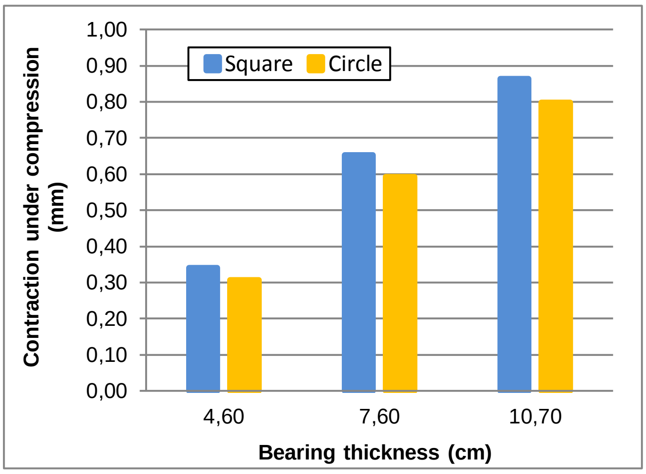

Fig. 6. Contraction values of square and circular bearings (Bezgin, 2002).

Figs. 7 and 8 show laterally deformed bearings under the action of 1150 kN vertical and 230 kN lateral forces going through the center of the bearings. The bearings are 7.6 cm thick and composed of 5-steel layers. All the bearings have an area of 1648 cm^2. The size of the square bearing is 40.6 cm by 40.6 cm and the circular bearing diameter is 45.8 cm. The lateral load is applied diagonally to the square bearing.

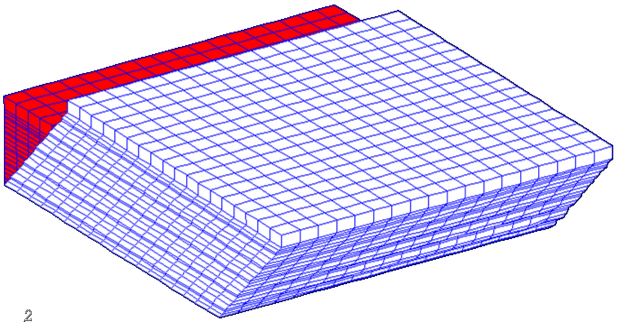

Fig. 7. Square bearing under diagonally applied lateral load (Bezgin, 2002).

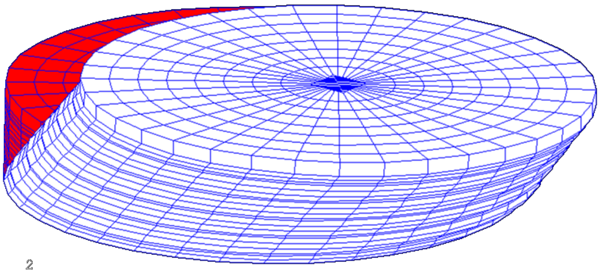

Fig. 8. Circular bearing under lateral load (Bezgin, 2002).

The lateral displacement of the bearings is 6.7 cm. Fig. 9 shows the vertical stress distribution in the elastomer layers of the bearings where the stress discontinuities and concentrations in the square bearing become apparent.

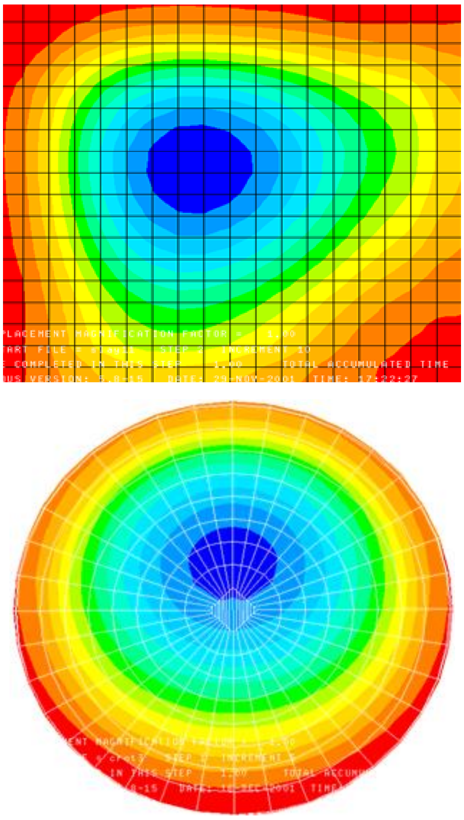

Fig. 9. Distribution of vertical stresses in bearings under lateral loads (Bezgin, 2002).

6. Conclusions

Cross sectional geometry affects the structural behaviour of elastomeric bearings. The shape factor represents this effect and it relates to the incompressibility of the elastomer and therefore relates to the influence of the freely deformable surface area on the bearing behaviour. The stiffness of elastomeric bearings can change by modifying the freely deformable surface area. This analytical study showed that circular bearings provide 10% higher stiffness than square bearings with the same area. The study also showed that distribution of interlayer vertical stresses under lateral loads is uniform in circular bearings compared to square bearings.

REFERENCES

Bauman JT (2008). Fatigue, Stress and Strain of Rubber Components – Guide for Design Engineer. Hanser, Munich.

Bezgin NÖ (2002). Geometric Effects on the Behavior of Elastomeric Bridge Bearings. *M.Sc. thesis*, Rutgers, The State University of New Jersey, UK.

Falconer K (2013). Fractals: A Very Short Introduction. Oxford University Press, Oxford.

Fediuc OD, Budescu M, Fediuc V, Venghiac VM (2013). Compression modulus of elastomers. *Buletinul Institutului Politehnic din Iași,* LIX (LXIII), f.2.

Najm H, Nassif H, Bezgin NÖ (2002). Circular Elastomeric Bearings. *Technical Report, FHWA-NJ-2002-005.*