Seismic Performance Assessment of Base Isolation System on Sloping Ground

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Abstract— **The base isolation is technique that has been used to protect the structures from the damaging effects of earthquake. The installation of isolators at the base increases the flexibility of the building structures. Base isolation is not about complete isolation of the structure from the ground, as with magnetic levitation, which may be very rarely practical. Most of the base isolation systems that have been developed over the years provide only 'partial' isolation. 'Partial' in the sense that much of the force transmitted, and the consequent responsive motions are only reduced by providing flexibility and energy dissipation mechanisms with the addition of base isolation devices to the structure. Base isolation, as a strategy to protect structure from earthquake, revolves around a few basic elements of understanding, changing the time period of the structure: Base isolator is a more flexible device compared to the flexibility of the structure. Thus, coupling both an isolator and the superstructure together increases the flexibility of the total isolated structural system. In this way, this technique lengthens the structures natural time period away from the predominant frequency of the ground motions, thus evading disastrous responses caused due to resonance. In present study modeling and analysis RC building is done in ETABS software for three different sloping angles i.e. 25 , 30 and 35 . The structure is base isolated and the building considered for the study represents building on sloping ground. IS 1893 Part (I) - 2016 Seismic response of building is compared with base isolation. The results obtained from analysis one represented through seismic response parameters such as displacement, storey drift, base shear and maximum forces. We have used lead rubber baring, double pendulum friction bearing and, tune mass damper for isolation.**

Index Terms— **Base Isolation, Sloping Ground, Equivalent static method, Response Spectrum Method., double pendulum friction bearing**

I. INTRODUCTION

Base isolation is one of the most popular means of protecting a structure against earthquake forces. It is one of most powerful tools of earthquake engineering pertaining to the passive structural vibration control technologies. A base isolated structure is supported by a series of bearing pads, which are placed between the buildings and building foundation. The concept of base isolation is explained through an example of building resting on frictionless rollers. When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to the shaking of the ground; simply, the building does not experience the earthquake. Now, if the same building is rested on the flexible pads that offer resistance against lateral movements, then some effect of the ground shaking will be transferred to the building. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a fixed base building. The flexible pads are called base-isolators, whereas the structures protected by means of these devices are called base-isolated buildings. The main feature of the base isolation technology is that it introduces flexibility in the structure. As a result, a robust medium-rise masonry or reinforced concrete building becomes extremely flexible.

Below figure shows the typical process of base isolation in a RCC building.

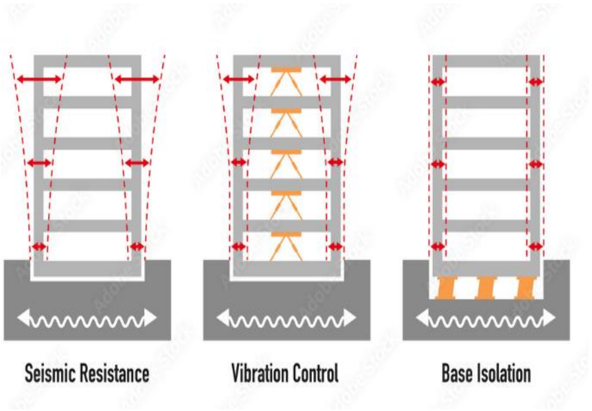

Figure 1.1: Base Isolation Structures

1.1 Components of Base Isolation

A base isolation system mainly consists of two components:

1. Isolation Units
2. Isolation Components

1. Isolation Units: An isolation unit is the basic component of the isolation system that performs of decoupling effect to the building structure or the non-building structure. Base isolation units consist of Linear-motion bearings that allow the building to move, oil dampers that absorb the forces generated by the movement of the building, and laminated rubber bearings that allow the building to return to its original position when the earthquake has ended.

2. Isolation Components: The isolation components are the connection units between the isolation units mentioned before. These components do not contribute to the decoupling process.

1.2 Principle of Base Isolation

The basic principle behind base isolation is that the response of the structure or a building is modified such that the ground below is capable of moving without transmitting minimal or no motion to the structure above. A complete separation is possible only in an ideal system. In a real world scenario, it is necessary to have a vertical support to transfer the vertical loads to the base. The relative displacement of ground and the structure is zero for a perfectly rigid, zero period structure, since the acceleration induced in the structure is same as that of ground motion. Whereas in an ideal flexible structure, there is no acceleration induced in the structure, thus relative displacement of the structure will be equal to the ground displacement. No Structure is perfectly rigid or flexible, therefore, the response of the structure will be between the two explained above. Maximum acceleration and displacements are a function of earthquake for periods between zero to infinity. During earthquakes there will be a range of periods at which acceleration in the building will be amplified beyond maximum ground acceleration, though relative displacements may not exceed peak ground displacements. Base isolation is the ideal method to cater this, by reducing the transfer of motion, the displacement of building is controlled.
Displacement occurs at CG of the structures for fixed base structures, which will be approx. two-third height for buildings and at isolation plane for base isolated structures with lesser displacement within the structure.

Basic requirements of an isolation system are as follows

1. Flexibility
2. Damping
3. Resistance to Vertical or other service loads

1.3 Need of Base Isolation

The Kutch Earthquake of January 26, 2001 in Gujarat, India, caused the destruction of a large number of modern 4 to 10-storied buildings. After this earthquake, doubts were raised about our professional practices, building by-laws, construction materials, building codes and education for civil engineers and architects. It was found that Most of the Buildings that were analyzed for lateral Seismic Analysis were observed to Ignore the Post-Yield Response (Nonlinear Response) subjected to Dynamic Loading which is the most important response of the system.

The use of Seismic Control Methods like the Base-Isolation is essential in controlling the Response of the structure. Therefore to Study the Post-Yield Response of the Structure a Significant Post Yield Analysis is needed which is called as the Non-Linear Time History Analysis. So this Analysis is an extensive one which is useful for knowing the effect of Real time Earthquake Ground Acceleration Loading on the Structure using Seismic Control Devices like the Base Isolators.

II. RELATED WORK

M. S. Mounashree et al. (2018) The main purpose of the isolation system is to extend the duration of the structure, thereby shifting the natural duration of the structure from the dominant duration of the earthquake. Isolators play three main roles: energy dissipation, stiffness, and horizontal flexibility with respect to lateral loads. The purpose of my project is to study the structural response of RC flat slabs and beam slab systems by response spectrum analysis. The demonstrating and study of the structure are approved out using ETABS 2016 software. The dynamic properties of the structure such as base shear, story drift, time period, and story displacement are found, and the comparison is made between them. [1]

Y. Rajesh Kumar (2018) The purpose of this study is to understand the seismic response of RC structures at various floor levels when exposed to seismic ground motions such as El-centro by using seismic isolation and fluid viscous dampers as vibration control systems. We will conduct a comparative study of the two vibrations. Control system. Various floor-level models with fixed-based structures of 5, 8, 12, and 15 are considered in the study and modal time history analysis is performed using ETABS software. All structures were modelled with seismic isolation devices and fluid viscous dampers, and changes in seismic response were observed. The parameters considered in this study were base shear, lateral roof displacement, and basic duration. It has been observed that base shear decreased largely to an extent of 96%, lateral roof displacement increases to an extent of 45% in base isolated structure whereas base shear decreased to an extent 38%, roof displacements decreased to an extent of 71% in structures with viscous dampers when compared to bare frame structures. [2]

Nefize Shaban and Alp Caner (2018) The focus of this study is a ball rubber bearing separation system compared to different or similar energy dissipation per cycle unit, such as elastomer bearings and lead rubber bearings, through a series of shaking table tests performed at low to moderate seismic levels. Is to identify the performance of. The shaketable test was conducted on a near-life-size short-span bridge. Testing has shown that ball rubber bearings are superior to elastomeric bearings in terms of energy dissipation per cycle and can rival the energy dissipation per cycle of lead rubber bearings. However, although lead rubber bearing and ball rubber bearing have the same energy dissipation per cycle, ball rubber bearing is more beneficial to use under low to moderate earthquakes since ball rubber bearing can transmit less force with larger displacement compared to lead rubber bearing and lead rubber bearing can sometimes stay in elastic range with an ineffective energy dissipation per cycle as a stiffer elastomeric bearing. [3]

Parham Shoaeia et al. (2018) in this paper, a seismic reliability-based approach is proposed to design inelastic steel moment frame structures isolated by lead-rubber bearing (LRB) systems. An equivalent two-degree-of-freedom system is assumed in which a bilinear behavior is assigned to both the superstructure and the base. Furthermore, uncertainties associated with the equivalent superstructure mass, stiffness, and yield properties are taken into account by employing proper probability density functions. The proposed design approach is twofold: 1) Reliability curves that return the key design parameters of the inelastic base-isolated structure including: the period of the superstructure, the target base displacement, and the ductility-dependent strength reduction factor for a given target reliability. 2) Regression equations, which estimate the displacement ductility demand of the inelastic superstructure and the optimal design properties of the lead-rubber bearing system including: the total initial stiffness and the total yield force. These regression equations are calibrated against a large set of optimally-designed base-isolated buildings using Genetic Algorithm. [4]

Md. Mohiuddin Ahmed et al. (2019) the seismic performance of both regular shape and irregular shape building depends on height of the building along with other important structural parameters. Increasing the building height increases base shear and base moment at the base of the building. During earthquake slender building are more vulnerable than any other building. The outputs of this present study will help other engineers and researchers to understand to understand the influence of vertical aspect ratio on building parameters. Base shear increases gradually with increase in building heights. The base shear is obtained lower for 5 storey building and higher for 20 storey buildings. Storey over turning moment increases gradually with increase in building height. Lowest value is obtained in case of 5 storey building where as highest in case of 20 storeys building. [5]

Yutaka Nakamura and Keiichi Okada (2019) this paper reviews building seismic isolation and response control approaches that have become popular in Japan over the last 30 years, making buildings resilient to earthquakes. The manuscript describes three types of laminated rubber bearings and three types of damping devices. The manuscript describes three of the most important response control dampers: steel hysteresis dampers, viscoelastic dampers, and viscous fluid dampers. The effects of isolation and response control methods were verified through shaking table tests, structural health monitoring and earthquake response analyses. [6]

Parham Shoaei and Mojtaba Mahsuli (2019) this paper puts forward a reliable method to seismic design of steel moment frame structures isolated with lead-rubber bearing plans. The system is modeled as an equivalent two-degree-of-freedom system in which the superstructure is assumed to remain elastic, while a bilinear behavior is assigned to the isolation level. Furthermore, the uncertainties associated with the superstructure properties including mass and stiffness are taken into account by adopting appropriate probability density functions. To design the base-isolated structure, the paper proposes “reliability curves” that given target reliability, return the two key design parameters: the natural period of the super-structure and the target base displacement. Given these two key parameters, the paper proposes a regression equation that predicts the optimal design variables of the base isolation system, i.e., the initial stiffness and the yield force. This equation is calibrated against a set of optimally designed base-isolated systems using the genetic algorithm. [7]

Weizhi Xu et al. (2019) this paper aimed to investigate the horizontal and vertical dynamic response of long-span gird structure, the shaking table tests of 1/20 scale long-span grid structures with and without base-isolation considering horizontal two-dimensional (2D) and three-dimensional (3D) seismic excitations were conducted. The test model was designed as ordinary long-span spatial grid structure, but with lead rubber bearings. Data on the acceleration, displacement, strain, and shear force of the base-isolation model and fixed-base model were collected and compared. The dynamic responses of the structure subjected to the horizontal and vertical ground motions with different intensities were studied. The experimental results showed that compared with the fixed-base model, the horizontal period and damping ratio of the base-isolation model can be significantly improved, reducing the horizontal dynamic response of the superstructure, and the horizontal isolation effect was improved with the increase of the seismic excitation intensity. [8]

Kun Ye et al. (2019) this research proposes a direct displacement-based design procedure to ensure that seismic isolated building structures with lead rubber bearings meet the performance goals defined by the displacement threshold. To this end, the direct-displacement based design for regular building structures is incorporated with the two-degree-of-freedom model of base-isolated building structures. This direct-displacement based design procedure is verified by numerical examples, in which the nonlinear time-history analysis of the designed structures yields seismic displacement results matching the preset target thresholds well. The design solutions of the proposed procedure are also compared with those given by an existing one. Numerical results indicate that the proposed direct-displacement based design procedure is reliable, Straightforward, and convenient for the seismic design of base-isolated building structures with Lead rubber bearing. [9]

Qiaoyun Wu et al. (2020) in this paper, the effects of control of a hybrid passive control system with energy consumption between the isolated structure and the adjacent structure, which was proposed recently by other researchers, is studied by shaking table test. Compared with a single seismic isolation system, this hybrid control system combines seismic isolation technique with damper energy dissipation and has strong robustness with application to seismic waves in different frequency domains. By inputting seismic waves in different frequency domains through shaking table tests, the effects of the control systems with different vibration reduction and isolation schemes under different frequency domain ground motions are studied. Finally, the finite element numerical simulations are compared with the test results. Research results show that, compared with ordinary periodic seismic waves, the long-period seismic waves have more obvious effects on structural displacement and acceleration, the overturning effect of high-rise isolated structures and the possibility of displacement over-limit of isolation bearings. [10]

Objectives of investigation:

1. To analyze the models on sloping ground with different angles with response spectrum methods and obtaining the values of lateral displacement for fixed base and isolated base.
2. To determine and compare the values of over-turning moment for fixed base and isolated base

with different base isolation techniques on sloping ground.

3. To determine and compare the values of base shear for fixed base and isolated base with different base isolation techniques on sloping ground.
4. To determine and compare the values of time period for fixed base and isolated base with different base isolation techniques on sloping ground.

5. To determine and compare the values of story drift for fixed base and isolated base with different base isolation techniques on sloping ground.

III. METHODOLOGY

In the current study, buildings are modelled using ETABS software. The analytical models of the building include all components that influence the mass, strength, stiffness and deformability of structure. The building structural system consists of beams, columns, and slab. The non-structural elements that do not significantly influence the building behaviour are not modelled. Modal analysis and Response spectrum analysis are performed on models. It is proposed to study the effectiveness of base isolation technique considering different sloping angles. The beam and column are modelled are two nodded line element with 6 DOF at each node. The slab is modelled using 4 nodded area elements.

In present work, 3D RC G + 12 storied buildings of 3 different sloping angles are taken which has situated in zone V, is taken for the study.

Details of models are shown in Table 3.1.

Table 3.1: Description of Models

Model	Sloping Angle	Sizes in Plan
Model - 1	0^0	20 m X 20 m
Model - 2	25^0	20 m X 20 m
Model - 2	30^0	20 m X 20 m
Model - 3	35^0	20 m X 20 m

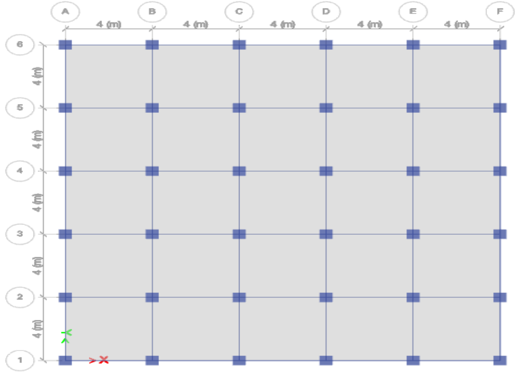

Fig.:-3.1 Plan of the Building in ETABS

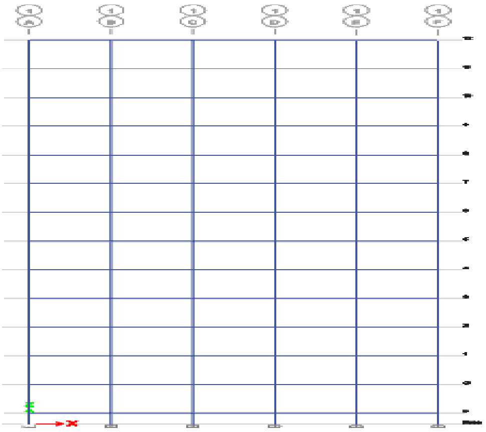

Figure 3.2 Elevation of Building with Sloping Angle 0^0

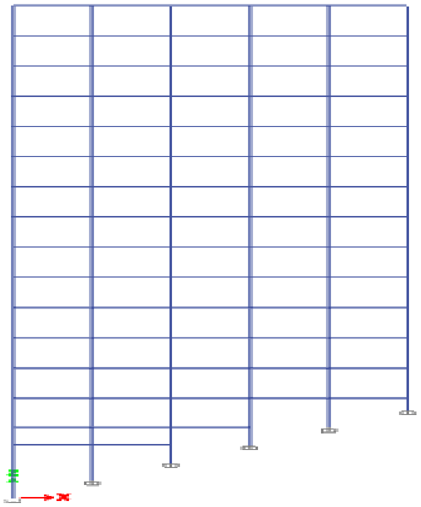

Figure 3.3 Elevation of Building with Sloping Angle 25^0

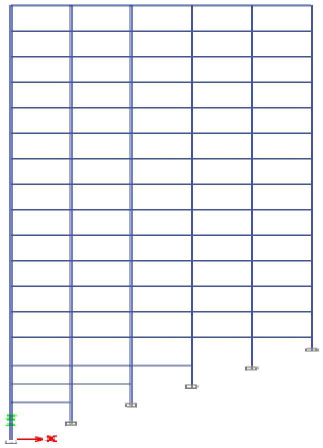

Figure 3.4 Elevation of Building with Sloping Angle 30^0

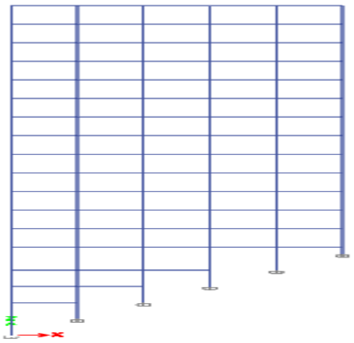

Figure 3.5 Elevation of Building with Sloping Angle 35^0

IV. RESULTS

All four models has been analyzed in ETABS with response spectrum analysis with the use of lead rubber bearing, double pendulum friction bearing and then for Tune mass damper. Various dynamic parameters has been studied like base shear, time period, story drift, displacement, over-turning moment, story stiffness etc. has been compared. The effect of base isolation methods and TMD has been shown with the help of comparative graphs and reduction in all parameters has been explained with these graphs.

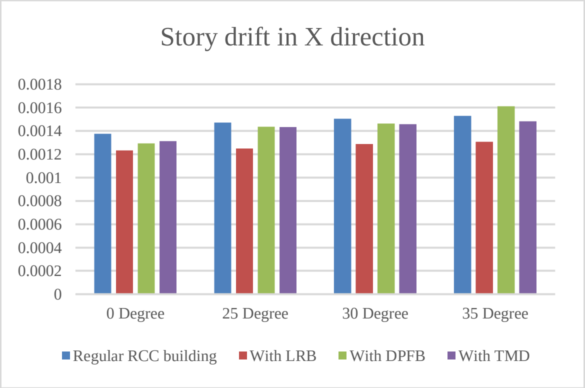

Figure 4.1 Variation of story drift in X direction

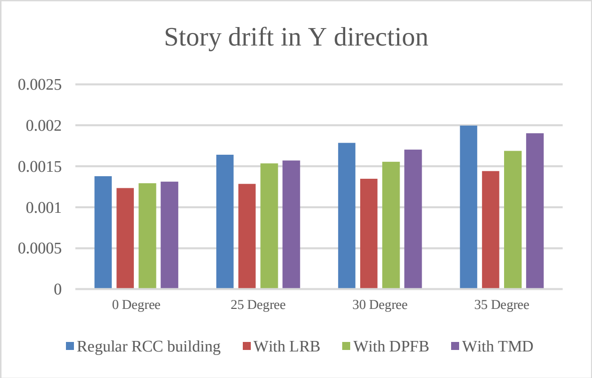

Figure 4.2 Variation of story drift in Y direction

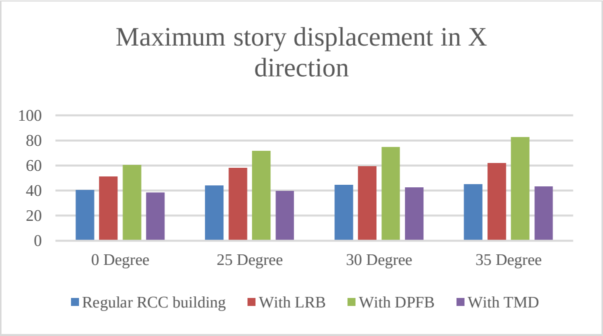

Figure 4.3 Variation of maximum story displacement in X direction

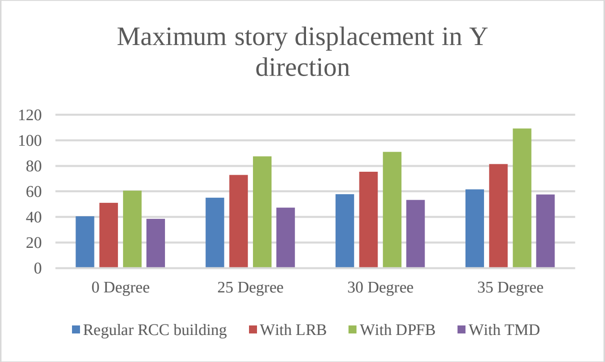

Fig: 4.4 Variation of maximum story displacement in Y direction

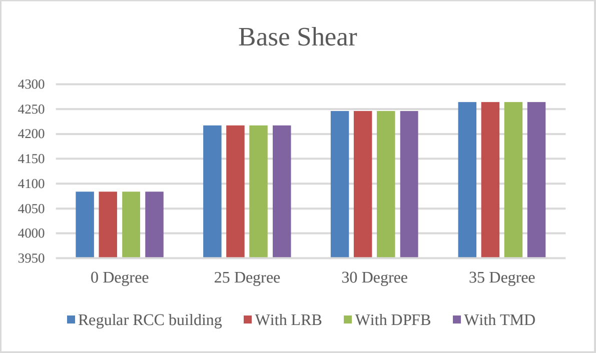

Figure 4.5 Variation of base shear

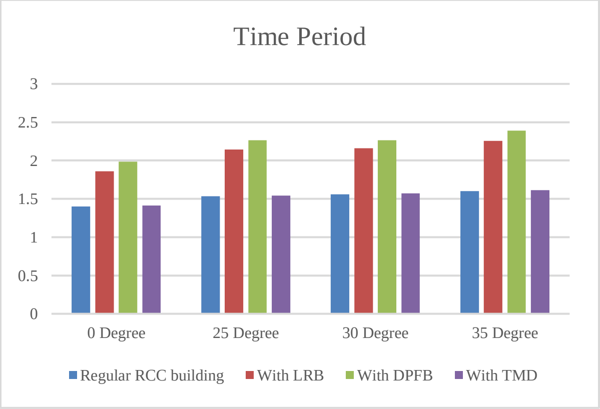

Figure 4.6 Variation of time period

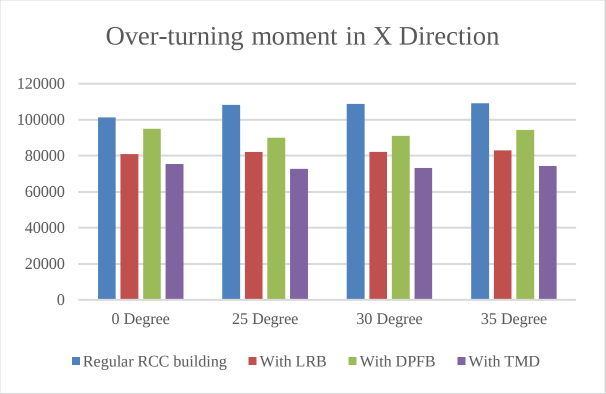

Figure: 4.7 Variation Over-turning moment in X Direction

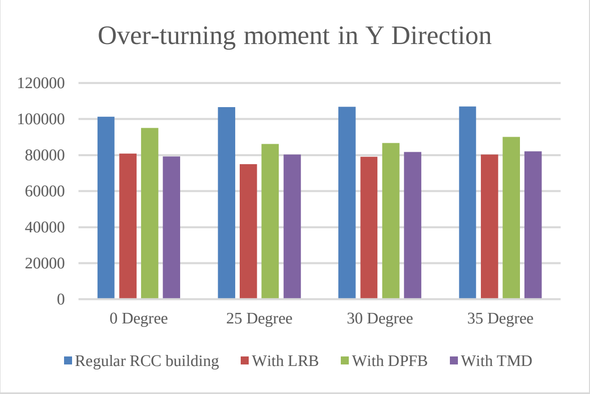

Figure: 4.8 Variation of Over-turning moment in Y Direction

Figure: 4.9 Variation of Storey stiffness

V. CONCLUSIONS

On the basis of the results and discussions obtained in this investigation, the following conclusions have been drawn.

- The base shear of building with DPFB, LRB and TMD are same as there is no increase in seismic weight of the buildings.
- The maximum storey displacement increases with the increase in slope angle with increment of 2-3% for each 5 degree slope angle. The maximum storey displacement of buildings with LRB and DPFB is more as compared to regular RCC building and TMD. For with TMD case displacement is minimum. For LRB case storey displacement is increased by 25-30 % as compared to regular RCC building. For DPFB case storey displacement is increased by 50-55% as compared to regular RCC building. For TMD case storey displacement is almost similar as compared to regular RCC building. We can conclude that for buildings on sloping ground it's better to use for TMD for reducing earthquake effects.
- The maximum storey drift of buildings increases with the increase in slope angle with increment of 2-3% for each 5 degree slope angle. The maximum storey drift of buildings with LRB, DPFB and TMD is less as compared to regular TCC building. For LRB case storey drift is reduced by 10-15% as compared to regular RCC building. For DPFB and TMD case storey drift is reduced by 5-7% as compared to regular RCC building. We can conclude that with the use of LRB and DPFB we can reduce story drift if it's exceeding IS 1893 code limits.
- Time period of normal RCC building is less than as compared to LRB and DPFB. There is 30% increase in time period with the use of LRB and there is around 40% increase in time period with the use of DPFB. With the use of TMD time period is almost in same range. With the increase in time period three is more ductility on the building so it will have slightly better in earthquake unless displacement increases too much beyond code limits. So we can conclude that if we can control displacements in the building for LRB and DPFB case it can reduce the effect of earthquake in RCC buildings considerably. LRB is better as compared to DPFB but LRB is slightly costly as compared to DPFB.
- Over turning moments are increased with the increase in slope values with increment of 1-2%. It decreases with the use of LRB, DPFB and TMD. With LRB over-turning moment is reduced by 20-25%. With the use of DPFB over-turning moment is reduced by 10-15% and with the use of TMD it

is reduced by 30-35%. We can conclude that by using DPFB and LRB we can reduce the effect of over-turning especially in the case of building resting on sloping ground.
- Storey stiffness of the building reduces with the increase in slope angle by 5-6%. With the use LRB, DPFB and TMD is almost similar with slight reduction of 1-2%.
- We can conclude that LRB gives better results as compared to double pendulum friction bearing. TMD is also a good substitute to increase the performance of the building especially in case of building resting on sloping ground.

VI. FUTURE SCOPE

Following are some points for future scope of this study:

- Vertical irregular structures can also be considered with transfer girders.
- High rise building can be considered for analysis.
- Shear walls can be used for analysis.
- Apart from response spectrum analysis time history analysis can also be done.

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