

Study of Seismic Behaviour of Bridges with Base Isolation

Sanath Kumar D¹, Dr. Sheik Kabeer Ahmed²

Student¹, Assistant Professor²

Department of Civil Engineering

Nitte (Deemed to be University), NMAM Institute of Technology

Corresponding Author's Email:- sanathnaik75@gmail.com

Abstract

Bridges play a significant role in transport connection as they ensure continuous transportation network between two inaccessible vicinity. During the period of natural disaster such as earthquakes, it provides an emergency services like supply of food, medicines etc.; hence, the bridges are lifeline structures. Bridges are very susceptible to ground motions due to simplicity in their construction; hence they are prone to damage and even collapse completely. "The general earthquake design principle is to design a structure to prevent complete collapse in case of strong earthquake ground motion". The resistance of structure to earthquake can be ensure either by building structural member strong enough so that it is capable to resist earthquake excitation or by use of dampers or by employing base isolation systems. Among these, base isolation is gaining significant popularity in the recent years.

So far, the performance of bridges under seismic loads has been evaluated by many with different isolators at the junction of the bridge deck and the top of pier cap. But very less such information is available for the seismic performance evaluation of bridges with base isolation at the foundation level. Hence the objective of this study is to assess the seismic performance of an RC bridge with three different types of isolators (ie., Lead Rubber Bearing, High Damping Rubber Bearing and Friction Pendulum System) at the bottom of the bridge piers.

Keywords— *Base isolation; Isolators; Isolation system; Lead Rubber Bearings; High Density Rubber Bearing; production; SAP2000; SACS ; Bridge with base isolators; seismic behavior on bridges; Type of Isolator; results using base isolators on bridge .*

INTRODUCTION

India had seen a number of the world's greatest earthquakes in the most recent century. As per IS 1893 (Part-1):2002, Map of seismic zones of India, there is more than fifty percent of area in this country is considered to be susceptible to damaging earthquakes. The complete Himalayan belt as well as the north- eastern part of the country is vulnerable to great earthquakes of magnitude more than 8.0. Also, a lot of efforts were focused on the need for enforcing legislation and making structural. Engineers and builders accountable for the safety of the structures under seismic loading.

Bridges are extremely important components of the transportation network in any country as they connect to inaccessible vicinities. At present in India the bridge design codes doesn't have any provision for seismic design. A huge number of bridges are analysed, designed and constructed without considering seismic forces.

Seismic isolation is an approach that attempts to decrease the seismic forces to or near the elastic capacity of the structural member, thereby reducing or eliminating the inelastic deformations of structure. The main theory behind isolation techniques is to reduce the fundamental frequency of structural vibration to a value lower than the predominant energy-containing frequencies of the earthquake.

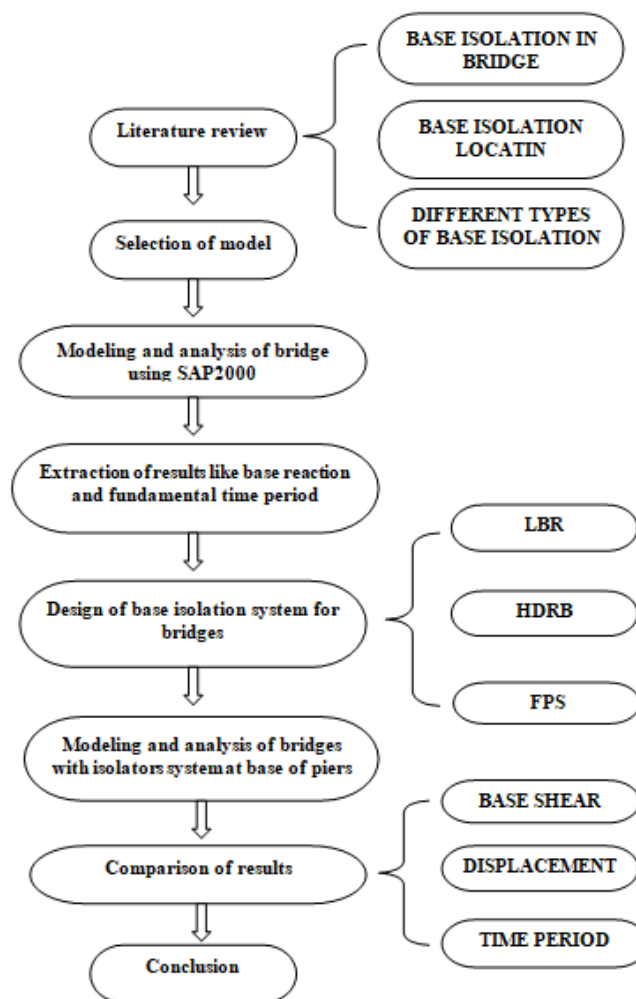
Many literatures are available in which they evaluated the performance evaluation of bridges with isolators replacing the traditional bearings system. If the bridges are provided with such isolation system at the bottom of their pier, then there will be lesser force transmission to the piers and super structure as majority of earthquake ground motions are dissipated by the isolators.

In order to address this problem, the aim of the present project is to study the seismic behavior of RC bridge with different isolation at the foundation level using linear equivalent

static analyses and non linear time history analysis. For this study the Finite element package (FEM) i.e., SAP2000 V 14.02 is used to analyze the bridge. Non linear time history analysis by using Bhuj earthquake data is adopted to evaluate seismic performance of the bridge to find the time period and frequency of the bridge for multi-modes.

Results obtained from equivalent static method and time history analyses are used. The effectiveness of base isolation is evaluated by comparing the results with the corresponding bridge models without an isolator and with isolators at the junction of bottom pier and top of foundation in terms of base shear, base moment, fundamental time period and top deck displacement

METHODOLOGY



- Selection of suitable bridge model for seismic behaviour analyses.

- Finite element package (FEM) i.e. SAP2000 is used for modelling of RCC Bridge with or without base isolators.
- From without isolated bridge base reaction and first mode frequency is collected.
- Design of different Isolator systems such as Lead Rubber Bearing, High Damping Rubber Bearing and Friction Pendulum System using collected base reaction.
- Modelling of bridges with different types of base isolators at the base of the pier in SAP2000.
- Two types of analysis are carried out such as linear equivalent static analysis and Non-Linear Time history analysis.
- For non linear time history analyses to resemble real seismic ground excitation Bhuj earthquake data is used.

LITERATUREREVIEW

M. C. Kunde and R. S. Jangid (2003), the damping constant Laminated rubber bearing system varies significantly with the strain level of the bearing (generally of the order of 10 percent) and the isolation effects in this type of system are produced not by absorbing the earthquake energy but by deflecting through the dynamics of the system. In case of Lead Rubber bearing the energy absorbing capacity by the lead core reduces the lateral displacements of the isolator. Generally, the lead yields at a relatively low stress of about 10 MPa in shear and behaves approximately as an elasto-plastic solid. The investigators also mentioned that in case of friction pendulum system, the isolation is achieved by means of an articulated slider on spherical, concave chrome surface. The slider is faced with a bearing material which when in contact with the polished chrome surface, results in a maximum sliding friction coefficient of the order of 0.1 or less at high velocity of sliding and a minimum friction coefficient of the order of 0.05 or less for very low velocities of sliding.

Khlood El-Bayoumi (2015) Triple friction pendulum (TFP) bearings are perfect earthquake protection technologies for use in performance-based design because they can be designed to attain multiple performance objectives corresponding to different levels of ground shaking. TFP bearings can bound structure displacement during a design basis (or maximum considered) earthquake, while the still effectively isolating the structure under the service level earthquake, reducing seismic demands on the structure and its non-structural components. In this paper writer also given the in detail modeling of TFP bearing in SAP2000.

Toshiyuki Sugiyama (2000) compares the seismic response between bridges with sliding type of base isolation system and that with laminated rubber bearing. For these studies four span continuous steel box girder elevated bridge located on Bay-area Line of Hanshin Express Highway, Japan was selected. Four kinds of laminated rubber bearings whose physical properties are dissimilar are taken into account in this study. The bridge is modeled as spring-mass-dash pot structural system. The structure of the bridge is composed of T-shaped concrete pier and pile foundation. In first case Lead laminated rubber bearings are equipped on the intermediate three piers and pivot-roller bearings are set up on both end piers, in second case sliding-type base-isolation system is equipped on the three intermediate piers. For time history analysis Newmarks B- method with earthquake motion data's of Kobe Earthquake, Pacoima Earthquake, Taft Earthquake, and so on whose amplitude is appropriately changed are used as input earthquake motions. In results reduction of girder acceleration point of view sliding-type base-isolation system is more effective than laminated rubber bearing in case that stronger earthquake attacks the bridge but for relatively weak earthquake no major differences are found between two different isolators.

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Vasant A. Matsagar and R.S. Jangid (2006) studied the seismic response of simply supported base-isolated bridge with different isolators. The seismic behavior of bridge is compared with different types of isolators such as laminated rubber bearing, Lead rubber bearing and Friction pendulum system. The isolated bridge deck is idealized using simplified model of a simply supported rigid deck with three degrees-of-freedom, two lateral translational, mutually

orthogonal and one rotational. In isolator dissimilarities considered are isolation stiffness and the yield force. The flexibility of abutments and bridge deck is ignored and two horizontal components of earthquake ground motion are applied, considering bi-directional interaction of the seismic response. The result shows that the eccentricities arose due to the dissimilar isolator properties in the base-isolated bridge affect its seismic response considerably and eccentricity arose due to the isolation stiffness affects more than that due to yield force. The effectiveness of isolation reduces at higher eccentricities due to the asymmetries in the isolator properties.

G. Ghosh et al. (2008) has carried out a comparative study of thermal and seismic response of (i) Traditional Roller-Rocker bearings, and (ii) Isolation Bearings viz. Elastomeric Bearings with and without Dampers, Friction Pendulum Systems (FPS) for a three-span continuous bridge. Based on the possible combination of bearing arrangement six different arrangements are considered. The effect of arrangement of the bearings for the bridge has also been examined. The range of the time period for the different arrangements of the bearings for the continuous bridge has also been obtained. A three dimensional model of the bridge has been developed. A site specific design response spectrum with a set of five acceleration time histories have been used for study of the seismic response. From result it has been observed that Isolation Bearings have distinct advantage over Traditional Bearings, both against thermal and seismic loading. The performances of FPS systems are quite satisfactory. However, in respect of restoring coefficient, the performances of the Viscous Damper along with Elastomeric Bearings are better than the FPS systems and it reduced deck displacements but higher forces in piers.

A. H. M. M. Billah and M. Shahria Alam (2010) presented the seismic behavior of multi span bridge with shape memory alloy (SMA) isolation device. A simple two span bridge located in the western part of Canada was used as the basis of the model analyzed in this study. The performance of SMA has been compared to that of other two types of isolation devices, which are high damping rubber bearing (HDRB) and lead rubber bearing (LRB). For strong ground motion the SMA bearings satisfactorily restrained the deck displacement and the relative displacement between the deck and the pier. Although the shear demand on the pier increased more than the lead-rubber bearing and high damping rubber bearing, they can safely restrain the deck from falling off the piers during strong earthquakes. The results also

showed that SMA devices were able to limit the relative motion between the base and the superstructure and could regain its original position after the earthquake and the SMA isolation system provides stiff connection between the pier and the deck for small external loading. The peak acceleration of the deck with an SMA device is greater than the acceleration response of the LRB and HDRB system.

Trevor E Kelly et al. describes the retrofit of an existing freeway overpass to improve the seismic performance by using lead rubber bearing between the super structure and the supporting column. At present configuration with steel bearing the column of the bridge are capable of resisting approximately one quarter the design site earthquake. The bridge was analyzed using ANSR-II computer program for three dimensional analyses of non-linear structure. The program provides response of the bridge to the both direction of the earthquake motion. Five different earthquake time histories are used for analyses of the bridge. The use of conventional strengthening measure was proved to be very expensive and difficult to implement, hence existing steel bearing were replaced by lead rubber bearing From results it is concluded that installation of lead rubber bearing reduces the force transmitted into weak column to such an extent that the bridge will respond elastically to the maximum design earthquake for the site.

Agim Seranaj and Forcim Softa (2014) [10] studied the influence of isolation location on the seismic response of the bridge. In order to analyze the influence of the location of isolators to the seismic response of the bridge three different models were created, they are bridge with isolators at top, middle and bottom of pier. Rubber bearing isolators are used for all three models and it is modeled as bilinear element. For analysis multi-continuous reinforced concrete bridge with ten piers and two abutments is considered. The dynamic properties and seismic behavior of three models are provided by three dimensional finite element nonlinear time history analysis, using the SAP2000 computer program. For dynamic time history analysis El Centro (1940) earthquake record of real acceleration were used Based on the analysis results, it has been concluded that the best location of isolators is on the middle of piers.

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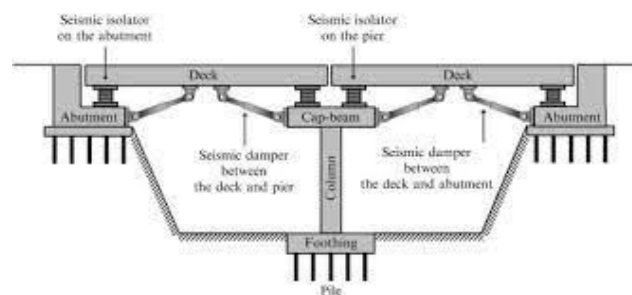


Figure 2.1 *The isolators located on top of piers*

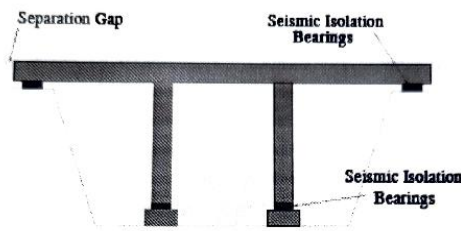


Figure 2.2 *The isolators located on bottom of piers*

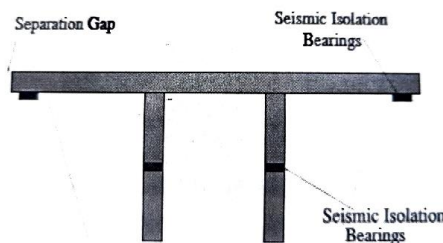


Figure 2.3 *The isolators located on middle of piers*

L. Di Sarno and B. Del Principe (2013) [12] evaluated the seismic assessment and retrofitting of existing railway bridges using different isolators such as lead rubber bearing and steel damper. The earthquake response analysis of typical existing bridges for high speed

railway was carried out through linear and nonlinear dynamic analyses using refined finite element three-dimensional lumped-plasticity models and multiple component ground motions by SAP2000. The double track simply supported bridge has a deck comprises four V-shaped precast prestressed beams with four pre-tensioned transverse elements are used for analyses. The displacements of this isolator under traffic railway loads, i.e. braking and starting actions, at ultimate limit state were assessed to estimate the feasibility of their application. The result displacement was 25 cm, which does not comply with provision railway code, but steel damper are found to be useful. From this investigation it is concluded that as-built bridge structure exhibits a ductility demand at the base of the pier due to high tensile action effects, the use of lead rubber bearing improve the seismic response of the bridge and fails in serviceability, but use of steel damper are found to be beneficial in terms of both serviceability and ultimate limit state.

M.N. Haque and A.R. Bhuiyan (2013) [15] performed a Non-linear time history analysis on a typical five-span highway bridge with lead rubber bearing under several earthquake ground motions. The entire bridge is approximated by a 2-D model bridge. Takeda trilinear model is used to model the mechanical behavior of the pier and simple elastic model is applied to model remaining portion of the bridge. Four different earthquake ground motions are considered and applied at the longitudinal direction of the bridge. In this paper, the bridge responses are discussed in terms of the base shear of the pier, deck acceleration, displacement of deck & pier top force. It is found that the success of base isolation technique is highly influenced by the properties of the isolated bridge as well as by the ground motion. From result it concluded that If the isolated frequency remains near the peak frequency of the earthquake then the efficiency of the isolation system reduces significantly.

H. Otsuka and H. Tanaka (2008) [16] used a nonlinear time history analyses as per Newmark β method (B-1/4) at interval period of 0.001 sec to presented the seismic behavior and displacement control of an existing three span continuous steel girder bridge with low friction sliding bearing support. To show the superiority of application of low friction sliding bearing support (LFSBS) for continuous girder bridges, seismic response analysis and shake table test using small steel girder bridge model is used. Use of LFSBS is expected to decrease the inertia forces from the superstructures to the substructures drastically, and the cost of the substructures and bearing supports are also reduced. In frame modeling column portions of

piers are assumed as nonlinear beam elements superstructure and abutment are assumed as linear beam elements, and overhang beams and footings are rigid body. For this the commercial software RESP-T is used. Seismic response analysis for the bridge with LFSBS is conducted to explain the dynamic performance for the large earthquake. From implementation of LFSBS in continuous bridge bending moments and shearing forces of substructures are reduced, because most of seismic forces are not transmitted between girders and substructures due to the low friction forces. There is necessity of installing displacement control device as after sliding occurs at bearing supports, girder vibrates separately which results in large response and residual displacement.

A. Ghobarah and H. M. Ali (1988) [20] an optimum seismic design for highway bridges should provide a reasonable balance between the shear forces transmitted to the supports and tolerable deck slab. They presented a simple design procedure for seismic design of base isolated highway bridges using the inelastic response spectrum approach. The use of base isolation devices between superstructure and the substructure can effectively reduce the forces induced in the bridge structure as compared to the non-isolated structures. With base isolation techniques, the bridge pier can be designed to remain elastic during major earthquake and provides economic design. For design lead rubber bearing base isolation is adopted. In this paper they provided a simple and reasonably accurate code type approach for the design of Highway Bridge with lead rubber base isolation system. This method is applicable for typical symmetrical highway bridges with rigid decks and pier flexibility is taken into consideration.

SCOPE OF PRESENT INVESTIGATION

A considerable amount of research has been done on bridges with base isolator at junction between deck slab and top of pier but very little work has been recorded on base isolator at different location in bridge other than junction between substructure and superstructure. It would be interesting and perhaps valuable to try bridges with base isolator located around the middle of pier and in between foundation top and bottom of pier. Hence attempt has been made to study the seismic behaviour of such bridge with base isolator system. The variable in the study is location of base isolation system in bridge and utilization of different base isolator system such as lead rubber bearing and friction pendulum system base isolators.

The present investigation is conducted to study the following

1. To understand the seismic behaviour of RC bridge with different base isolators at top of piers, the middle of pier and the bottom of pier.
2. To compare the various parameters in bridge with and without isolators such as
 - a) Base shear
 - b) Displacement of deck slab
 - c) Capacity of pier, girder and deck
3. To check effectiveness of different isolators.

A review of the literature reveals that, the quantity of work that has been carried out on bridges with base isolation system at junction of foundation top and pier bottom and base isolator located around the middle of pier till date is insufficient. In the present investigation the seismic behaviour of such base isolated system with different base isolators has been examined.

OBJECTIVES

- Assess the seismic performance of bridges with base isolation systems under different levels of ground shaking.
- Investigate the effectiveness of various types of base isolation devices in reducing bridge damage during earthquakes.
- Analyze the dynamic response of base-isolated bridges and compare it with conventionally designed bridges.
- Study the influence of bridge geometry and structural configuration on the seismic behavior of isolated bridges.
- Evaluate the long-term durability and maintenance requirements of base isolation systems in bridges.
- Examine the economic benefits and cost-effectiveness of implementing base isolation in bridge design and retrofitting.
- Investigate the impact of soil-structure interaction on the seismic response of base-isolated bridges.
- Study the behavior of base isolation systems under extreme seismic events and assess their resilience.
- Develop numerical models and simulations to predict the performance of base-isolated bridges.

- Propose design guidelines and best practices for the implementation of base isolation in bridge engineering to enhance seismic resilience.

BASE ISOLATION SYSTEM

Base isolation, is a seismic resistant design concept in which flexible and dissipative elements are inserted at the interface between the foundation and the base of the structure or between the substructure and superstructure of the bridge structure to reduce the seismic force transmitted from the soil to the structure. Base isolation is a passive control system; it does not require any external source of force or energy for its activation. It is essential to recognize the main function of adopting base isolation in order to enhance performance levels of the structure subjected to seismic excitations.

The main purpose of providing base isolation system is to spread the load acting on and self-weight of superstructures on to the substructure in such a manner that bearing stress induced on the material of the substructure is within the permissible limit To design structure in such a way, that it may survive the actual force by fixed base structure elastically, is not realistic in two senses. First, the construction cost of the structure will be highly uneconomical. Second, if the overall strength of the structure is increased by making it more rigid, then it will be at the expense of imparting actual ground forces to the structural contents, thus causing heavy non-structural damage. Actually, as the name implies base isolation tries to decouple the structure from the damaging effects of ground motion in the event of an earthquake. Base isolation is not about total isolation of the structure from the ground motion, as with magnetic levitation, which may be not often practical.

Types of Base Isolators

Based on the use of the type of the material the bearing can be classified into many types. In basic there are two types of isolation systems ie, elastomeric bearings and sliding bearings. The following are different types of isolators which are commonly used.

Elastomeric Bearings

An elastomeric bearing consists of alternating layers of rubber and steel shims bonded together to form a unit. Rubber layers are typically 8 mm to 20 mm thick, separated by 2 mm or 3 mm thick steel shims. The steel shims prevent the rubber layers from bulging and so the

unit can support high vertical loads with small vertical deflections (typically 1 mm to 3 mm under full gravity load). The internal shims do not restrict horizontal deformations of the rubber layers in shear and so the bearing is much more flexible under lateral loads than vertical loads, typically by at least two orders of magnitude.

HIGH DAMPING RUBBER BEARINGS (HDRB)

The term high damping rubber bearing is applied to elastomeric bearings where the elastomer used (either natural or synthetic rubber) provides a significant amount of damping, usually from 8% to 15% of critical. This compares to the more "usual" rubber compounds, which provide around 2% damping. The additional damping is produced by modifying the compounding of the rubber and altering the cross link density of the molecules to provide a hysteresis curve in the rubber. Therefore, the damping provided is hysteretic in nature (displacement dependent). For most HDR compounds the viscous component of damping (velocity dependent) remains relatively small (about 2% to 5% of critical).

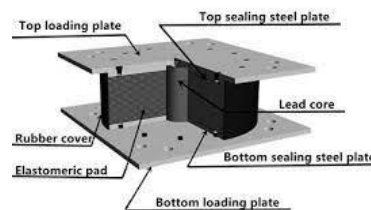


Figure 3.1 The high damping rubber bearing

LAMINATED RUBBER BEARINGS (LRB)

The laminated rubber bearing (LRB) is most commonly used base isolation system. The basic components of LRB system are steel and rubber plates built in the alternate layer. The governing features of LRB system are the parallel action of linear spring and damping. Normally, the LRB system exhibits high-damping capacity, horizontal flexibility and high vertical stiffness. The dominant features of LRB system are the parallel action of linear spring and damping. Generally, the LRB system exhibits high-damping capacity, horizontal flexibility and high vertical stiffness.

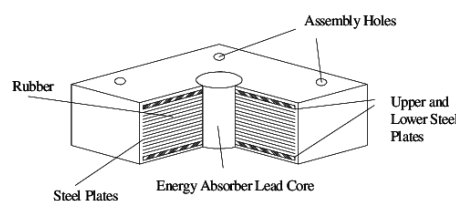


Figure 3.2 Laminated Rubber Bearing

LEAD RUBBER BEARINGS (N-Z)

A lead-rubber bearing is formed of a lead plug force-fitted into a pre-formed hole in an elastomeric bearing. The lead core provides rigidity under service loads and energy dissipation under high lateral loads. Top and bottom steel plates, thicker than the internal shims, are used to accommodate mounting hardware. The entire bearing is encased in cover rubber to provide environmental protection. This system provides the combined features of vertical load support, horizontal flexibility, restoring force and damping in a single unit.

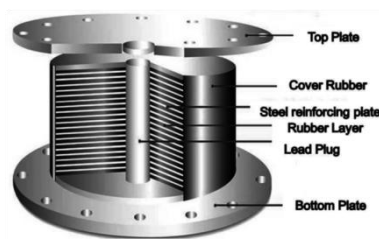


Figure 3.3 Lead rubber bearing

CURVED SLIDER (FRICTION PENDULUM) BEARINGS

Although a number of curved shapes are possible, the only curved sliding bearing which has been extensively used is a patented device in which the sliding surface is spherical in shape rather than flat, termed the Friction Pendulum System. The schematic characteristics of this device are shown in Figure 3.9. The isolator provides a resistance to service load by the coefficient of friction, as for a flat slider. Once the coefficient of friction is overcome the articulated slider moves and because of the spherical shape a lateral movement is accompanied with a vertical movement of the mass.

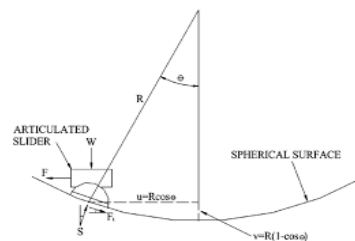
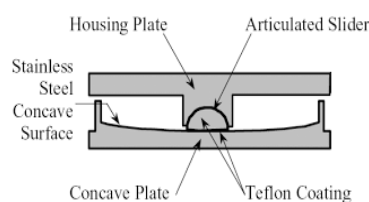


Figure 3.4: Friction pendulum system Figure 3.5 Pendulum action

SAP2000- FINITE ELEMENT SOFTWARE

The SAP2000 software is the most advanced and approachable version of the SAP software family. When it was first introduced in 1996, SAP2000—integrated software for structural analysis and design—became the first version of SAP to be fully integrated within Microsoft Windows. Modern analytical techniques have long been associated with the SAP moniker.

Following in the same tradition, SAP2000 offers engineers working on transportation, industrial, public works, sporting, and other facilities a very advanced, versatile, and intuitive user interface backed by an unparalleled analysis engine.

DEFINING MATERIAL PROPERTIES

The materials which are required in analyses are needed to be defined in SAP program prior to its assignment. In the property data area, name of the material, modulus of elasticity, Poisson's ratio, mass per unit volume and weight per unit volume should be specified for each type of material defined. The mass per unit volume is used in the computation of self-mass of the configuration. The self weight of the structure is estimated based on the weight per unit volume of the material defined.

ANALYSIS FOR GRAVITY LOADS AND LATERAL LOADS USING SAP

Defining Loads

Dead load, Super dead load for wearing coat and cross barrier and seismic loading for the equivalent static analysis can be defined under the 'static load case' option "define" menu. Different types of load combinations can also be defined in the load combinations' option of the "define" menu

Mass Source

In seismic analysis, mass of the structure is considered rather than the weight. In SAP, by default it assumes the self-mass of the structure as the mass for seismic analysis. To assign the correct mass, select the option from loads and add the type of loads and its coefficients in the drop down menu in the 'mass source' option and assign the factor obtained from the load combination as per IS-1893: 2002: Part I

Interpretation of Results

Once the analysis is performed on SAP2000 the results can be extracted either in graphical or tabular form. The results obtained for gravity analysis are in the form of internal forces, deformations, support reactions and stresses. For modal analyses, modal time period and modal frequency for different modes are obtained under modal result tabular form. The result collected for time history analyses are base shear, base moment, top deck slab displacement and top link displacement in both direction

TIME HISTORY ANALYSIS USING SAP

SAP provides a powerful tool for the linear and non-linear time history analysis of structure using any time history function. Any time data can be modified suitably to adopt in the time history analysis using SAP. Time history analysis in SAP can be performed in two ways.

Modal Time-History Analysis

A very accurate and effective method for performing time-history analysis is modal superposition. The response is calculated by summing the linear variations of the time functions, $f_i(t)$, between the time points of the input data using closed-form integration of the modal equations. As a result, there are no issues with numerical instability, and the time increment can be any sampling value that is thought to be fine enough to catch the maximum response values. The standard recommendation is one-tenth of the time period of the highest mode; however, if the contribution of the higher modes is minimal, a larger number may result in an equally accurate cu rate sampling.

DIRECT-INTEGRATION TIME-HISTORY ANALYSIS

- Selection of Ground Motion; Choose a set of recorded ground motion records (accelerograms) that represent the hazard in the region of interest. These records should cover earthquake magnitudes and frequencies.
- Numerical Integration; Apply the selected ground motion records as input to the model. Perform numerical integration of the equations of motion over time. Common numerical integration methods include the Newmark method and the Runge Kutta method.
- Analysis Setup; Specify analysis parameters such, as time step size, duration of analysis damping models and initial conditions. Ensure proper consideration is given to damping in the base isolators and other components to accurately capture energy dissipation

VALIDATION

To validate this software, Design example problem 7.5 given in "Design of Bridges" by N. Krishnaraju (Page number 126 -137) is chosen. It is modeled and analyzed using SAP2000 V.14.02 and analyses results are compared with textbook results.

The bridge under study is an R.C.C. Tee beam girder bridge with following suitable data.

Table 4.1 Bridge data for validation

1	Clear width of roadway	75m
2	Span (centre to centre of bearings)	16 m
3	Live load	IRC Class AA tracked vehicle.
4	Average thickness of wearing coat	80mm
5	Concrete mix	M-25 grade
6	Steel	Fe-415 grade HYSD bars

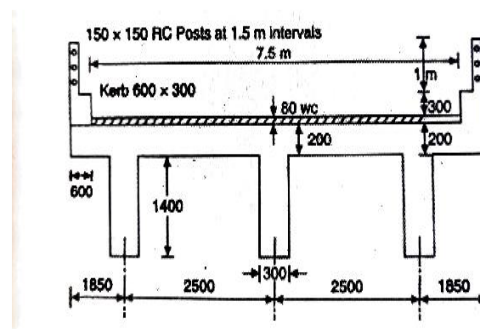


Figure 4.1 Elevation of Bridge given in Krishnaraju text book



Figure 4.3 SAP modeling of the above bridge defined



Figure 4.4 Deformed shape of the bridge under dead load



Figure 4.5 stress distribution contour on deck slab under loading

COMPARISON OF RESULTS

Table 4.2 Comparison of bending moment and shear force in main girder

		SAP2000			Text Book
		Dead	Live	Total	Total
Moment (kN-m)	Outer girder	959.76	1899.95	2859.7	2731
	Inner girder	880.64	1316.33	2196.97	2130
Shear (kN)	Outer girder	213.78	213.78	611.4	572.1
	Inner girder	229.43	229.43	680.02	694.6

Table 4.3 Comparison of bending moment and shear force in cross girder

	SAP2000			Text book
	Dead	Live	Total	Total
Moment (kN-m)	38.78	298.97	337.57	318.47
Shear (kN)	19.76	215.38	235.14	229.39

From above comparisons, it can be concluded that,

1. All results of SAP2000 are closely matching with the N. Krishnaraju text book results.
2. SAP 2000 is very convenient to perform any analysis;
3. The stress contour and the bending moment contour can be used easily to obtain the results at each and every point on the structure.

PERFORMANCE EVALUATION OF THE BRIDGE

A reinforced concrete village road bridge proposed to be constructed across Canal crossing joining Bidari and Kavatagi village in Belgaum District is considered for the seismic assessment. It is a multi-span simply supported RCC Tee beam bridge having a total length of 56.04m with five spans of unequal length. Entire bridge supported on four column type piers, at each pier it contain three columns which are transversely connected by the bent cap at top and tie beam at intermediate suitable distance. The bridge piers and abutments are supported on pile foundations. The cross sectional details of different components of the bridge are given in Table 5.1. The geometrical and structural information of the bridge are collected. These drawings comprises of plans, elevations and reinforcement details: Below Figure shows the General Arrangement Drawing (GAD) of the bridge under study.

MODELLING OF BRIDGE AND ISOLATION SYSTEM

Base isolation is modeled by using the nonlinear link elements available in SAP2000. First the bridge is modeled with connection at junction of Deck & pier cap and foundation level. Then bridge is modeled with different isolator bearing at the bottom of the piers for each span.

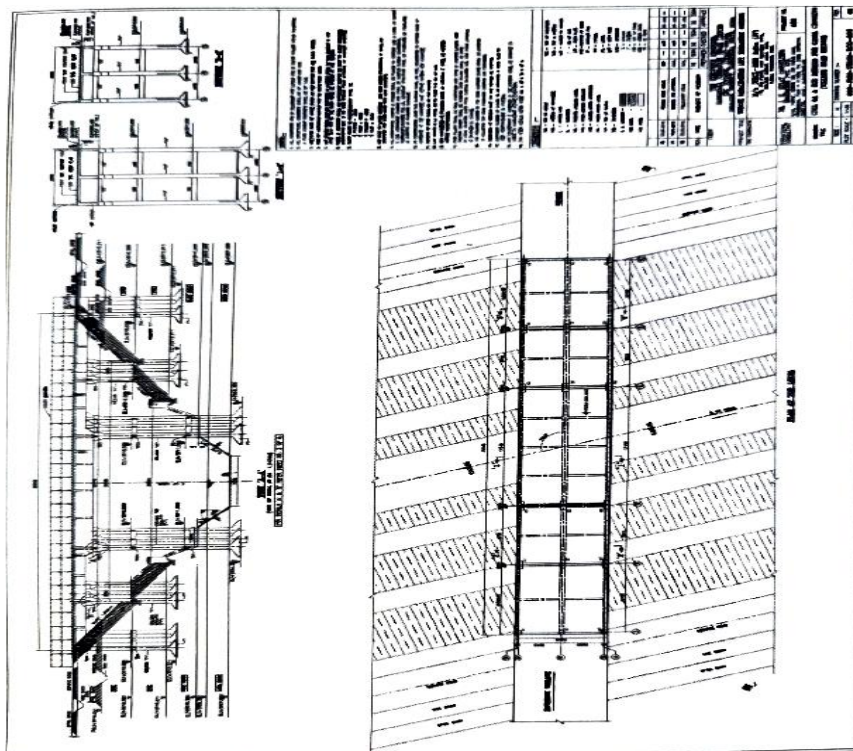
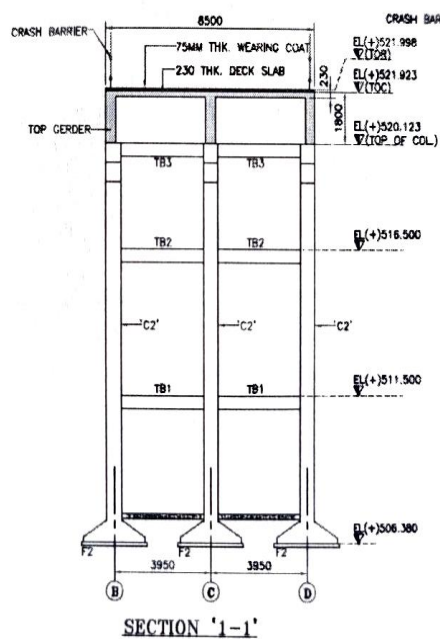


Figure 5.1 General Arrangement Drawing (GAD) of the study bridge



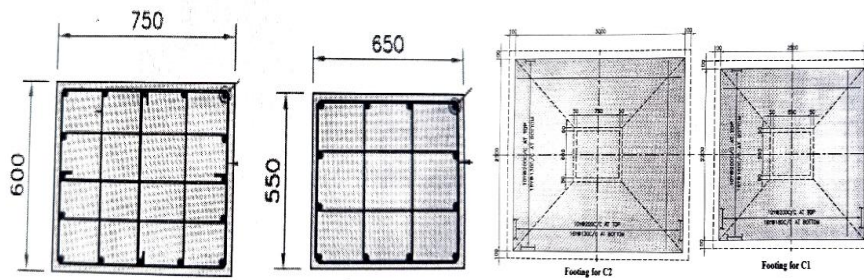


Figure 5.2 details of typical pier

Table 5.2 Details of seismic data

Type of structure	Bridge
Zone	III
Zone factor (Z)	0.16
Response reduction factor (R)	3
Importance factor (I)	1.5
Soil type	1 (Hard)
Damping ratio	0.05

5.5 TIME HISTORY DATA

A typical nonlinear time history analysis is carried out on bridges with and without isolation system. Time history data of Bhuj earthquake is used for the analysis. Figure 5.3 shows the time history function of Bhuj earthquake used in the present study.

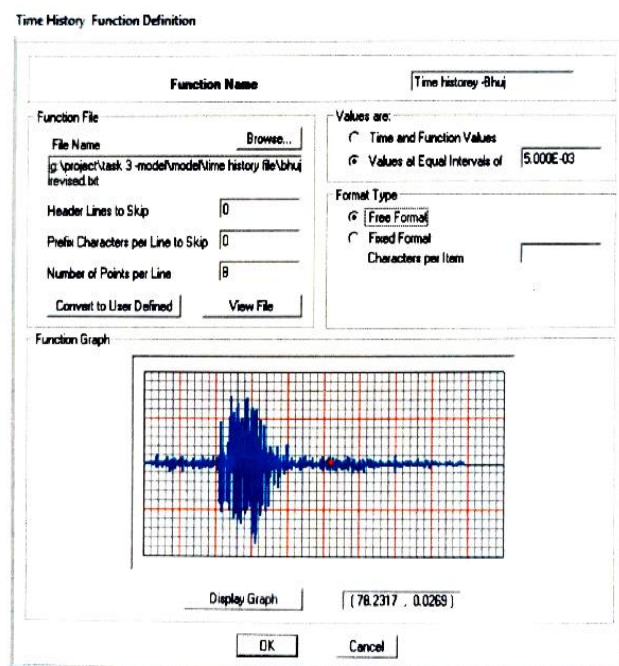


Figure 5.3 Time History Function of Bhuj Earthquake

Table 5.3 Details of Time History data

Earth quake name	BHUJ
Date	26-01-2001
Time	08:46:42
Magnitude	7.6
Latitude & Longitude	23 02 N, 72 38 E
Initial velocity(m/s)	-0.1411x10
Initial displacement (mm)	3.97
Peak acceleration (m/s/s)	-1.0382
Total acceleration data	26706

5.6 BRIDGE MODELING USING SAP

Computer software SAP2000 version 14.2 was used to model the bridge. The Bridge wizard option is used to generate a bridge model. The Bridge wizard provides a step-by-step guide through the modeling process using SAP2000's Bridge Information Modeler.

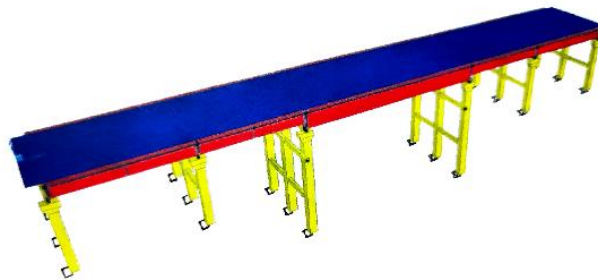


Figure 5.4 SAP model of Study Bridge without isolator

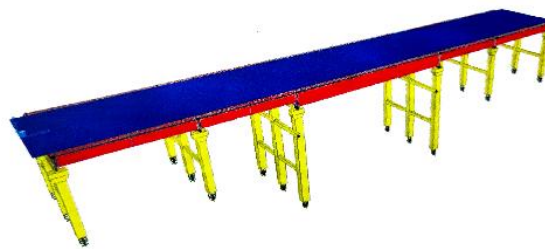


Figure 5.5 SAP model of Study Bridge with LRB Isolator at the bottom pier

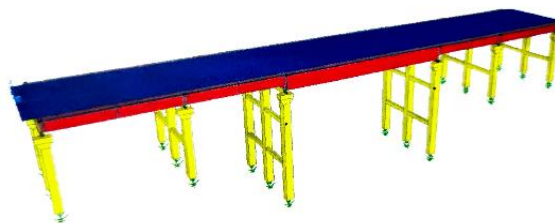


Figure 5.7 SAP model of study bridge with fps Isolator at the bottom pier

5.7 CHECK FOR SLAB THICKNESS

To confirm whether the provided slab thick can able to withstand during service load, the stresses developed on deck slab due to gravity load from analyses are extracted and it is verified with as per IS code provision. The allowable positive and negative principal stress can be given by a, $\sigma_c \text{ max} - 0.45 f_{ex}$ and o, $\Sigma t \text{ Max max} - 0.7 f_{ck}$ respectively.

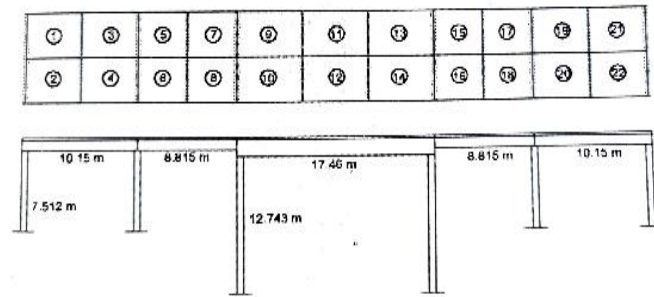


Table 5.4 Stress on deck slab due to dead load and super dead load

Slab	$\Sigma c \text{ Max}$	$\Sigma t \text{ Max}$	Slab no	$\Sigma c \text{ max}$	$\Sigma t \text{ max}$
1	0.591	-0.657	12	1.489	-1.578
2	0.591	-0.675	13	0.954	-1.007
3	0.375	-0.419	14	0.954	-1.007
4	0.375	-0.419	15	1.029	-0.308
5	0.501	-0.369	16	1.029	-0.308
6	0.591	-0.369	17	0.489	-0.36
7	1.035	-0.308	18	0.489	-0.36
8	1.035	-0.308	19	0.356	-0.408
9	1.019	-1.079	20	0.356	-0.408
10	1.019	-1.079	21	0.579	-0.664
11	1.489	-1.578	22	0.579	-0.664

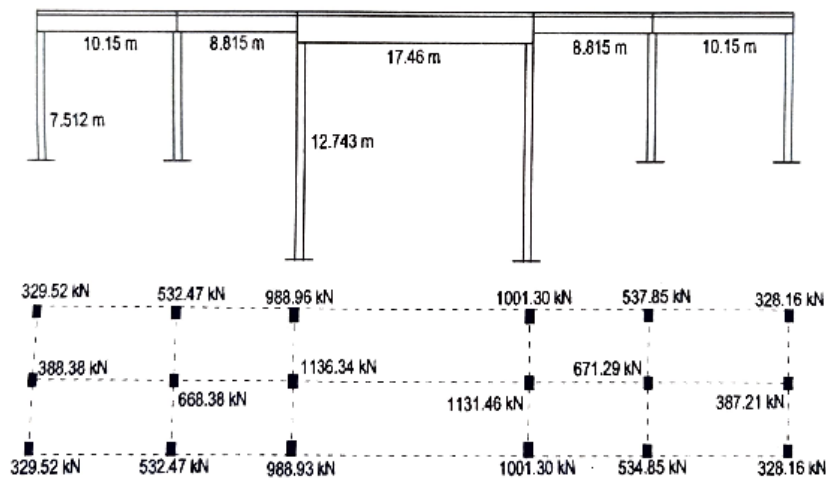


Figure 6.1 Load on column in bridge

6.2 HIGH DAMPING RUBBER BEARING (HDRB)

The rubber layers constituting the HDRB are usually made of materials that are highly nonlinear in terms of shear strains but for the purpose of preliminary design HDRB are assumed to be linear elastic and isotropic.

Target design period (TD) of the isolated structure should be greater than three times the fixed-base period. For fixed base condition the value of time period (T) obtained from SAP2000 for Mode 1 is equal to 0.84 sec. Let us assume, Target period $T_o = 2,5$ sec

For Laminated rubber bearing assume the following data

- Maximum shear strain $Y = 150\%$,
- Effective damping ratio is $\gamma = 20\%$.

From Table 1623.2.2.1 of the IBC 2000, for an isolation system with $\gamma = 20\%$

Damping coefficient $B_o = 1.5$

From Table 1615.1.2(2) of the IBC 2000, for the site condition of isolated structure with long period, Seismic coefficient is $S_p = 0.4$

ANALYSIS

a) The effective horizontal stiffness K_{eff} of the isolator is

$$K_{eff} = \frac{W}{g} \left(\frac{2\pi}{T_d} \right)^2$$

Where

W = Maximum sustainable load in KN

g = Acceleration due to gravity = 9.8 m/s^2

$$K_{eff} = \frac{1136.34}{9.8} \left(\frac{2\pi}{2.5} \right)^2 = 732.4 \text{ kN/m} = 0.7324 \text{ MN/m}$$

b) Based on Equation 16-79 of IBC 2000, the design displacement DD is: $\left(\frac{9.8}{4\pi^2} \right) \left(\frac{0.4 \times 2.5}{1.5} \right) = 0.17$

$m \leq 0.3 \text{ m} \rightarrow \text{OK c)}$

The short term yield force Q_d is

$$Q_d = \frac{W_d}{4DD}$$

W_D = Energy dissipated per cycle = $2\pi K_{eff} D^2 K_{\Sigma}^{-eff}$

$$Q_d = \frac{\pi}{2} K_{eff} D_d K_{\Sigma}^{-eff}$$

$$= \frac{\pi}{2} \times 732.4 \times 0.2 \times 0.17 = 39.12 \text{ Kn}$$

6.2.2 DESIGN

6.2.2.1 Determine the isolator size

- a) The total rubber height (t_r)

$$t_r = D_D / Y_{\max}$$

$$= 0.17 / 1.5 = 0.11 \text{ m}$$

$$\text{Use } t_r = 0.3 \text{ m} > 0.11 \text{ m}$$

- b) Calculate the area A and thickness t of individual rubber layers.

Select the shape factor S

$$\frac{E(1+2kS^2)}{G} \geq 400$$

$$\frac{445(1+2 \times 0.57S^2)}{106} \geq 400$$

$$S > 9.09 \rightarrow \text{Use } S = 20$$

Compression modulus of the rubber-steel composite E_c

$$E_c = E(1+2kS^2)$$

$$= 445(1+2 \times 0.57 \times 20^2)$$

$$= 203365 \text{ N/cm}^2 = 2033.65 \text{ MN/m}^2$$

- c) Design cross sectional area

- i) Determine the effective area A_0 for the bearing based on the allowable axial stress σ_c

for the vertical load case P_{DL+LL}

$$\sigma_c = 80 \text{ kgf/cm}^2 = 7.84 \text{ MN/m}^2$$

$$\sigma_c = \frac{P_{DL+LL}}{A_0} \leq 7.84 \text{ MN/m}^2$$

$$\frac{1136.34 \text{ kN}}{A_0} \leq 7.84 \text{ MN/m}^2$$

$$A_0 = 0.145 \text{ m}^2$$

- ii) Determine the effective area A_1 for the bearing from the shear strain condition under

the vertical load case P_{DL+LL}

$$Y_c = 6S \frac{P_{DL+LL}}{E_c A_1} \leq \frac{\epsilon_b}{3}$$

$$= 6 \times 20 \times \frac{1.13634}{2033.65 A_1} \leq \frac{500\%}{3} \rightarrow A_1 > 0.04 \text{ m}^2$$

iii) Obtain the minimum area A_{sf} for shear failure of the bearing

$$G = \frac{K_{eff} t_r}{A_{sf}}$$

$$A_{sf} = \frac{K_{eff} t_r}{G}$$

$$= \frac{0.7324 \times 0.3}{1.06} = 0.207 \text{ m}^2$$

For a circular bearing, the diameter corresponding to the area A_{sf} is $d = 0.51 \approx 0.55 \text{ m}$.

The effective cross-sectional area A_2 is computed as the reduced area A_{re}

$$A_{re} = \frac{d^2}{4} (\beta - \sin \beta) \quad (\text{for circular bearing})$$

$$\beta = 2 \cos^{-1} \left(\frac{D_p}{d} \right) = 2 \cos^{-1} \left(\frac{0.17}{0.55} \right) = 143.99^\circ = 2.51 \text{ rad}$$

$$A_{re} = \frac{0.55^2}{4} (2.51 - \sin(143.99)) = 0.143 \text{ m}^2 = A_2$$

The design cross sectional area for the bearing is maximum of A_0 , A_1 and A_2

$$A = 0.145 \text{ m}^2$$

Assume $d = 0.7 \text{ m}$, Area $A = 0.385 \text{ m}^2$, Reduced area $A_{re} = 0.267 \text{ m}^2$

d) Single layer thickness (t) and Number of layers (N) for circular bearing

$$S = \frac{d}{4t} \rightarrow 20 = \frac{70}{4t} \rightarrow t = 0.88 \text{ cm}$$

Use $t = 1 \text{ cm}$

$$\text{Number of layers (N)} = \frac{t_r}{t} = \frac{30}{1} = 30$$

e) Determine the steel plate thickness (t_s)

$$t_s \geq \frac{2(t_i + t_{i+1}) P_{DL+LL}}{A_{re} F_s} \geq 2 \text{ mm}$$

Where,

t_i, t_{i+1} = rubber layer thickness in top and bottom of the steel plate

$F_s = 0.6 F_y$ (F_y = yield strength of the steel plate)

For A36 steel, $F_s = 0.6 \times 274.4 = 164.6 \text{ MN/m}^2$

$$t_s \geq \frac{2(0.01 + 0.01) \times 1.136}{0.267 \times (0.6 \times 274.4)} = 0.00103 \text{ m} = 1.03 \text{ mm} \quad (\text{Use } t_s = 2 \text{ mm})$$

Table 6.2 Dimensions of HDRB

a	Dia of the bearing (d)	70cm
b	Total height of the bearing	40.8cm
c	Number of rubber layers	30
d	Thickness of individual layers (t)	1cm
e	Number of steel plates (Ns)	29
f	Thickness of individual plates (ts)	2mm
g	Thickness of top and bottom cover plates	2.5cm

Table 6.3 SAP2000 Properties of HDRB

a	Moment of inertia (I)	1.05x10¹⁰mm
B	Total weight	4.3kN
C	Effective stiffness (Keff)	1173.5kN/m
D	Effective damping	20%
E	Distance from END-J	41.5mm
F	Elastic stiffness (Ke)	943.4kN/m
G	Yield Strength (Fy)	199.5kN/m
h	Post yield stiffness ratio	0.1

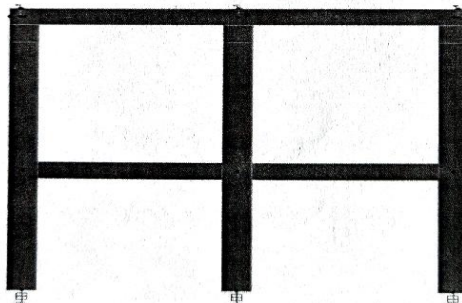


Figure 6.2 SAP model of HDRB at the bottom of the pier

6.3 LEAD RUBBER BEARING (LRB)

The LRB are typically made of alternating layers of steel plates and natural rubber with a central hole into which the lead core is inserted. When LRB is subjected to lateral shear forces, the lead core deforms about in pure shear, yields at low level of shear stresses, approximately 8 to 10 MPa at normal (20°C) temperature. The one of the most useful

advantage of lead core is that it can recrystallize at normal temperature hence it will not cause fatigue failure under cyclic loading

For fixed base condition the value of time period (T) obtained from SAP2000 for Mode I is equal to 0.84 sec. Let us assume, Target period $T_D = 2.5$ sec

For Laminated rubber bearing assume the following data

Maximum shear strain $\gamma_{max} 50\%$,

Effective damping ratio ε_{eff} is 10%.

From Table 1623.2.2.1 of the IBC 2000, for an isolation system with $E_r 10\%$

Damping coefficient $B_D = 1.2$

From Table 1615.1.2(2) of the IBC 2000, for the site condition of isolated structure with long period, Seismic coefficient is $S_D=0.4$

6.3.1 ANALYSI

a) The effective horizontal stiffness K_{eff} of the isolator is

$$K_{eff} = \frac{W}{g} \left(\frac{2\pi}{T_d} \right)^2$$

W = Maximum sustainable load in KN

g = Acceleration due to gravity = 9.8 m/s^2

$$K_{eff} = \frac{1136.34}{9.8} \left(\frac{2\pi}{2.5} \right)^2 = 732.4 \text{ kN/m } 0.7324 \text{ MN/m}$$

b) Based on Equation 16-79 of IBC 2000, the design displacement D_D is: $\left(\frac{9.8}{4\pi^2} \right) \left(\frac{0.4 \times 2.5}{1.2} \right) = 0.21 \text{ m} \leq 0.3 \text{ m} \rightarrow \text{OK}$

c) The short term yield force Q_d is

$$Q_d = \frac{W_d}{4D_D}$$

W_D = Energy dissipated per cycle = $2\pi K_{eff} D^2 K_{\Sigma_{eff}}$

$$Q_d = \frac{\pi}{2} K_{eff} D_d K_{\Sigma_{eff}}$$

$$= \frac{\pi}{2} \times 732.4 \times 0.21 \times 0.21 = 24.12 \text{ kN}$$

Use the following properties for the rubber as per given in Table 6.1 above

Hardness IRHD-60,

Elongation at break $\varepsilon_b = 500\%$

Young's Modulus (E) - $445 \text{ N/cm}^2 = 4.45 \text{ MN/m}^2$

Shear modulus (G) $106 \text{ N/cm}^2 = 1.06 \text{ MN/m}$

Modified factor (k) = 0.57

DESIGN

Design of lead core

Assume the yield strength of the lead core to be $f_{py} = 8.82 \text{ MN/m}^2$

The required lead area is

$$A_p = \frac{Q_d}{f_{py}} = \frac{24.2}{8.82 \times 10^3} = 2.74 \times 10^{-3} \text{ m}^2$$

Diameter of lead core $d_p = 5.9 \text{ cm}$

Use Diameter of lead core $d_p = 10 \text{ cm}$ and $A_p = 78.53 \text{ cm}^2$

$$\text{Characteristic strength } Q_d - A_p \times f_{py} = 78.53 \times 10^{-4} \times 8.82 \times 10^3 = 69.3$$

6.3.2.2 Design the area and dimensions of rubber layers

a) the total rubber height $t_f = Dd/Y_{\max}$

$$= 0.21/0.5 = 0.42 \text{ m}$$

b) Select the shape factor S

$$= \frac{E(1 + 2kS^2)}{G} \geq 400$$

$$\frac{445(1 + 2 \times 0.57S^2)}{106} \geq 400$$

$$S > 9.09 \rightarrow \text{Use } S = 20$$

Compression modulus of the rubber-steel composite E_c

$$E_c = E(1 + 2kS^2) = 445(1 + 2 \times 0.57 \times 20^2)$$

$$= 203365 \text{ N/cm}^2 = 2033.65 \text{ MN/m}^2$$

c) Design cross sectional area

i) Determine the effective area A_0 for the bearing based on the allowable axial stress σ_c

for the vertical load case P_{DL+LL}

$$\sigma_c = 80 \text{ kgf/cm}^2 = 7.84 \text{ MN/m}^2$$

$$\sigma_c = \frac{P_{DL+LL}}{A_0} \leq 7.84 \text{ MN/m}^2 \rightarrow \frac{1136.34 \text{ kN}}{A_0} \leq 7.84 \text{ MN/m}^2$$

$$A_0 = 0.145 \text{ m}^2$$

ii) Determine the effective area A_1 for the bearing from the shear strain condition under

the vertical load case P_{DL+LL}

$$\gamma_c = 6S \frac{P_{DL+LL}}{E_c A_1} \leq \frac{\epsilon_b}{3} \rightarrow 6 \times 20 \times \frac{1.13634}{2033.65 A_1} \leq \frac{500}{3}$$

$$A_1 > 0.04 \text{ m}^2$$

$$A_{re} = \frac{0.43^2}{4} (2.12 - \sin(121.53)) = 0.058 \text{ m}^2 = A_2$$

The design cross sectional area for the bearing is maximum of A_0 , and A_1

$$A = 0.145 \text{ m}^2$$

Assume $d = 0.7 \text{ m}$, Area $A = 0.385 \text{ m}^2$, Reduced area $A_{re} = 0.267 \text{ m}^2$

d) Single layer thickness (t) and Number of layers (N) for circular bearing

$$S = \frac{d}{4t} \rightarrow 20 = \frac{70}{4t} \rightarrow t = 0.88 \text{ cm}$$

Use $t = 1 \text{ cm}$

$$\text{Number of layers (N)} = \frac{t_r}{t} = \frac{42}{1} = 42$$

c) Determine the steel plate thickness (t_s)

$$t_s \geq \frac{2(t_i + t_{i+1}) P_{DL+LL}}{A_{re} \cdot F_s} \geq 2\text{mm}$$

Where,

t_i, t_{i+1} = rubber layer thickness in top and bottom of the steel plate

$F_s = 0.6 F_y$ (F_y = yield strength of the steel plate)

For A36 steel, $F_s = 0.6 \times 274.4 = 164.6 \text{ MN/m}^2$

$$t_s \geq \frac{2(0.01+0.01) \times 1.136}{0.267 \times (0.6 \times 274.4)} = 0.00103 \text{ m} = 1.03\text{mm}$$

Use $t_s = 2\text{mm}$

f) Total height h of the bearing

Assume both the top and bottom cover plates are 2.5 cm thick.

Total height of the bearing is

$$h = t_r + 41 \times t_s + 2 \times 2.5 + 41 \times 0.2 + 5 = 55.2 \text{ cm}$$

6.3.3 PROPERTIES

Gross Area $A_g = 0.385 \text{ m}^2$

Area Lead Plug, $A_{pl} = 7.853 \times 10^{-03} \text{ m}^2$

Rubber Area, $A_r = 0.385 - 7.853 \times 10^{-03} = 0.377 \text{ m}^2$

Assuming 10mm Rubber cover

Bonded Dimension = $700 - 2 \times 10 = 680 \text{ mm}$

$$\begin{aligned} \text{Moment of inertia (I)} &= \frac{\pi \times 680^4}{64} \\ &= 1.05 \times 10^{10} \text{ mm}^4 = 0.0105 \text{ m}^4 \end{aligned}$$

i) Post- Yield Stiffness (K_p)

$$\begin{aligned} K_p &= \frac{G A_r}{T_r} \\ &= \frac{1.06 \times 10^3 \times 0.377}{0.42} = 951.5 \text{ kN/m} \end{aligned}$$

ii) Elastic stiffness (K_e)

K_e is minimum of

$$i) K_e = 25 K_P = 25 \times 951.5 = 23787.5 \text{ kN/m}$$

$$ii) K_e = 6.5K_P \left(1 + 12 \frac{A_P l}{A_r} \right) \\ = 6.5 \times 951.5 \left(1 + 12 \times \frac{0.007853}{0.377} \right) = 7730 \text{ kN/m}$$

□ Elastic stiffness $K_e = 7730 \text{ kN/m}$

iii) Yield displacement (D_y)

$$D_y = \frac{Q}{K_e - K_P} \\ = \frac{69.3}{7730 - 951.5} = 0.01022 \text{ m} = 10.22 \text{ mm}$$

Distance from END -J = 10.22 mm

iv) Post - Yield stiffness ratio

$$= \frac{K_P}{K_e} = \frac{951.5}{7730} = 0.123 > 0.1$$

v) Yield Force (F_y)

$$F_y = Q + K_P D_y \\ = 69.3 + 951.5 \times 0.01022 = 79 \text{ kN}$$

vi) Maximum Force (F_m)

$$F_m = Q + K_P D_D \\ = 69.3 + 951.5 \times 0.21 = 269.1 \text{ kN}$$

vii) Effective stiffness (K_{eff})

$$K_{eff} = \frac{F_m}{D_D} = \frac{269.1}{0.21} = 1281.4 \text{ kN/m}$$

viii) Equivalent Viscous Damping (β_{eqv})

Area Hysteresis Loop (A_h)

$$A_h = 4Q (D_D - D_y) \\ = 4 \times 69.3 (0.21 - 0.01022) = 55.38 \text{ m}^2$$

$$\beta_{eqv} = \frac{A_h}{2 \pi K_{eff} D D^2} = \frac{55.38}{2 \pi \times 1281.4 \times 0.21^2} = 0.156$$

Assuming structural damping $\beta_{str} = 5\%$

Effective Damping = $\beta_{eqv} - \beta_{str} = 0.156 - 0.05 = 0.106 = 10.6\%$

ix) Vertical stiffness

$$K_v = \frac{E_c A_r}{t_r} = \frac{2033.65 \times 10^3 \times 0.377}{0.42} = 1825442 \text{ kN/m}$$

x) To get weight of bearing

Unit wt of rubber = 9.1 kN/m^3

Unit wt of lead = 111.2 kN/m^3

Unit wt of steel = 78.5 kN/m^3

Weight of rubber layer = $42 \times 0.377 \times 0.01 \times 9.1 = 1.44 \text{ kN}$

Weight of lead plug = $0.007853 \times 0.124 \times 111.2 = 0.108 \text{ kN}$

Weight of steel shims = $41 \times 0.377 \times 0.002 \times 78.5 = 2.43 \text{ kN}$

Weight of end plate = $2 \times 0.385 \times 0.025 \times 78.5 = 1.51 \text{ kN}$

Total weight = 5.5 kN

Total mass = 0.55 tonne

6.3.3 SHEAR STRAIN AND STABILITY CONDITIONS

i) Shear strain requirement under the vertical load P_{DL+LL}

$$\gamma_{C, DL+LL} = 6S \cdot \epsilon_c = 6S \cdot \frac{P_{DL+LL}}{E_c A} \leq \frac{\epsilon_b}{3} = 6 \times 20 \times \frac{1.13634}{2033.65 \times 0.385} = 0.174$$

$$\leq \frac{\epsilon_b}{3} = \frac{500\%}{3} = 1.667 \rightarrow \text{hence OK}$$

ii) Stability check

$$\sigma_c = \frac{P}{A} = \frac{1136.34}{0.385} = 2951.5 \text{ kN/m}^2$$

$$\leq \sigma_c = \frac{G S L}{2.5 t_r} = \frac{(1.06 \times 10^3) \times 20 \times 0.7}{2.5 \times 0.42} = 14133 \text{ kN/m}^2 \rightarrow \text{Hence OK}$$

L = diameter d of the circular bearing.

iii) Check on the diameter of the load core

$$= 1.25 \leq \frac{H_p}{D_p} = \frac{42}{10} = 4.2 \leq 5.0 \rightarrow \text{ok}$$

Table 6.4 Dimensions of the LRB

a	Dia of the bearing (d)	70cm
b	Total height of the bearing	55.2cm
c	Number of rubber layers	42
d	Thickness of individual layers (t)	1cm
e	Number of steel plates (Ns)	41
f	Thickness of individual plates (ts)	2mm
g	Thickness of top and bottom cover plates	2.5cm
h	Dia of the lead core	10cm

Table 6.5 SAP 2000 Properties for LRB

a	Moment of inertia (I)	$1.05 \times 10^{10} \text{mm}^4$
b	Total weight	5.5kN
c	Effective stiffness (K_{eff})	1281.4kN/
d	Effective damping	10.6%
e	Distance from END-J	10.25mm
f	Elastic stiffness (K_e)	7730kN/m
g	Yield Strength (F_y)	79kN/m
h	Post yield stiffness ratio	0.123

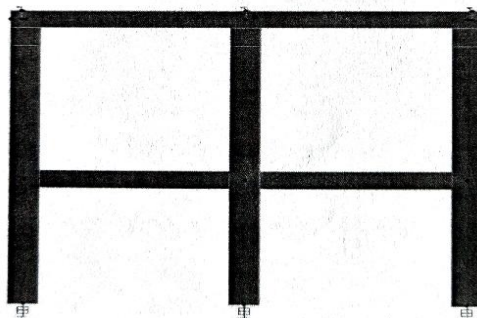


Figure 6.3 SAP model of LRB at the bottom of the pier

6.4 FRICTION PENDULUM SYSTEM (FPS)

The frictional pendulum bearing permits the supported structure to come back to its original position through use of a spherical concave sliding surface. The main factor need to be

consider while designing friction pendulum system is to make the natural period (TD) long enough, so that force excited from the ground to the superstructure can be greatly reduced. The longer time period can be ensured by proper choice of radius of curvature of spherical sliding surface. Target design period (TD) of the isolated structure should be greater than three times the fixed-base period. For fixed base condition the value of time period (T) obtained from SAP2000 for Mode 1 is equal to 0.84 sec. Let us assume ,Target period $T_0=2.5\text{sec}$

Assume Friction coefficient of the spherical sliding surface of the FPS $\mu = 0.06$

Horizontal displacement $D=20\text{cm}$

Rate parameter= 0.05

- a) Determine the size of the FPS

The radius of curvature of the spherical sliding surface of the isolator is

$$R = g \left(\frac{T_D}{2\pi} \right)^2$$

$$= 9.8 \times \left(\frac{2.5}{2\pi} \right)^2 = 1.55\text{m}$$

Use $R=1.5\text{m}$

- a) The total effective stiffness of the isolators system

$$= \sum K_{eff} = \frac{W_T}{R} + \frac{\mu W_T}{D}$$

$$= \frac{11813.6}{1.5} + \frac{0.06 \times 11813.6}{0.2}$$

$$= 11420\text{kN/m}$$

Thus the average effective stiffness K_{en} for a single FPS isolator is $11420/18=635\text{ kN/m}$

- b) The effective damping & provided by the isolator depends on the design displacement D

$$\epsilon_{eff} = \frac{2}{\pi} \frac{\mu}{\mu + \frac{D}{R}} = \frac{2}{\pi} \frac{0.06}{0.06 + \frac{0.2}{1.5}} = 0.198$$

From Table 1623.2.2.1 of the IBC 2000, for an isolation system with $\epsilon = 20\%$ for FPS isolation system

Damping coefficient $B_p = 1.5$

From Table 1615.1.2(2) of the IBC 2000, for the site condition of isolate structure with long period

Seismic coefficient is $S_p=0.4$

c) Post- Yield stiffness

Antonious Lousidis (2015)[24] in his thesis provided the formula calculating post yield stiffness for FPS and from test results he concluded that the for Elastic stiffness (K_e) of friction pendulum is normally 100 times that's of post yield stiffness (K_p)

$$K_p = \frac{W_T}{R} = \frac{11813.6}{1.5} = 7875.73$$

$$K_e = 100 K_p = 100 \times 7875.73 = 787573.3 \text{ kN/m}$$

d) Check for design displacement D_D

$$D_D = \left(\frac{g}{4\pi^2} \right) \frac{S_D T_D}{B_D}$$

$$= \left(\frac{9.8}{4\pi^2} \right) \frac{0.4 \times 2.5}{1.5} = 0.17 \text{ m} \leq 0.3 \text{ m OK}$$

e) Estimation of vertical displacement

$$\delta_v = \frac{D^2}{2R} = \frac{0.2^2}{2 \times 1.5} = 0.013 \text{ m}$$

$$= 13 \text{ cm}$$

Use depth 8-1.7 cm for the disk.

Use diameter $d=45\text{cm}$ for the disk of the FPS ($>2D$) and height $h=35\text{cm}$

Table 6.6 Dimensions of the FPS

a	Radius of curvature of the spherical surface (R)	1.5m
b	Depth of disk (δ)	1.7cm
c	Diameter of the disk (d)	45cm
d	Height of the disk (h)	35cm

Table 6.7 SAP 2000 Properties of the FPS

a	Effective damping ratio is	20%
b	Damping coefficient (B_0)	1.5
c	Frictional coefficient (p)	0.06
d	Rate parameter	0.05
e	Effective stiffness (K)	635kN/m
f	Elastic stiffness (K_e)	43754kN/m

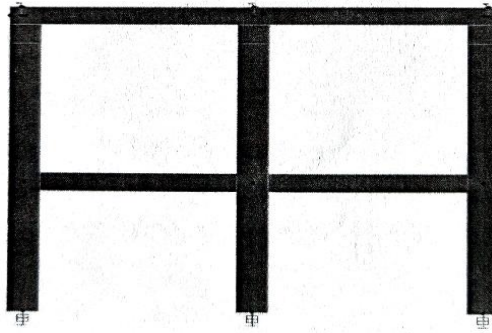


Figure 6.4 SAP model of FPS at the bottom of the pier

RESULTS AND DISCUSSIONS

The seismic behavior of selected bridge model is analysed using linear equivalent static method and non linear Time history method. This chapter presents elastic modal properties of bridge, base shear and top joint displacement under static earthquake load, time history analysis results and discussion. The results obtained from these analyses are checked with three different isolator systems. For time history analyses to replicate true condition, Bhuj earthquake data are used and results obtained from this analyses is presented in the graphs.

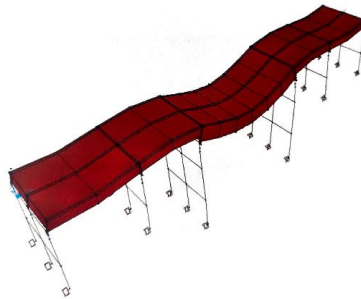


Figure 7.1 Deformed Due To Dead Load on Bridge

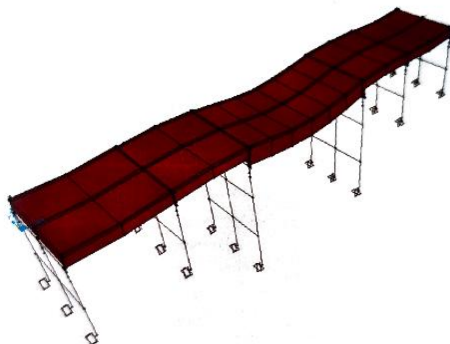


Figure 7.2 Deformation Due To super Dead Load on Bridge

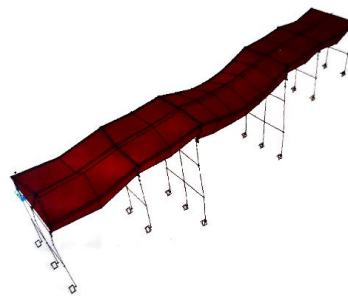


Figure 7.3 Deformation Due To moving Load on Bridge

EQUIVALENT STATIC ANALYSIS RESULTS

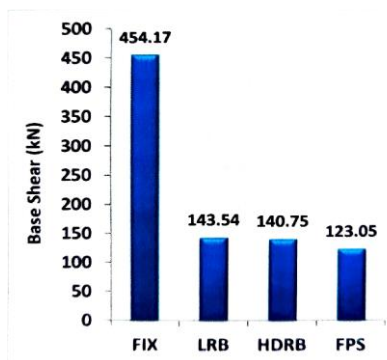
To demonstrate linear analysis of bridge, the equivalent static analyses is carried out along two direction as per guidance of IS 1893: Part 3 and IRC 6-2014. The result of linear equivalent static analysis are compared in terms of Base shear, Deck slab displacement and Top pier displacement between without isolated bridge and bridges with different isolators at junction of pier bottom and foundation top are presented.

BASE SHEAR

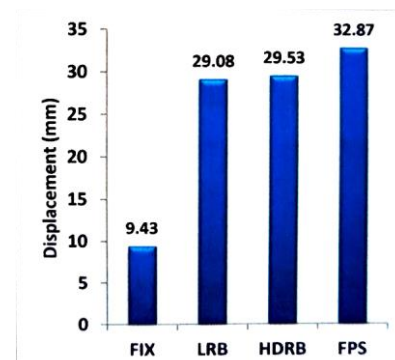
It is estimated maximum values of lateral force that will occur due to seismic ground excitation at the base of a bridge. Base shear values along two lateral directions are represented in below graphs

Table 7.3 Base shear for bridge along X and Y direction

Case	Without Isolator	Lead Rubber Bearing	High Damping Rubber bearing	Friction Pendulum system
Eqx (kN)	454.17	143.54	140.75	123.05
Eqy (kN)	662.28	101.96	97.68	95.02



Graph 7.3 Base Shear comparison along Y-Direction



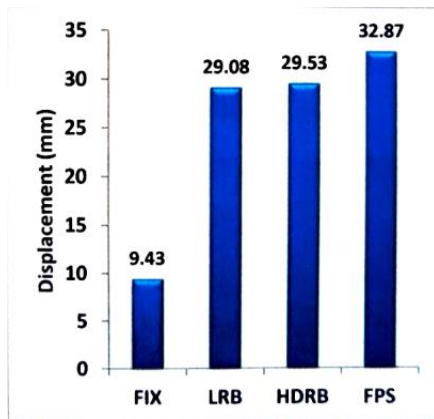
Graph 7.4 Base Shear comparison along Y-Direction

7.2.2.2 DECK SLAB DISPLACEMENT

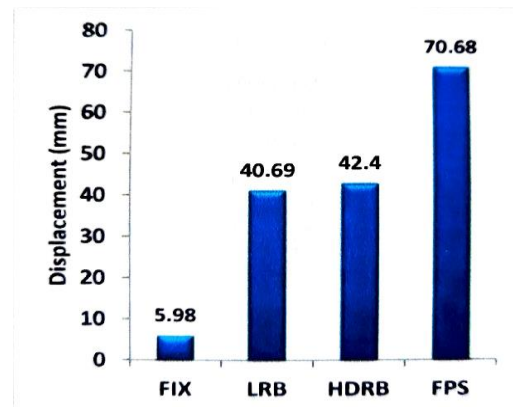
The total displacement of deck slab from its original position along both lateral directions are extracted for one of the top joint and represented in graphical format below.

Table 7.4 Deck slab displacement of Bridge along X and Y Direction

Case	Without Isolator	Lead Rubber Bearing	High Damping Rubber bearing	Friction Pendulum system
Eqx (mm)	9.43	29.08	29.53	32.87
Eqy (mm)	5.98	40.69	42.4	70.68



Graph 7.5 Comparison of Deck slab displacement along X-Direction

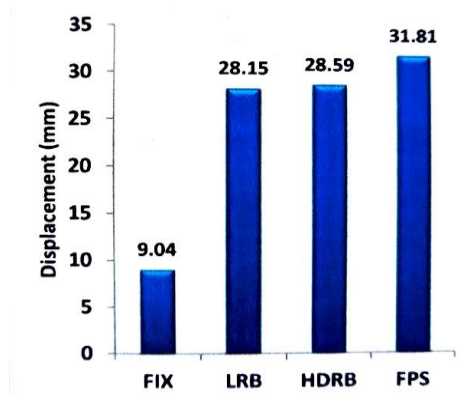


Graph 7.6 Comparison of Deck slab displacement along Y-Direction

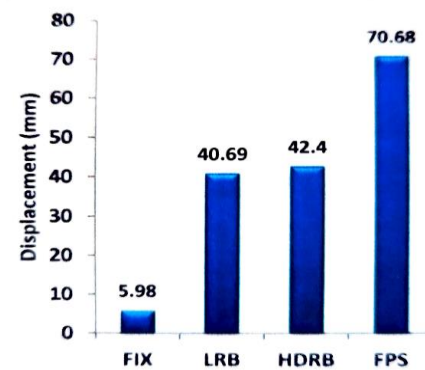
TOP PIER DISPLACEMENT

Table 7.5 Pier top displacement of bridges along X and Y direction

Case	Without Isolator	Lead Rubber Bearing	High Damping Rubber bearing	Friction Pendulum system
Eqx (mm)	9.04	28.15	28.59	31.81
Eqy (mm)	5.77	35.81	37.32	62.3



Graph 7.7 Comparison of Pier top displacement along X-Direction



Graph 7.8 Comparison of Pier top displacement along Y-Displacement

CONCLUSIONS

To determine the values of base isolation of bridges, a RC bridge has been seismically evaluated by using finite element software SAP2000. From the results obtained by Equivalent static analysis and time history analysis methods, the following conclusions are drawn.

1. From the analytical result it is concluded that, it is most reliable to adopt isolation system for effective earthquake resistance design. The result of the analysis shows that the reaction of the structure can be reduced by the use of Lead Rubber Bearing (LRB), High Density Rubber Bearing (HDRB) and Friction Pendulum System (FPS) isolators.
2. From equivalent static method it is concluded that the base shear in X-direction is reduced by 68% in LRB, 69% in HDRB and it is reduced by 73% by the use of FPS. Also in Y-direction it is reduced by 84% in LRB, 85% in HDRB and in FPS it is reduced by 86%. Thus isolated structures will give better protection during earthquake excitation.
3. The bridge with base isolation system such as LRB, HDRB and FPS will shows more deck slab displacement and top pier displacement as compared to non isolated bridge in both X and Y directions.
4. From the results of modal analysis, Structures with base isolation shows higher modal time periods and lower modal frequency as compared with non-isolated bridge. The bridge with isolation system at base level, indicating the increased flexibility of the bridge.
5. From comparison of modal time period at first in isolated structure with non-isolated structure it is found that there is increase in time period of 77.6% by LRB, 78.5% by HDRB and 83.6% by use of FPS.

6. By conducting the nonlinear time history analysis it was shown that isolation increases the flexibility at the base of the structure which helps in energy dissipation due to the horizontal component of the earthquake and hence superstructure's seismic demand drastically reduced as compared to the fixed base structure
7. From Time history analyses graph it is found that there is enough reduction in bases hear for isolated bridge in the longitudinal as well as transverse direction but there is considerable variation of base moment between isolated and non-isolated bridge system,
8. From time history analyses it is concluded that, the displacement of deck slab for base isolated bridges is much more as compared to non isolated bridge in both direction.

SCOPE OF FUTURE WORK

In the present study, analysis was carried out for the bridge model using different kind of isolators at base level of pier at seismic zone I using SAP2000. The following suggestions are made for future studies

1. **Experimental Validation:** Conducting large-scale experimental tests on isolated bridge models to validate and refine the findings of the current study. This will provide more accurate data to support the seismic performance of base isolation systems.
2. **Performance under Multi-Hazard Scenarios:** Investigating the performance of base-isolated bridges under multiple hazards, such as simultaneous seismic and environmental loading (e.g., floods, tsunamis), to ensure the overall resilience of the structure.
- Nonlinear Analysis:** Performing advanced nonlinear analyses to understand the behavior of base isolation systems beyond linear elastic models. This will provide insights into the system's behavior during large seismic events.
3. **Field Studies:** Conducting field investigations of real-life base-isolated bridges to monitor and assess their performance during actual seismic events. This will help validate theoretical models and identify any potential areas for improvement.
4. **Performance of Existing Bridges:** Studying the retrofitting of existing bridges with base isolation systems and assessing the performance of retrofitted structures during seismic events.
5. **Optimal Design and Parameter Optimization:** Exploring optimization techniques to find the most effective and cost-efficient design parameters for base isolation systems in bridge engineering.

6. Influence of New Materials: Investigating the use of innovative materials for base isolation systems, such as smart materials and advanced composites, to enhance the seismic performance of bridges.
7. Resilience and Post-Earthquake Functionality: Analyzing the resilience and post-earthquake functionality of base-isolated bridges to ensure their capacity to resume traffic and emergency services after a seismic event

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