

Nonlinear Dynamic Analysis of Base Isolated Reinforced Concrete Building

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ABSTRACT: The main aim of providing base isolation is to decouple the building structure from the damaging components of the earthquake input ground motion, that is, to prevent the superstructure of the building from absorbing the earthquake energy. In this paper, a ten story building is used to study the top floor absolute acceleration, base shear and lateral displacement of a building isolated with laminated rubber bearing. The nonlinear time history analysis is carried out using SAP 2000 for both the fixed base and base isolated structure. The structure is subjected to two different ground motion time histories recorded at near fault, the Imperial Valley and Northridge earthquakes. It is observed that the incorporation of the laminated rubber bearing at the base of the structure reduces the structural demand significantly as compared to a fixed base structure.

KEYWORDS: Nonlinear time history analysis, Base isolation, Laminated rubber bearing, base shear

I. INTRODUCTION

Most of the earthquakes occurring on our planet are moderate in magnitude and destructive potential of these earthquakes is negligible in terms of life and property. Only a small percentage of the earthquakes are severe enough to cause vast destruction. These severe earthquakes sometimes strike when least expected and cause enormous loss of lives and economy. Base isolation is one of the techniques that can be used to greatly reduce the damage that can occur on structures due to earthquakes. This technique was first proposed in the beginning of the 20th century. In low-rise and mid-rise buildings, the best way to achieve the required behaviour is by concentrating the flexibility at the foundation level with the use of base isolators.

Base isolation is an earthquake resistant design technique in which the superstructure is isolated from ground movement to reduce the transfer of inertia forces. The superstructure is isolated from the foundation by isolation bearings having very low lateral stiffness which shifts the fundamental time period of the structure to a higher value. This shift in the time period gives the structure a fundamental frequency which is much lower than the predominant frequencies of the ground motion which in turn significantly reduces the earthquake energy transmitted to the structure was discussed by Kelly[1] and Jangid and Dutta[2].

The first rubber bearings used had the vertical stiffness almost equal with the horizontal which makes the vertical and horizontal time periods of the building to be almost equal and causes undesirable bouncing and rocking was detailed by Buckle and Mayes [3]. This undesirable effect is avoided by making the isolator significantly stiffer in the vertical direction by manufacturing it with an alternating layer of steel sheet and rubber. Later on, rubber isolators were also manufactured with lead plugs to improve the damping property and increase the initial stiffness.

Nagarajaiah et al. [4] proposed an analytical model and a solution algorithm developed for nonlinear dynamic analysis of three-dimensional RC base-isolated structure with elastomeric and/or sliding isolation systems. Biaxial and uniaxial models for both elastomeric and sliding isolation bearings have been presented. Deb [5] analyzed 3-d nonlinear analysis procedure of base isolated building. Important issues like effects of soft soil on performance of base isolated

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building and effects of near fault motion have been discussed. Jangid and Kulkarni [6] made a comparison in their study of the seismic response of a multi-story base-isolated building by idealizing the superstructure as rigid and flexible. The top floor acceleration and bearing displacement of the system are plotted for different system parameters and compared with the corresponding response under rigid superstructure conditions to study the influence of superstructure flexibility. Aiken et al. [7] proposed an hysteretic model for elastomeric isolation bearing for accurately predicting the seismic response of base isolated structures. Extensive series of experimental tests were carried out to fully identify the mechanical characteristics. Aiken [8] discussed the important characteristics of isolation devices and the influence of these characteristics on testing, in terms of such parameters as displacement, force, rate of loading, and test temperature.

We find that all the base isolation systems have certain features in common. They have flexibility and energy absorbing capacity. A variety of isolation devices such as the elastomeric bearings with and without lead core, the roller bearings and the friction pendulum bearings have been developed and found application in effectively reducing the seismic forces generated. Numerous researchers have studied the behaviour of base isolated structures under earthquake using bearings. The behaviour of isolation systems and the base isolated structures is now well established and codes have been developed for designing the base-isolated structures.

Though the application of base isolators is the same everywhere, there is a lack of proper research to implement the base isolators especially in India which is a home to many earthquakes. This region has been divided into four seismic zones according to the Indian code, IS 1893 (Part 1): 2002 for seismic analysis. A detailed and comprehensive study has been initiated in this paper to study the non-linear time history response of a ten story single bay 2d-frame structure with and without base isolation. The dynamic analysis for the seismic forces is performed to satisfy the displacement limitation. The non- linear time history analysis is been performed using SAP 2000 which is found to be compatible for the analysis and design of the model initiated for the study. The prime objective of this study is to identify the effectiveness of laminated rubber bearing in reducing the overall drift of the given structure caused by the lateral earthquake forces.

II. DETAILS OF THE MODEL

The different parameters involved in creating the models are tabulated in Table 1.

Table 1.Modelling Details

1.	Type of structure	Multistory rigid jointed plane frame
2.	Number of stories	Ten (G+9)
3.	Floor height	All floors, 3.2 m
4.	Total height of model	32 m
5.	Plan of the model	single bay @ 5 m
8.	Infill walls	230 mm thick brick masonry wall
9.	Column size	500 mm X 500 mm
10.	Beam size	450 mm X 450 mm
11.	Slab depth	120 mm
12.	Live load	On floor = 3 kN/mm ² , On roof = 1.5 kN/mm ²
13.	Floor finishes	0.5 kN/mm ²
14.	Material	M 30 grade concrete and Fe – 415 steel
15.	Unit weight of concrete	25 kN/mm ³

III.ANALYSIS OF THE BUILDING MODEL

A single bay 2d building frame of ten story height has been investigated to study the response of base-isolated building. The model is been analyzed for two different cases. In the first case the model is analyzed assuming fixed support

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condition at the base of the columns and in the second case analyzed using laminated rubber bearing as base isolators. The dynamic non-linear time history analysis is been performed using SAP 2000 for both the fixed support condition and also using laminated rubber bearings as base isolators.

IV. SEISMIC INPUT

The structural models are analysed under two records of near fault ground motions. Two earthquake events selected as near source ground motions are the 1994 Northridge and the 1979 Imperial Valley earthquakes. These records contain strong velocity and displacement pulses of relatively long periods which distinguish them from typical far field earthquakes.

V. DESIGN OF LAMINATED RUBBER BEARING

The main requirements for the design of a base-isolation system are (i) the ability to sustain gravity loads, (ii) low horizontal stiffness that can lengthen the fundamental time period to a desired value, (iii) large vertical stiffness to minimize amplification in vertical direction and complications arising due to rocking, (iv) energy dissipation capacity to keep displacements at the isolation level within acceptable limits, and (v) sufficient initial stiffness to avoid unwanted vibrations due to wind loads and frequent minor seismic events.

The dissipation of kinetic energy during seismic ground motions in a conventional fixed base structure takes place by internal damping, friction damping at the supports, and radiation damping through the base and side soils. In base isolated structures, additional damping is achieved by placing the base isolators after necessary design. Following assumptions are made for the structural system under consideration: The effects of soil– structure interaction are not taken into consideration, The columns are inextensible and weightless providing the lateral stiffness, The floors are assumed rigid in its own plane and the mass is supposed to be lumped at each floor level, The system is subjected to single horizontal component of the earthquake ground motion.

The following procedure is adopted for the design of the bearing.

Step 1: A time period value for the base isolated structure T_b is initially evaluated. This value is taken approximately three times that of fixed base structure.

Step 2: The minimum horizontal effective stiffness of the bearing is calculated and is given by equation 1.

$$K_{\min} = \frac{R \times 4\pi^2}{g \times T_b^2} \quad (1)$$

Where $K_{\min}$ is the minimum effective horizontal stiffness

R is the maximum axial load under the column

g is the acceleration due to gravity

T_b is the assumed value of time period for base isolated structure

Step 3: The spectral displacement is calculated with the help of the response spectra for rock and soil sites for 5% damping using the spectral acceleration coefficient value provided in the Indian standard for seismic design and using equation 2.

$$S_d = \frac{S_a \times T_b^2}{4\pi^2} \quad (2)$$

Where S_d is the spectral displacement

S_a is the spectral acceleration

Step 4: The total rubber thickness of the rubber bearing isolator is now calculated and is given by equation 3.

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$$t_r = \frac{Sd}{\gamma} \quad (3)$$

Where t_r is the total thickness of the rubber bearing isolator
 γ is the allowable maximum shear strain for the bearing taken as 100%

Step 5: The area of the isolator is calculated and is given by equation 4. The diameter of the circular bearing is hence obtained.

$$A = \frac{K_{min} \times t_r}{G} \quad (4)$$

Where A is the area of the rubber bearing isolator
G is the shear modulus of rubber bearing isolator taken as 1000N/ mm²

Step 6: The shape factor S is calculated and is given by equation 5.

$$S = \frac{d}{4t} \quad (5)$$

Where S is the shape factor
d is the diameter of the rubber bearing isolator
t is the thickness of the individual rubber layers

Step 7: The compression modulus of elasticity for a circular rubber bearing isolator without holes is calculated and is given by equation 6.

$$E_c = 6GS^2 \quad (6)$$

Where E_c is the compression modulus of elasticity

Step 8: The vertical stiffness is calculated and is given by equation 7.

$$K_v = \frac{E_c \times A}{t_r} \quad (7)$$

Where K_v is the vertical stiffness

Step 9: The bearing dimensions and other parameters obtained are introduced into the fixed base model and the dynamic non-linear time history analysis is performed analytically for the base isolated structure using SAP 2000.

VI. RESULTS AND CONCLUSION

The different parameters considered for the study are the top floor absolute acceleration, base shear and lateral displacement of a building isolated with laminated rubber bearing for the Northridge and Imperial Valley earthquakes are tabulated in Table 2. and Table 3. respectively.

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Table 2: Result for Northridge Earthquake

Different Parameters Under Study	Fixed Base Structure	Base Isolated Structure
Top Floor Absolute Acceleration (g)	1.222	0.482
Base Shear (kN)	345	147
Top Floor Lateral Displacement (cm)	18.25	11.25

Table 3: Result for Imperial Valley Earthquake

Different Parameters Under Study	Fixed Base Structure	Base Isolated Structure
Top Floor Absolute Acceleration (g)	1.056	0.342
Base Shear (kN)	325	135
Top Floor Lateral Displacement (cm)	16.52	6.45

Analytical results from the model reveal that energy dissipation can be achieved for both the near fault ground motions by incorporation of bearing at the base. It can be observed that top floor absolute acceleration, base shear and top floor lateral displacement are considerably reduced by the use of the laminated bearing. When a building is isolated, the maximum elastic forces are reduced considerably due to period shift and energy dissipation. If a stiff building, with a fixed-base is isolated, then its fundamental period will be increased. This results in a reduced design force but more importantly the probable yield strength of the isolated building is approximately the same as the maximum forces to which it will be subjected. Therefore, there will be little or no ductility demand on the structural system and the lateral design forces can be theoretically reduced considerably. This justifies the reduction in need for the area of the structural elements especially in the upper floors for both the horizontal members (beam) and vertical members (column) and also a reduced need for the area of reinforcement leading to net overall savings even though there is an initial increase in cost for the bearing installation. Therefore seismic isolation is most applicable to building structure both in terms of application and also net cost savings of the project. Also, the incorporation of base isolators ensures the structural integrity of the structure during an earthquake and hence economic sustainability of the structure is justified.

REFERENCES

- [1] Kelly, J.M., A seismic base isolation: review and bibliography. *Soil Dynamics and Earthquake Engineering* 1986; 5: 202– 216.
- [2] Jangid, R.S., Datta, T.K., Seismic behavior of base-isolated buildings: a state-of-the-art review. *Structural Building* 1995; 110: 186–203.
- [3] Buckle, I.G., Mayes, R.L., Seismic isolation: history, application and performance-A world over-view. *Earthquake Spectra* 1990; 6 (2): 161–202.
- [4] Nagarajaiah, S., Reinhorn, A. M., Constantinou, M. C., Nonlinear dynamic analysis of 3-d base-isolated structures. *Journal of Structural Engineering* 1991; 117: 2035-2054.
- [5] Deb, S. K., Seismic base isolation – An overview. *Current Science* 2004; 87: 1426-1430.
- [6] Jangid, R.S., Kulkarni, J.A., Rigid body response of base-isolated structures. *Journal of Structural Control* 2002; 9: 171–188.
- [7] Aiken I.D., et al. An analytical hysteresis model for elastomeric seismic isolation bearings. *Earthquake Engineering and Structural Engineering* 1997; 26: 1-17.
- [8] Aiken I.D., Testing of seismic isolators and dampers-considerations and limitations. *Proceedings, Structural Engineering World Congress, San-francisco, California, 1988; 1-8*