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Effect of Base Isolation in Multi-Storeyed RC Building

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Abstract: Base isolation is one of the most widely accepted seismic protection systems used in building structures in earthquake prone areas. The base isolation system separates the structure from its foundation and primarily moves it relative to the upper structure. The purpose of this study is to investigate to increase in time period and decrease in base shear due to earthquake ground excitation, applied to superstructure of the building by installing base isolated devices at the foundation level and then to compare the different concepts between the fixed base condition and base isolated condition by using ETABS 2015 software. In this study, G+3 and G+20 storey RCC building are used as test model. High rise, low rise, plan irregular and vertical irregular buildings are considered for this project. Lead rubber bearing is used as base isolation in this study. Linear time history analysis with El-Centro time history data is used on both fixed and base isolated buildings. The base shear and time period are compared from two time history analysis between fixed and base isolated condition. It was observed that base isolation increases the time period of the building and hence correspondingly reduces the base shear for all the cases considered.

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I. INTRODUCTION

Earthquakes are one of nature's greatest hazards, throughout historic time they have caused significant loss of life and severe damage to property, especially to man-made structures. The first step in understanding earthquake risk is to dissect the earthquake risk or loss process into its constituent steps. Earthquake risk begins with the occurrence of the earthquake, which results in a number of earthquake hazards. The most fundamental of these hazards is faulting, that is, the surface expression of the differential movement of blocks of the Earth's crust.[6] The traditional design principle of the earthquake resistant structures is that each element of the structure is able to resist the applied seismic forces with enough plasticity to absorb vibration energy caused by the earthquake. In this case, a large plastic deformation in the structural elements will occur that are difficult to repair and restore after the earthquake and might develop to an irreparable structure.[11]

Recently, even the structures constructed with good techniques and machines were also destroyed due to earthquakes leading to immense loss of life and property and immeasurable sufferings to the survivors of the earthquake hit area. This compelled the engineers and scientists to think of new techniques and methods to save the structures from the destructive forces of earthquake. The earthquakes in the recent past have given new ideas to them by giving enough evidence of performance of different type of structures under different earthquake conditions and foundation conditions. This has given birth to different type of innovative techniques to save the structures from the earthquakes. The technique of base isolation was developed in an attempt to reduce the response on buildings and their contents during earthquake attacks and has proven to be one of the most effective methods for a wide range of seismic design problems on buildings in the last two decades.[6]

To control the effect of earthquake on building the base isolation technique is one of the best solutions. Seismic isolation consists of essentially the installation of mechanisms such as isolators which decouple the structure from base. The seismic isolation system is mounted beneath the structure and is referred as 'Base Isolation'. The idea of separating the superstructure from the substructure has dependably been an elegant thought in principle, at present it has been incorporated into a suitable solution. The objective is to have flexible material in the horizontal plane that is equipped for anticipating vitality stream into the superstructure. This flexibility expands the superstructure's period, which, thus, lessens the induced acceleration.

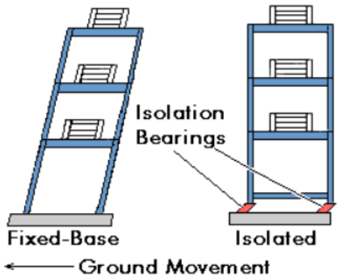

Figure 1: Behavior of the building with base isolators

II. OBJECTIVE AND SCOPE OF THE PROJECT

This paper deals with a new type of base isolation application. The work includes design of G+5 and G+17-storey reinforced concrete building in accordance with IS 1893:2002 provisions; one with fixed base and other is base isolated. By analyzing the fixed base buildings, we get maximum reactions under each column. For these maximum values Lead Rubber Bearings (LRBs) were designed manually in order to isolate the superstructure from substructure. Time History Analysis (THA) is carried out by taking El-Centro earthquake ground motion records.

The objectives of this work are as follows:

- To carry out modeling and analysis of fixed base and base isolated buildings by using E-TABS software and study the effects of earthquake ground motions on these models.
- To design and study the effectiveness of lead rubber bearing used as base isolation system.
- To compare between fixed base and base isolated building on the basis of their vital dynamic properties such as base shear and time period.
- To study the behavior of high rise, low rise, plan irregular and vertical irregular building with LRB under strong earthquake ground motion.

  Hence, it would be possible to decide the effectiveness of this base isolation system, giving advices for future possible applications.

III. TIME HISTORY ANALYSIS (THA)

This method calculates response of structure subjected to earthquake excitation at every instant of time (hence the name Time History). Various seismic data are necessary to carry out the seismic analysis namely acceleration, velocity, displacement data etc., which can be easily procured from seismograph data's analysis for any particular earthquake. It is an important technique for structural seismic analysis especially when the evaluated structural response is nonlinear.[26]

In time history analyses the structural response is computed at a number of subsequent time instants. In other words, time histories of the structural response to a given input are obtained as a result. THA of structures is carried out when the input is in the form of specified time history of ground motion.

IV. VALIDATION OF THE SOFTWARE

A building model with G+5 storey was considered for validation study. In the present study analysis has been done by using ETABS 2015 software and time period for fixed base structure is calculated. This value is then compared with the referred literature [1] and validated.

4.1 Mathematical Model

Six storeyed building was considered for the validation. The plan of G+5 storeyed building is shown in Figure 2.

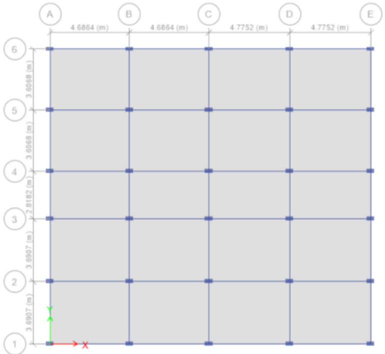

Figure 2: Plan for G+5 storey model

The building parameters chosen for validation of the model are given in Table 1 and dimensions were adopted from literature reviewed.[1]

Table 1: Building details choosen for validation [1]

Grade of concrete	M30
Grade of steel	Fe500
Storey Height	3 m
Beam Size	230 x 410 mm
Column Size	230 x 450 mm
Wall Thickness	230 mm
Parapet Height	1 m
LL on the floor	2.5 kN/m^2
LL on the roof	1.25 kN/m^2
Zone	3
Importance factor, I	1
Building type	SMRF
Soil profile	Medium sites

Mathematical modeling is done on ETABS 2015 to calculate the natural time period of fixed base system. Table 2 provides the validation of results. From the validation result, it is apparent that ETABS 2015 can be used for analysis of the isolated building.

Table 2: Validation Results

Sl. No.	Value obtained from	Time Period
1	As per literature reviewed [1]	0.934
2	ETABS 2015 (present study)	1.008

V. METHODOLOGY

In the present study, two structural models of G+3 storeyed and G+20 storeyed conventional and base-isolated multi-storeyed buildings were modeled and analyzed using ETABS V.15. The conventional building was modeled with fixed support at the base and the base-isolated building was modeled incorporating rubber bearings near the base of the columns. Those models included structural components such as RC columns, beams, shear walls and slab. The connections between beams and columns were assumed to be rigid. A Time history analysis was carried out for the 1940 El - Centro earthquake.

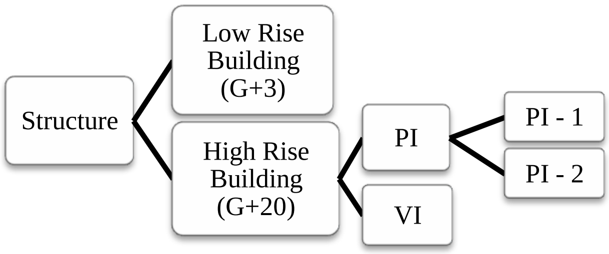

Figure 3: Models to be considered for analysis

5.1 Description of the Building

Comparison of seismic responses of base isolated structures with fixed base was performed. Two different structures are presented in the project, first structure is low rise building and second is high rise building. Same base plan was taken for all models which is shown in Figure 4. Time history analysis has been performed on earthquakes El Centro, 1940.

Figure 4: Plan view for the models

5.2 Models considered for the analysis

G+3 Storey building

Model 1: Low rise RC building with fixed base.

Model 2: Low rise RC building with LRB.

G+20 Storey building

Model 3: High rise RC building with fixed base.

Model 4: High rise RC building with LRB.

Model 5: Plan irregular (PI-1) RC building with fixed base.

Model 6: Plan irregular (PI-1) RC building with LRB.

Model 7: Plan irregular (PI-2) RC building with fixed base.

Model 8: Plan irregular (PI-2) RC building with LRB.

Model 9: Vertical irregular RC building with fixed base.

Model 10: Vertical irregular RC building with LRB.

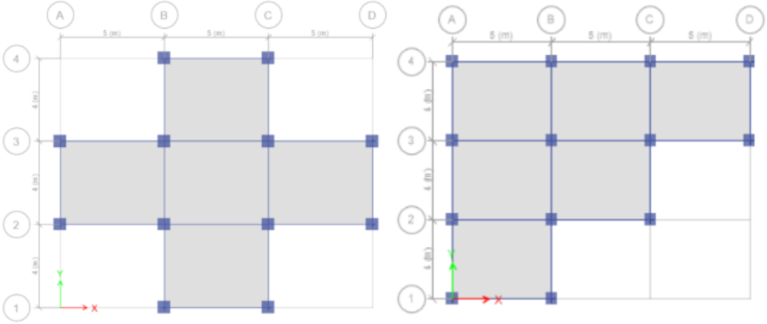

Figure 5: Plan view for model 5 nad model 8

Similar loadings and seismic properties were considered for low rise and high rise building and are shown in Table 3 Table 4 respectively.

Table 3 : Loading for models

LL on the floor	3 kN/m^2
LL on the roof	1.5 kN/m^2
DL on the floor	1 kN/m^2
DL on the roof	2 kN/m^2
Wall load on the floor beams	16 kN/m
Wall load on the roof beam due to 1m high parapet	6 kN/m

Table 4 : Seismic properties

Zone	IV
Importance factor	1
Type of soil	Medium
SMRF	R = 5
Earthquake loads are taken as per IS 1893(part 1):2002	

5.3 Design of LRB

The maximum gravity service load on the column at the base of structure was considered to design the LRB. Maximum service load is obtained by considering the base of the structure as fixed.

The calculation of lead rubber bearing is carried out as follows:

1. The first step is to decide the minimum rubber bearing diameter depending on vertical reaction. This maximum vertical reaction obtained from analysis result of fixed base building which is taken as supporting weight LRBs.
2. To set the target period T_{eff}(2 seconds appears to be the desired one) and the effective damping β is assumed to be 5% for reinforced concrete structure according to IS 1893:2002, Clause7.8.2.1.
3. The spectral acceleration S_a from the response spectrum graph in relation with the desired period is found.
4. Calculation of design displacement,

$d_{bd}= \left(\frac{\text{Teff}}{2\pi}\right) S_a$

where,

S_a= spectral acceleration

T_{eff}= Target period

d_{bd}= Design displacement of isolator

5. The required stiffness to provide a T_{eff} period is the effective stiffness:

$K_{eff} = \left(\frac{2\pi}{\text{Teff}}\right)^2 \frac{Wi}{g}$

where,

T_{eff}= Effective fundamental period of the superstructure corresponding to horizontal translation, the superstructureassumed as a rigid body

W_i= The weight on the isolator i.e. maximum vertical reaction

K_{eff}= Effective stiffness of the isolation systemin the principal horizontal direction under consideration, at a displacement equal to the designdisplacementd$_{bd}$.

6. Dissipated energy per cycle at the design displacement:

$E_D = 2K_{eff}\, d_{bd}^{\,2}\, \beta$

where,

β = effective damping

7. Force at zero displacement under cyclic loading,

$F_o = \frac{E_D}{4d_{bd}}$

8. Stiffness of lead core of lead-rubber bearing,

$K_{pb} = \frac{Fo}{d_{bd}}$

9. Stiffness of rubber in LRB,

$K_r = K_{eff} - K_{pb}$

10. Total thickness of LRB,

$t_r = \frac{d_{bd}}{\gamma}$

11. Diameter of lead rubber bearing,

$D_{bearing} = \sqrt{\frac{K_r t_r}{400\pi}}$

12. Total loaded area (A_L) calculation
    - Diameter of lead core of LRB

$D_{pb} = \sqrt{\frac{4F_o}{\pi\, \sigma_{pb}}}$

where,

σ_{pb} = Total yield stress in lead, it is assumed to be 11 MPa

- Area of lead core in LRB

  $A_{pb} = \frac{\pi}{4}\left(D_{pb}{}^2\right)$

- Force free area

  $A_{ff} = \frac{\pi}{4}\left(D_{pb}{}^2\right)$

- Total loaded area

$A_L = A_{ff} - A_{pb}$

13. Circumference of force free section

$C_f = \pi t D_{ff}$

14. Shape factor

$S_i = \frac{AL}{Cf}$

15. Total height of LRB

$H = Nt + (N-1)t_s + 2t_{ap}$

where,

t = Single rubber layer thickness (0.01m)

t_s = Thickness of steel lamination (0.003m)

t_{ap}= Laminated anchor plate thickness (0.04m)

16. Bearing horizontal stiffness,

$K_b = \frac{GAr}{H}$

where,

G = shear modulus (varying from 0.4 to 1.1Mpa) Adopting 1 Mpa

A_r = rubber layer area

H = Height of LRB

17. Total bearing vertical stiffness

$K_v = \frac{6GS_i^2 A_r k}{(6GS_i^2 + k)H}$

where,

S_i= Shape factor = 10

k = rubber compression modulus = 2000 MPa

The main objective of work is to reduce dynamic properties of structure by providing base isolation. Thus by using above design procedure of LRB isolator, five different LRB isolators for different models were manually designed by considering the maximum base shear obtained from the corresponding fixed model. The parameters that were calculated are tabulated below.

Table 5 : Design paremeters of LRB for low rise and high rise building.

Properties	Low rise (G+3)	High rise (G+20)
Required Stiffness, U2 & U3 (kN/m)	472.86	998.03
Bearing horizontal Stiffness, K_b(kN/m)	110.39	246
Vertical Stiffness, U1 (kN/m)	17.88 x10^3	80.812 x10^3
Yield force, F (kN)	2.75	5.8
Stiffness ratio	0.1	0.1
Damping	0.05	0.05

Table 6 : Design parameters of LRB for irregular buildings

Properties	Plan Irregularity		Vertical Irregularity
	PI - 1	PI - 2	
Required Stiffness, U2 & U3 (kN/m)	641.88	745.5	876.3
Bearing horizontal Stiffness, K_b(kN/m)	154	180.119	215.43
Vertical Stiffness, U1 (kN/m)	33772	45308	63350
Yield force, F (kN)	3.73	4.335	5.09
Stiffness ratio	0.1	0.1	0.1
Damping	0.05	0.05	0.05

Then the isolated models are analysed and designed by providing the above LRB parameters to the corresponding fixed models.

VI. RESULTS AND DISCUSSIONS

Both fixed base and isolated bearing models were analysed and designed in ETABS 2015 software. The models were designed as per IS456:2000 and found that the selected sections are safe under given loading and seismic condition and thus the study was further proceeded. The main seismic parameters selected for the comparison of models are time period and base shear.

6.1 Time period

Table 7: Time period for different models

Building Model	Time Period (s)	
	Fixed Base	LRB
Low rise (G+3)	0.815	3.682
High rise (G+20)	2.529	7.811
Plan irregular : PI-1 (G+20)	2.576	8.926
Plan irregular : PI-2 (G+20)	2.665	7.698
Vertical Irregular (G+20)	2.118	7.132

The mode period of the structure being 0.815 sec in fixed condition is increased to 3.682 sec after providing base isolator. Hence, the time period of G+3 storey (low rise) building almost increases by 77.8% after providing lead rubber isolator when compared to fixed base building.

The mode period of the structure being 2.529 sec in fixed condition is increased to 7.811 sec after providing base isolator. Hence, the time period of G+20 storey (high rise) building increases by 67.6% after providing lead rubber isolator when compared to fixed base building.

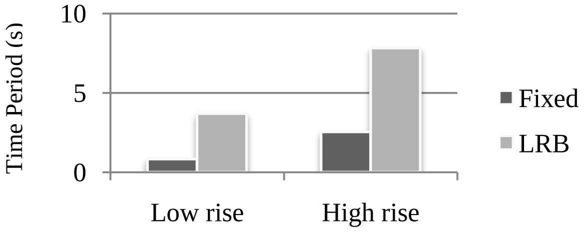

Figure 6: Variation of time period for low rise and high rise building

The mode period of the structure being 2.576 sec in fixed condition is increase to 8.926 sec after providing base isolator. The time period of plan irregular(PI - 1) building increased by 70.1% after providing lead rubber isolator when compared to fixed base building.

The mode period of the structure being 2.665 sec in fixed condition is increase to 7.698 sec after providing base isolator. This shows that the time period of plan irregular(PI - 2) building almost increased by 65.4% after providing lead rubber isolator when compared to fixed base building.

The mode period of the structure being 2.118 sec in fixed condition is increase to 7.132 sec after providing base isolator. Hence, the time period of vertical irregular building almost increased by 65.4% after providing lead rubber isolator when compared to fixed base building.

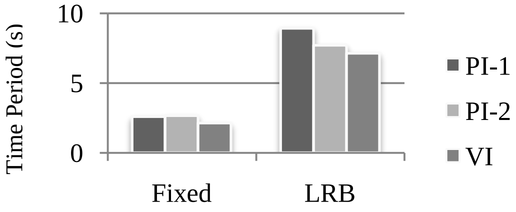

Figure 7: Variation of time period for irregular buildings

6.2 Base isolation

Table 8: Base shear for different models

Building Model	Base Shear (kN)	
	Fixed Base	LRB
Low rise (G+3)	469	104
High rise (G+20)	992	598
Plan irregular : PI-1 (G+20)	638	385
Plan irregular : PI-2 (G+20)	741	438
Vertical Irregular (G+20)	871	436

The base shear obtained in G+3 storey (low rise) building is 469 kN for fixed base and 104 kN for rubber isolated building. Thus the base shears of the building is reduced by 77.8% for lead rubber isolator when compared to fixed base.

The base shear obtained in G+20 storey (high rise) building is 992 kN for fixed base and 598 kN for rubber isolated building. Thus the base shears of the building is reduced by 39.7% for lead rubber isolator when compared to fixed base.

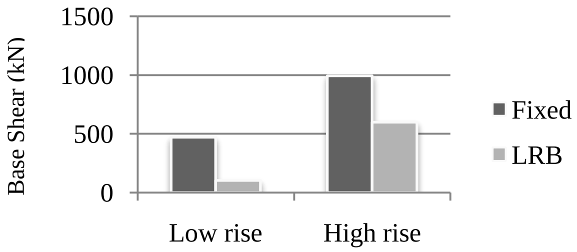

Figure 8: Variation of base shear for low rise and high rise building

The base shear obtained in plan irregular (PI - 1) building is 638 kN for fixed base and 385 kN for rubber isolated building. Thus, the base shears of the building is reduced by 39.7% for lead rubber isolator when compared to fixed base.

The base shear obtained in plan irregular (PI - 2) building is 741 kN for fixed base and 438 kN for rubber isolated building. Thus, the base shear of the building is reduced by 40.9% for lead rubber isolator when compared to fixed base.

The base shear obtained in vertical irregular building is 871 kN for fixed base and 436 kN for rubber isolated building. Thus, the base shear of the building is reduced by 49.9% for lead rubber isolator when compared to fixed base.

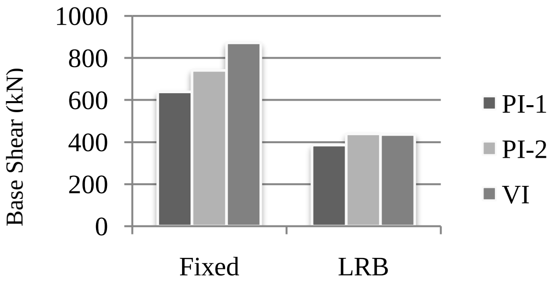

Figure 9 : Variation of base shear for irregular buildings

VII. CONCLUSIONS

From the study the following conclusions were arrived.

- Base isolation method has proved to be a better method of earthquake resistant design.
- The results show that the responses of structures can be reduced by the use of LRB.

- Time period of the structure increases by the use of LRB which reduces the transfer of lateral forces at the time of earthquake.
- Increase in time period is more in low rise base isolated building compared to high rise base isolated building.
- The increase in time period of the structure is found to be more in vertical irregular base isolated building compared to plan irregular base isolated building.
- Results shows that base shear considerably reduces by using base isolation devices over the conventional structure.
- The reduction in base shear of the structure is found to be more in low rise base isolated building compared to high rise base isolated building.
- Reduction in base shear is more in vertical irregular base isolated building compared to plan irregular base isolated building.

Hence, usage of LRB is an effective base isolation technique which reduces the impact of the earthquake on the structure.

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