

# **Comparative Study on Fixed base and Base Isolated Buildings on Sloping Ground**

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**ABSTRACT:** Building frames on sloping ground (hilly areas) one of the factors which reduces the capacity of the structure due to the fact that the column in the ground storey are of different heights which leads to combination of short column and long column. Along with this if building has an open ground storey, it is often induced in structures either due to client requirement or improper planning. If this structure is subjected to earthquake which becomes more vulnerable in severe zones. The present comparative study made an attempt to understand the effect of earthquake load on building frames on sloping ground with fixed base and isolated base under severe zone. The computation models of ordinary moment resisting frame was developed in SAP2000 as 3D space frame to carry the dynamic linear seismic analysis as per IS 1893 Part (I) -2002 respectively. The vertical and horizontal stiffness of lead rubber isolator is designed for maximum gravity load and design displacement of the structure and values were assigned for isolated models. This study may help to understand the effect of base isolation under seismic forces, the efficient level and stability of the lead rubber isolator for different storey buildings with base isolation on different sloping ground. Analysis results shows reduction in base shear and story acceleration values for base isolated building. The displacement, story drift and time period of base isolated structure is increased as compared to fixed base structure on different slope. Comparative results shows that the efficient level of base isolation is at the foundation.

**KEYWORDS:** Base isolation, sloping ground, Hilly area, led rubber.

## **1. INTRODUCTION**

The financial development and fast urbanization in uneven district has quickened the land improvement. Because of this, populace thickness in the sloping region has expanded enormously. Along these lines, there is popular and pressing demand for the development of multi-story structures on sloping ground and around the urban areas. A lack of plain ground in also compels the construction activity on sloping ground. Hill buildings are different from those in plains; they are very irregular and unsymmetrical in horizontal and vertical planes, and torsional coupled. Most of the hilly areas come under seismic zones, in such cases building built on sloping grounds are highly vulnerable to earthquake. This is due to the fact that columns in the ground floor differ in their heights according to the slope of the ground. For tall buildings and high towers, wind load may also be taken as critical loading. The knowledge of seismic and wind performances on the sloping ground buildings becomes an essential part in the engineering design works. For resisting the lateral forces acting due to seismic and wind loadings the shear walls or bracings are provided to resist the lateral sway. Hence, they are susceptible to severe damage when affected by earthquake ground motion. Shear wall system are one of the most commonly used lateral load resisting in high rise building. Shear wall has high in plane stiffness and strength which can be used to simultaneously resist large horizontal loads and support gravity loads. For the buildings on sloping ground, the height of columns below plinth level is not same which affects the performance of building during earthquake. Hence to improve the seismic performance of building shear walls play very important role. So the there is need to study the shape and positioning of shear walls on seismic performance of building situated on sloping ground. Buildings constructed in hilly areas have peculiar structural configurations. Successive floors of such buildings step back towards the hill slope and sometimes, the buildings also set back, lateral stiffness of uphill and

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downhill side frames. The Torsional behaviour of these buildings is much more complex than that of buildings on flat ground due to shifting of centre of stiffness and centre of mass with floor level.

### Base isolation:

Base isolation device reduces the stiffness and increases the flexibility in the structure. The basic concept of base isolation technique is “to increase time period and reduce acceleration of fixed base structure” from this, reduction of the seismic effect on structure is seen. Base isolation, otherwise called seismic base disconnection or base detachment framework, is a standout amongst the most famous method for securing a structure against earthquake forces. In the base isolation building, the base isolation device or dampers is introduced between foundation and super structure of the building. Idea behind this technique is to detach the building from ground and providing dampers, by doing so the energy induced by earthquake is not transmitted up through building.

In numerous, yet not all, applications the seismic isolation device is mounted underneath the structure hence it is called as “base isolation”. The base isolation device provided in between the superstructure and foundation of a building should have lower horizontal stiffness and higher damping characteristics. By using base isolation device in building will reduces base shear, acceleration and increases the time period. It avoids seismic damage of the building. Hence base isolator is used in this project to study the effect of base isolator on building on sloping ground as these buildings have higher base shear. Also these buildings are more susceptible to earthquake forces.

### Principle of Base Isolation:

The fundamental focus with seismic isolation is to present horizontally flexible but vertically stiff material (base isolators) at the base of a structure to substantially uncouple the superstructure of the building from high-frequency earthquake shaking. The main concept of base isolation system is increasing the natural period of the fixed base building.

The advantages of adding a base isolation system at the foundation are as follows

- (a) Base isolation Lengthens the period of the structure reduces the spectral acceleration for earthquake shaking.
- (b) By providing the damping to the isolation systems reduce displacements in the seismic isolators.

### Basic requirements of Seismic Isolation Systems:

Following are three requirements of seismic isolation system.

1. Except for very soft soil sites, sufficient horizontal flexibility should provide for all buildings to increase the structural period and spectral demands.
2. For the isolators should provide sufficient energy dissipation capacity or damping to reduce the displacement.
3. Isolated building should not differ from a fixed-base building under service loading for that provides sufficient rigidity.

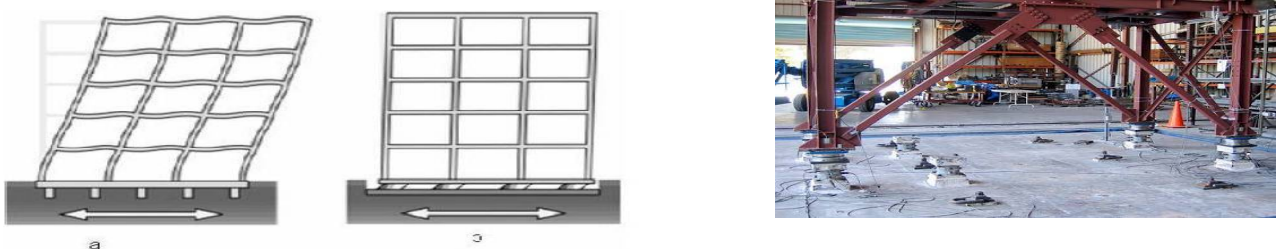


Fig 1.7 Behaviour and implementation of base isolator

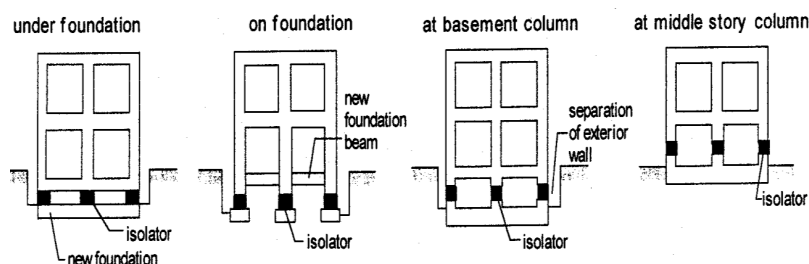


Fig.1.8 Location of base isolator in buildings

**Types of isolation devices:**

The various types of isolation devices are

1. High damping rubber bearing.
2. Friction pendulum bearing
3. Sliding bearing.
4. Lead core rubber isolator.
5. Laminated rubber bearing.



Fig. 1.9 Firemen barracks during the construction

Friction pendulum: This is known as sliding isolator the concept is developed based on the pendulum effect. In this system a articulated slider moves to and fro on a concave surface when a seismic moment occurs uplift of superstructure takes place.

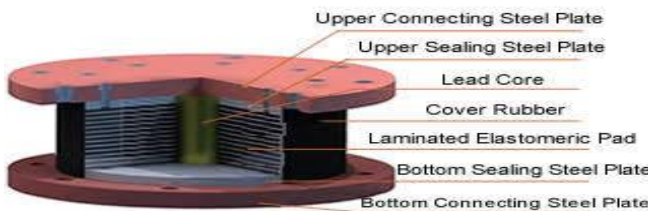


Fig.1.10: Rubber pad base isolator



Fig.1.11: Friction pendulum base isolator

**II. RELATED WORK**

Sikkim, Gangtok city earthquake as one of the most destructive events recorded so far in India in terms of death toll, damage to infrastructure and devastation in the last fifty years. It has been observed that the principal reasons of failure may be accounted to soft stories, majority of the buildings is constructed on the hill slopes with irregular structural configuration having foundations at different levels. Mass irregularities, poor quality of construction material and faulty construction practices etc. Current literature survey includes earthquake response of multi storey building frames on sloping ground. Some of the literatures emphasized on critical location of multistory buildings on sloping ground under severe seismic forces. Authors conducted the parametric and comparative study for the buildings on different ground slope models based on past structural failures by linear and nonlinear analysis to know the performance. The literatures which relates to present study are discussed below

**Singh Y et al.** <sup>[1]</sup>, Studied the seismic behavior of building located on sloping ground by using 9 storey RC building using 2 different building configurations (6 storey below ground level and 3 storey above ground level as shown in fig 2.1). For this study they considered 45° slope, response spectrum analysis and pushover analysis is conducted on buildings located in zone IV. From this study they concluded that the lateral displacement is less in building type 1 as compared to building type 2 and torsion is observed in all stories of building type 1 but in building type 2 torsion is observed only in 3 stories. By nonlinear analysis they claimed that hinges were developed in each building, in type 1

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building hinges were exceeded collapse prevention limit. In both the buildings the hinges were developed in short columns remaining columns are safer.

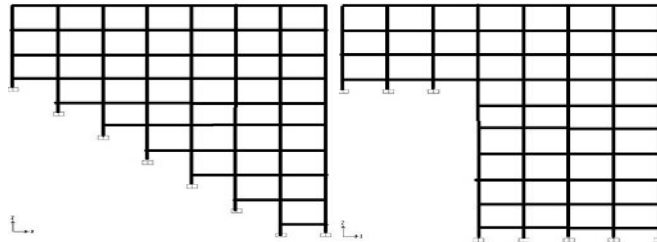


Fig.2.1 Different configuration of building considered for study

**Nagargoje S M et al.** <sup>[2]</sup>, Studied on building constructed on sloping ground by using 3 different configurations,

- Step back (S1)
- Set back –Step back (S2)
- Set back (S3)

Height of building varied from 4 to 15 storeys and response spectrum analysis is conducted in zone III. From this study they concluded that set back building shows more displacement than other buildings (22.85mm) and maximum base shear is observed in set back- step back building (414.84kN) and they even concluded that on sloping ground set back- step back building is most favorable.

**Birajdar B G et al.** <sup>[3]</sup>, Conducted study on building on sloping ground by using building with storey height varying from 4 storey to 11 storey. Response spectrum analysis is conducted by considering zone III. In this study 3 different configuration of building is considered (Step back building, Set back –Step back building, Set back building)

From this study they concluded that,

1. Step back building is more vulnerable for under the action of earthquake forces even torsional behavior is also more in step back building.
2. Set back –Step back building's extreme left column (short column) is worstly affected and base shear is much more than that of right column (long column).
3. Set back – Step back building is most suitable for sloping ground pattern.

**Surveshjain K et al.** <sup>[4]</sup>, Conducted comparative study on base isolated building and fixed base building by using 6 storey building. Time history analysis is conducted by using darmashala, uttarakashi and koyna earthquake spectrum.

From this study they concluded that base shear for base isolated building is reduced to 0.28 times of maximum base shear in fixed base building. they even concluded that the max storey drift and roof acceleration is also reduced to base isolated building as compared to fixed base building as shown in table 2.1.

**Sabha K et al.** <sup>[5]</sup>,

Studied the behavior of base isolated building under the action seismic force by using 6 storey building in zone IV. They used time history analysis by using Elcentro spectrum of magnitude 7. From this study they concluded that reduction in displacement in base isolated building is 8.91% with increase in storey height and reduction in acceleration at top floor is 53.41% with a damping of 20% for lead rubber bearing.

They compared result with fixed base building and concluded that storey drift is less for base isolated building as compared to normal fixed base building and they even concluded that base shear is also less for base isolated building, base shear reduction for base isolated building is observed up to 50.75% as compared to base isolated building .

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Table 2.1: Comparison between base isolated building and fixed base building

Earthquake	Base Shear (KN) Roof Acceleration		(m/s/s)		Max. Storey Drift(%)	
	Fixed building	Base isolated	Fixed building	Base isolated	Fixed building	Base isolated
NE India (Berlongfer Stn.)	8758	4366	3.94	3.11	0.46	0.33
Dharamshala	4604	2631	2.07	2.35	0.24	0.20
Koyna	15085	4311	6.81	2.38	0.78	0.28
NE India (Silchar Stn.)	3358	3325	1.51	1.47	0.17	0.24
Uttarkashi	8546	3931	3.86	2.21	0.44	0.29

**Shirule .P.A et al.** <sup>[6]</sup>, studied the effect of base isolator on 18 storeys fixed base RCC building model by using time history method in zone IV with Lead rubber bearing (LRB) and friction base bearing. Objective of this study was to compare performances of fixed building at base (without isolator) with building with isolator (LRB and FB). Another objective was comparative study of performance of building with different past time history like BHUJ, KOYANA and LACC T.H. Finally base shear, acceleration and displacements were compared for all building models. Results shows base shear was reduced by 46% for building with lead rubber bearing and 35% for friction base bearing. Displacement was increased for isolated building. It shows the reduction of base shear for both in X-direction and Y- direction was more in KOYANA time history than BHUJ and LACC

**H P Santhosh et al.** <sup>[7]</sup>, Conducted comparative study on low rise and medium rise base isolated and fixed base building. a 6 storey building model is prepared analyzed by using response spectrum method, considering zone III in soil type II (medium). From this study they concluded that base shear reduces for base isolation building as compare to the fixed base. Also time period increases for base isolation building up to 3.3 sec as compare to the fixed base building that is 1.4 sec. Acceleration is about 1.7 m/sec<sup>2</sup> for base isolated and 2.7 m/sec<sup>2</sup> for fixed base building. Storey shear for fixed base building is 1800 kN and for base isolated building 800 kN. Acceleration and storey shear were reduced for base isolated building.

**S. M. Dhawade et al.** <sup>[8]</sup>, studied the behavior of base isolated building and compared results with fixed base building. A G+14 storey building is analyzed by using ETABS software. Static equivalent method is used according to UBC 97 and design is done according to IS1893-2002 (part-1). High damping rubber bearing (HDRB) is used as isolator. Top storey displacement for base isolated building is found to be 0.0020 and 0.000 in X and Y direction respectively and for fixed base building the top storey displacement is about 0.2782 and 0.1133 in X and Y direction respectively. For base isolated building storey drift also less.

**Bakre S.V et al.** <sup>[9]</sup>, Conducted study on elastomeric base isolation building of four storey by considering different time history data (El centro, Kobe, Northridge earthquakes). All design parameters were taken according UBC97. Results were compared with fixed base building. From this study they concluded that base shear of base isolated building was 39% of fixed base building in case of El Centro, 55% for Kobe and 25% for Northridge Earthquakes. The roof drift ratio was reduced 56% in case of El-Centro, 63% for Kobe and 90% in case of Northridge Earthquake.

**Dr. Rajesh Prasanna P et al.** <sup>[10]</sup>, Study is conducted on base isolated four storied MRF (moment resisting frame) with elastomeric seismic isolation bearing by using SAP2000 software. Dynamic analysis was carried out for the moment resisting frame with base isolation building and the results were compared with, fixed base building. Building was located in zone V and the frame taken for study was moment resisting fame with shear wall. This study concludes that the displacement for fixed base building is 0.06 m and 0.0031 m for fixed base building. And reduction in base shear was observed up to 88.38% for base isolated building as compare to fixed base building.

### III. OBJECTIVES AND SCOPE OF PRESENT STUDY

- To study the behaviour of structure on sloping ground with base isolation as compare to conventional fixed base under seismic forces.
- To study the behaviour of base isolation at different level of structure like above and below the end of column.
- To suggest the efficient base isolation level for the structure on sloping ground.

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- To study the variation of base reaction and know the stability base isolated building resting on sloping ground.

The dynamic linear analysis carried out to study behaviour of structure on sloping ground with base isolation, also the efficient level of base isolation suggested from and same analysis were carried out to study the stability of lead rubber isolation for different storey buildings on sloping ground.

## IV. STRUCTURAL MODELLING AND METHODOLOGY

A six, eight and ten storey building, with ordinary moment resisting frames on sloping ground in two orthogonal directions, was selected for the study. The building had a one brick thick exterior infill wall along the periphery and model details are shown in Table 3.1. It was considered to be located in severe zone on type II soil as per IS 1893: 2002. Base isolation is one of the earthquake resistant methods. The buildings are modelled in SAP 2000 software for both with and without isolators. The plan, load and building details are given below. Step by step design procedures are carried out of base isolators. The dimensions of isolators are depending on the axial load and lateral load coming on individual column. Seismic design procedure has been using IS 1893:2002 (Part-II) the following methodology is used to achieve the defined objectives.

- A six, eight and ten storey building will be designed for gravity loadings only, the designed beam and column details such as sizes and reinforcement details will be assigned for seismic analysis.
- The dynamic linear analysis will be carried out for the first series models to study the effect of seismic on building frame resting on sloping ground with fixed base.
- From the analysis results the horizontal and vertical stiffness of lead rubber base isolator is designed for the maximum column forces obtained by load combination.
- Same analysis will be carried out for the second series models to know the performance of building frame with designed base isolator.
- The level of base isolator will be assigned at the foundation, above the foundation and in between the column for second models to suggest the efficient level of base isolator based on obtained results.
- Same analysis carried out for third series analysis to know the stability of lead rubber isolator for different storey buildings on sloping ground.

The building structural system consists of beam, column, and slab. Beam, column and slab modelled as frame element, membrane shell element respectively. Foundation for the columns was assumed as isolated footing and it is assigned as fixed support. First, a regular reference building on sloping ground with fixed base ( $\Theta=25^\circ, 30^\circ, 35^\circ$ ) was modelled. Next, two series of models were modelled with isolated base. The masonry wall load and parapet wall load assigned as uniformly distributed load on beam. Floor loads were assigned as a two way frame load on slabs. SAP 2000 software is one of the best software used to analyse the building and bridges. By assigning the material properties and the elements of appropriate sizes the 3D model of building with and without base isolators are modelled and analysed. The 3D six, eight and ten storey models developed in SAP software as shown in following figures.

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Table 3.1: Model and loading details

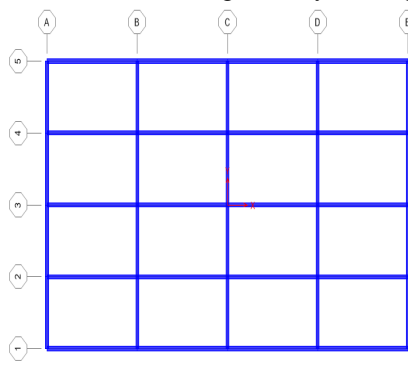
Bays along Y		4 at each 4m
Bays along X ( $\Theta=25^\circ$ )		4 at each 6.8624m
Bays along X ( $\Theta=30^\circ$ )		4 at each 5.5426m
Bays along X ( $\Theta=35^\circ$ )		4 at each 4.5701m
Storey height		3.3 m
Plinth height from foundation		2.0 m
Slab		150 mm
Beams		230 mm×375 mm
Columns		375 mm×375mm
Exterior infill wall		230 mm
Partition Wall		115 mm
Parapet height		750 mm
Unit weight of concrete		25 kN/m <sup>3</sup>
Unit weight of brick infill		20 kN/m <sup>3</sup>
Storeys	Live load	4 kN/m <sup>2</sup>
	Finish	0.75 kN/m <sup>2</sup>
Roof	Live load (with access)	2 kN/m <sup>2</sup>
	Finish	1.5kN/m <sup>2</sup>

**Building Models:**

**Series I: Buildings on sloping ground with fixed and isolated base:**

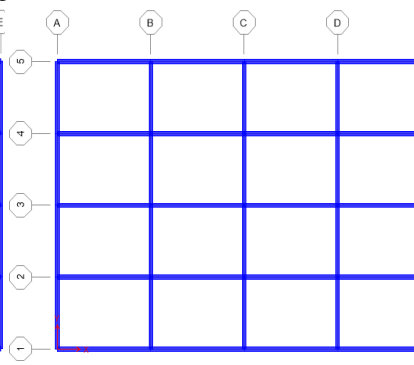
Fig.3.1. shows the plan and elevation of conventional building 3D frame model with fixed base on ground slope ( $25^\circ$ ,  $30^\circ$ ,  $35^\circ$ ) which has 4 bays at 4m each on Y axis.

(a) Plan of building 4 bays along X=6.8624m

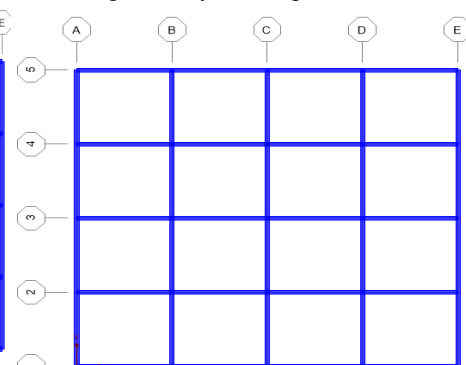


(a) Plan of building 4 bays along X=6.8624m

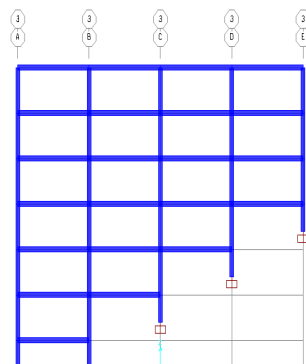
(b) Plan of building 4 bays along X=5.5426m



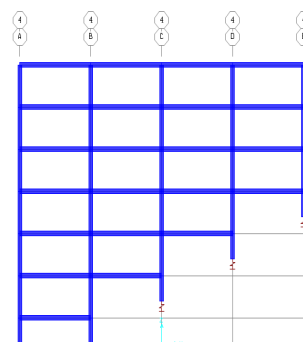
(b) Plan of building 4 bays along X=5.5426m



(c) Plan of building 4 bays along X=4.5701m



(d) Front view of fixed basemodel



(e) Front view of base isolated model

Fig.3.1: Plans and front view of models resting on different ground slope with fixed and isolated base

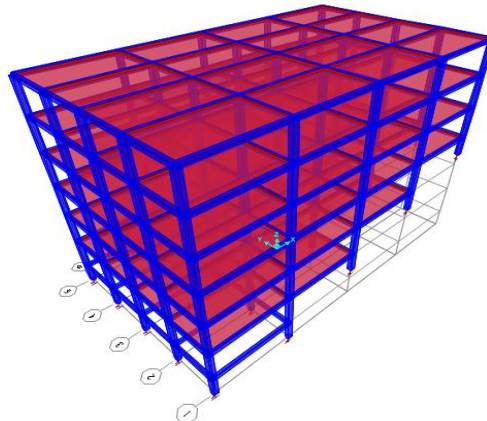


Fig.3.2:3D view of frame resting on sloping ground

**Series II: Buildings on sloping ground with isolated base at different level:**

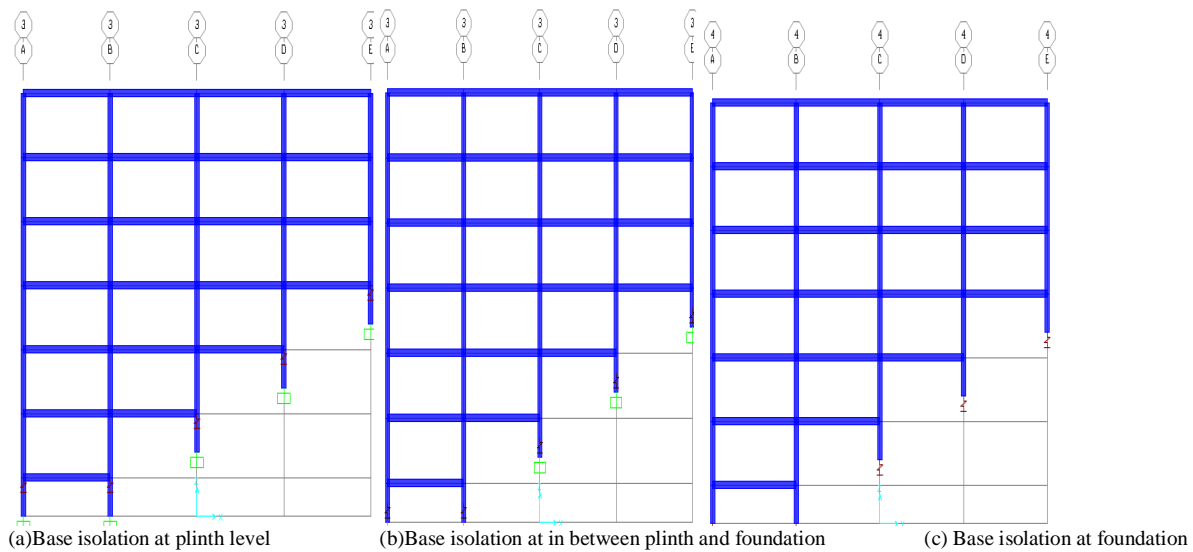


Fig.3.3. shows the elevation of building 3D frame model with isolated base at plinth, in between plinth and foundation, and foundation level on sloping ground (25°, 30°, 35°)



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### Series III: Different storey Buildings on sloping ground with isolated base:

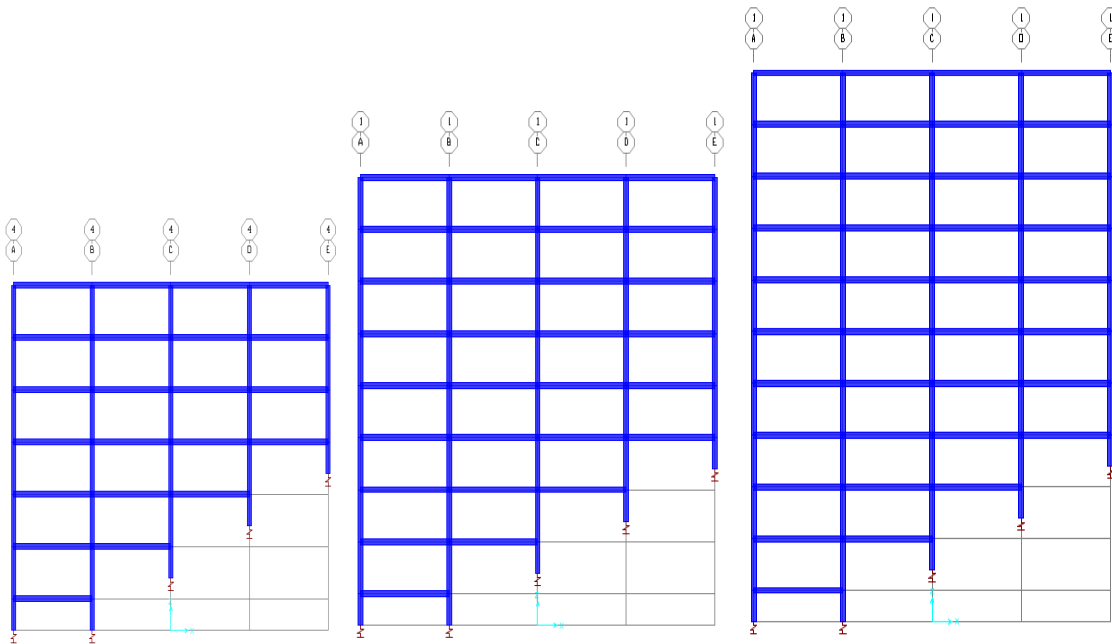


Fig.3.4: Six, eight and ten storey buildings with base isolation

### Design of Base Isolators:

Table 4.1 shows the vertical reaction of the columns for combined gravity loads, the maximum force was considered for the design of selected lead rubber base isolator. This base isolator provides low lateral stiffness (achieves enough flexibility in structure to resist lateral loads) and high vertical stiffness (To withstand high concentrated vertical loads).

Table 4.1: Six, eight and ten storey building vertical reaction

Ground Slope 25 Degree			Ground Slope 30 Degree			Ground Slope 35 Degree		
Five	Eight	Ten	Five	Eight	Ten	Five	Eight	Ten
DL+LL	DL+LL	DL+LL	DL+LL	DL+LL	DL+LL	DL+LL	DL+LL	DL+LL
965.7	1301.8	1635.4	837.9	1133.7	1427.8	745.9	1013.3	1279.6
1329.2	1760.3	2184.4	1169.8	1551.7	1928.7	1054.6	1401.6	1745.0
1345.2	1794.6	2239.5	1183.3	1581.6	1977.0	1066.2	1428.2	1788.2
1329.2	1760.3	2184.4	1169.8	1551.7	1928.7	1054.6	1401.6	1745.0
965.7	1301.8	1635.4	837.9	1133.7	1427.8	745.9	1013.3	1279.6
1520.9	2041.6	2552.8	1257.8	1682.0	2094.4	1060.7	1412.4	1751.3
2007.6	2648.4	3271.2	1673.5	2198.8	2705.9	1423.3	1862.1	2283.3
<b>2032.5</b>	<b>2697.4</b>	<b>3347.8</b>	<b>1692.8</b>	<b>2238.1</b>	<b>2767.6</b>	<b>1438.5</b>	<b>1894.0</b>	<b>2333.8</b>
2007.6	2648.4	3271.2	1673.5	2198.8	2705.9	1423.3	1862.1	2283.3
1520.9	2041.6	2552.8	1257.8	1682.0	2094.4	1060.7	1412.4	1751.3
1323.5	1851.8	2376.0	1103.0	1542.0	1975.4	941.0	1313.9	1679.3
1067.9	1589.6	2105.0	889.7	1321.2	1743.8	758.4	1123.1	1476.9

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541.6	859.0	1173.1	465.2	740.8	1014.2	409.4	655.0	899.3
1801.8	2462.8	3110.4	1511.6	2063.7	2603.1	1298.5	1769.9	2228.2
1472.1	2136.5	2783.7	1234.9	1787.6	2322.8	1060.2	1530.2	1982.6
792.6	1228.6	1655.7	690.1	1073.8	1450.8	615.5	961.6	1303.0
1817.6	2500.5	3174.8	1523.7	2094.1	2655.5	1307.9	1794.9	2271.7
1480.0	2162.3	2833.1	1240.4	1807.9	2362.3	1063.9	1546.5	2014.8
792.6	1238.1	1678.9	689.5	1081.5	1470.5	614.4	968.1	1320.3
1801.8	2462.8	3110.4	1511.6	2063.7	2603.1	1298.5	1769.9	2228.2
1472.1	2136.5	2783.7	1234.9	1787.6	2322.8	1060.2	1530.2	1982.6
792.6	1228.6	1655.7	690.1	1073.8	1450.8	615.5	961.6	1303.0
1323.5	1851.8	2376.0	1103.0	1542.0	1975.4	941.0	1313.9	1679.3
1067.9	1589.6	2105.0	889.7	1321.2	1743.8	758.4	1123.1	1476.9
541.6	859.0	1173.1	465.2	740.8	1014.2	409.4	655.0	899.3

## V. RESULT AND DISCUSSION

After analysing building models, the base shear, storey displacement, acceleration, time period and storey drift have been studied for fixed base building, building with lead rubber bearing (Series I) resting on different ground slope. Here, base isolation devices are provided below the foundation. Lead rubber bearing provided in between the column for (G+6) storey (Series II) and different storey buildings on different slope (Series III). The results have been studied in 3 cases,

Case 1 consists of comparison of the results of series I models between fixed base and isolated base

Case 2 consists of comparison of the results of series II models between base isolation at different level.

Case 3 comparison of the results of series III models between different storey buildings resting on different slope.

### Horizontal displacement:

The lateral displacement of the structure is known as horizontal displacement which is associated with 1<sup>st</sup> mode shape of structure. When horizontal displacement exceeds its limit (H/250) the structure undergoes with huge moment and shear force. Increased displacement of building increases the time period and acceleration of the structure which intern increases base shear and velocity of building components and causes damage of them. From Fig.5.1 it is clear that displacement of base isolated building is more than the fixed base building. As base isolation increases the displacement and decreases the seismic energy to restore in building component, and also shows that base isolation even increases displacement at base level and plinth level. Roof displacement in fixed base buildings displacement increases by 13% to 15% at top storey as ground slope increases by 20% this is obviously due additional support offered by the ground slope at the extreme end of the building and reduction in building height, and there is no significant changes at lower storeys. The displacement in base isolated buildings resting on 25, 30 and 35 degree ground slope were 2.02, 2.32 and 2.61 times more respectively as compared to fixed base buildings. There is no accountable effect on displacement as ground slope increases in base isolated buildings. Lesser stiffens value and higher damping coefficient of bearing, will increases the displacement of the building.

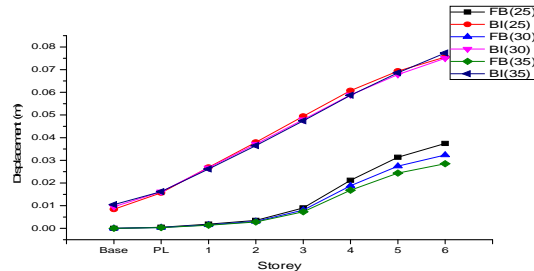


Fig.5.1: Variation of Displacement for fixed base and base isolated buildings resting on different ground slope

### Storey drift:

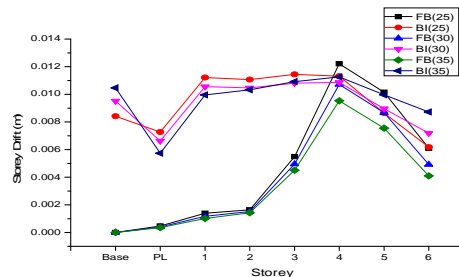


Fig.5.2: Variation of Displacement for fixed base and base isolated on different ground slope buildings

Storey drift or drift is defined as difference in lateral displacement of adjacent upper storey according to IS1893-2002(part-1) the prescribed limiting drift is 0.004 times the storey height. When drift increases in any of the storey it increases distress in those building components causing excessive cracking, loss of stiffness and consequent failure by soft storey. From Fig.5.2 shows that drift of the base isolated building is more than fixed base building as displacement of building is more. From graph it is seen that drift of base isolated buildings is decreased as slope of ground decreased at upper stories, more drift is observed at 4<sup>th</sup> storey level for 6<sup>th</sup> storey fixed buildings. Maximum drift is observed on 25 degree slope and minimum on 35 degree. Limiting storey drift value is  $(0.004 \times h)$  i.e. 13.2mm, all model are within the limiting value.

### Base shear:

Fig.5.3 shows that base shear versus different slope, it is observed that base shear of fixed base building is more than base isolated building. Base isolation increases the flexibility of the building and hence less seismic energy is transmitted to the base of the building which results in decreased base shear. As slope increases from 25 degree to 35 degree, averagely 55% decrease in base shear is observed this is obviously due to higher time period lower the frequency hence low frequency attracts lesser seismic force for base isolated buildings resting on sloping ground. Thus there is no requirement of providing shear wall, bracing and ductile detailing for beam column joint.

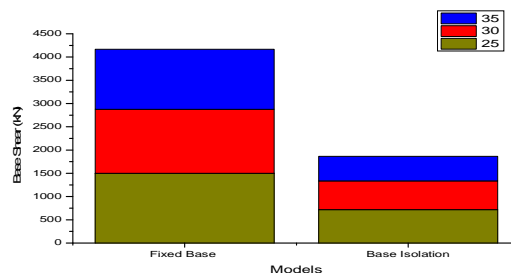


Fig.5.3: Variation of base shear for fixed base and isolated base for different slopes

### Time period:

Time period of structure is defined as time taken to complete one oscillation usually time period is more for 1<sup>st</sup> mode shape which is known as fundamental period. Increased time period reduces response of earthquake and at the same

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time it reduces base shear. Based on time period building is classified as rigid (time period  $<0.3$  sec), semi-rigid (time period  $>0.3 < 1$  sec) and flexible (time period  $> 1$  sec). From time period versus different degree of slope it is seen that time period for base isolated building 2.65 times more than fixed base building. This is due to the presence of low stiff base isolator which increases the displacement of building, hence more time period and less seismic energy in building components. As slope angle increases the time period decreases this is due to the presence of short column which makes building stiffer.

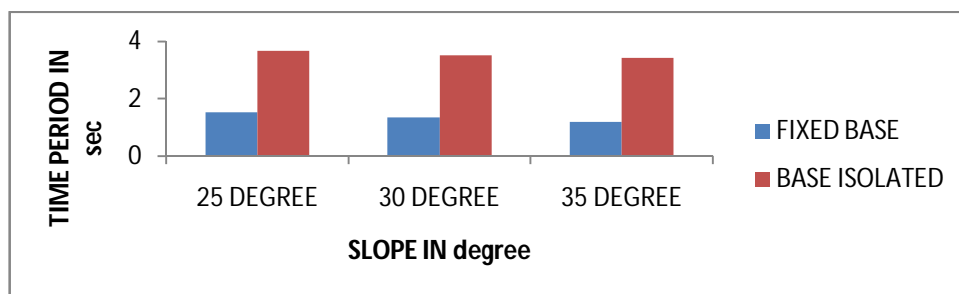


Fig.5.4: Variation of time period for fixed base and isolated base for different slopes

### Storey acceleration:

The Fig.5.5 shows the storey acceleration for buildings with and without base isolators the storey acceleration of the building with respect to different floors. The storey acceleration in base isolated buildings on different ground slope affects at lower stories and it is nearly constant from 3<sup>rd</sup> to 6<sup>th</sup> storey and shows reversal behaviour in fixed base buildings. By using base isolation devices in building time period will increase. As the time period of building increases acceleration gets reduced.

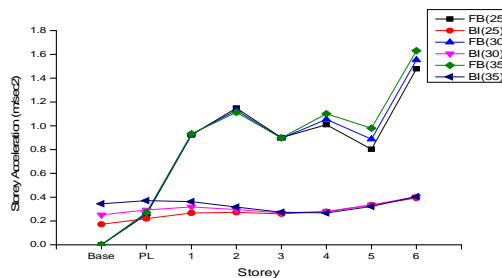


Fig.5.5: Variation of time period for fixed base and isolated base for different slopes

### Response of the base isolation in buildings at different level for different ground slope: Displacement

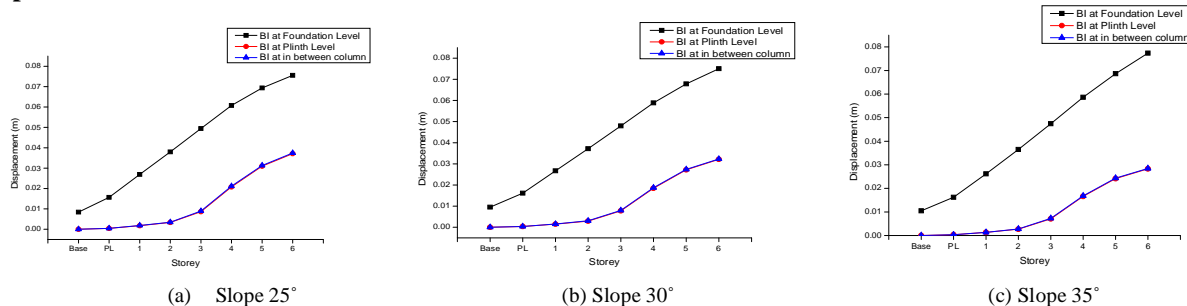


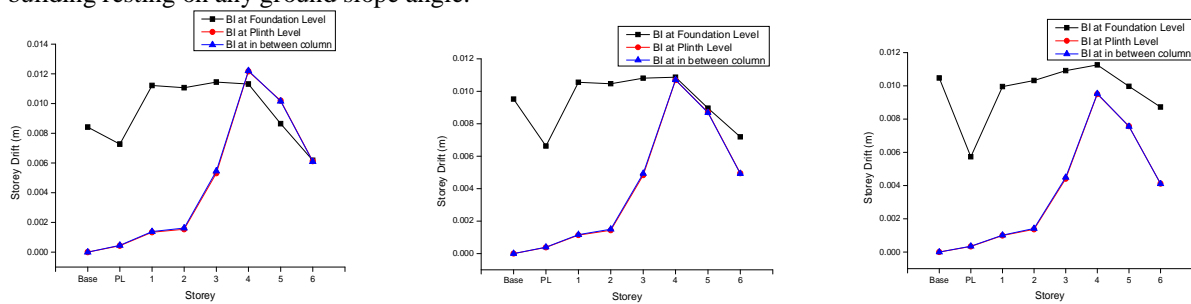
Fig.5.6 (a, b, and c): Variation of displacement isolated base at different levels in building resting on different slopes

It can be stated that from Fig.5.6 the displacement is 2.02, 2.32 and 2.7 times more when base isolation device is placed at foundation level compared to at plinth level and in between column to the buildings resting on any ground slope. There is no variation in displacement at each floor of buildings with base isolation at plinth and in between column,

from results it can be concluded that base isolation other than foundation level acts as a fixed base buildings, hence it is advisable to device the base isolation at foundation or below the foundation only.

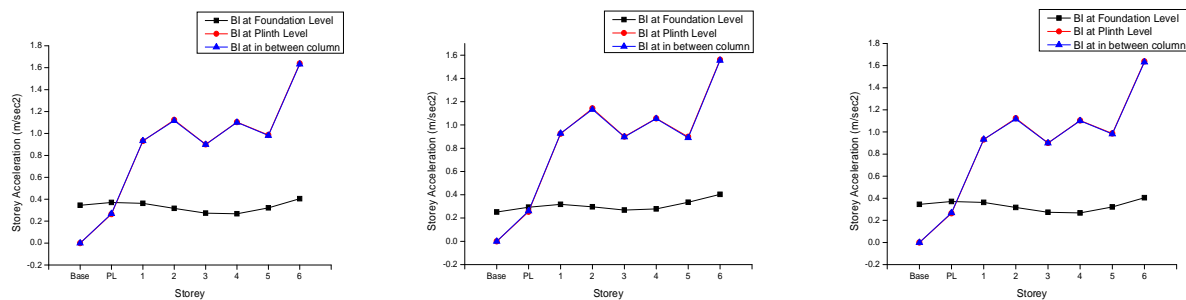
### Storey drift and acceleration:

Fig.5.7 shows that the storey drift as discussed earlier, here the isolated base at foundation level is more and constant for some stories but in other level of base isolation at every storey the drift is varying and more drift is seen at 4<sup>th</sup> floor in building resting on any ground slope angle.



(a) Slope 25° (b) Slope 30° (c) Slope 35°  
Fig.5.7 (a, b, and c): Variation of storey drift isolated base at different levels in building resting on different slopes

Fig.5.8 shows that the storey acceleration as discussed earlier, as time period decreases storey acceleration decreases. Base isolation at foundation level showing a constant acceleration at all floors, other level of base isolation behaving same and shows an increased storey acceleration and variation at each floor of building resting on any ground slope.



(a) Slope 25° (b) Slope 30° (c) Slope 35°  
Fig.5.8 (a, b, and c): Variation of storey acceleration isolated base at different levels in building resting on different slopes

### Base shear:

Fig.5.9 shows that variation of base shear with respect to different ground slope and base isolation at different level. The base shear is 50% less in models assigned with isolated base at foundation as compared to other level of isolated base and its acting same as fixed base even though base isolation provided at different location. The plot 5.9 shows that base shear of building on 35° is 60% is lesser than other levels of base isolation on same ground slope.

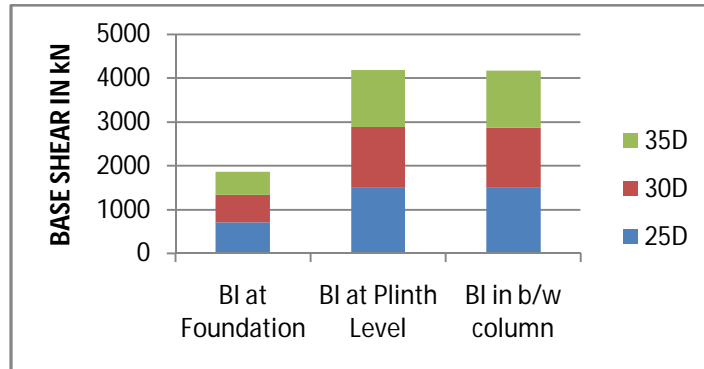
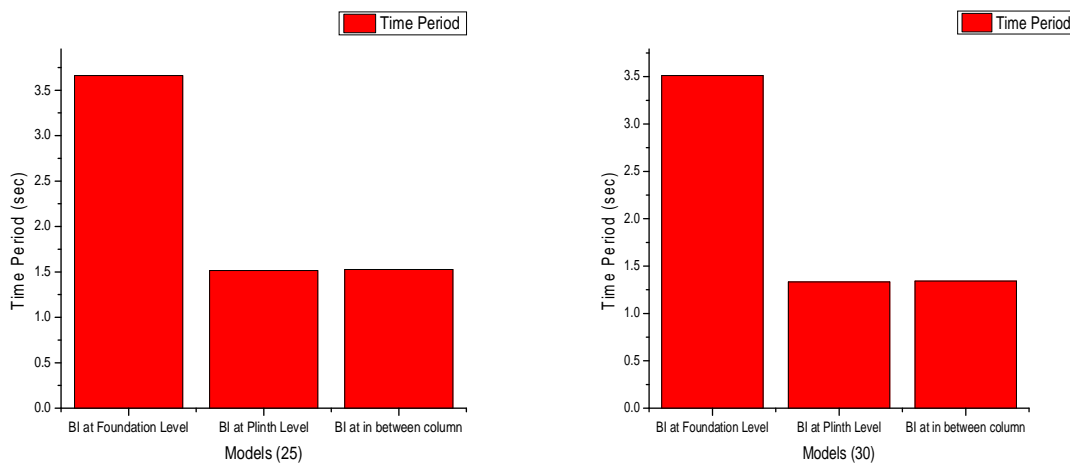


Fig.5.9: Variation of base shear isolated base at different levels in building resting on different slopes

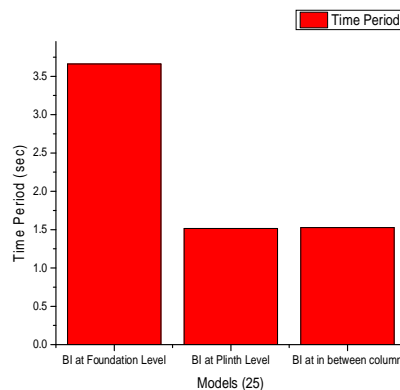
**Time period:**



(a)

(b)

Time period is a function of stiffness and mass, devising the base isolation at the foundation level results in flexibility of the structure due to increased displacement. Base isolation at plinth and in between column stiffens at the base and displacement is also less, therefore time period is almost 2.2 to 2.4 times more in isolated base at foundation compared to others as per Fig.5.10.



(c)

Fig.5.10: Variation of time period in structure with position of base isolator

**Axial force:**

The exterior ground storey column for earthquake force in line of sloping ground is considered for the comparison purpose from graph of axial force versus position of base isolator clears that axial force 13.64% to 26.22% is less when base isolator is provided at foundation in all other cases the axial force variation is nearly equal due to the constant spectral acceleration for the lesser time period.

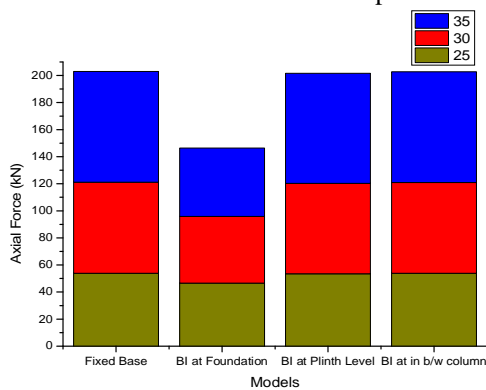


Fig.5.11: Variation of axial force in column with Position of base isolator

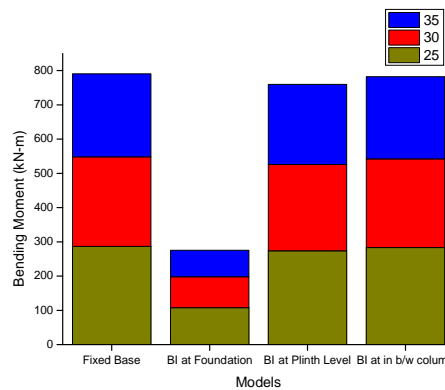


Fig.5.12: Variation of bending moment in column with position of base isolator

From Fig.5.12 of moment versus position of base isolator it can be seen that moment in column 60 to 70% is less when base isolator is provided at the base of foundation in all other cases the moment is nearly equal to fixed base buildings resting on different slope. The reduction in bending moment directly implies that saving area of steel in reinforced concrete design.

**Base reaction of different storey buildings with base isolation for different ground slope:**

**Base Shear:**

The following base reaction of buildings were discussed for the earthquake force in the direction of line of ground slope Fig.5.13 shows base shear versus number of storey it is seen that as number of storey increases from 6 to 8 storey base shear for base isolated building is increased at the same time fixed base building shows decreased base reaction. It is due to mass of building, as mass of building is increases the base shear decreases in base isolated building due to base of the building attracts less energy in building components. But fixed base building with increase is storey number acts as a flexible building and due to this a part of energy is absorbed by building component hence less base reaction is observed. From Fig.5.13 it can be concluded that as slope of ground increases the base reaction is also increase this is of long column effect.

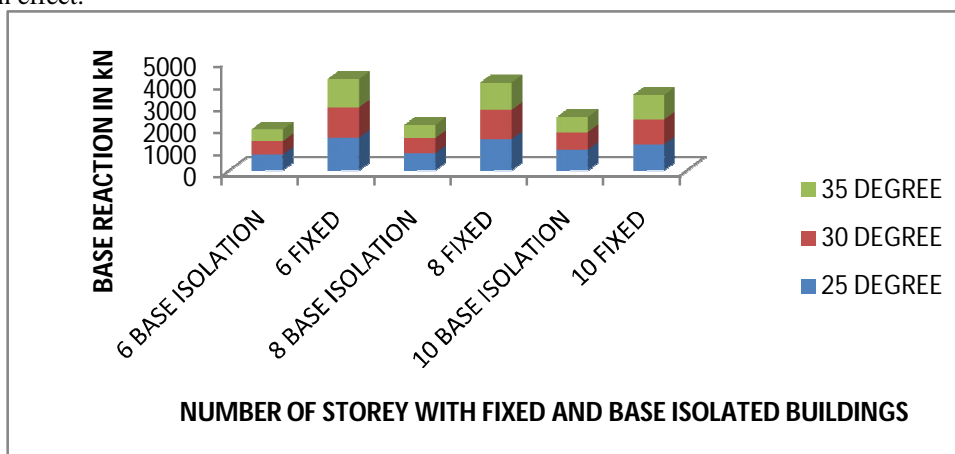


Fig.5.13 Variation of base shear with number of stories

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### Vertical force:

Fig.5.14 shows the vertical force versus number of storey in different slopes it can be concluded that vertical force for base isolated structure is more as compared to fixed base building. This is due to whenever earthquake strikes the base isolated building shifts its mass in horizontal and vertical direction. As storey height increases the vertical base reaction also increases. From the same graph it is clear that as slope of ground increases the vertical reaction also increases. Punching shear will occur in case of 10 storey because of larger diameter of bearing.

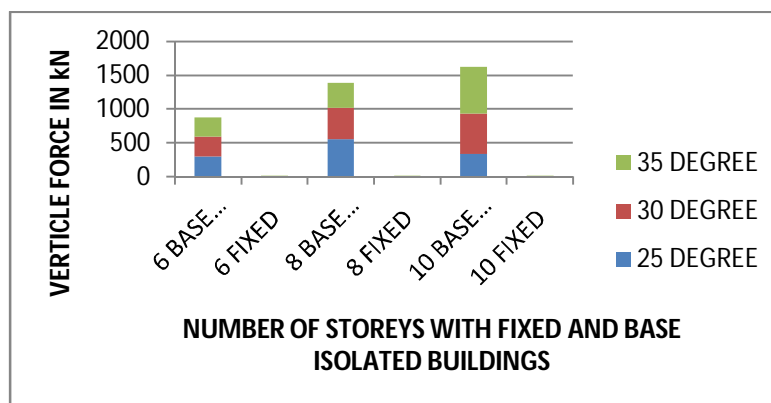


Fig.5.14 Variation of Vertical reaction with number of stories

### Moment/ Overturning Moment:

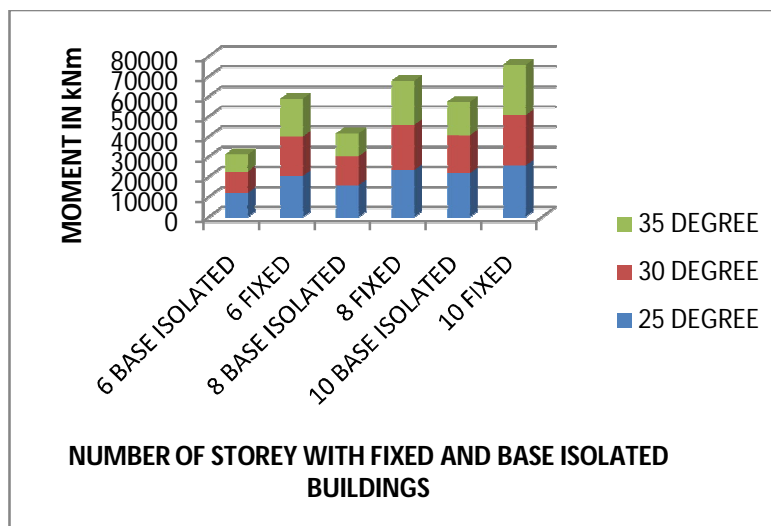


Fig.5.15 Variation of base moment with number of storey

Fig.5.15 of moment versus number of storey it can be concluded that moment for base isolated building is less than fixed base building it is result of detaching building at base due to isolation building offers less resistance to the earthquake forces hence less force is transferred to the superstructure hence less bending moment in superstructure is observed. From the graph it is clear that as sloping angle and number of storey increases moment are also increases for both fixed base and base isolated building. As a result of increased mass, if height increases, overturning of building will found.



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## VI. CONCLUSION

- By providing led rubber base isolation the displacement in base isolated buildings resting on 25, 30 and 35 degree ground slope were increases 2.02, 2.32 and 2.61 times more respectively as compared to fixed base buildings.
- Base isolation devices increases storey drift due to increase in storey displacement, also it can be concluded that as ground slope increases storey drift decreases.
- Decreases the base shear averagely by 55% as ground slope increases from 25° to 35°, Thus there is no requirement of providing shear wall, bracing and ductile detailing for beam column joint.
- Time period increases 2.65 times in isolated base structure compared to fixed base structures on sloping ground and also increases storey acceleration.
- By providing base isolation device at different level in the building on sloping ground from results it can be concluded that base isolation at foundation level gives more efficient results as compared to other position.
- Base isolation at plinth level and at in between column behaves same and compared to fix base building, there is no significant changes in result.
- Provision of base isolation decreases the internal forces like axial force and bending moment in column, hence economic design can be achieved.
- When compare the design LRB isolator and base reactions for 6, 8 and 10 storey, it conclude that the base isolation device (LRB) is suitable for low to medium rise buildings.

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