DYNAMIC ANALYSIS OF BUILDING RESTING ON SLOPING GROUND

A Thesis

Submitted by

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In partial fulfillment of the requirement for

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DELHI TECHNOLOGICAL UNIVERSITY

DTU, NEW DELHI, INDIA

CERTIFICATE

This is certifying that the thesis entitled “**DYNAMIC ANALYSIS OF BUILDINGS RESTING ON SLOPING GROUND”** *submitted by* **Praveen Kumar Agrawal** bearing roll no.

2K16/STE/14 *in partial fulfillment of the requirements for the award of* **Master of Technology** *degree in* **Civil Engineering** *with specialization in* **Structural Engineering** *during2016-2018 session to the* **DELHI TECHNOLOGICAL UNIVERSITY (DTU) NEW DELHI** *is an authentic work carried out by the him under my supervision and guidance. The contents of this research work in full or in parts have not been submitted to any other institute or university for the award of any degree or diploma.*

DATE:

PROF. NIRENDRA DEV

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Dedicated

To

MY BELOVED PARENTS

&

TEACHERS

ACKNOWLEDGEMENTS

I am very thankful to God who helped me throughout my life and grants wisdom to human beings to express our thoughts.

I express my gratitude and sincere thanks to **Prof. Nirendra Dev**, for his guidance and continuous support and encouragement during entire course of work during the research work. I truly appreciate his unconditional support and his immeasurable contribution through the knowledge and advices. It is my utmost fortunate to work under highly respected professor and his company will be remembered lifelong at the time of crisis.

A special thanks to **Prof. Alok Verma** my faculty and first year advisor and all the faculties **Prof. A.K.Gupta, Prof. Awadhesh Kumar, Dr. Rituraj, Mr. Rishikesh Dubey** for helping me to clear all the semester exams.

I am highly thankful to my father and mothers for infinite blessings and supporting me morally, without them I could not have achieved the successful completion of my work.

Praveen Kumar Agrawal

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ABSTRACT

The building structures situated in hilly area are much more vulnerable to earthquake environment in comparison to the building structures located in flat regions. Structures situated on sloping ground differs from other building structures because they are irregular both vertically and horizontally hence torsion moments so these structures are more susceptible to severe damage when subjected to earthquake vibrations. The columns of ground storey building have varying height of columns due to sloping ground. In this research work, behavior of 4 to 11 storey with different configuration step back, step back set back and set back building is analyzed using structural analysis tool STAAD Pro. By performing a linear time history analysis. From the above analysis it is observed that stiffness of the model increases due to decreases in height of short column which results in increases in seismic forces on short column which is about 75% of total base shear and chances of damage is increased considerably due to formation of plastic hinges therefore proper analysis is required to quantify the various building configuration for more suitability on sloping ground.

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INTRODUCTION

INTRODUCTION

1.1 INTRODUCTION

Earthquake is the most dangerous & non predictable disaster of nature. Loss of human lives due to earthquake forces on the building structures does not cause directly but due to the damages causes of the building structures that leads to the collapse of the structures and hence to the livelihood and to the property. There is a special need of investigation required to reduce the mass destruction of the low and high rise of building structures due to earthquake in the developing nation like INDIA.

Building structures subjected to seismic forces are always more prone to collapse and if this phenomenon occurs on a sloping ground building structures as on hills which lies at some inclination angle to the ground, chances of damage suddenly increase much more due to increase in lateral forces like seismic and wind on short column on upward hill side and on the short column side more number of plastic hinges forms. Building structures built on sloping terrain differs from those which are on plains because sloping structures have irregularity in horizontally as well as vertically.

In the northen and north-eastern parts of INDIA, have huge part of sloping ground which comes in the categories of seismic zone 1V and V. Recently there was huge destruction in Nepal earthquake (2015), Doda earthquake (2013), Sikkim earthquake (2011) because of majority of hilly ground location. Due to rapid urbanization and economic development of INDIA there is a huge demand of multistory RC framed building structure in that region. Due to more population density and scarcity of plain ground we are bounded to construct the building structures in that sloping terrain.

In present work 24 multistory building frames with different no of storey with varying no of bays with an inclination to 27^0 to the ground subjected to sinusoidal ground motion is prepared and analysis of these building frames is done on design software (STAAD Pro) .

1.2 RELEVENCE OF WORK

Due to difference in the ground condition of building structures in plains to the sloping terrain of horizontal as well as vertical plains situations. Sloping ground building structures have more predictable to severe damage due to worse effect of earthquake ground motion. The appraoch & the accuracy of analytical results depend upon the characteristics of geometry of the structure & the loading on the structure.

The present work aims at providing an analytical approach for finding out the displacements, storey drifts, fundamental time period, base shear for a multistory building structures resting on a sloping ground terrain subjected to earthquake load. Response spectrum analysis (RSA) based on the IS (1893:2002) PART 1 codal provisions is to be performed on the FINITE ELEMENT model using suitable FINITE ELEMENT ANALYSIS platform. Using the displacement characteristics various structural outputs such as time period, storey drift, base shear are to be computed.

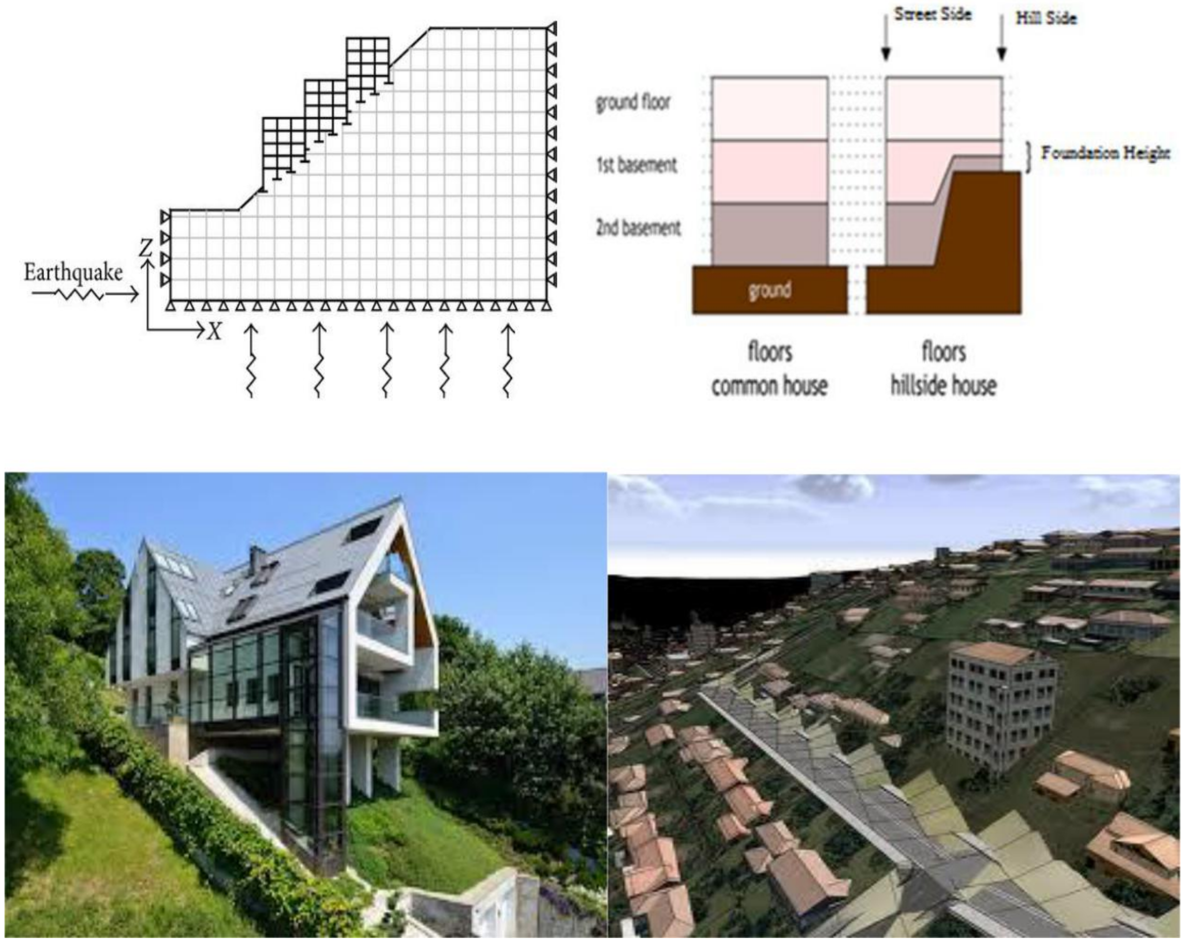


Figure 1 : Building on the sloping ground

1.3 ORIGIN OF THE PROJECT

Some researchers and analyst has done few research works on the earthquake nature on the building structures on the slopes subjected to ground motion of sinusoidal behavior due to earthquake vibration. Ramanchrla and Sreerama (2013) have numerically studied the effect of earthquake vibration on different sloping angle and compare these numerical results with the same on flat ground condition. Still no work has been carried regarding the vibrative nature of the building structures on hilly ground with an experimental setup in laboratory by simulating the same field condition. So keeping the present situation of population scenario, this project ….

……… may play a vital role to solve out the space scarcity in the hilly region in north eastern region of India.

1.4 RESEARCH SIGNIFICANCE

There is great amount of mountains in INDIA which consists of Himalayas region in the northen part which is formed by the collision of tectonic plates. In this particular sloping region population density were 62159 per square km as per census of 2011. Hence there is great requirement in the study of earthquake safety and designing criteria of the building structures on the sloping terrain.

The response and severity of damage depends on the frequency of the earthquake because it affects the building structure performance when it is subjected to ground motion. In this research work analytical study is done on different multy storey building of different configuration like STEP BACK, SET BACK – STEP BACK & SET BACK.

Table 1 : Earthquake Classification

MAGNITUDE OF EARTHQUAKE	CLASSIFICATION OF EARTHQUAKE
Less then 3	Micro
3 to 4.9	Intermediate
5 to 5.9	Moderate
6 to 6.9	Strong
7 to 7.9	Major
Greater than 8	Sevier

1.5 OBJECTIVE AND SCOPE OF PROJECT

The purpose of this research work is to study numerically the seismic behavior of sloping ground building structures subjected to earthquake vibration causing sinusoidal ground motion and seismic excitations.

The objective of this thesis is summarized as follows:

- Three dimensional (3-D) RC space frame analysis has been done on three different configuration of building structures which are varying height of due to varying storey from 15.75 m to 40.25 m height (4 to 11 storey)situated on sloping and flat terrain under the effect of earthquake loads.
- Due to seismic analysis dynamic characteristics like base shear, natural time period and top storey sway of the building structures is presented.
- Comparison of results within the considered building structure's configuration and with other configuration of the structures.
- A most suitable building configuration economically as well as strength point of view is suggested in the sloping terrain.
- By structural analysis tool STAAD PRO a linear time history analytical study is performed as per spectra of IS 1893 (PART 1) :2002 for a hard soil condition and 5% critical damping.

Chapter 2

LITERATURE REVIEW

LITERATURE REVIEW

2.1 OVERVIEW

Dynamic analysis performed on RC space frame building structures with three different configurations like step back, step back –set back and set back buildings and analytical results are presented. Response spectrum method is used for three dimensional analyses in which torsion effect is also considered generated from accidental eccentricity. The seismic response characteristics i.e. natural time period, top storey sway and base shear. According to building structures configuration best suitability of column on sloping ground is analyze. From analytical results it is observed that step back set back buildings are found to be more suitable on the hilly terrain.

2.2 SEISMIC BEHAVIOUR OF IRREGULAR BUILDINGS ON SLOPING GROUND IN INDIA

RAVIKUMAR AL. (2012) studied mainly two types of irregularities in building structures model 1) plan irregularity i.e. horizontal discontinuity in configuration 2) elevation irregularity with set back and sloping ground terrain. To identify the seismic behavior, push over analysis was carried out by taking different lateral load condition in all three directions respectively. All the structures considered were three storied with different plan and elevation irregularities pattern. Due to lesser amount of forces generated on plan irregular models give more deformation. The execution of all models lies in between life safety criteria and collapse prevention expect for models resting on sloping ground. Thus it can be conclude that structures resting on sloping terrain are more prone to damage rather than structures resting on flat ground even with horizontal irregularities.

RAMANCHRLA AND SREERAMA (2013) observed about recently earthquakes like Bihar-Nepal ,Shilong plateau collision and the Kangra earthquake was cause of more than 3,75,000 people death and over 1 lac of the building structure got damaged and collapsed. Seismic features of the building structures resting on plain ground differs to buildings rested on hilly terrain sloping ground in the plan as well as elevation difference in the building configuration. Due to this irregular behavior the centroid (C.G) and the stiffness center don't match with each other corresponding torsion effect generated due to eccentricity. The mass and stiffness of the beam element differs with in the building storey causes increment in the base shear forces on column on uphill side and prone to damages. They analyze five G+3 building structure of different slope angle 0^0,15^0,30^0,45^0,60^0 which were designed and analyzed using IS-456 and SAP-2000. They conclude that shorter column attracts more amounts of lateral forces due to increment in the stiffness. As the slope angle increases base shear on the shorter column increases and forces value decreases as the slope angle increases for the other columns.

Figure 2: Buildings damage on sloping ground due to earthquake

As the slope angle increases fundamental time period decreases and most of the base shear is ….

…….resisted by short column as the long column are flexible and cannot resist that much lateral loads.

PATEL AL. (2014) studied three dimensional model of eight stories building and analyzed by a software E-Tabs with regular and irregular configure model to study the effect of variation of height of columns due to hilly sloping ground and the effect of RCC shear wall at different position during earthquake. In the present study, as per seismic code IS-1893 PART 1 earthquake load analysis is done and proper assessment for dynamic vulnerability for building structure is performed by pushover analysis. It was seen that due to creation of plastic hinges on columns susceptibility of building structures on building structures on sloped ground increases at every base level of beam element in particular storey level at their performance point. As the irregularity increases more no. of plastic hinges forms. Building structures resting on hilly terrain gives more storey sway as compared to buildings rests on plain ground without having any shear wall. By providing the shear wall in the structures Base shear and lateral sway can be reduced.

Figure 3 : Cracks on sloping ground buildings due to earthquake

2.3 DYANMIC BEHAVIOUR OF BUILDING STRUCTURES WITH DIFFERENT CONFIGURATION

BIRAJDAR AND NALAWADE (2004) studied 3 –dimensional three different configuration like set back, set back – step back, step back building structures of 24 RC space frame. Torsion effect due to accidental eccentricity is analyzed by response spectra. The dynamic characteristics like top storey sway, base shear and natural time period have been analyzed according to best suitability of building structures on sloping terrain. In this study three types of configuration as discussed above are used in which two of them step back and set back-step back rested on sloping ground while the third one set back is used on flat ground. This study of analysis is done on 27^{o} sloping angle.

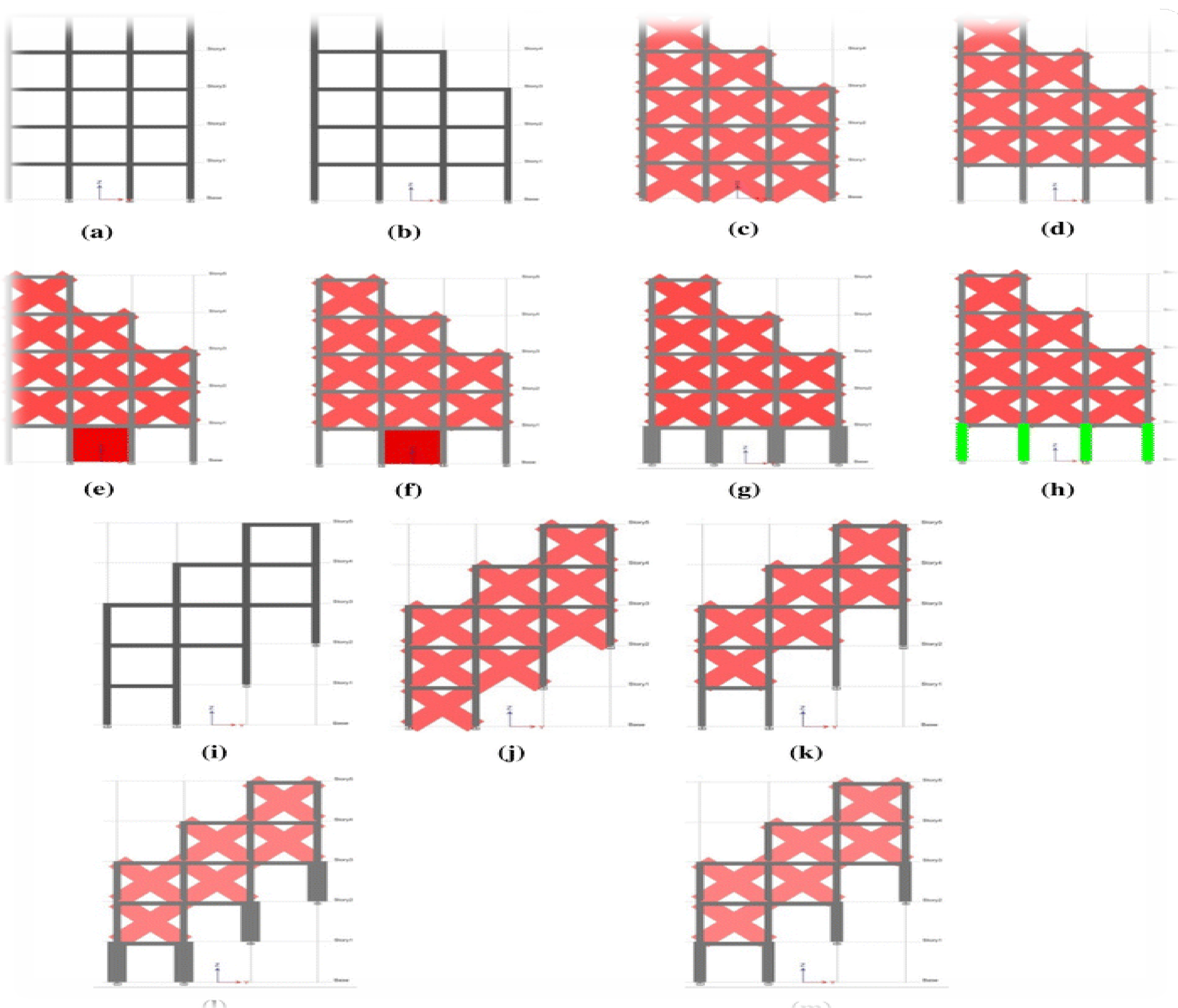
Total of 24 RC buildings frames from 4 to 11 stories, analytical study is done.

a) **Step back building** – there is linear increment in top storey sway as the number of stories increases and natural time period also increase in longitudinal direction. Due to the effect of static and accidental eccentricity, torsion moments increases corresponds the value of top storey sway. Time period in lateral direction gives higher value compare to longitudinal direction. From design point of view special mention should be given to the strength, configuration and stiffness. Safety is ensure under worst load combination at short column on sloping ground in X and Z direction.

b) **Step back-set back building –** results obtained in the static and dynamic analysis should not differ as in the case of step back building structures. The top storey sway is about 3.8 to 4 times greater in lateral direction compare to longitudinal direction's sway.

c) **Set back building** – base shear forces generated in set back structures is minimum compare to the other two structures. In set back building structures shear forces distribution is even and there is little problem of generation of torsion moments.

The generation of torsion moments are highest in step back building and step back structures are most vulnerary comparison to other geometry and column at base level is worst affected.



SINGH AL. (2012) performed an analytical study using linear and non linear fundamental time period history. On sloping terrain with 45 degree to the horizon a 9 storey RC frame step back building structure is considered. The no. storey varies from 3 to 9 and 7 bays along the slope. They analyzed 5 sets of ground motion condition i.e. chi-chi (1999),Imperial valley (1979),Northridge (1994),Sun ferno (1971) and kobe (1995)from strong data basis of Pacific Earthquake Engineering Research Centre (PEER)

They observed that short column resist most of the storey base shear. The ratio of maximum to average inter storey sway ($\Delta_{max}/\Delta_{avg.}$) in a storey represents the effect of torsion irregularities due to accidental and static eccentricity. They observed that considerable amount of torsion effects applied under cross slope excitetions in step back building structure.

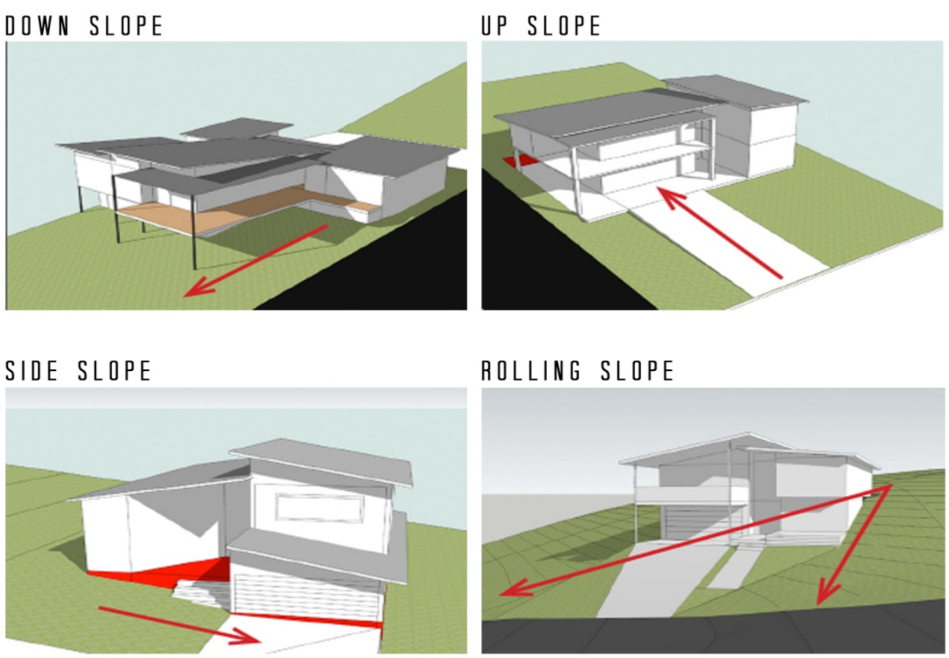


Figure 5 : Different slope condition of ground buildings

BABU AL. (2012) studied pushover analysis on various symmetric and asymmetric building structures built on plain terrain as well as sloped terrain. They analyzed the structures with different configuration which are plan symmetrical and asymmetrical having different bay sizes. They studied a 4 storey structures in which one storey is above ground level and that is built at a 30 degree sloping angle. It was noticed that shorter column affects most damage severity. They obtain sway about 104mm and base shear force as $2.77*10^3$ KN. Based on above results they presented push over curves with X-axis as displacement and Z- axis for base shear. They conclude that failure limit for max. sway by regular structures is 70% and for irregular structure, it is about 24% more than the plain ground structures. It is also analyzed that buildings are less seviour in plan compare to elevation irregularity.

At 27 degree sloping angle building structures with five bays along the slope is formed. Special moment resisting frame (SMRF), frame system is considered. In this study, they observed 1.975 sec natural time period which is about 95-130% higher as compare to the building structures having infill-walls causing in the increment in the stiffness so natural frequency also increases.

They also observed that in case of bare frame due to absence of infill wall and decreased stiffness, the sway of the building is more. They conclude that base shear in infilled frames is 250% more as compare to bare frames. Therefore more plastic hinges forms in soft storey bare frames.

HALKUDE AL. (2013) studied dynamic analysis of building structures situated on varying sloping angle terrain and varying number of bays of structures. According to variation in number of stories and bays along the ground slope, they studied the dynamic characteristics ………

……….of the building structure i.e. base shear, storey drift and fundamental time period. In longitudinal direction 4 to 11 stories with 3 to 6 bays a step building is considered. In lateral direction bays variation is not considered so in Z-direction there kept only single bay. They consider the seismic zone III with varying slope angle as 16.25^0, 21.60^o, 26.56^o, 31.50 degree with horizon. In all the building models it was observed that base shear value increases with increment in number of storey and number of bays but as slope angle increases base shear value decreases. Comparing within different geometry of building structures step back building structures gives higher base shear value compare to step back set back building structures.

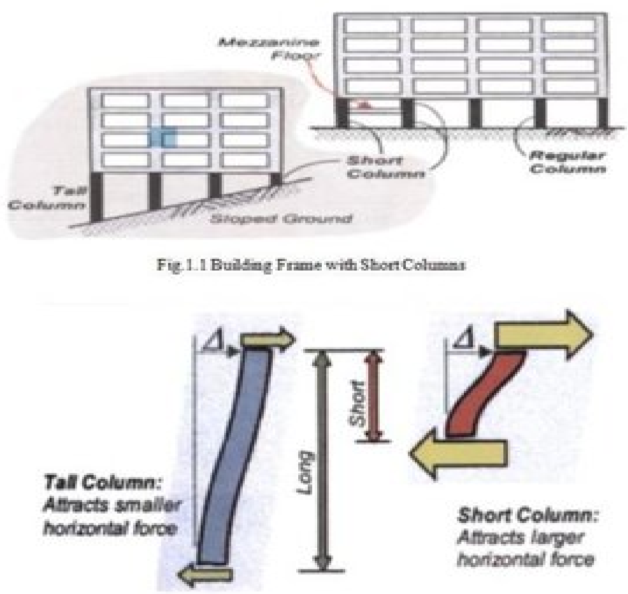


Figure 6 : Short column condition

They also observed that with increase in number of storey, fundamental time period increases. In step back structures natural time period increases as number of bays increases while in step back set back building time period decreases as bays increases. As the slope angle increase stiffness of the structure increase therefore fundamental time period decreases in each structure………

………As storey number increases, top storey sway increases and top storey decreases as hill slope increases and sway decreases as number of bays increases. They conclude that more no. of bays are better to increase the natural time period and therefore by increasing the stiffness of building top storey displacement reduces.

Chapter 3

MODELLING

3.1 FRAME MODELLING IN STAAD PRO.

In this research work, three groups of building structures with different configuration are considered. Out of them step back structures and step back set back structures resting on sloping ground and set back structures rest on plain ground. The ground slope is 27 degree with horizontal which is neither steep nor flat.

- The building structures model shown in figures having step back configuration are labeled from STEP 4 to STEP 11 for four to eleven stories.
- Step back-Set back building configuration having 4 to 11 number of stories are labeled as STEP SET 4 to STEP SET 11 as shown in figures.
- SET 4 to SET 11 are labeled for set back building structures resting on flat ground having 4 to 11 number of bays.
- All the building structures having same number of stories and same no of bays have same floor area in all the three configuration.
- The properties of beam element of building RC frame that are considered for study are given in the table.
- The depth of footing below the ground level is taken 1.75 m where the hard rocky stratum is available.
- The height and length of the building structures in a particular frame are in multiple of blocks in plan and elevation view, the size of each block is tried to maintain at 7 m x5 m x3.5 min three dimensions.

Table 3.1: Geometrical properties of members for different configuration

<table>
<tr><th>BUILDING CONFIGURATION</th><th colspan="2">SIZE OF COLUMN (MM)</th><th>SIZE OF BEAM (MM)</th></tr>
<tr><td rowspan="4">Step-back Building</td><td>STEP 4 & STEP 5</td><td>230 mm x 500 mm</td><td rowspan="4">230 mm x500 mm</td></tr>
<tr><td>STEP 6 & STEP 7</td><td>230 mm x 650 mm</td></tr>
<tr><td>STEP 8 & STEP 9</td><td>300 mm x650 mm</td></tr>
<tr><td>STEP 10&STEP11</td><td>300 mm x850 mm</td></tr>
<tr><td>Step back- set back Building</td><td>STEP SET 4 to STEP SET 11</td><td>230 mm x 500 mm</td><td>230 mm x 500 mm</td></tr>
<tr><td>Set-back Building</td><td>SET 4 to SET 11</td><td>230 mm x 500 mm</td><td>230 mm x 500 mm</td></tr>
</table>

- In above table size of each beam element is shown.
- Size of beam kept constant 230 mm x 500 mm in each and every configuration at each level.
- As storey number increases size of column also increases.
- Mostly variation of column size in step back building configuration because there is severe base shear condition in upward hill side.

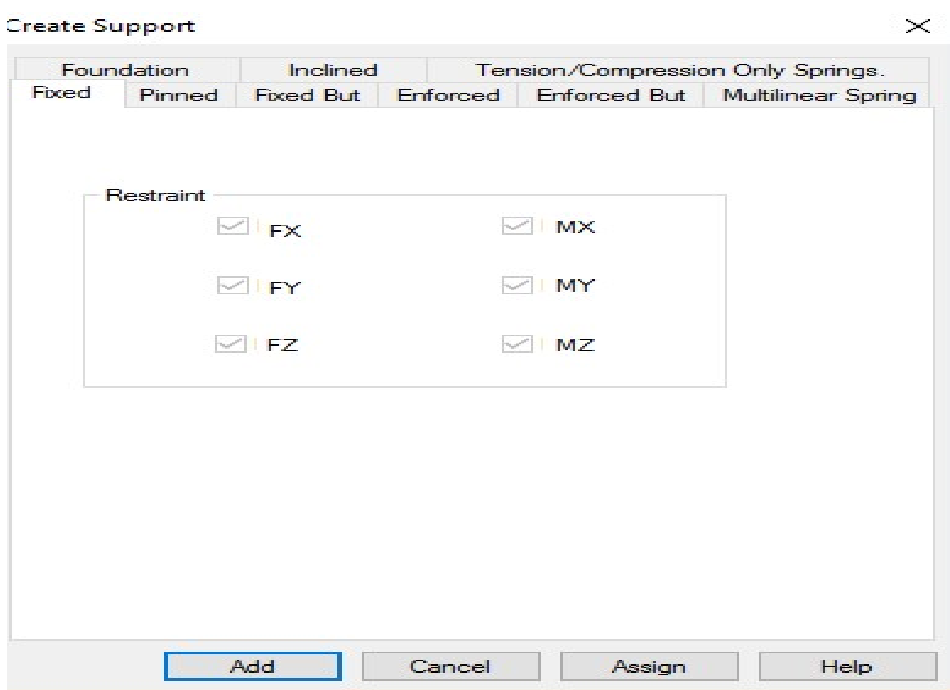
3.2: MATERIAL PROPERTIES –

Table 3.2: Material – Properties

PROPERPIES	
Modulus of Elasticity	25000 N/mm^2
Poissions Ratio	0.20
Density	25 kN/m^3
Thermal coefficient	$1x10^{-5}$
Critical Damping	.05

Note: Concrete M-25 used in each column & beam

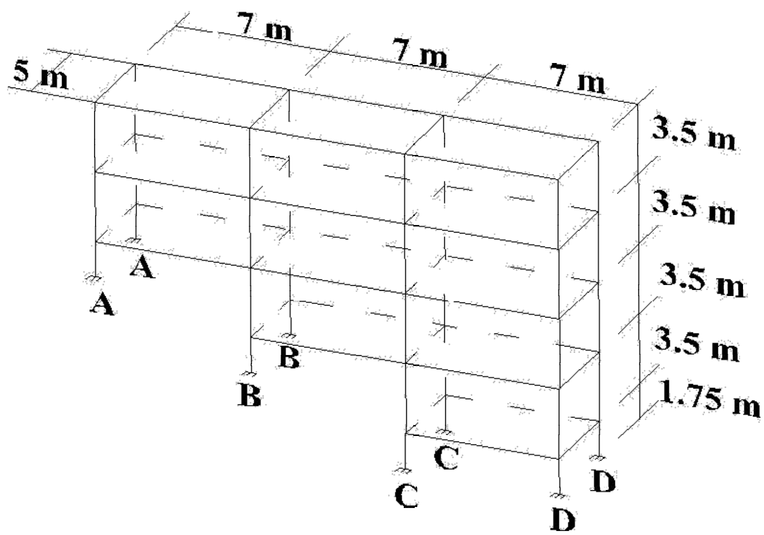
3.3 SUPPORT CONDITION:



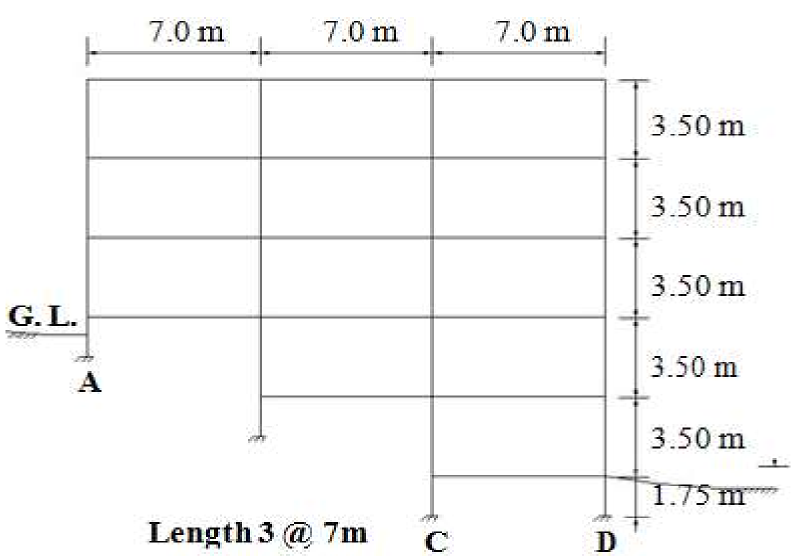
- Fixed support condition is used at every column base.

3.4: BUILDING CONFIGURATIONS –

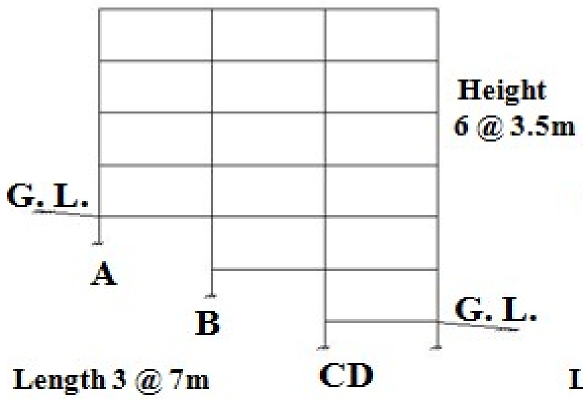
3.4.1 STEP BACK BUILDING MODELS:



STEP 4



STEP 5



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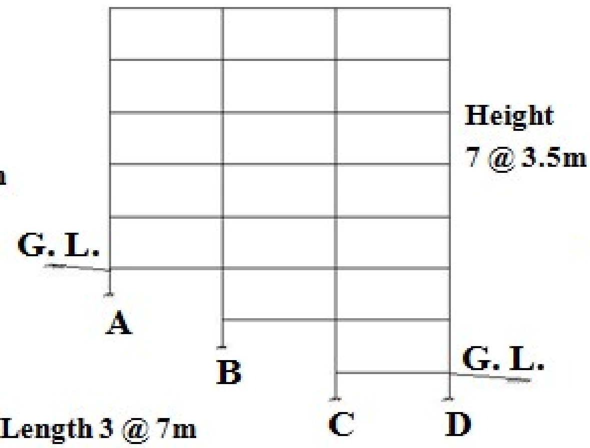

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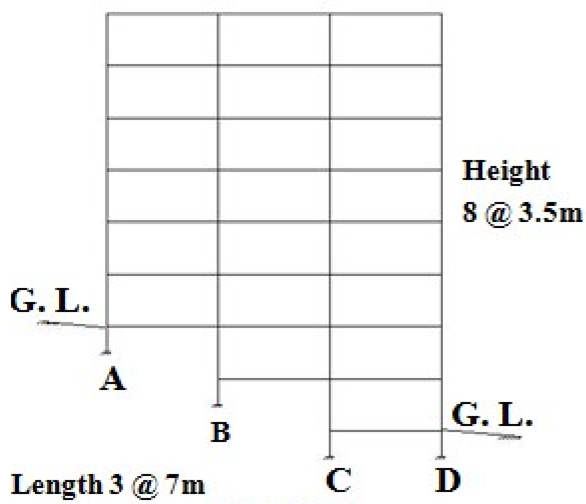

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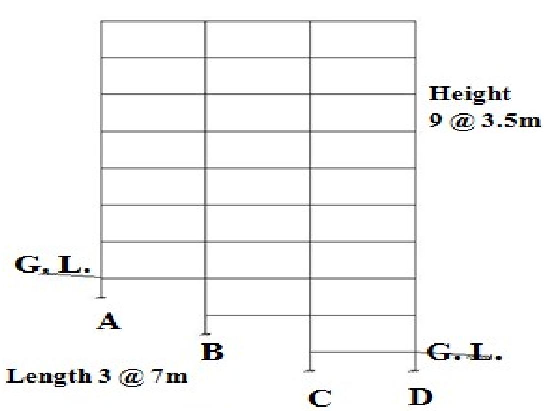

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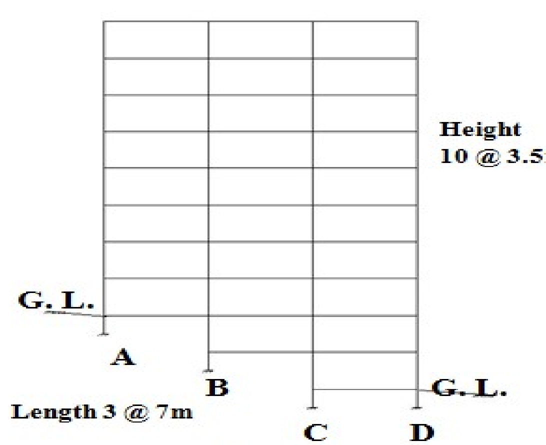

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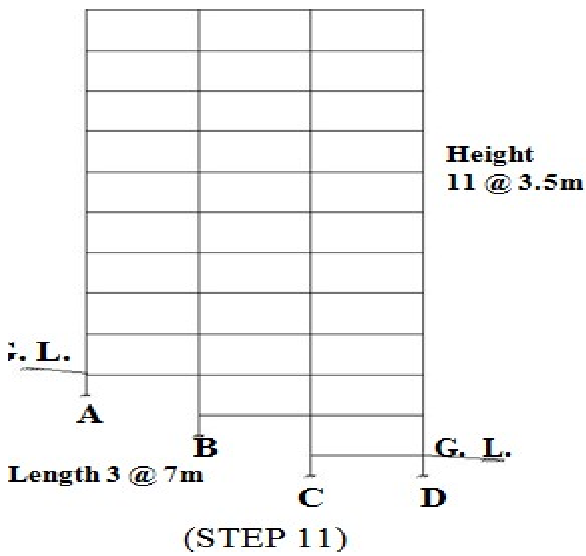
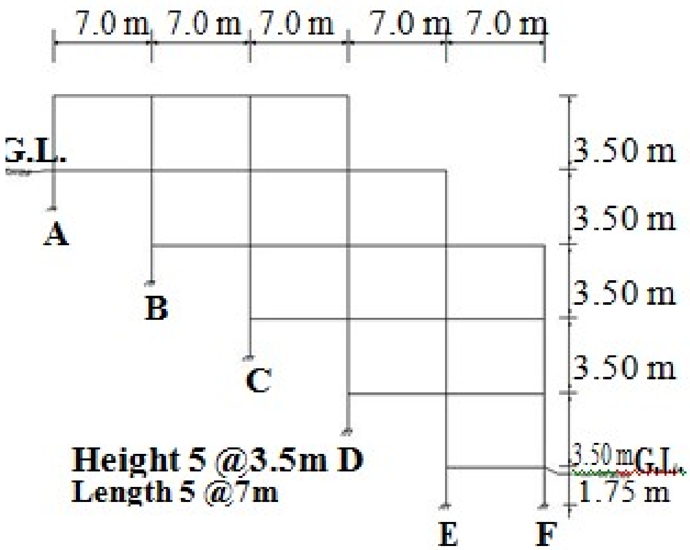
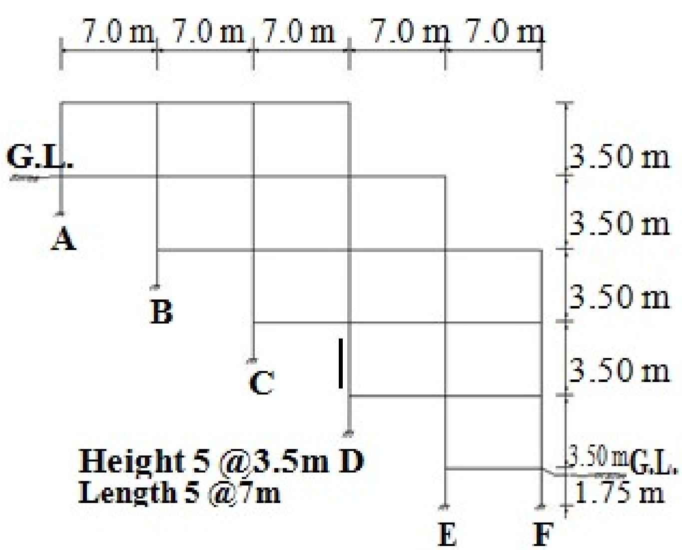


FIGURE 3.1: BUILDING MODELS FOR STEP BACK CONFIGURATION ON SLOPING GROUND (4 TO 11 STOREYS)

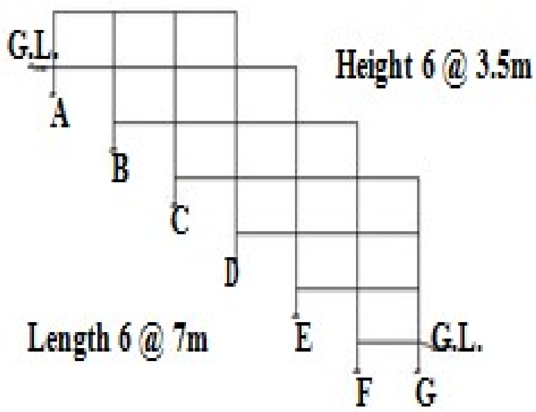
3.4.2 STEP BACK SET BACK BUILDING MODELS:



STEP SET 4



STEP SET 5



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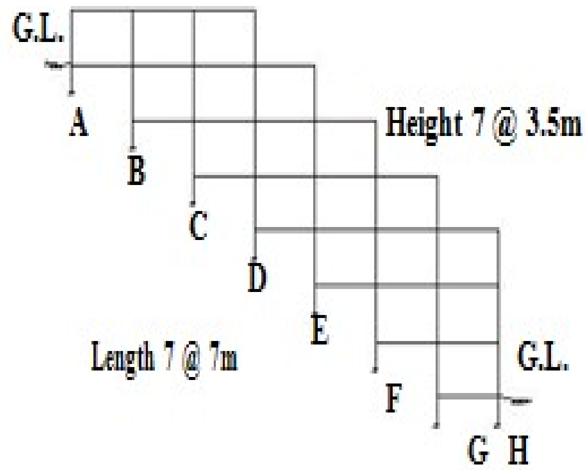

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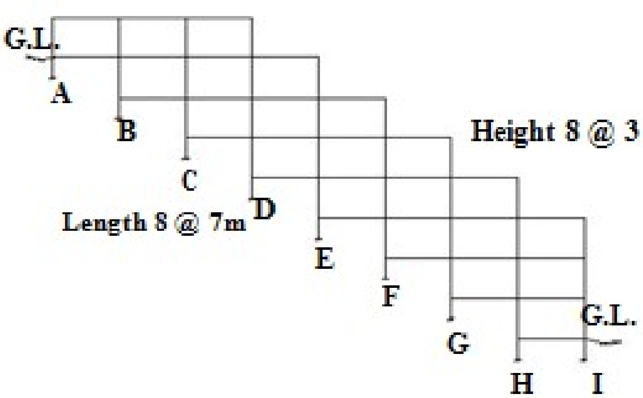

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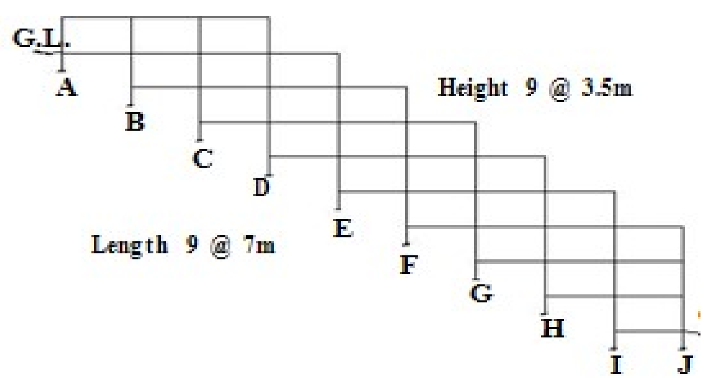

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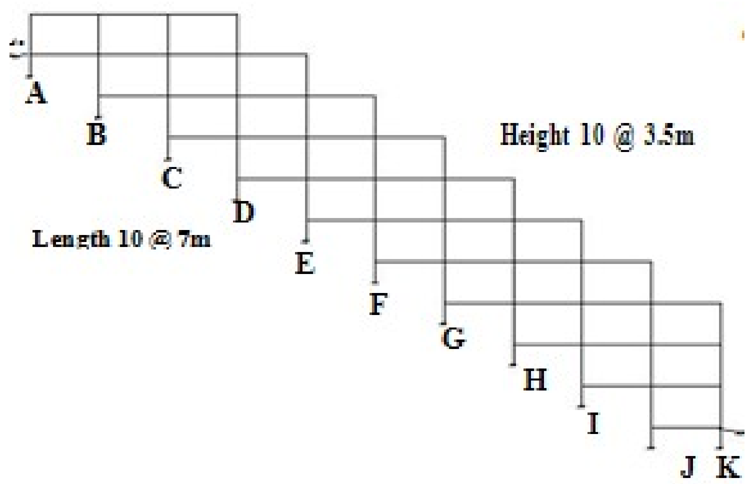
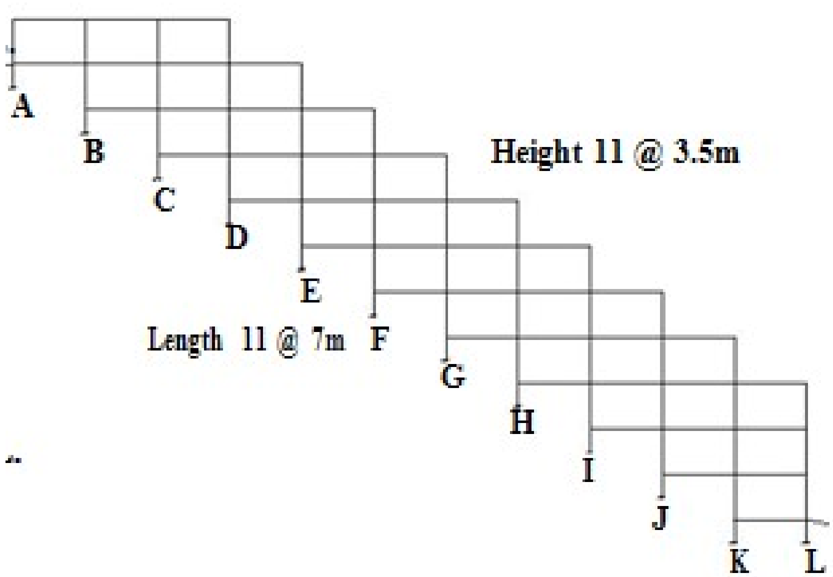


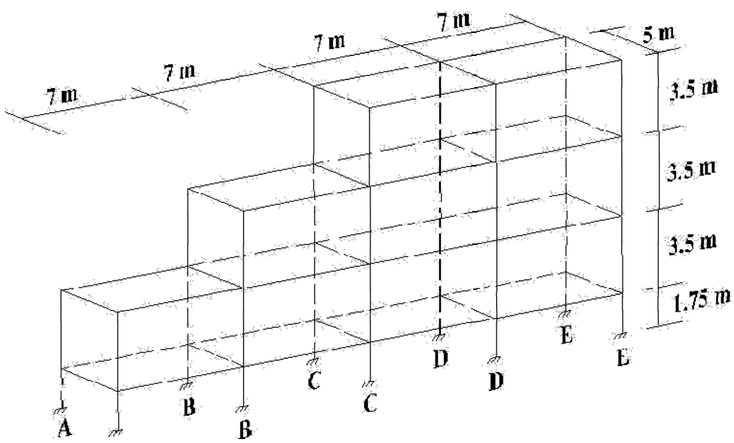
STEP SET 10



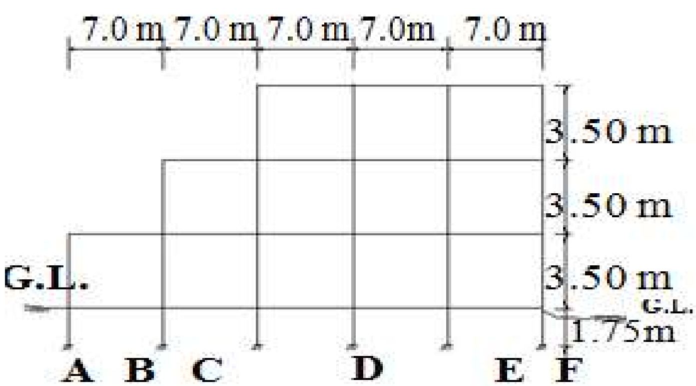
STEP SET 11

FIGURE 3.2 BUILDING MODEL FOR STEP BACK SET BACK CONFIGURATION ON SLOPING GROUND (4 TO 11 BAYS)

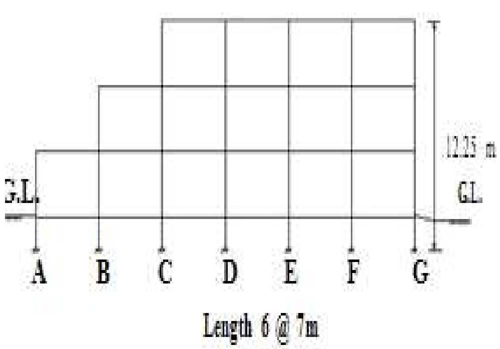
3.4.3 SET BACK BUILDING:



SET 4



SET 5



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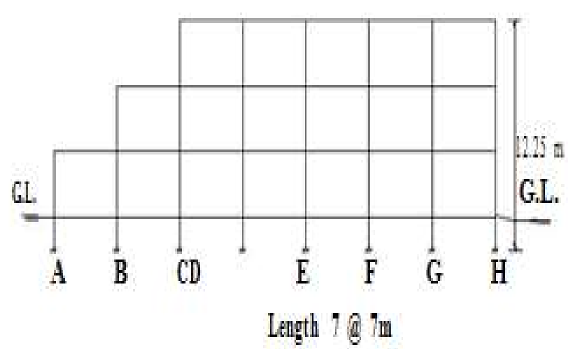

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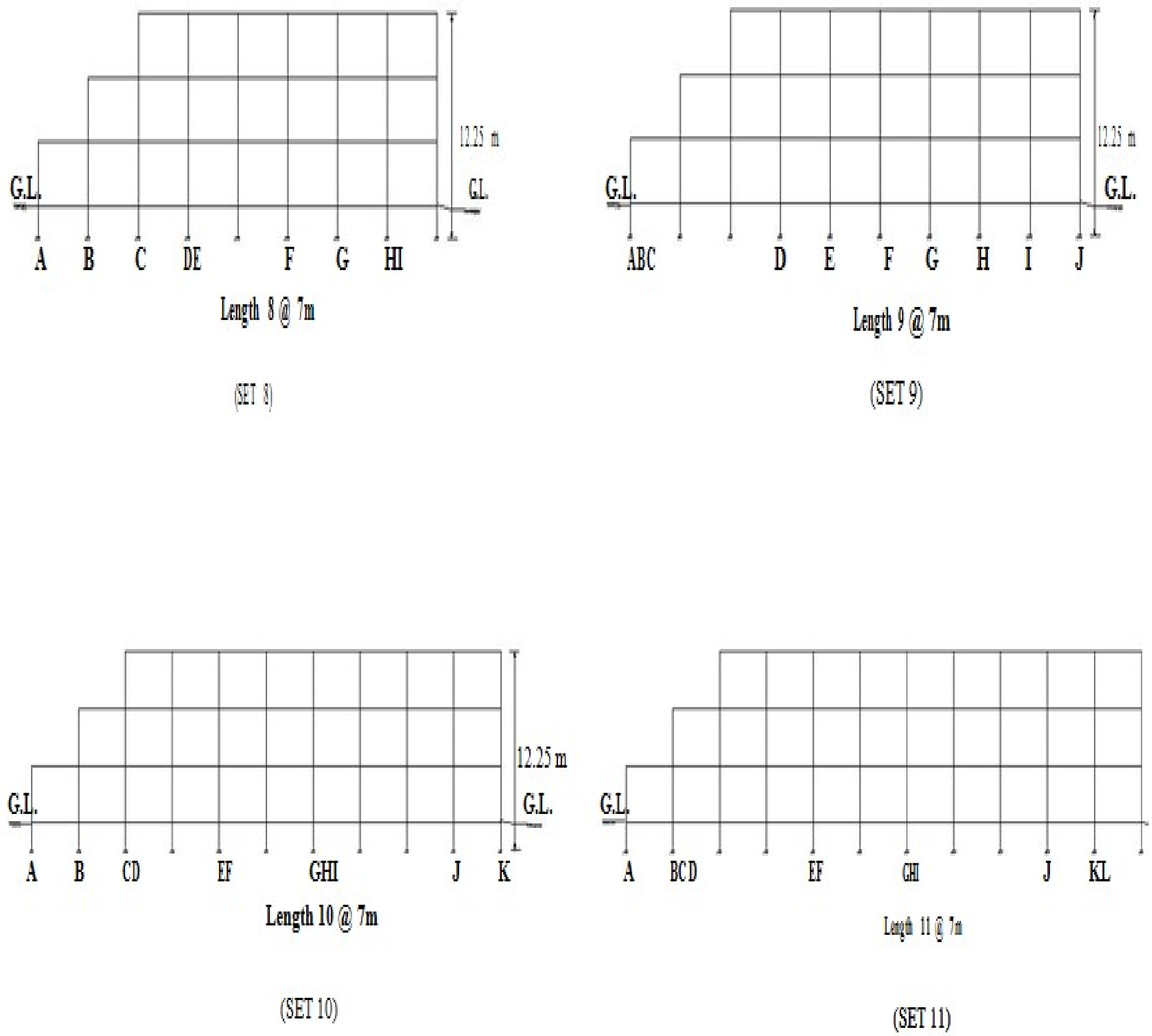


FIGURE 3.3: BUILDING MODEL FOR SET BACK CONFIGURATION ON PLAIN GROUND

Chapter 4

ANALYSIS

4.1 RESPONSE SPECTRUM ANALYSIS (RAS):

Response spectrum analysis method is used for dynamic analysis of all building structures configurations by using IS: 1893 (PART 1)-2002.Due to static and accidental generation of eccentricity torsion effect is also considered. The other parameters used in dynamic analysis are as given below –

- Seismic zone – moderate (zone III)
- Zone factor - .016
- Importance factor -1.0
- Damping – 5%
- Response reduction factor (s_a /g) – 3.0

Assumed that all the building configuration and height of building structures is considered under ordinary moment resisting frame (OMRF).

For each building structure configuration, minimum six modes considered in which, the summation of modal masses of all modes was at least 99 % of the total earthquake/ seismic mass. Due to seismic loading, member forces were computed for each contributing mode and the modal responses were combined together using CQC method.

The following design spectrum was utilized in response spectrum analysis (s_a/g):

$$S_a/g = \begin{cases} 1+15T & \text{when } 0.0 \le T \le 0.10 \text{ seconds} \\ 2.50 & 0.0 \le T \le 0.40 \text{ seconds} \\ 1/T & 0.40 \le T \le 4.0 \text{ seconds} \end{cases}$$

First, the seismic analysis of building structure was carried out without shifting the center of mass (C.G.) from their real position. Then the results got from the application of torsion moment at each floor level equal to lateral force times to the addition result of static and accidental eccentricity at that were superimposed on the results from seismic analysis.

4.2 ASSUMPTIONS USED IN ANALYSIS:

The analysis is based on these following assumptions.

- Material is homogeneous, isotropic and elastic in nature.
- In this analysis secondary effects like P-Δ effect, shrinkage and creep effects are not considered.
- The floor diaphragms are rigid by nature in their plane.
- In columns axial deformation is considered.
- Each and every nodal point has six degree of freedom, three in translations and three in rotations.
- Induced torsion effects are considered as per IS-1893(Part 1).
- The value of modulus of elasticity and passions ratio are $2*10^5$ N/mm^2 and 0.20 respectively

4.3ANALYSIS OF RESULTS:

In all 24 building structures seismic analysis have been done with earthquake loads with an effect of accidental eccentricity. The seismic load was applied in X and Z direction means along the structures and across the structures applies independently. The important got results are described in the following sections.

4.3.1 STEP BACK BUILDING:

In this building configuration, total eight no. of structures models have been analyzed with varying height 15.75 m to 40.25 m from 4 to 11 storeys. This building rests on 27 degree angle of ground slope.

Case a: When earthquake force in X-direction (along the slope line):

The seismic response of each step back building in terms of natural time period, maximum top storey sway and base shear values in column base at ground level is presented in table 4.1(a). It was seen that there was linear increment in the top storey sway and time period value increases as the height of step building increases.

Though the building structure configuration is regular along the slope line and in X direction torsion effect is insignificant due to accidental eccentricity. It is observed that in the extreme left column shear force is significant higher as comparison to rest of the column at ground level for different heights of building. Comparatively, extreme right and adjacent to it like frame D and frame C at ground level, shear force is very less, it is about 5 to 7% of the extreme left columns normalized shear force.

Table 4.1(a): Dynamic Response Properties of STEP BACK Building due to Earthquake Force in X- Direction.

Designation	Storey no.	Storey height (m.)	Max.- displacement (mm)	Base shear force at ground level(kN)			
				Frame A	Frame B	Frame C	Frame D
Step 4	4	15.75	9.75	131.1	45.7	8.6	9.1
Step 5	5	19.25	19.86	175.5	58.1	11.3	10.9
Step 6	6	22.75	24.07	224.2	48.3	9.7	10.1
Step 7	7	26.25	31.45	247.9	51.9	10.5	10.5
Step 8	8	29.75	36.78	274.7	48.5	10.7	10.9
Step 9	9	33.25	44.54	287.9	52.5	11.3	12.5
Step 10	10	36.75	47.54	346.2	59.2	17.6	16.7
Step 11	11	40.25	57.05	360.3	61.0	15.4	15.5

Case b: when earthquake force in Z – direction (across the slope line):

Table 4.1(b) shows the dynamic characteristics of each step back building structure for excitation in z direction. When earthquake force is in Z direction, the effect of static and accidental eccentricity is reduced.

Table 4.1(b): Seismic Response Properties of STEP BACK Building due to Earthquake Force in z- direction

Designation	Storey no.	Storey height (m.)	Max.- displacement (mm)	Base shear force at ground level(KN)			
				Frame A	Frame B	Frame C	Frame D
Step 4	4	15.75	44.29	64.7	52.1	21.4	30.6
Step 5	5	19.25	48.57	59.6	44.8	18.8	26.6
Step 6	6	22.75	50.87	71.5	48.3	17.3	22.5
Step 7	7	26.25	64.41	77.6	49.3	17.2	24.7
Step 8	8	29.75	57.92	82.2	49.8	13.3	22.4
Step 9	9	33.25	66.98	86.2	50.1	14.5	23.6
Step 10	10	36.75	74.99	101.2	51.8	13.4	17.7
Step 11	11	40.25	78.97	108.4	63.2	25.1	32.5

Torsion moment is maximum in Z – direction due to the effect of eccentricity generated, the normalized value of base shear force in extreme left column (frame A) at ground level is comparative less from the normalized value of base shear in X – direction. From design consideration special attention should be given to the size (strength) of the beam element, orientation of element (stiffness) and ductility and extreme left column at ground level should be in safety condition under worst load combination in X and Z direction.

4.3.2 STEP BACK SET BACK BUILDING:

Case (a) when Earthquake Force in X- direction (along the slope line)

- Frame A attracts maximum shear varying between the columns at extreme left
- The last two frames (Frame K and Frame L) to the extreme right of the structures are subjected to least shear forces.
- Adjacent frames to extreme left (Frame B and onwards) attracts varying shear forces.
- Storey displacement also comes out to be very less and variation among the drift values is very less.
- Its base shear values at extreme left column on upward hill side is comparative lesser to step back building.
- In this building configuration seismic activity is discontinuous in between so lesser base shear occurs.

Table 4.2 (a): Seismic Response Properties of STEP BACK SET BACK Building due to Earthquake Force in X- Direction.

Designation	Storey No.	Storey Height (m)	Max. Displacement (mm)	Base Shear Force at Ground Level (KN)							
				Frame A	Frame B	Frame C	Frame D	Frame I	Frame J	Frame K	Frame L
Step 4	4	15.75	3.59	86.26	50.74	29.06	6.52				
Step 5	5	19.25	3.93	93.93	63.67	54.61	29.97				
Step 6	6	22.75	4.15	98.1	67.0	74.36	57.20				
Step 7	7	26.25	4.12	96.92	62.97	75.94	76.65				
Step 8	8	29.75	4.20	99.07	62.48	76.32	87.45	6.95			
Step 9	9	33.25	4.25	100.9	61.45	72.99	88.54	8.04	8.25		
Step 10	10	36.75	4.45	102.6	58.93	71.87	87.95	27.70	7.12	5.26	
Step 11	11	40.25	4.29	103.8	54.47	66.88	81.43	56.15	25.13	5.47	6.71

Case (b) when Earthquake Force in Z direction (across the slope line):

When seismic force is applied in Z direction, it is observed from table 4.2 (b) that-

- There is less significant variation of base shear force in all frames, in this configuration due to earthquake force X direction extreme left Frame A is not severely stressed including the lateral forces in Z direction cause in significant effect due to torsion.
- Results obtained from seismic analysis are dominant for design purpose against of results obtained from static analysis for the building structure of step back set back configuration having height 8 to 11 storey.
- The natural time period in Z direction by seismic analysis is not so much affected by the height of Step Back Set Back building structures whereas according to IS -1893 (PART 1) time period linearly varies with the height of building.
- It is perceived that in Step Back Set Back building structures, when earthquake force in X direction the required action force are dominant for design purpose.
- The tope storey sway is lesser in X direction about 3.8 to 4 times comparatively Z direction values under dynamic forces.
- From design consideration , the uniform section having constant area of steel and constant area of concrete throughout from base level to top for extreme left column frame A, would be sufficient for fulfill the design purpose , requirements for heights of Step Back Set Back building structures considered . For the rest of the column similar trend is observed.

Table 4.2 (b): Seismic Response Properties of STEP BACK SET BACK Building due to Earthquake force in Z direction

Designation	Storey no.	Storey Height (m)	Max. Displacement (mm)	Base Shear Force at Ground Level (KN)							
				Frame A	Frame B	Frame C	Frame D	Frame I	Frame J	Frame K	Frame L
Step 4	4	15.75	13.41	43.14	40.85	36.00	14.09				
Step 5	5	19.25	15.52	35.31	41.15	38.45	32.02				
Step 6	6	22.75	13.62	31.29	36.85	37.84	32.60				
Step 7	7	26.25	12.61	22.95	22.80	31.19	29.85				
Step 8	8	29.75	13.42	21.59	25.56	28.68	29.45	11.50			
Step 9	9	33.25	13.32	19.96	23.89	27.08	28.32	8.29	12.38		
Step 10	10	36.75	12.45	18.92	24.31	27.48	27.96	18.92	16.39	7.93	
Step 11	11	40.25	13.50	18.24	27.29	26.96	26.24	24.41	15.59	8.90	11.12

4.3.3 SET BACK BUILDING ON PLAIN GROUND:

For earthquake force in X as well as in Z directions Set back configurations of eight building structures on plain ground have been analyzed.

- The floor area of each set back building structures on flat terrain is same as that of the other configuration like Step Back and Step Back Set back building resting on sloping ground.
- Floor area of SET 4 =STEP 4 =STEPSET 4 and so on.
- This set back building configuration results intended to create a plain ground in a natural sloping ground terrain, extra cost will be added to make the plain level ground of sloped ground.
- In this present study of analysis only structural behavior under the seismic forces has been carried without any emphasis in cost construction.

Case (a): when earthquake force is in X direction:

Table 4.3(a) shows the results obtained from seismic analysis of Set back building structures. It is to be noted that the peripheral frames (boundary surface) are found to carry lesser amount of shear force compared to interior frames.

Table 4.3 (a): Seismic Response Properties of SET BACK Building due to Earthquake Force In X direction

Designation	Storey no.	Storey Height (m)	Max. Displacement (mm)	Base Shear Force at Ground Level (KN)							
				Frame A	Frame B	Frame C	Frame D	Frame I	Frame J	Frame K	Frame L
Step 4	4	15.75	12.46	27.02	40.73	40.11	41.58				
Step 5	5	19.25	13.41	28.44	44.20	43.71	43.60				
Step 6	6	22.75	13.62	30.20	45.29	44.80	44.71				
Step 7	7	26.25	14.47	35.31	47.34	47.82	45.72				
Step 8	8	29.75	14.86	33.33	49.88	49.35	49.25	35.64			
Step 9	9	33.25	15.13	36.05	52.95	50.43	51.32	52.01	36.39		
Step 10	10	36.75	15.33	33.35	51.85	51.31	51.31	51.31	52.31	36.97	
Step 11	11	40.25	15.47	35.09	54.43	51.89	52.89	53.89	51.89	53.89	35.57

Case (b): when earthquake force in Z direction:

Due to action of earthquake forces in Z direction, it is observed that base shear in columns at base levels for different frames in Set back configuration is more or less same.

- The natural time period is constant for all the Set Back building structures as predicted by IS : 1893 (Part 1) where prediction using response spectrum analysis (RSA) are found to achieve higher value of time period.
- The top storey sway in X direction is 3.5 times lesser than the values obtained from Z direction.
- The value of base shear is comparatively much higher i.e. about 2.835 to 3.025.
- These values of base shear ratio shows that in Set backin every building structures, the design of column is mainly influenced by action forces induced in Z directions.
- Set back building structure configuration is suitable if making the hilly terrain to flat ground economical.

Table 4.3 (b): Seismic Response Properties of SET BACK Building due to Earthquake Force In Z direction

Designation	Storey no.	Storey Height (m)	Max. Displacement (mm)	Base shear Force at Ground Level (KN)							
				Frame A	Frame B	Frame C	Frame D	Frame I	Frame J	Frame K	Frame L
Step 4	4	15.75	41.94	44.37	42.30	41.60	41.33				
Step 5	5	19.25	39.44	43.75	41.69	42.80	42.89				
Step 6	6	22.75	46.68	49.49	47.45	44.83	43.84				
Step 7	7	26.25	47.68	51.26	49.30	46.48	48.17				
Step 8	8	29.75	51.17	55.05	58.30	51.55	50.16	68.20			
Step 9	9	33.25	41.76	55.85	53.62	52.85	51.17	58.85	62.19		
Step 10	10	36.75	52.24	59.47	58.80	55.90	54.23	63.89	68.00	72.30	
Step 11	11	40.25	54.01	60.85	59.85	57.55	55.38	60.12	64.28	64.50	72.43

4.4 COPARATIVE STUDY OF THREE BUILDIND CONFIGURATION:

4.4.1 Step Back Building v/s Step Back Set Back Building:

- In Step Back building structure, higher base force is attracted by Frame A compare to Frame B,C and D. This uneven distribution of base shear force in the various frames suggests development of torsion moment due to static and accidental eccentricity which has shown that profound effect in Step Back building structures.
- In Step Back Set Back building structure configuration also seen the uneven distribution of base shear force in various frames. However this unequal distribution of base shear force is low to moderate. In this configuration also torsion moments develops under earthquake force due to accidental eccentricity but in lesser magnitude.
- The Step Back Set Back building configuration has an advantages to neutralizing the torsion moments effects.
- Step back set back building performs better than the Step back building during earthquake ground motion, provided short columns are taken special care of in design and detailing of reinforcement.
- From observation table it is clear that Step Back building structures are subjected to higher amount of torsion moments due to irregularity compared to Step Back Set Back structures
- Step Back structures may prove more vulnerability during earthquake excitations than Step Back Set Back configuration.
- Both structures rest on sloping ground but have different seismic resisting capacity because of different configuration of the structures.

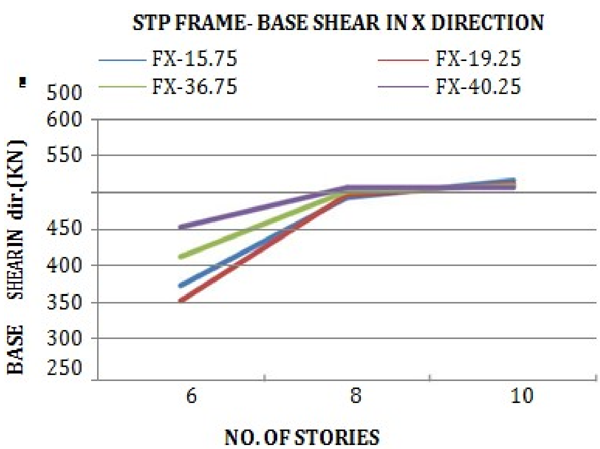
4.4.2 Step Back Set Back Building v/s Set Back Building:

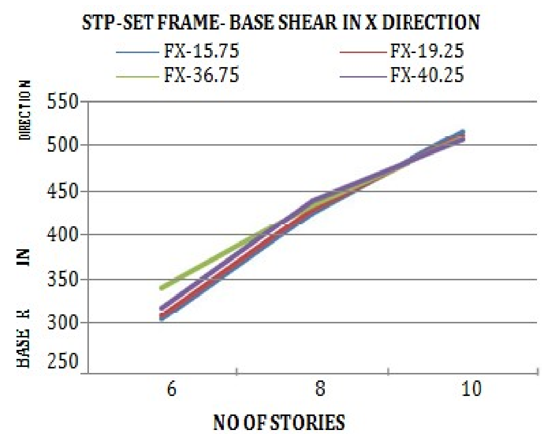
- Base shear action induced in Set Back building structures on plain ground is moderately lesser as compare to Step Back Set Back building structures configuration.
- It is to be noted that higher stiffness is required in X direction in Step Back Set Back building structures where as in Set Back building structure more stiffness is required in Z directions.
- Set Back building structures on plain terrain may be more preferable than the Step Back Set Back building structures if economy of cutting the hilly sloped comes under control condition and other related issue is within acceptable limits.
- In Set Back building structures configuration stability of slopes and vulnerability during earthquake ground motion are less concerned.

4.5 GRAPHICAL REPRESENTATION OF RESULTS:

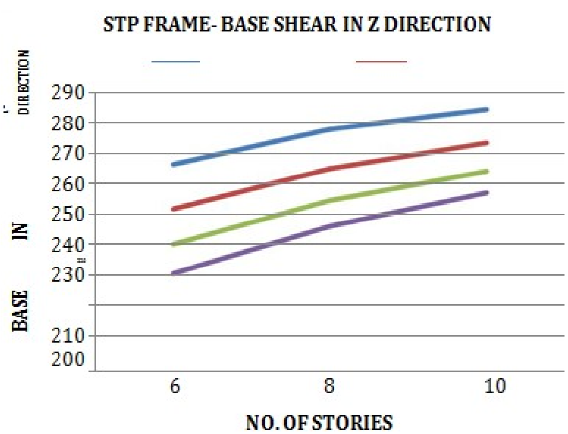
A. Comparison between Step frame v/s Step Back Set Back Frame with respect to base Shear and no. of stories:

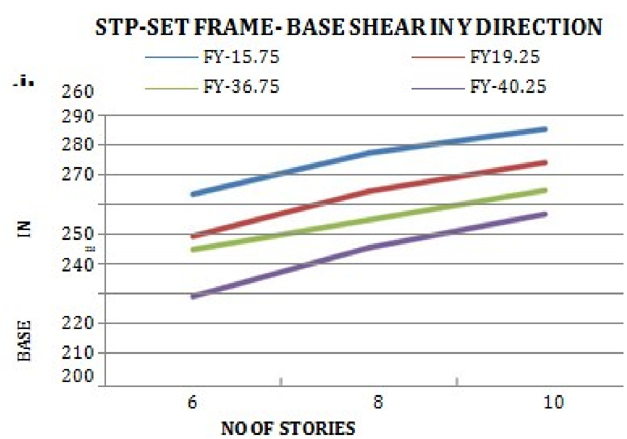
Case a- when earthquake force in X- direction





Case b- When Earthquake force in Z direction

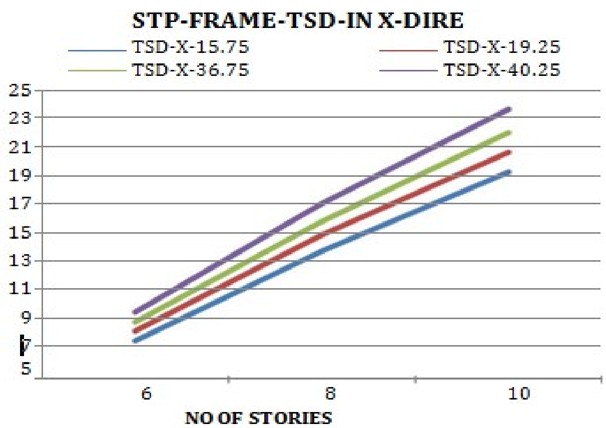


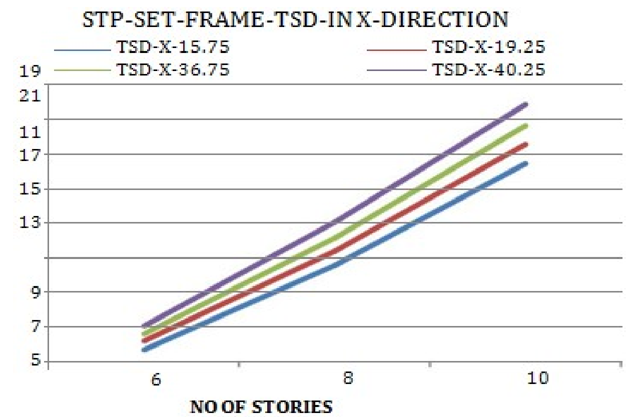


- There is rise in base shear value with respect to increase in storey height in X direction
- In Z direction rate of increase is almost same.

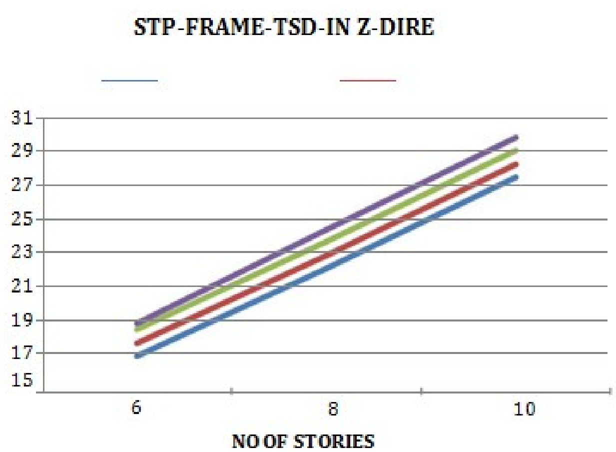
B. **Comparison between Step frame v/s Step Back Set Back Frame with respect to top Storey sway (mm) and no. of stories:**

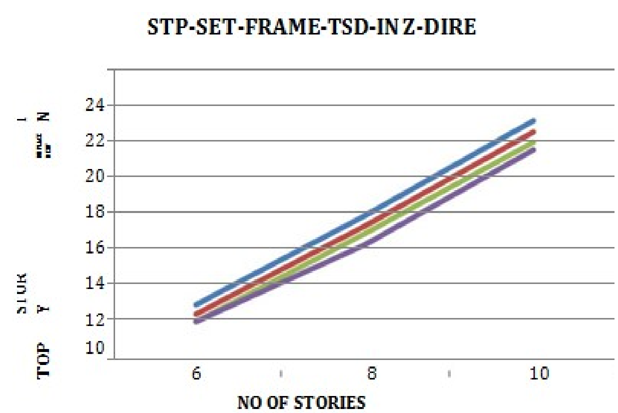
Case a- When Earthquake Force in X direction:





Case b- When Earthquake Force in Z direction:





- The variation of top storey displacement is linearly varies with the height of building.
- The sway does not show much variation with the sloping angle but as the height of building varies, this variation can be seen clearly.

Chapter 5

SUMMARY

&

CONCLUSION

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

Due to ground motion (vibrations), earthquake is caused and because of this structures got damage. To compensate these effects it is more important to know the characteristics of earthquake and predicts it's all possible response which occurs on the building structures. These properties which should be properly study are base shear action, maximum storey sway, velocity of nodes and acceleration etc.

In this research work, analysis has been done with validation of the data on structure analysis software STAAD PRO. to know the response of the building structure under ground motion. The results of response for each configuration is carefully studied and compared.

5.2 CONCLUSIONS

Based on the seismic analysis of three different configurations of building structures, the following conclusions can be drawn.

- The performance of STEP BACK building configuration during earthquake excitations could prove more vulnerable than other configuration like Step Back Set Back and Set Back building structures.
- In Step Back Set Back building configuration torsion moment due to accidental generates in lesser amount compare to Step Back building configuration. Hence Step Back Set Back building Structures are found to be less susceptible than Step Back building against seismic ground motions.

- In step back and step back set back building structures, it is observed that extreme left column at ground level which is shorter, worst affected so special attention is required for these columns in design and detailing.
- Although the Set Back configuration resting on flat ground attracts lesser base shear action compared to step back set back configuration overall economical cost involved to level the sloping ground and other related issue with this is need to study in detail.
- As angle of ground increases top storey displacement decreases.
- Top storey sway decreases as number of bays increases therefore it is confirmed that greater number of bays are observed to be better under seismic conditions.

5.3 FUTURE WORK

There is a great scope for future research work in this area of study. This analysis can be analyzed for different varying frequency content i.e. low frequency, intermediate frequency and high natural frequency content. In this transient linear time history analysis is performed, one can performed non linear time history analysis for the sloping frame model. Wind analysis of sloping structures can also be performed in future.

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