IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X
PP 65-70
www.iosrjournals.org

Seismic Isolation Strategies for Active Components Mounted On R.C.C. Structures

Raviteja Chilukuri [1], G. R. Reddy [2], M. R. Srikanthan[3], S. Karimulla [4]
[1,2,3,4] *Bhabha Atomic Research Centre, India.*

ABSTRACT: Base isolation of structures is regarded as a promising solution for earthquake resistant design. This technique ensures the safety of structural and non structural elements, thereby keeping the building and equipment functional during and after a severe earthquake. Seismic isolation of active components mounted on structures may be achieved by isolating the structure on which the active component rests or by isolating the active components itself. Former may serve dual purpose as it optimizes the seismic design of structures as well the machine. The present work would deal with the design of 3D isolation system, using laminated rubber bearings with thick, thin rubber layers, helical springs and their combination. Experimental modal analysis of isolator is carried out to validate the design procedures followed. The effectiveness of 3D isolation over conventional seismic design is numerically studied using a case study of a industrial structure which houses rotating equipment. From the floor response spectra generated, it is observed that seismic accelerations on the floor mounted active components are drastically reduced in 3D isolated structure.

Keywords: *Seismic Isolation, 3D seismic isolation, seismic protection ,Base isolation, Active components isolation*

I. INTRODUCTION

So far several major earthquakes such as Latur, 1995, Bhuj, 2001 etc. have been experienced, all of which have caused damage to life and property. As such there has been an increasing awareness among structural engineers regarding the seismic safety of structures and components .The fundamental frequency of vibration in conventional midrise buildings is in the range of frequencies with maximum earthquake energy content. Thus the building acts as an amplifier of the ground acceleration, and the accelerations at each floor level increases to the top. This leads either to damage or to loss of functionality of the various components mounted on different floor levels. Present Base-isolation components cannot effectively decrease vertical earthquake action, sometimes even result in disadvantage. Plenty of recent earthquake records show that vertical ground motions especially in near-field earthquake or close to earthquake fault, sometimes exceeds horizontal earthquake motion. In addition active components mounted on floors, may need to be isolated to take care of normal vibrations in vertical directions. Developing a generalized base isolation to take care of three dimensional vibration as well as earthquake motion is the subject of ongoing research. Moreover, to develop isolation device combining vertical isolation with horizontal isolation is an important problem to be addressed.

Design of 3D Isolator

Three dimensional base isolation system is designed using a series connection of horizontal isolator and vertical isolator. For ideal 3D seismic isolation the isolator should be able to achieve 0.5HZ frequency in both horizontal and vertical directions. Three types of new 3D isolators are designed as shown in Fig.1. Isolator-I is designed as a base isolator for a load of 270 tons, to achieve 0.5 Hz horizontal frequency using HDLR bearings and 1Hz vertical frequency using LRB with thick rubber layers as shown in Fig.1.(a). Isolator-II is designed as a base isolator for 270 tons load, to achieve 0.5 Hz horizontal frequency using HDLR bearings and 0.5 Hz vertical frequency using helical springs as shown in Fig.1.(b). Isolator-III is designed as a floor isolator for 21.6 tons load, to achieve 0.5 Hz horizontal frequency and 1 Hz vertical frequency using helical springs as shown in Fig.1.(c). Isolators are designed for normal compressive loads and shear loads under maximum considered earthquake, checked for stability as per standard LRB design procedures[1]. To avoid buckling problems in the design of vertical isolator encasement is provided in the form of steel plate [2] as shown in

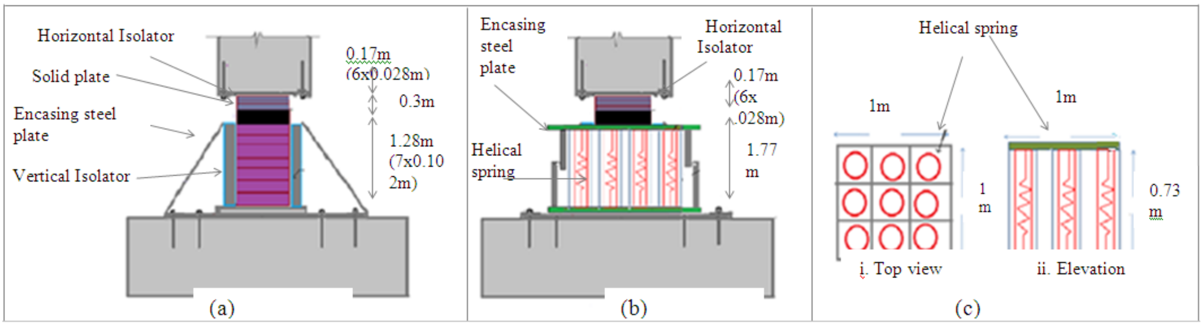


Fig.1.(a). The effect of encasement on rubber isolator is practically studied in section3.

II. EXPERIMENTAL DEMONSTRATION

Free vibration testing of a laminated Rubber isolator is carried out to obtain natural frequencies. Experimental modal analysis is carried out by FFT (Fast Fourier Transformation) analyzer, data acquisition system and OROS software under impact excitation to identify natural frequencies of the model. The model is also analyzed numerically and the results are compared with experiments to validate the methodology used. The experimental model consists Square Rubber Isolator laminated with steel shims is having a footprint size of 52mm and height of 116 mm as shown in Fig.2.1. Isolator consists of 9 number of rubber layers laminated between 8 steel shims of each 2mm thickness. Encasing is provided up to 63 mm height to study the stiffness variations as shown in Fig.2.1.(b).

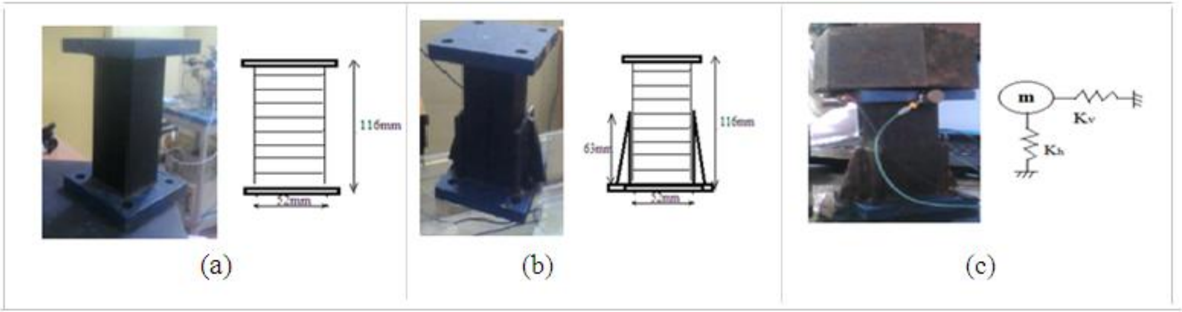


Fig. 2.1 Experimental model of rubber isolator (a) without Encasing (b) with Encasing(c) with mass, accelerometer

3.1 Experimental modal analysis

The phenomenon of resonance is used to find the natural frequencies of isolator with various heights. Experimental modal analysis involved the installation of a high-resolution uni-axial accelerometer as shown in the Fig.2.1. The installed accelerometers are connected to charge amplifier, which is used to amplify the signal received from the accelerometer. The recorded accelerations were then analyzed using FFT analyzer to obtain system's natural frequencies. Modal analysis of isolator has been carried out with different masses of 1.27 kg, 5.94 kg, 10.94 kg and 15.94 kg and corresponding natural frequencies are recorded. Encasing effect on isolator has been tested.

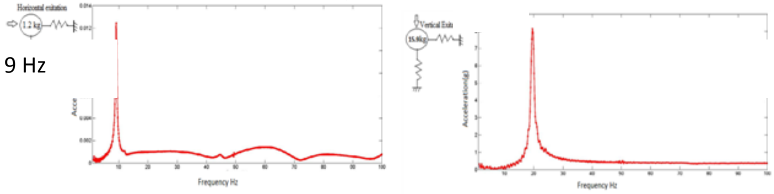
3.1.1 Isolator without Encasement

Isolator is as shown in Fig.2(a) and it is having 9 numbers of 9mm rubber layers with 8 steel shims of 2mm size .Shear modulus of 0.55Mpa and allowable compressive stress of 5Mpa with a Vertical load capacity of 10.8 KN.

Vertical stiffness of rubber isolator: $K_v = \frac{AE(1+2ks^2)}{t_i n}$=246KN/m … (1)

Horizontal shear stiffness of rubber isolator: $K_H = \frac{AG}{\sum t_i}$ =12.768 KN/m … (2)

As the isolator aspect ratio is more than one (height to width), flexure deformation along with shear deformations needs to be considered for evaluating combined stiffness in horizontal direction, calculated using Dunkerley's formulae. Experimental modal analysis of Rubber isolator with different masses is performed and results are tabulated in TABLE 1.1. FFT output of rubber isolator with 1.27 kg mass and 15.9 kg mass, under horizontal and vertical excitations respectively as shown in Fig.2.2. It shows peaks at 9 HZ for horizontal excitation and 20 Hz under vertical excitation. Fig.2.3 shows variation of frequency with mass for the case of experimental and theoretical evaluations. Fig. 2.3.(a) shows vertical frequency curves which are in good agreement with the experimental results. Theoretically calculated horizontal frequencies are lower than experimentally measured frequencies, which can be observed in Fig. 2.3(b). This is mainly because of dominant flexure behavior of isolator, which is imparting nonlinearity since the isolator is stiffer in compression compared to tension. And also dunkerley’s formula ignores the harmonics of vibration and always gives lower value of frequency which is used for theoretical frequency calculations. A correction factor of 0.833 is applied on experimental results which are plotted in Fig. 2.3.c.



(a).Attached with 1.27 kg mass (b). Attached with 15.9 kg mass

Fig 2.2 FFT output-natural frequencies for Isolator

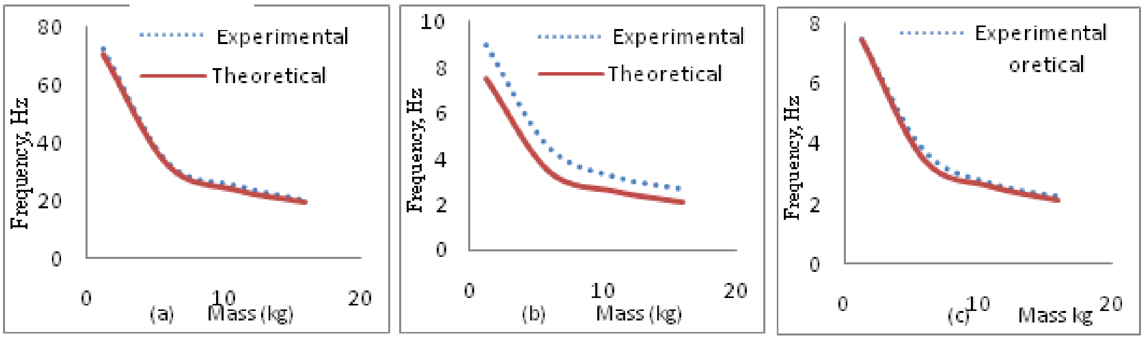


Fig.2.3 Frequency curves a) Vertical frequency b)Horizontal frequency c)Corrected horizontal frequency

Table 1.1 Experimentally measured frequencies and Stiffness’s of Isolator (Without encasement)

Mass in Kg	Horizontal Frequency f_H in HZ	Corresponding Stiffness K_H in KN/m	Vertical Frequency f_V in HZ	Corresponding Stiffness K_V in KN/m
1.27	9	4.06	72	259.9
5.94	4.5	4.74	33	255.3
10.94	3.2	4.4	25	269.9
15.94	2.67	4.5	20	251.71
800kg(Extrapolated)	0.37	4.5	2.8	250

3.1.2 Isolator with Encasement

Casing has been provided up to 63mm height from bottom as shown in Fig.2.(c)

Vertical stiffness of rubber isolator as per equation 1 is 246KN/m
Horizontal shear stiffness of rubber isolator as per equation 2 is 2KN/m

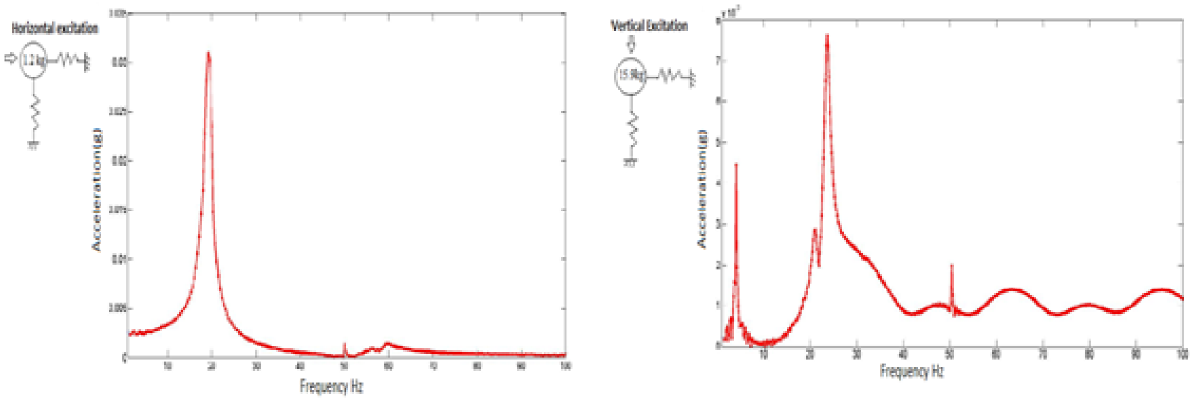
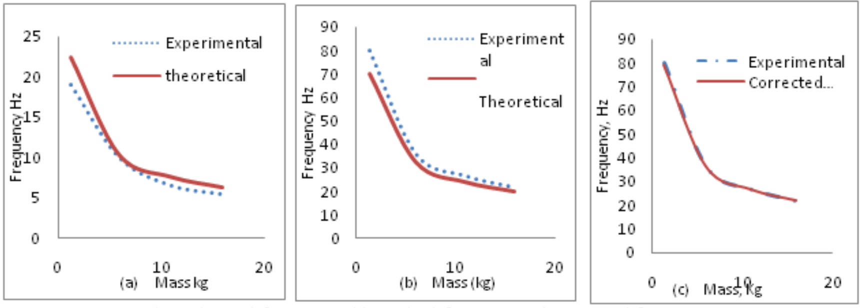


Fig.2.2 .FFT output-natural frequencies a). Isolator with 1.27 kg mass b). Isolator with 15.9 kg mass

Fig.2.4 shows FFT output of encased rubber isolator with mass of 1.27 kg and 15.9 kg, under horizontal and vertical excitations respectively. It shows peaks at 19 HZ for horizontal excitation and 21.97 Hz under vertical excitation Experimental modal analysis of encased Rubber isolator with different masses is performed and results are tabulated in TABLE.1.2.



a) Horizontal frequency b) vertical frequency c)Corrected frequency
Fig.2.5 Frequency curves for Encased bearing

Fig.2.5 shows variation of frequency with mass for the case of experimental and theoretical evaluations.. For the encased bearing experimental horizontal frequencies are lower than theoretical frequencies, mainly because of increase in flexibility caused by 8 mm rubber cover which encloses steel shims. If encasing is provided up to steel shims it will nullify the effect of rubber cover. Good agreement between theoretical and experimentally measured horizontal frequencies can be observed in Fig.2.5 (a) even neglecting the rubber cover effect. From Fig.2.5(b), we can conclude that encasing effect significantly increased the vertical stiffness of isolator. This effect has to be considered in the design of encased isolators. The main reason for increase in vertical stiffness is due to restriction to bulging of rubber provided by encasing which should be considered in the design. The corrected frequency mass curves for encasing effect with a correction factor of 1.13 (multiplied with theoretical calculations) are shown in Fig.2.5. (c).

Table 1.2 Experimentally measured frequencies and Stiffness's of Encased Isolator

Mass in Kg	Horizontal Frequency f_H in HZ	Corresponding Stiffness K_H in KN/m	Vertical Frequency f_V in HZ	Corresponding Stiffness K_V in KN/m
1.27	19	18.09	80	320
5.94	10	23	36.29	309
10.94	6.54	18.5	26.87	312
15.94	5.45	18.7	21.97	304

800kg(Extrapolated)	0.75 Hz	18	3Hz	305

Encased rubber isolator used in experimentation, is able to achieve 0.75 Hz horizontal frequency and 3 Hz vertical frequency under 800 kg mass. Stiffness Correction for encasement effect is carried out. The methodology used for design of 3D isolation system, is validated experimentally with good agreement in results.

III. CASE STUDY

Numerical analysis of a safety related two storey industrial structure housing high speed rotating machinery is considered as case study. The R.C.C structure is having a footprint size of 48m x47.2 m with a height of 26m as shown in Fig.3. Static and dynamic analysis of structure is carried out by analytical and numerical methods. The R.C.C structure is analyzed numerically using FEM analysis [3] as per different codal provisions [4, 5].

Fig.3. a) 3D Finite Element model b) Seismic drifts in fixed base structure c) Seismic drifts in base isolated structure

The complete structure is idealized as three-dimensional space frame using commercial Finite element software. Beam and column is idealized as Beam element and slab as plate element. Dynamic analysis is carried out independently as per input data given in TECDOC -1347 and I.S-1893 [4, 5] using Response Spectrum method [6,7] considering earthquake motion in three orthogonal directions (two horizontal and one vertical) simultaneously. Structure is analyzed with and without 3D isolators described in section 2 and Floor response spectra (FRS) is generated for both the cases and compared as shown in Fig's 3.1, 3.2 and 3.3. Seismic drifts in isolated building are decreased by more than 90% are shown in Fig.3. Fig.3.1 shows FRS Comparison for Fixed base and Base isolated structures isolated with Isolator- I and it can be observed that in horizontal FRS 88% reduction in spectral accelerations and in vertical FRS 86.2% reduction in spectral accelerations corresponding to machine natural frequency of 9Hz in case of iso (b) structure. Fig.3.1.(c) shows FRS Comparison for Fixed base and Base isolated structures Isolator I and II and it can be observed that 86.2%, 96.9% reduction in spectral accelerations and in base isolated structure with isolator-I (1Hz), isolator-II (0.5Hz) respectively corresponding to machine natural frequency of 9Hz. Fig.3.2 shows FRS Comparison for Fixed base and Floor isolated structures isolated with Isolator -III and it can be observed that 79.3% reduction in horizontal FRS and 89% reduction in vertical FRS.

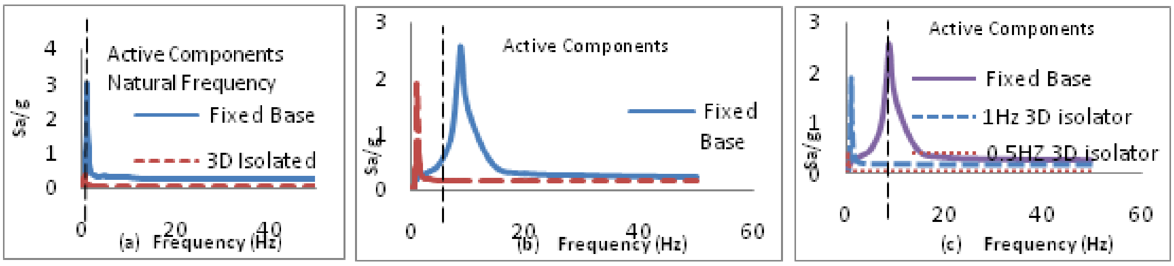


Fig.3.1 a) Horizontal FRS at 10.3m b) Vertical FRS at 10.3m c)Vertical Floor response spectra at 10.3m

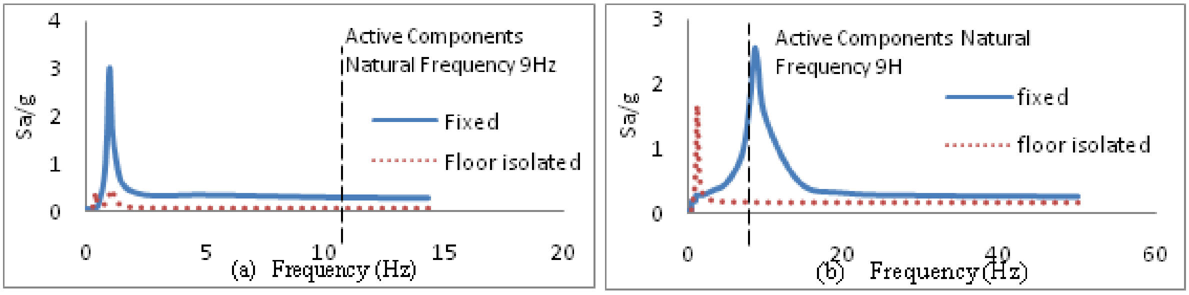


Fig.3.2. a) Horizontal Floor response spectra b) Vertical Floor response spectra at 10.3m

IV. CONCLUSIONS

3D seismic isolation system can be designed to protect the building and also its contents from high floor accelerations. From experimental and numerical analysis the following conclusions were made.

Design concepts of three types of 3D isolators are presented. Effectiveness of 3D isolators to control the response of structure is presented.

Experimental modal analysis results obtained by impact excitation are in good agreement with that of numerical results. The methodology used for design of 3D isolators is experimentally validated. The increase in vertical stiffness with encasing effect has to be considered in the design.

Seismic effects in isolated building are negligible with designed isolators. Seismic drifts in isolated building are decreased by more than 90% (by a factor of 11.6).

Floor response spectra with 3D isolators show 79% to 96.9% reduction in spectral accelerations in both vertical and horizontal directions corresponding to machine frequency of 9Hz .

Seismic loads on active components are significantly reduced and resonance with seismic frequencies is avoided by shifting the resonance frequency.

REFERNCES

[1] T. E. Kelly, R . I. Skinner, and B. W. H Robinson, Seismic isolation for designers & Structural engineers, (Nicee publications, 2010).

[2] Shuichi YABANA And Akihiro MATSUDA, mechanical properties of laminated rubber bearings for Three-dimensional seismic isolation, Proc. of the 12th WCEE, 2000.

[3] David V Hutton, (Fundamentals of Finite element analysis, McGraw hill editions, 2005).

[4] TECDOC-1347, Consideration of external events in the design of nuclear facilities other than nuclear power plants, with emphasis on earthquakes, IAEA, 200).

[5] IS-1893, Criteria for Earthquake Resistant Design of Structures – General Provisions and Buildings, Bureau of Indian Standards, New Delhi, 2002.

[6] Clough R.W and Penzine J, Dynamics of Structures, (Computers and structures lnc.. Berkeley, USA, 1995).

[7] P. Agarwal and M. Shrikhande, (Earthquake Resistant Design of Structures, Prentice Hall, India, 2007).