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Seismic Control of a Concrete Bridge with Hybrid Passive Control Devices

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Abstract: This study focuses on the seismic response of a three-span deck slab RCC T-Girder bridge with and without LRB (Lead Rubber Bearing) and in combination with LRB and FVD (Fluid Viscous Damper). The bridge is subjected to AASHTO, IRC design standards, and IRC Class A vehicle load. Linear time history analysis using CsiBridge and SAPfire is conducted to assess the bridge's seismic behavior. Excessive deck displacement, which can lead to deck failure and bridge closure, is a key concern. The study utilizes finite element analysis with Csibridge and incorporates viscous dampers throughout the bridge. The findings show that the presence of supplemental dampers significantly reduces pier top displacements. Base shear, deck displacement, pier response, and structural time period are the primary response parameters examined. The effectiveness of different isolation system configurations is compared to the non-isolated bridge in terms of these response characteristics. The study offers suggestions for design improvements to enhance the structure's performance.
Keywords: RCC T-Girder bridge, LRB and FVD, CSiBridge software, IRC class vehicle, Ground Motion Records, Linear Time History.

I. INTRODUCTION

This paper explores the use of hybrid passive devices, including elastomeric bearings and viscous dampers, in RC bridges to enhance seismic behavior. Upgrading bridges is vital to mitigate collapse and lengthy closures due to excessive deck displacement. Base isolation and dampers effectively improve seismic performance, allowing non-structural components to withstand earthquake forces. While elastomeric bearings can resist minor vibrations, dampers optimize structural performance during strong seismic events. Energy dissipation devices like laminated rubber bearings increase damping and reduce displacement demands. The study emphasizes the need for strong, flexible, and deformable structures to dissipate transient inputs. Additional dampers absorb energy, reducing stress and deflection. The research focuses on fluid viscous dampers using linear time history analysis for bridge applications.

II. LITERATURE REVIEW

1) M. C. Kunde and R. S. Jangid [1]. (*Effects of Pier and Deck Flexibility on the Seismic Response of Isolated Bridges*.) A study analyzed isolated bridges' seismic response using elastomeric bearings and sliding mechanisms with real earthquake ground motions. Different mathematical models yielded similar results, emphasizing the effectiveness of isolation systems in reducing earthquake impact on bridges.
2) Seyed Saman Khedmatgozar Dolati, Armin Mehrabi and Seyed Sasan Khedmatgozar Dolati [2]. *(Application of Viscous Damper and Laminated Rubber Bearing Pads for Bridges in Seismic Regions*)Study investigates the use of VD-LRBPs (viscous dampers and laminated rubber bearing pads) in reducing bridge displacement during earthquakes. Results show VD-LRBPs effectively decrease residual displacement, facilitate self-centering, minimize force transfer to the foundation, and dissipate seismic energy. Promising potential for seismic zones.
3) Li Zhen, Li Dejian,Peng Leihua, Lu Yao,Cheng Kepei and Wu Qianqiu[2]. *(Study on the damping efficiency of continuous beam bridge with constant cross-section applied by lead rubber bearings and fluid viscous dampers.)* Modifying seismic properties impacts multi-span bridge responses. Achieving effective isolation in both horizontal directions is challenging. Lead rubber bearings provide insulation and energy absorption, while fluid viscous dampers dissipate seismic energy. However, lead rubber bearings have limited horizontal resistance under severe earthquake loads due to decreasing stiffness after yielding.
4) CSiBridge Bridge Superstructure Design IRC-2011[6]. CSiBridge is a comprehensive software for bridge modeling, analysis, and design, capable of handling various bridge types. It automates design tasks based on load patterns, but users need to verify results and address other design aspects not covered by the software. Results can be visualized graphically and printed with customized reports, enhancing the bridge superstructure design process.

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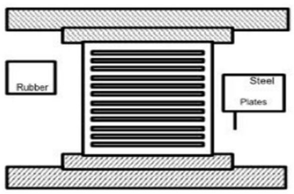
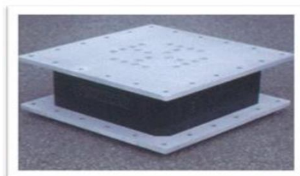
5) IRC 2011, IS 1893, and IRC 84 ,IRC83 & SP-114(2018). The literature review covers four Indian codes relevant to highway and bridge design. IRC 2011 guides highway bridge design with earthquake-resistant provisions. IS 1893 is the standard code for seismic design, including seismic zones and analysis. IRC 84 provides rural bridge design standards, including earthquake resilience. IRC 83 focuses on elastomeric bridge bearings, detailing material properties, design criteria, testing, and inspection.

III. LAMINATED RUBBER BEARING AND FLUID VISCOUS DAMPER

High density rubber bearing (HDRB) is another type of elastomeric bearing which consist of thin layers of high damping rubber and steel plates in alternate layers. The rubber used is either natural rubber or synthetic rubber which provide a sufficient amount of damping.





$$T_b = \frac{2\pi}{\omega_b} \text{ and } \qquad \omega_b = \sqrt{\frac{k_b}{m}}$$

$$2\xi\omega_b = \frac{c_b}{m}$$

$$M = m_b + \sum_{j=0}^{n} m_j$$

$$F_b = c_b \dot{x}_b + k_b x_b$$

c_b and k_b represent damping and bearing stiffness. The mentioned damping and stiffness in a LRB system have specified values of isolation period (T_b) and the damping ratio (ξ_b). F_b the restoring force, x_b the relative base displacement, $\dot{x}_b$ the relative base velocity. A spreadsheet is evaluated for getting the MoI in order to get response from bearing.

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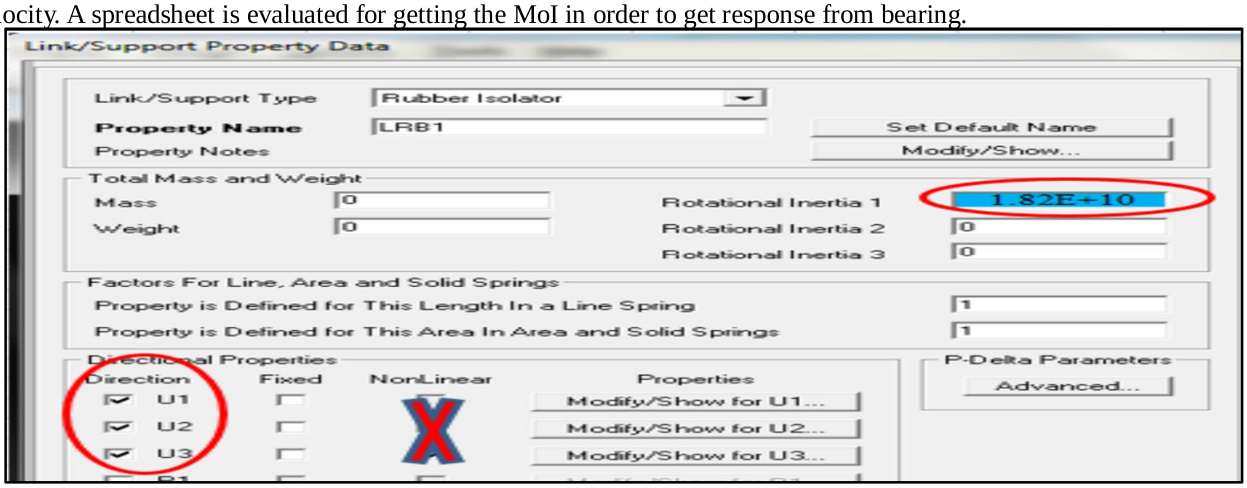
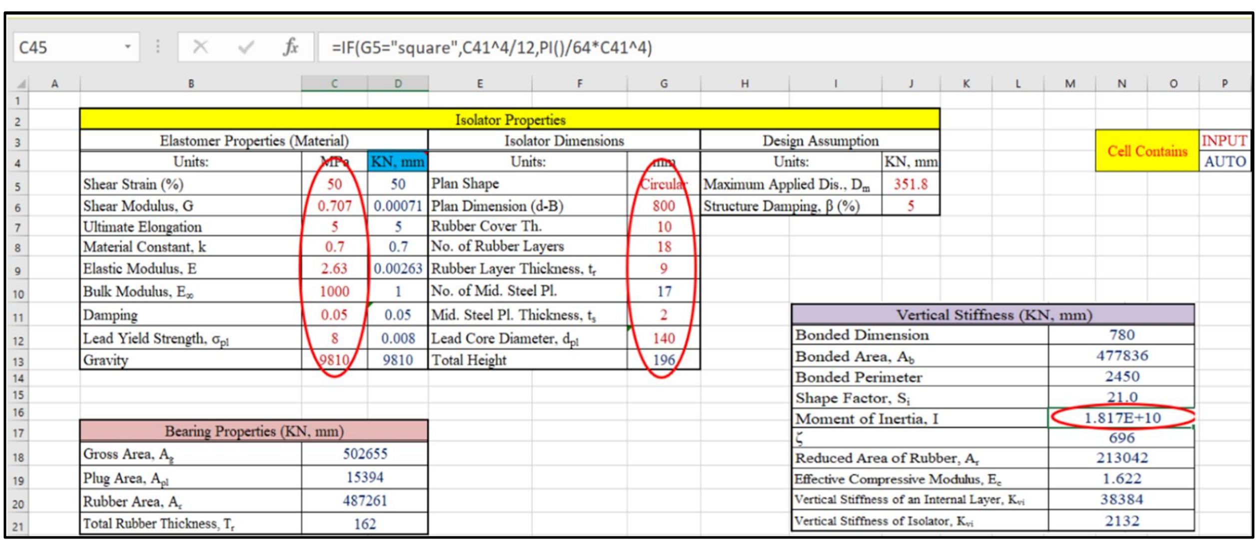


CSIBRIDGE INTERFACE FOR DATA FEEDING FOR BEARING



C45 =IF(G5="square",C41^4/12,PI()/64*C41^4)

Isolator Properties				
Elastomer Properties (Material)			Isolator Dimensions	
Units:	MPa	KN, mm	Units:	mm
Shear Strain (%)	50	50	Plan Shape	Circular
Shear Modulus, G	0.707	0.00071	Plan Dimension (d-B)	800
Ultimate Elongation	5	5	Rubber Cover Th.	10
Material Constant, k	0.7	0.7	No. of Rubber Layers	18
Elastic Modulus, E	2.63	0.00263	Rubber Layer Thickness, t_r	9
Bulk Modulus, E_∞	1000	1	No. of Mid. Steel Pl.	17
Damping	0.05	0.05	Mid. Steel Pl. Thickness, t_s	2
Lead Yield Strength, σ_{pl}	8	0.008	Lead Core Diameter, d_{pl}	140
Gravity	9810	9810	Total Height	196

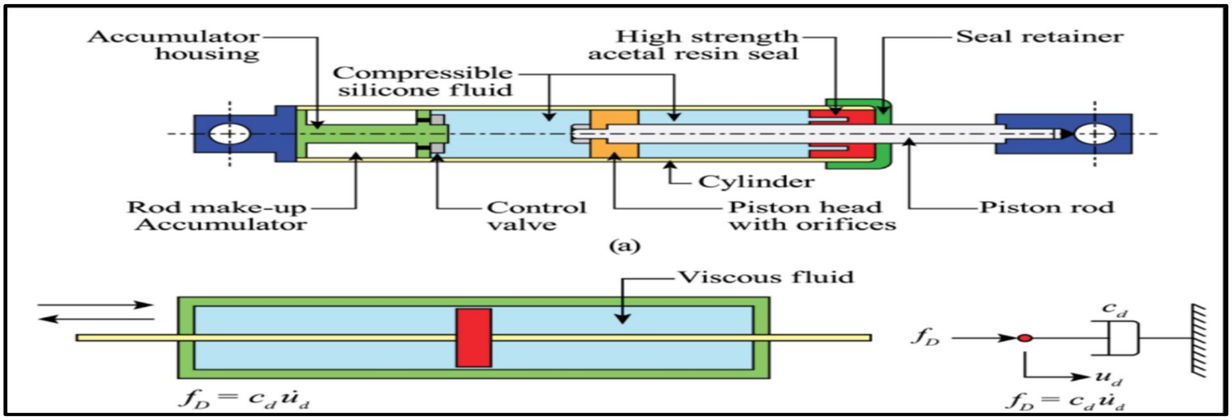
Design Assumption	
Units:	KN, mm
Maximum Applied Dis., D_m	351.8
Structure Damping, β (%)	5

Cell Contains	
	INPUT
	AUTO

Bearing Properties (KN, mm)	
Gross Area, A_g	502655
Plug Area, A_{pl}	15394
Rubber Area, A_r	487261
Total Rubber Thickness, T_r	162

Vertical Stiffness (KN, mm)	
Bonded Dimension	780
Bonded Area, A_b	477836
Bonded Perimeter	2450
Shape Factor, S_i	21.0
Moment of Inertia, I	1.817E+10
ζ	696
Reduced Area of Rubber, A_r	213042
Effective Compressive Modulus, E_c	1.622
Vertical Stiffness of an Internal Layer, K_{vi}	38384
Vertical Stiffness of Isolator, K_{vi}	2132

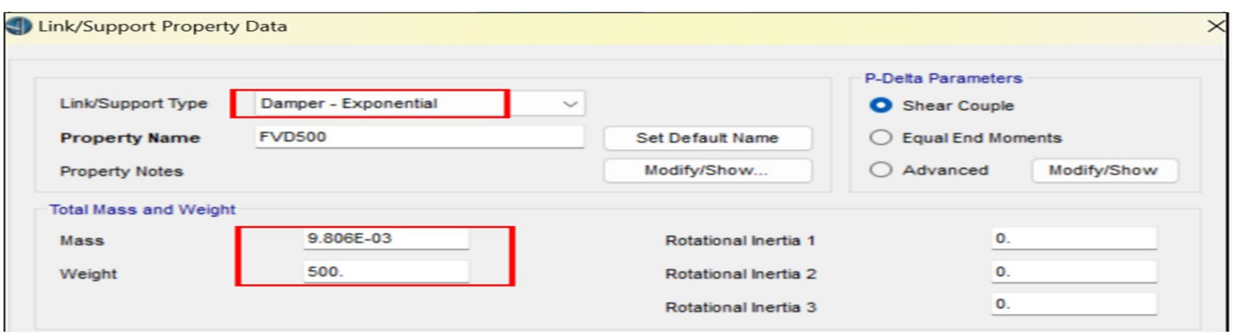
1) *Viscous Dampers:* The Viscous dampers are passive energy dissipation device which is added to structure to increase the effective stiffness of new and existing structures. They are very robust material and energy is transferred by piston and absorbed or vanishes by silicone-based fluid flowing between the piston and cylinder arrangement. The properties of the Viscous Damper are considered as provided by the manufacturing company Taylor Device Inc. The force and weight value of the FVD500 is interpreted by the following literature made available by company and fed into the software.



LONGITUDINAL SECTION OF VISCOUS DAMPER DAMPER

FORCE (kN)	TAYLOR DEVICES MODEL NUMBER	SPHERICAL BEARING BORE DIAMETER (mm)	MID-STROKE LENGTH (mm)	STROKE (mm)	CLEVIS THICKNESS (mm)	MAXIMUM CLEVIS WIDTH (mm)	CLEVIS DEPTH (mm)	BEARING THICKNESS (mm)	MAXIMUM CYLINDER DIAMETER (mm)	WEIGHT (kg)
250	17120	38.10	787	±75	43	100	83	33	114	44
500	17130	50.80	997	±100	55	127	102	44	150	98
750	17140	57.15	1016	±100	59	155	129	50	184	168
1000	17150	69.85	1048	±100	71	185	150	61	210	254
1500	17160	76.20	1105	±100	77	205	162	67	241	306
2000	17170	88.90	1346	±125	91	230	191	78	286	500
3000	17180	101.60	1441	±125	117	290	203	89	350	800
4000	17190	127.00	1645	±125	142	325	273	111	425	1088
6500	17200	152.40	1752	±125	154	350	305	121	515	1930
8000	17210	177.80	1867	±125	178	415	317	135	565	2625

SECTION DETAILS OF VISCOUS DAMPER DAMPER



CSIBRIDGE INTERFACE FOR VISCOUS DAMPER DAMPER DATA

IV. CSIBRIDGE SOFTWARE.

CSiBridge is a powerful bridge analysis and design software that uses a parametric object-based modeling approach. It simplifies the creation of bridge systems by allowing designers to assemble and assign bridge components easily. The software's SAPFire Analysis Engine automatically converts the model into a mathematical finite-element model, enabling structural optimization and cost-saving designs. CSiBridge enables quick generation and analysis of vehicle loading scenarios, enhancing design checks, especially for steel/composite bridge decks. Its influence-based enveloping analysis is particularly useful for analyzing moving vehicle loads.

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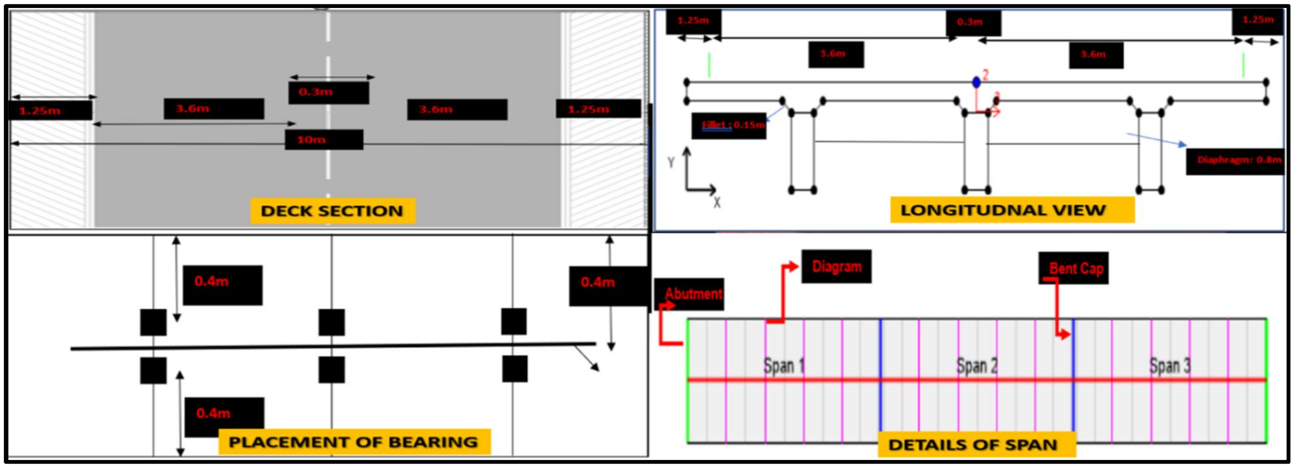
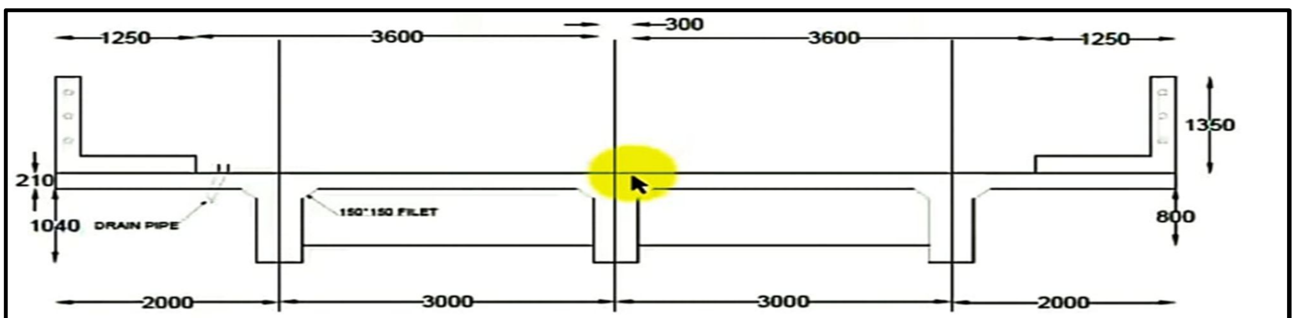
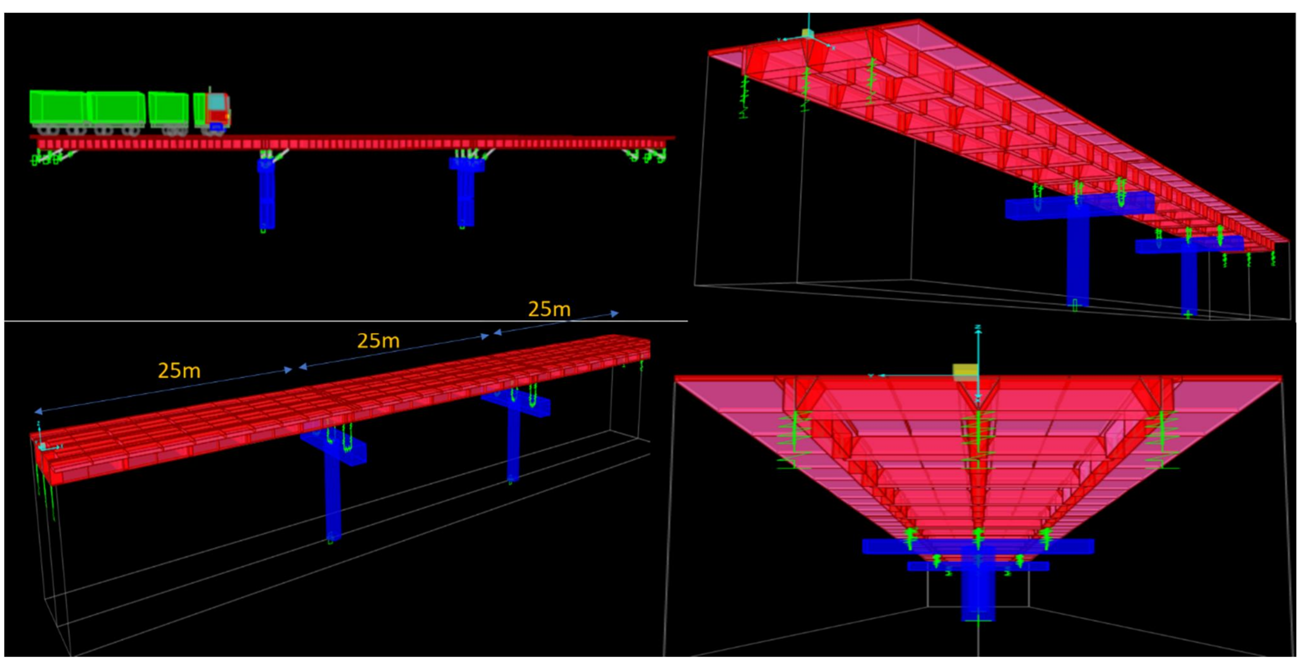
V. TYPES OF LOADS/CASES ON BRIDGE AND SECTION DETAILS

The software automatically calculates and takes into consideration the self-weight of the three girders and the deck section that are represented. According to IRC 6, the carriageway width of the Benchmark bridge should be adopted for bridges with carriageway widths between 5.3m and 9.6m. This corresponds to either one lane of Class 70R or two lanes of Class A vehicle loading. As a result, the bridge now has two lanes of Class A vehicle load operating at a speed of 50 km/hr. The section Details are shown below :

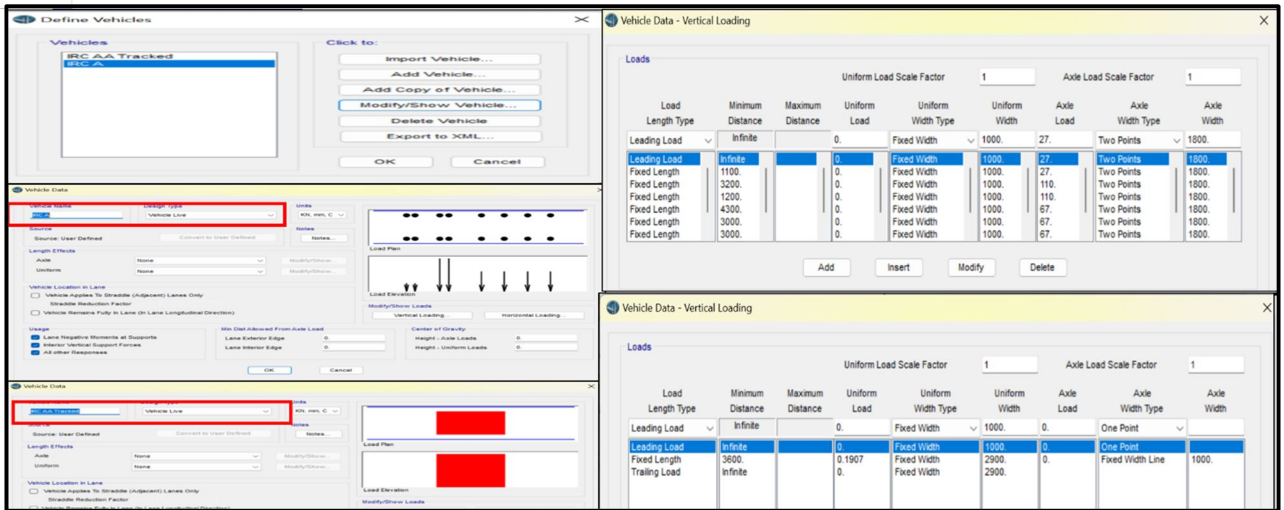




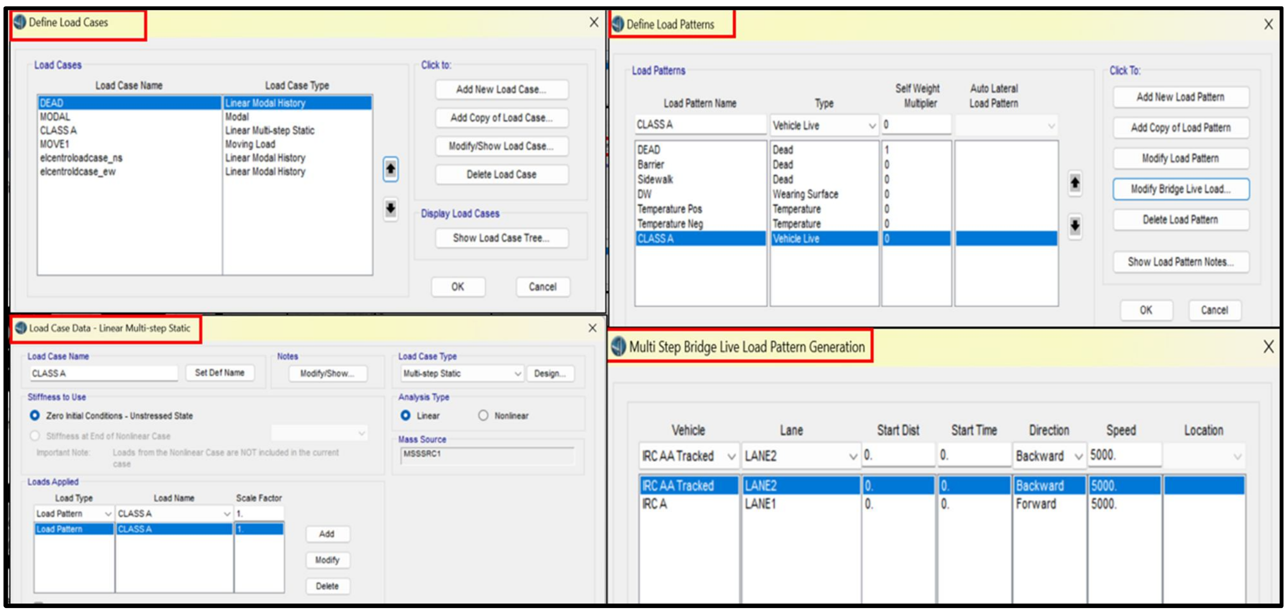
X-SECTION DETAILS OF T-GIRDER RCC BRIDGE



THREE SPAN RCC T-GIRDER BRIDGE



CSIBRIDGE INTERFACE FOR DATA FEEDING FOR IRC VEHICLE AXEL LOAD



CSIBRIDGE INTERFACE FOR L0AD CASES

VI. PROCESS OF MODELLING OF THE BRIDGE

The following process in Brief is as followed: -

1) *Creating Layout Line:* It is used for defining the horizontal and vertical alignment of the bridge and the vehicle lanes. The bridge under modelling is a straight bridge 3span of length 25m c/c of abutments and pier. So, the initial station was set to 0 and the end station to 75m, with no change in vertical layout data.
2) *Assigning Material Property:* M25 grade concrete is used for the construction of deck slab and girder.
3) *Frame Sections*: The frame section properties of the precast girders are defined by entering their sectional dimensions.

a) *Deck Section:* The dimensions of the bridge superstructure are defined and the precast concrete girder is used.
b) *Bearing and Damper Properties:* Bearing property is user-defined and allows each of the six degrees of freedom to be specified as fixed, free or partially restrained with a specified spring constant. The bridge is simply supported, so hinge and roller bearing properties are assigned.
c) *Bridge Object Modelling:* In this, all the data regarding the bridge such as the number and length of spans, location of its abutments in terms of its elevation and bearing are added.
d) *Bridge Lane Data:* Lanes must be defined to analyse the bridge for vehicle live loads.
e) *Vehicle Data:* Vehicle loads are applied to the structure through lanes.

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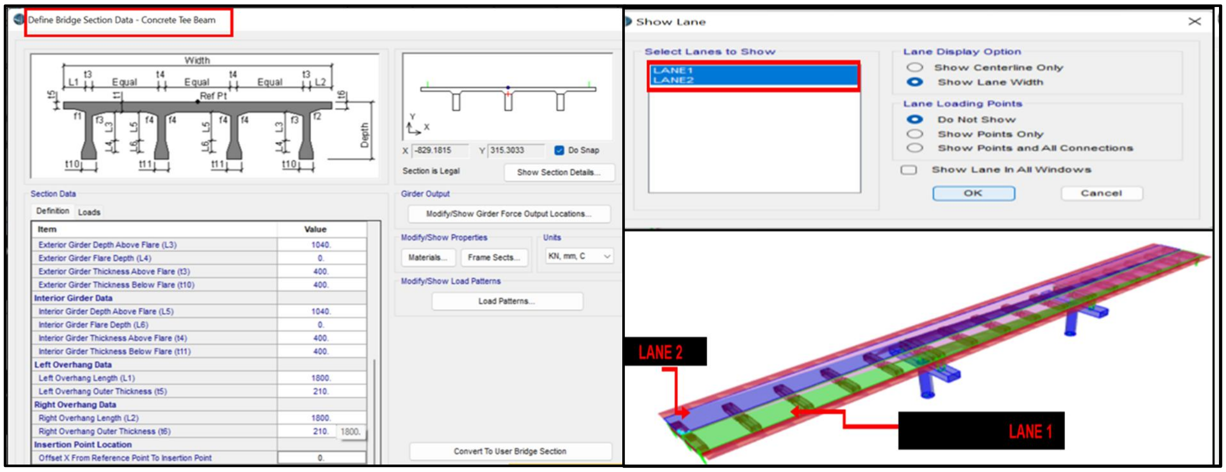
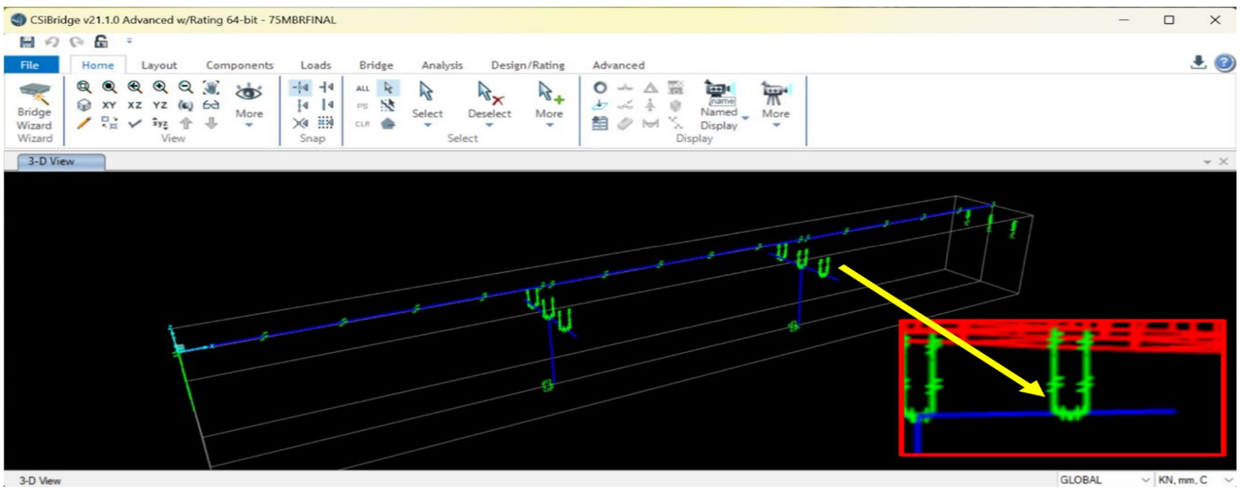
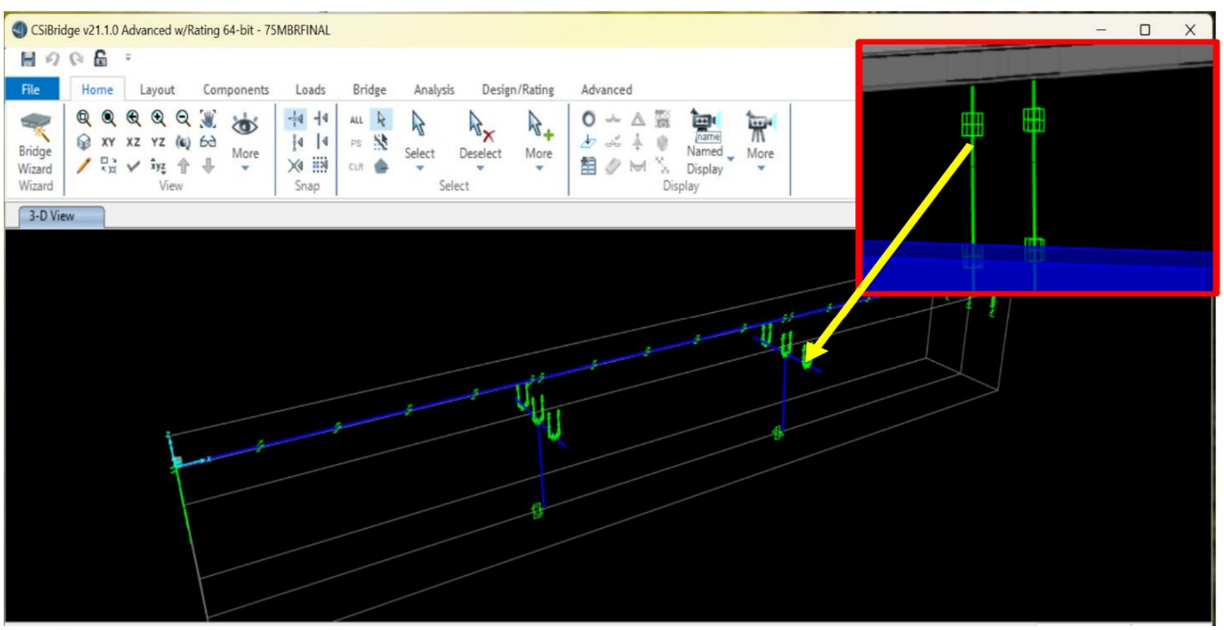


X-SECTION DETAILS OF T-GIRDER RCC BRIDGE



CSIBRIDGE INTERFACE FOR LINEAR LINK



CSIBRIDGE INTERFACE FOR LRB

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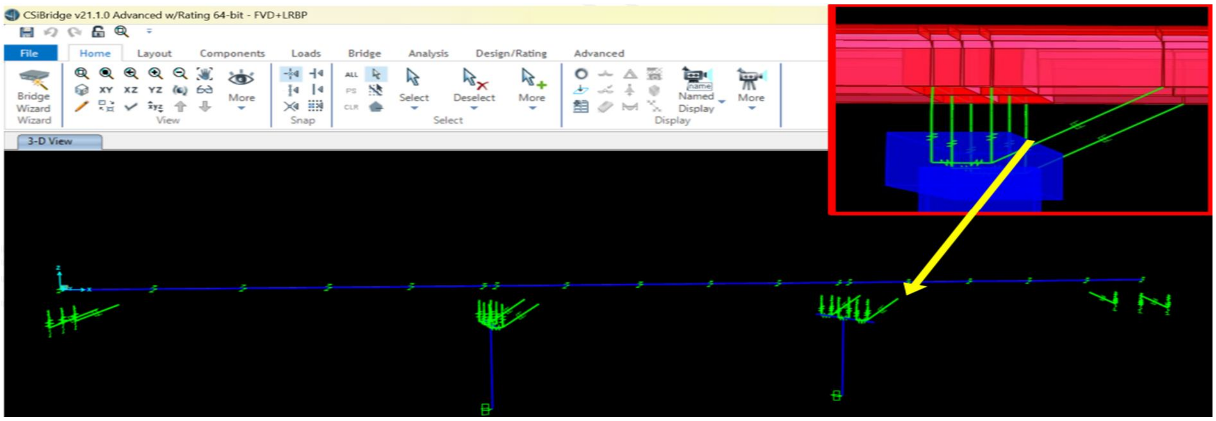
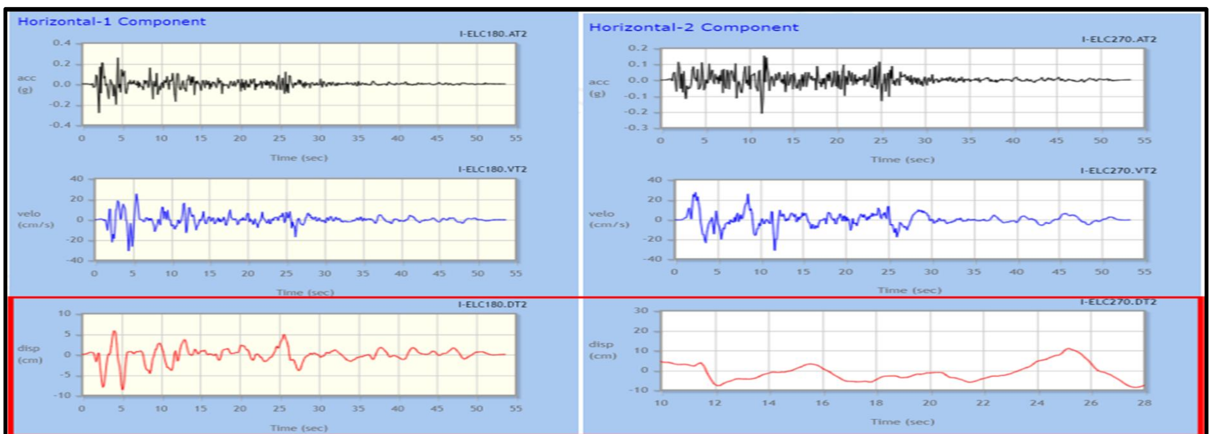


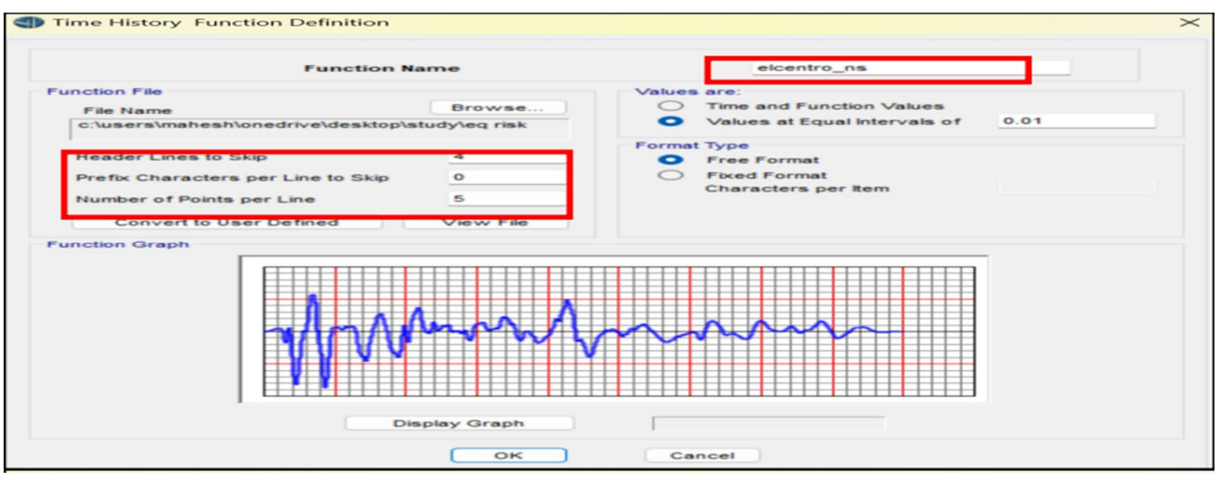
CSIBRIDGE INTERFACE FOR LRB + FVD

VII. ANALYSIS PROCEDURE

In this study, a three-span continuous deck slab bridge is analyzed using linear time history analysis. The bridge is subjected to displacement ground motions in the transverse direction. The El Centro 1940 ground motions, scaled to 0.4g, are used for the analysis. The CSiBridge program is employed to calculate the maximum and minimum response quantities by utilizing influence-based enveloping analysis. The program automatically places vehicles on the bridge lanes to generate influence surfaces and lines, allowing for effective analysis of vehicle loads and validation of the design. Response quantities such as shear force, bending moment, deflection, axial force, and torsion are evaluated using this approach.



NS & EW COMPONENTS OF EL CENTRO GROUND MOTION [Pacific Earthquake Engineering Research]



CSIBRIDGE INTERFACE FOR TIME HISTORY FUNCTION

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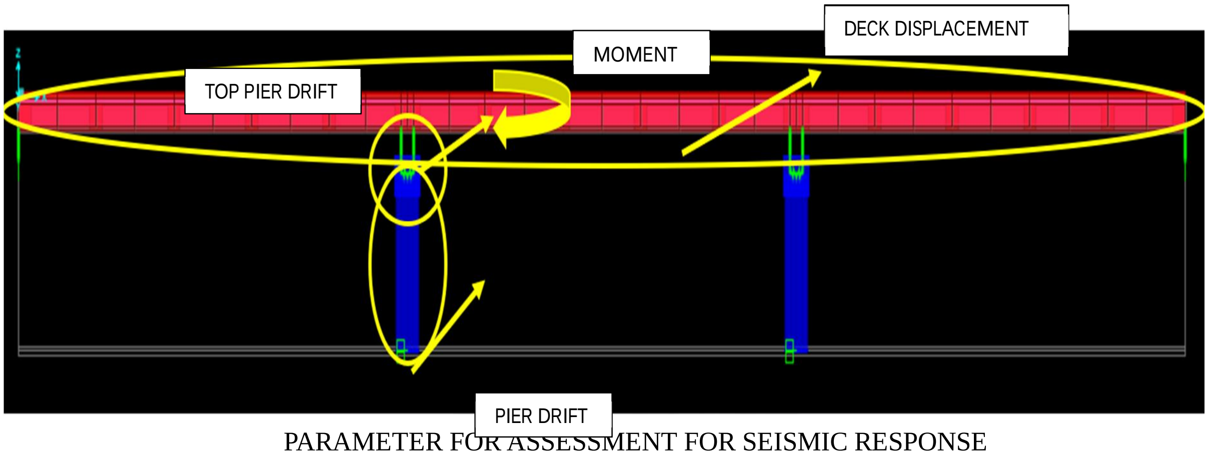
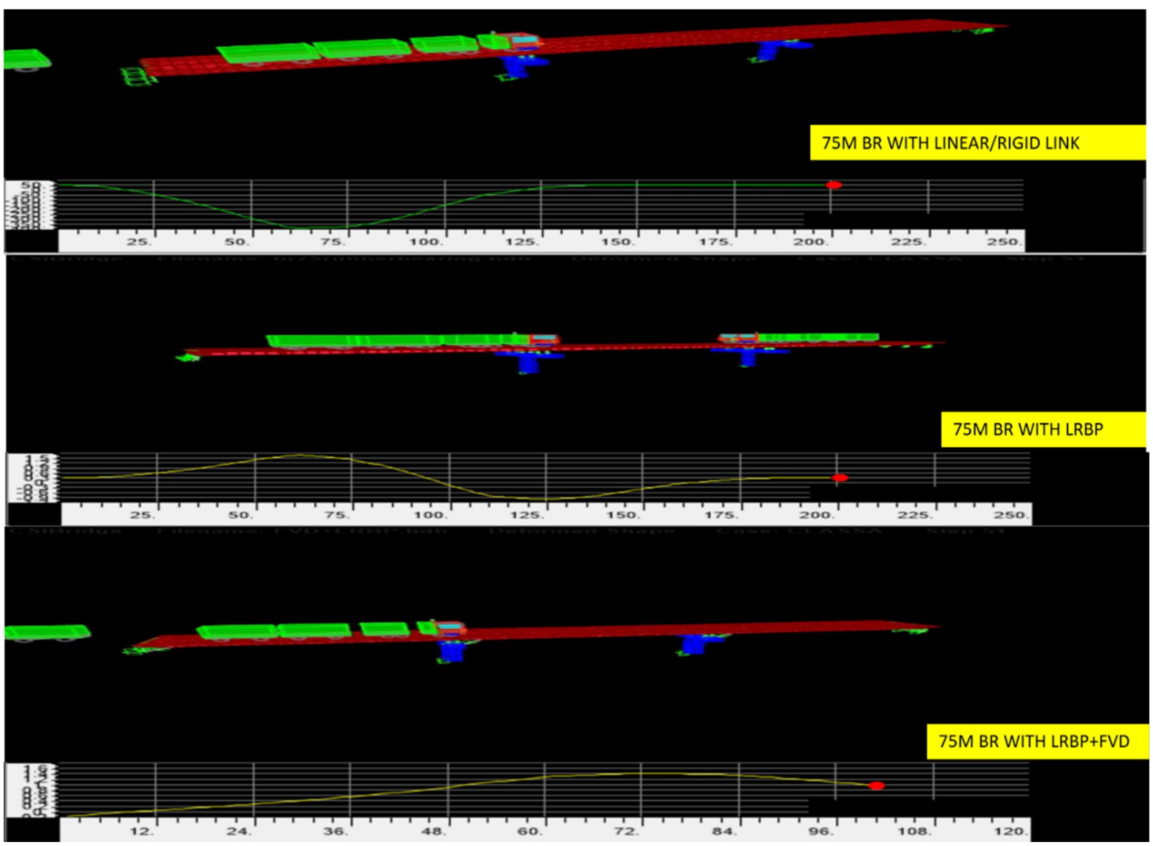
VIII. RESULTS FOR A THREE SPAN RCC BRIDGE

The parameter for assessment of results are as under :-



PARAMETER FOR ASSESSMENT FOR SEISMIC RESPONSE

1) *Class A/AA: Br Transverse Displacement*. By combining LRB with FVD, the bridge's ability to resist transverse displacement is enhanced compared to using LRB or rigid link alone. The added damping properties of FVD contribute to reducing the overall transverse displacement of the bridge during seismic events.



Sr No	Configuration	Displacement (mm)	LOAD CL A/AA:2 LANE(IRC) A and AA
(a)	Linear/Rigid link	50	
(b)	LRPB	1.5	
(c)	LRPB + FVD	1.4	

CSIBRIDGE INTERFACE FOR DYNAMIC RESPONSE OF BRIDGE WITH IRC VEH LOAD

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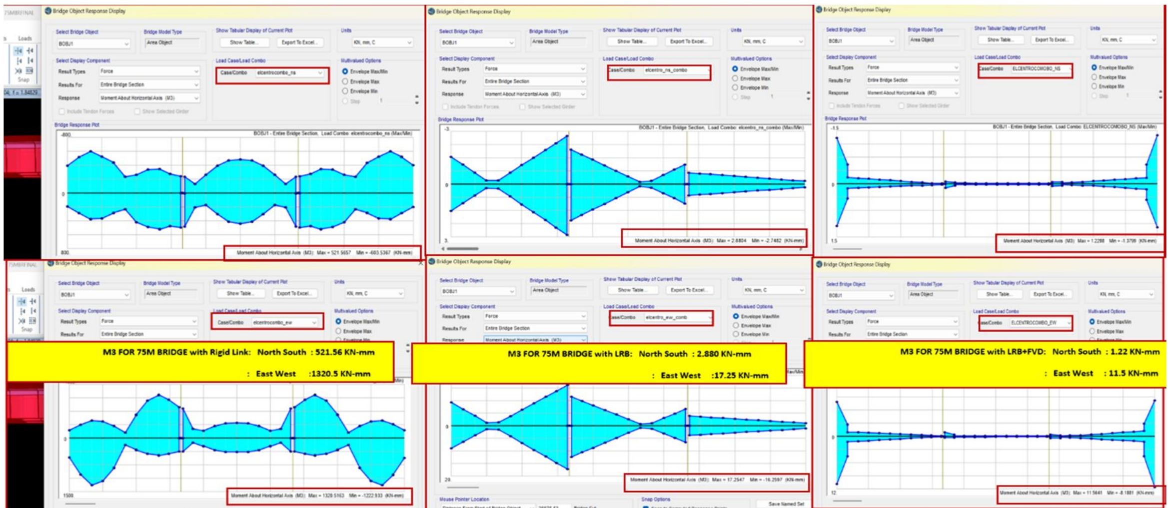
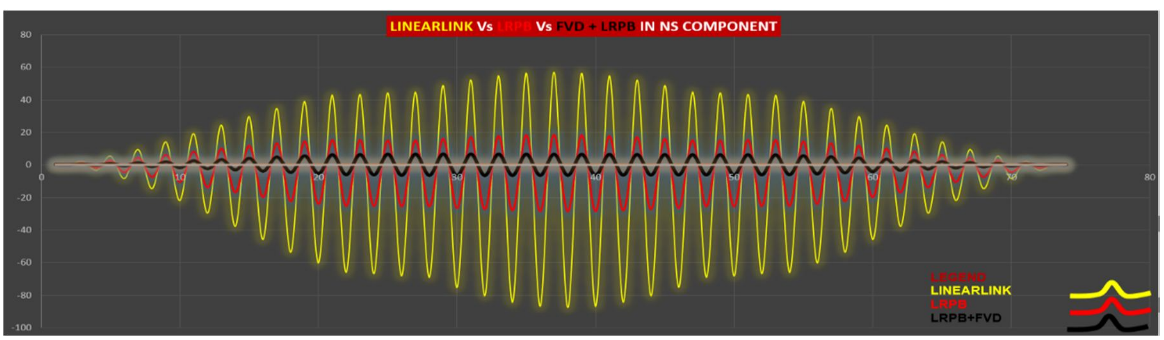
2) *Force/Moment about Horizonal Axis under scaled ground motion.* The application of Laminated Rubber Bearings (LRB) reduces the moment response of a bridge by providing flexibility and isolation. When combined with Fluid Viscous Dampers (FVD), the moment response is further reduced due to additional damping and energy dissipation. The combination of LRB and FVD enhances the bridge's ability to resist moment forces and improves its seismic performance.

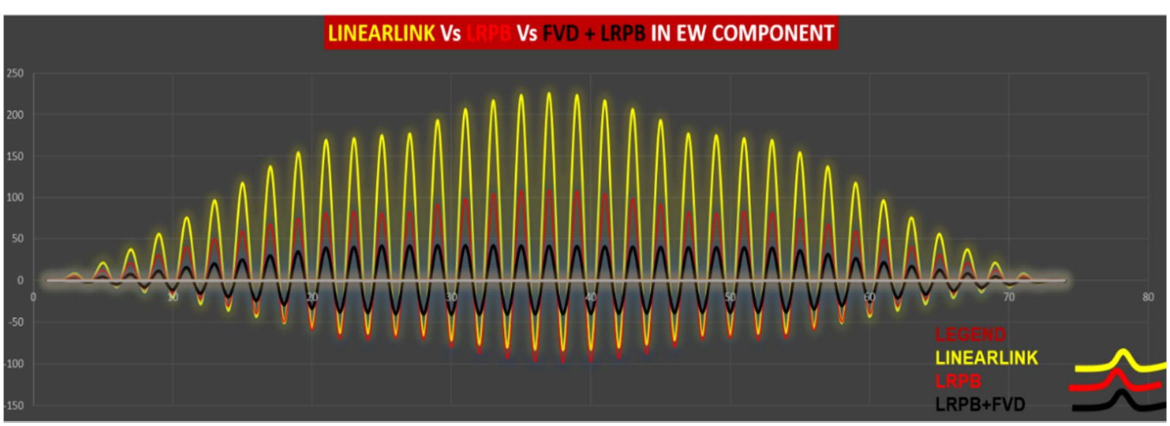


Sr No	Configuration	Moment(KN-mm)		Load(0.4g)
		NS	EW	ELCENTRO
(a)	Linear/Rigid link	522	1321	
(b)	LRPB	3	18	
(c)	LRPB + FVD	1.22	11.5	

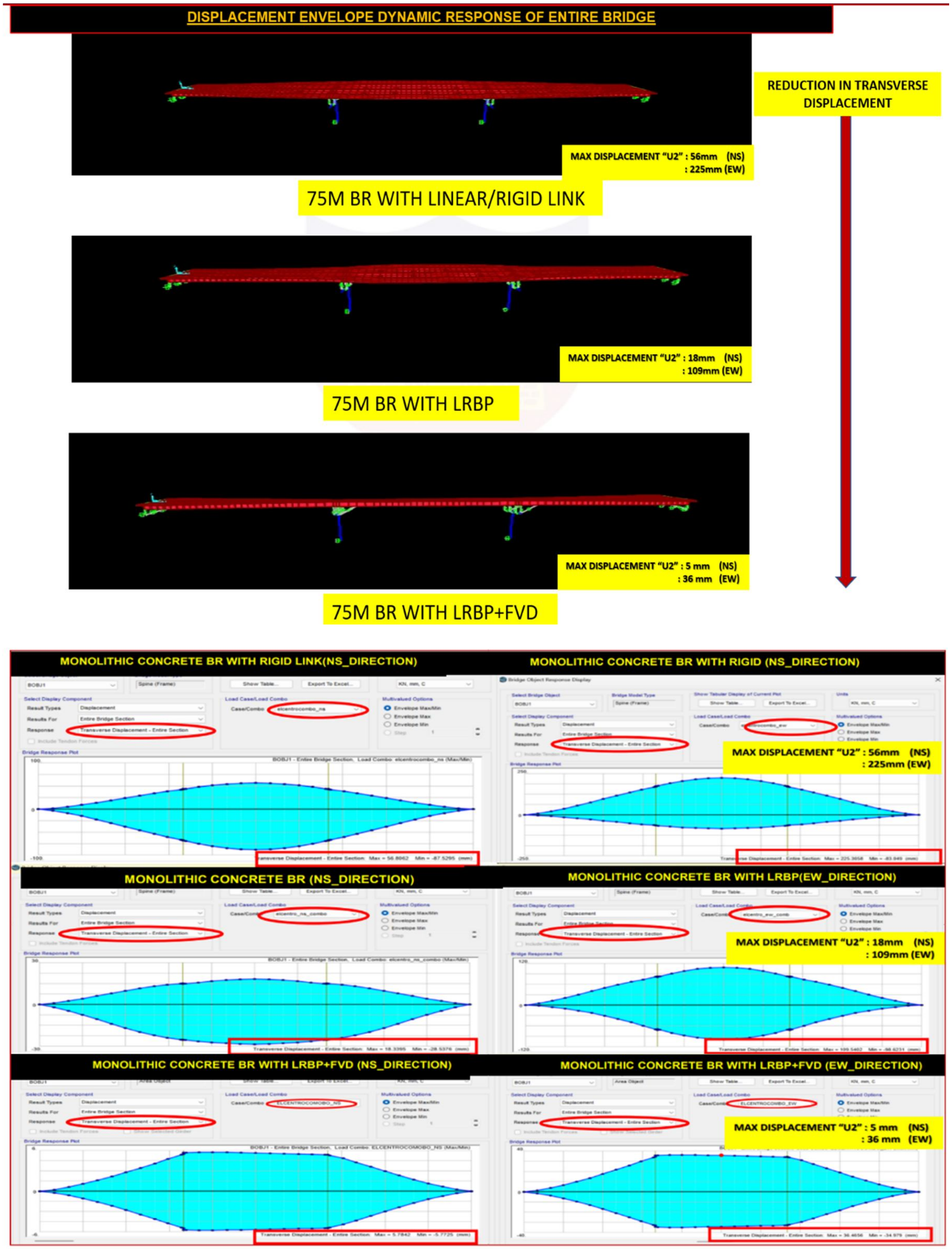
CSIBRIDGE INTERFACE FOR MOMENT OF BRIDGE WITH NS AND EW COMPONENT OF EQ



CSIBRIDGE INTERFACE FOR DECREASED DISPLACEMENT OF BRIDGE WITH NS COMPONENT OF EQ

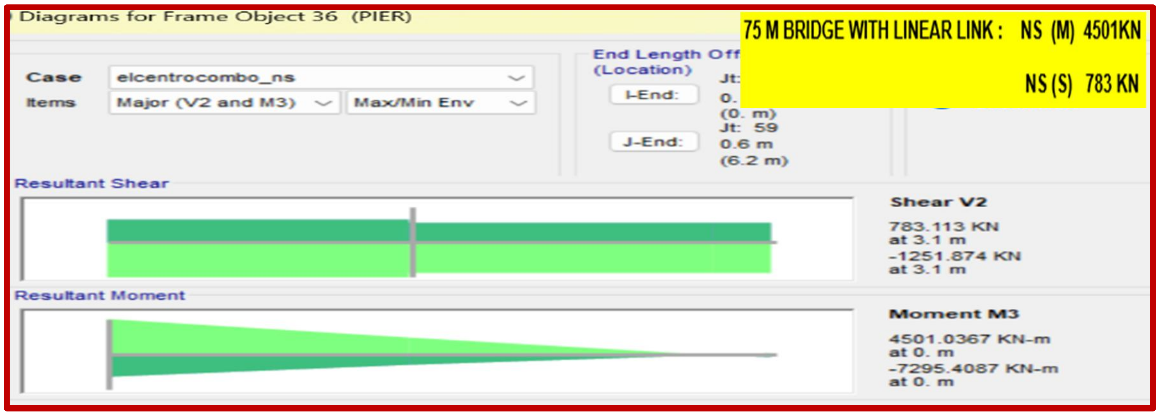


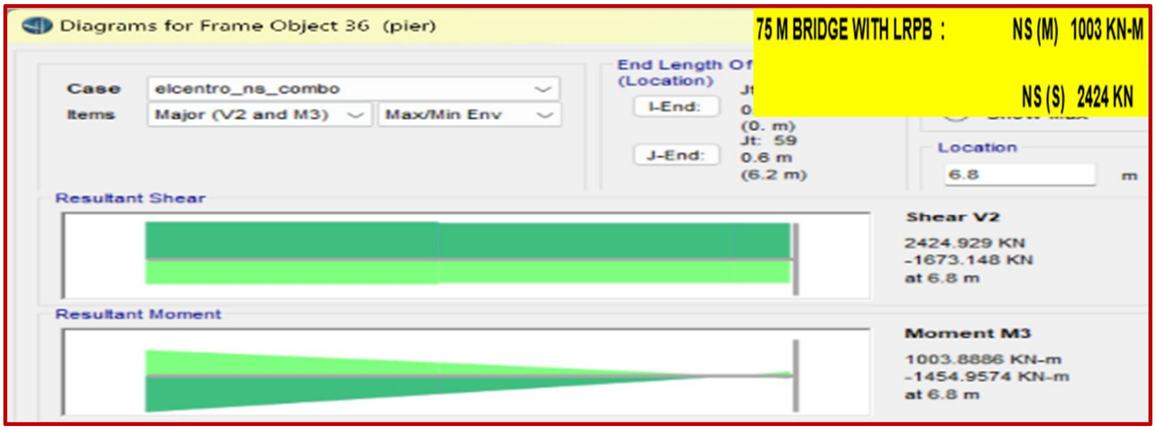
CSIBRIDGE INTERFACE FOR DECREASED DISPLACEMENT OF BRIDGE WITH EW COMPONENT OF EQ

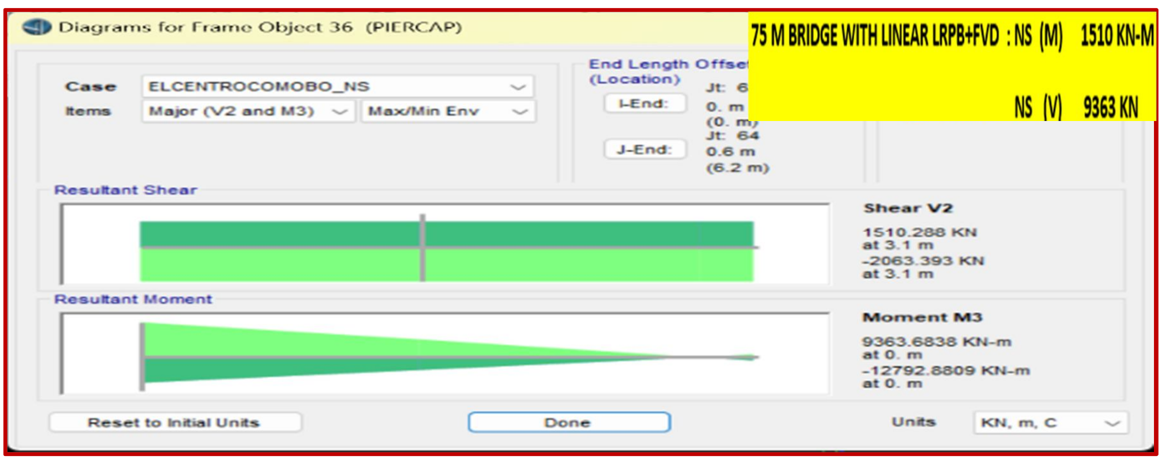


CSIBRIDGE INTERFACE ILD FOR DECREASED DISPLACEMENT OF BRIDGE

3) *Dynamic Response of Pier.* when Laminated Rubber Bearings (LRB) are used in bridge piers, they can potentially increase the shear response. However, the moment response and axial forces of the piers is effectively reduced due to the flexibility and rotational capacity provided by LRBs. When LRBs are combined with Fluid Viscous Dampers (FVD), the overall response of the piers in terms of both shear and moment can be controlled and mitigated effectively.







Sr No	Configuration	Force		Load (0.4g)
		MOMENT (KN-M)	SHEAR(KN)	ELCENTRO_NS COMPONENT. ADDITIONAL DAMPING HAS INCREASED THE STIFFNESS THERE BY CONTIBUTING TO INCREASED MOMENT AND SHEAR VALUES.
(a)	Linear/Rigid link	4501	783	
(b)	LRPB	1003	2424	
(c)	LRPB + FVD	1510	9363	

CSIBRIDGE INTERFACE FOR DECREASED MOMENT OF BRIDGE PIER

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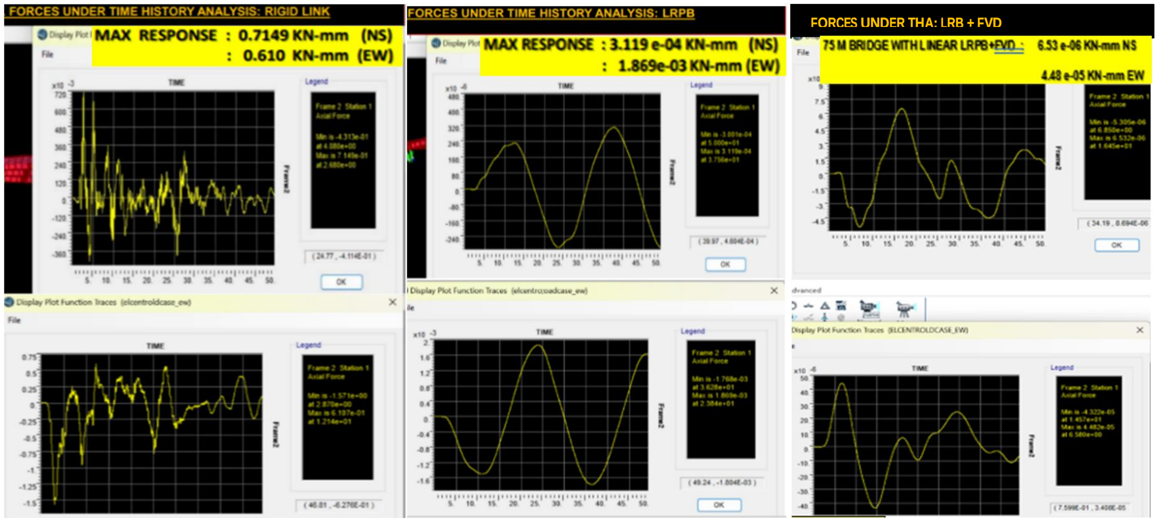
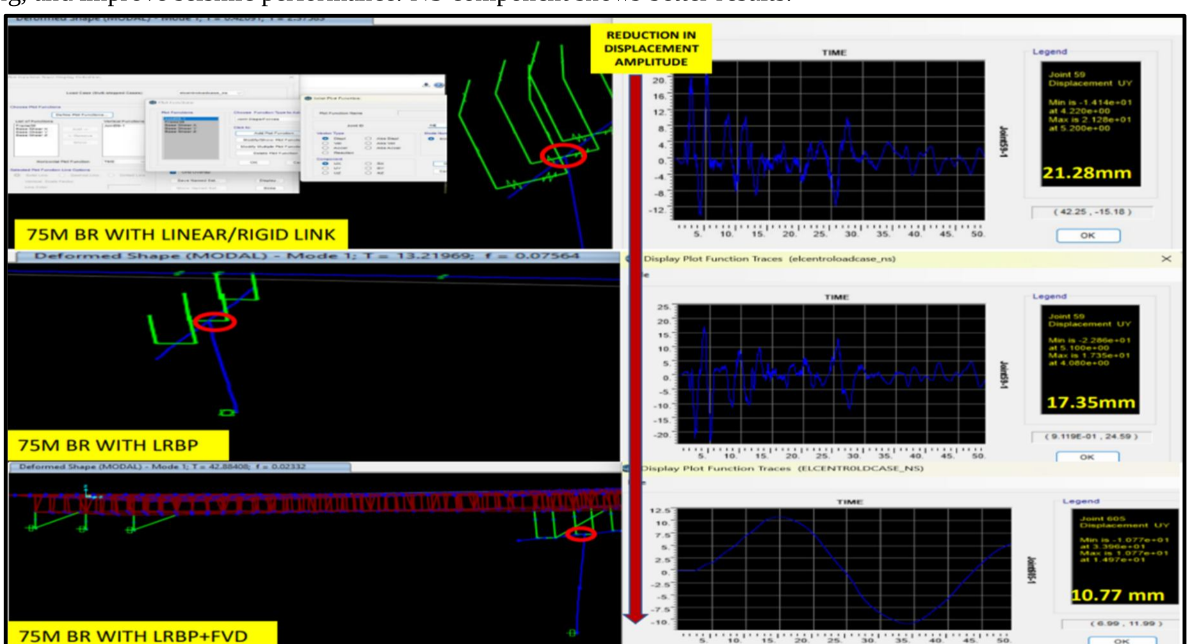


Sr No	Configuration	Force (KN-mm)		Load (0.4g)
		NS	EW	ELCENTRO NS AND EW
(a)	Linear/Rigid link	0.7149	0.610	
(b)	LRPB	3.11×10^{-4}	1.87×10^{-3}	
(c)	LRPB + FVD	6.53×10^{-6}	4.48×10^{-5}	

CSIBRIDGE INTERFACE FOR DECREASED AXIAL FORCES OF BRIDGE PIER

4) *Pier Top Response (Uy).* LRBs in bridge piers limit pier top drift by providing flexibility and lateral displacement. They absorb and dissipate energy, reducing displacement during seismic events. Combined with FVDs, they control pier top drift, enhance damping, and improve seismic performance. NS component shows better results.



Sr No	Configuration	Displacement(mm)		Load (0.4g)
		NS	EW	ELCENTRO
(a)	Linear/Rigid link	21.28	21.31	EW INCR DUE TO ADDN DAMPING BUT INCREASE IS WITHIN PERMISSIBLE LIMITS.
(b)	LRPB	17.35	60.27	
(c)	LRPB + FVD	10.77	65.42	

CSIBRIDGE INTERFACE FOR DECREASED AXIAL FORCES OF BRIDGE PIER

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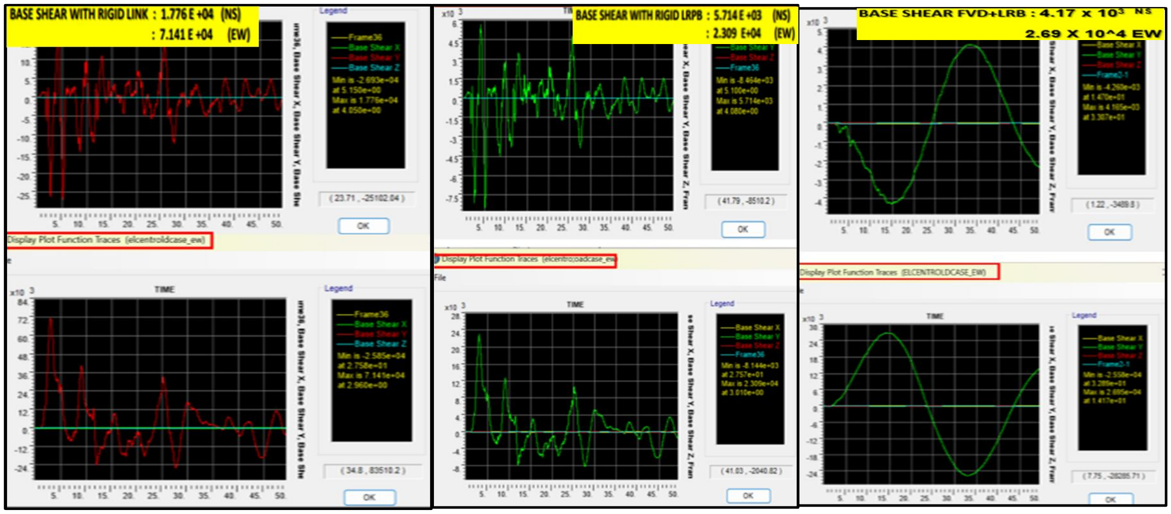
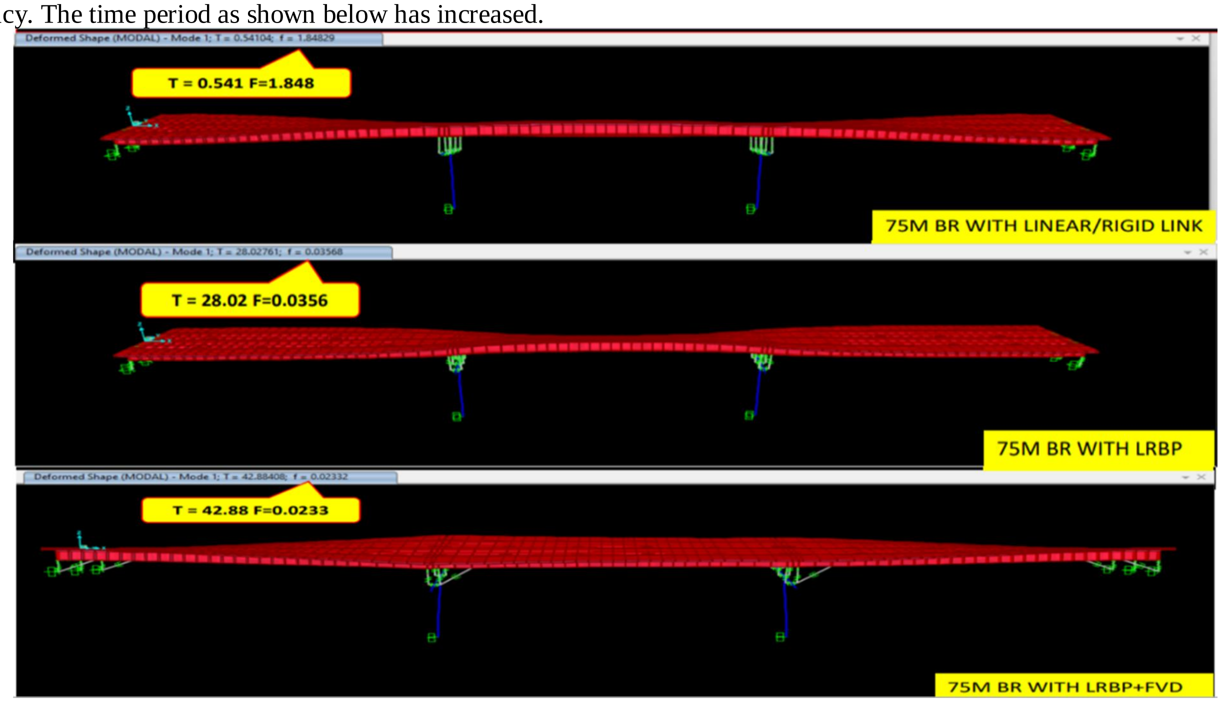
5) *Base Shear of System (Transverse Direction).* When both Laminated Rubber Bearings (LRB) and Fluid Viscous Dampers (FVD) are used in bridge piers, they can further contribute to reducing the base shear. LRBs provide flexibility to absorb seismic forces, while FVDs add damping properties to dissipate energy. This combined effect helps mitigate the base shear by absorbing and dissipating seismic energy, resulting in improved seismic performance and reduced demands on the bridge pier.



Sr No	Configuration	Base Shear (KN)		Load (0.4g)
		NS	EW	ELCENTRO
(a)	Linear/Rigid link	1.77×10^4	7.14×10^4	
(b)	LRPB	5.71×10^3	2.31×10^4	
(c)	LRPB + FVD	4.17×10^3	2.69×10^4	

CSIBRIDGE INTERFACE FOR DECREASED BASE SHEAR OF BRIDGE

6) *Time And Frequency Response.* The installation of isolators in a bridge reduces its natural frequency, making it less responsive to higher frequency vibrations. This can improve user comfort, reduce fatigue damage, and enhance the bridge's resistance to earthquake loads. The study analysed different bearing configurations and their effects on the bridge's response over time and frequency. The time period as shown below has increased.



CSIBRIDGE INTERFACE FOR INCREASED TIME PERIOD

IX. CONCLUSIONS

This study examined the effectiveness of VD-LRBPs (Viscous Dampers combined with Bearing) in controlling large displacements between the superstructure and substructure during Elcentro earthquakes in the transverse direction. Detailed FEM modelling, vehicle simulation, and dynamic analysis were conducted. The results showed that the combination of rubber bearings and viscous dampers increased flexibility and reduced the bridge's response to seismic excitation. The addition of viscous dampers also reduced axial forces in most cases but increased shear values, which could be mitigated by additional damping from the bearing and FVD. The exponential damper with $\alpha=1$ was found to effectively control displacements, providing a simple methodology for selecting optimal damper characteristics. Transverse moments in the column were reduced, particularly in the NS component. The shift in fundamental time period increased the bridge's flexibility, and the base shear of the bridge structure was significantly reduced after isolation.

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