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Seismic and Wind Analysis of RC Structures with Base Isolator and Fixed Base

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Abstract: This Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking but may sustain damage to non-structural elements and to some structural members in the building. This may render the building non-functional after the earthquake, which is not acceptable for important buildings, like hospitals, fire stations, etc. Special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. Buildings with such improved seismic performance usually cost more than normal buildings do. However, this cost is justified through improved earthquake performance. One of the technologies used to protect buildings from damaging earthquake effects is "Base Isolation". The idea behind base isolation is to detach (isolate) the building from the ground in such a way that earthquake motions are not transmitted up through the building, or at least greatly reduced. In this project static and dynamic earthquake and wind analysis performed and compared the results. The fundamental goal of base isolation is to reduce substantially the absorption of the earthquake induced force and energy by the structure. This is accomplished by placing a structure on a support mechanism with low lateral stiffness so that in an event of earthquake, when the ground undergoes strong motion, only moderate motion is induced in the structure itself. Base isolation system significantly reduces the super structure lateral stiffness and ductility compared to un-isolated structure which is demonstrated by the results of this work. This allow cost saving from less material being spend on lateral system and implication of structural detailing.
Keywords: Base isolation system, Lead rubber bearings (LRB) Friction pendulum bearings (FPB), Elastomeric rubber bearing (ERB) High damping rubber bearings (HDRB), Low damping rubber bearing (LDRB) Earthquake

I. INTRODUCTION

A. General

The field of seismic design is a subject directly concerned with both life safety and cautious and slow to innovate. Like other code-dominated issues, and like airplane safety, seismic safety has never been much of an important issue. In short, seismic safety is generally taken for granted. Improvements in seismic safety, since the time of the San Francisco earthquake of 1906, have been due primarily to acceptance of ever-increasing force levels to which buildings must be designed. Development of structural systems that perform reasonably well and enable materials such as steel and reinforced concrete is necessary. The choices for lateral resistance lie among shear walls, braced frames, and moment resistant frames.

The codes have mandated steadily increasing force levels, in a severe earthquake a building, if it were to remain elastic, would still encounter forces several times above its designed capacity. This situation is quite different from that for vertical forces, in which safety factors ensure that actual forces will not exceed 50% of designed capacity unless a serious mistake has been made. For vertical forces, this is easy to do. But to achieve similar performance for seismic forces, the structure would be unacceptably expensive.

This disagreement between seismic demand and capacity is traditionally accommodated by reserve capacity, which includes uncalculated additional strength in the structure and often the contribution of portions and exterior cladding to the strength and stiffness of the building. In addition, the ability of materials such as steel to dissipate energy by permanent deformation—which is called ductility—greatly reduces the likelihood of total collapse.

Modern buildings contain extremely sensitive and costly equipment. These building contents are more costly and valuable than the buildings themselves. Furthermore, hospitals, communication and emergency centers, and police and fire stations must be operational when needed most immediately after an earthquake. Conventional construction can cause very high floor accelerations in stiff buildings and large interstorey drifts in flexible structures as shown in FIGURE 1. These two factors cause difficulties in ensuring the safety of the building components and contents. Hence, it's necessary to incorporate a new design approach which will reduce the earthquake forces up to an extent and does not damage the structure.

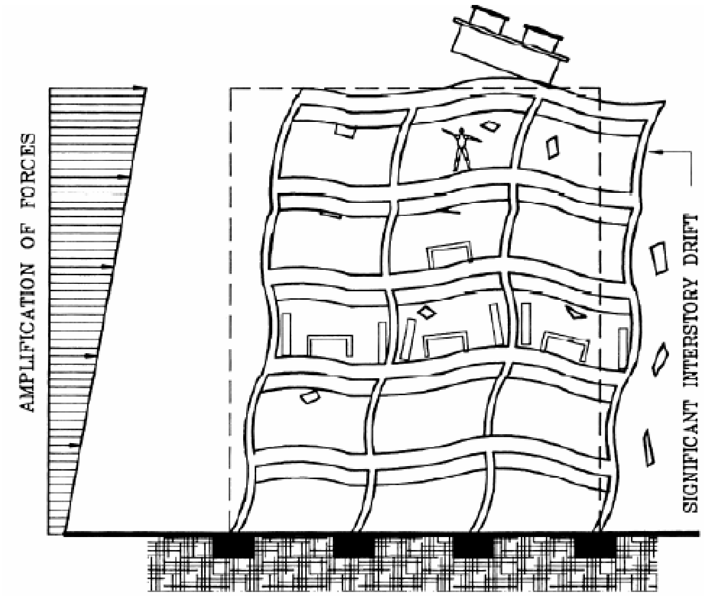

Figure 1: Conventional Building

B. Background

Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking but may sustain damage to non-structural elements and to some structural members in the building. Hence, it may cause large floor accelerations in stiff buildings and large interstorey drifts in flexible buildings. This may render the building non-functional after the earthquake, which may be problematic in some structures, like hospitals, police & fire stations, etc. which need to remain functional after the earthquake. Hence, special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. One basic technology is used nowadays to protect buildings from damaging earthquake effects. This is the Base Isolation technology. The idea behind base isolation is to detach (isolate) the building from the ground in such a way that earthquake motions are not transmitted up through the building, or at least greatly reduced.

The principle of seismic isolation is to introduce flexibility at the base of a structure in the horizontal plane, while at the same time introducing damping elements to restrict the amplitude of the motion caused by the earthquake. Mounting buildings on an isolation system will prevent most of the horizontal movement of the ground from being transmitted to the buildings. This results in a significant reduction in floor accelerations and interstorey drifts, thereby providing protection to the building contents and components as shown in FIGURE .

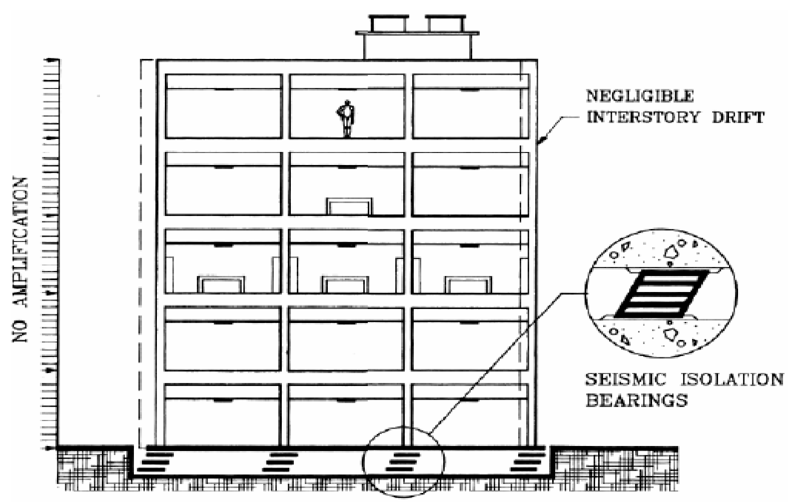

Figure 2 : Isolated building

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Importance is given to the concept of seismic isolation by the successful development of mechanical-energy dissipaters and elastomers with high damping properties. Mechanical energy dissipaters, when used in combination with a flexible isolation device, can control the response of the structure by limiting displacements and forces, thereby significantly improving seismic performance. The seismic energy is dissipated in components specifically designed for that purpose, relieving structural elements, such as beams and columns, from energy-dissipation roles (and thus damage).
The advantages of seismic isolation include the ability to eliminate or very significantly reduce structural and nonstructural damage, to enhance the safety of the building contents and architectural facades, and to reduce seismic design forces. These potential benefits are greatest for stiff structures fixed rigidly to the ground, such as low- and medium-rise buildings, nuclear power plants, bridges, and many types of equipment. Some tectonic and soil-foundation conditions may, however, prevent the use of seismic isolation.

C. Objective Of Work

With above mentioned background, following objective was derived for the work: -
1) Understand the fundamentals of Base Isolation systems for an undertaken R.C.C building.
2) Design a suitable Base Isolation system; and
3) Comparison of Base Isolated & Non-base Isolated buildings & allied parameters.

D. Scope of The Study

Following line of action was decided to fulfill the above-mentioned objective.
1) Obtaining response of 3D fixed base RCC building
2) Defining target parameters
3) Analysis & Design of base isolation system
4) Obtaining response of base isolated RCC building
5) Comparison of fixed base & isolated base RCC building

a) Base Isolation: Isolation layer is located on the base of building.

- *Advantages*
  - Minimal added structural costs.
  - Separation at the level of base is easy to incorporate.
  - Base of Columns may be connected by diaphragm.
  - Easy to incorporate back-up systems for vertical loads.
- *Disadvantage*
  - May require cantilever pit.

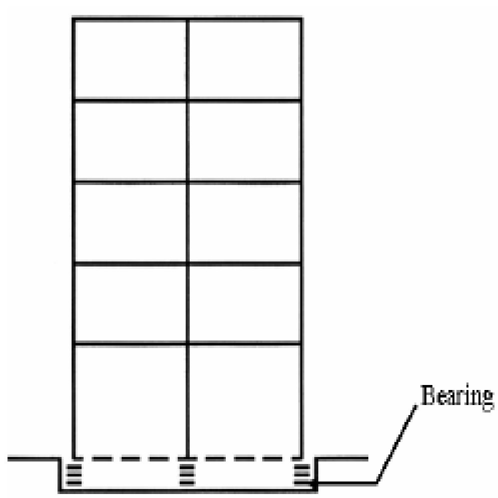

Figure 3 : Base Isolation

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b) *Basement Isolation:* Isolation layer located on the certain story of the basement.

- *Advantages*
  - No Sub-basement required.
  - Minimal added structural costs.
  - Base of columns connected by diaphragm at isolation level.
  - Back-up system for vertical loads provided by columns.
  - No special detailing required for separation of internal services such as elevator and stairways.
  - No special cladding separation details.
  - Base of columns connected by diaphragm at isolation level.
- *Disadvantage*
  - May require cantilevered elevated shaft below first floor level.
  - Special treatment required for internal stairways below first floor level.
  - Added structural costs unless sub-basement required for other purposes.
  - Requires a separate retaining wall.

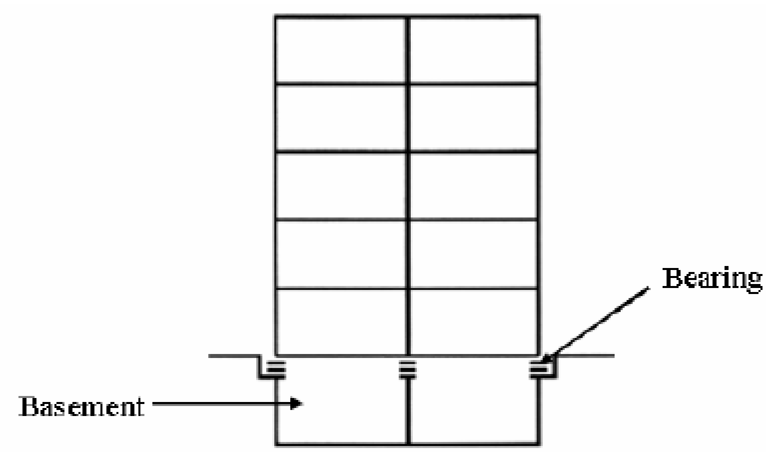

Figure 4 Basement Isolation

c) *Story Isolation:* Isolation layer is located on the top of the first story or certain storey of super structure.

- *Advantages*
  - Minimal added structural costs.
  - Economic if first level is for parking.
  - Back-up system for vertical loads provided by columns.
- *Disadvantages*
  - Special detail required for elevators and stairs.
  - Special cladding details required if first level is not open.
  - Special details required for vertical services.

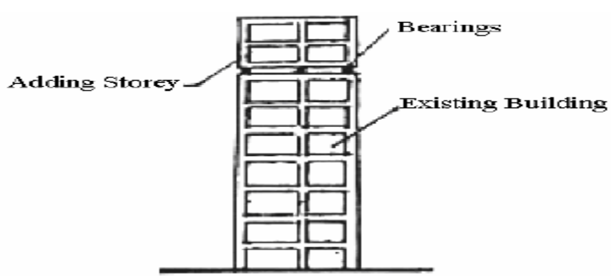

Figure 5 : Story Isolation

II. LITERATURE REVIEW

Many researchers have considered various aspects of ground-borne vibration and its effects on buildings and their occupants, and several detailed studies have already been undertaken. Some of the papers giving thought to Base Isolation of Buildings, retrofitting of building by Seismic Base Isolation and the study of structural response due to actual earthquake are studied and abstract of the same are presented below. This literature review provides an overview of previous research in this field, with particular emphasis on the work of direct relevance to base-isolated buildings.

1) Farzad Naeim, Ronald L Mayes [1] presented the principles, benefits and the feasibility of Seismic Isolation. The basic principles of Seismic Isolation were introduced first. Force-deflection characteristics of commonly used Isolation devices are introduced, followed by guidelines for evaluation of the feasibility of Seismic Isolation as an alternative for a given project. The differences in approach to new construction and rehabilitation of existing structures are highlighted. The building code provisions for seismic isolation are covered next. The IBC-2000 design provisions for seismic isolation are discussed in detail. A simple preliminary design procedure is provided to aid engineers in initial sizing of the isolation devices. Several examples are provided to illustrate the practical application of the material covered. The results show that the theory of Seismic Isolation permits substantial cost savings for isolated buildings compared to conventional construction. However, the initial construction cost may exceed the cost for a similarly situated fixed base building by as much 5 %. For the retrofit of buildings, seismic isolation may only be technically applicable in 1 out of approximately 8 buildings.
2) Yeong-Bin Yang, Kuo-Chun Chang, Jong-Dar Yau [2] presented the philosophy behind Seismic Isolation systems, basic requirements of Seismic Isolation systems and the design criteria for Isolation devices like HDR, LRB & FPS. Example is provided to illustrate the practical application of the design concept and a comparison is carried out for the three types of bearings for the same project. It was concluded by the author that the procedures presented here serve merely as a key concept involved in initial sizing of the base isolation systems. Extra care must be given in applying isolators to the rehabilitation of existing buildings.
3) Rihui Zhang [3] presented basic concepts, modeling and analysis for an isolated structure. Seismic Isolation and Energy Dissipation devices like elastomeric isolators, sliding isolators and few dampers are presented. This is followed up by performance and testing requirements for isolation devices. Design guidelines and design examples are presented, where the design guidelines follow AASHTO guidelines for bridges and UBC guidelines for buildings. This guideline contains general requirements for isolation, selecting proper isolation device, methods of analysis, design displacement & design force. Recent development in this field and application are presented. The author has made an attempt to introduce the basic concepts of seismic isolation and supplemental energy dissipation devices and their history, current developments, applications, and design related issues.

III.METHODOLOGY

Analysis methods are widely characterized as linear and nonlinear static and dynamic. The main difference between the equivalent static procedure and dynamic analysis procedure lies in the magnitude and distribution of lateral forces over the height of the buildings.

A. Seismic Analysis

In the dynamic analysis procedure, the lateral forces are based on properties of the natural vibration modes of the building, which are determined by the distribution of mass and stiffness over height. In the equivalent lateral force procedure, the magnitude of forces is based on an estimation of the fundamental period and on the distribution of forces as given by a simple formula that is appropriate only for regular buildings. In the preliminary design process, equivalent static seismic forces are used to determine the design internal forces of structural members using linear elastic analyzed structure and, in turn, determine the design member strength demands. Such static seismic forces are simply determined corresponding to the elastic design acceleration spectrum divided by a structural strength reduction factor particularly called the response modification factor R.

Usually, the elastic design spectrum, which is often related to 5% or 10% Probability of Exceedance (POE) in 50 years, is defined smoothly as a reasonable representation of the seismic action demand on the structure at the site of interest. The adopted strength reduction factor is thus intended to represent an expected inelastic response demand or expected damage level demand, which may be induced during earthquake excitation.

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B. Equivalent Static Load (ESL) Method

Along the principal direction, the total design lateral force or design base shear is given in terms of design horizontal seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor (Z) of the site, importance factor (I) of the structure, response reduction factor (R) of the lateral load resisting elements and the fundamental period of the structure. The following are the major steps for determining the forces by equivalent static procedure.

1) *Determination of Base Shear:* The total design lateral force or base shear along the principal direction shall be determined by following expression, Clause 7.2.1 of IS 1893 (Part 1): 2016

$$V_B = A_h W$$

Where,

A_h= Design horizontal seismic coefficient for a structure.

W= Seismic weight of building

A_h Shall be determined by the following expression:

$$A_h = \frac{I}{R}\,\frac{Z}{2}\,\frac{S_g}{g}$$

Note: The value of A_h will not be taken less than $\frac{Z}{2}$.

In factor $\frac{Z}{2}$, Z is the zone factor given in table 3 of IS 1893 (Part 1): 2016, for the Maximum Considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the Maximum Considered Earthquake (MCE) zone factor to the factor for Design Basis Earthquake (DBE). For this project Guwahati city is considered which is located in zone V.

In factor $\frac{I}{R}$, I is the importance factor, depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historic value, or economic importance. The minimum value of importance factor are given in table 8 of IS 1893 (Part 1): 2016. For this project a residential building is considered with the importance factor 1.2.

R is the response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformation. The need of incorporation of factor R in base shear formula is an attempt to consider the structures inelastic characteristic in linear analysis method since it is undesirable as well as uneconomical that a structure will be designed on the basis that it will remain in elastic range for all major earthquake. The base shear equation produces force levels that are probably more nearly representative of those occurring in an actual structure. It is achieved by applying base shear for linear design that are reduced by a factor $\frac{1}{R}$ for those that would be obtained from fully elastic response. The value of R are prescribed in table 9 of IS 1893 (Part 1): 2016. In this project R value is taken as 5 which is for dual lateral load resisting system.

Factor $\frac{S_g}{g}$ is the average response acceleration coefficient for rock and soil sites as given by fig. 2 of IS 1893 (Part 1): 2016 and by the equation describe in clause 6.4.2 of IS 1893 (Part 1): 2016 for different soil condition based on appropriate natural periods of the structure. These values are given for 5% of damping of the structure; for other value of damping it is modified according to table 4 of IS 1893 (Part 1): 2002. These curves represents free field ground motion.

The fundamental natural period for buildings are given in clause 7.6.2 of IS 1893 (Part 1): 2016.

In equivalent lateral force procedure, the magnitude of lateral force is based on the fundamental period of vibration, the other periods and shapes of natural modes are not required.

IS 1893 (Part 1): 2016 uses a parabolic distribution of lateral force along the height of the building as per the following expression.

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{i=1}^{n} W_i h_i^2}$$

Where,

Qi = Design lateral force at floor *i*

W*i* = Seismic weight of floor i

h*i* = Height of floor *i* measured from base, and

n = Number of stories in the building is the number of levels at which masses are located.

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IV. MODELING AND ANALYSIS

All real physical structures, when subjected to loads or displacements, behave dynamically. The additional inertia forces, from Newton's second law, are equal to the mass times the acceleration. If the loads or displacements are applied very slowly then the inertia forces can be neglected and a static load analysis can be justified.

Hence, dynamic analysis is a simple extension of static analysis. All real structures potentially have an infinite number of displacements.

Therefore, the most critical phase of a structural analysis is to create a computer model, with a finite number of mass less members and a finite number of joint displacements that will simulate the behavior of the real structure. The mass of a structural system, which can be accurately estimated, is lumped at the nodes.

Also, for linear elastic structures the stiffness properties of the members can be approximated with a high degree of confidence. However, the dynamic loading, energy dissipation properties and boundary (foundation) conditions for many structures are difficult to estimate.

To reduce the errors in calculations it is necessary to conduct many different dynamic analyses using different computer models, loading and boundary conditions.

Because of the large number of computer runs required for a typical dynamic analysis, it is very important that accurate and numerically efficient methods be used within computer programs. So, proper knowledge of the dynamic analysis is very much essential.

Some computer program like DRAIN-2DX is available which is able to perform base isolation with dynamic analysis. The other software available to perform base isolation with dynamic analysis is ETABS & SAP2000. Out of this software two software's were available at departmental computer laboratory namely ETABS version 18.1.1. Extended Three-Dimensional Buildings Systems (ETABS) and Structural Analysis Program (SAP) are the products of Computer and Structures, Inc. These are the commercial windows finite element program that works with complex geometry and has inbuilt feature of provision of non-linear and linear bearings in the form of link element. With these built-in features it can model LRB, HDR and FPS bearings with different properties.

A. Material Properties

Concrete grade: M30
Steel grade: HYSD500

B. Trial Sizes of Elements

Beam- 450X600 MM
Column- 600X900 MM
Slab thickness- 250 MM

C. Load Combinations

1) Strength load Combinations

1.5 (DL + L.L) 1.2 (DL + LL ± EQX)
1.5 (DL ± EQX) 1.2 (DL + LL ± EQY)
1.5 (DL ± EQY) 1.2 (DL + LL ± WLX)
1.5 (DL ± WLX) 1.2 (DL + LL ± WLY)
1.5 (DL ± WLY) 0.9 DL ± 1.5 WLX
0.9 DL ± 1.5 EQX 0.9 DL ± 1.5 WLY
0.9 DL ± 1.5 EQY

2) Service load Combinations

1 (DL + LL) 0.8 DL + 0.8 LL ± 0.8 EQX
1 (DL ± EQX) 0.8 DL + 0.8 LL ± 0.8 EQY
1 (DL ± EQY) 0.8 DL + 0.8 LL ± 0.8 WLX
1 (DL ± WLX) 0.8 DL + 0.8 LL ± 0.8 WLY
1 (DL ± WLX)

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Storey	Building without Base Isolator		Building with Base Isolator	
	EQ-X	EQ-Y	EQ-X	EQ-Y
Terrace	0.0010	0.0014	0.0009	0.001
20	0.0016	0.0021	0.0012	0.002
19	0.0021	0.0027	0.0016	0.002
18	0.0025	0.0032	0.0019	0.003
17	0.0029	0.0037	0.0022	0.003
16	0.0032	0.0040	0.0025	0.003
15	0.0035	0.0043	0.0028	0.004
14	0.0037	0.0046	0.0030	0.004
13	0.0039	0.0049	0.0032	0.004
12	0.0041	0.0051	0.0035	0.005
11	0.0043	0.0053	0.0036	0.005
10	0.0045	0.0056	0.0038	0.005
09	0.0047	0.0058	0.0040	0.005
08	0.0049	0.0059	0.0041	0.006
07	0.0050	0.0061	0.0043	0.006
06	0.0051	0.0063	0.0044	0.006
05	0.0053	0.0064	0.0046	0.006
04	0.0054	0.0066	0.0047	0.006
03	0.0056	0.0068	0.0049	0.007
02	0.0061	0.0073	0.0055	0.007
01	0.0068	0.0078	0.0076	0.010
Base	0.0023	0.0027	0.0092	0.011

TABLE 1 **:** Drift with Base Isolator in X-Dir and Drift without Base Isolator in X-Dir.

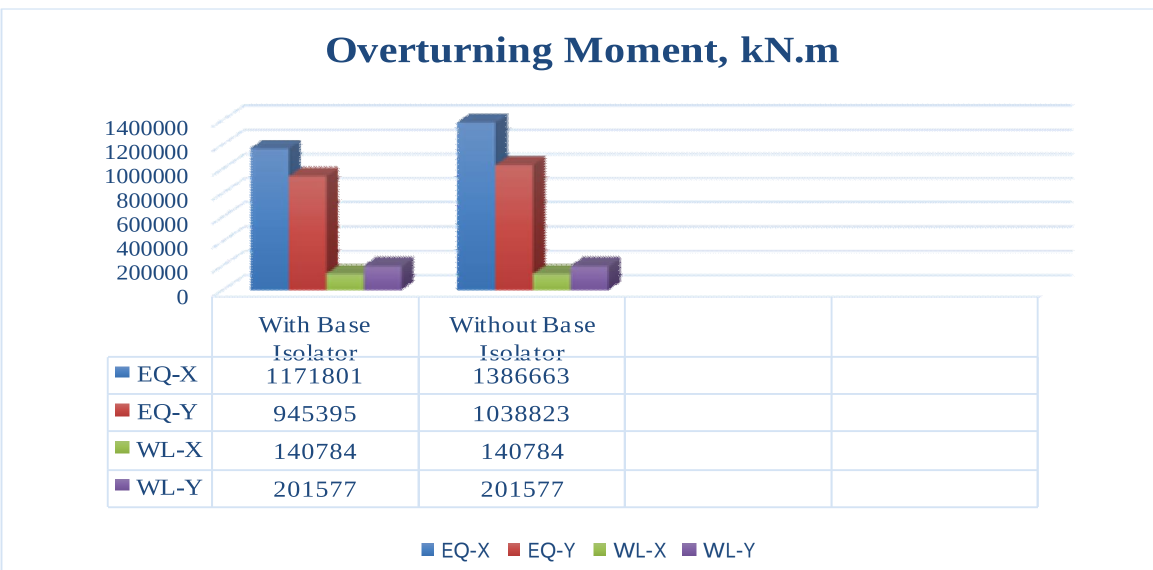

Figure 6 : Overturning moment with base isolator and without base isolator

The location of center of mass and center of stiffness in the structure is very important in overturning moment. As the center of mass and center of stiffness far from each other, maximum will be the overturning moment so as torsional moment in the structure. To avoid higher torsional moment in the structure IS 1893:2016 (Part-I) has given certain calculation in clause 7.8. As per this clause, eccentricity between center of mass and center of stiffness shall be maintained. Also, some types of vertical irregularities also cause overturning moment in the structure.

D. Base Shear

Then, from base shear plots that were obtained after analysis for MRF building frame, buildings without & with base isolator, Base shear is the maximum lateral force at the base of the structure due to seismic/wind activities. Based on base shear value, behavior or responses of building can be determined.

When base shear value is very high then the structure is either very heavy or very stiff. Based on some formulation, base shear which is earthquake force attracted by any structure can be calculated. Building weight, stiffness plays vital role in base shear and also in overall behavior of structure. Base shear of structure is directly proportional to the weight of the structure.

Percentage of earthquake force attracts by both buildings.

As the mass participation considered for earthquake analysis is 100% of dead load and 25% of live load.

Horizontal seismic coefficient (Ah) for G+50 Building = I/R x Sa/g x Z/2
= 1.2/5 x 2.5 x 0.36/2
= 0.108

Percentage of earthquake in any system = (Base shear in any Direction) / (DL+0.25 x LL)

	Without Base Isolator	With Base Isolator
Base shear EQX (kN)	32055.5576	27342.7983
Base shear EQY (kN)	24218.2589	22012.1422
Dead Load (kN)	445495.7246	445495.7246
Live Load (kN)	75264	75264
% of earthquake (EQX)	6.9	5.88
% of earthquake (EQY)	5.21	4.74

Table 2. Base shear in Structure Due to Earthquake

	Without Base Isolator	With Base Isolator
Base shear WLX (kN)	3509.47	3509.47
Base shear WLY (kN)	5024.92	5024.92

Table 3. Base shear in Structure Due to Wind

From table, it is observed that the earthquake percentage is reducing due to base isolator hance the reduction in base shear, as explained above if the value of base shear is less then the structure is more flexible, ductile. Also, more flexible building causes proper behavior of building during any lateral force application. From above table, it is observed that around 10 to 15% earthquake get reduced. Base shear due to wind forces does not show any variation, hence for wind forces, it can be assumed that the base isolation system will become more effective as the building height get increased.

E. Discussion

After carrying out the dynamic analysis for fixed base and isolated base building, the results obtained are compared & discussed here.

1) One of the main criteria for base isolation is that the time period of a base isolated structure should be at least three times higher than that of a fixed base building.
2) From the results available in Table 7.1 we can clearly see that the time period for a base isolated structure is three times higher than that of a fixed base structure.

V. CONCLUSION

On the basis of present study and reviewed literature the following conclusions can be drawn:

A. Story shear reduced after the lead rubber bearing (LRB) is provided as base isolation system which reduces the seismic effect on building.
B. Base shear is also reduced after providing LRB which makes structure stable during earthquake.
C. Story drift are reduced in higher stories which makes structure safe against earthquake.

D. Point displacements are increased in every stories after providing LRB which is important to make a structure flexible during earthquake.
E. Mode periods are increased which increases reaction time of a structure during earthquake.
F. Finally, it is concluded that after LRB is provided as base isolation system it increases the structures stability against earthquake and reduces reinforcement hence make structure economical.
G. Torsion in building is reduced in structure which makes structure more stable, flexible and ductile.

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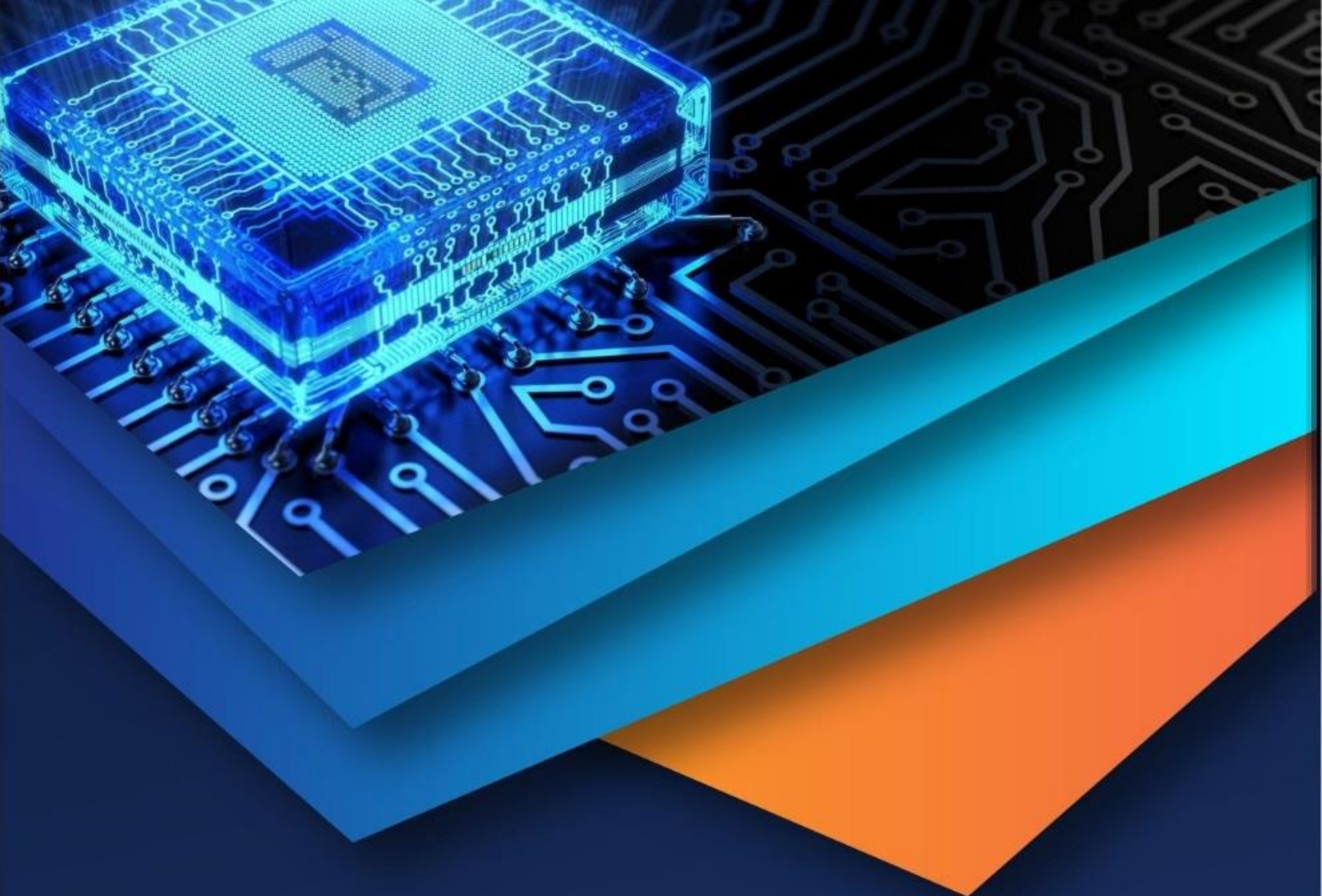

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