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Finite Element Modelling and Link Element Analysis for Load Behaviour in Elastomeric Bearings: An Approach to Satisfy Design Check

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Abstract: The focus of this study is on the finite element modelling (FEM) and link element analysis of elastomeric bearings to evaluate load behaviour and ensure compliance with design standards. A detailed FEM was developed, incorporating material properties and boundary conditions to simulate the load transfer mechanisms that were provided through link element analysis. The results were validated against design codes and input data from analysis software data, confirming the model's accuracy. A reliable method for optimizing elastomeric bearing design, improving structural safety, and satisfying critical design checks has presented. Total 10 Models taken with its variations and design checks applied over the same with the conclusion of whether it would be suitable or not aiming to improve design practices and address the challenges of modern bridge engineering.
Keywords: Link element, Elastomer, Steel laminates, Bridge, 70R loading, Data validation.

I. INTRODUCTION

Bridge engineering is recognized as a crucial field in infrastructure development, ensuring the safe and efficient movement of people and goods across natural and man-made obstacles. Bridges are subjected to various dynamic loads, including vehicular traffic, wind forces, thermal expansion, and seismic activity. To manage these forces and maintain structural integrity, the use of specialized components, such as bearings, is required. Bearings are employed to allow controlled movement between the bridge superstructure and substructure, while the distribution of loads is managed, minimizing stress on critical elements.

Elastomeric bearings, which are widely used, are designed to handle vertical loads while permitting horizontal movement and rotation. These bearings are composed of alternating layers of rubber (elastomer) and steel shims, allowing vibrations to be absorbed, effects of temperature changes to be mitigated, and deflections due to seismic and wind forces to be accommodated. Their flexible nature provides a cost-effective and low-maintenance solution for various bridge types, including highway and railway bridges.

II. APPLICATION OF ELASTOMERIC BEARING

The application of elastomeric bearings in bridge engineering ensures that smoother load distribution is achieved, the lifespan of the structure is prolonged, and the overall safety and durability of the bridge are enhanced. However, careful consideration of material properties, load conditions, and deformation behaviour has required in their design, making finite element modeling (FEM) an essential tool for analysing and optimizing their performance. By predicting how elastomeric bearings respond to various load scenarios, critical design checks can be satisfied, contributing to the long-term reliability of bridges.

In the figure below, the bridge firstly was supported only on the girder merged to the pier. Then the Elastomeric bearing applied to ROB after re-refection of actual shear forces, bending moment and torsional moment

Fig. 1: Elastomeric bearing used in ROB

III. RESEARCH OBJECTIVES

On keeping in mind the above problem statement outlined for new research work for elastomeric bearing are given below :-

1) To check behavior in the analysis, it is recommended to take different Model cases considering the thickness of each layer of bearing as constant throughout all model cases and changing only bearing pad dimensions as variable.
2) For accuracy in analysis, it has recommended to make the variants of each of the model cases
3) To simulate precisely, it has recommended to use the FEM analysis over each variants.
4) Loading used over the bridge should be highest as per IRC 6:2017.
5) For the stability in the simulation, it has suggested that to conduct different design checks for the values obtained as per the output parameters decided.
6) At last, in the research, the most stable cases list after passing the design tests can be taken into account that provides the recommendations that will made a feasible construction reference.

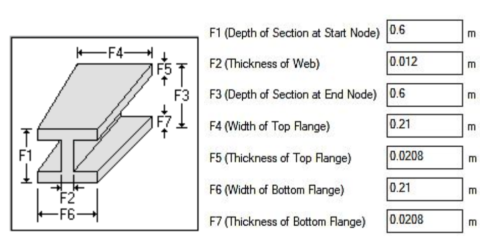
IV. 3D MODELLING OF THE STRUCTURE

Comprehensive input data and its descriptions about the model given below. The input data used for creation of elastomeric bearing using link element using general data and loading data have shown below:-

Table 1: Loading data used for all model cases

Constraint	Data used for all cases
IRC loading	70R
Vehicle width	2.79 m
Dead load	Self-Weight

Table 2: General input data used for all model cases

Constraint	Data used for all cases
Deck Span length	12m
Deck width	5m
Deck Span thickness	300mm
Transverse girder properties	500 mm x 300 mm
Number of plate meshing	10 x 10
Longitudinal girder properties	Beam selected = tapered I section
	Property used = Steel section
	
Concrete & Rebar grade	M30 & FE 500
Shear Modulus (G)	0.9 N/sq. mm (IRC 83, Table 1)
Modulus of Elasticity of Elastomer (E)	617263 KG/sq. m (from Ref. paper 1)

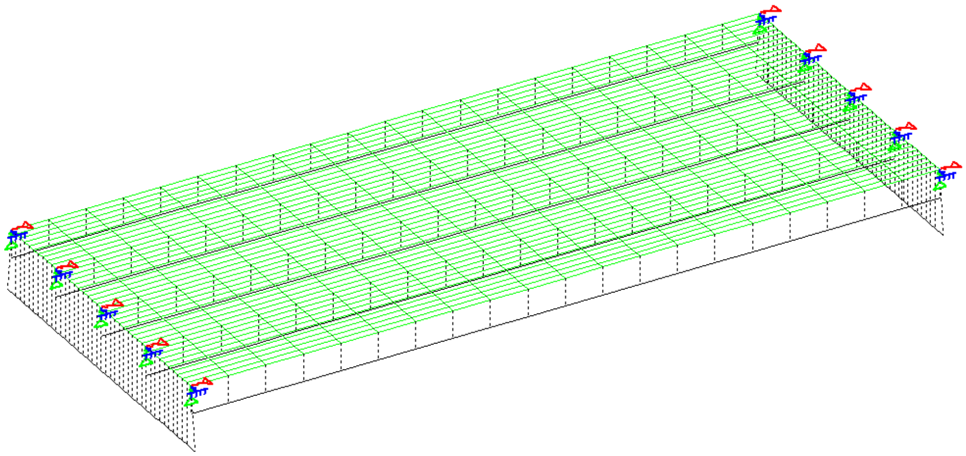


Fig. 2: Plan view of bridge

Table 3: Various model cases used for analysis with subsequent variant and its configuration

Models framed for analysis	Abbreviation	Subsequent variant	Variant Configuration
Bridge deck supported over laminated elastomeric bearing with effective area of 160mm x 250mm	Model 1	EB1A	1E, 2O, 2S
		EB1B	2E, 2O, 3S
		EB1C	3E, 2O, 4S
		EB1D	4E, 2O, 5S
Bridge deck supported over laminated elastomeric bearing with effective area of 160mm x 320mm	Model 2	EB2A	1E, 2O, 2S
		EB2B	2E, 2O, 3S
		EB2C	3E, 2O, 4S
		EB2D	4E, 2O, 5S
Bridge deck supported over laminated elastomeric bearing with effective area of 200mm x 320mm	Model 3	EB3A	1E, 2O, 2S
		EB3B	2E, 2O, 3S
		EB3C	3E, 2O, 4S
		EB3D	4E, 2O, 5S
Bridge deck supported over laminated elastomeric bearing with effective area of 200mm x 400mm	Model 4	EB4A	1E, 2O, 2S
		EB4B	2E, 2O, 3S
		EB4C	3E, 2O, 4S
		EB4D	4E, 2O, 5S
Bridge deck supported over laminated elastomeric bearing with effective area of 250mm x 400mm	Model 5	EB5A	1E, 2O, 2S
		EB5B	2E, 2O, 3S
		EB5C	3E, 2O, 4S
		EB5D	4E, 2O, 5S
Bridge deck supported over laminated elastomeric bearing with effective area of 250mm x 500mm	Model 6	EB6A	1E, 2O, 2S
		EB6B	2E, 2O, 3S
		EB6C	3E, 2O, 4S
		EB6D	4E, 2O, 5S
Bridge deck supported over laminated elastomeric bearing with effective area of 320mm x 500mm	Model 7	EB7A	1E, 2O, 2S
		EB7B	2E, 2O, 3S
		EB7C	3E, 2O, 4S
		EB7D	4E, 2O, 5S
		EB7E	5E, 2O, 6S
Bridge deck supported over laminated elastomeric	Model 8	EB8A	1E, 2O, 2S

bearing with effective area of 320mm x 630mm		EB8B	2E, 2O, 3S
		EB8C	3E, 2O, 4S
		EB8D	4E, 2O, 5S
		EB8E	5E, 2O, 6S
Bridge deck supported over laminated elastomeric bearing with effective area of 320mm x 630mm	Model 9	EB9A	1E, 2O, 2S
		EB9B	2E, 2O, 3S
		EB9C	3E, 2O, 4S
		EB9D	4E, 2O, 5S
		EB9E	5E, 2O, 6S
Bridge deck supported over laminated elastomeric bearing with effective area of 400mm x 800mm	Model 10	EB10A	1E, 2O, 2S
		EB10B	2E, 2O, 3S
		EB10C	3E, 2O, 4S
		EB10D	4E, 2O, 5S
		EB10E	5E, 2O, 6S
		EB10F	6E, 2O, 7S

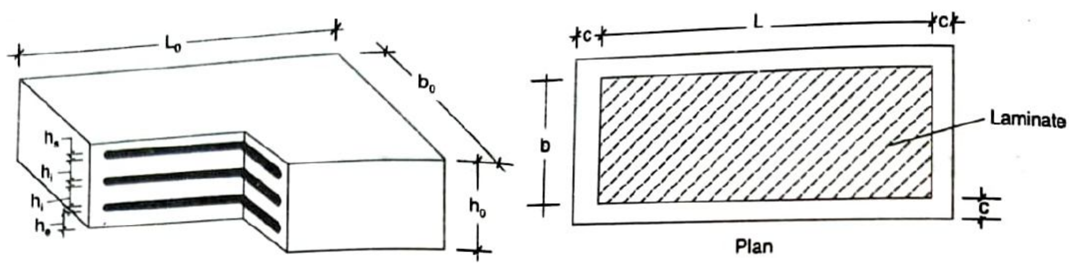
Here,
EB = Elastomeric Bearing,
9A = Variant A for model number 9
1E = 1 Elastomeric sheet layer
2O = 2 Outer Elastomeric layer
2S = 2 Steel laminate layer

V. DESIGN CHECK PROCEDURE OF BEARING AS PER IRC 83

The procedure followed to observe whether the bearing created by link element has safe to resist from failure mentioned below:-

Laminated Elastomeric Bearing Design

Max. DL Reaction per bearing	DL		KN	input value
Max. LL Reaction per bearing	LL		KN	input value
Longitudenal force due to friction per bearing	f		KN	input value
Effective span of girder	span length		m	input value
Shear strain due to creep, shrinkage and temp.	shear strain		mm/mm	
Concrete Grade	Fck		N/sq. mm	input value



(I) Selection of bearing pad dimensions

Maximum vertical load	Nmax		KN	answer
Minimum vertical load	Nmin		KN	From IRC 83, Appendix I
Plan dimentions of bearing selection	b		mm	From IRC 83, Appendix I
	L		mm	From IRC 83, Appendix I
Loaded area	A2		sq. mm	From IRC 83, Appendix I
Allowable contact pressure	σ c		N/sq. mm	answer
Effective area of bearing	Aeff.		sq. mm	answer

Value < Value
Hence ok safe !!

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Bearing stress	αm		N/sq. mm	answer		
Taking different thickness of individual layers						
(a) Elastomeric Layers	hi		x		mm	From IRC 83, 916.3.3, pno. 10
(b) Thickness of outer layer	he		x		mm	From IRC 83, 916.3.3, pno. 10
(c) Thickness of steel laminates	hs		x		mm	From IRC 83, 916.3.3, pno. 10
Side covering	c		mm			From IRC 83, 916.2.2, pno. 9
Overall Thickness	ho		mm	answer		
Shape factor						
It should be greater than 6 and less than 12	S			answer		
	Value	>	Value	<	Value	
	Hence ok safe !!		From IRC 83, 916.3.3, pno. 10			

(II) Shear strain due to creep, shrinkage and temperature

	γcst		From IRC 83, 916.3.4, pno. 10

(III) Shear strain due to transational moment

	γd		answer	
		Value	<	0.7
	Hence ok safe !!		From IRC 83, 916.3.4, pno. 10	

(IV) Permissible rotation

	σ m		N/sq. mm	From IRC 83, 916.3.5, pno. 10
	$\alpha_{bi\ max}$		radians	answer
	β		N/sq. mm	answer
no. of internal layers	n		nos.	answer
Permissible rotation	α_d	Value	>	Value
	Hence ok safe !!		From IRC 83:2018, 5.1.3.6, pno. 17	

(V) Shear strain due to friction

	γf			
		Value	>	Value
	Hence ok safe !!		From IRC 83, 916.3.6, pno. 11	
		and		
	Value	≥	Value	≥ Value
	Hence ok safe !!		From IRC 83, 916.3.3, pno. 10	

(VI) Total shear stress

(a) Due to compression		N/sq. mm		
(b) Due to horizontal deformation		N/sq. mm		
(c) Due to rotation		N/sq. mm		
Total shear stress		N/sq. mm		
	Value	<	Value	and < 7 , From IRC 83:2018, 5.1.3.(a)
Hence ok safe !!		From IRC 83, 916.3.7, pno. 11		

Check for Bearing (Pass/Fail)			
(I) Selection of bearing pad dimensions	Value	<	Value
(II) Shear strain due to creep, shrinkage and temperature	Value	<	Value
(III) Shear strain due to transational moment	Value	<	Value
(IV) Permissible rotation	Value	>	Value
(V) Shear strain due to friction	Value	>	Value
(VI) Total shear stress	Value	<	Value

Fig. 3: Sample of different checks conducted for model

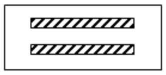
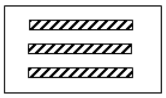
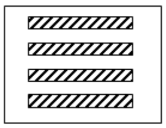
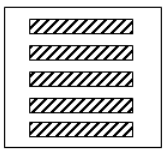
VI. RESULTS AND DISCUSSION

Though our result analysis consists Total 10 distinct model cases and each having different variants of elastomeric bearing cases. The result analysis approach allowed us to observe a range of outcomes for each case within the structure since different variants shows different behaviour under 70R loading. As a result of this comparative analysis, we obtained subsequent findings for the mentioned cases provided below:-

Table 4: Result analysis for various models with notes

Results for Model 1

On analyzing Model EB1A, EB1B, EB1C and EB1D all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.

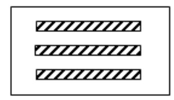
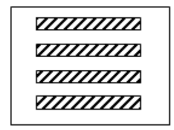
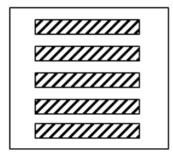
Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 1	160 x 250		A	1 elastomeric layer 2 outer layers 2 steel laminates	Fail
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Fail
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Fail
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Fail

Model Notes

Area of 160 x 250 is restricted for 70R loading used in analysis

Results for Model 2

On analyzing Model EB2A, EB2B, EB2C and EB2D all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.

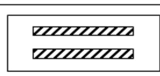
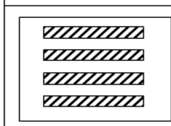
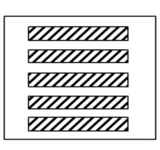
Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 2	160 x 320		A	1 elastomeric layer 2 outer layers 2 steel laminates	Fail
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Fail
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Fail
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Fail

Model Notes

Area of 160 x 320 is restricted for 70R loading used in analysis

Results for Model 3

On analyzing Model EB3A, EB3B, EB3C and EB3D all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.

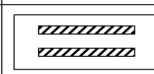
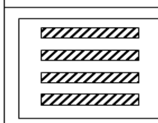
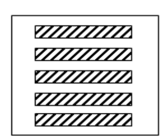
Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 3	200 x 320		A	1 elastomeric layer 2 outer layers 2 steel laminates	Fail
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Fail
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Fail
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Fail

Model Notes

Area of 200 x 320 is restricted for 70R loading used in analysis

Results for Model 4

On analyzing Model EB4A, EB4B, EB4C and EB4D all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.

Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 4	200 x 400		A	1 elastomeric layer 2 outer layers 2 steel laminates	Fail
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Fail
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Fail
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Fail

Model Notes

Area of 200 x 400 is restricted for 70R loading used in analysis

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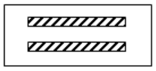
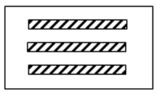
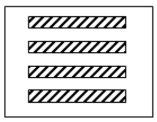
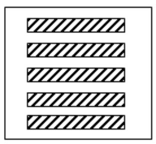
Results for Model 5

On analyzing Model EB5A, EB5B, EB5C and EB5D all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.

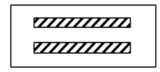
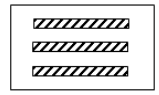
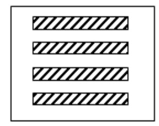
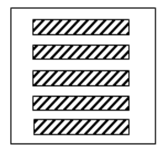
Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 5	250 x 400		A	1 elastomeric layer 2 outer layers 2 steel laminates	Fail
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Fail
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Fail
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Fail

Model Notes

Area of 250 x 400 is restricted for 70R loading used in analysis

Results for Model 6

On analyzing Model EB6A, EB6B, EB6C and EB6D all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.

Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 6	250 x 500		A	1 elastomeric layer 2 outer layers 2 steel laminates	Fail
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Fail
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Fail
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Fail

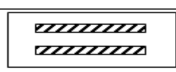
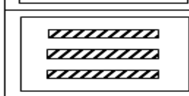
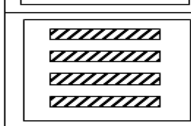
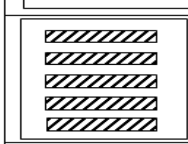
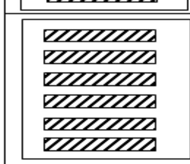
Model Notes

Area of 250 x 500 is restricted for 70R loading used in analysis

Results for Model 7

On analyzing Model EB7A, EB7B and EB7E all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.

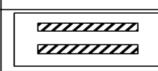
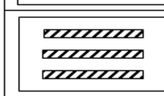
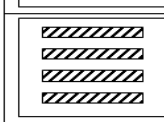
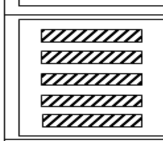
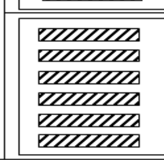
On analyzing Model EB7C and EB7D, all 6 different checks for elastomeric bearing by IRC 83 have performed and are within the limit and hence passed.

Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 7	320 x 500		A	1 elastomeric layer 2 outer layers 2 steel laminates	Fail
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Fail
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Pass
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Pass
			E	4 elastomeric layer 2 outer layers 5 steel laminates	Fail

Results for Model 8

On analyzing Model EB8A and EB8E, all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.

On analyzing Model EB8B, EB8C and EB8D all 6 different checks for elastomeric bearing by IRC 83 have performed and are within the limit and hence passed.

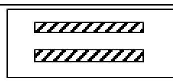
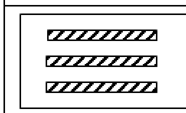
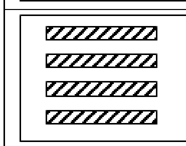
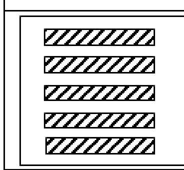
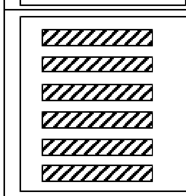
Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 8	320 x 630		A	1 elastomeric layer 2 outer layers 2 steel laminates	Fail
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Pass
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Pass
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Pass
			E	5 elastomeric layer 2 outer layers 6 steel laminates	Fail

<u>Model Notes</u>
Area of 320 x 500 is used in analysis
Minimum no. of steel laminates can be used = 4
Maximum no. of steel laminates can be used = 5
Minimum no. of elastomeric layer can be used = 3
Maximum no. of elastomeric layer can be used = 4
Use of overall thickness 52 mm to 65 mm is permissible with 5mm side covering.

<u>Model Notes</u>
Area of 320 x 630 is used in analysis
Minimum no. of steel laminates can be used = 3
Maximum no. of steel laminates can be used = 5
Minimum no. of elastomeric layer can be used = 2
Maximum no. of elastomeric layer can be used = 4
Use of overall thickness 39 mm to 78 mm is permissible with 5mm side covering.

Results for Model 9

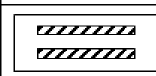
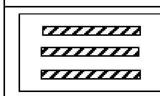
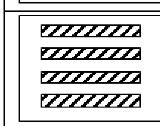
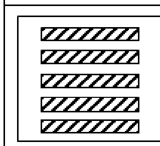
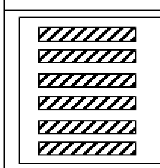
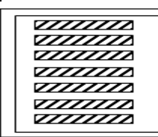
On analyzing Model EB9A and EB9E, all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.
On analyzing Model EB9B, EB9C and EB9D all 6 different checks for elastomeric bearing by IRC 83 have performed and are within the limit and hence passed.

Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 9	400 x 630		A	1 elastomeric layer 2 outer layers 2 steel laminates	Fail
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Pass
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Pass
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Pass
			E	5 elastomeric layer 2 outer layers 6 steel laminates	Fail

<u>Model Notes</u>
Area of 400 x 630 is used in analysis
Minimum no. of steel laminates can be used = 3
Maximum no. of steel laminates can be used = 5
Minimum no. of elastomeric layer can be used = 2
Maximum no. of elastomeric layer can be used = 4
Use of overall thickness 26 mm to 65 mm is permissible with 5mm side covering.

Results for Model 10

On analyzing Model EB10A, EB10B, EB10C, EB10D and EB10E all 6 different checks for elastomeric bearing by IRC 83 have performed and are within the limit and hence passed.
On analyzing Model EB10F, all 6 different checks for elastomeric bearing by IRC 83 have performed and are not within the limit and hence failed.

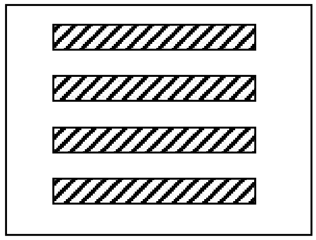
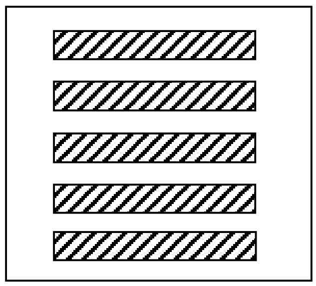
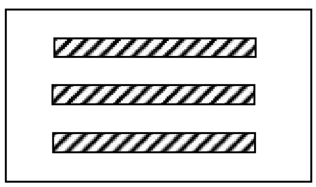
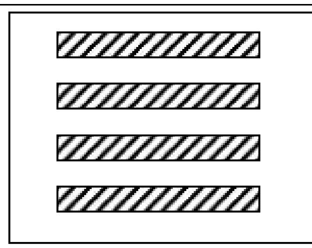
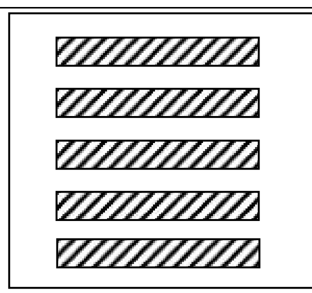
Model (Under 70R Loading)	Area	Thickness figure		Thickness configuration	Pass/Fail
Model 10	400 x 800		A	1 elastomeric layer 2 outer layers 2 steel laminates	Pass
			B	2 elastomeric layer 2 outer layers 3 steel laminates	Pass
			C	3 elastomeric layer 2 outer layers 4 steel laminates	Pass
			D	4 elastomeric layer 2 outer layers 5 steel laminates	Pass
			E	5 elastomeric layer 2 outer layers 6 steel laminates	Pass
			F	6 elastomeric layer 2 outer layers 7 steel laminates	Fail

<u>Model Notes</u>
Area of 400 x 800 is used in analysis
Minimum no. of steel laminates can be used = 2
Maximum no. of steel laminates can be used = 6
Minimum no. of elastomeric layer can be used = 1
Maximum no. of elastomeric layer can be used = 5
Use of overall thickness 26 mm to 78 mm is permissible with 5mm side covering.

VII. CONCLUSIONS

This project concluded that the simulation for 70R loading on different elastomeric pad dimensions, comparing each model having each variants, some model variants are failed but some are passed. Details of recommended variants are mentioned below:-

Table 5: Passed models recommendation

Model (Under 70R Loading)	Area	Thickness figure	Thickness configuration		Passed models
Model 7	320 x 500		C	3 elastomeric layer	Pass
				2 outer layers	
				4 steel laminates	
Model 7	320 x 500		D	4 elastomeric layer	Pass
				2 outer layers	
				5 steel laminates	
Model 8	320 x 630		B	2 elastomeric layer	Pass
				2 outer layers	
				3 steel laminates	
Model 8	320 x 630		C	3 elastomeric layer	Pass
				2 outer layers	
				4 steel laminates	
Model 8	320 x 630		D	4 elastomeric layer	Pass
				2 outer layers	
				5 steel laminates	

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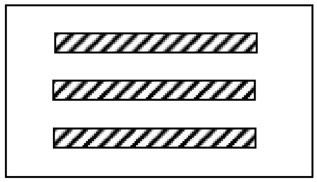
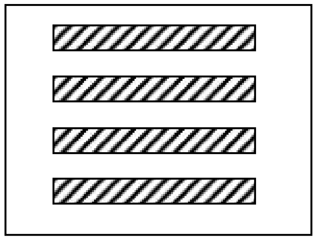
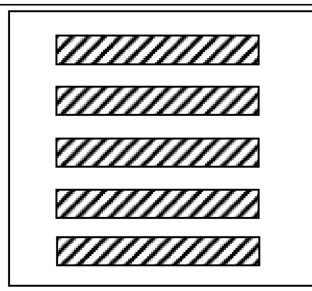
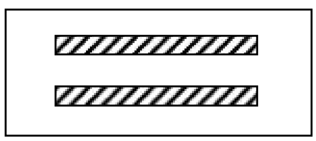
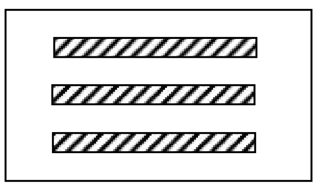
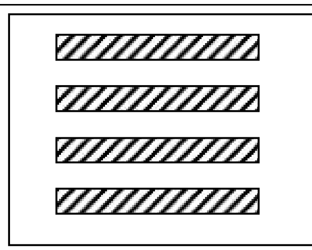
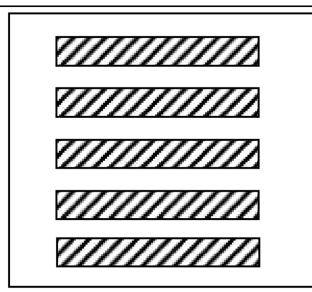
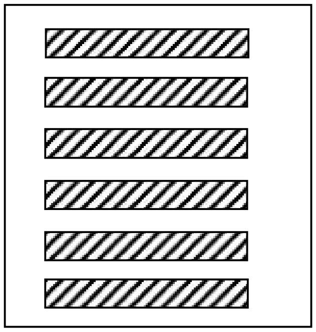
Model 9	400 x 630		B	2 elastomeric layer 2 outer layers 3 steel laminates	Pass
Model 9	400 x 630		C	3 elastomeric layer 2 outer layers 4 steel laminates	Pass
Model 9	400 x 630		D	4 elastomeric layer 2 outer layers 5 steel laminates	Pass
Model 10	400 x 800		A	1 elastomeric layer 2 outer layers 2 steel laminates	Pass
Model 10	400 x 800		B	2 elastomeric layer 2 outer layers 3 steel laminates	Pass
Model 10	400 x 800		C	3 elastomeric layer 2 outer layers 4 steel laminates	Pass
Model 10	400 x 800		D	4 elastomeric layer 2 outer layers 5 steel laminates	Pass

Model 10	400 x 800		E	5 elastomeric layer 2 outer layers 6 steel laminates	Pass

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