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Design and Study of Seismic Base Isolators

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Abstract—*This paper aims at the design of the various seismic energy dissipation devices and to analytically study its effectiveness against the energy caused by the shaking of ground. The method of energy dissipation chosen was Base isolation process through Rubber Isolators.*
Four different types of Isolators were selected which are as follows:

- *(i) Elastomeric Rubber Isolator*
- *(ii) Lead Rubber Isolator*
- *(iii) Spring-Lead Rubber Isolator*
- *(iv) Carbon Rubber Isolator*

A G+5 steel frame building was taken to study its response in normal fixed base conditions and base isolated conditions under seismic loading. The above mentioned four types of isolators were designed depending upon the superstructure weight and its natural frequency. The building was modeled in SAP2000 v15.0. The design values of the isolators were used to model it in the same software. The building was then assigned for fixed base as well as isolated base of the four different types. Time history analysis was performed on the building under fixed base and the different isolator bases. Two different time histories were selected and were used in the time history analysis in SAP2000.
Comparison of the time period, joint displacements and base shear were done to highlight the effects of the base isolation systems for any structure when subjected to forces due to earthquake. The performance of the isolators was studied through the Hysteresis curves plotted for its response to the seismic excitation during the Time history analysis in SAP2000. The reduction in forces due to installation of base isolation systems ensure the buildings to sustain longer during any earthquake activity. This can later lead to a safer society for both structures and mankind.

1. INTRODUCTION

An Earthquake is a naturally occurring phenomenon which has over the years caused tremendous damages in terms of both economy and mankind. Earthquake can never be prevented or stopped. But the effects caused due to an earthquake can be controlled and delayed. Due to this, the people living there can utilize the extra delay to reach some place safe. The materials used for the same purpose are known as seismic energy dissipation devices. One of these devices is Base isolators and the process is known as Base Isolation. Base isolators are attached between the superstructure column and footing as shown in Fig. 1.

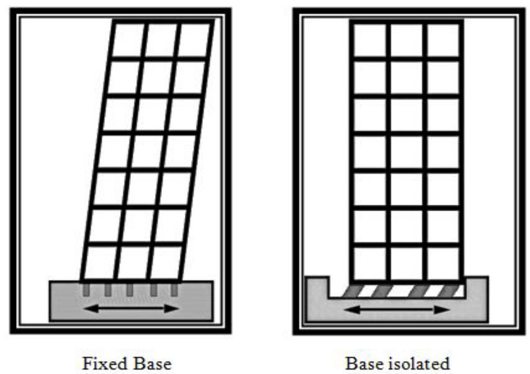

Fig. 1: General Representation of a base isolated structure

The main function of the base isolators is that it will itself get deformed or displaced due to the high seismic force. Thus, the high energy from the seismic waves gets dissipated due to the base isolators. As a result, low energy is transmitted to the superstructure above and thus the superstructure will show better resistance to the earthquake force. Also base isolators shift the time period of the superstructure thereby making it more flexible as compared to the normal superstructure. This decreases the seismic effect on the superstructure.

2. REVIEW OF LITERATURE

D. M. Lee and I. C.Mediand [(1)] presented a paper of the evolution of a technique for protecting a structure from earthquake attack is traced from its beginning through to its currently most effective form, and this form, the Base Isolation System, is compared to other currently available techniques. The influence of higher mode effects in base isolated multi-storey structures is investigated and shown to be of considerable significance in determining the shear forces in the upper levels of a structure. Because of these higher mode effects the responses of appendages on isolated structures, while still being less than those for appendages on unisolated structures, can be significantly larger than previous 1-D analyses had suggested. A standard set of distributions of inter-storey shear up a multi-storey structure is presented with each distribution being defined by a parameter which varies from zero to unity.

Chandak N. R[2] gave the main aim of using seismic base isolation tool is to reduce the inertia forces introduced in the structure due to earthquake by shifting the fundamental period of the structure out of dangerous resonance range and concentration of the deformation demand at the isolation system. In the paper a parametric study on Reinforced Concrete (RC) building with fixed and isolated base with rubber bearing (RB) and friction isolator (FI) are carried out using response spectrum method. Two different floor plans that are symmetric (SB) and unsymmetric (UB) with torsional irregularity are taken as sample building. To evaluate the seismic response of the buildings, elastic analysis was performed using the computer program SAP2000. It was observed from the comparative study that the building response with isolated base is very less to that of building with fixed base in all the cases and IS code depict higher values in all the cases with and without isolation, when compared to that of Euro code.

S.J.Patil & G.R.Reddy [3] presented an overview of the present state of base isolation techniques with special emphasis and a brief on other techniques developed world over for mitigating earthquake forces on the structures. The dynamic analysis procedure for isolated structures is briefly explained. The provisions of FEMA 450 for base isolated structures are highlighted. The effects of base isolation on structures located on soft soils and near active faults are given in brief. Simple case study on natural base isolation using naturally available soils is presented.

3. THEORETICAL DESIGN OF ISOLATORS

Four different types of isolators were selected for the study of base isolation viz. Elastomeric Rubber Isolator, Lead Rubber Isolator, Spring – Lead Rubber Isolator and Carbon Rubber Isolator. The total load (W) and fundamental time period of the superstructure (T) are determined. Depending on that the time period of isolators (T_b) are taken as three times that of the superstructure.

Horizontal Stiffness $K_{eff} = \frac{W*(2\Pi)*(2\Pi)}{g*Tb*Tb}$ …... (2.1)

Design Displacement S_d – $\frac{Sa*Tb*Tb}{4*\square*\square}$ ………… …….. (2.2)

Work done by Isolator (W_d) – $2*\Pi*K_{eff}*S_d*S_d*\eta$… . (2.3)

Yield Force (Q) - $\frac{Wd}{4(Sd-Dy)}$ (2.4)

Minimum Dimension of Lead core - $A_p = \frac{Q}{fpy}$ … ….. (2.5)

Height of Rubber layers (t_r) - $\frac{Sd}{\square max}$ ………… ……... (2.6)

Minimum Side Length (A) – K_{eff} * H / G …. …… (2.7)

Vertical Stiffness (K_v) – E * A / t_r ……… ………. (2.8)

Using above equations [4], we determine the properties of the different types of isolators using the respective material properties for designing each of the four types. The properties determined were used in software for the analytical study.

4. DETAILS OF MODEL

4.1 Superstructure Model

A G+5 Steel frame building will be considered as the superstructure for the analytical study as shown in Fig. 2.

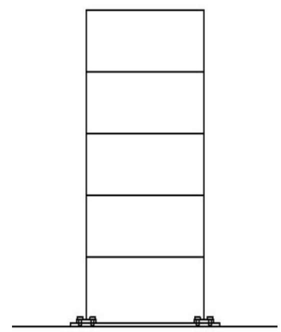

Fig. 2: Elevation view of the superstructure model

Superstructure Geometry Details:

Plan – 600 mm X 600 mm

Floor to Floor height – 1250 mm

Section Used – Steel Hollow Box Section – 25 mm X 25 mm X 5 mm (thickness)

4.2 Isolator Model

Depending upon the superstructure, the isolator design as shown in equations 2.1 – 2.8 was carried out. The section found suitable after the design is shown in Fig. 3. 120 mm X 120 mm X 100 mm square bearing was selected for the analytical study of Base isolation on the superstructure.

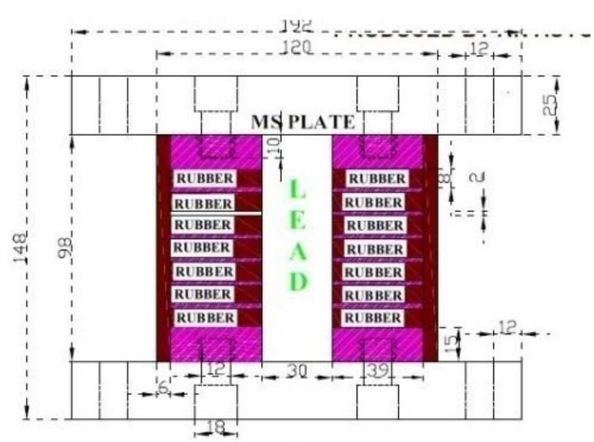

Fig. 3: Shows the cross section of a Lead Rubber Isolator

The dimensions of all the four types of rubber isolator were taken same. Elastomeric Rubber Bearing has no central lead core. Lead Rubber Bearing is as shown above. Spring Lead Rubber Bearing has an extra linear spring of stiffness 10 N/mm attached at its periphery. Carbon Rubber Isolator has carbon fibre rod as the central core. Carbon Fibre Rod has a shear modulus of 5 GPa. Lead Core has a shear modulus of about 10 MPa. These properties of the respective isolators are used to model them in software.

5. PARTICULARS OF ANALYTICAL STUDY

For the purpose of analytical study, SAP2000 v15 was used. It is a user friendly interface that helps the user to achieve the results easier, faster and accurately. It automatically generates the different charts or graphs upon analysis. Modelling in SAP2000 is also very easier to carry out.

The Superstructure was modeled as a normal 3D frame structure. Grids were created and corresponding members of the respective dimensions were plotted on it. All the four types of isolator were modelled with the properties obtained from the design.

6. RESULTS FROM ANALYTICAL STUDY

The superstructure was analyzed under two different conditions: Fixed base and Base Isolated. Modal Analysis was carried out to determine the time period of the structure under both the conditions. Fig. 4 shows the comparison of the time period under the different base conditions.

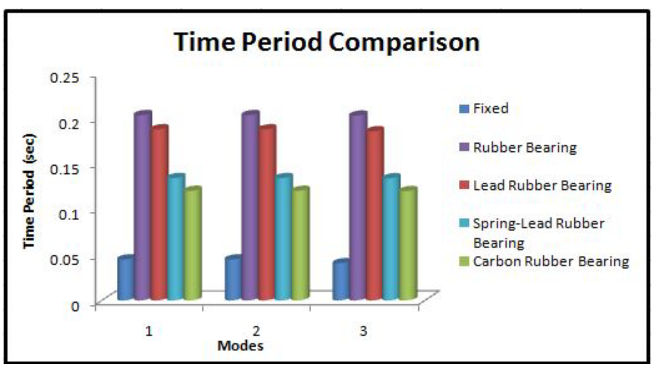

Fig. 4: Comparison of the Time period under the different base conditions

Table 1: Time Period Comparison

Modes	Fixed Base	Lead Rubber	Rubber Bearing	Spring-Lead Rubber	Carbon Rubber
1	0.0450	0.1879	0.2035	0.1344	0.1203
2	0.0450	0.1879	0.2035	0.1344	0.1203
3	0.0408	0.1857	0.2030	0.1341	0.1200

Table 1 shows the comparison of the time period for the three fundamental modes of vibration with different base conditions. After modal analysis, Time history analysis was performed on the superstructure under the two different conditions viz. fixed and base isolated. Two different time histories were used: Imperial Valley Earthquake – El Centro and San Fernando Earthquake.

6.1 El Centro Time History

Displacement of a top storey joint was compared under fixed and isolated base condition as shown in **Fig.** 5.

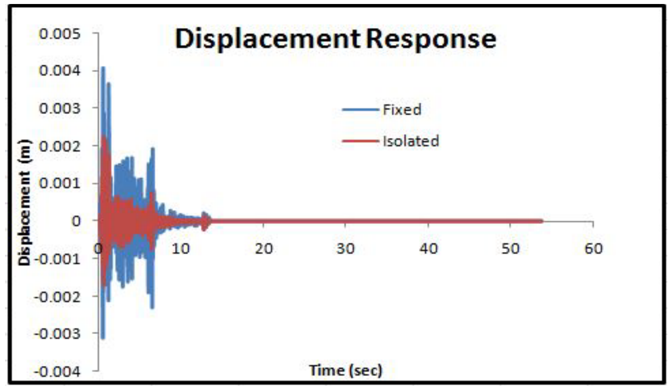

Fig. 5: Displacement comparison of Top storey joint

Displacement comparison of the top storey joint with fixed and respective different base isolation systems are given in Fig. 6 and Fig. 7.

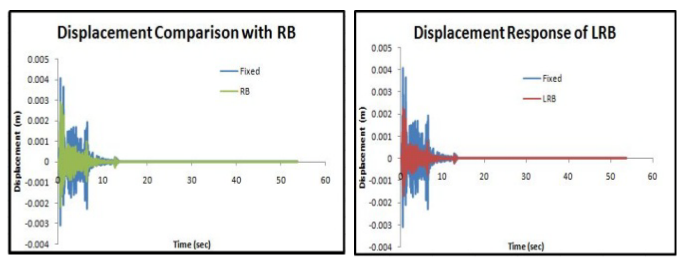

Fig. 6: Displacement Comparison of Elastomeric Rubber Bearing and Lead Rubber Bearing with Fixed Base

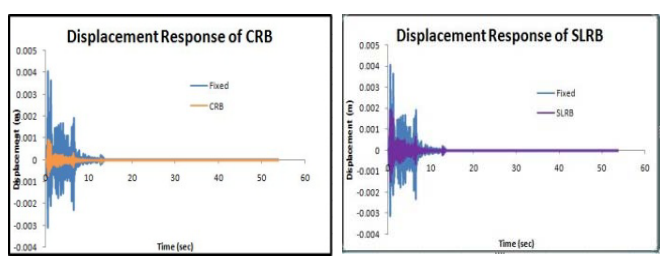

Fig. 7: Displacement Comparison of Carbon Rubber and Spring Lead Rubber with Fixed Base

Relative Storey Displacement of fixed base and the different base isolation system is shown in **Fig.** 8.

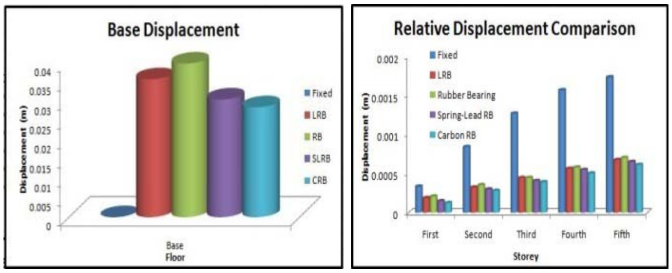

Fig. 8: Relative Base and Storey Displacement Comparison between Fixed and Different Base isolation system

General Base Shear Comparison of fixed base and isolated base condition is shown in Fig. 9.

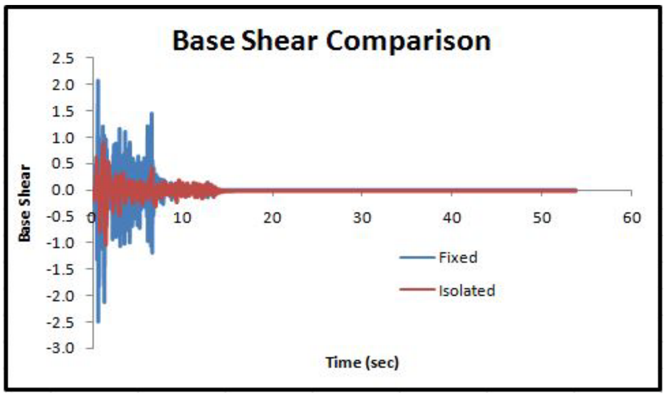

Fig. 9: Base Shear Comparison between fixed and isolated base

Base Shear Comparison of fixed base and different types of Base isolation system is shown in Fig. 10 and Fig. 11.

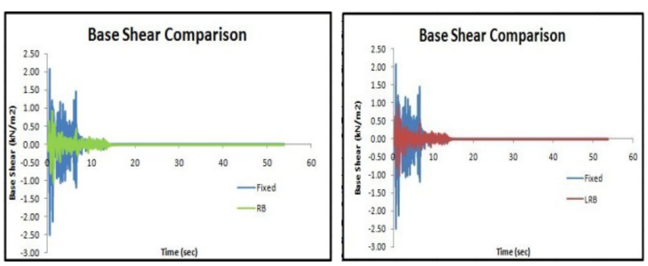

Fig. 10: shows the base shear comparison between Elastomeric Rubber and Lead Rubber Bearing with Fixed base

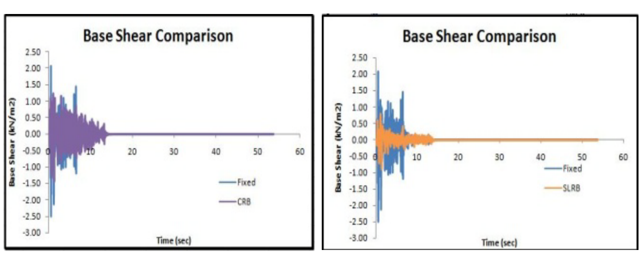

Fig. 11: Shows the base shear comparison between carbon rubber and Spring Lead Rubber with Fixed Base

Hysteresis curves of all the Base Isolators were plotted for this time history. Due to the cyclic loading of the time history, the hysteresis curve obtained is shown in Fig. 12 and Fig. 13.

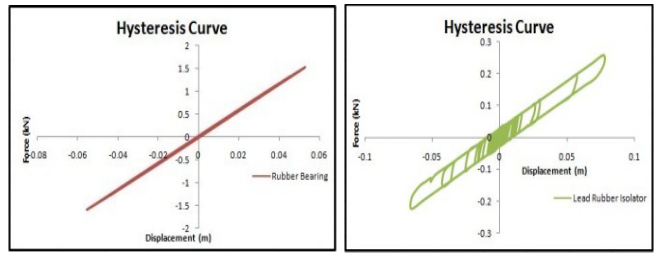

Fig. 12: Shows the hysteresis curve of Elastomeric Rubber and Lead Rubber Isolator

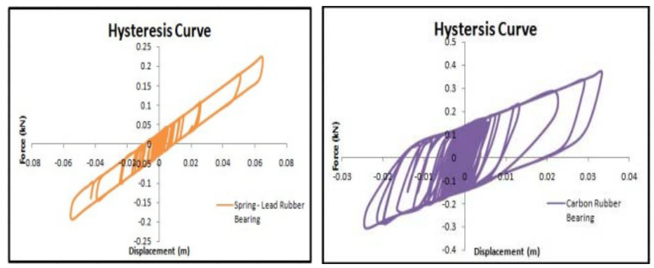

Fig. 13: Shows the hysteresis curve of Spring Lead Rubber and Carbon Rubber Isolator

6.2 San Fernando Earthquake

Displacement of a top storey joint was compared under fixed and isolated base condition as shown in **Fig.** 14.

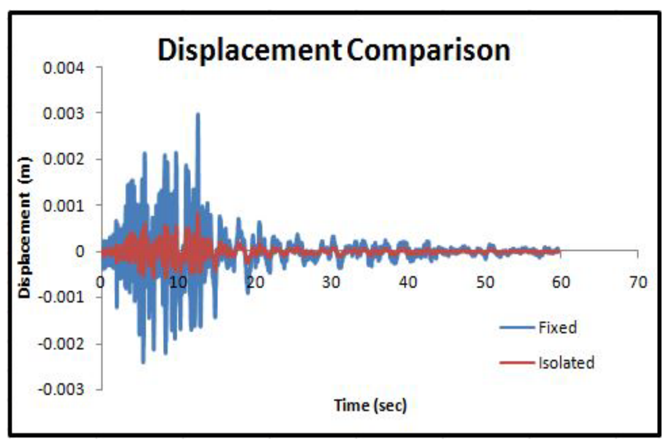

Fig. 14: Displacement comparison of Top storey joint

Displacement comparison of the top storey joint with fixed and respective different base isolation systems are given in Fig. 15 and Fig. 16.

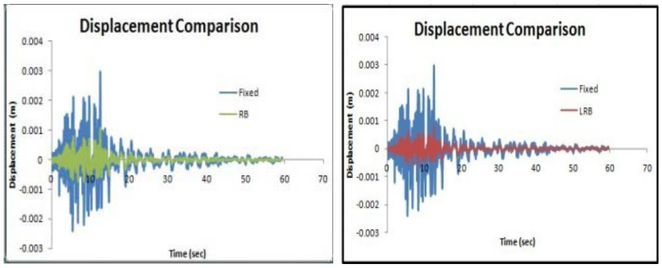

Fig. 15: Displacement Comparison of Elastomeric Rubber Bearing and Lead Rubber Bearing with Fixed Base

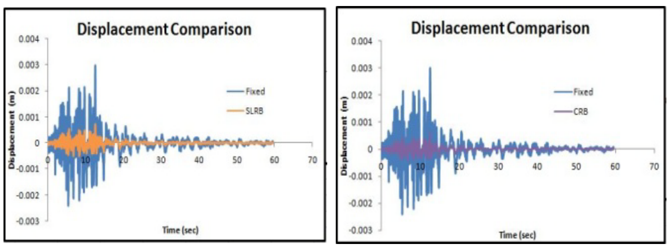

Fig. 16: Displacement Comparison of Carbon Rubber and Spring Lead Rubber with Fixed Base

Relative Storey Displacement of fixed base and the different base isolation system is shown in **Fig.** 17.

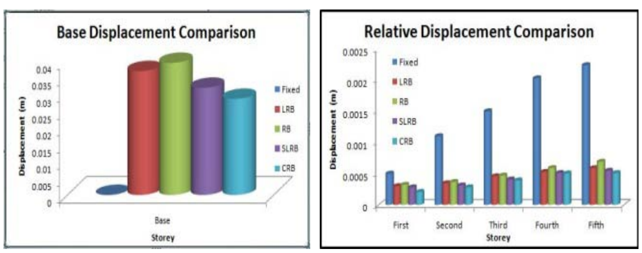

Fig. 17: Relative Base and Storey Displacement Comparison between Fixed and Different Base isolation system

General Base Shear Comparison of fixed base and isolated base condition is shown in Fig. 18

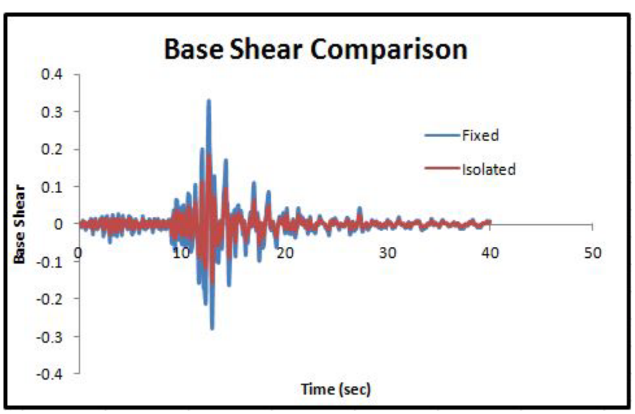

Fig. 18: Base Shear Comparison between fixed and isolated base

Base Shear Comparison of fixed base and different types of Base isolation system is shown in Fig. 19 and Fig. 20.

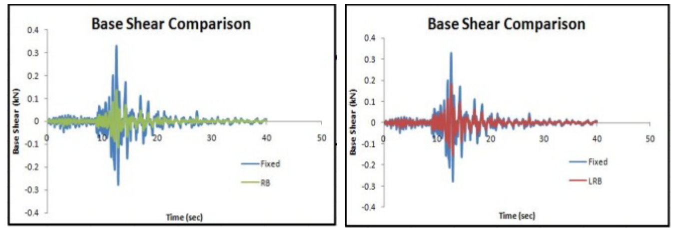

Fig. 19 shows the base shear comparison between Elastomeric Rubber and Lead Rubber Bearing with Fixed base

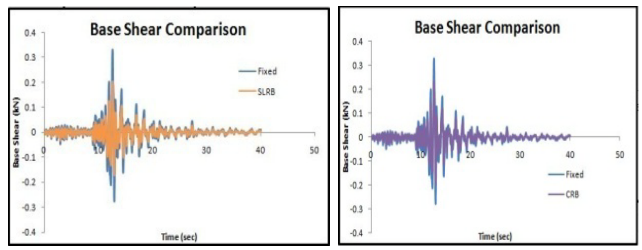

Fig. 20: Shows the base shear comparison between carbon rubber and Spring Lead Rubber with Fixed Base

Hysteresis curves of all the Base Isolators were plotted for this time history. Due to the cyclic loading of the time history, the hysteresis curve obtained is shown in Fig. 21 and Fig. 22.

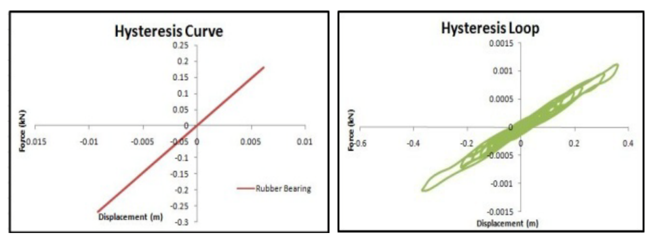

Fig. 21: Shows the hysteresis curve of Elastomeric Rubber and Lead Rubber Isolator

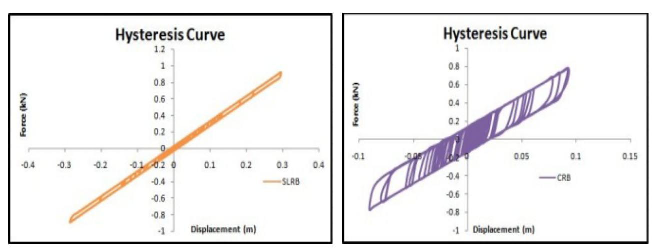

Fig. 22: Shows the hysteresis curve of Spring Lead Rubber and Carbon Rubber Isolator

7. CONCLUSION

(i) As seen from Fig. 4, Base isolated structure has a higher time period as compared to a fixed base structure. This makes the structure more flexible. Thus, due to its flexibility, the amount of seismic force acting on the structure reduces as the storey displacement has increased. This reduces the heavy impact of the impulse caused due to the seismic force which causes more damage in case of a fixed base structure.

(ii) As observed from Fig. 5 & Fig. 14, the relative displacement of the joint has decreased in case of a base isolated structure. Thus, it will help reduce the harmful effects of the seismic force.

(iii) As seen from Fig. 8 and Fig. 17, Base Displacement of a base isolated structure is more than that of a fixed structure since base isolators are more flexible material. However the relative storey displacements of base isolated structure are lesser than that of fixed base structure. Thus, it helps to reduce the distortions caused to the storey under seismic force.

(iv) Base Shear for a base isolated structure has considerably reduced as compared to the fixed base structure as seen from Fig. 9 and Fig. 18. Thus, the structure will be less affected by the seismic force.

(v) The performance of all the types of isolators can be seen in Fig. 6, Fig. 7, Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 15, Fig. 16, Fig. 19, Fig. 20, Fig. 21 and Fig. 22. All of them can be used as a Base isolation system to help reduce the damage caused by the seismic forces.

(vi) Since the time periods of the isolators used are different, thus their performance cannot be compared with each other. However, their effectiveness as a tool for seismic energy dissipation can be observed.

8. FUTURE SCOPE

This work can be extended by fabricating the above mentioned different isolators and experimentally measuring the response of the superstructure under both fixed and isolated conditions on a shake table.

The model can be analyzed with scaled time histories for further scope.

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