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Seismic Evaluation of a Bridge with Different Isolators at Different Locations

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Abstract: In this analysis, we investigate the role of the location of isolators on the seismic behaviour of an RCC bridge with three different isolator systems. The isolation system in the structure will reduce the external ground motion approaching the structure, so that the structural elements do not behave in a nonlinear fashion, and no damage is caused or cracks develop to structural elements as all the deformations are absorbed by the isolator system. To study the role of isolation location on seismic response, an upcoming five-span RCC village road bridge across a canal crossing in Belgaum district is considered. To analyse the influence of the isolation location on different isolators systems, each isolator was modelled with three different cases: The first model was with isolators at the top of the piers, the second at the middle and the third at the bottom. Three types of isolators, i.e., Lead Rubber Bearing (LRB), High Damping Rubber Bearing (HDRB) and Friction Pendulum System (FPS) were modelled as bilinear link elements. The analysis role of isolation location on modal time period, base shear and displacement of structural elements. The analysis shows that the best location for the isolator to provide full functional benefit is at the bottom of the pier.
Keywords: Bridge, Isolation system, Isolation location, Time-history analysis, Modal time period, and Base shear.

I. INTRODUCTION

Bridges are prime components in transportation network and serve as a lifeline structure. They play a vital role in emergency services like supply of medicine, food and other necessary provisions during the period of natural calamities such as earthquakes. They are very vulnerable to seismic excitation as they are simple in construction, and hence greater care should be taken while constructing them. However, due to insufficient knowledge in structural design, the bridges fail to perform their intended role during an earthquake and may finally collapse also completely. The basic premise behind the design of any structure to make them earthquake-resistant is to design them in such a way that it should not collapse completely in case of very strong earthquake acceleration. If the structure disintegrates completely during an earthquake or any other natural disaster takes place then it is impossible to repair and bring it to its original form. A structure can be made earthquake- resistant by constructing the structural member strong enough so that it is capable of withstanding strong earthquakes or by making it flexible so that it dissipates the energy imparted on it due to earthquake force. For dissipation of energy imparted on it and to reduce shear acting at the base, either dampers or isolation systems were used earlier, but the recent trend is application of isolation systems for earthquake resistance.

To make an earthquake-resistant design of structures, an energy absorber and flexible elements are inserted at the junction of the base of the structure and the foundation or between the superstructure and the substructure of the bridge to decrease the seismic energy transmitted from soil to the structure and to the structural elements well within its elastic boundary. If the structural member reaches the inelastic limit due to large energy transmission during earthquake ground motion then there will be a major deformation of the structural member or it fails completely in which situation the isolation approach is the most efficient. The main purpose of using the isolation system in structures is to reduce the base shear and to shift the time period so that the frequency of structural vibration is less than the predominant frequency of vibration. Usually, the fundamental period of vibration of bridges is in the range of 0.2 to 1 s and it is very close to the predominant period of earthquake motion, which results in heavy response from the structure during earthquake waves. Nowadays, a variety of isolators and a number of isolator structures are available worldwide. In this work, we have used three types of isolators, i.e., Lead Rubber Bearing (LRB), High Damping Rubber Bearing (HDRB) and Friction Pendulum System (FPS). LRB and HDRB are elastomeric bearings and FPS, a sliding type of isolation system.

Investigations by Sugiyama (2000) [11] and Ghosh et al. (2008) [12] reveal that the installation of an isolation unit will increase the time period and also there is a maximum deck displacement of the bridge. They found enough reduction in girder acceleration with sliding-type base-isolation system as compared to laminated rubber bearing.

The effect of isolation will vary depending on the location where it is set in any structure. For this work, isolators are inserted at three different locations, the first one with isolator at the junction of the top of the pier and the bottom of the deck slab, the second, with isolator at the middle of the piers and the third, with isolator at the junction of the bottom of the pier and the foundation.

Seranaj and Softa (2014) [7] studied the influence of isolation location on the seismic response of the bridge using nonlinear time-history analysis. They have analysed the same bridge model with isolator at three different locations using the LRB isolator and found that the best location of isolator is at the middle of the pier.

The aim of the present study is to evaluate the seismic performance of an RCC bridge with different isolators at different locations by using linear static analysis and nonlinear time-history analysis.

II. DESCRIPTION OF THE BRIDGE UNDER STUDY

For seismic assessment, an upcoming village road bridge to be built across a canal crossing connecting two villages in Belgaum District is considered. It is a multi-span simply supported RCC Tee girder bridge with a total span of 56.04 m. The entire bridge is divided into five spans of unequal length. The superstructure consists of Tee beam girder deck slab with three main longitudinal girders for each span. The entire bridge is supported on two abutments at the end and four piers at the intermediate, and at each abutment and pier it has three columns, which are transversely connected by the bent cap at the top and tie beam at an intermediate distance. At foundation, piers and abutments are supported on pile foundations. Expansion joints are provided at the end of each span. For construction, M25-grade concrete and HYSD Fe-500-grade steel are used as reinforcement at all sections of the bridge. The details of sectional dimension are given in Table 1

Table 1. Cross-sectional details of the bridge under study

Bridge component		Description	Size (mm)
Deck slab		Width Thickness	8500 230
Longitudinal girders	Mid-span	Depth Thickness	1800 400
Longitudinal girders	Others	Depth Thickness	1200 400
Cross girders	Mid-span	Depth Thickness	1800 250
Cross girders	Others	Depth Thickness	1200 250
Bent column (C1)	Others	Length Width Height	550 650 7512
Bent column (C2)	Mid-Span	Length Width Height	600 750 12743
Abutment		Length Width Height	550 650 7512

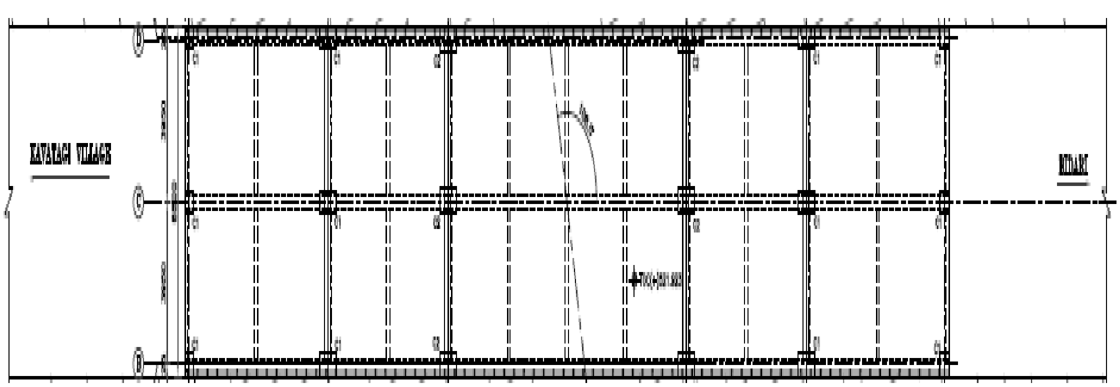

Fig. 1 Plan of the bridge

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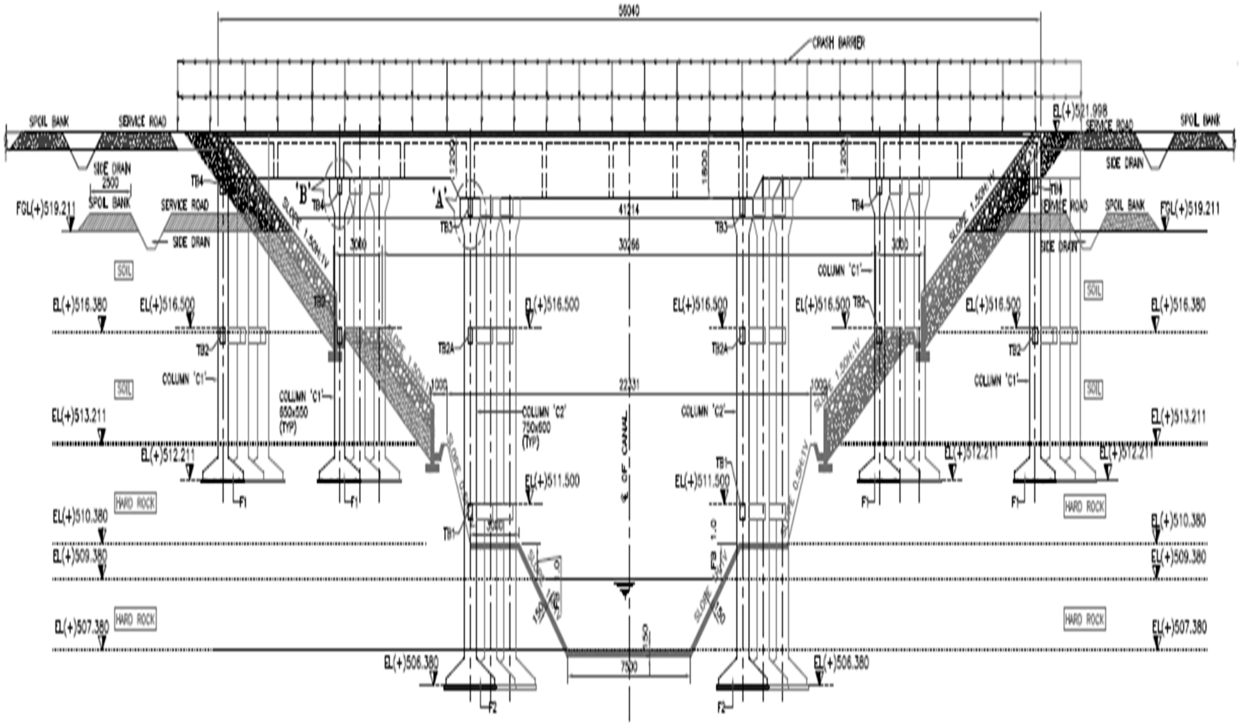

Fig. 2 Elevation of the bridge

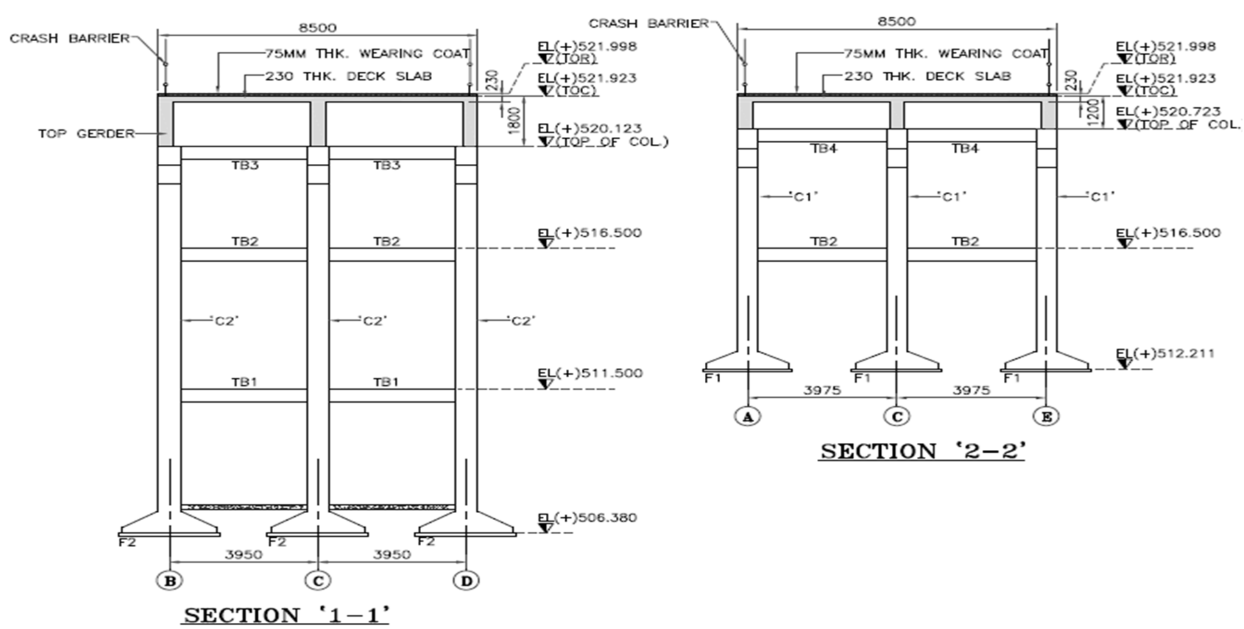

Fig. 3 Typical cross-sectional elevation of the bridge

III. METHODOLOGY

A. Modelling Of The Bridge

For modelling and analysis, a finite-element software tool SAP2000 v 14.2 is used. The selected RCC bridge is modelled as a three-dimensional finite-element model. The shell element is used for modelling the superstructure. The deck is assumed to be rigid and supported on the bridge bearings at the bottom of the girders. An RCC frame element with nonlinear properties at the possible yield level is used for modelling of piers, abutments, tie beam and pier cap. For this analysis, a total of ten models with three different isolators at three different locations are modelled and analysed. They are:

1) *Using Lead Rubber Bearing (LRB):*
a) Bridge with LRB at the top of the piers,
b) Bridge with LRB at the middle of the piers, and
c) Bridge with LRB at the bottom of the piers.

2) *Using High Damping Rubber Bearing (HDRB):*
a) Bridge with HDRB at the top of the piers,
b) Bridge with HDRB at the middle of the piers, and
c) Bridge with HDRB at the bottom of the piers.

3) *Using Friction Pendulum System Bearing (FPS):*
a) Bridge with FPS at the top of the piers,
b) Bridge with FPS at the middle of the piers, and
c) Bridge with FPS at the bottom of the piers.

For modelling of the isolation system, the guidelines of Chen & Scawthorn (2013) [21] and Naeim & Kelly (1999) [1] were followed and it is developed as a bilinear link element with vertical, horizontal and rotation stiffness in SAP2000.

Table 2. Properties of the FPS

a.	Radius of curvature of the spherical surface (R)	1.5 m
b.	Effective stiffness (K_{eff})	635 kN/m
c.	Elastic stiffness (Ke)	43754 kN/m
d.	Frictional coefficient (μ)	0.06
e.	Rate parameter	0.05

Table 3. Properties of the HDRB

a.	Effective stiffness (K_{eff})	1173.5 kN/m
b.	Effective damping (ξ_{eff})	20%.= 0.2
c.	Elastic stiffness (K_e)	943.4 kN/m
d.	Yield strength (Fy)	199.5 kN

Table 4. Properties of the LRB

a.	Effective stiffness (K_{eff})	1281.4 kN/m
b.	Effective damping (ξ_{eff})	10.6%.= 0.106
c.	Elastic stiffness (K_e)	7730 kN/m
d.	Yield strength (Fy)	79 kN

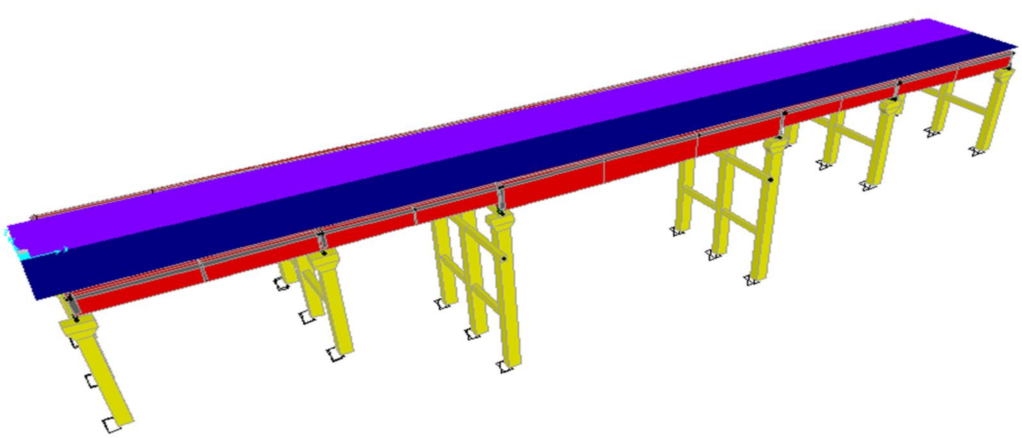

Fig. 4 SAP model of the study bridge without isolator.

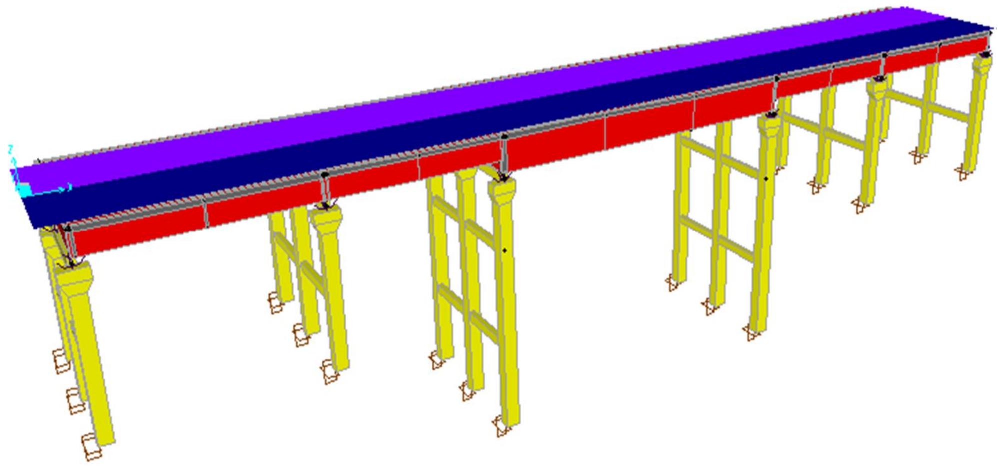

Fig. 5 SAP model of the study bridge with isolators at the top of the piers.

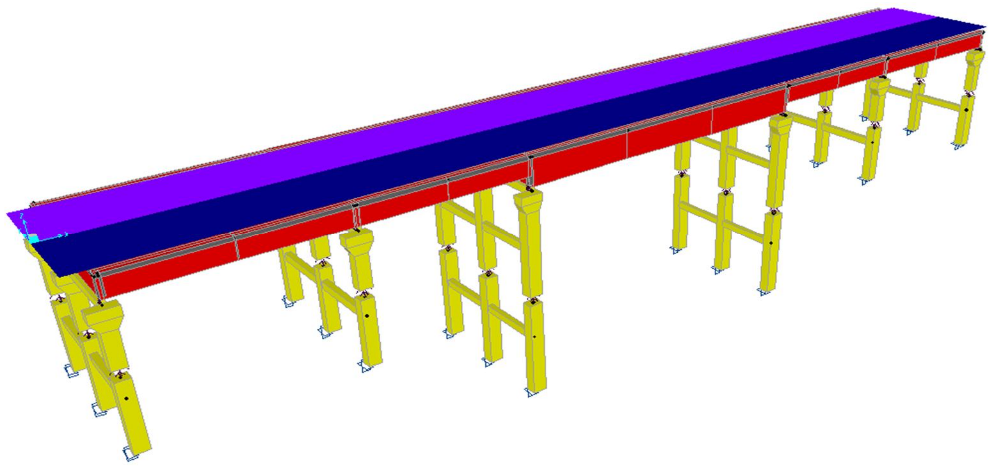

Fig. 6 SAP model of the study bridge with isolators at the middle of the piers.

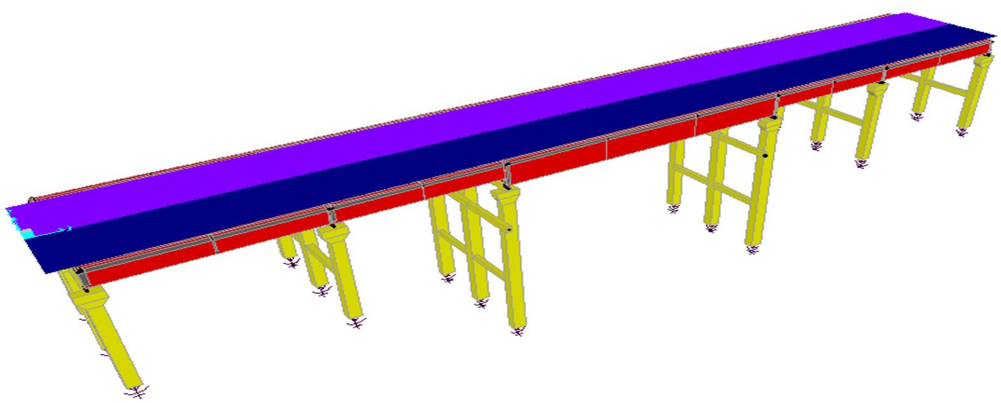

Fig. 7 SAP model of the study bridge with isolators at the bottom of the piers.

B. Analysis Of The Bridge Models

To evaluate the seismic response of the bridge with different isolators at different locations both linear equivalent static and nonlinear time-history analyses methods have been selected. For linear static analysis, the required values are taken from the guidelines in IRC: 06-2014 and IS:1893 (Part-3) and for nonlinear time-history analysis to replicate the effect of the actual seismic excitation, the January 26, 2001 earthquake data of Bhuj, Gujarat, India were used.

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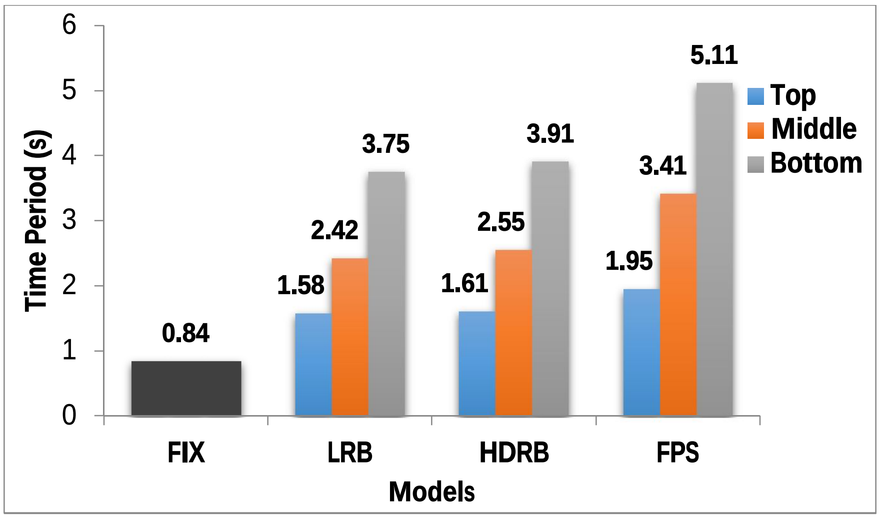
IV. RESULTS AND DISCUSSION

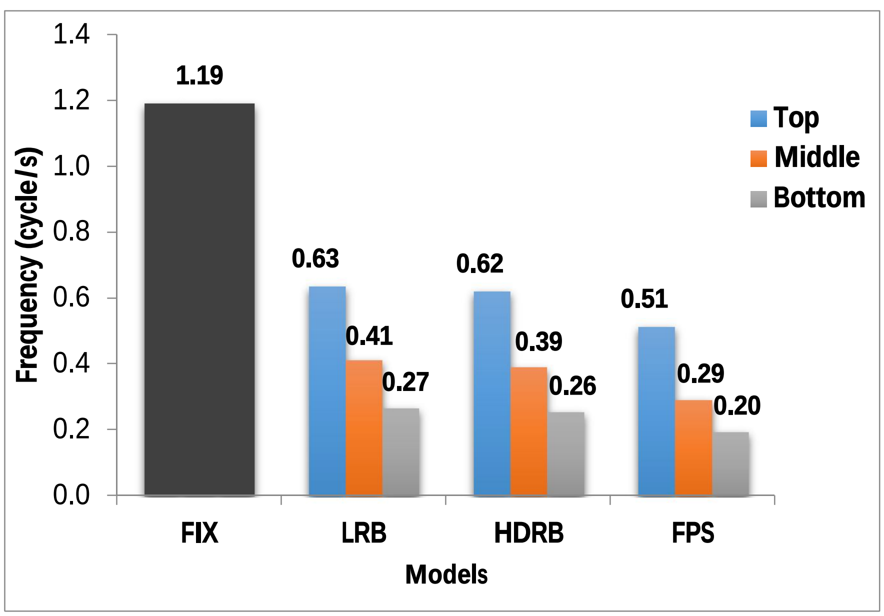
For the seismic response of the bridge with different isolators at different locations, both linear static and nonlinear time-history analyses, results have been extracted from SAP2000 and compared for modal properties, base shear, base moment and deck slab displacement. The results have also been checked and compared with all ten different bridge models. Time-history data of Bhuj earthquake were used for the analysis and the results are presented in graphs.

A. Modal Analysis Results

1) *Modal Time Period and Frequency:* As the first mode shape is very important for analysis and the design of any structure. From modal analysis, the time period and modal frequencies related to the first fundamental mode are extracted and presented in graphical format.



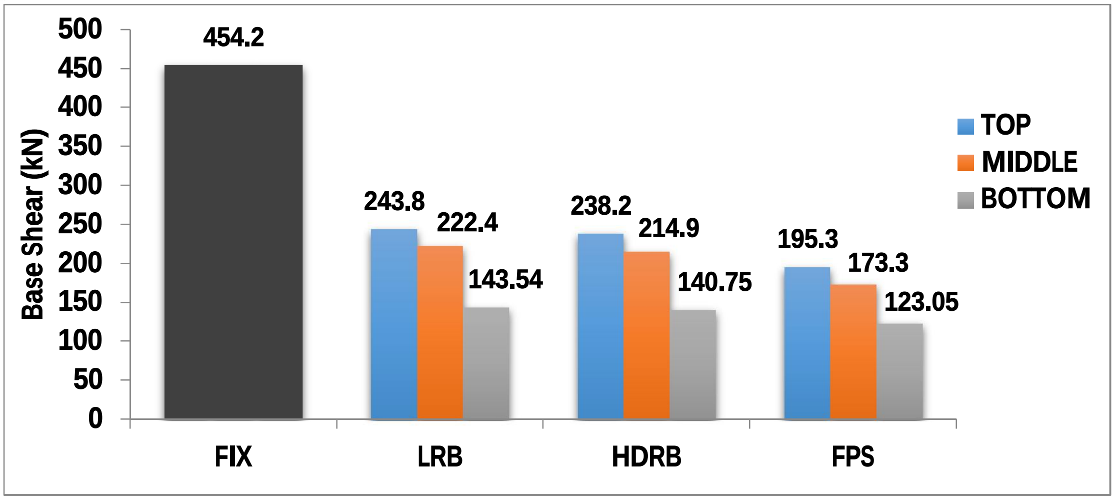
Graph 1. Comparison of modal time periods.



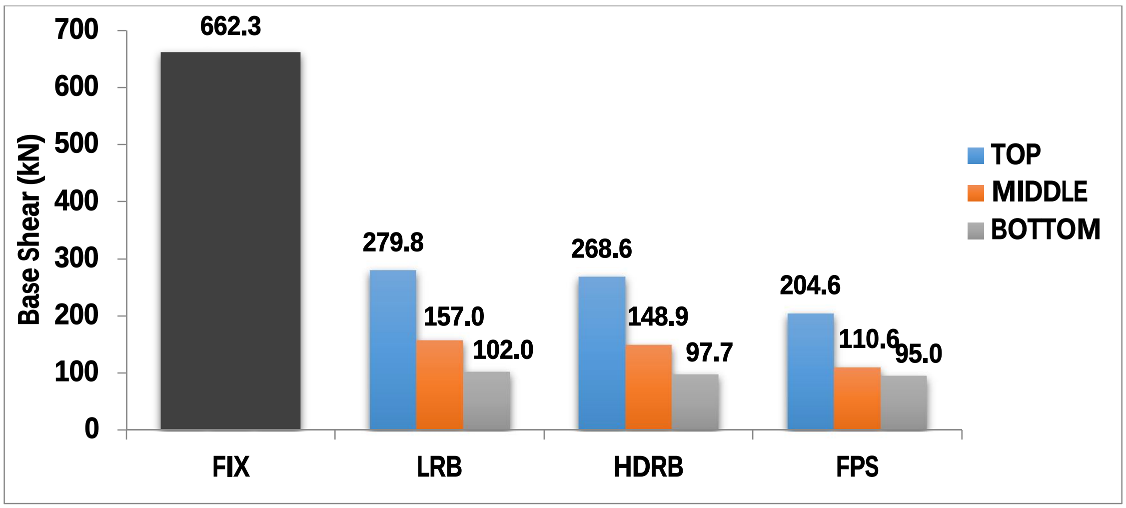
Graph 2. Comparison of modal frequencies.

B. Equivalent Static Analysis

1) *Base Shear:* It is estimated that the maximum values of lateral force will occur due to seismic ground excitation at the base of a bridge. Base shear values along two lateral directions are shown in graphs below.

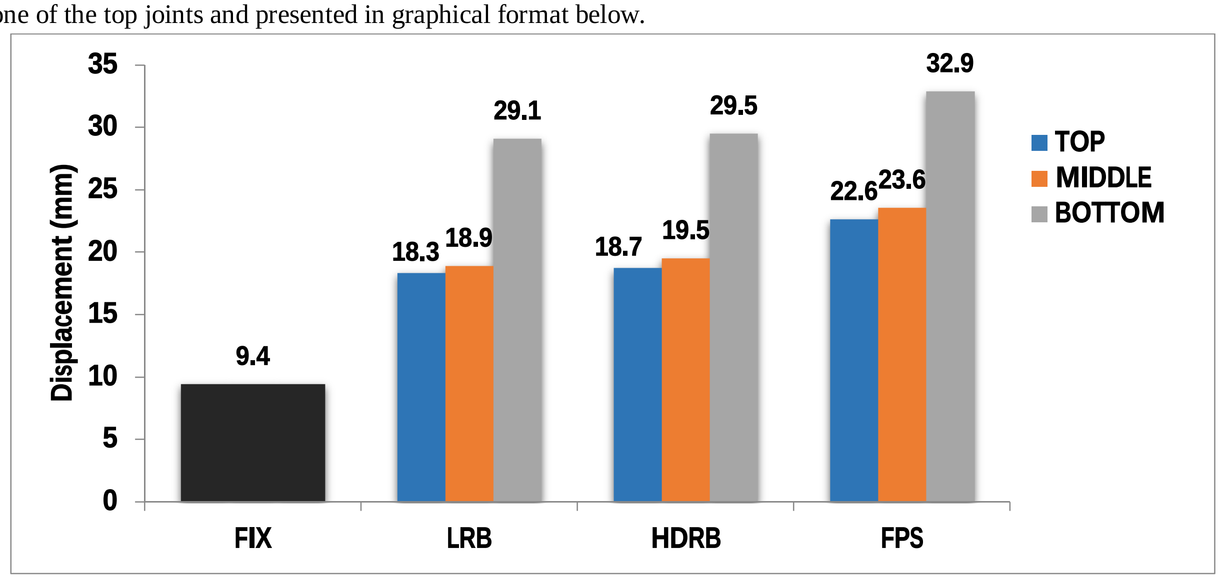


Graph 3. Base shear comparison along the X-direction.

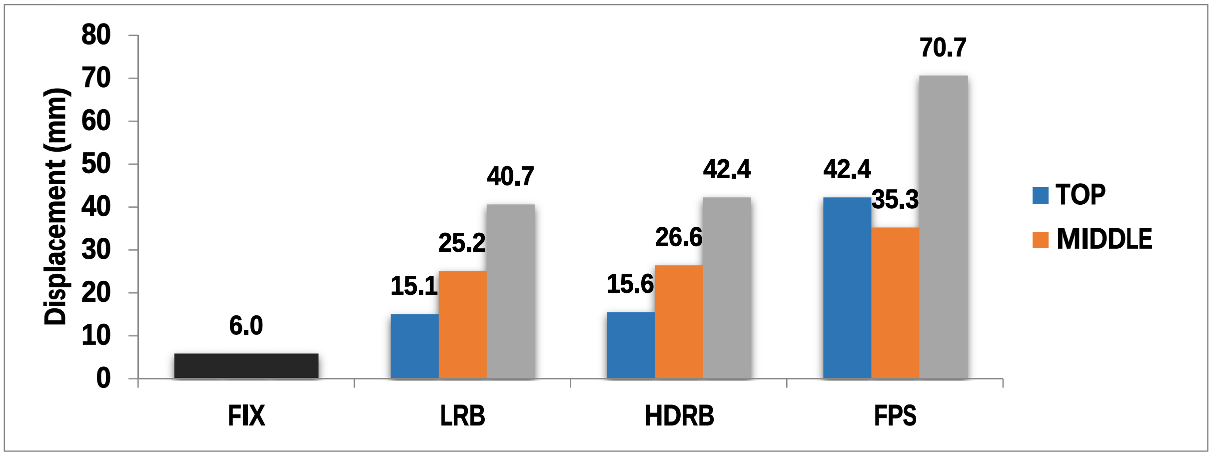


Graph 4. Base shear comparison along the Y-direction.

2) *Deck Slab Displacement:* The total displacement of deck slab from its original position along both lateral directions is extracted for one of the top joints and presented in graphical format below.



Graph 5. Comparison of deck slab displacement along the X-direction.

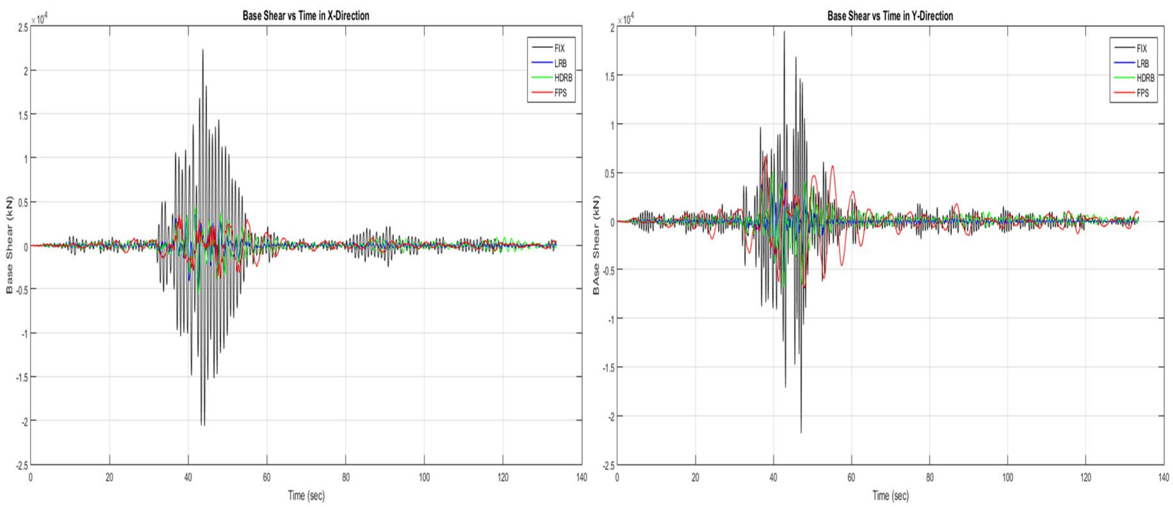


Graph 6. Comparison of deck slab displacement along the Y-direction.

C.Time-History Analysis

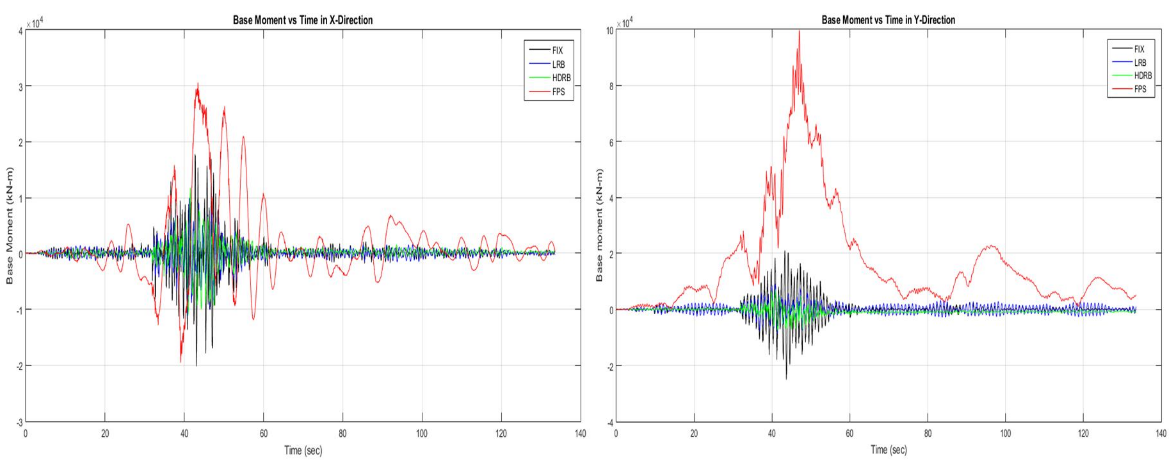
1) At The Top

a) Base Shear



Graph 7. Comparison of base shear of a typical pier at the base level in X- and Y- directions.

b) Base Moment



Graph 8. Comparison of the base moment of a typical pier at the base level in X- and Y- directions.

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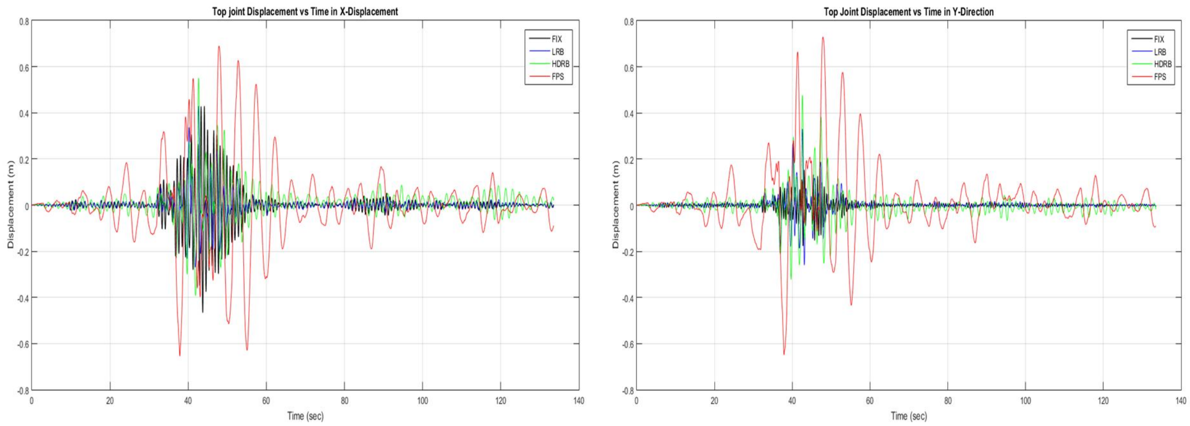
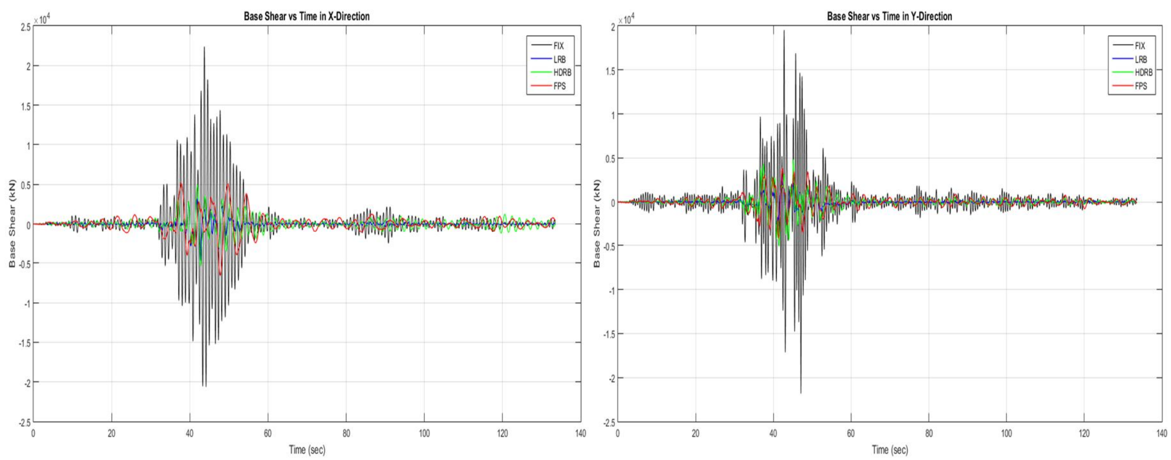
c) Deck Slab Displacement



Graph 9. Comparison of deck slab displacement of the bridge at the top level in X- and Y-directions.

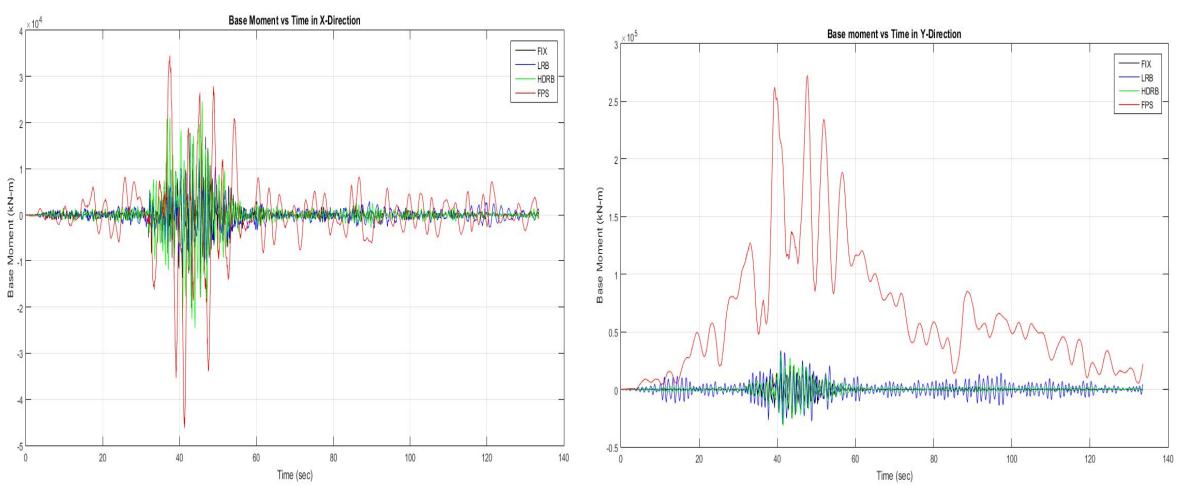
2) At The Middle

a) Base shear



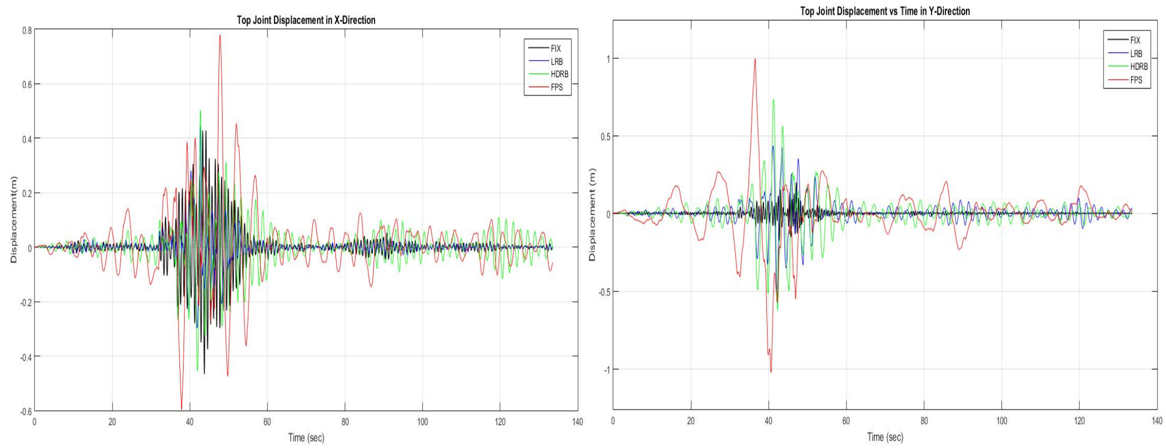
Graph 10. Comparison of base shear of a typical pier at the base level in X- and Y- directions.

b) Base Moment



Graph 11. Comparison of the base moment of a typical pier at the base level in X- and Y-directions.

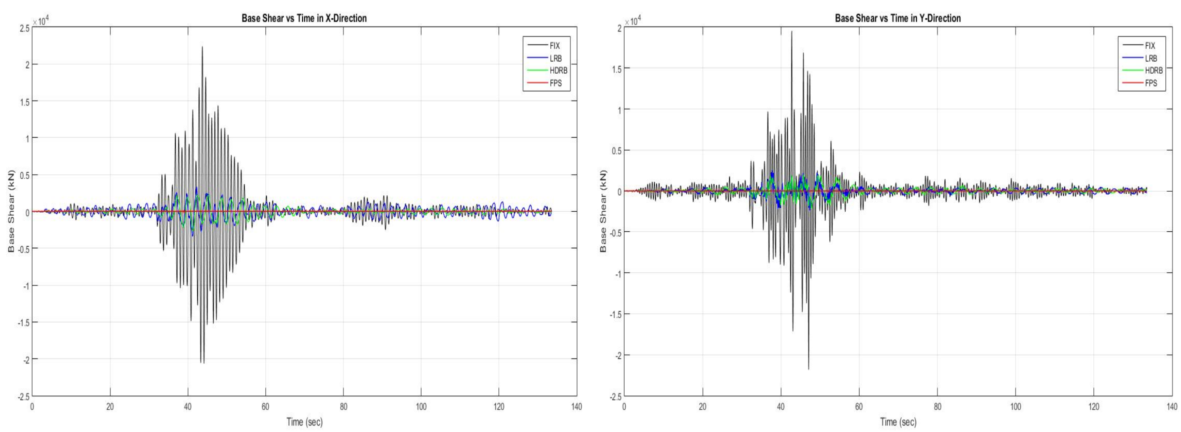
c) Deck Slab Displacement



Graph 12. Comparison of deck slab displacement of the bridge at the top level in X- and Y- directions.

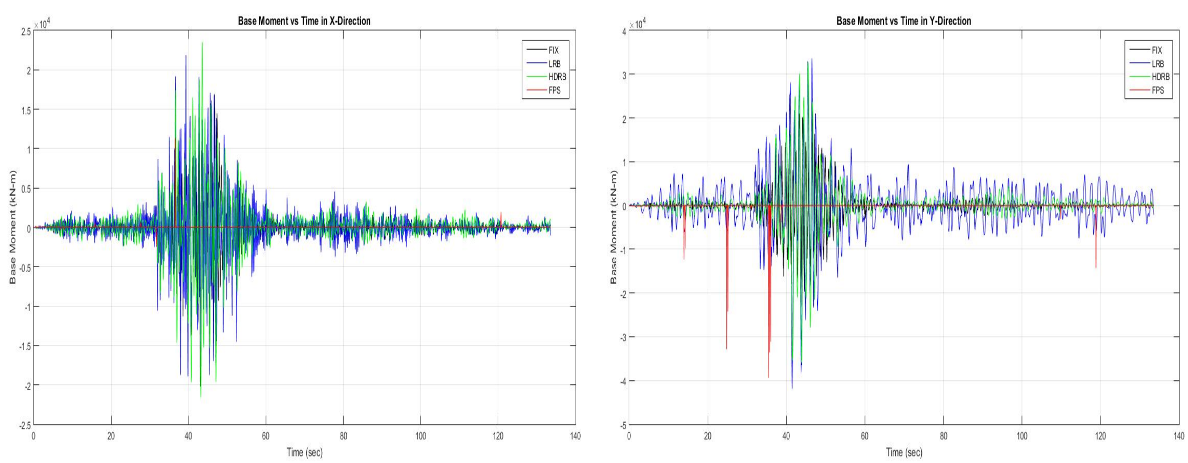
3) At The Bottom

a) Base Shear



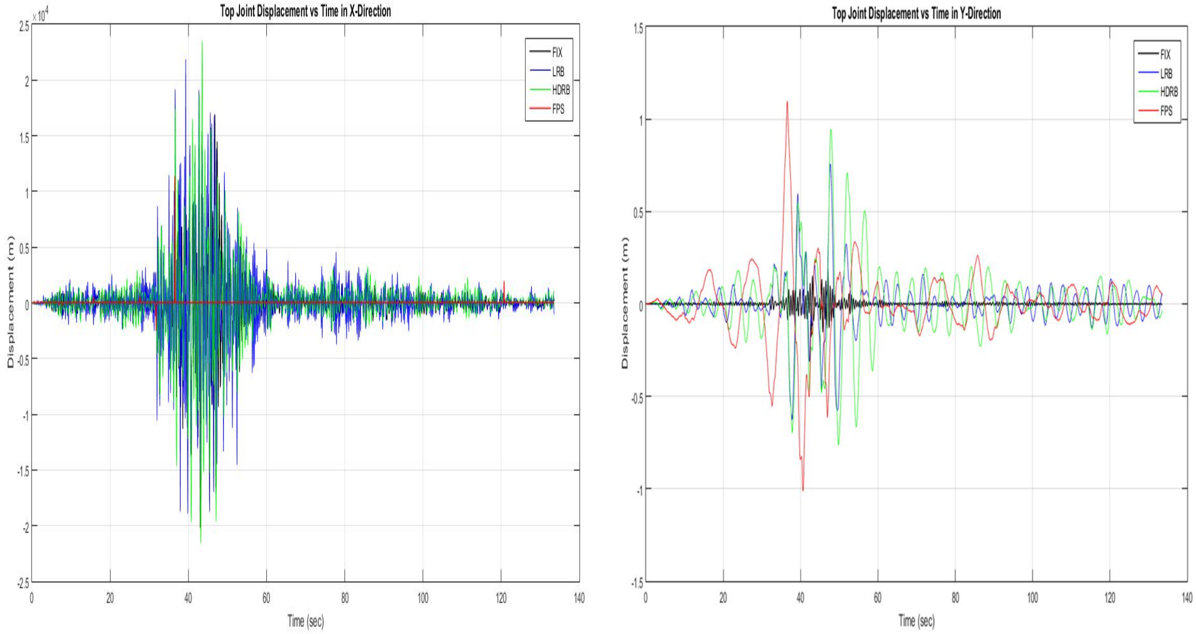
Graph 13. Comparison of the base shear of a typical pier at the base level in X- and Y- directions.

b) Base Moment



Graph 14. Comparison of the base moment of a typical pier at the base level in X- and Y-directions.

c) Deck Slab Displacement



Graph 15. Comparison of deck slab displacement of the bridge at the top level in X- and Y- directions.

V. CONCLUSIONS

To check the role of the location of isolation on different isolator systems, an RCC bridge with ten different configurations is modelled and analysed using the finite-element software SAP2000 V14.2. The following conclusions are drawn from the analysis:

A. The bridge with the isolator at the bottom of the pier has very less frequency and more modal time period as compared to the other two locations.

B. By comparing the isolators at the base of the piers, the FPS system has increased the time period by nearly six times as compared to those without the isolators.

C. The application of the isolation system at the base of the pier will reduce the base shear and increase the deck slab displacement in all isolators as compared to isolations at other locations and bridges without the isolators.

D. Time-history analysis shows a reduction in the base shear but increase in the deck slab displacement for base-isolated bridges in both directions.

E. Time-history analysis shows that by using the isolation system in bridges we can prevent damages to structures in quakes like the one at Bhuj.

F. On overall comparison, the best location for isolation is at the junction of the bottom of the pier and the foundation.

G. FPS is effective in reducing the base shear and in increasing the modal time as compared to the other two.

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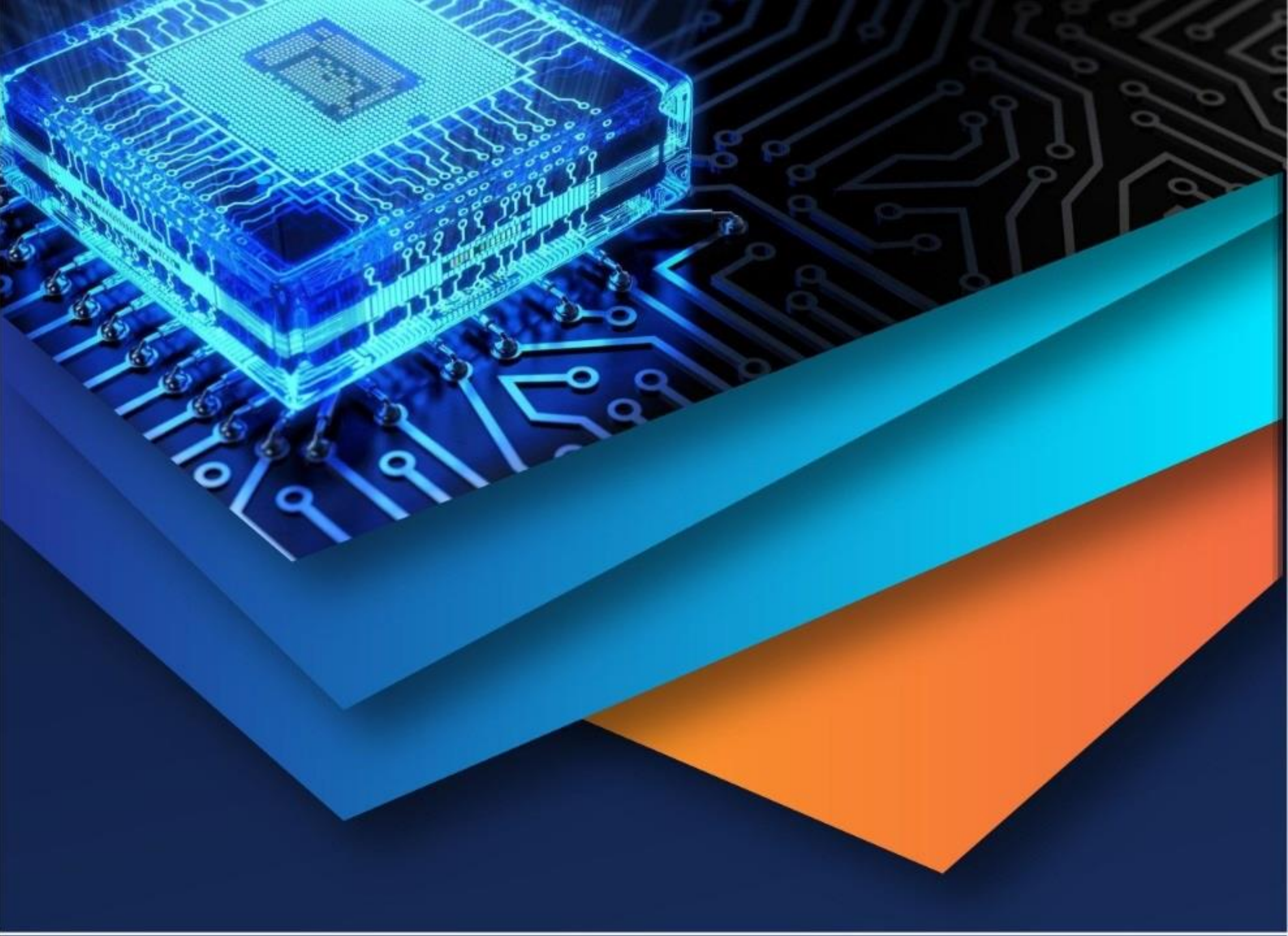

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