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# '' SEISMIC ANALYSIS OF BUILDINGS RESTING ON SLOPING GROUND ''

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**ABSTRACT**

*Results from seismic analyses performed on 24 RC buildings with three different configurations like, Step back building, Step back Set back building and Set back building are presented. 3 –D analysis including torsional effect has been carried out by using response spectrum method. The dynamic response properties i.e. fundamental time period, top storey displacement and, the base shear action induced in columns have been studied with reference to the suitability of a building configuration on sloping ground. It is observed that Step back Set back buildings are found to be more suitable on sloping ground.*

***Keywords: Hill slope angle, number of bays, response spectrum analysis, step back frames, step back & set back frames , Etabs 2013.***

## 1. INTRODUCTION

Earthquake is the most disastrous and unpredictable phenomenon of nature. When a structure is subjected to seismic forces it does not cause loss to human lives directly but due to the damage cause to the structures that leads to the collapse of the building and hence to the occupants and the property. Mass destruction of the low and high rise buildings in the recent earthquakes leads to the need of investigation especially in a developing country like India. Structure subjected to seismic/earthquake forces are always vulnerable to damage and if it occurs on a sloped building as on hills which is at some inclination to the ground the chances of damage increases much more due to increased lateral forces on short columns on uphill side and thus leads to the formation of plastic hinges. Structures on slopes differ from those on plains because they are irregular horizontally as well as vertically. In north and north-eastern parts of India have large scale of hilly terrain which fall in the category of seismic zone IV and V. Recently Sikkim (2011), Doda (2013) and Nepal earthquake (2015) caused huge destruction. In this region there is a demand of construction of multi-storey RC framed buildings due to the rapid urbanization and increase in economic growth and therefore increase in population density. Due to the scarcity of the plain terrain in this region there is an obligation of the construction of the buildings on the sloping ground. The economic growth and 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 and pressing demand for the construction of multi-storey buildings on hill slope in and around the cities.

## 2.SCOPE:

Three dimensional space frame analysis is carried out for three different configurations of buildings ranging from 4 to 11 storey (15.75 m to 40.25 m height) resting on sloping and plain ground under the action of seismic load. Dynamic response of these buildings, in terms of base shear, fundamental time period and top floor displacement is presented, and compared within the considered configuration as well as with other configurations. At the end, a suitable configuration of building to be used in hilly area is suggested.

## 3. OBJECTIVES:

Response of building frame on sloping ground depends on many parameters such as number of bays, hill slope angle and number of stories etc. In the study, two building configurations are considered namely step back frames and step back & set back frames. The objective of study is as follows:

1. To study the effectiveness of configuration of building frames such as step back and step back & set back frames.

2. To study the variation of base shear with respect to variation in number of bays, hill slope angle, storey height for different configurations of building frames.

3. To study the variation of time period with respect to variation in number of bays, hill slope angle, storey height for different configurations of building frames.

4. To study the variation of top storey displacement with respect to variation in number of bays, hill slope angle, storey height for different configurations of building frames.

## 4. FORMULA

- SCALE FACTOR = I*G/2R
- REVISED SCALE FACTOR= 0.85X IG/2R X Static base shear/Dynamic base shear
- BASE SHEAR RATIO $\lambda$ =Vb/VB

where I=Importance factor , G=standard acceleration due to gravity=9810 mm/s$^2$

R=response reduction factor , Vb = Static base shear , VB= Dynamic base shear

The spectrum ordinates defined within various code options, including IS:1893, are normalized values in which spectral accelerations are divided by gravity acceleration. The spectrum must be converted to the specific set of units used throughout the model by applying a scale factor given as the value of gravity acceleration in the current units of your model.

Note that the design spectrum of IS:1893 is actually the MCE-level spectrum which must be reduced by dividing this value by a factor of 2R, in which R is the response reduction factor. In the first run, the value of the scale factor should be SF = I*g/(2R), in which I is the importance factor. After the first run, check the base shear which develops in the model, and if this value is less than the code-prescribed minimum, then increase the scale factor of the first run such that the resultant base shear matches the code specification.

## 5. MODELLING

### 5.1 Statement of Problem:

In this study various numbers of structures are modelled and analyzed which are same in plan but vary in total height of building i.e. number of story variations. All columns, beams and structural slabs were included in the model of each building**.** All models are subjected to dynamic analysis with the help of ETABS 2013. The dimension of all the beams and columns are design according to IS 456-2000 .The building is designed to resist dead load, live load & seismic load and all the result based on IS1893:2000 13 combination are taken for the analysis and design all 24 model.

As per IS 1893:2002 [8] the following seismic parameters were used to calculate the seismic forces and design.

Zone factor = 0.16 (Zone IV)

Importance factor = 1.0 (Residential Building)

Response reduction factor = 5

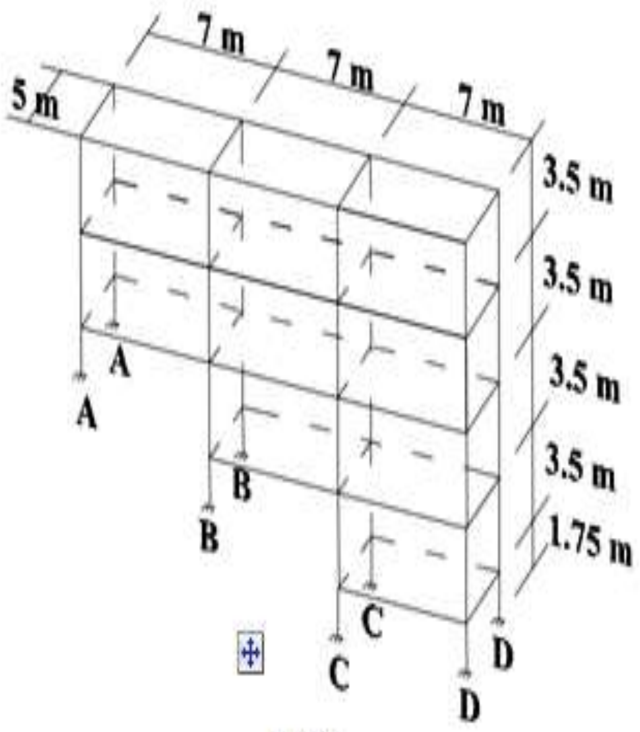
Type of Frame= Special moment resting frame (SMRF)

The other detailed description is as follows:

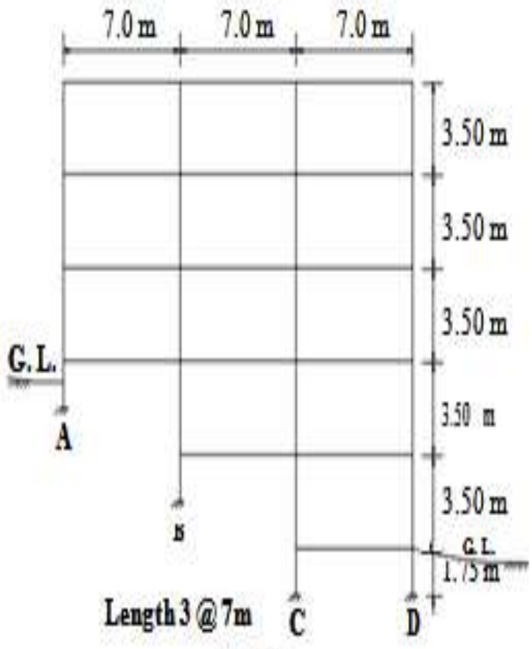
1. Size of Building: 7m X 5m.
2. Floor to floor height: 3.5 m
3. Bottom floor height:1.75 m
4. Slab thickness: 125 mm
5. Wall thickness: 230 mm
6. Grade of concrete (Beam): M30
7. Grade of concrete (Column):M30
8. Grade of steel: Fe 500
9. Density of concrete: 25 kN/m3
10. Density of masonry wall: 20 kN/m3
11. Modulus of elasticity for concrete: 27386.13 Mpa
12. Poissons Ratio : 0.2

**Geometrical properties of members for different configurations of building.**

| Building configuration | configuration | Size of column | Size of Beam | Size of slab |
|---|---|---|---|---|
| Step Back Buildings | STEP 4 | 230x500 mm | 300 x 600 mm | 125 mm |
| | STEP 5 To STEP 8 | 300x500 mm | | |
| | STEP 9 | 300x600 mm | | |
| | STEPSET 10 To STEPSET 11 | 300x700 mm | | |
| Step Back & Set Back Buildings | STEPSET 4 To STEPSET 7 | 230x500 mm | 300 x 600 mm | 125 mm |
| | STEPSET 8 To STEPSET 11 | 300x600 mm | | |
| Step Back Buildings | SET 6 & SET8 | 230x500 mm | 300x500 mm | 125mm |
| | SET 4 TO SET 11 | 230x500 mm | 300x600 mm | |



(STEP 4)



(STEP 5)

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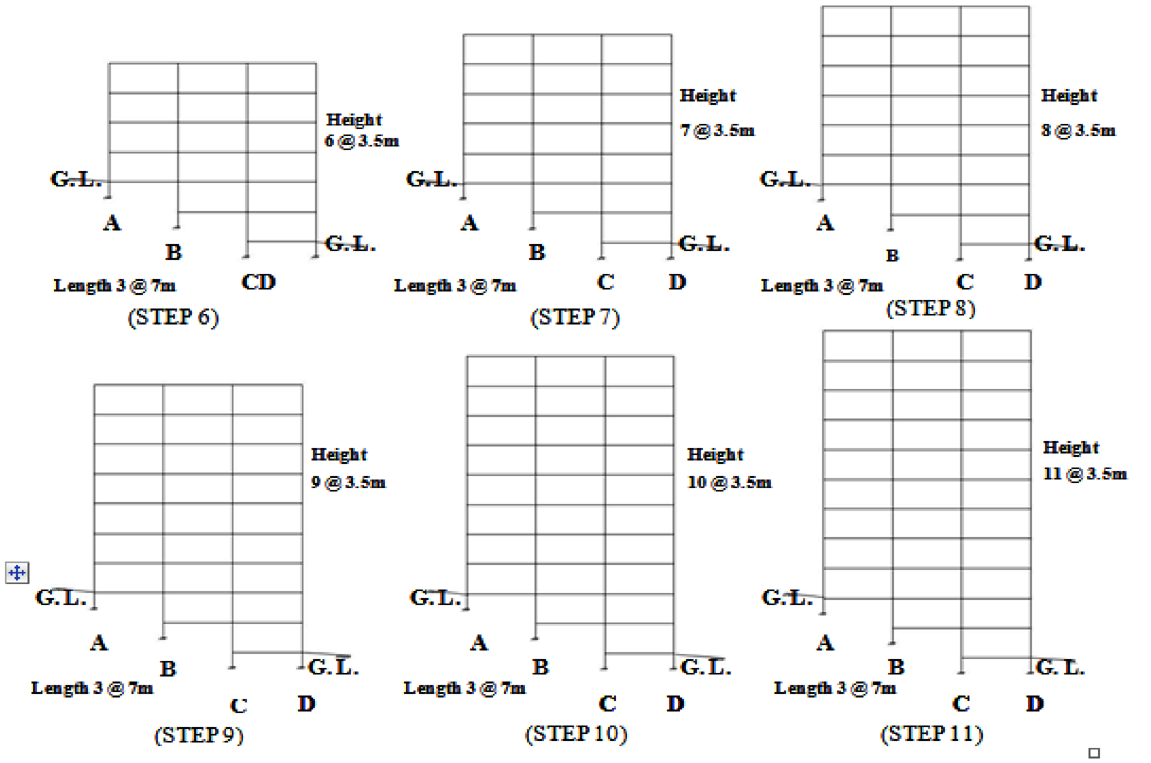
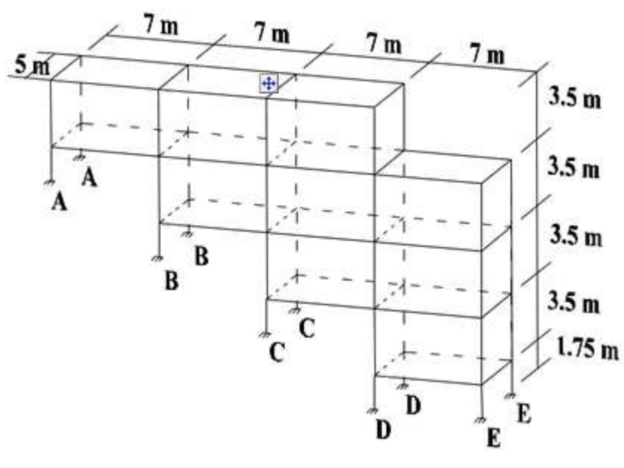
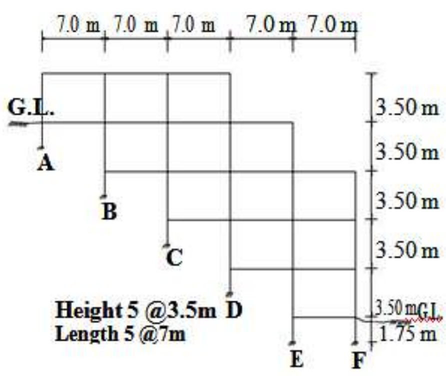



STEP BACK BUILDINGS ON SLOPING GROUND (4 TO 11 STOREY)




(STPSET 4)

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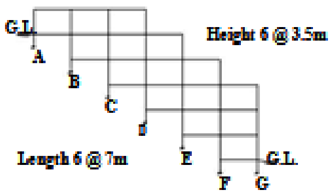


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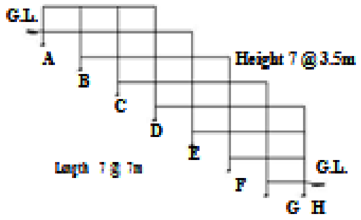
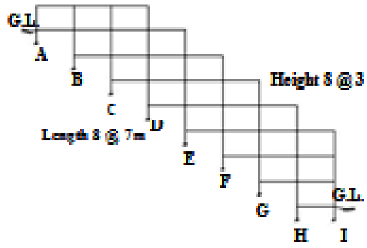



(STPSET 7)

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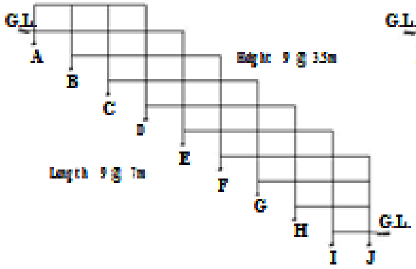


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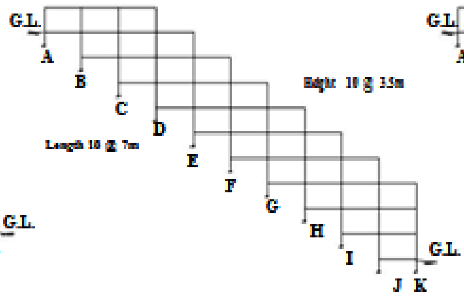
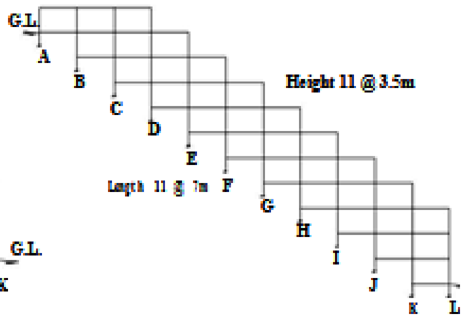
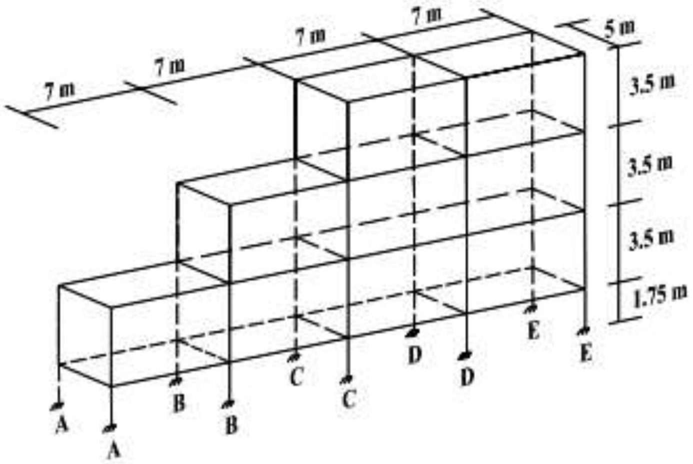



(STPSET 10)




(STPSET 11)

**STEP BACK SET BACK BUILDINGS ON SLOPING GROUND (4 to 11 storey)**

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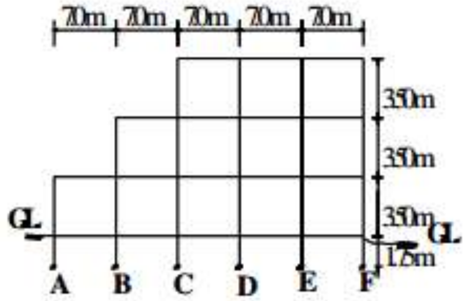


( SET 5)

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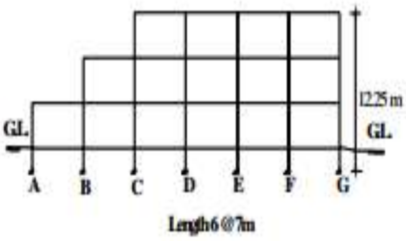
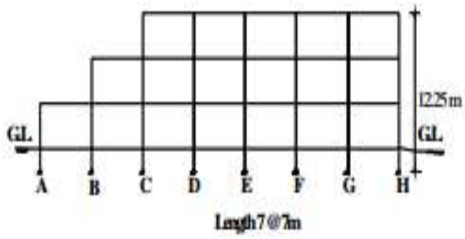
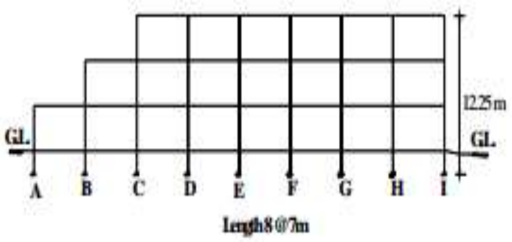


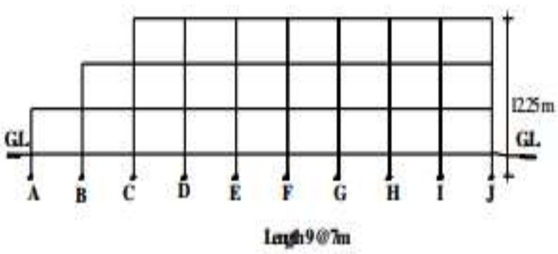

(SET6)



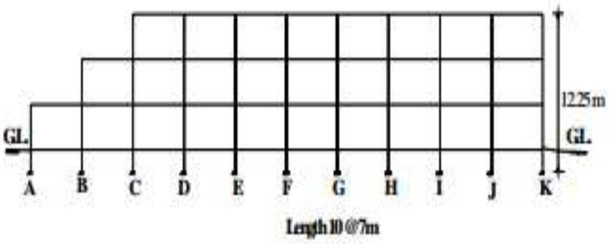

(SET7)




(SET8)




(SET9)

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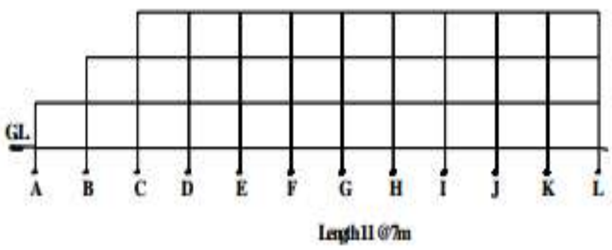


(SET 11)

## SET BACK BUILDINGS ON PLAIN GROUND

| TIME PERIOD CALCULATION STATIC AND DYNAMIC | | | | | |
|---|---|---|---|---|---|
| DESIGNATION | NO OF STOREY | HT IN METERS | TIME PERIIOD BY IS:1893(I)-2002 IN SEC. | | FUNDAMENTAL TIME PERIOD IN RSA IN SEC |
| | | | X DIR | Y DIR | |
| STEP 4 | 1 | 15.75 | 0.31 | 0.633 | 1.358 |
| STEP 5 | 2 | 19.25 | 0.378 | 0.774 | 1.363 |
| STEP 6 | 3 | 22.75 | 0.446 | 0.915 | 1.643 |
| STEP 7 | 4 | 26.25 | 0.515 | 1.056 | 1.949 |
| STEP 8 | 5 | 29.75 | 0.584 | 1.197 | 1.962 |
| STEP 9 | 6 | 33.25 | 0.653 | 1.338 | 2.426 |

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| | | | | | |
|---|---|---|---|---|---|
| STEP 10 | 7 | 36.75 | 0.721 | 1.479 | 2.45 |
| STEP 11 | 8 | 40.25 | 0.79 | 1.62 | 2.851 |

| TIME PERIOD CALCULATION STATIC AND DYNAMIC | | | | | |
|---|---|---|---|---|---|
| DESIGNATION | NO OF STOREY | HT IN METERS | TIME PERIIOD BY IS:1893(I)-2002 IN SEC. | | FUNDAMENTAL TIME PERIOD IN RSA IN SEC |
| | | | X DIR | Y DIR | |
| STEP SET 4 | 1 | 15.75 | 0.267 | 0.634 | 1.102 |
| STEP SET 5 | 2 | 19.25 | 0.293 | 0.775 | 1.133 |
| STEP SET 6 | 3 | 22.75 | 0.316 | 0.915 | 1.159 |
| STEP SET 7 | 4 | 26.25 | 0.337 | 1.056 | 1.176 |
| STEP SET 8 | 5 | 29.75 | 0.358 | 1.197 | 0.993 |
| STEP SET 9 | 6 | 33.25 | 0.377 | 1.338 | 0.932 |
| STEP SET 10 | 7 | 36.75 | 0.395 | 1.479 | 1.005 |
| STEP SET 11 | 8 | 40.25 | 0.413 | 1.62 | 0.855 |

| TIME PERIOD CALCULATION STATIC AND DYNAMIC | | | | | |
|---|---|---|---|---|---|
| DESIGNATION | NO OF STOREY | HT IN METERS | TIME PERIIOD BY IS:1893(I)-2002 IN SEC. | | FUNDAMENTAL TIME PERIOD IN RSA IN SEC |
| | | | X DIR | Y DIR | |
| SET 4 | 1 | 12.25 | 0.2083 | 0.493 | 1.097 |
| SET 5 | 2 | 12.25 | 0.1863 | 0.493 | 0.995 |
| SET 6 | 3 | 12.25 | 0.1701 | 0.493 | 1.039 |
| SET 7 | 4 | 12.25 | 0.1575 | 0.493 | 1.038 |
| SET 8 | 5 | 12.25 | 0.1475 | 0.493 | 1.265 |
| SET 9 | 6 | 12.25 | 0.1389 | 0.493 | 1.218 |
| SET 10 | 7 | 12.25 | 0.1317 | 0.493 | 1.227 |
| SET 11 | 8 | 12.25 | 0.1256 | 0.493 | 0.959 |

**6.4 Dynamic response properties of STEP BACK & SET BACK building due to Combined loading in X & direction**

| DESIGNATION | HT IN METERS | Normalized Value Of SF In Columns at Ground In KN (X DIR) | | | | Normalized Value Of SF In Columns at Ground In KN (Y DIR) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Frame A | Frame B | Frame C | Frame D | Frame A | Frame B | Frame C | Frame D |
| STEP 4 | 15.75 | 189.47 | 59.11 | 31.12 | 122.85 | 83.12 | 59.98 | 33.5 | 43.9 |
| STEP 5 | 19.25 | 231.06 | 70.72 | 31.78 | 129 | 132.39 | 89.36 | 45.56 | 61.96 |
| STEP 6 | 22.75 | 193.46 | 63.49 | 32.23 | 127.46 | 103.52 | 76.3 | 45.48 | 61.87 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| STEP 7 | 26.25 | 187.32 | 61.96 | 32.11 | 127.53 | 102.94 | 75.32 | 45.03 | 61.24 |
| STEP 8 | 29.75 | 103.96 | 29.94 | 8.33 | 111.56 | 103.16 | 85.86 | 58.33 | 85.81 |
| STEP 9 | 33.25 | 211.06 | 74.42 | 31.69 | 128.31 | 113.25 | 78.54 | 45.36 | 61.26 |
| STEP 10 | 36.75 | 265.1 | 98.35 | 28.65 | 123.23 | 131.22 | 85.02 | 47.07 | 62.13 |
| STEP 11 | 40.25 | 260.32 | 106.61 | 11.35 | 86.33 | 109.11 | 83.16 | 34.2 | 44.73 |

**6.4 Dynamic response properties of STEP BACK & SET BACK building due to Combined loading in X direction**

| DESIGNATION | HT IN METERS | Normalized Value Of SF In Columns at Ground In KN | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frame A | Frame B | Frame C | Frame D | Frame E | Frame F | Frame G | Frame H | Frame I | Frame J | Frame K | Frame L |
| STEPSET 4 | 15.75 | 164.6 | 95.09 | 50.82 | 32.44 | 123.4 | | | | | | | |
| STEPSET 5 | 19.25 | 203.1 | 95.43 | 86.08 | 44.99 | 32.77 | 124 | | | | | | |
| STEPSET 6 | 22.75 | 231 | 103.4 | 63.35 | 59.39 | 27.97 | 33.87 | 124.1 | | | | | |
| STEPSET 7 | 26.25 | 250.1 | 125.6 | 76 | 52.76 | 49.94 | 22.09 | 34.41 | 124.1 | | | | |
| STEPSET 8 | 29.75 | 344.1 | 209.9 | 175.6 | 135.5 | 105.2 | 102.4 | 6.65 | 50.28 | 183.3 | | | |
| STEPSET 9 | 33.25 | 318.8 | 209.5 | 174.4 | 138 | 104.1 | 76.92 | 66.03 | 36.67 | 29.33 | 22.54 | | |
| STEPSET 10 | 36.75 | 399 | 240.6 | 204.3 | 165.8 | 127.8 | 92.15 | 62.3 | 60.33 | 25.09 | 0.059 | 165.9 | |
| STEPSET 11 | 40.25 | 294.1 | 215 | 185.7 | 154 | 122.5 | 93.86 | 66.92 | 45.09 | 43.63 | 18.02 | 36.97 | 129.5 |

**6.4 Dynamic response properties of STEP BACK & SET BACK building due to Combined loading in Y direction**

| DESIGNATION | HT IN METERS | Normalized Value Of SF In Columns at Ground In KN | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frame A | Frame B | Frame C | Frame D | Frame E | Frame F | Frame G | Frame H | Frame I | Frame J | Frame K | Frame L |
| STEPSET 4 | 15.75 | 86.28 | 65.17 | 65.51 | 33.44 | 42.87 | | | | | | | |
| STEPSET 5 | 19.25 | 92.9 | 77.24 | 61.18 | 50.65 | 41.18 | 40.17 | | | | | | |
| STEPSET 6 | 22.75 | 44.94 | 34.27 | 22.64 | 10.8 | 3.43 | 9.27 | 4.78 | | | | | |
| STEPSET 7 | 26.25 | 88.22 | 77.18 | 66.65 | 55.56 | 45.12 | 39 | 31.25 | 32.94 | | | | |
| STEPSET 8 | 29.75 | 86.49 | 77.97 | 67.78 | 55.16 | 40.92 | 25.67 | 3.46 | 9.87 | 9.84 | | | |
| STEPSET 9 | 33.25 | 136.6 | 129.5 | 114 | 95.95 | 78.05 | 61.54 | 47.23 | 40.43 | 4.41 | 13.49 | | |
| STEPSET 10 | 36.75 | 178 | 172.7 | 156.6 | 138 | 119.1 | 101.6 | 85.92 | 72.46 | 65.53 | 57.18 | 61.72 | |

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**6.10 Dynamic response properties of SET BACK building due to Combined loading in X direction**

| DESIGNATION | HT IN METERS | Normalized Value Of SF In Columns at Ground In KN | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frame A | Frame B | Frame C | Frame D | Frame E | Frame F | Frame G | Frame H | Frame I | Frame J | Frame K | Frame L |
| SET 4 | 12.25 | 5.91 | 79.09 | 73.63 | 70.04 | 139.3 | | | | | | | |
| SET 5 | 12.25 | 2.09 | 69.57 | 64.61 | 63.9 | 62.18 | 102 | | | | | | |
| SET 6 | 12.25 | 0.95 | 48.39 | 48.79 | 46.73 | 46.58 | 44.77 | 86.44 | | | | | |
| SET 7 | 12.25 | 28.2 | 58.01 | 53.84 | 52.76 | 52.68 | 52.06 | 47.29 | 100.5 | | | | |
| SET 8 | 12.25 | 3.49 | 51.5 | 50.52 | 49.94 | 50.23 | 50.15 | 50.65 | 49.86 | 76.29 | | | |
| SET 9 | 12.25 | 4.43 | 143.9 | 73.7 | 75.86 | 75.74 | 75.14 | 74.68 | 74.4 | 71.49 | 138.6 | | |
| SET 10 | 12.25 | 3.58 | 108.3 | 74.26 | 74.97 | 75 | 74.28 | 73.87 | 73.4 | 73.14 | 70.2 | 137.7 | |
| SET 11 | 12.25 | 4.13 | 72.05 | 67.45 | 66.49 | 66.4 | 65.76 | 65.33 | 65.02 | 64.7 | 64.52 | 62.58 | 108.2 |

**6.11 Dynamic response properties of SET BACK building due to Combined loading in Y direction**

| DESIGNATION | HT IN METERS | Normalized Value Of SF In Columns at Ground In KN | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frame A | Frame B | Frame C | Frame D | Frame E | Frame F | Frame G | Frame H | Frame I | Frame J | Frame K | Frame L |
| SET 4 | 12.25 | 62.13 | 100.9 | 113.8 | 126.3 | 114.8 | | | | | | | |
| SET 5 | 12.25 | 55.07 | 88.05 | 95.17 | 101.8 | 108.2 | 92.6 | | | | | | |
| SET 6 | 12.25 | 41.09 | 61.65 | 66.07 | 71.16 | 70.31 | 81.62 | 73.8 | | | | | |
| SET 7 | 12.25 | 49.25 | 74.32 | 78.49 | 82.12 | 85.51 | 88.7 | 92.19 | 79.95 | | | | |
| SET 8 | 12.25 | 39 | 56.28 | 59.49 | 63.33 | 66.95 | 70.34 | 73.51 | 76.47 | 67.49 | | | |
| SET 9 | 12.25 | 83.06 | 113.4 | 108.7 | 114.9 | 120.2 | 124.4 | 127.8 | 130.5 | 132.6 | 110.5 | | |
| SET 10 | 12.25 | 73.19 | 101.5 | 107.5 | 113.5 | 118.5 | 122.4 | 125.3 | 127.5 | 129.2 | 130.4 | 103.3 | |
| SET 11 | 12.25 | 51.99 | 76.03 | 79.73 | 82.71 | 85.22 | 87.14 | 88.5 | 89.5 | 89.99 | 90.1 | 89.88 | 74.04 |

For each building case, adequate modes (minimum six) were considered, in which, the sum of modal masses of all modes was at least 99 % of the total seismic mass. The member forces for each contributing mode due to dynamic loading were computed and the modal responses were combined using CQC method.

### 7.1 Step Back Buildings:

In this configuration, total eight buildings have been analyzed, with varying height from 15.75 m to 40.25m.

EQ. force in X direction and Y direction

The dynamic response of each step back building in term of fundamental time period, top storey displacement and, base shear in columns at ground level is presented in table 6.1 and 6.4. The fundamental time period and base shear ratio (λ) as per IS : 1893 (I)-2002 [2], in the same table. It is observed that there is linear increase in the value of top storey displacement and time period as the height of step back building increases. The value of fundamental time period by dynamic analysis is substantially higher than the values estimated by empirical equation given in IS: 1893 (I) –2002. Hence, the value of shear coefficient by dynamic analysis is less than the static method as per IS : 1893 (I)-2002. Though the building plan is symmetrical along the sloping line and the torsional effect including accidental eccentricity is insignificant in x direction, it is observed the shear force in the column towards extreme left is significantly higher as compared to the rest of the columns at ground level for different heights of buildings. Comparatively, in the extreme right columns and adjacent to them (frame D & frame C) at ground level, normalized values of shear force are just 5 to 7 % of that of the extreme left columns.

shows the dynamic properties of each of the step back building for excitation in Y direction. The effect of accidental eccentricity is substantial when earthquake force is in Y direction. The torsional moments due to an accidental eccentricity on each floor, which varies from 1.58 kN-m to 9.98 kN-m in column and 32.45 to 158.35 in beam. From design point of view, it is to be noted that particular attention should be given to the size (strength), orientation (stiffness) and ductility demand of the extreme left column at ground level such that it is safe under worst possible load combinations in X and Y directions.

### 7.2 Step Back Set Back Buildings:

The results of dynamic analysis of step back set back buildings are presented in Table. It is seen that the evaluation of fundamental time period using dynamic analysis (RSA) for 4 to 11 storey height of buildings varies in the range of 0.855 sec. to 1.10 seconds in X direction and in the range of 0.96 sec to 1.10 seconds in Y direction Whereas, it has varies from 0.267 sec. to 0.413 seconds .when evaluation using static method. On the whole it is observed that the value of base shear ratio varies 1.22 to 1.48, indicating that the results the results obtained from static and dynamic analysis do not differ substantially as the case of step back buildings.

Observations from Table 6.8 and 6.9 indicates that,

i) the columns at extreme left (frame A) attracts maximum shear varying between 203 to 399 kN.

iii) the last two frames to the extreme right are subjected to least shear forces.

### 7.3 Set Back Buildings on Plain Ground:

The results obtained from dynamic analysis of set back building. It is observed that the time period by RSA for SET 4 to SET 11 buildings has decreased from 1.09 sec. to 0.96 seconds, whereas for the same buildings, the value of time period predicted by IS:1893(I) –2002 has decreased from 0.2083 sec. to 0.1256 seconds and Y direction is constant The base shear ratio (λ) is found to vary between 1.93 to 1.36. and Y direction vary between 1.13 to 1.57  It is to note that the peripheral frames are found to carry fewer shears as compared to interior frames. Due to action of earthquake in Y direction, it is noticed that shear force in columns at ground level for different frames is more or less same. The fundamental time period as predicted by IS: 1893(I)-2002 is constant for all set back buildings, whereas, prediction using RSA are found to yield higher value of time period. The top storey displacement in y direction is less than the corresponding values in X direction. The base shear ratio has been found to vary between 2.835 to 3.025, which is significantly high. This indicates that in set back buildings the design of column will primarily be controlled by actions induced in Y direction.

**Step back- set back buildings Vs. Set back buildings:**

Shear action induced in Step back Set back buildings is moderately higher as compared to Set back buildings on plain ground. It is to be noted that in Step back Set back buildings, higher stiffness is required in X direction whereas, in Set back buildings more stiffness is required in Y direction. If, cost component of cutting the sloping ground and other related issues, is within the acceptable limits, set back buildings on plain ground may be preferred than the step back Set back buildings. In addition to this, issues viz. stability of slopes and vulnerability during the earthquake ground motion are less concerned in set back building.

## CONCLUSION

Based on dynamic analysis of three different configurations of buildings, the following conclusions can be drawn.

1) The performance of STEP back building during seismic excitation could prove more vulnerable than other configurations of buildings.

2) The development of torsional moments in Step back buildings is higher than that in the Step back Set back buildings. Hence, Step back Set back buildings are found to be less vulnerable than Step back building against seismic ground motion.

3) In Step back buildings and Step back-Set back buildings, it is observed that extreme left column at ground level, which are short, are the worst affected. Special attention should be given to these columns in design and detailing.

4) Although, the Set back buildings on plain ground attract less action forces as compared to Step back Set back buildings, overall economic cost involved in levelling the sloping ground and other related issues needs to be studied in detail.

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