# ANALYSIS OF SET BACK STEP-BACK BUILDING RESTING ON SLOPING GROUND

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***Abstract*— The buildings situated on hill slopes in earthquake prone areas are generally irregular, torsionally coupled & hence, susceptible to serve damage when affected by earthquake ground motion. Such buildings have mass & stiffness varying along the vertical & horizontal planes, resulting the center of mass & center of rigidity do not coincide on various floors, hence they demand torsional analysis, in addition to lateral forces under the action of earthquakes. These unsymmetrical buildings require great attention in the analysis & design. Analysis of hill buildings is somewhat different than the buildings on leveled ground, since the column of hill building rests at different levels on the slope. The shorter column attracts more forces & undergoes damage, when subjected to earthquakes. The various floors of such building steps back towards the hill slope and at the same time buildings may have setbacks also. Buildings situated in hilly areas are much more vulnerable to seismic environment. In this study, 3D analytical model of 10,15 & 20 storied buildings have been generated for symmetric and asymmetric building Models and analyzed using structural analysis tool 'STADD-PRO" to study the effect of varying height of columns in ground stored due to sloping ground and the effect of shear wall at different positions during earthquake***

***KEYWORDS* - Seismic, Building, Sloping ,Ground, Set back, step back, short column, Long column, Time history method and response spectrum method.**

## I. INTRODUCTION

Earthquakes themselves do not kill people, rather the colossal loss of human lives and properties occur due to the destruction of structures. Building structures collapse during severe earthquakes, and cause direct loss of human lives. Numerous research works have been directed worldwide in last few decades to investigate the cause of failure of different types of buildings under severe seismic excitations. Massive destruction of high-rise as well as low rise buildings in recent devastating earthquake proves that in developing counties like India, such investigation is the need of the hour. Hence, seismic behavior of asymmetric building structures has become a topic of worldwide active research. Many Investigations have been conducted on elastic and inelastic seismic behavior of asymmetric systems to find out the cause of seismic vulnerability of such structures. The purpose of the paper is to perform linear static analysis of medium height RC buildings and investigate the changes in structural behavior due to consideration of sloping ground. The economic growth & rapid urbanization in hilly region has accelerated the real estate development. Due to this, population density in the hilly region has increased enormously. Therefore; there is popular & pressing demand for the construction of multi -storey buildings on hill slope in and around the cities

## II SEISMIC BEHAVIOUR OF BUILDINGS ON SLOPES IN INDIA

North and northeastern parts of India have large scales of hilly region, which are categorized under seismic zone IV and V. In this region the construction of multistory RC framed buildings on hill slopes has a popular and pressing demand, due to its economic growth and rapid urbanization. This growth in construction activity is adding increase in population density. While construction, it must be noted that Hill buildings are different from those in plains i.e., they are very irregular and unsymmetrical in horizontal and vertical planes, and torsionally coupled. Since there is scarcity of plain ground in hilly areas, it obligates the construction of buildings on slopes. During past earthquakes, reinforced concrete (RC) frame buildings that have columns of different heights within one storey, suffered more damage in the shorter columns as compared to taller columns in the same storey. One example of buildings with short columns in buildings on a sloping ground can be seen in the figure (1.1) given Poor behavior of short columns is due to the fact that in an earthquake, a tall column and a short column of same cross section move horizontally by same amount which can be seen from the given figure below However, the short column is stiffer as compared to the tall column, and it attracts larger earthquake force. Stiffness of a column means resistance to deformation- the larger is the stiffness, larger is the force required to deform it. If a short column is not adequately designed for such a large force, it can suffer significant damage during an earthquake. This behavior is called *Short Column Effect.* The damage in these short columns is often in the form of X-shaped cracking - this type of damage of columns is due to shear failure. Many situations with short column effect arise in buildings. When a building is rested on sloped ground, during earthquake shaking all columns move horizontally by the same amount along with the floor slab at a particular level (this is called *rigid floor diaphragm action).* If short and tall columns exist within the same storey level, then the short columns attract several times larger earthquake force and suffer more damage as compared to taller ones. The short column effect also occurs in columns that support mezzanine floors or loft slabs that are added in between two regular floors.

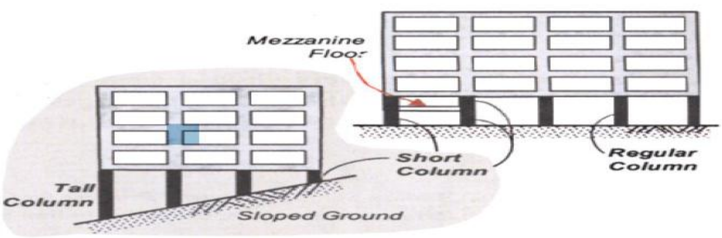



Fig. 1.1 Building frame with short column

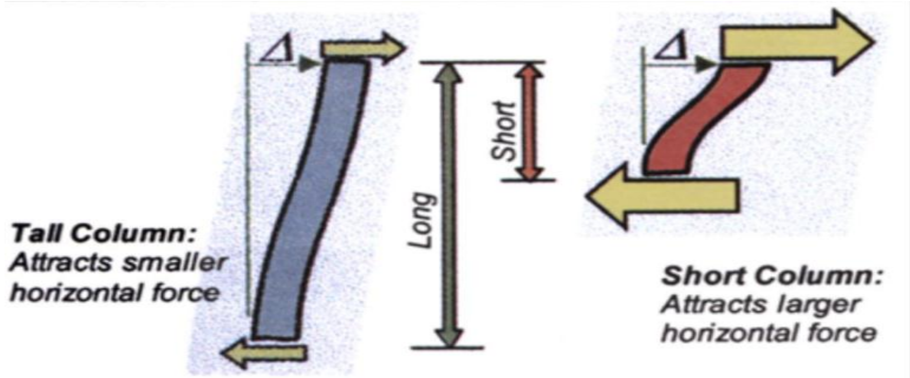



Fig. 1.2 Structural behavior of short column under lateral load

## III SIGNIFICANCE OF STUDY

The economic growth & rapid urbanization in hilly region has accelerated the real estate development. Due to this, population density in the hilly region has increased enormously. Therefore; there is popular & pressing demand for the construction of multi -storey buildings on hill slope in and around the cities. The adobe burnt brick, stone masonry & dressed stone masonry buildings are generally made over level ground in hilly regions. Since level land in hilly regions is very limited, there is a pressing demand to construct buildings on hill slope. Hence construction of multi-storey R.C. Frame buildings on hill slope is the only feasible choice to accommodate increasing demand of residential & commercial activities. It is observed from the past earthquakes, buildings in hilly regions have experienced high degree of demand leading to collapse though they have been designed for safety of the occupants against natural hazards. Hence, while adopting practice of multi -storey buildings in these hilly & seismically active areas, utmost care should be taken, making these buildings earthquake resistant.

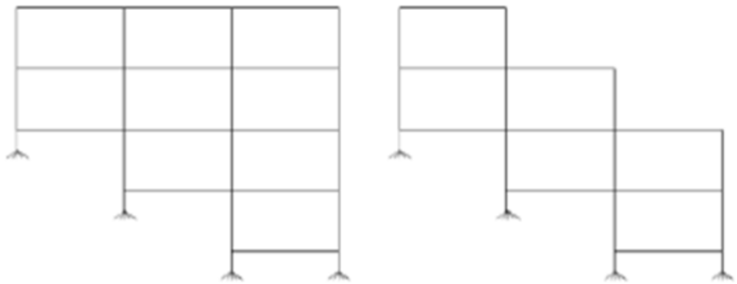


Fig 1.3 : (a) Step back building, (b) Step back Set back building

The scarcity of plain ground in hilly areas compels construction activity on sloping ground resulting in various important buildings such as reinforced concrete framed hospitals, colleges, hotels and offices resting on hilly slopes. The various floors of such buildings step back toward the hill slope and at the same time building may have setback also, as shown in Figure 1.3. Due to the varied configurations of buildings in hilly areas, these buildings become highly irregular and asymmetric, due to variation in mass and stiffness distributions on different vertical axis at each floor. Such construction in seismically prone areas makes them exposed to greater shear and torsion as compared to conventional construction. Further, due to site conditions, buildings on hill slope are characterized by unequal column heights within a story, which results in drastic variation in stiffness of columns of the same storey. The short, stiff columns on uphill side attract much higher lateral forces and are prone to damage. As per IS 1893: (part 1) 2002 ,different vertical irregular configurations of buildings have been defined, as shown in Figure 1.4. Which are stiffness irregularity (soft storey) ,mass irregularity, vertical irregularity (set back).

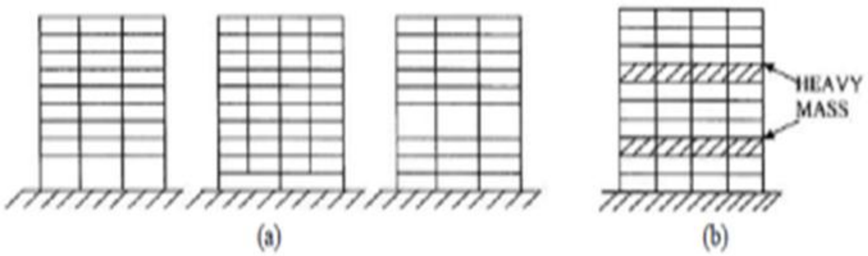



Fig-1.4: (a) Stiffness/strength irregularity (b) Mass irregularity (c) Vertical geometric irregularity or Set back (d) In-plane discontinuity in Vertical elements resisting lateral force when b > a.

## IV SCOPE OF STUDY

1. Three dimensional space frame analysis is carried out for three different configurations such as
   i. Step back
   ii. Step back-Setback
   iii. Setback
2. Height of buildings is ranging from 33m, 48m and 63m (10 to 20 storey) resting on sloping & plain ground.
3. Slope of ground ranging from 0°, 10°, 15° and 20°.
4. Dynamic response of these buildings, in terms of base shear & top floor displacement is presented & compared within the considered configuration as well as with other configurations.
5. At the end, a suitable configuration of building to be used in hilly area is suggested.

**Building Configuration**

Three different configurations are considered,

**1)** Step back (Resting on sloping ground)
**2)** Step back –Setback (Resting on sloping ground)
**3)** Setback .(Resting on plain ground.

## V. OBJECTIVE OF THE STUDY

This project report comprises of seismic analysis a R.C. building with rectangular plan .The design philosophy was established considering the following aspects:

1. The structure should withstand the moderate earthquakes, which may be expected to occur during the service life of structure with damage within acceptable limits. Such earthquakes are characterized as Design Basis Earthquakes (DBE).
2. The building is modeled as a 3D space frame with six degrees of freedom at each node using the software STAAD- PRO.
3. Building (G+10, 15 and 20) is analyzed using Response Spectrum method on 0°, 10°, 15°, 20° slope ground.
4. The Response Spectra as per IS 1893 (Part 1):2002 for medium soil is used.
5. Comparison of results for (G+10), (G+15), (G+20) building is done for same slope and same soil condition.

Various static checks are applied on the results.

## VI OUTLINE OF PROJECT

The project work is divided into seven stages with following contents.

Stage 1 deal with the introduction on the building and specific objective of the project are presented in it.

Stage 2 studies of different research papers and journals on modeling and analysis of different types of soil conditions with different ground slope.

Stage 3 Mathematical modeling of building for different ground slopes is carried out.

Stage 4 It covered the response spectrum analysis of different structure by taking earthquake data.

Stage 5 gives the comparison between different buildings by response spectra method.

Stage 6 it covers interpret conclusion from various results.

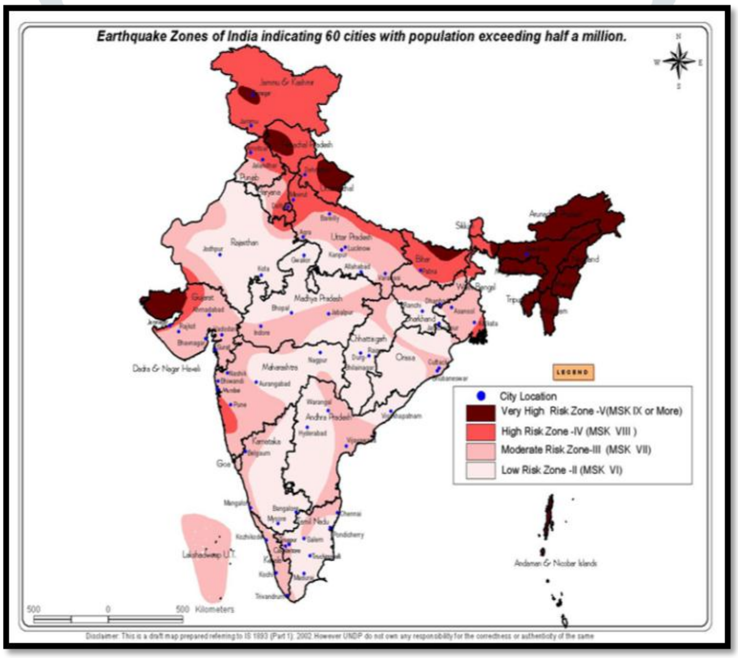



**Figure : Different Earthquake Zones of India**

## VII. METHODOLOGY

The earthquake load is considered as per IS:1893 (Part I):2002,for the zone IV and medium soil with importance factor 1.0 and Reduction factor 5.

Seismic zone factor Z for Zone IV =0.24

Scale factor = (Z/2)*(I/R)*g

The seismic load is calculated as per IS 1893(Part 1):2002.The building is analysed in two principal horizontal directions.

Fundamental time period of building are calculated as per IS 1893(Part 1):2002 by using Response spectra method.

Seismic coefficient Ah =(Sa/g)*(Z/2)*(I/R)

Base shear VB =Ah*W

For medium soil sites

Sa/g =1+15*T  $0.00 \leq T \leq 0.10$

=2.5  $0.10 \leq T \leq 0.55$

=1.36/T  $0.55 \leq T \leq 4.00$

## VIII. PROBLEM STATEMENT

The building considered in the present report is G+10, 15, 20 storied R.C framed building of symmetrical rectangular plan configuration. Complete analysis is carried out for dead load, live load & seismic load using STAD-Pro. Response spectrum method of seismic analysis is used. All combinations are Considered as per IS 1893:2002.

Typical plan of building is shown in Fig.

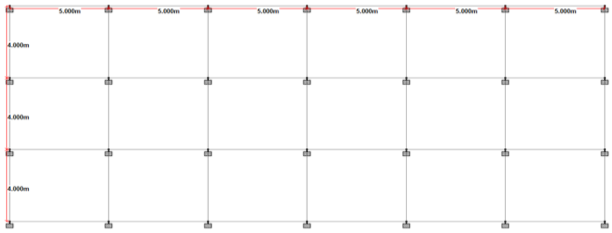


**FIG Plan of G+10,15,20 RC framed structure**

Building properties
Site Properties:
Details of building:: G+10, 15, 20.
Plan Dimension:: 30m x 12m
Outer wall thickness:: 230mm
Inner wall thickness:: 230mm
Floor height ::3 m
Parking floor height :: 3m
Seismic Properties
Seismic zone:: IV
Zone factor:: 0.24
Importance factor:: 1.0
Response Reduction factor R:: 5
Soil Type:: medium
Material Properties
Material grades of M35 & Fe500 were used for the design.

Loading on structure
Dead load :: self-weight of structure
Weight of 230mm wall :: 13.8 kN/m²
Live load:: For G+15:: 2.5 kN/m²
Roof :: 1.5 kN/m²
Wind load :: Not considered
Seismic load:: Seismic Zone IV

Preliminary Sizes of members
Column:: 700mm x 400mm
Beam:: 300mm x 550mm
Slab thickness:: 120mm

4.3 Load Combinations
Load combinations that are to be used for Limit state Design of reinforced concrete structure are listed below.
1. 1.5(DL+LL)
2. 1.2(DL+LL±EQ-X)
3. 1.2(DL+LL±EQ-Y)
4. 1.5(DL±EQ-X)
5. 1.5(DL±EQ-Y)
6. 0.9DL±1.5EQ-X
7. 0.9DL±1.5EQ-Y

RCC G+10 building with setback, set – step back and step back on $0^0$, $10^0$, $15^0$, $20^0$slope ground

**Lateral displacement of RCC G+10 on plain ground**

| **RCC G+10 ON PLAIN GROUND** | | | | |
|---|---|---|---|---|
| | Horizontal | Vertical | Horizontal | Resultant |
| Node | X mm | Y mm | Z mm | mm |
| 383 | 33.848 | -5.189 | 0.016 | 34.244 |
| 350 | -33.848 | -6.816 | 0.015 | 34.528 |
| 380 | 0 | 0.942 | 36.708 | 36.72 |
| 378 | 0 | -9.93 | -0.026 | 9.93 |
| 374 | 0 | -5.294 | 55.108 | 55.362 |

| | | | | |
|---|---|---|---|---|
| 380 | 0 | -8.118 | -55.108 | 55.703 |
| 88 | 0 | -1.912 | 13.985 | 14.115 |
| 109 | 0 | -3.274 | -13.985 | 14.363 |
| 363 | -0.09 | -5.034 | 53.836 | 54.071 |
| 342 | -0.113 | -7.79 | -53.836 | 54.397 |
| 98 | 8.179 | -1.949 | -0.001 | 8.408 |
| 92 | -8.179 | -2.739 | -0.001 | 8.625 |
| 378 | 0 | -8.466 | -55.076 | 55.722 |

**Table Lateral displacement of RCC G+10 with setback on plain ground**

| RCC G+10 WITH SETBACK ON PLAIN GROUND | | | | |
|---|---|---|---|---|
| | Horizontal | Vertical | Horizontal | Resultant |
| Node | X mm | Y mm | Z mm | mm |
| 348 | 30.186 | -7.756 | 0.019 | 31.167 |
| 350 | -29.678 | -4.3 | 0.009 | 29.988 |
| 364 | 8.618 | 1.014 | 46.484 | 47.287 |
| 349 | 0.254 | -9.43 | 0.026 | 9.433 |
| 343 | 13.254 | -3.253 | 69.761 | 71.084 |
| 364 | -12.601 | -6.296 | -69.761 | 71.169 |
| 91 | 3.602 | -1.092 | 17.947 | 18.338 |
| 112 | -3.467 | -2.572 | -17.947 | 18.459 |
| 312 | 13.409 | -4.567 | 41.346 | 43.705 |
| 333 | -11.994 | -6.606 | -41.346 | 43.554 |
| 98 | 7.685 | -1.997 | -0.001 | 7.94 |
| 92 | -7.578 | -2.208 | -0.001 | 7.893 |
| 364 | -12.601 | -6.296 | -69.761 | 71.169 |

**Table Lateral displacement of RCC G+10 with setback on $10^0$ slope ground**

| RCC G+10 WITH SETBACK ON $10^0$ SLOPE GROUND | | | | |
|---|---|---|---|---|
| | Horizontal | Vertical | Horizontal | Resultant |
| Node | X mm | Y mm | Z mm | mm |
| 344 | 26.105 | -2.826 | 0.01 | 26.257 |
| 350 | -28.577 | -4.843 | 0.013 | 28.985 |
| 359 | 6.4 | 0.893 | 35.642 | 36.223 |
| 345 | -1.591 | -9.024 | 0.025 | 9.163 |
| 337 | 8.241 | -3.399 | 59.786 | 60.447 |
| 358 | -10.961 | -6.075 | -59.786 | 61.086 |
| 113 | 2.431 | -1.579 | 21.557 | 21.751 |
| 134 | -3.042 | -3.246 | -21.557 | 22.011 |
| 361 | 8.113 | -4.7 | 39.501 | 40.599 |
| 340 | -11.093 | -6.623 | -39.501 | 41.561 |
| 98 | 2.252 | -0.534 | -0.001 | 2.315 |
| 367 | -1.368 | -0.332 | -0.001 | 1.407 |
| 358 | -10.961 | -6.075 | -59.786 | 61.086 |

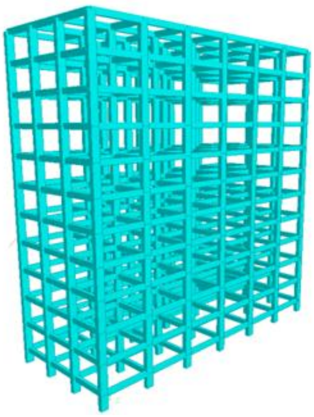
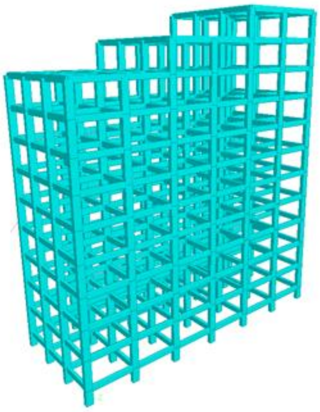
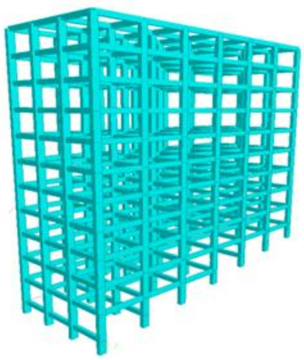
**Table Lateral displacement of RCC G+10 with set – step back on $10^0$ slope ground**

| RCC G+10 WITH SET- STEP BACK ON $10^0$SLOPE GROUND | | | | |
|---|---|---|---|---|
| | Horizontal | Vertical | Horizontal | Resultant |
| Node | X mm | Y mm | Z mm | mm |
| 348 | 22.066 | -3.732 | 0.01 | 22.38 |

| | | | | |
|---|---|---|---|---|
| 350 | -23.939 | -4.746 | 0.013 | 24.405 |
| 342 | 2.781 | 0.602 | 26.31 | 26.463 |
| 348 | -1.376 | -7.502 | 0.022 | 7.628 |
| 343 | 3.058 | -2.441 | 41.119 | 41.305 |
| 364 | -5.286 | -4.181 | -41.119 | 41.667 |
| 119 | 0.873 | -0.712 | 8.244 | 8.321 |
| 140 | -1.289 | -1.432 | -8.244 | 8.466 |
| 312 | 3.432 | -3.879 | 32.141 | 32.556 |
| 333 | -4.743 | -5.382 | -32.141 | 32.932 |
| 98 | 2.023 | -0.551 | -0.001 | 2.097 |
| 367 | -1.22 | -0.322 | -0.001 | 1.261 |
| 364 | -5.286 | -4.181 | -41.119 | 41.667 |

**Table Lateral displacement of RCC G+10 with setback on $15^0$ slope ground**

| RCC G+10 WITH SETBACK ON $15^0$ SLOPE GROUND | | | | |
|---|---|---|---|---|
| | Horizontal | Vertical | Horizontal | Resultant |
| Node | X mm | Y mm | Z mm | mm |
| 344 | 22.553 | -2.845 | 0.01 | 22.732 |
| 350 | -25.803 | -3.99 | 0.012 | 26.109 |
| 358 | 7.079 | 0.877 | 39.9 | 40.533 |
| 345 | -2.157 | -8.791 | 0.025 | 9.052 |
| 337 | 8.779 | -3.407 | 59.886 | 60.622 |
| 358 | -12.457 | -6.038 | -59.886 | 61.465 |
| 113 | 1.778 | -1.586 | 20.947 | 21.082 |
| 134 | -2.332 | -3.222 | -20.947 | 21.321 |
| 361 | 8.654 | -4.298 | 36.418 | 37.678 |
| 340 | -12.581 | -6.039 | -36.418 | 39 |
| 126 | 2.771 | -0.541 | -0.002 | 2.823 |
| 366 | -1.506 | -0.297 | -0.001 | 1.535 |
| | -12.457 | -6.038 | -59.886 | 61.465 |

## IX. OBSERVATIONS & GRAPHS

In the present project report seismic design analysis of a rectangular plan building is carried out. Building is modelled as a 3D frame using STAAD – Pro software which is analysed by Response Spectrum method. Following observations have been drawn from the seismic analysis.

1. Following table shows maximum base shear on different slope of ground for varying height of structure

| Table - MAXIMUM BASE SHEAR IN X - DIR (KN) | | | |
|---|---|---|---|
| **TYPE OF STRUCTURE** | **G+10** | **G+15** | **G+20** |
| ON PLAIN GROUND | 1788.38 | 2204.12 | 2725.62 |

| | | | |
|---|---|---|---|
| WITH SETBACK ON PLAIN GROUND | 1788.66 | 2076.42 | 2287.61 |
| WITH SETBACK ON $10^0$ SLOPE GROUND | 1729.38 | 2020.62 | 2323.91 |
| WITH SET- STEP BACK ON $10^0$ SLOPE GROUND | 1548.88 | 1828.54 | 2227.1 |
| WITH SETBACK ON $15^0$ SLOPE GROUND | 1665.21 | 1974.58 | 2291.89 |
| WITH SET- STEP BACK ON $15^0$ SLOPE GROUND | 1512.21 | 1846.62 | 2164.85 |
| WITH SETBACK ON $20^0$ SLOPE GROUND | 1569.85 | 1928.9 | 2222.99 |
| WITH SET- STEP BACK ON $20^0$ SLOPE GROUND | 1419.27 | 1800.51 | 2110.95 |

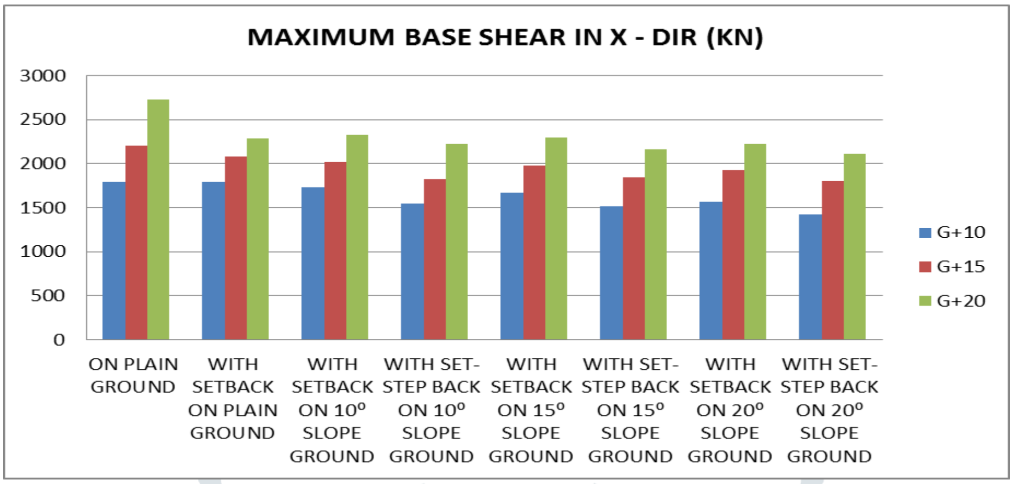



Fig. Maximum base shear in x - dir (KN)

| Table - MAXIMUM BASE SHEAR IN Z - DIR (KN) | | | |
|---|---|---|---|
| **TYPE OF STRUCTURE** | **G+10** | **G+15** | **G+20** |
| ON PLAIN GROUND | 2192.75 | 1801.78 | 2938.77 |
| WITH SETBACK ON PLAIN GROUND | 1775.02 | 2013.86 | 2302.92 |
| WITH SETBACK ON $10^0$ SLOPE GROUND | 1714.61 | 2029.71 | 2320.17 |
| WITH SET- STEP BACK ON $10^0$ SLOPE GROUND | 1522.35 | 1914.82 | 2214.37 |
| WITH SETBACK ON $15^0$ SLOPE GROUND | 1657.62 | 1950.62 | 2271.86 |
| WITH SET- STEP BACK ON $15^0$ SLOPE GROUND | 1492.04 | 1896.09 | 2187.81 |
| WITH SETBACK ON $20^0$ SLOPE GROUND | 1581.79 | 1933.03 | 2222.56 |
| WITH SET- STEP BACK ON $20^0$ SLOPE GROUND | 1408.98 | 1806.27 | 2129.45 |

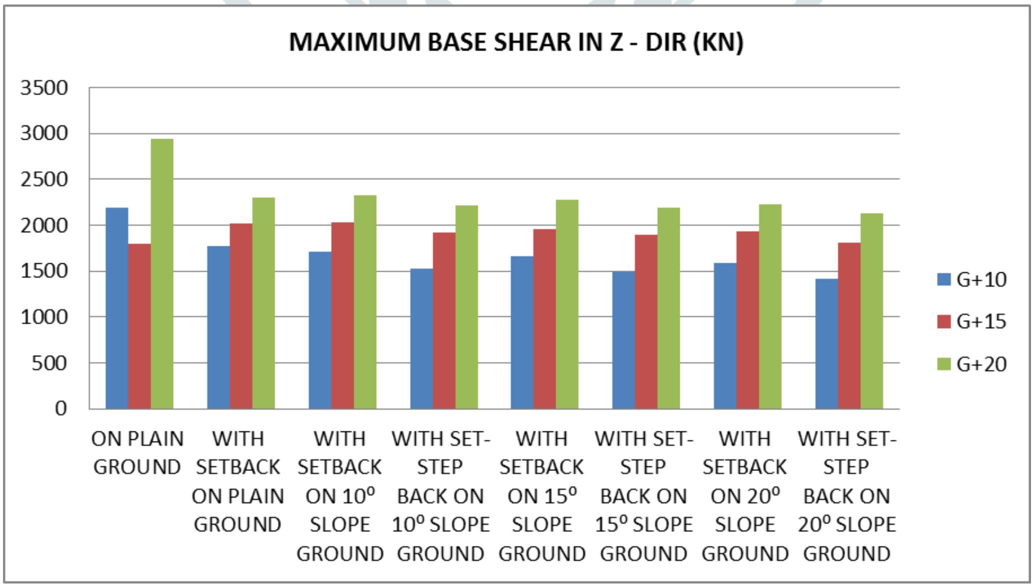



**Fig. Maximum base shear in z - dir (KN)**

## X. CONCLUSIONS

- Buildings resting on sloping ground have less base shear compared to buildings on Plain ground.
- Base shear increases as slope of ground increase.
- Buildings resting on sloping ground have more lateral displacement compared to buildings on Plain ground.
- Buildings with set back – step back is showing less displacement than step back model.

- Building is showing high value of displacement in z- direction than in x direction.
- The critical axial force in columns is more on plain ground than on sloping ground.
- The shear force and moment in columns is more on sloping ground than on plain ground.
- The shear force and bending moment value in beams is high in plain ground model than on sloping ground model.
- The performance of set- step back building during seismic excitation could prove more vulnerable than other configurations of buildings.
- The development of moments in set - step back buildings is higher than that in the set back building. Hence, Set back buildings are found to be less vulnerable building against seismic ground motion.
- Step back Set back buildings, overall economic cost involved in leveling the sloping ground and other related issues needs to be studied in detail.

## XI. FUTURE SCOPE

- Analysis can be carried out using time history method.
- Comparison of Time history method and response spectrum method can be done.
- Analysis can be doing with different soil conditions.
- The study can be further extended to analysis of irregular building.
- Irregular buildings with different position of shear wall can be analysed.
- Analysis can be done by using software SAP 2000, ETAB etc.

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