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COMPARATIVE ANALYSIS OF STEEL ARCH BRIDGE WITH AND WITHOUT BASE ISOLATION DAMPERS IN SEISMIC ZONE V

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Abstract According to IS 1893 (Part 1): 2016, the most severe seismic zone, this study compares the seismic performance of steel arch bridges with and without foundation isolation dampers in Seismic Zone V. The purpose of this research is to determine if base isolation technologies are useful for making bridges more resilient and safer by lowering the seismic loads on important parts of the structure. The ETABS program is used to create a comprehensive 3D model of the steel arch bridge. Utilising representative ground motion data for Zone V, the structural analysis integrates both linear and nonlinear dynamic approaches, namely Response Spectrum Analysis and Time History Analysis. To assess the effect of base isolation on seismic response characteristics such acceleration, natural period, base shear, and lateral displacement, dampers are used in the modelling process.

The results show that seismic forces communicated to the superstructure are much reduced when base isolation dampers are used, which improves energy dissipation and structural stability. Base shear and lateral displacement are significantly reduced in the isolated model when contrasted with the fixed-base model. The purpose of this research is to determine whether or not steel arch bridges in high seismic zone perform better when base isolation devices are used, and to provide useful suggestions for future design decisions based on those findings.

Keywords: ETABS, Steel Arch Bridge, Base Isolation, Dampers, Seismic Zone V, Dampers, Time History Analysis, Response Spectrum Analysis.

1. Introduction

Existing bridges do not need as much maintenance as new ones. However, bridges play an essential role in the transportation networks of any country. As of right now, seismic design is not a part of India's bridge design regulations. A large number of bridges are built without considering seismic pressures. Therefore, it is of the utmost importance to evaluate the present bridges' capacity to endure seismic force demands. Currently, structural engineers do not have access to comprehensive guidelines that would aid them in the assessment of older bridges and the provision of design and retrofit plans [1]. Using nonlinear static (Response spec) analysis, this work aims to evaluate an existing RC bridge for seismic activity in order to resolve this problem. Nonlinear static (response spec) analysis is not allowed for bridge structures under FEMA 356 [2]. The structural differences between a bridge and a multi-story skyscraper are vast. Hence, this study additionally uses Time history analysis and an improved Response spectrum analysis to back up the results [3,4].

Using ETABS Software, we will analyse the bridge model. Then, we will study the seismic behaviour of the bridge according to IS 1893:2002. Finally, we will compare the results of the fixed base, rubber base, and friction base isolation bridges that we obtained from ETABS Software. Lastly, we will determine which method, between the friction pendulum isolator and the rubber base isolator, is suitable for two span minor bridges.

Recognised for its strength, stability, and aesthetic appeal, an arch bridge is among the oldest bridge forms in human history. The foundation of its design is the arch form, which effectively distributes weight towards the end supports (abutments) by naturally transferring loads and forces into horizontal thrusts. Because of this structural concept, arch bridges may use less material to cover more distances than simple beam bridges [5]. The Romans, who excelled in building stone arches, are among the first known builders of arch bridges, but the practice predates them by thousands of years. Longer spans and contemporary architectural uses were made possible as a result of the gradual transition from stone and brick to steel and reinforced concrete (Fig. 1). These days, arch bridges are commonplace on roadways, trains, and pedestrian paths—anywhere practicality and aesthetics are paramount. They are recognisable landmarks in many cities throughout the globe due to its curved form, which serves as both a structural element and an aesthetic enhancement [6,7].

Fig 1: Arch Bridge

Base Isolation

All of the methods used to protect structures from earthquakes, guaranteeing safety and comfort under service loads, and which include adding particular kinds of additional components to the bridge, are collectively known as seismic isolation general. Seismic isolation is achieved by buildings using a number of methods. It would be prudent to examine seismic isolation in the context of basic dynamics before implementing these devices. From a basic dynamics perspective, it is possible to maintain seismic isolation in a bridge by manipulating its mass, damping, and the seismic forces acting on it. Everyone knows that when a bridge is exposed to ground motion, its mass, stiffness, and energy-dampening properties, together with any external seismic forces that might affect the structure, affect the equation of motion. One way to control the response force characteristics is to change the stiffness of the bridge. Loss of stiffness in the bridge causes displacements to increase and reaction acceleration to decrease [8, 9]. On the other side, you may lessen the reaction to acceleration and displacement by making the bridge more damping. The structure is flexible enough to function with many types of dampers and combinations of them. Changing the total mass and its distribution within the system may modify the structural system's dynamic characteristics. By separating it from the earth, the bridge may be better prepared for and controlled by seismic pressures.

Rubber Bearings:

These systems include a wide variety of materials, including neoprene, steel laminated rubber, and steel laminated rubber with a lead nucleus. The natural and synthetic rubber bearings used in bridge bearings were later transformed into elastomeric bearings. Using these bearings as seismic isolation devices is standard procedure. Rubber laminated isolators are made by vulcanising thin steel plates to rubber plates. Their most developed form is the lead-nucleus laminated rubber kind. The lead nucleus is implanted in the centre of lead laminated rubber bearing systems, which are highly sophisticated seismic isolators composed of steel/rubber laminated layers.

You may also get laminated rubber isolators that allow for larger lateral displacements called slider laminated rubber isolators. In these versions, the cylindrical laminated rubber mass is encased in a moveable plate. The sliding rubber isolator can only accommodate displacements up to a certain size, and a circular steel stopper is used to achieve this. Thus, in smaller seismic occurrences, the layered rubber's deformation reduces vibrations, while in larger earthquakes, the sliding plate allows the structure to move more horizontally.

In terms of horizontal flexibility, these bearings are rather stiff in the vertical direction. As seen in figure 2, these bearings convey the vertical components of earthquake forces to the structure, isolating it from the horizontal components subjected to seismic stresses. They are suitable for usage on pre-stressed, low-rise, stiff bridges. Seismic loading causes imbalances in internal forces and displacements in non-symmetrically built systems due to architectural factors. For such structures, rubber bearings are an excellent choice.

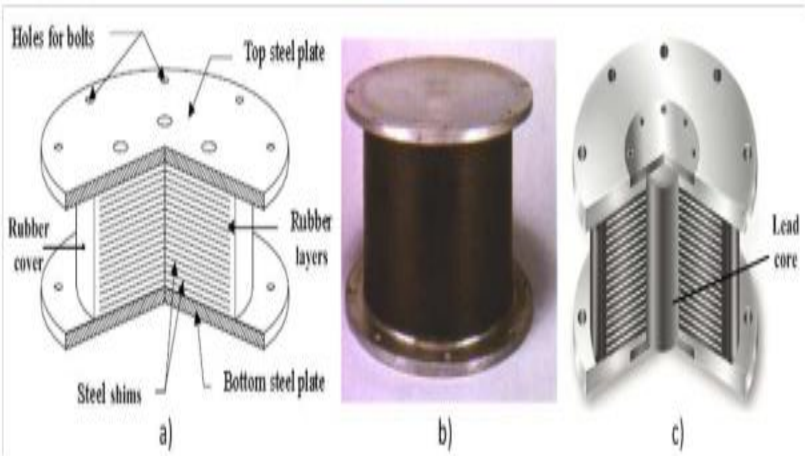


Fig 2: Elastomeric bearings: a) Natural Rubber Bearing (NRB), b) elastomeric bearing device, c) Lead Rubber Bearing (LRB)

Base isolators are positioned to balance the centre of mass and centre of stiffness. In doing so, the structural system's inhomogeneous layout is rendered harmless. Unlike mechanical devices, these bearings may glide in one or more directions and handle large pressure loads. Due to its low shear modulus, rubber loses some of its torsion freedom and gains a lot of shear stiffness when steel laminates are added to it. These bearings are durable and impervious to environmental stresses. Elastomeric bearings are not designed to handle the tensile stress that is generated by overturning moments. Attaching tensile-force-resistant equipment to this isolator makes its construction more stiffer. To create elastomeric bearings, you may utilise rubber that is either very dry or very wet. The minimum vibration allows the equipment inside the buildings that employ these bearings to remain unharmed, even when the displacements are substantial.

Friction pendulum bearings:

Friction pendulum systems are the most common kinematic systems, especially when the base is isolated. In a pendulum system, either a spherical part with global contact surfaces or a steel globe mounted on two concave curved surfaces are used. These parts make use of special metals. These bearings, which have all the benefits of rubber bearings but also employ a gliding bearing component on a concave surface, raise the bridge during lateral motion, thereby reducing the effect of earthquakes, and this is seen in figure 3. Lots of different kinds of big roof systems, spans, and buildings may make use of these bearings. You may utilise them effectively in cold locations where freezing temperatures are a possibility because of the mechanical properties of the special metals used in their manufacturing

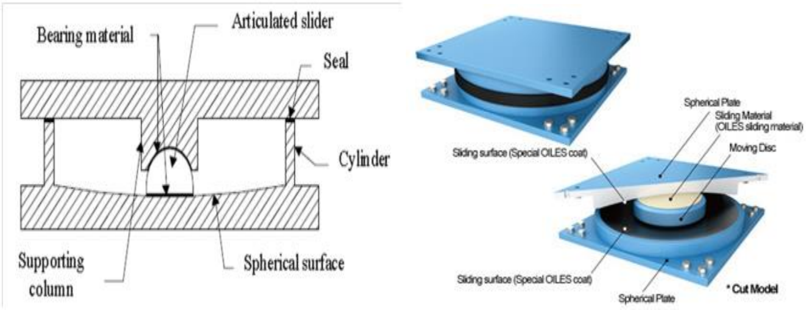


Fig3: Flat Friction pendulum section cut and Curved / spherical Friction pendulum Section

2. Literature Reviews

In a study involving an irregularly designed multi-story RC building, **Donato Cancellara et al. (2016)** investigated the dynamic nonlinear analysis of multiple base isolation systems. An investigation was conducted to compare and analyse the seismic behaviour of two different base isolation systems in relation to a multi-story reinforced concrete structure. A comparative analysis is presented to evaluate the seismic response of an isolated irregular structure. We studied two base isolation systems: one that used a Lead Rubber Bearing (LRB) and the other that used a High Damping Rubber Bearing (HDRB) and a Friction Slider (FS).

To model how hybrid base isolation systems react to seismic stimulation, **Athanasios et al. (2016)** investigated. investigated the seismic response of a hybrid base isolation system. The base isolation system consists of low-friction sliding bearings and rubber bearings that provide effective damping. To numerically model the high damping rubber bearing component, two separate models—a bilinear and a trilinear system—are used in conjunction with a linear viscous damper.

In the presence of bidirectional ground movements, **Fabio De Angelis et al. (2016)** examined the nonlinear dynamics of RC structures using hybrid base isolation systems. This article compared three different hybrid base isolation methods for preventing bidirectional ground vibrations from damaging reinforced concrete buildings. Elastomeric spring dampers and friction sliders, lead rubber bearings and friction sliders, and high damping rubber bearings and friction sliders were the three hybrid base isolation systems that were considered.

3. Methodology Used

3.1 Response Spectrum Analysis

As it uses a specified reaction spectrum to predict the maximum structural response to earthquake ground movements, reaction Spectrum Analysis (RSA) is a commonly used approach for seismic analysis. Based on the correct soil type and seismic zone factor for Zone V circumstances, this study was conducted in compliance with IS 1893-2016 (Part 1). This approach assessed the bridge's seismic response using the ETABS program. In accordance with the rules of the IS code, the conventional design response spectrum curve for medium soil types was used, which plots time period against spectral acceleration (Sa/g).

The response to seismic loading is estimated using this approach, which includes base shear, lateral displacement, bending moments, torsion, and acceleration. The time-dependent fluctuation of forces and displacements during the earthquake cannot be captured by response spectrum analysis, which is based on peak response values. Regular buildings of modest height are often good candidates for the strategy. Dynamic time history analysis and non-linear static analysis are two examples of the more sophisticated approaches that are often necessary for very tall and irregular bridges as well as those that are vital to disaster response networks.

3.2 Time History Analysis

One of the most precise seismic analysis approaches is Time History Analysis (THA), which incorporates actual or simulated earthquake ground motion recordings into the structural model. This approach is superior to static or spectrum-based techniques for critical infrastructure because it captures the time-dependent behaviour of the bridge during seismic excitation. The researchers in this work used ETABS to do nonlinear time series analysis. The data used for input was seismic ground motion data that was indicative of Seismic Zone V conditions according to IS 1893:2016. The Fixed Base Model, the Rubber Bearing Isolated Model, and the Friction Pendulum Isolated Model three bridge modelswere subjected to all applicable load scenarios mentioned in 4th chapter below.

The study set out to assess the bridge's seismic performance in the face of intense earthquake shaking. Time History Analysis provides more light on acceleration response, torsional effects, displacement, base shear, bending moments, and torsional effects than Response Spectrum Analysis.

4. Modeling of bridge

The bridge is modelled using the finite element program ETABS. The four-noded shell components represent the deck slab, while the frame (beam) elements are used to simulate the girders and cross-girders. Piers are represented by the elastic material properties of beam-column components. The expectation that plastic hinges will mostly develop in the piers dictates that they be installed near the base of the piers (FEMA 356, 2000). All of the pier base's degrees of freedom are limited since the foundation is considered a fixed support. Impacts of interactions between soil and structure are neglected.

4.1 Geometrical properties

The below details show the parameters of the assumptions used in the model for the analysis and seismic evaluation considered for the bridge model made with various base isolations namely rubber base isolation and friction pendulum system.

1.	Length of the bridge	=	500 m
2.	Width of the bridge	=	30 m
3.	Span in both the directions	=	500m X 30 m
4.	Height of the bridge	=	81.3 m
5.	Number of lanes	=	2
6.	Slab Thickness	=	500 mm
7.	Grade of the concrete	=	M 50
8.	Grade of the steel	=	Fe 500
9.	Support	=	Fixed, lead rubber, friction pendulum
10.	Column sizes	=	2m Dia
11.	Beam Size	=	1mx2m
12.	Seismic zone	=	V (0.36)
13.	Soil Type	=	II (Medium soil)
14.	Wind speed	=	44m/s
15.	Terrain category	=	1
16.	RCC Code	=	IS: 456-2000
17.	Seismic code	=	IS 1893-2016
18.	Wind code	=	IS 875-2015s

4.2 Loads considered for this Bridge design modelling

Dead load: The dead load is considered as per IS: 875 (Part-1) -2015.

Imposed Load: The imposed load is considered as per IS :875 (Part-2) – 2015,

Live load for floors: 3.0 kN/m2, Floor Finish: 12.5 kN/m, Wallload 11.14 kN/m.

Seismic load: The seismic load is considered as per IS 1893: 2016

4.3Base isolation Properties

Rubber Base Isolation Stiffness values

1. U1- Effective stiffness -15000000 kN/m
2. U2 –Non linearEffective stiffness-800 kN/m

Stiffness-250 kN/m
Yield strength-80 kN
Post Yield strength ratio – 0.1,

3. U3 –Non linearEffective stiffness-800 kN/m

Stiffness-250 kN/m
Yield strength-80 kN
Post Yield strength ratio – 0.1,

Friction pendulum Isolation stiffness values

1. U1-Stiffness -15000000 kN
2. U2- Non linearEffective stiffness – 70 kN/m

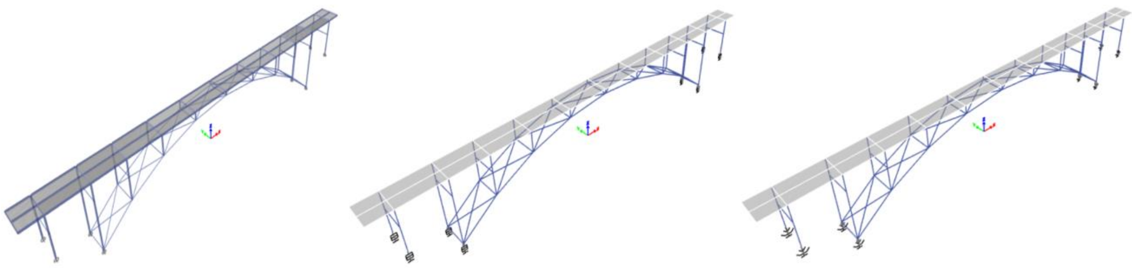
Stiffness – 1500 kN/m
Friction cost slow – 0.03,
Friction cost fast – 0.05,
Rate parameter - 40,
Radius of sliding - 2.23,

3. U3- Non linearEffective stiffness – 70 kN/m

Stiffness – 1500 kN/m
Friction cost slow – 0.03,
Friction cost fast – 0.05,
Rate parameter - 40,
Radius of sliding - 2.23

4.4 BridgeModels in ETABS Software

Images below demonstrate the ETABS-created arch bridge model with a fixed support, rubber base isolation, and friction pendulum mechanism. The needs of the bridge model dictate the first selection of material qualities. Afterwards, the attributes pertaining to the sizes of the columns, beams, and slab members are determined in accordance with the considerations of the bridge model, as seen in Figure 4. Following the application of the load cases in accordance with the provisions of the IS code, the bridge model is subjected to various combinations of support conditions and loads. The model is then analysed to verify its results under various base isolation conditions, including those pertaining to rubber base isolation and the friction pendulum system.



(a) (b) (c)

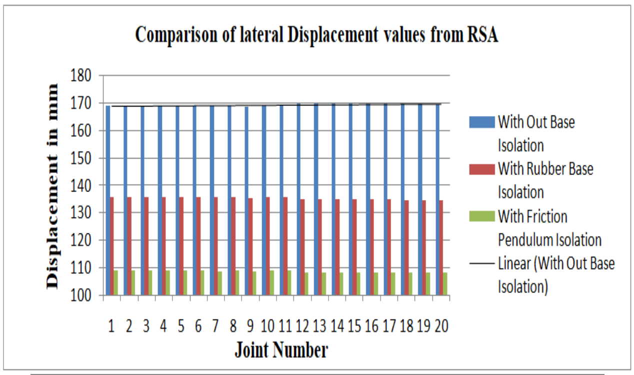
Fig 4:(a) Bridge model with fixed Supports, (b) Bridge model with rubber base isolation, (c) Bridge model with friction pendulum isolation

5. Results and analysis

The seismic reactions of three different bridge models—the Rubber Base, the Fixed Base Model Isolation Model, and the Friction Pendulum Isolation Model—were a part of this study. In order to guarantee consistency in assessment, all models have been tested using the same ground motion data, loading circumstances, and design parameters. Acceleration, lateral displacement, base shear, and natural time period, the four most important metrics for seismic performance assessmentare used to present the results. It is easy to see how different base separation solutions lessen seismic stress and enhance structural stability by comparing these results.

5.1 Lateral displacement

The defect impact of the bridge model when forces are applied in a horizontal direction is lateral displacement. The fluctuations are taken into account according to the conditions of the response spectrum analysis and the time history analysis, as the seismic force is providing mode deflection values when compared with other load instances.



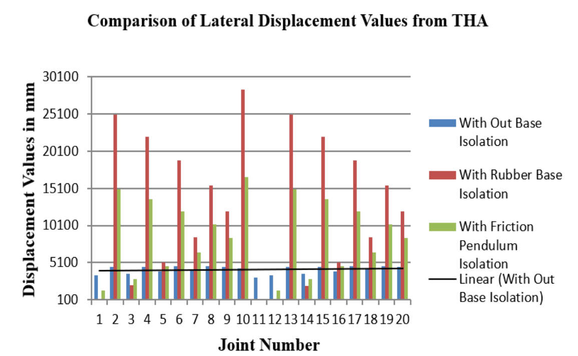


Fig 5(a) Comparison of lateral displacement from RSA results, (b) Comparison of lateral displacement from THA results.

From the above graphs related to Response spectrum analysis Fig 5 (a) and time history analysis Fig 5 (b) it was concluded that by using base isolation system the defection of building model is decreasing due to the effect of stiffness value we are providing for the U1 direction.

5.2 Base shear

One way to calculate the entire seismic force that a building has to endure at its base is by multiplying its total effective seismic weight (W) by a seismic response coefficient (Cs) or horizontal acceleration coefficient (Ah). This value is called base shear. Based on the area's seismic threat, the building's fundamental period of vibration, and its structural system, this coefficient is determined using seismic standards as per IS 1893 in India.

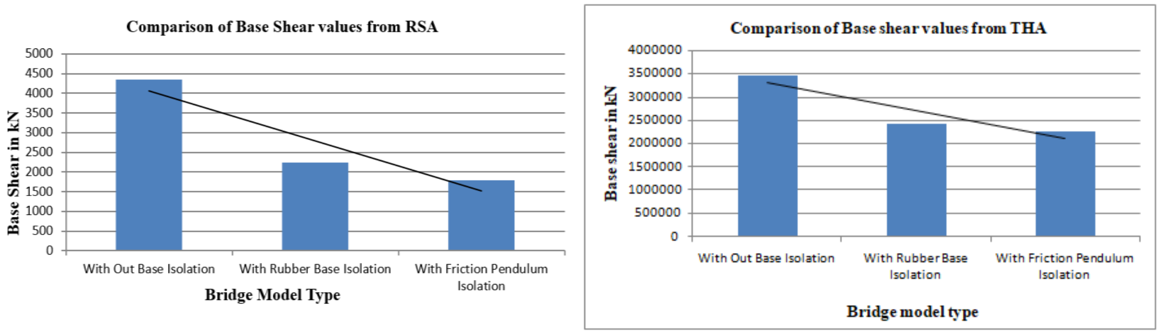


Fig 6(a) Comparison of Base shear from RSA results, (b) Comparison of Base shear from THA results.

As per the both analysis methods it was concluded that bridge model made with friction pendulum system is giving less values of Base shear refer Fig 6 (a), Fig 6 (b). So as per the seismic weight consideration the friction pendulum system will give less weight to entire bridge model when we compared with rubber base isolation model.

5.3 Time period

Structures that can withstand earthquakes are designed with time in mind. The basic period of vibration is evaluated by taking into account the total height of the building or the number of storeys, according to regulations such as Indian code (IS), United States (US), and Egyptian codes, as well as by following the suggestions given by researchers.

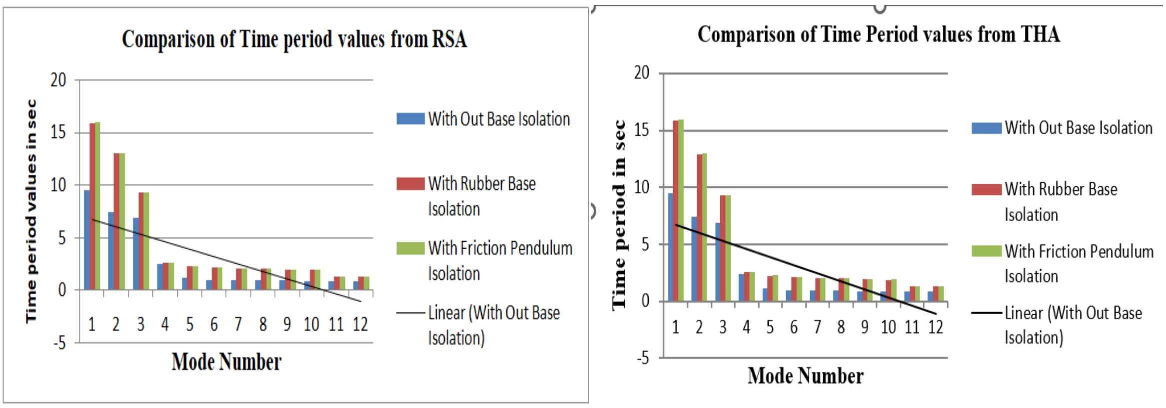
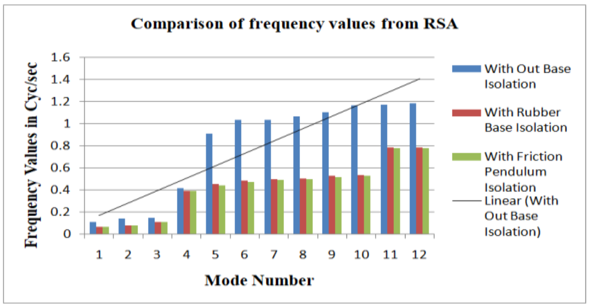


Fig 7(a) Comparison of time periodfrom RSA results, (b) Comparison of time periodfrom THA results.

There is no effect on the time period values as per the seismic load consideration using Response spectrum method Refer Fig 7 (a) and time history method Refer Fig 7 (b). The bridge model made with rubber base isolation has higher values when we compared with without base isolation and having higher values for the friction pendulum system as we compared with rubber base isolation and fixed base model.

5.4 Comparison of Frequency Values

Similar to other activities, it is crucial to understand common frequencies and modular damping proportions of structures in order to estimate or perceive vibrations. There is some validity to regular recurrence evaluation methods, however it is challenging to appropriately measure modular damping proportions in the modern day. Damping estimates derived from real-world construction estimating data are wildly different. The intentional characteristics are affected by a variety of variables, including the quantity of nonstructural part, sufficiency proportions, underlying segments, base structures, and other such things.



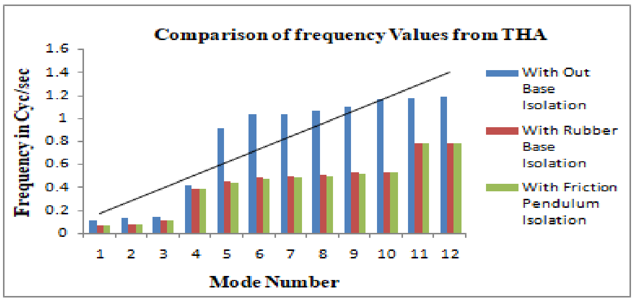
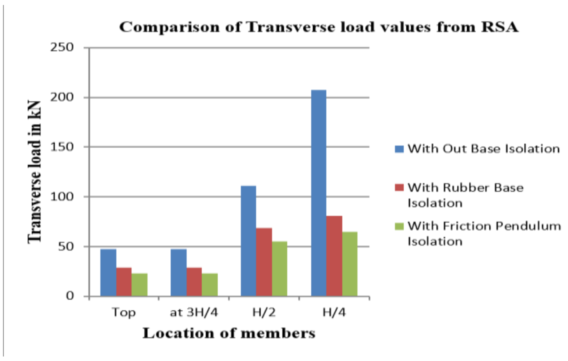


Fig 8 (a) Comparison of frequencyfrom RSA results, (b) Comparison of frequencyfrom THA results

There is no effect on the frequency values also as per the seismic load consideration using Response spectrum method Refer Fig 8 (a) and time history method Refer Fig 8 (b). The bridge model made with rubber base isolation has less values when we compared with without base isolation and having less frequency values for the friction pendulum system as we compared with rubber base isolation and fixed base model.

5.5 Transverse Load P

Loads that run parallel to the ground, or flat powers that follow an edge, are called sidelong loads. Their values change in response to gravity loads, such as rising and falling forces. The most common kinds of sidelong loads are wind load, seismic burden, water pressure, and earth pressure. While wind load may not be a big issue for small, big, low-rise buildings, it becomes more of a concern as buildings are taller, when lighter materials are used, and when features that affect wind current, such different kinds of rooftops, are used. Seismic loads may be particularly damaging to buildings during earthquakes (Relative Performance of fixed based and base limited solid edge, H. W. Shenton1 III and A. N. Lin2). They will likely be rather fast loads, in contrast to wind loads. In order to prevent implosion in the event of an earthquake, buildings in seismically active areas should be designed accordingly.



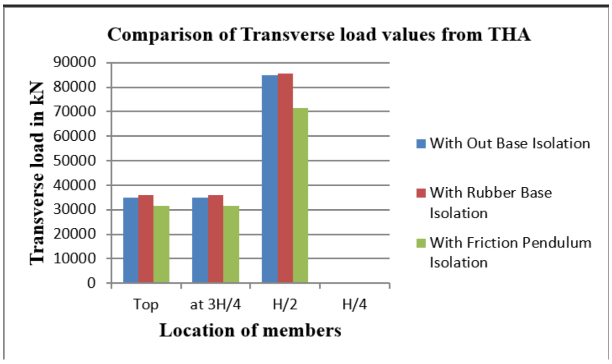


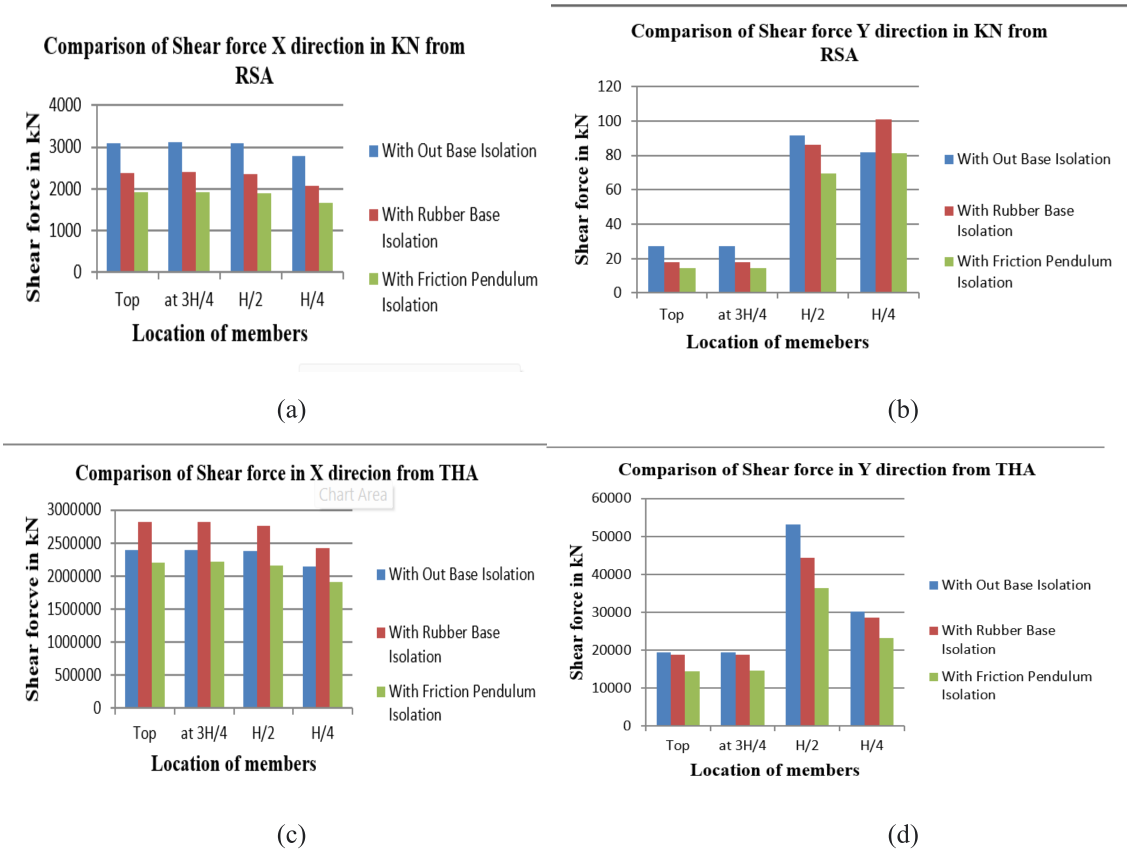
Fig 9 (a) Comparison of lateral load Pfrom RSA results, (b) Comparison of Lateral load Pfrom THA results

The above graphs shows the variation of transverse load in zone V seismic condition shown in Fig 9(a) and Fig 9(b) due to time history analysis where H is height of the bridge model. The bridge model created using friction pendulum system is having less transverse load when we compared with without base isolation and rubber base isolation model.

5.6 Comparison of Shear force V

Shear force is a load that acts the other way of the surface that is applied opposite to it. Shear load is the result of this. To put it another way, one segment of the surface is moved one way while another is pushed the other way.

The values of the variation of shear force in X direction in the fig 10(a), fig 10(c) and shear force in Y direction in the fig 10(b), fig 10(d) for both Response spectrum analysis and time history analysis are displayed in the graphs, it was determined that the bridge model made with friction pendulum system has less values of shear in comparison to the rubber base isolation system's fixed basis. A base-isolated structure's reduced shear force shows that the isolation from earthquakes system is successfully lowering the forces that are transferred from the earth to the structure in question during an earthquake.



(a) (b)

(c) (d)

Fig 10 (a) Comparison of Shear force X direction from RSA results, (b) Comparison of Shear force Y direction from RSA results, (c) Comparison of Shear force X direction from THA results, (b) Comparison of Shear force Y direction from THA results.

5.7 Torsion T

Twist is the strain condition of a material that has been bent by a force. When a bending action exposes an underlying portion, this happens. Rubber bar with square forms recorded on one side and retained on the other is a twisting device because the shapes bow or twist when one side spins relative to the other.

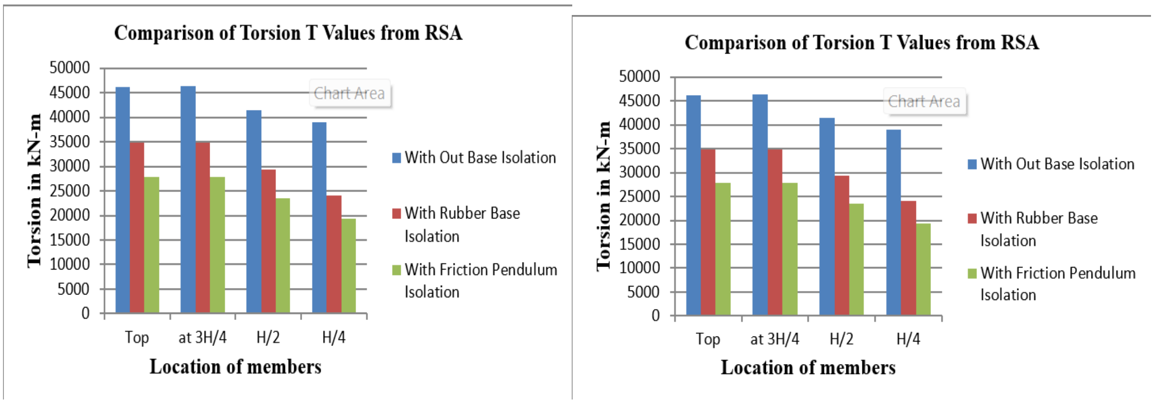
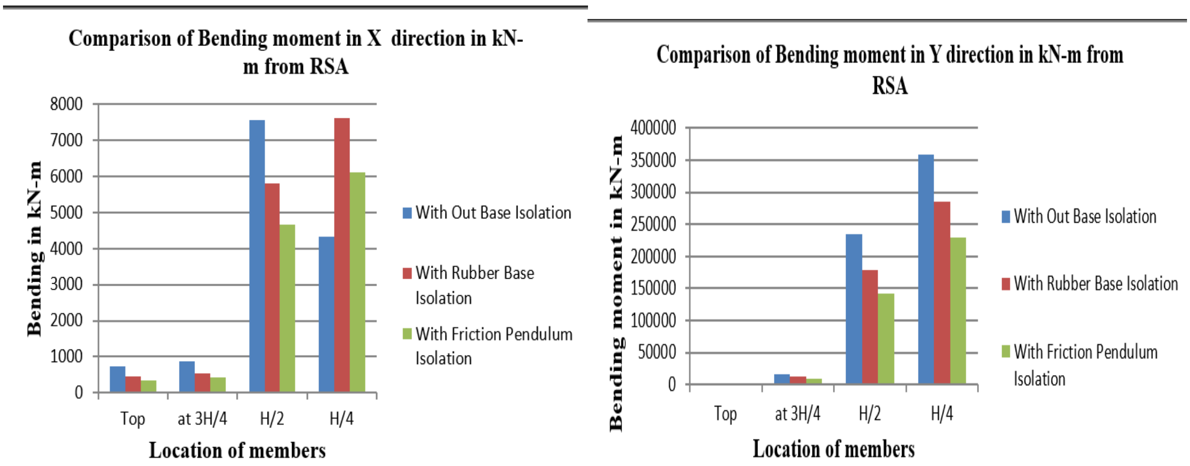


Fig 11(a) Comparison of Torsion T from RSA results, (b) Comparison of Torsion T from THA results.

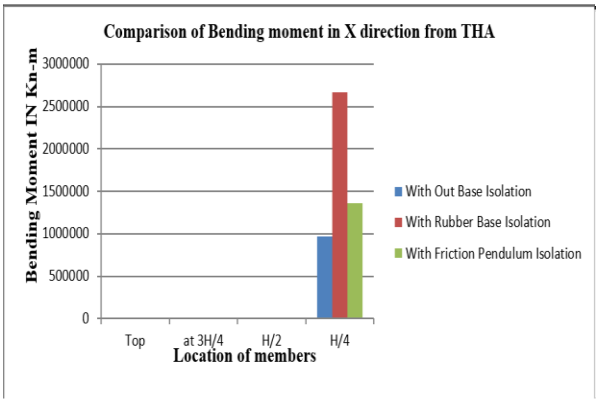
The square forms have been deformed by twist, a state of pressure that is entirely composed of pure shear. The rubber bar's twist would try to get it back to its original shape. Shear foces are created by twist, which is the same as applying friction and pressure at the correct locations.The primary goal of base isolation in a seismic context is to reduce the forces and resulting stresses (like bending moment and torsion) transmitted from the ground into the superstructure. Since the Friction Pendulum Isolation system demonstrates the lowest Torsion T values, it is the best model for reducing this specific detrimental effect, suggesting it provides the superior structural protection against twisting loads compared to both the Fixed Base and the Rubber Base Isolation systems. This reduced torsion translates to lower stress on the structure, likely resulting in less damage during a seismic or high-force event

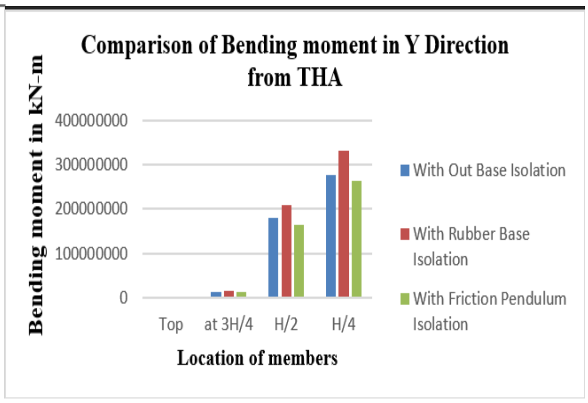
5.8 Bending Moment M

Any structural element, like a beam, has an internal force called a bending moment that acts as a resistance to any moments or pressures applied to the element from outside. The moment arm, which is perpendicular to the direction of application, and the applied force are multiplied to get the result. Units of force times distance, such as Newton-meters (N-m), are used to measure the internal stresses caused by the bending moment, which cause compression on one side of the beam and tension on the other.



(a) (b)





(c) (d)

Fig 12(a) Comparison of Bending moment in X direction from RSA results, (b) Comparison of Bending moment in Y direction from RSA results, (c) Comparison of Bending moment in X direction from THA results, (d) Comparison of Bending moment in X direction from THA results.

Therefore, using rubber bearings or friction pendulum systems, do decrease the bending moment in a bridge model because they decouple the structure from the ground's seismic motion, lengthening the structure's natural period and dissipating energy through flexible or sliding components, thereby reducing the forces transmitted to the bridge.

6. Conclusions

The efficacy of base separation technologies during earthquakes is the intended outcome of this study. The following conclusions are drawn from the analysis.

1. The time period value of base isolated structures is lower than that of fixed base structures.
2. The bottom of the bridge has an isolation mechanism that reduces the frequency values; this mechanism consists of a rubber bearing and a friction pendulum.
3. The shear force values in the X and Y directions were larger with the fixed base than with the isolation approach (rubber bearing, friction pendulum).
4. The fixed basis produced greater X and Y bending moment values in comparison to the separate system (rubber bearing, friction pendulum).
5. Torsion values were greater in the fixed base system compared to the isolation system.
6. The software output makes it simple to retrieve these findings, which include bending moments and shear force at every single node at every position within the element.

Use of an isolation system may reduce the shear, flexing, torsion, duration, and frequency of the bridge, as shown in the research.

Recommendations

For the future studies the following points are considered

1. The cable Bridge can be made in the future studies by considering base isolation systems namely rubber base isolation and friction pendulum system.
2. The arch bridge in this research used in medium soil condition, but we can study in loose as well as rock soil condition in future studies.
3. The span can be increased to 60m, 70m, 80m etc in the future studies to check the stability as per base isolations consideration.
4. The span length between the supports can be decreased or increased in the future studies to check the analysis results as per the considerations.

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