RESEARCH ARTICLE OPEN ACCESS

Application of Base Seperation Method Using Latin Plumbub Elastic Substance Bearing Profiles Under Passive Vibration Control Over Determined Structures

Yamala Dhana Lakshmi[1] S.Sravanthi[2]

[1]P.G.Scholor, VITAM, [2]Assistant Professor, Dept. of Civil Engineering. VITAM,Visakhapatnam, Andhra Pradesh, INDIA.

Abstract:

Free vibration and forced vibration analysis was carried out on the framed structure by the use of computer program SAP 2012 v12.0.0 and validating the same experimentally. The results of the free vibration analysis like time period, frequency, mode shape and modal mass participating ratios of the framed structure were found out. From modal analysis the first mode time period of fixed base building is found to be 0.56 sec whereas the first mode period of isolated building is found to be 3.11s (approximately 6 times the fixed-base period!). This value is away from the dominant spectral period range of design earthquake. Forced vibration analysis (non-linear time history analysis) was done to determine the response of framed structures and to find out the vibration control efficiency of framed structures using lead rubber bearing. Isolation bearings in this study are modelled by a bilinear model. Under favourable conditions, the isolation system reduces the interstorey drift in the superstructure by a factor of at least two and sometimes by a factor of at least five. Acceleration responses are also reduced in the structure by an amount of 55-75% although the amount of reduction depends upon the force deflection characteristic of the isolators. A better performance of the isolated structure with respect to the fixed base structure is also observed in floor displacements, base shear (75-85% reduction), floor acceleration relative to the ground(less acceleration imparted on each floor and their magnitude is approximately same in each floor), roof displacement. Introduction of horizontal flexibility at the base helps in proper energy dissipation at the base level thus reducing the seismic demand of the super structure to be considered during design.

INTRODUCTION

For seismic design of building structures, the traditional method, *i.e.*, strengthening the stiffness, strength, and ductility of the structures, has been in common use for a long time. Therefore, the dimensions of structural members and the consumption of material are expected to be increased, which leads to higher cost of the buildings as well as larger seismic responses due to larger stiffness of the structures. Thus, the efficiency of the traditional method is constrained. To overcome these disadvantages associated with the traditional method, many vibration-control measures, called structural control, have been studied and remarkable advances in this respect have been made over recent years. Structural Control is a diverse field of study. Structural Control is the one of the areas of current research aims to reduce structural vibrations during loading such as earthquakes and strong winds.

The passive control is more studied and applied to the existing buildings than the others. Base isolation is a passive vibration control system that does not require any external power source for its operation and utilizes the motion of the structure to develop the control forces. Performance of base isolated buildings in different parts of the world during earthquakes in the recent past established that the base isolation technology is a viable alternative to conventional earthquake-resistant design of medium-rise buildings. The application of this technology may keep the building to remain essentially elastic and thus ensure safety during large earthquakes. Since a base-isolated structure has fundamental frequency lower than both its fixed base frequency and the dominant frequencies of ground motion, the first mode of vibration of isolated structure involves deformation only in the isolation system whereas superstructure remains almost rigid. In this way, the isolation becomes an attractive approach where protection of expensive sensitive equipments and internal non-structural components is needed. It was of interest to check the difference between the responses of a fixed-base building frame and the isolated-base building frame under seismic loading. This was the primary motivation of the present study.

LITERATURE SURVEY

Thus the modal analysis of framed Structure is of great technical importance for understanding the behaviour of the framed Structure under applied dynamic loading. The study of response analysis methodology (Experimental or Analytical) of a base isolated framed structure with a fixed base otherwise similar framed structure is essential to conclude the effectiveness of base isolation using rubber bearing.

"Earthquake proof structures" generally mean the structures which resist the earthquake and save and maintain their functions. The key points for their design includes select good ground for the site, make them light, make them strong, make them ductile, shift the natural period of the structures from the predominant period of earthquake motion, heighten the damping capacity.

Izumi Masanory [1] studied on the remained literature, the first base isolated structure was proposed by Kawai in 1981 after the Nobi Earthquake (M=8.0) on journal of Architecture and building Science. His structure has rollers at its foundation mat of logs put on several steps by lengthwise and crosswise manually. After the San Francisco Earthquake (M=7.8) an English doctor J.A. Calantarients patented a construction by putting a talc between the foundations in 1909. The first base isolated systems actually constructed in the world are the Fudo Bank Buildings in Himeji and Simonoseki, Japan designed by R. Oka. After the world War-II, the U.S took a leading part of Earthquake Engineering. **Garevski** A *et al.* [2] The primary school "Pestalozzi" in Skopje, built in 1969, is the first building in the world for which natural rubber isolators were used for its protection against strong earthquakes. The first base isolated building in the United States is the Foothill Communities of Law And Justice Centre completed in 1985 having four stories high with a full basement and sub-basement for isolation system which consists of 98 isolators of multilayered natural rubber bearings reinforced with steel plates. The Superstructure of the building has a Structural Steel frame stiffened by braced frames in some Bays [3]. In India, base isolation technique was first demonstrated after the 1993 Killari (Maharashtra) Earthquake [EERI, 1999]. Two single storey buildings (one school building and another shopping complex building) in newly relocated Killari town were built with rubber base isolators resting on hard ground. Both were brick masonry buildings with concrete roof. After the 2001 Bhuj (Gujarat) earthquake, the four-storey Bhuj Hospital building was built with base isolation technique

The Base isolation system has been introduced in some books of dynamic Engineering and the number of scholars has been increasing in the world.

Modal Analysis:

Modal analysis is the study of the dynamic properties of structures under vibration excitation. In structural engineering, modal analysis uses the overall mass and stiffness of a structure to find the various periods at which it will naturally resonate. A normal mode of an oscillating system is a pattern of motion in which all parts of the system move sinusoidally with the same frequency and with a fixed phase relation. Eigenvector analysis determines the undamped free-vibration mode shapes and frequencies of the system. These natural modes provide an excellent insight into the behaviour of the structure. Ritz vector analysis seeks to find modes that are excited by a particular loading. Ritz vectors can provide a better basis than do eigenvectors when used for response-spectrum or time-history analyses that are based on modal superposition. Thus, modal analysis is done by following methods,

1. Eigenvector analysis
2. Ritzvector analysis

3.3.1 Modal hammer

The modal hammer excites the structure with a constant force over a frequency range of interest. Three interchange tips are provided which determine the width of the input pulse and thus the band width of the hammer structure is acceleration compensated to avoid glitches in the spectrum due to hammer structure resonance. For present experiment modal hammer type 2302-5 was used, which is shown in Fig. 6.

3.3.2 Accelerometer:

Accelerometer combines high sensitivity, low and small physical dimensions making them ideally suited for modal analysis. It can be easily fitted to different test objects using a selection of mounting clips. For the present experiment accelerometer type 4507 was used and which was fixed on plates by using bee wax. The accelerometer which is used in the present free vibration test is presented in Fig. 7.

3.3.3 Portable FFT Analyzer - type (3560C)

Bruel and kajer pulse analyzer system type –3560 software analysis was used to measure the frequency for any structure. It can be used for both free vibration as well as forced vibration study. The system has some channels to connect the cables for analyzing both input and output signals. Bruel Kajer FFT analyzer is shown in Fig. 8

Fig. 3. Bruel & Kajer FFT (spectrum) Analyzer

3.3.4 Display unit

This is mainly in the form of PC (Laptop).When the excitation occurs to the structure, the signals transfer to the portable PULSE and after conversion this comes in graphical form through the software and display on the screen of laptop. Mainly the data includes graphs of force Vs time, frequency Vs time resonance frequency data etc. The display unit is shown below in Fig. 9.

Fig. 4. Display unit used in Free Vibration Test.

3.4 Time-History Analysis:

Time history analysis of the frame was carried out to determine the response of the frame under a given dynamic loading.

Time history analysis is the most natural and intuitive approach. The response history is divided into time increments t and the structure is subjected to a sequence of individual time-independent force pulses f (*t*). The nonlinear response is thus approximated by series of piecewise linear systems.

Here time history records of Northridge Earthquake, Century City (17/01/1994) data recorded at LACC NORTH available from PEER Strong Motion Database (http://peer.berkeley.edu/svbin/download/qid=131&sid=428) (Fig-1) is used for the time history analysis. From the available time history functions file in SAP2000 two records lacc nor-1.th and lacc nor-2.th are chosen for analysis which are shown in the form of function graph as shown below. Each record is divided into 3000 points of acceleration data equally spaced at .020 sec. (Units: cm/sec/sec).

lacc nor-1.th

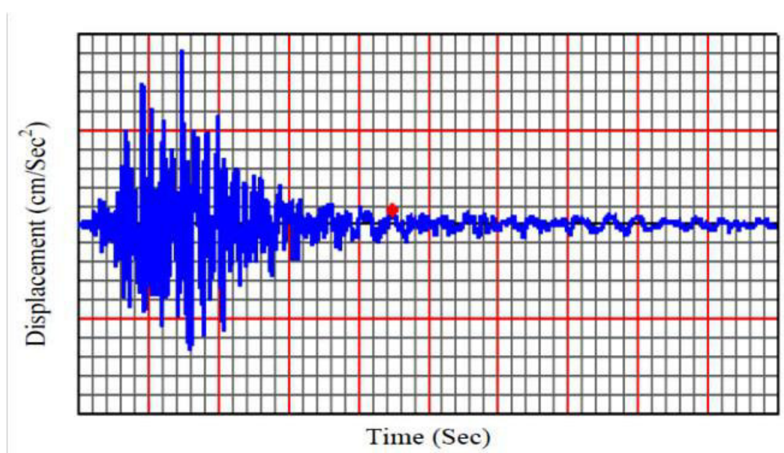

Fig. 5. Time history function record lacc nor-1.th (from SAP window).

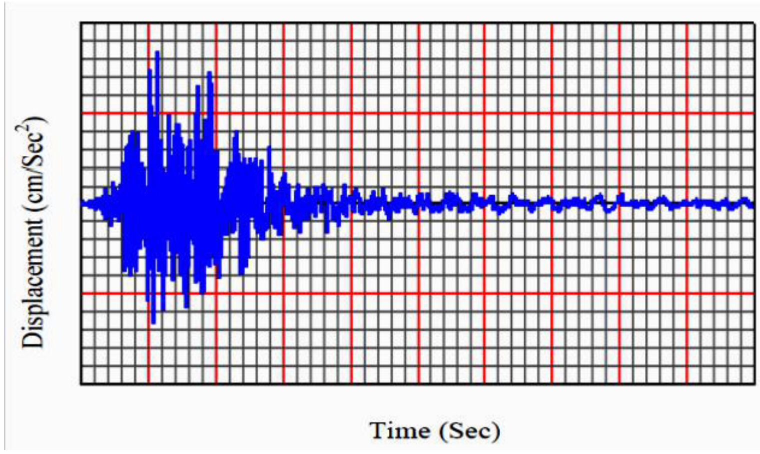

Fig. 6. Time history function record lacc nor-2.th (from SAP window).

3.5 Earthquake time histories

For input to the time-history analysis Northridge earthquake record was used. Non linear time history analysis was done by the use of Northridge earthquake record to get the result. In this study, the time history analyses of the selected building were carried out for bidirectional ground motions record of Northridge earthquake in two perpendicular directions.

Northridge earthquake

The Northridge earthquake was a massive earthquake that occurred on January 17, 1994 in Reseda, a neighbourhood in the city of Los Angeles, California, lasting for about 10–20 seconds. The earthquake had a "strong" moment magnitude of 6.7, but the ground acceleration was one of the highest ever instrumentally recorded.

3.6 Lead rubber bearing:

In the present paper, the isolators were initially designed to follow some available recommendations of the Uniform Building Code (UBC-97). The mechanical properties of the LRB isolation system were set to comply with a recommendation of the UBC-97 building code. The design parameters considered here are: the ratio Q/W of the characteristic strength Q over the total weight on the isolation system W, the yield force Fy , the isolator diameter

D, the lead core diameter d, the number of rubber layers n, and the layer thickness t. For design and analysis, the shape of the nonlinear force–deflection relationship, termed the hysteresis loop (represented as a bilinear curve as shown in Fig. 4), has an elastic (or unloading) stiffness k_e and a yielded (or post-elastic) stiffness k_p.

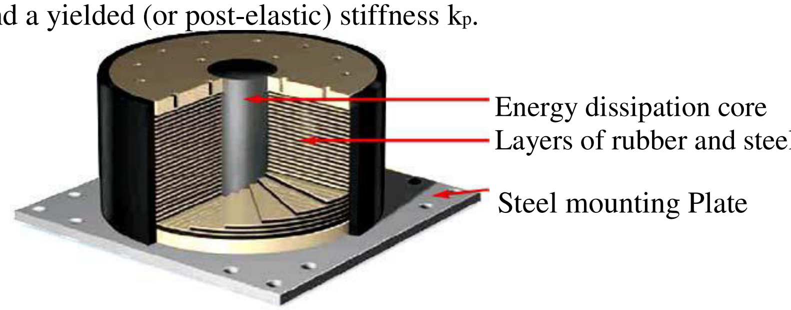

Fig. 7. The Lead rubber Bearing. (The top mounting plate is not shown)

RESULTS

First modal analysis of a benchmark problem is solved using SAP2000. The benchmark problem is taken from literature (Bezerra and Carneiro, 2003). The details of the problem are discussed in the following section.

4.1 Modal Analysis of a Benchmark Problem

Modal analysis of a typical building structure frame is done to determine the dynamic parametres like natural frequency, time period, modal participating mass ratios and their corresponding mode shapes. Typical building structure frame (Fig. 10) made of reinforced concrete has four floors and composed of columns 3.0m height and of cross section 30×50 cm^2 with I = $3.1\times10^{-3}m^4$, and beams with span of 4.5m, cross-section 24x55 cm^2, and inertia I = $3.5\times10^{-3}m^4$. The first natural frequency of the building is 2.3Hz.

From the modal analysis time period, frequencies are noted for modes with considerable mass participation. These are the important modes of consideration. The first natural frequency of the

Table 3.Time period and frequency of the building for first three modes.

Mode	T (s)	f (cps)	UX (%)	UY (%)	RZ (%)
1	0.43	2.3195	0	86	0
2	0.35	2.8713	0	0	85
3	0.34	2.9387	83	0	0

	f (cps)	
	(Bezerra and Carneiro, 2003)	SAP output
First mode	2.3	2.3195

4.6.3 Horizontal flexibility:

Base isolation increases the horizontal flexibility of the structure at the base in both X and Y direction as compared to the conventional fixed base one which is indicated from the curve (Fig. 23 and Fig. 24) below. Introduction of horizontal flexibility causes dissipation of horizontal component of earthquake ground motion effectively, so that transmission of ground motion to the superstructure is less which results in less damage and prevention of collapse in structure.

.5 Rigidity of the superstructure above isolator:

Entire super structure behaves almost as a rigid one due to the presence of isolator. Here floor displacement and roof displacement response curves of the isolated structure are plotted which equivalents (Fig. 26). The superstructure of a base-isolated building is relatively rigid compared with the isolation system. This can lead to idealization of the superstructure as a rigid body, modelling the base-isolated structure as a single-degree-of-freedom system. Introduction of flexible superstructure decreases the effectiveness and goal of using base isolation. Entire superstructure is considered to be rigid and linear. The nonlinearity are supposed to be concentrated in isolator level only.

4.6.6 Time histories of Base shear response:

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. It has been observed that base isolation process is very effective in reducing the base shear as compared to conventional fixed base structure. As a result the potential damage to the bottom level of two-storey frame

is reduced. The seismic demand of the structure to be considered during design is drastically decreased. (Fig. 27.)

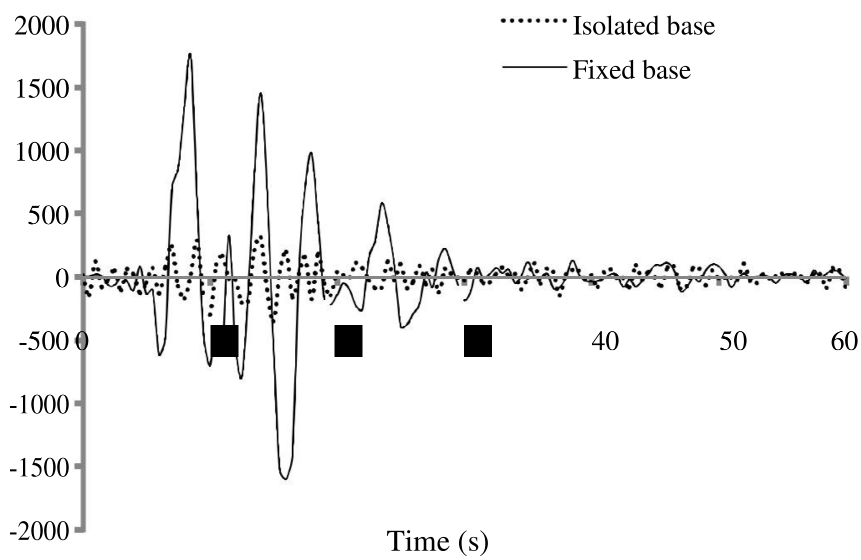

Fig. 27. Time history of base shear response.

The summary of the base shear response presented in Fig. 27 is presented in Table 7 as follows:

Table 7. Base shear response of base-isolated framed structure as compared to its fixed base framed structure.

		Isolated	Fixed
Maximum	Base Shear (kN)	307.47	1736.00
	Time (s)	14.00	16.00
	Reduction in base shear = 82.30 %		
Minimum	Base Shear (kN)	-351.33	-1604.00
	Time (S)	14.00	8.50
	Reduction in base shear = 78.10 %		

4.6.7 Time histor y of Displa cement response:

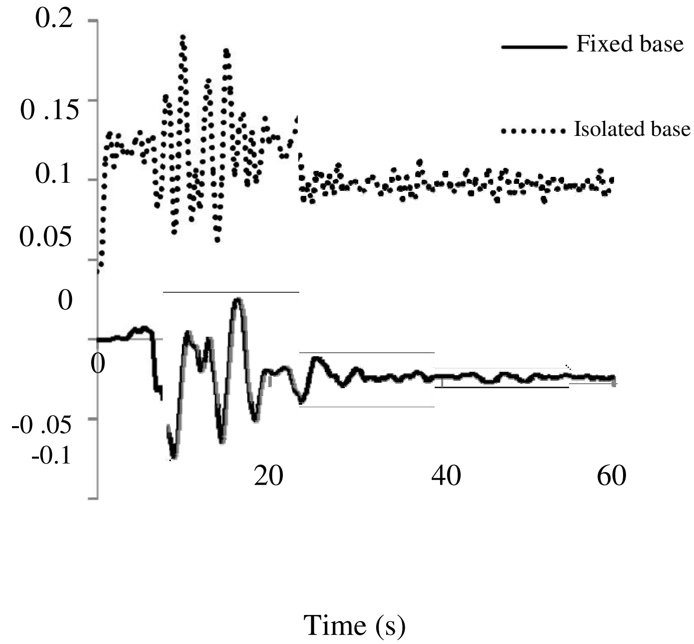

Fig. 28. T ime histor of displacement resp onse at roof.

4.6.8 Time histor y of Velocit y response :

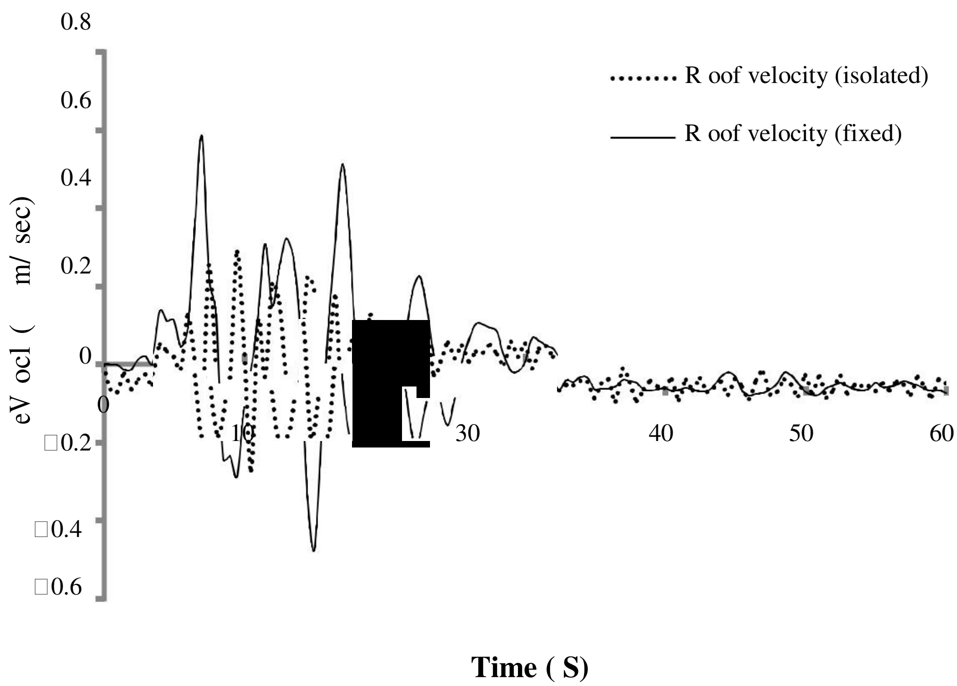

Fig. 29. Time history of velo city respon e at roof.

Table 8. Velocity response of base-isolated framed structure as compared to its fixed base framed structure.

		Isolated	Fixed
Maximum	Velocity (m/sec)	0.26	0.55
	Time (S)	9.50	7.00
			Reduction = 53.30 %
Minimum	Velocity (m/sec)	-0.29	-0.50
	Time (S)	10.50	15.00
			Reduction = 40.60 %

Fig. 28 presents the displacement response of the building roof subjected to Northridge Earthquake at base. This figure shows that the roof displacement of isolated base and fixed base building are quite similar in nature except there is a translational shift of the mean displacement by 0.12m (approx.) in case of isolated base building. However, the displacement range (maximum – minimum) is little more for isolated base.

Similar results are shown in Fig. 29 for the velocity response. This figure shows that unlike displacement response the velocity of both the buildings is oscillating with a zero mean velocity. It is found that the velocity range (maximum – minimum) is approximately 60% more for fixed base building. Table 8 presents the summary of the roof velocity response of the two building models.

Similar results are shown in Fig. 30 for the acceleration response. This figure shows that unlike displacement response the acceleration response of both the buildings is oscillating with a zero mean velocity. It is found that the acceleration range (maximum – minimum) is approximately 30% more for fixed base building. Table 9 presents the summary of the roof acceleration response of the two building models.

4.6.11 Relative measure of Floor displacements with respect the base of the frame.

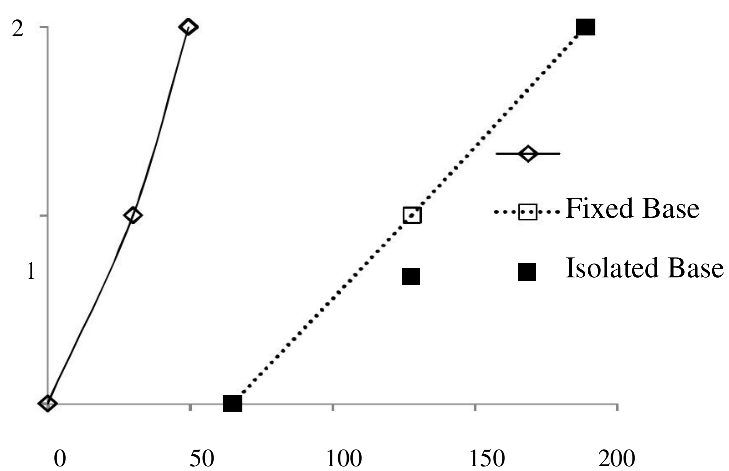

Fig. 32. Floor displacements with respect the base of the frame.

In case of isolated framed structure the displacement of the framed structure at each floor is more as compared to its corresponding fixed base one (Fig. 32.) with respect to the base of the frame. The increase in displacement is more uniform in isolated base as compared to the fixed base framed structure.

4.6.12 Relative measure of Floor displacements with respect the base of the frame.

n case of isolated framed structure the acceleration of the framed structure at each floor is less as compared to its corresponding fixed base one (Fig. 33.) with respect to the ground. The magnitude of acceleration imparted at each floor is approximately equal which signifies the rigidity of the superstructure above the isolator and the entire superstructure can be idealised as an S-DOF system. The increase in displacement is uniform in fixed base framed structure.

5.2 CONCLUSION

Modal analysis study: From the modal analysis study natural frequency and the mode shape of the framed structure is obtained. The determination of mode shape is essential to analyse the behaviour of the structure under applied dynamic loading. From the modal analysis of the Aluminium frame natural frequency, mode shapes and corresponding modal participating mass ratios are obtained. The mode shapes for which modal partiapting mass ratios are maximum taken into consideration. SAP 2000 is very effective tool to validate the results obtained experimentally. From the modal analysis first mode time period of fixed base building is found to be 0.56 sec whereas the first mode period of isolated building is found to be 3.11s (approximately 6 times the fixed-base period!). This value is away from the dominant spectral period range of design earthquake. Similar Shift was also observed in the higher modes, which shows the effectiveness of base isolation.

Time history analysis study: By conducting the nonlinear time history analysis it was shown that base isolation increases the flexibility at the base of the structure (Figs. 19 and 20), 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 conventional fixed base structure. The lead core present at the centre increases the energy absorption capacity of the isolator (Fig. 3). The area of each cyclic loop represents the energy dissipated per cycle (Fig. 21). Here floor displacement and roof displacement response curves of the isolated structure are plotted which are equivalent and it indicates the rigidity of the superstructure above the isolator (Fig. 22). Base isolation reduces the base shear by 75-85% (Fig. 23) and reduces the velocity, acceleration response by 55-75% (Figs. 25 and 26). It also reduces interstory drift as compared to the conventional fixed base structure. It reduces the force imparted on the structure at each floor (Fig. 29) and the force imparted is equivalent at each floor as compared to the fixed base structure.

5.3 FUTURE SCOPE OF STUDY:

The vibration control technology is developing and its application is spreading in various fields of engineering structures. Factories, hospitals and residential houses will be protected from environmental vibration. It is evident that this technology will be progressed and become more important in the coming century.

In the present study natural frequency, mode shape, modal mass participating ratios of the structural model and nonlinear time history analysis was carried out to determine the behaviour of the structure under dynamic loading. Effectiveness of base isolation was studied by considering bilinear model of the LRB and modelling the same and superstructure by SAP 2000. The future scope of the present study can be extending as follows:

Introduction of analysis software such as ETABS, SAP 2000 and LARSA help in explicit modelling of isolators which exhibit mildly nonlinear behaviour during dynamic loading.

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