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Parametric study of laminated elastomeric bearing using FEM

Hawraa Sami Malik[†], David A.M. Jawad[‡], Shifaa N.A. Hussain[†]

[†] Department of Civil Engineering, Al-Maaqal University, Basra, Iraq, hawraa.sami@almaaqal.edu.iq
[‡]Department of Civil Engineering, University of Basra, Basra, Iraq
[†]Department of Civil Engineering, University of Thi-Qar, Thi-Qar, Iraq

Abstract:

The structures are flexible and their structural stability should be provided under all conditions. The bearings are the key member that offers freedom of movement between the superstructure and the foundation while accommodating vertical loads and rotation. Based on the finite element software ANSYS19.2, the FE model for a reinforcement elastomeric bearing is developed. The design parameters of the bearing, including elastomer thickness, shape factor, steel thickness, b/h ratio and number of steel shims are examined, and numerical results are verified by results of the previous researches. In this study, for the specific elastomeric bearing, the effect of shape factor and the number and thickness of reinforcing plates on its compression and shear stiffness is studied by using ANSYS Mechanical APDL. Results show that the FE model is capable of predicting the vertical stiffness and size of bulging (horizontal movement).

Keywords: Elastomeric bearing; elastomer; reinforcing plate; compressive stiffness; shear stiffness; finite element analysis; numerical simulation

1. Introduction

A bearing is defined by AASHTO as a structural tool that transmits loads while enable rotation and/or translation. Concrete and steel are the two main structural materials that are used in construction of bridges. Although there is a wide variety of structural systems that can be used in bridges, a girder bridge is the most widely used system. A girder system is usually divided into a superstructure and a substructure, the critical link between these two divisions is the bridge bearings. The main function of the bearing is to resist the reactions of the girder as well as accommodating the translations and rotational deformations that occur at the supports of bridge due to the thermal changes in the bridge environment and from the applied loading. Steel girders are usually used for long span bridges, the longer span girders result in larger reactions at support that the bearings must accommodate in comparison with the shorter concrete girder reactions **[1]**. A wide range of loads can be accommodated by changing the plan area, the hardness of elastomer and the thickness of internal elastomer layers. Bearings can be made as circular, square, rectangular or other shapes, See Figure (1). Note that, clipped corners, custom shapes, slotted, tapered and skewed bearings may carry cost premiums because of the mold modifications.

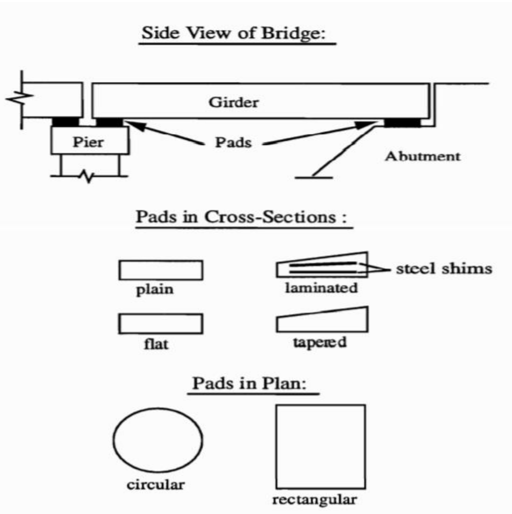


Fig.1 Elastomeric bridge bearings **[2]**

The elastomeric bearing is the most common bearing types that used on highway bridges, there are three important advantages of using an elastomeric bearing ,the bearings are effective, economical and do not need maintenance. In comparison with other bearing, an elastomeric bearing is more ease of construction, economical due to its simple design and the low costs of material **[2]**.
The two types of the Elastomeric bearings are plain (unreinforced) pads and laminated (reinforced) pads that consist of thin steel plates embedded at specific intervals within the elastomer **[2]**. Both plain and laminated bearings accommodate longitudinal displacements of the bridge by shear deformation (Figure 2.c). Shear deformations depends on elastomer thickness. Once the bridge horizontal movements are known, the rubber thickness can be chosen. The unreinforced pad has

different behavior from a laminated bearing when subjected to a compressive force. This difference has to do with vertical deformation and with the bulging that occurring around the bearing. The using of steel laminates drastically decrease the vertical deformation and bulging effect Figures (2.d) and (2.e). The bulging pattern can be controlled by controlling the bearing shape, the cross-sectional area and the elastomer thickness **[3].** The shape factors for most reinforced bridge bearings fall between 4 and 12. This shape influence may be numerically expressed as the shape factor(s). The value of shape factor is defined as:

$$S = \frac{\text{Loaded plan area of the bearing}}{\text{Area free to bulg}} \quad \ldots..(1)$$

For a rectangular bearing

$$S = \frac{LW}{2t(L+W)} \quad \ldots..(2)$$

For a circular bearing

$$S = \frac{d}{4t} \quad \ldots..(3)$$

Where;
L: bearing length
W: bearing width
t: thickness of elastomer layer and
d: bearing diameter.

The shape factor, which varies with changing the layer thickness and plan dimensions, affects compressive and rotational stiffness that restraints the elastomer strain and stress in the steel layers. It doesn't affect the deformation capacity or the translational stiffness **[3]**.

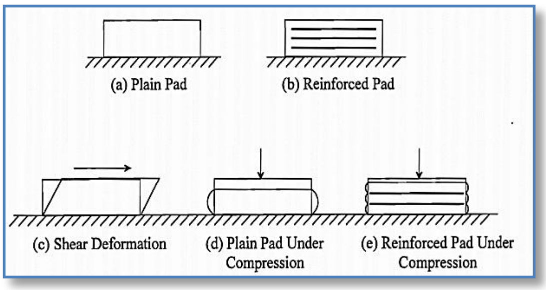


Fig. 2 Plain and reinforced elastomeric bearings

The shear stiffness of the laminated elastomeric bearings is low, however, they are too stiff under compression as a result of the presence of steel reinforcing plates **[4]**. The addition number of reinforcement layers can decrease the vertical movements and bulging pattern.

2. Failure modes

Throughout the bearing design life, a various structural failure modes can occur in the bearing due to many type of loads. The most common modes are the compression and shear modes.

2.1 Compression mode failure

Compressive loads include dead loads and live loads (traffic loads) **[3]**. The two possible modes in which the laminated bearing can fail when subjected to compression. The first one happened when the elastomer deboned at the edge of reinforced layer, this failure mode does not effect on the bearing capacity, however, to avoid this kind of failure, the free area of bulging must be increased and the effectiveness of the steel plates must be reduced Figure (3.a). The second mode of failure occur when the steel reinforcement has been yield and potentially fracturing Figure (3.b). This failure type is less frequent because the required failure load can reach to 10 times the design value **[1]**.

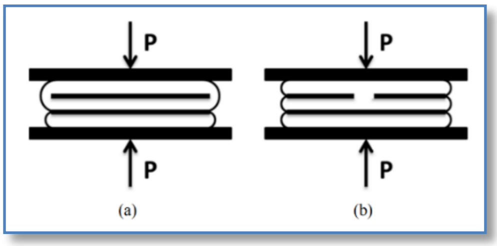


Fig. 3 Compression failure modes (a) tension deboning and (b) fractured steel plates

2.2 Shear failure mode

Horizontal loads to the bearing caused by translation movement induced by thermal effects, shrinkage, creep and dynamic loading came from the traffic load **[3]**. Elastomeric bearings are generally designed to withstand these translational movements through shearing deformation of the elastomeric **[1]**.

3. Bearing capabilities for laminated elastomeric bearing

Bearing devices should be designed to transmit horizontal forces (both longitudinal and transverse forces) and vertical forces due to factored design and construction loads **[5]**. The American Association of State Highway and Transportation Officials (AASHTO) discussed the design requirements of the elastomeric bearings. The requirements restricted the maximum horizontal movements of the bearing to half the elastomer's thickness. The compressive stress was limited to (3.45MPa) for dead load and (5.52MPa) for combined dead and live load **[2]**.

As per AASHTO LFRD bridge design specifications, the steel reinforced elastomeric bearings can be designed by either Method (A) or Method (B). The designs according to the provisions of Method (B) permit a maximum compressive stress of (12.0 MPa) for fixed bearings and (11 MPa) for bearings subject to shear deformations; while Method (A) permits a compressive stress up to (6.9 MPa). Since bearings designed under Method (B) have higher permissible stress limits and additional, more comprehensive, design restrictions, AASHTO LRFD needs more extensive testing and quality control. While the shear deformation is limited to ±0.5 of total elastomer height to avoid rollover at the bearing edges and delamination due to fatigue **[6]**.

4. Validation of ANSYS model

To validate the ANSYS structural model, the bearing movements and stressed were compared to those obtained by Febymol and Rohini **[7]**. Detailed geometrical information about this bearing is given in Table (1). The ANSYS model is shown in Figure (4) the material properties used in the model are listed as:
Rubber is a hyper-elastic material and the material property is defined by strain energy function (W).

W=C10 (I1-3) + C01 (I2- 3) + C20 (I1-3)2 + C02 (I2-3)2 + C11 (I1-3) (I2-3) …. (4)

The polynomial 2-P function is used here and the parameters of the elastomer materials were obtained as follows:
C10 = 0.797, C01= -0.0591, C20= 0.01609,
C02= -0.00529, C11 = 1.103 e-3

Steel is modeled as linearly elastic and isotropic material with E= 2×10^5 MPa and υ=0.3.

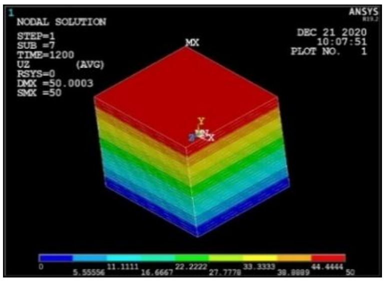
Table 1 Dimensions of the bearing

Size of bearing	*380 × 380 mm*
No. of rubber layers	*30*
Thickness of rubber layers	*12 mm*
Thickness of steel plate	*10 mm*

The Bearings were analyzed by applying vertical load equal to 1200 kN and 50 mm horizontal displacement, they are applied to the top nodes of the bearing. Table (2) shows the value of horizontal stiffness and deflection for bearings.

Table2: Deflection and stiffness of the elastomeric bearing.

Deflection (mm)			*Stiffness N/mm*		
Ref [7]	*Ansys19.2*	*Diff.*	*Ref [7]*	*Ansys19.2*	*Diff.*
51.9038	*50*	*0.037*	*87.298*	*91.968*	*0.053*


Deflected shape of bearing

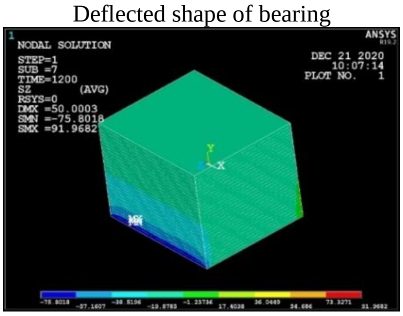
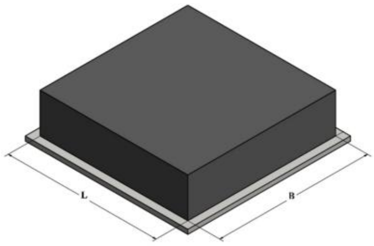
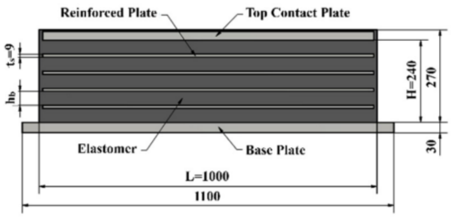

Horizontal stiffness of bearing

Fig.4 Results of the elastomeric bearing found by ANSYS 192.

Also the ANSYS validity has been checked by compared the compressive stiffness of the bearing with those obtained by DongSeop Han and MooHyun Kim **[8]**. The elastomeric bearing is a laminated structure of steel plate and neoprene synthetic rubber. The elastomer bearing model and its schematics are shown in Figure (5) and the material properties are listed in Table (3)


3D Model of elastomeric bearing



Schematics of elastomeric bearing

Fig. 5 The schematics an elastomeric bearing pad:

Table 3 The material properties of the laminated bearing.

Mechanical properties for steel	
Young's Modulus E	*200000Mpa*
Poisson's Ratio	*0.3*
Yield Strength Fy	*355*
Mooney–Rivlin constants of the elastomer material	
C10	*0.382Mpa*
C1	*0.096Mpa*

The bearing is analyzed by applying vertical displacement on the upper nodes of the bearing equal to (3mm), the researchers found that compressive stiffness value is equal to (47.3Mpa), while the compressive stiffness from the finite element (ANSYS19.2) is (47.475Mpa) as shown in Figure (6). The results from both models are compared very well with (ANSYS 19.2) software.

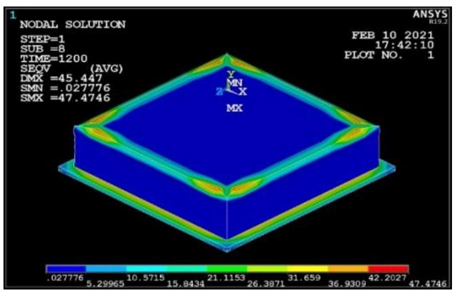
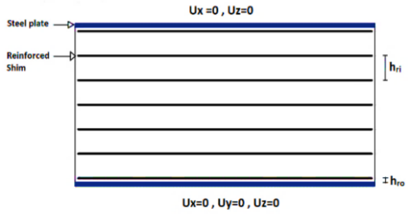


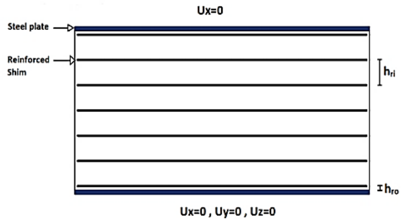
Fig. 6 Von-Mises stress of the elastomeric bearing.

5.Numerical examples

This study deals with the effect of reinforcement effects, primarily number of elastomeric layers and their thickness. In order to examine the basic behaviors of elastomeric bearings numerically, three-dimensional finite element modeling was conducted using a commercial program, (ANSYS 19.2) the hypothetical elastomeric bearing used has dimensions of 500mm (length) by 450mm (width), with a total of eight elastomer layers and seven reinforcing steel shims. The thickness of the interior layers was varied while that of the exterior layers was fixed at 6.25mm, also the elastomeric bearing with different number of reinforcement steel plat was examined. The type of element used for modelling the elastomer and the reinforcing steel shims was a 3-Dimensional, 20-node structural SOLID 186 with six degrees of freedom per node, in both compression and shear modeling, the boundary conditions for elastomeric bearings are presented in Figure (7), the bottom rigid block was fixed at the bottom, while the top of the top block was gradually displaced in the directions of the applied loads.



Boundary condition on bearing under compression load



Boundary condition on bearing under shear load

Fig. 7 Laminated bearing with the boundary condition

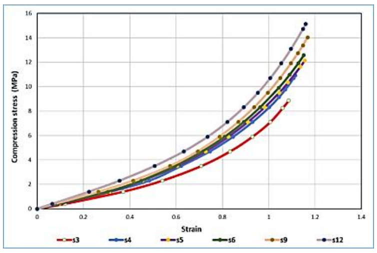
Steel plates were assumed to be rigid plates, loadings were applied to these rigid plates. The steel reinforcement shims were assumed to be perfectly elasto-plastic with elastic modulus E = 200000 Mpa and yielding stress Fy = 355 Mpa, Yoeh's model was used to represent the hyper-elastic material behavior of the elastomer with the parameters:

C10 =0.31385Mpa, C20 =0.021319Mpa, C30 =0.0007Mpa

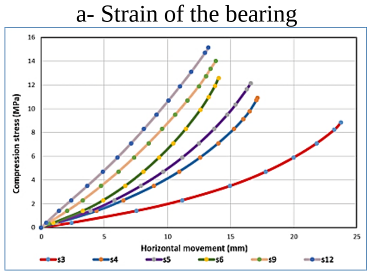
The shape factor (S) of the reinforced elastomeric bearing can be increased by decreasing the total thickness of the elastomer and/or by increasing the cross-sectional area. In order to investigate the effects of the shape factor that is defined in Equation (2), the thickness of the elastomer layers was varied so that the values of the shape factor, S, varied from 3 to 12 as shown in Table (4).

Table 4 Reinforced elastomeric bearing with different thickness of the elastomer layers

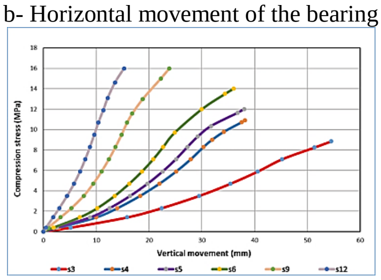
elastomer thickness (hri)(mm)	*Total bearing height (mm)*	*Shape factor*	*Applied compressive stress (MPa)*	*Strain*	*Horizontal movement (mm)*	*Vertical movement (mm)*
9.9	*72*	*12*	*15.140*	*1.160*	*13.242*	*15.279*
13.16	*91.5*	*9*	*14.031*	*1.168*	*13.844*	*23.872*
19.74	*131*	*6*	*12.577*	*1.152*	*14.063*	*34.842*
23.7	*154.7*	*5*	*12.128*	*1.155*	*16.595*	*36.782*
26.315	*168.5*	*4*	*10.915*	*1.116*	*17.126*	*38.176*
39.5	*249.5*	*3*	*8.857*	*1.086*	*23.752*	*54.515*



a- Strain of the bearing

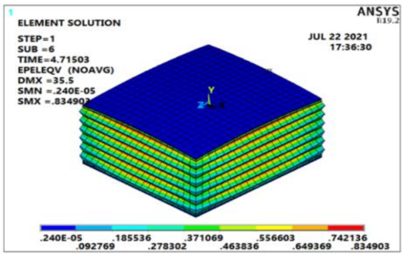


b- Horizontal movement of the bearing

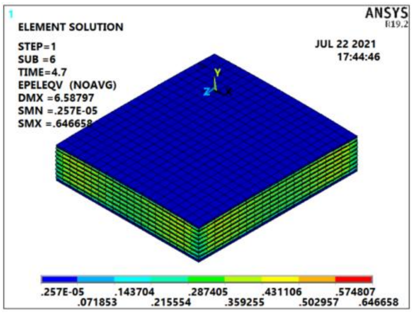


c- Vertical movement of the bearing

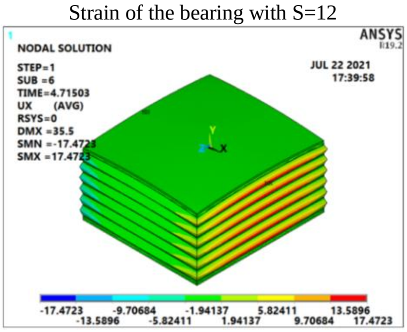
Fig. 8 Elastomeric bearing with different shape factor.



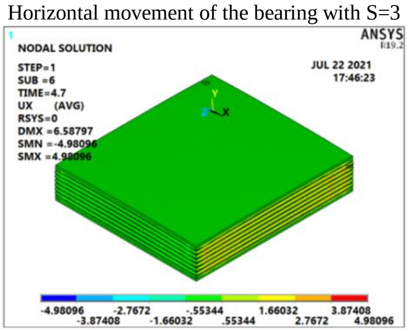
Strain of the bearing with S=3



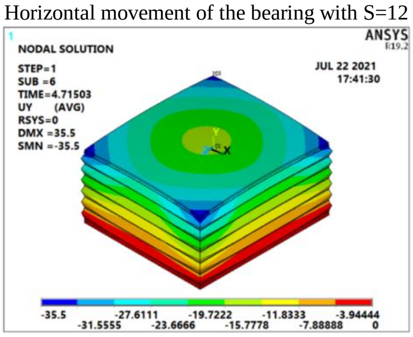
Strain of the bearing with S=12



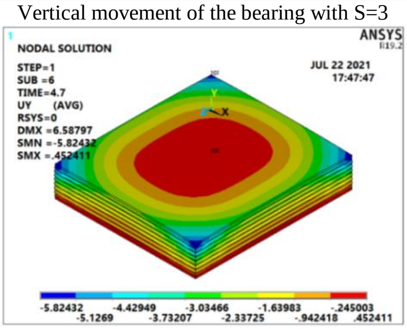
Horizontal movement of the bearing with S=3



Horizontal movement of the bearing with S=12



Vertical movement of the bearing with S=3



Vertical movement of the bearing with S=12

Fig. 9 Bearing with different shape factor

The vertical stiffness (compression stiffness) of elastomeric bearings is a very important property of the bearing considering both compressions from the reaction of the girders and for accommodating the girder rotation. For steel box girder systems where lift-off between the box girder and the bearing can be a concern, the vertical stiffness is an important thing Lift-off is described as the phenomenon where the disconnection happens between the box girder and the bearing under rotation, reducing the area of the compression resistance **[3]**. It can be observed from Figure (8) that the compressive stiffness of the steel reinforced elastomeric bearing can be increased by increasing the shape factor. Also it can be seen that as the thickness of the elastomer increases the horizontal and vertical movements have been increased and this is one of the purposes of increasing the elastomer thickness.

The main function of the steel shim is to improve the bearing behavior and to provide horizontal stiffness to the laminated bearing by controlling bulging. As a consequence, in-plane tensile stresses are occurred in the steel shim when the bearing is under compression load. So, the steel layer must be designed to withstand these tensile stresses. However, the steel plate thickness that is normally needed to sustain the vertical loads will generally be less than the actual thickness required for manufacturing purposes **[1]**.

The AASHTO LRFD Bridge Design specifies the maximum steel reinforcement thickness (h_s) as:

At the service limit state:

$$h_s \geq \frac{3\, h_{max}\, \sigma_s}{F_y} \qquad \ldots..(5)$$

At the fatigue limit state:

$$h_s \geq \frac{2\, h_{max}\, \sigma_l}{\Delta F_{TH}} \qquad \ldots..(6)$$

Where:

ΔF_{TH} = constant amplitude fatigue

h_{max} = thickness of the thickest elastomer layer (mm)

σ_L = service average compressive stress due to live load (Mpa)

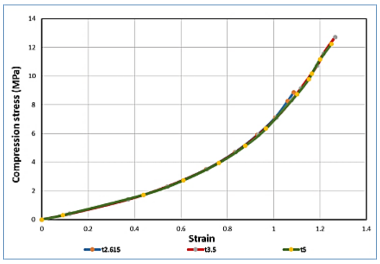
σ_s = service average compressive stress due to total load (Mpa)

F_y = yield strength compressive stress due to total load (Mpa) [6].

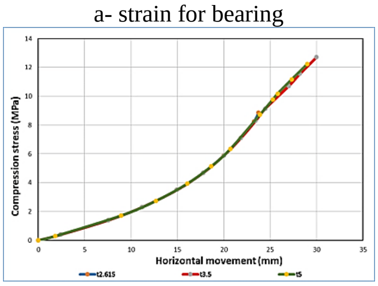
The performance of a bearing can be significantly affected by the amount, type, and layout of the reinforcement **[1]**. For examining the steel effect, different steel plate thickness and different number of reinforcement were studied as presented in Tables (5) and (6)

Table 5 Reinforced elastomeric bearing with different thickness of steel layers

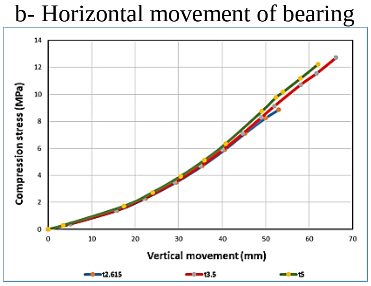
steel thickness (mm)	*Shape factor*	*Applied compressive stress (MPa)*	*Strain*	*Horizontal movement (mm)*	*Vertical movement(mm)*
2.615	*3*	*9.1575*	*1.086*	*23.752*	*54.514*
3.5	*3*	*12.716*	*1.265*	*30.454*	*66.116*
5	*3*	*12.227*	*1.248*	*29.313*	*63.224*



a- strain for bearing

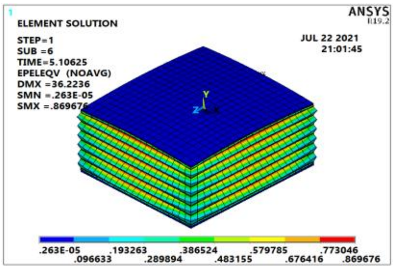


b- Horizontal movement of bearing

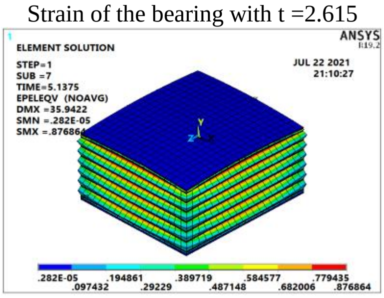


c- Vertical movement of the bearing

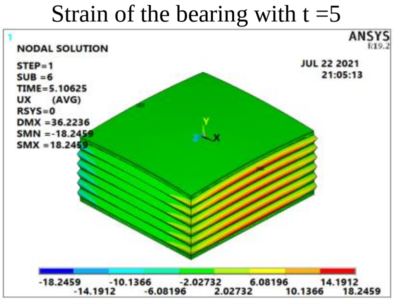
Fig.10 Elastomeric bearing with different steel thickness



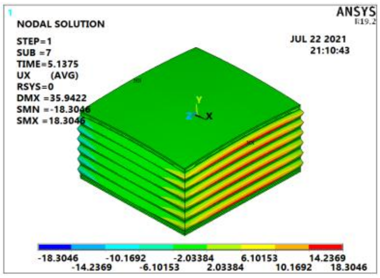
Strain of the bearing with t =2.615



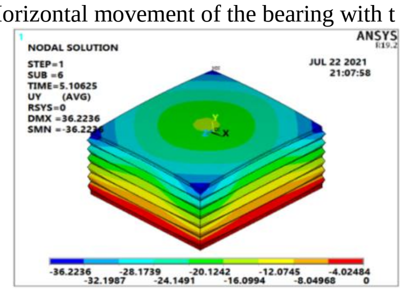
Strain of the bearing with t =5



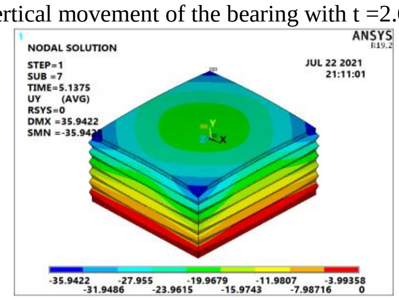
Horizontal movement of the bearing with t =2.615



Horizontal movement of the bearing with t =5



Vertical movement of the bearing with t =2.615



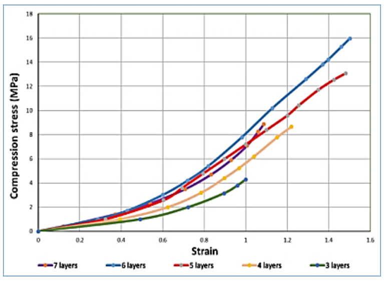
Horizontal movement of the bearing with t =5

Fig.11 Bearing with different steel layer thickness

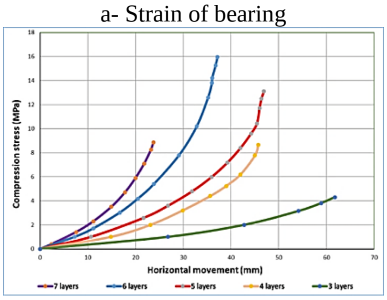
When a laminated bearing is subjected to a compression load, the steel shim restrains the elastomer bulging and in turn creates a large tensile stress. This failure can be avoided by decrease the compressive forces on the reinforced elastomeric bearing or choosing thicker steel plates **[3]**. From Figure (10) it has been noticed that when the thickness of the steel is increased, the elastomeric bearing can hold a larger compressive stress, but when the bearings are subjected to the same compression load, the effect of changing the steel thickness on the strain, vertical displacement and horizontal displacement is very little. In order to increase the vertical stiffness (K_{comp}) of the reinforced elastomeric bearing , the number of steel layer has to be increased, adding steel shims at specific intervals inside the bearing will increase the shape factor (s) which will reduce the bulging of the bearing **[3]**.

Table 6 Reinforced elastomeric bearing with different number of steel layers

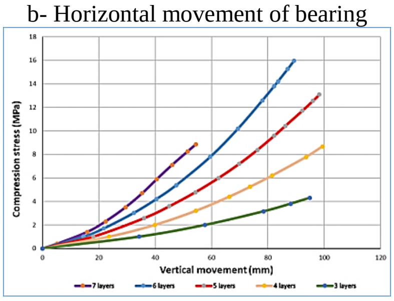
Number of Steel layer	*elastomer height (mm)*	*Shape factor (s)*	*Applied compressive load (MPa)*	*Strain*	*Horizontal movement (mm)*	*Vertical movement (mm)*
3	118.5	1	4.300	1.000	61.758	94.867
4	79.00	1.5	8.672	1.220	45.728	99.446
5	59.25	2	13.058	1.482	46.910	98.279
6	47.40	2.5	15.964	1.502	37.180	89.341
7	39.50	3	9.158	1.086	23.752	54.515



a- Strain of bearing



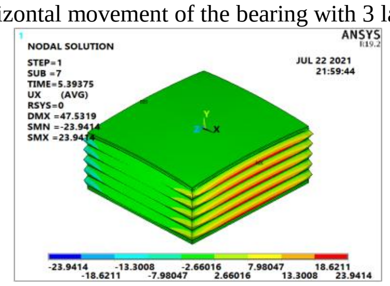
b- Horizontal movement of bearing



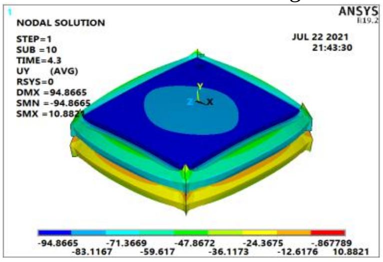
c- Vertical movement of bearing

Fig. 12 Elastomeric bearing with different number of steel layers

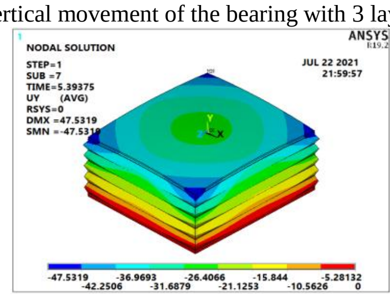
Horizontal movement of the bearing with 3 layers



Horizontal movement of the bearing with 3 layers

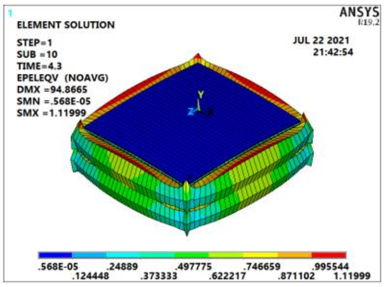


Vertical movement of the bearing with 3 layers

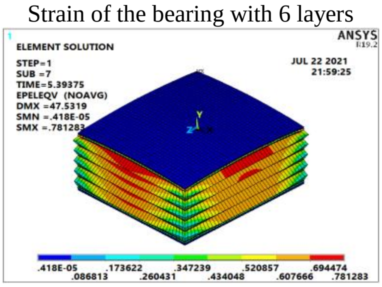


Vertical movement of the bearing with 6 layers

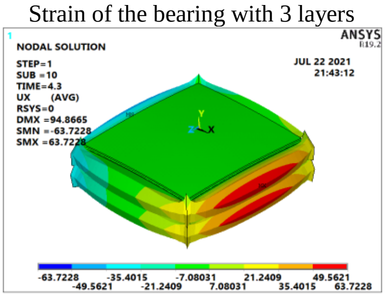
Fig.13 Bearing with different number of steel layer



Strain of the bearing with 6 layers

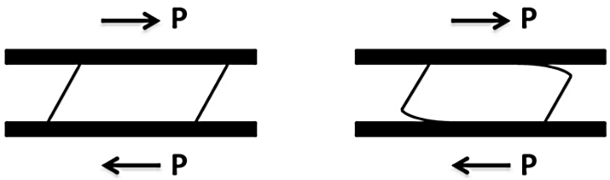


Strain of the bearing with 3 layers



The results from Figures (12) and (13) showed that the compression stiffness and the horizontal deformation can be reduced by increasing the number of steel layers.

A laminated bearing consists of layers of steel and elastomer. The elastomer is the material that accommodates the horizontal thermal movements. A bearing with poorly detailed bearing may cause rollover as depicted in Figure (14.b). The minimum effective thickness of elastomer is twice the design value of shear deformation to avoid rollover at the bearing edges as depicted in Figure (14.a) **[2]**.



(a) (b)

Fig.14 Bearing (a) without and (b) with rollover at the edge

In the case of shear study, the elastomeric bearing with different shape factor, different number of steel layers and different steel thickness were examined. Shear study was carried out by applying a compression stress equal to (5.2Mpa) and horizontal displacement (uz) at the top plate of the bearing. The relationship between the applied compressive load and the shear stress depends directly on shape factor, with higher shape factors leading to higher capacities. If movements are accommodated by shear deformations of the elastomer, they cause shear stresses in the elastomer, these add to the shear stresses caused by compressive load, so a lower load limit is specified. The results of this parametric study are shown in Tables (7) to (10).

Table 7 Reinforced elastomeric bearing with different thickness of the elastomer layers

Elastomer thickness (mm)	*Max deflection (mm)*	*Applied displace-ment (mm)*	*Shape factor*	*Shear stress of steel plates (MPa)*	*Shear stress of elastomer (MPa)*	*Shear strain of steel plates*	*Shear strain of elastomer*	*Horizontal movement (mm)*	*Vertical movement (mm)*
39.5	55	16	3	112.71	0.639	0.00146	0.269	31.122	40.851
26.315	30	16	4	93.469	0.439	0.00121	0.198	24.608	24.381
23.7	23	16	5	98.416	0.445	0.00121	0.196	23.305	22.829
19.74	16	16	6	88.402	0.445	0.00114	0.193	21.587	19.207

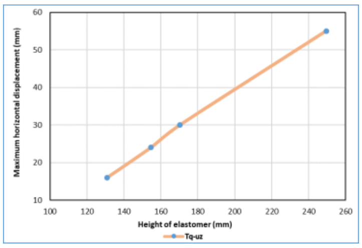
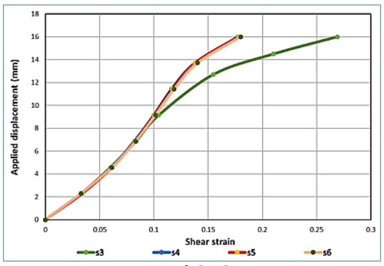
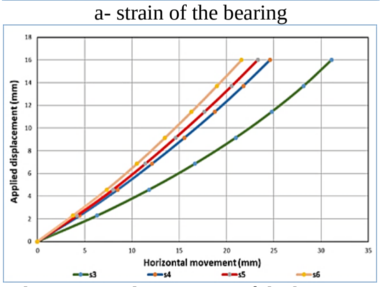


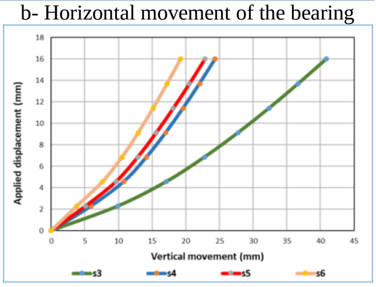
Fig. 15 Variation of maximum horizontal displacement with elastomeric height



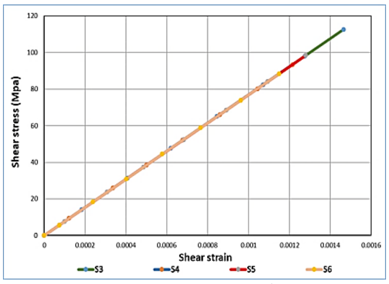
a- strain of the bearing



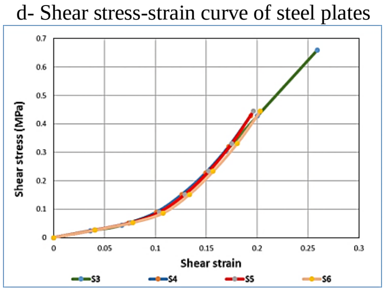
b- Horizontal movement of the bearing



c- Vertical movement of the bearing

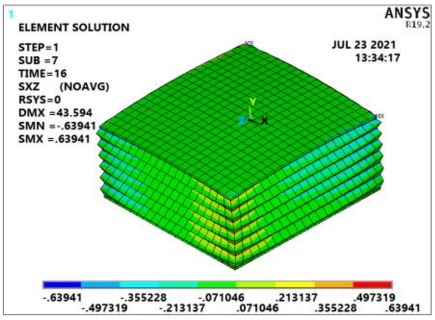


d- Shear stress-strain curve of steel plates

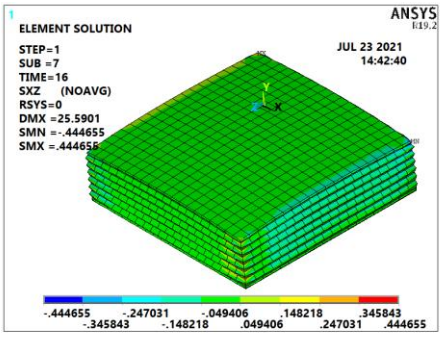


e- Shear stress- strain curve of the elastomer

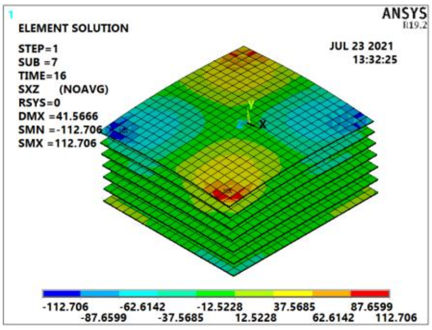
Fig.16 Elastomeric bearing with different shape factor



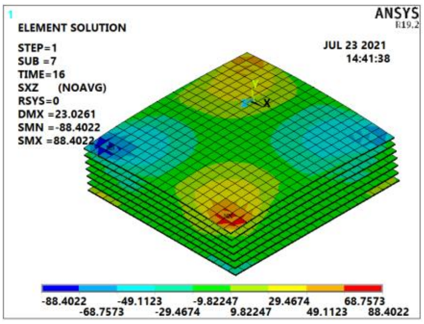
Shear stress of the elastomer with S=3



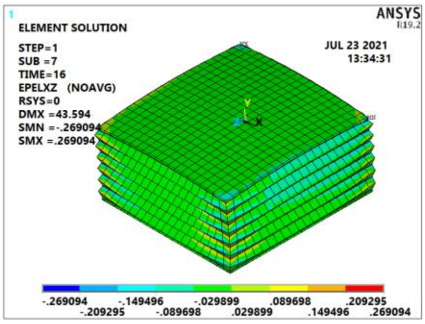
Shear stress of the elastomer with S=6



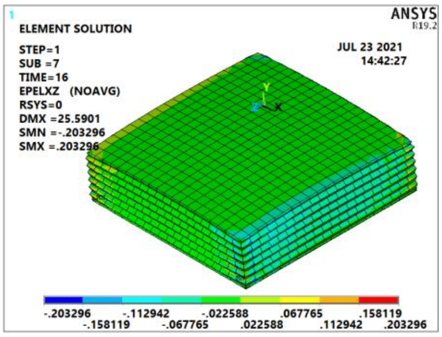
Shear stress of the steel with S=3



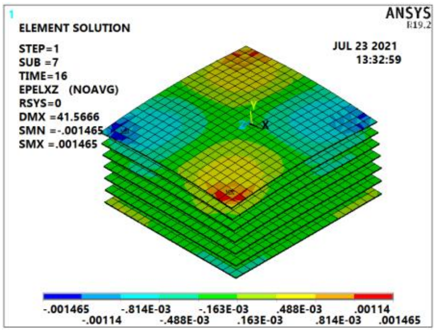
Shear stress of the steel with S=6



Shear strain of the elastomer with S=3



Shear strain of the elastomer with S=6



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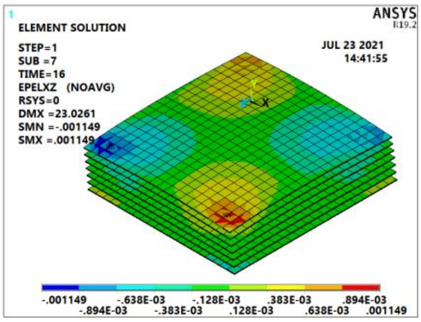
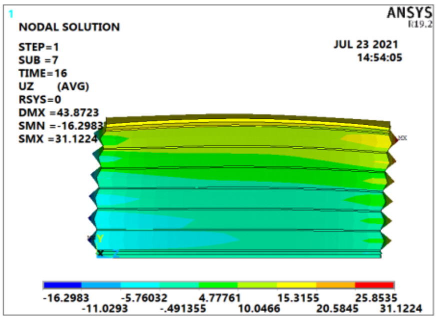
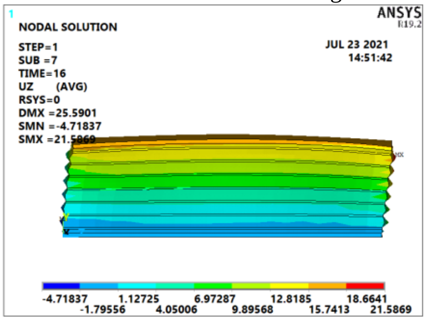


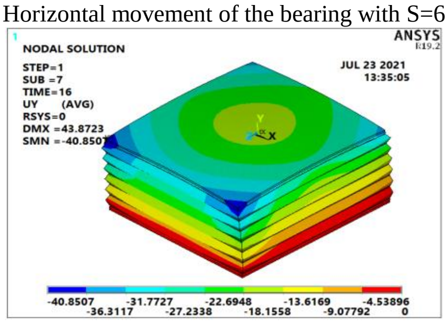
Shear strain of the steel with S=6



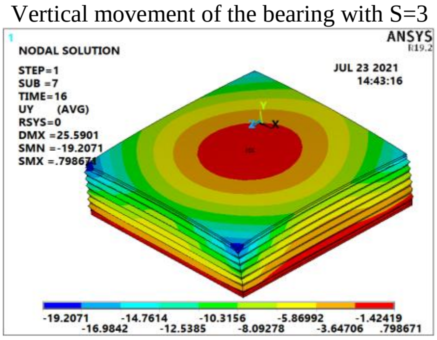
Horizontal movement of the bearing with S=3



Horizontal movement of the bearing with S=6



Vertical movement of the bearing with S=3

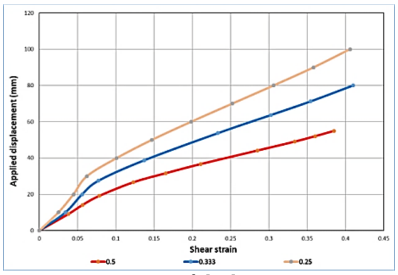


Vertical movement of the bearing with S=6

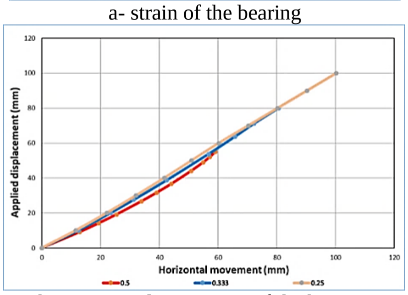
Fig.17 Bearing with different shape factor

Table 8 Reinforced elastomeric bearing with different h/b

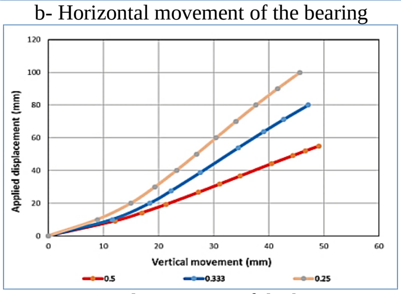
Height/width h/b	*h/b*	*Max displac-ement (mm)*	*Shape factor*	*Shear stress of steel plates (MPa)*	*Shear stress of elastomer (MPa)*	*Shear strain of steel plates*	*Shear strain of elastomer*	*Horizontal movement (mm)*	*Vertical movement (mm)*
250/500	*0.5*	*55*	*3*	*90.107*	*0.949*	*0.00117*	*0.3851*	*59.128*	*49.103*
250/750	*0.33*	*80*	*4.75*	*98.750*	*1.080*	*0.00128*	*0.4098*	*80.593*	*47.188*
250/1000	*0.25*	*100*	*8.47*	*88.879*	*1.008*	*0.00115*	*0.4059*	*100.244*	*45.655*



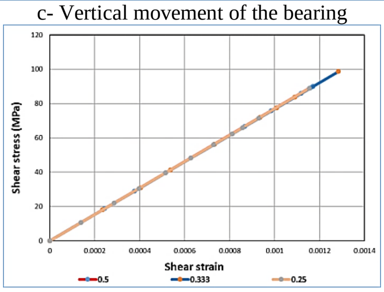
a- strain of the bearing



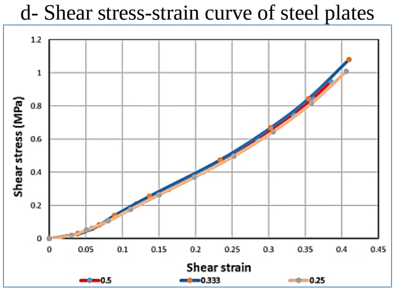
b- Horizontal movement of the bearing



c- Vertical movement of the bearing



d- Shear stress-strain curve of steel plates

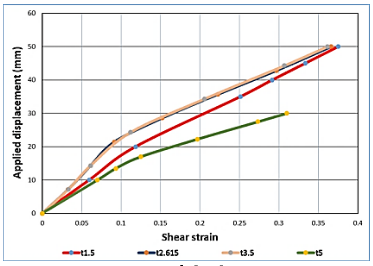


e- Shear stress- strain curve of the elastomer

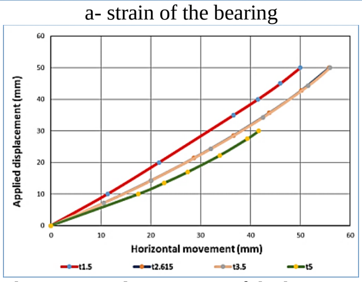
Fig.18 Elastomeric bearing with different h/b

Table 9 Reinforced elastomeric bearing with different thickness of steel shims

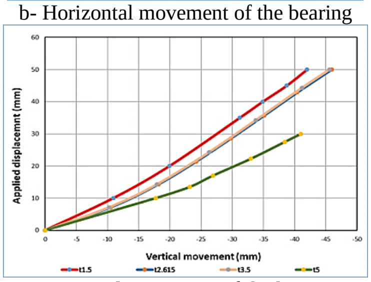
Steel thickness (mm)	*Shape factor*	*Applied displacement (mm)*	*Shear stress of steel plates (Mpa)*	*Shear stress of elastomer (Mpa)*	*Shear strain of steel plates*	*Shear strain of elastomer*	*Horizontal movement (mm)*	*Vertical movement (mm)*
1.5	3	50	151.934	0.780	0.001975	0.370	50.000	41.991
2.615	3	50	89.4980	0.881	0.001163	0.366	55.822	45.948
3.5	3	50	92.5620	0.861	0.001203	0.362	55.987	45.583
5	3	30	101.114	0.722	0.001314	0.310	41.684	41.000



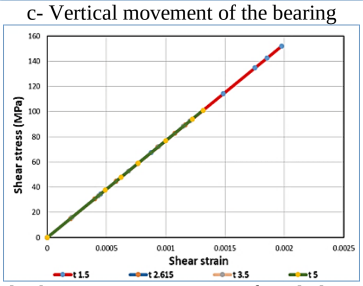
a- strain of the bearing



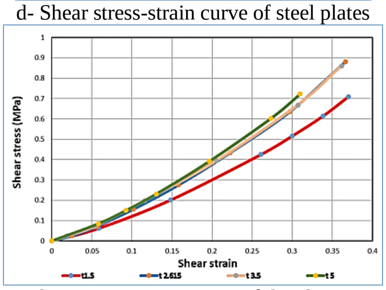
b- Horizontal movement of the bearing



c- Vertical movement of the bearing



d- Shear stress-strain curve of steel plates

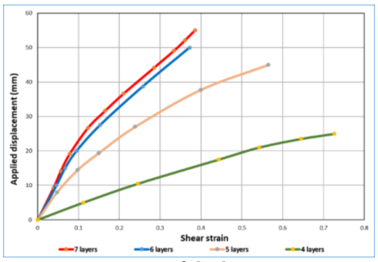


e- Shear stress-strain curve of the elastomer

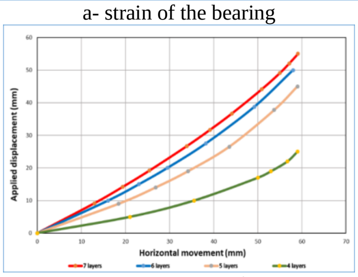
Fig. 19 Elastomeric bearing with different steel thickness

Table 10 Reinforced elastomeric bearing with different number of steel plates

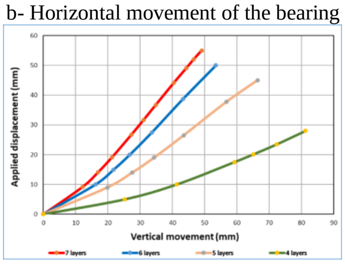
Number of Steel layers	*height of elastomer layer (mm)*	*Shape factor (s)*	*Max Applied displacement (mm)*	*Shear stress of steel plates (MPa)*	*Shear stress of elastomer (MPa)*	*Shear strain of steel plates*	*Shear strain of elastomer*	*Horizontal movement (mm)*	*Vertical movement (mm)*
7	39.5	3	55	90.107	0.9498	0.001171	0.3851	59.128	49.103
6	47.4	2.5	50	87.958	0.9909	0.001143	0.3995	57.253	53.498
5	59.25	2	45	101.15	1.7339	0.001315	0.6174	57.620	66.455
4	79	1.5	25	124.436	2.3724	0.001618	0.7398	55.500	81.284



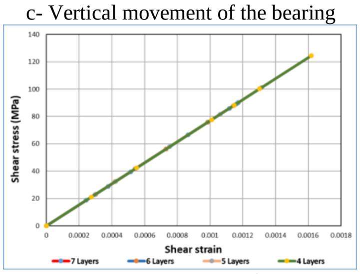
a- strain of the bearing



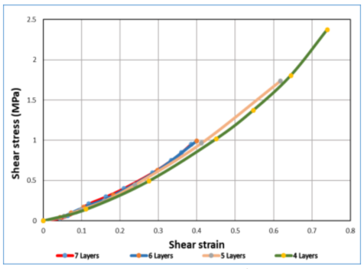
b- Horizontal movement of the bearing



c- Vertical movement of the bearing



d- Shear stress-strain curve of steel plates



e- Shear stress-strain curve of the elastomer

Fig. 20 Elastomeric bearing with different number steel shims

The most advantage of the steel reinforced elastomeric bearings are their relatively small horizontal stiffness in comparison with the axial stiffness. So, the reinforced elastomeric bearing allow the translational deformations through shearing of the elastomer while resisting vertical deformation. In order to increase the horizontal stiffness of the bearing, higher elastomer layer can be used as shown in Table (7) and Figures (15) and (16). In spite of the AASHTO LRFD has specified the horizontal deflection equal to (± 0.5 total elastomer height) but this doesn't apply to all bearings, the Shear deformation that created in the elastomer layers effected by the dimensions, so the elastomer height to the bearing width was studied and it was noticed that the limits of shear deformation can be fulfilled in the case of (h/b =0.25) as shown in Table (8) and Figure (18)

The behavior of an elastomeric bearing depends on the elastomer properties used for its fabrication. For structural applications, most elastomeric bearings are reinforced with steel shims to improve the bearings behavior. The performance of the reinforced elastomeric bearing can be affected by the amount, type, and the reinforcement layout. The purpose behind the use of reinforcement is to provide in-plane stiffness while also controlling the effects of bulging.

From Figure (19) it can be seen that when the steel thickness is increase, it increase the ability of the elastomeric bearing to withstand the horizontal deformation, it can also be seen that the best steel thickness are calculated from equation (5) (hs≥1.8). Figure (19.d) showed that the stress-strain curve of the elastomer and steel increases with increasing the steel thickness. Finally, the effect of varying the number of steel layers on behavior of the bearing was studied, and the results were summarized in Table (10) and Figure (20), where it was showed that the increase in the number of layers leads to the ability of the bearing to withstand higher shear deformation as well as reduce the vertical displacement.

Conclusions

Finite Element Modeling is conducted to examine the basic behaviors of the elastomeric bearings under compression and shear loads, different parameters as shape factor, number of steel layers and steel shim thickness were examined:

1- The results from the verification study of the laminated bearing show acceptable agreement between the results from previous researchs and the Finite Element Modelling results.
2- Under the compression load, the compressive stiffness of the laminated elastomeric bearing is increased by increasing the shape factor. Also, it can be observed that as the elastomer thickness increases then the horizontal and vertical movements will be increased.
3- The elastomeric bearing can withstand larger compressive stress by increase the steel plate thickness, but under the same compressive stress, the steel thickness has very little effect on the strain, vertical displacement and horizontal displacement.
4- To increase the vertical stiffness (K_{comp}) of the reinforced elastomeric bearing, the number of steel layers has to be increased, thus reducing the bulging of the bearing.
5- By studying the ratio of the elastomer height to the bearing width, it was noticed that the limits of shear deformation can be fulfilled in the case of (h/b =0.25).

6- The ability of the elastomeric bearing to withstand the shear deformation can increase by increasing the steel thickness and the number of steel layers, it can also be seen that the best steel thickness is calculated from equation (5) (hs≥1.8).

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