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Evaluation of Load Response in Elastomeric Bearings Through Link Element and Finite Element Modelling

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Abstract: The Finite element modeling (FEM) and link element analysis of elastomeric bearings were conducted in this study to evaluate load behaviour and ensure compliance with design standards. A detailed FEM was developed, where material properties and boundary conditions were incorporated to simulate load transfer mechanisms, which were enhanced through link element analysis. Validation of results was performed against design codes and analysis software data, confirming the model's accuracy. A reliable method for optimizing elastomeric bearing design, improving structural safety, and meeting essential design checks was presented. Ten models in total were analyzed with variations, firstly the models were selected as per the design checks criteria. Then selected parameter's output values are compared with each passed model case and then to finalize the research conducted, the data validation table has created with providing recommendations to show the suitability, aiming to improve design practices and address challenges in modern bridge engineering.
Keywords: Link element, Elastomer, Steel laminates, Bridge, 70R loading, Data validation.

I. INTRODUCTION - ELASTOMERIC BEARING

The field of bridge engineering is recognized as vital in infrastructure expansion, where the safe and efficient movement of people and goods across natural and man-made obstacles is ensured. Various dynamic loads, including vehicular traffic, wind forces, thermal expansion, and seismic activity, are experienced by bridges. To manage these forces and maintain structural integrity, specialized components, such as bearings, are required. Controlled movement between the bridge superstructure and substructure is allowed by bearings, and load distribution is managed to minimize stress on critical elements. Generally used elastomeric bearings 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, the effects of temperature changes to be mitigated, and deflections due to seismic and wind forces to be accommodated. A cost-effective and low-maintenance solution is provided by their flexible nature for various bridge types.

II. APPLICATION OF BEARING USING LINK ELEMENT ANALYSIS

The application of elastomeric bearings in bridge simulation is very difficult since it has not been possible for any analysis software that can analyse the layers between the Elastomeric bearing and its behaviour.

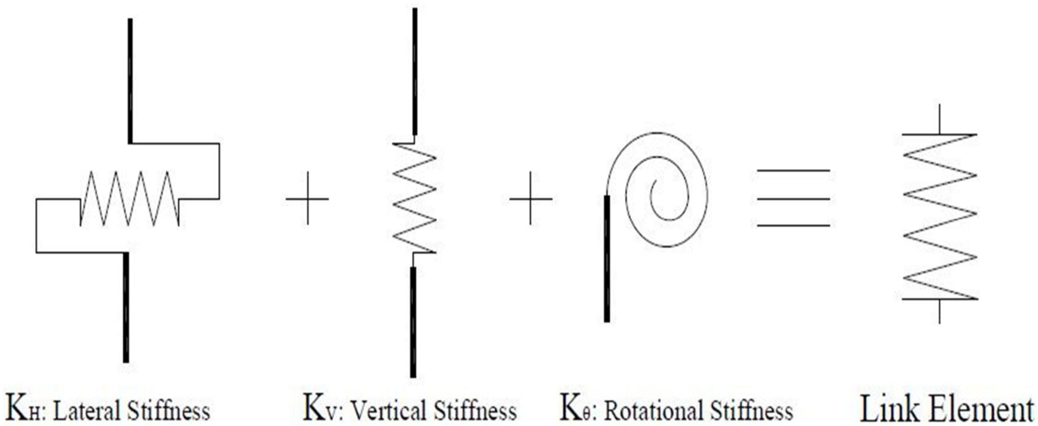

Fig. 1: Link elements used to perform the simulation

Figure 1 shown above is the analysis method to perform the elastomeric bearing simulation known as link element analysis, consist of lateral stiffness, vertical stiffness and rotational stiffness. Link element analysis allows for a more accurate representation of the load paths in elastomeric bearings by accounting for specific points of force transfer that are crucial for realistic load distribution in the model. By integrating this analysis into FEM, it refines the load behaviour simulation, leading to more precise predictions of performance under various loading conditions.

III. RESEARCH OBJECTIVES

On keeping in mind the above problem statement outlined for new research work for elastomeric bearing, the first and foremost thing is 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. Then for accuracy in analysis, it has recommended to make the variants of each of the model cases. To simulate precisely, it has recommended to use the FEM analysis over each variants with loading used over the bridge should be highest as per IRC 6:2017. The current research has to pass through different design checks for the values obtained as per the output parameters decided. Then, the most stable cases list after passing the design tests can be taken into account that provides the recommendations that will make a feasible construction reference. Then the determination of output parameters for nodal behaviour like nodal displacement and DL and LL reactions, plate behaviour like maximum shear forces, bending moment and stresses in plate members and longitudinal girder behaviour like shear forces, bending moment and torsional moment as per simulation performed. Finally, to create the data validation table as per selected recommendation models using different output parameters.

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 applied to the structure such that the Vehicle width has taken as 2.79m along with dead load as self-weight and live load taken as IRC class 70R according to IRC 6:2017. The general data taken such as deck width has taken as 5m with deck span length of 12m respectively. The thickness of the deck has taken as 300mm, transverse girder properties has taken as 500mm x 300mm. The FEM analysis has taken into consideration while detailing the input parameter of the structure as quadrilateral type of meshing of 10 x 10 size. Beam taken as I section of material structural steel of taper in nature. M30 grade of concrete and FE 500 steel with shear modulus taken as 0.9N/sq. mm as per IRC 83, Table 1 and Modulus of Elasticity of Elastomer (E) has taken as 617263 KG/sq. m.

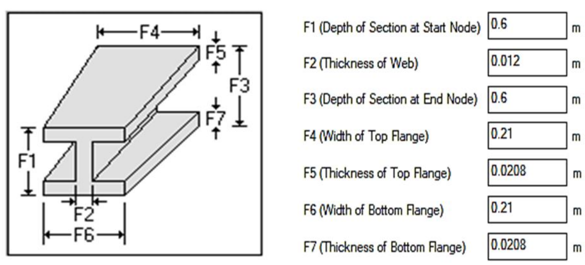

Fig. 2: Cross section of tapered I section with its physical dimention

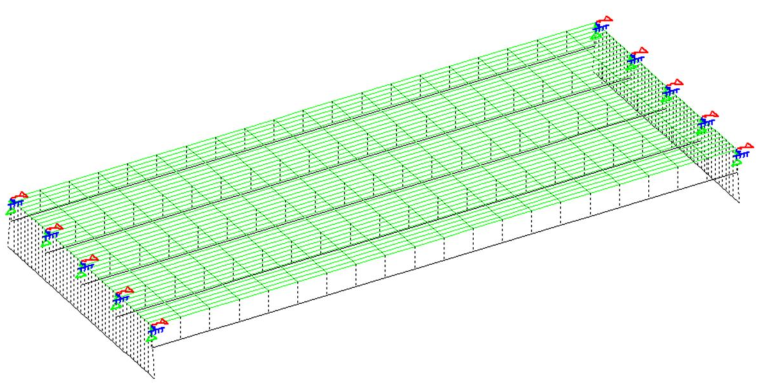

Fig. 3: Plan view of bridge

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Table 1: 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 bearing with effective area of 320mm x 630mm	Model 8	EB8A	1E, 2O, 2S
		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

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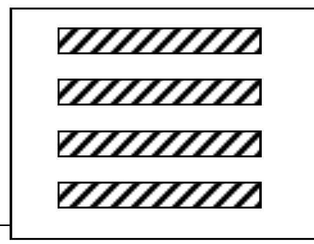
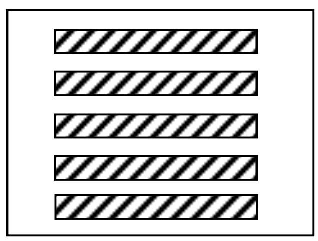
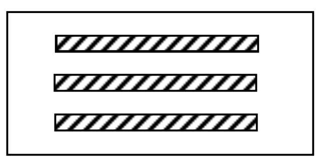
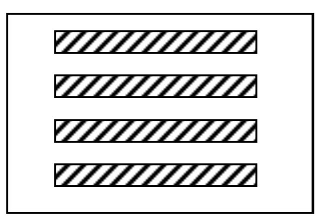
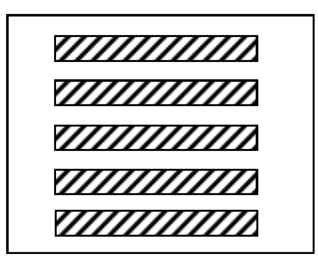
Here,	
EB = Elastomeric Bearing,	
9A = Variant A for model number 9	2O = 2 Outer Elastomeric layer
1E = 1 Elastomeric sheet layer	2S = 2 Steel laminate layer

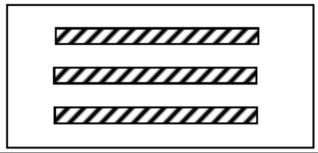
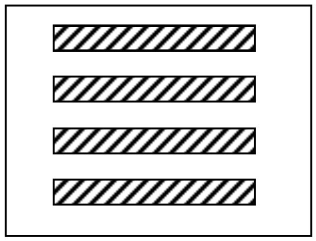
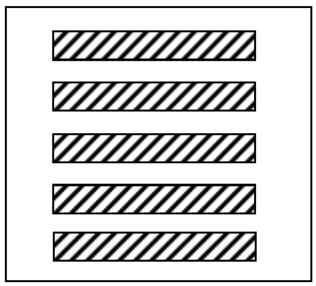
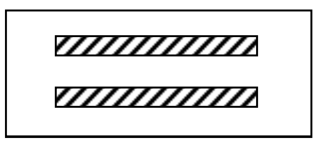
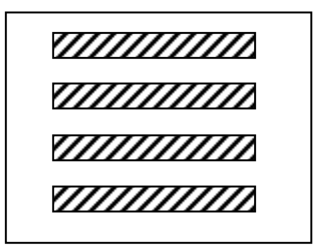
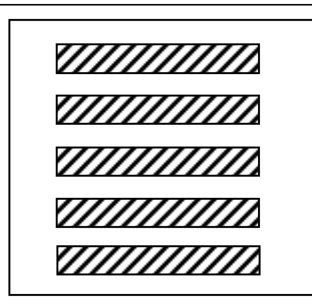
V. RESULTS AND DISCUSSION

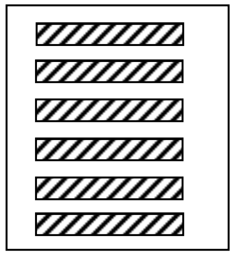
- **Design checks applied to bearing as per IRC 83:**

This project started with 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 passed variants are mentioned below:-

Table 2: 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	

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

VI. CONCLUSIONS

This project concluded that the simulation for 70R loading on different elastomeric pad dimensions, comparing each model having different variants. The passed models are taken into consideration and compared them with respect of various parameters. Details of recommended variants are mentioned from table 3 to table 8 below:-

Table 3: Data validation table using displacement

Case	Maximum displacement		
	For X Direction (mm)	For Y Direction (mm)	For Z Direction (mm)
EB7C	0.124	4.174	0.075
EB7D	0.128	4.354	0.074
EB8B	0.118	3.903	0.074
EB8C	0.122	4.066	0.074
EB8D	0.126	4.223	0.074
EB9B	0.117	3.857	0.073
EB9C	0.121	4.006	0.073
EB9D	0.124	4.151	0.073
EB10A	0.112	3.655	0.072
EB10B	0.115	3.788	0.073
EB10C	0.119	3.918	0.073
EB10D	0.122	4.044	0.073
EB10E	0.125	4.167	0.073

Table 4: Data validation table using dead load support reactions

Case	Maximum dead load support reactions					
	Fx (KN)	Fy (KN)	Fz (KN)	Mx (KNm)	My (KNm)	Mz (KNm)
EB7C	0.063	67.476	0.073	Values not to be used	Values not to be used	105.129
EB7D	0.045	66.677	0.058			102.559
EB8B	0.12	68.616	0.12			109.071
EB8C	0.083	68.042	0.091			106.639
EB8D	0.061	67.398	0.073			104.334
EB9B	0.151	68.743	0.148			109.69
EB9C	0.105	68.365	0.112			107.426
EB9D	0.078	67.873	0.089			105.265
EB10A	0.310	70.251	0.276			112.732
EB10B	0.196	68.79	0.186			110.696
EB10C	0.139	68.617	0.141			108.718
EB10D	0.104	68.297	0.113			106.81
EB10E	0.081	67.907	0.094			104.979

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Table 5: Data validation table using live load support reactions

<table>
<tr><th rowspan="2">Case</th><th colspan="6">Maximum live load support reactions</th></tr>
<tr><th>Fx (KN)</th><th>Fy (KN)</th><th>Fz (KN)</th><th>Mx (KNm)</th><th>My (KNm)</th><th>Mz (KNm)</th></tr>
<tr><td>EB7C</td><td>0.235</td><td>201.668</td><td>0.267</td><td rowspan="13">Values not to be used</td><td rowspan="13">Values not to be used</td><td>386.207</td></tr>
<tr><td>EB7D</td><td>0.167</td><td>198.197</td><td>0.213</td><td>376.258</td></tr>
<tr><td>EB8B</td><td>0.455</td><td>209.742</td><td>0.447</td><td>402.098</td></tr>
<tr><td>EB8C</td><td>0.313</td><td>205.076</td><td>0.335</td><td>392.148</td></tr>
<tr><td>EB8D</td><td>0.228</td><td>201.498</td><td>0.267</td><td>383.055</td></tr>
<tr><td>EB9B</td><td>0.577</td><td>212.9</td><td>0.553</td><td>404.713</td></tr>
<tr><td>EB9C</td><td>0.400</td><td>208.212</td><td>0.415</td><td>395.285</td></tr>
<tr><td>EB9D</td><td>0.294</td><td>204.563</td><td>0.331</td><td>386.64</td></tr>
<tr><td>EB10A</td><td>1.193</td><td>222.518</td><td>1.037</td><td>418.425</td></tr>
<tr><td>EB10B</td><td>0.753</td><td>216.437</td><td>0.697</td><td>409.095</td></tr>
<tr><td>EB10C</td><td>0.53</td><td>211.82</td><td>0.524</td><td>400.605</td></tr>
<tr><td>EB10D</td><td>0.396</td><td>208.157</td><td>0.418</td><td>392.776</td></tr>
<tr><td>EB10E</td><td>0.306</td><td>205.156</td><td>0.347</td><td>385.486</td></tr>
</table>

Table 6: Data validation table using shear and bending in plates

Case	Maximum shear and bending in plates			
	SQx (N/sq. mm)	SQy (N/sq. mm)	Mx (KNm/m)	My (KNm/m)
EB7C	1.051	0.207	45.273	30.066
EB7D	1.062	0.208	44.979	30.281
EB8B	1.029	0.203	45.654	8.808
EB8C	1.042	0.206	45.396	29.923
EB8D	1.054	0.207	45.167	30.125
EB9B	1.023	0.201	45.9	29.618
EB9C	1.037	0.204	45.429	29.836
EB9D	1.048	0.206	45.23	30.029
EB10A	1.002	0.194	47.129	29.288
EB10B	1.016	0.199	46.299	29.508
EB10C	1.029	0.202	45.539	29.706
EB10D	1.039	0.204	45.357	29.884
EB10E	1.048	0.205	45.179	30.045

Table 7: Data validation table using shear and bending in plates

Case	Maximum shear and bending in plates			
	SQx (N/sq. mm)	SQy (N/sq. mm)	Mx (KNm/m)	My (KNm/m)
EB7C	1.051	0.207	45.273	30.066
EB7D	1.062	0.208	44.979	30.281
EB8B	1.029	0.203	45.654	8.808
EB8C	1.042	0.206	45.396	29.923
EB8D	1.054	0.207	45.167	30.125
EB9B	1.023	0.201	45.9	29.618
EB9C	1.037	0.204	45.429	29.836
EB9D	1.048	0.206	45.23	30.029
EB10A	1.002	0.194	47.129	29.288
EB10B	1.016	0.199	46.299	29.508
EB10C	1.029	0.202	45.539	29.706
EB10D	1.039	0.204	45.357	29.884
EB10E	1.048	0.205	45.179	30.045

Table 8: Data validation table using shear forces, bending moment and torsional moment in longitudinal girder

Case	Maximum Shear Forces (KN)	Maximum Bending Moment (KNm)	Maximum Torsional Moment (KNm)
EB7C	179.616	143.511	0.016
EB7D	179.557	142.307	0.016
EB8B	179.708	144.816	0.016
EB8C	179.649	144.04	0.016
EB8D	179.595	143.094	0.016
EB9B	179.719	144.88	0.016
EB9C	179.663	144.214	0.016
EB9D	179.612	143.389	0.016
EB10A	179.793	145.357	0.016
EB10B	179.741	145.054	0.016
EB10C	179.691	144.563	0.016
EB10D	179.645	143.935	0.016
EB10E	179.602	143.202	0.016

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