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Seismic Response of Multi Storey RC Building with Isolators Using SAP2000

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***Abstract*- Earthquakes are one amongst nature's greatest hazards; throughout historic time they have caused significant loss of life and severe damage to property, especially to man-made structures. A large proportion of world's population lives in regions of seismic hazards. The application of the base isolation techniques to protect structures against damage from earthquake attacks has been considered as one of the most effective approaches and has gained increasing acceptance during the last two decades. Seismic isolation system consists of the installation mechanisms which isolates the structure from the base by providing seismic isolators. The seismic isolation system is mounted beneath the superstructure and is referred as 'Base Isolation'. The main purpose of the base isolation device is to minimize the horizontal acceleration transmitted to the superstructure. Base isolation is very promising technology to protect different structures like building, bridges, airport terminals and nuclear power plants etc. from seismic excitation.**

This work pertains to the study of a G+8 storeyed hospital building. To compare the seismic effects of fixed base structure with respect to isolated structure, the building was analysed using response spectrum and Time history(El-Centro, having magnitude 6.9)methods. When the fixed frame structure was analyzed, the top storey displacement, base shear, inter storey drifts and end moments were found to be beyond the limits of IS1983-2002. Inorder to reduce them, LRB(Lead Rubber Bearing) base isolators were installed at the base of the building. The report also includes the comparative study of the building with and without isolators.

***Index Terms*: -- Base isolation, Response spectrum analysis, Time History analysis, Inter storey Drift, Lead rubber bearing**

I. INTRODUCTION

Earthquakes are unconstrained in nature. Civil engineering structures such as bridges, buildings, towers etc. are subjected to time varying loads as a result of strong winds or earthquake excitations in addition to gravity loads. Hence while designing process we have to accept the demand and ensure that the capacity exceeds it. As the ground accelerations increases, the strength of the building ie. the capacity, must be increased to avoid structural damage. Over the past few decades designing structures to withstand seismic effects have been based on the traditional approaches ie. to increase the strength of the structure indefinitely. It is not practical to continue to increase the strength of the building indefinitely.

In high seismic zones the accelerations causing forces in the building may exceed one or even two times the acceleration due to gravity, g. It is easy to visualize the strength needed for this level of load – strength to resist 1g means that the building could resist gravity applied sideways, which means that the building could be tipped on its side and held horizontal without damage. Designing for this level of strength is not easy, nor cheap. So most of the codes allow engineers to use ductility to achieve the capacity. Ductility is a concept of allowing the structural elements to deform beyond their elastic limit in a controlled manner. Beyond this limit, the structural elements soften and the displacements increase with only a small increase in force.

A design philosophy focused on capacity leads to two choices [1]:

1) Continue to increase the elastic strength. This is expensive and for buildings leads to higher floor accelerations. Mitigation of structural damage by further strengthening may cause more damage to the contents than would occur in a building with less strength.

2) Limit the elastic strength and detail for ductility. This approach accepts damage to structural components, which may not be repairable.

Base isolation takes the opposite approach, it attempts to reduce the demand rather than increase the capacity. We cannot control the earthquake itself but we can modify the demand it makes on the structure by preventing the motions being transmitted from the foundation into the structure above. So, the primary reason to use isolation is to mitigate earthquake effects. Naturally, there is a cost associated with isolation and so it only makes sense to use it when the benefits exceed this cost. 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. The application of this technology may keep the building to remain essentially elastic and thus ensure safety during large earthquakes.

II. CONCEPT AND TYPES OF ISOLATORS

The main principle of base isolation is to separate the building from its foundation so that during ground motions the building stays unaffected. This reduces the storey displacement and the building components are less harmed. Total separation is provided in the model, but practically there is some co relation between the ground and the building which provides flexibility to the structure. During the ground movement, amount of acceleration entrusted in the structure is the same of ground acceleration that results in zero displacement between the structure and the ground. The cross section of LRB is shown in Fig.1.

The most commonly used base isolators in building are

1. Laminated Rubber (Elastomeric) Bearing. a. Natural and synthetic rubber bearing(low damping). b. Natural rubber bearing (high damping). 2. Lead Rubber Bearing (LRB) 3. Friction Pendulum (FPS) System Bearing

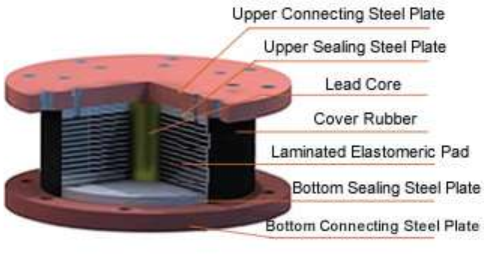

Fig.1 Cross section of LRB[4]

III. DESIGN OF ISOLATORS

The rubber-based bearings isolation system consists of layers of rubber and steel with the rubber being vulcanized to the steel plates for the horizontal flexibility and the vertical stiffness. In this paper, LRB isolator case will be investigated with a typical configuration shown in Fig. 3. This isolator consists of a lead-plug insert which provides its characteristic hysteretic energy-dissipation effect. Therefore LRB system is able to support the structure vertically, to provide the horizontal flexibility together with the restoring force, and to provide the required hysteretic damping. These specific isolators provide hysteretic damping through the yielding of the lead core.

The total seismic weight, number of layers and the corresponding thickness of the bearings are taken as the initial input. The design procedures has been adopted from the simplified design procedures for rubber bearing isolators[3].The isolator parameters are computed. These parameters are then defined in SAP2000. The rubber bearings are linked at the bottom of each column. Dynamic analysis of the three dimensional building has been carried out considering the associated nonlinearities. The general dimension of isolator is given in Table 1.

Table 1. General dimension of isolator

Parameter	**Dimensions(mm)**
Layer thickness	10
No of Layers	16
Lead Core size	150
Shape	Circular

As per Saiful Islam et. al, the non-linear force deformation behaviour of the isolation system is modelled through the bilinear hysteresis loop characterized by three parameters namely: i) characteristic strength, Qd, ii) post-elastic stiffness, Kr, iii) Yield displacement, Δy[3] . The relation between force intercept at zero displacement and yield strength of isolator is given by Eq.(1).

$$Qd = \sigma_y A_{pl} \qquad \text{Eq.(1)}$$

Post elastic stiffness is given by;

$$Kr = G_r A_r / T_r \qquad \text{Eq.(2)}$$

The common rubber properties chosen for the isolators were shear modulus: 400 kPa, ultimate elongation:

650%, material constant k: 0.87, elastic modulus: 1350 kPa. This is basic information used for the design process. The design dimensions were obtained from [3]. These isolators were installed at the bottom of the model.

IV. MODELLING AND ANALYSIS OF THE BUILDING

A Hospital building having the beam and column layout as shown in Fig. 2have been modelled for G+8 storeys. Each floor has height of 3m and the basement has height of 3.5m. The actual plan of the building is divided into several grids for easier analysis.

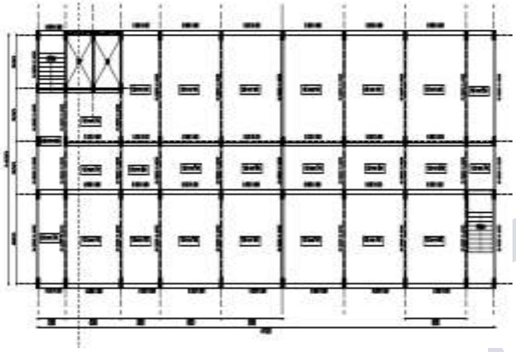

Fig.2 Beam and column layout of the building

The base isolators are fixed to the foundation at the bottom and to the base mass at the top. As per IS: 875(Part-2)-1987,

i. Live load intensity on slabs = 3kN/mm^2,
ii. Live load intensity on passage and corridor = 4kN/mm^2,
iii. Live load intensity on stairs = 4kN/mm^2,

Live load intensity on office rooms =2.5kN/mm^2,has been assumed on each storey and the roof has been assumed a uniform live load intensity in 1.5kN/mm^2.

A. *Static Analysis*

The isolators are designed considering earthquake and wind loads to be static. The procedure mentioned in IS1893-2002 is used to compute static loads due to earthquake and wind is considered. Lateral loads for the building located in Trivandrum, Kerala are determined considering Z (seismic zone factor), R (response modification factor), C (coefficient for soil profile) and I (importance factor). The base shear due to earthquake and wind can be calculated using Eq(3).

$$\text{Base shear}=W(ZIS/2Rg) \qquad (3)$$

The wind pressure intensity is found out from the equation (2).

$$\text{Pressure, } P=.6V_Z^2 \qquad (4)$$

$$V_z=V_b\times k_1\times k_2\times k_3 \qquad (5)$$

On calculation the Pressure intensity on the model was found to be .87kN/m^2.

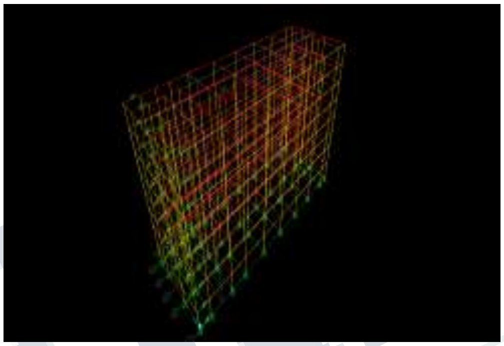

Fig.3 Wind load assignment to the model

B. *Analysis Procedure*

Linear dynamic procedure is adopted here. The ldp includes two analysis methods, namely, the response spectrum method and the time history method. The response spectrum method uses peak modal responses calculated from dynamic analysis of a mathematical model. The time history method (also termed response- history analysis) involves a time-step-by-time-step evaluation of building response, using discredited recorded or synthetic earthquake records as base motion input. Fig. 4 shows the time history of el-Centro earthquake.

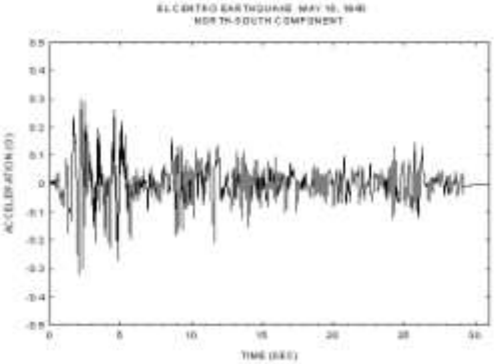

Fig. 4 time history of el- centro earthquake

TABLE 2: GENERAL ANALYSIS RESULTS

Sl No	Result
Total Weight(kN)	85116.988kN
Base shear due to EQ (kN)	2641.999kN
Base shear due to WL (kN)	1982.21kN
Top floor displacement(EQ)	25mm
Top floor displacement(WL)	20.12mm

V. RESULT AND DISCUSSION

The building model was subjected to response spectrum and time history analysis with and without isolators to understand the response of various parameters such as inters storey drift, displacement, floor acceleration etc.

A. Response spectrum analysis

a) ***Time Period****:* Time period of the base isolated structure was increased by about 37% than that of the fixed model. Hence the effect of seismic impact will be reduced when compared to that of the fixed base building.

Table 2: Time Period of BI and FB model

Mode	Fixed Base	Base Isolated
1	2.1248	3.322s

b) ***Force demand:*** The force demand for the base isolated structure was found to be 1398.773kN when compared to the fixed base structure which was found to be 2645.202.

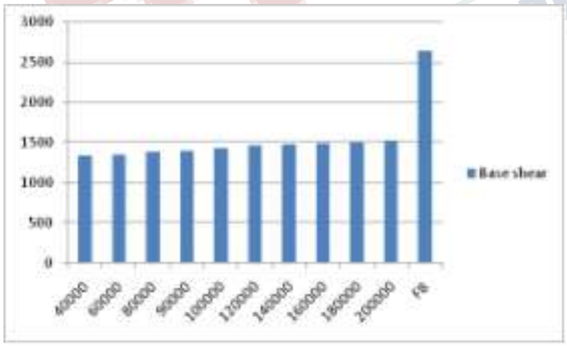

Fig. 5 Histogram showing variation of base shear with stiffness

This shows that even though the displacements are more, the model acts as a rigid body and force demand is lesser for the model. Base shear reductions occur when the period of vibration of the structure is lengthened as shown in Fig.5. It predicts a good amount of structural savings and economic assistances as well.

c) ***Inter storey Drift****:* Inter storey drift of the isolated building was reduced to 38% than that of the fixed building, showing that the floors are least affected by the Earthquake force when compared to that of the FB model. The graph is shown in Fig.6.

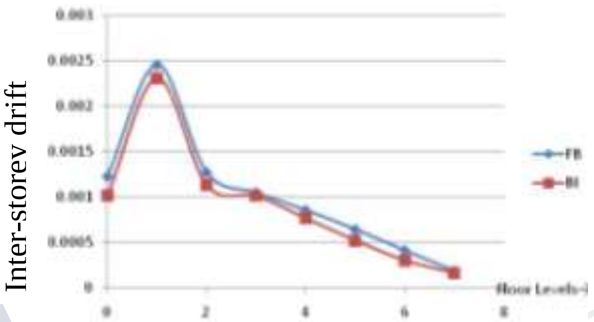

Fig.6 Interstorey Drift of FB and BI model

d) **Floor accelerations:**

Table 3: Variation of floor acceleration with floor level

Floor Level	FB	BI(90000kN/m)
8	0.40531	0.29118
7	0.36355	0.24561
6	0.32227	0.20145
5	0.30859	0.20502
4	0.28934	0.20294
3	0.2755	0.20686
2	0.26122	0.22063
1	0.13226	0.13742
0	0	0.00989

The top floor acceleration of the base isolated building have reduced to about 30% than that of the fixed base building as shown in table 3. The isolated building exerts a good amount of acceleration at the base.

e. ***Moment (M3):*** The moment acting on the components have reduced drastically on the base isolated structure when compared to that of the fixed base structure as shown in Table 4. The model begins to vibrate as a rigid body with least effects on the internal components. So the building becomes more stabilized compared to the FB structure. The building experiences more flexibility even when using the same structural element configuration.

Table 4: Moment for FB and BI case

FB	BI
30.98kNm	4.87kNm

f) Stiffness of 90000kN/m could be adopted for the isolator because the moment, base shear values are stable for that stiffness.

B. Time history analysis

a) Displacement

The top storey displacement of the FB building subjected to time history analysis was found to be 0.0476m while that of the BI building was found to be 0.038m. The variation of displacement along the floor is shown in the Fig.7.

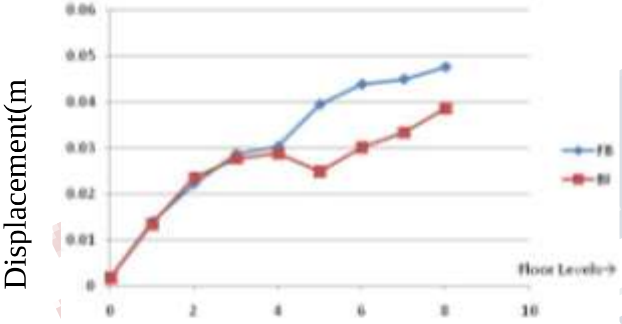

Fig.7 Variation of displacement along floor height for FB and BI model

b) Floor acceleration

The top floor acceleration of the FB building was found to be 6.27m/s^2 while that of the BI building was found to be 3.21m/s^2.

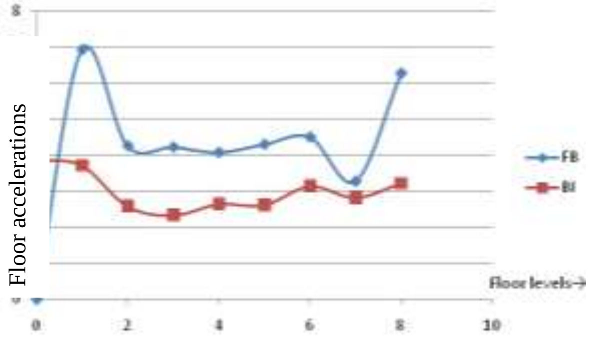

Fig.8 Variation of Floor acceleration along the height of the building

c) Base reaction

The base reaction of the FB building was found to be 10077.006kN whereas that of the BI building was found to be 4788.143kN.

VI. CONCLUSION

The analysis shows the effectiveness of the seismic isolation in the form of lead rubber bearings for buildings. By incorporating isolators, the structural elements of multi-storey building under lateral earthquake load experiences lower shear, moment and lateral deformation. The selected isolator yields lower isolation frequencies and lower structural peak parameters. While performing analytical studies it was found that there is a drastic reduction of inter storey drift by about 38%, end moments by 85%, force demand by 45% and the time period increased to 3.322s. In the case of BI building, the horizontal accelerations are muscularly reduced with respect to corresponding accelerations evaluated for FB building. It could also be seen that for the isolated case the model becomes more stable under excitation than that of the fixed base case. This behaviour is expected due to the low frequencies observed for main building modes.

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