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INFLUENCE OF SOIL STRUCTURE INTERACTION IN SEISMIC BEHAVIOR OF BUILDINGS ON HILL SLOPES

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Abstract: In a few parts of this world, especially the hilly areas are more prone to seismic movement; e.g. northeast region locale of India. In this sloping areas, customarily material like, the adobe, brunt block, stone brick work and dressed stone masonry, timber reinforced concrete, bamboo, and so on., which is by regional standards accessible, is utilized for the building of houses. There is a shortage of plain ground in hilly regions which constrains the construction or building activity on such a ground that is hilly. Hill building developed in workmanship with mud mortar/concrete mortar without complying with seismic codal procurements have demonstrated risky and, brought about death toll and property when subjected to Earthquake ground movements. The vast majority of the slope territories in the Indian Peninsula fall in dynamic seismic belts and because of lack of plain land, sloping area is in effect progressively utilized for built and non-engineered building Construction. Because of financial improvement and brutal natural conditions, stone brick work and bamboo construction is slowly being supplanted by Reinforcement framed concrete building. In numerous hilly areas, multi-storeyed reinforced concrete framed building lay on slope slants. Because of hilly slopes these building venture back towards the slope incline and in the meantime they may have setback likewise, having unequal statures at the same floor level. Building on slope inclines is profoundly unpredictable because of their fluctuated setups and asymmetry of variety in mass and stiffness distribution. During the activity of a earthquake these unpredictable and asymmetrical building usually come across lateral shears and torsional moments thus unable to withstand the twisting minutes and pivotal powers created by static loads in isolation.

1. SOIL STRUCTURE INTERACTION

The building structures are subjected to movements on account of the waves reaching them due to the impact of a earthquake. Such movements within the structure have great dependence on the vibrational attributes and the design of the building. In order that the building responds to such movements it must be in a position to conquer inertia of its own that leads to an interaction between the building and the associated soil. Properties of the soil and the structure such as the relative mass and its stiffness are relied in the observation of the degree up to which the structural response may change the earthquakes characteristic movements at the stage of foundation. Thus for the purpose of earthquake response of building, the physical property of the foundation medium that supports the building turns out to be a very necessary and essential element.

There are two types of building foundation interaction during quakes, which are of essential significance to earthquake designing. The first one being the response of the structure to the earthquake movements that is supported on a deformable soil as compared to the response of the structure to such earthquake movements that lie on a rigid foundation. The second interaction is, the difference in the recording of the movement at the structure base or in the immediate vicinity from the movement that is recorded when there would be no building.

Perceptions of the reaction of the building during earthquakes have demonstrated that the reaction of common building can be especially impacted by the soil properties if the soils are adequately soft. Moreover, for moderately rigid building, for example, atomic reactor control building, interaction impacts can be important even for generally firm soils in light of the fact that the critical parameter clearly is not the stiffness of the soil, but rather the relative stiffness of the building and its foundation. As far as the dynamic properties of building foundation framework, past studies have demonstrated that the interaction will, by and large, be decreasing the fundamental frequency of the system from that of the rigid base structure, dissipating a fraction of vibrational energy of the building by means of wave radiation into the medium of foundation and will also change the structures base movement as compared to the free field movement. Although every one of these impacts may be available in some degree for each structure, the critical point is to set up under what conditions the impacts are of functional significance.

2. OBJECTIVE OF THE STUDY

The most vital objective of the project is the seismic conduct of building on slope slants considering soil structure interaction. In uneven districts the conventional non-built developments are bit by bit offering approach to designed development entirely taking after the customary structure. In the seismically inclined ranges, presence of such developments lead to the structures being exposed to quite prominent shears and torsions as compared to the mediocre developments. So as to highlight the distinctions in conduct, which may further be affected by the attributes of the by regional standards accessible foundation material, study has been led on six delegate building.

- To perform a point by point study on the past accessible writing in the present range of study.
- Perform three dimensional space outline investigation for two unique arrangements of 4 and 11 story building laying on slanting under the activity of seismic burden with fluctuating bolster conditions.
- To present and analyze Dynamic reaction of these building, as far as base shear, essential time period and top floor uprooting inside of the considered arrangement and additionally with different setups.
- To propose a suitable setup of building to be utilized as a part of bumpy range.

3. SCOPE OF THE STUDY

With a specific end goal to accomplish the mentioned targets the following assignments have been done:

- All building are modelled using FEA package SAP2000 V 15.
- A three dimensional space frame along with the two nodded components of the beam having diaphragm indication is used to depict the Super structure of the building frame.
- The static and dynamic analysis has been completed for both the base conditions namely the rigid and flexible.
- A statically equivalent spring with a freedom of six degree has been used to replace the foundation in the analysis of the flexibility of foundation.

3.1 STUDIES ON SEISMIC ANALYSIS OF HILL BUILDINGS

B.G. Birajdar *et al.,* (2004) mulled over seismic analysis of buildings lying on inclining Plain. Seismic analysis performed on buildings of 24 RC with three distinct setups like, Step back building, Step back Set back building and Set back building were displayed. 3D analytical observations were done so as to include torsional impact has been done response range strategy. The dynamic response Characteristics i.e. basic time period, The top story dislodging and, the base shear activity incited on sections have been concentrated on source to the compatibility of the building arrangement resting on inclining plain. It is watched that Step back Set back buildings are observed to be more suitable on inclining ground.

Prabhat Kumar *et al.,* (2012) researched over the impact of Soil-Structure interface in seismic reaction of step back-set back buildings. They led a parametric study on eight delegate buildings keeping in mind the end goal to highlight the differences of behavior of step back-set back building frequently experienced in hilly regions this type of constructions in seismically active zones are highly bare to superior shears and torsional forces when contrasted with conservative methods of construction, the further results might be affected by the uniqueness of the base material available in the locality.

MODELING AND ANALYSIS

GENERAL

A detailed plan for the present study is envisioned based on the review of the available literature and accordingly the investigations are carried out.

Two configurations of building that are supposed to be resting on the sloping ground are considered in the present study. The first configuration being the step back buildings and second being the step back-setback buildings. Three dimensional space frame analysis is carried out for these configurations of buildings for 4 & 11 storey (15.75 m& 40.25 m height) with fixed base condition using SAP2000 V15 software package. , This constitutes the non interaction study.

The structures response is affected by the buildings dynamic analysis and the structures interaction with the soil foundation underneath the structure on the basis of the foundation soil's elastic properties, the kind of foundation used and its dimensions. Soil structure interaction is analyzed for such buildings under construction. In the following analysis the flexibility of foundation is being taken into account by replacing the foundation of soil with springs that are equivalent statically and have a freedom of degree six. An effort has be made to study the activities of these hill buildings with different soil conditions in terms of base shear, fundamental time period, top floor displacement and column forces.

BUILDING CONFIGURATION

The present study considers two types of building configurations are resting on ground that has a slope. The first configuration is the step back buildings and second one is the step back-setback buildings. The slope of ground is 27 degree with respect to the horizontal plane, that is not very steep and not very flat (Birajdar and Nalawada). The height and length of the structure in a particular pattern are found in multiple of blocks (in vertical and horizontal direction), the size of block is being maintained at 7 m x 5 m x 3.5 m. The depth of footing below ground level is taken as 1.75 m where, the hard stratum is available.

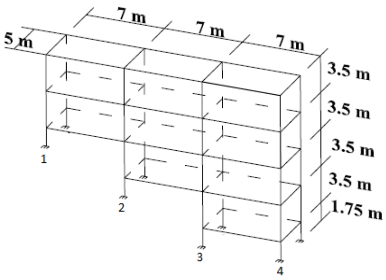

Fig 3.1: 4 Storey Step Back Building

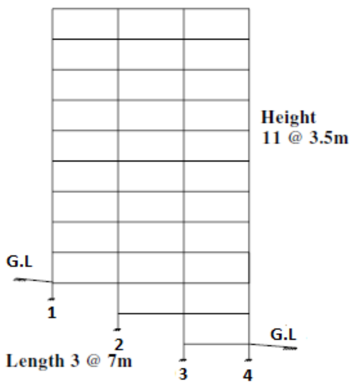

Fig 3.2: 11 Storey Step Back Building

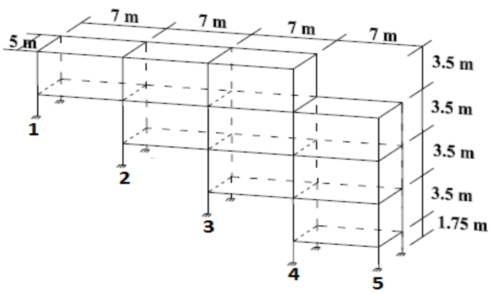

Fig 3.3: 4 Storey Step Back Set Back Building

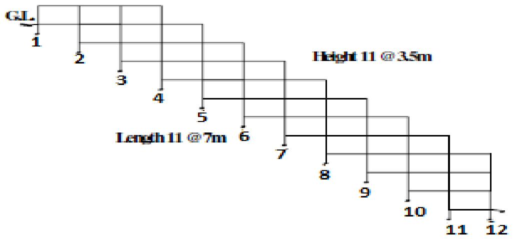

Fig 3.4: 11 Storey Step Back Set Back Building

4. RESULTS AND DISCUSSION

In the following section presentation of the results obtained from static and dynamic analysis of structure with various kinds of soil conditions in relation to the fixed base support is done.

In the present study, two configurations of building with 4 and 11 storey are considered with different type of soil conditions. The first one is step back buildings and second one is step back-setback buildings. A neither too sheer nor steep nor too flat angle is considered for the slope of the ground which is 27 degree with respect to the horizontal. Both the static and dynamic analyses have been evaluated for the conditions of flexible and rigid base. In the following analysis the foundation flexibility is taken into consideration by replacing the foundation by springs that are statically equivalent with a freedom of degree six. Further the adopted building configurations are subjected to statical analysis, which is carried out on the gravity loads. The method of Response Spectrum is used with IS: 1893 (Part 1): 2002 for the purpose of seismic analysis on all the considered buildings.

In the provided analysis the foundation flexibility is taken in to account by modelling the foundation soil as a spring that is statically equivalent and has been accomplished by means of adopting the spring constants as provided by Wolf (1985).For both the soft rock and soft soil, the elastic properties are taken into account in order to determine the spring constants for the purpose of isolated footing. The following parameters studied in the present work are, natural vibration characteristics, story displacements, shear force ground floor columns and seismic base shear.

4.1 STATIC ANALYSIS

In order to evaluate the behavior of the irregular buildings and to bring out the comparison and differences of the consequence of soil springs on the following displacements and various prevailing design forces, a static analysis is performed upon the gravity loads on the configurations of the adopted buildings.

The obtained values are articulated in terms of parameter ratio, that is the maximum top story displacement considering both horizontal and vertical and shear force for various type of soil conditions in relation to the fixed base support.

4.1.1 STATIC ANALYSIS OF STEP BACK BUILDINGS:

TABLE 4.1(a): Static analysis of step-back buildings with fixed base condition

No of storeys (Ht in m)	Max top storey vertical disp. (mm)	Shear force in columns at ground level (kN) FIXED support			
		F1	F2	F3	F4
15.75 (4)	3.537	28.06	26.63	24.74	24.68
40.25 (11)	23.98	30.29	28.87	27.52	27.48

TABLE 4.1(b) Static analysis of step-back buildings with soft rock support

No of storeys (Ht in m)	Ratio Max top storey vertical disp.	Ratio shear force in columns at ground level SOFT ROCK support			
		F1	F2	F3	F4
15.75 (4)	1.27	0.982	0.983	0.988	0.988
40.25 (11)	1.12	0.974	0.976	0.977	0.978

TABLE 4.1(c) Static analysis of step-back buildings with soft soil support

No of storeys (Ht in m)	Ratio Max top storey vertical disp.	Ratio shear force in columns at ground level SOFT SOIL support			
		F1	F2	F3	F4
15.75 (4)	10.08	0.690	0.704	0.730	0.731
40.25 (11)	5.1 0.500	0.481	0.533	0.533	0.535

In Step Back buildings that have the spring support because of the soft rock soil, the shear force ratio for frame 1, which is supposed to be the shortest frame, would vary from 0.956 values to the 0.982 value which is minimum to maximum respectively. The exterior frame ratio values would vary from 0.963 to 0.988. This result provides a view that these frames have lower value as compared to the fixed support value.

For the spring support because of the soft soil, the shear force ratio for frame 1, which is supposed to be the shortest frame, would vary from a minimum to maximum value of 0.5 and 0.69 respectively. And the exterior frame ratio would have the values ranging from 0.535 to 0.731, depicting that the considered frame values are quite lower than the fixed support values.

From the given Figure 4.1 it can be observed that the shear force in the columns reduces with decrease in shear modulus of soil. The rise in the left end of the graph shows that, the value of shear force in extreme left column i.e. shorter exterior column is higher than other columns.

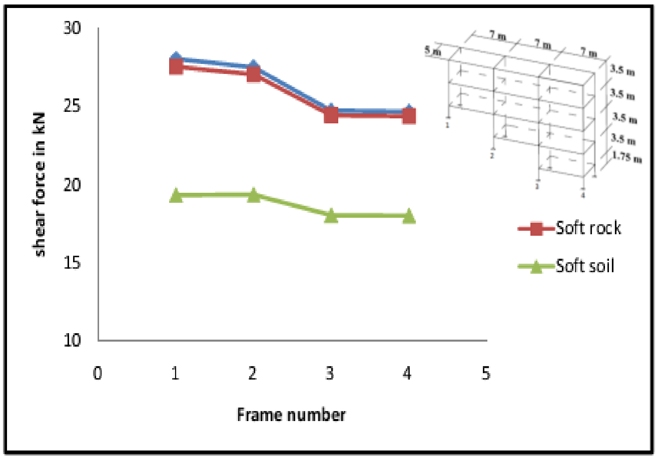

Fig. 4.1 (a):

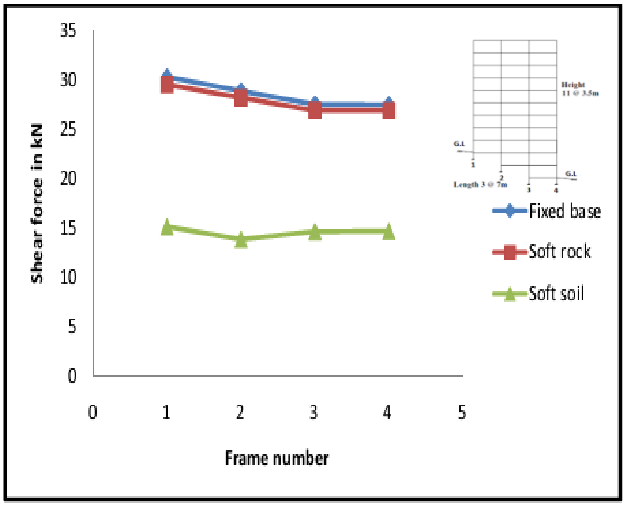

Fig. 4.1 (b): Shear force at ground level in columns (kN) (a) 4-stepback building (b) 11-stepback building

4.2 STATIC ANALYSIS OF STEPBACK-SETBACK BUILDINGS

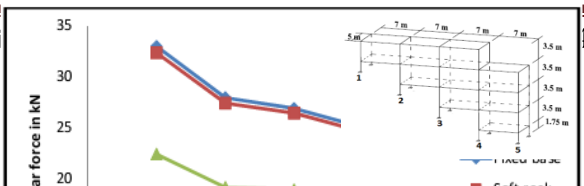

Fig 4.2 (a)

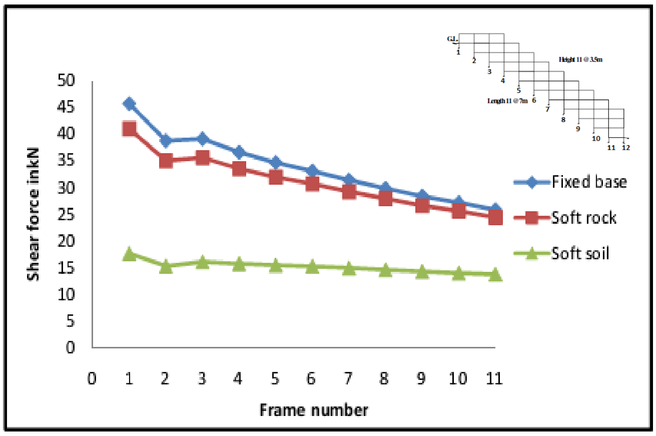

Fig 4.2 (b)Shear force in columns at ground level (kN) (a) 4- step-back-setback building, (b) 11- step-back-setback building.

4.3 DYNAMIC ANALYSIS

The method of response spectrum is used in order to carry out the seismic analysis of all the buildings by using IS: 1893 (I) –2002, which has different foundation media. The various other parameters that are used in seismic analysis are as follows, moderate seismic zone (III), zone factor of the value 0.16, importance factor of the value 1.0, damping ratio of 5% and a factor of response reduction with the value 3.0, while presuming ordinary moment resistant frame for all kinds of height and configuration of buildings. The above stated analysis has been carried out in both the directions that are X and Y.

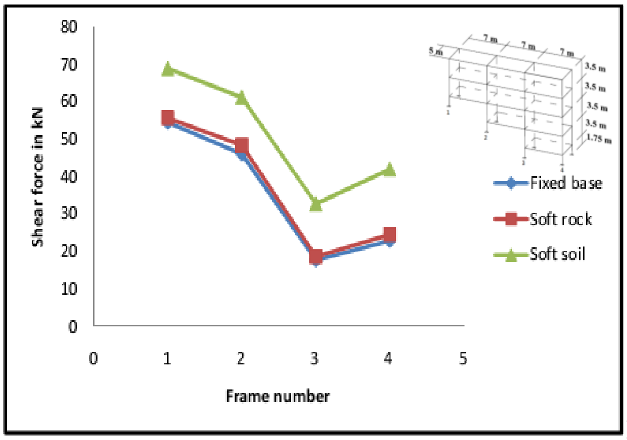

Fig4.3 (a):

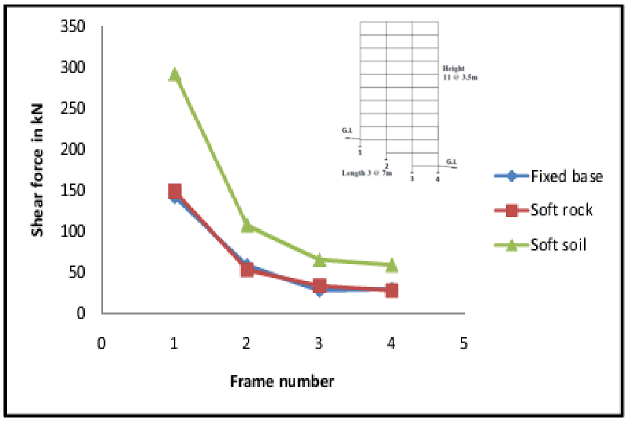

Fig 4.3 (b):
Normalized shear force in columns at ground level (kN) in x-direction (a) 4-stepback building (b) 11-step-back building.

The dynamic response of each of the step back building in term of fundamental or basic time period, top storey displacement and, base shear in columns at ground level is presented in Fig 4.3

The fundamental time period and base shear ratio (λ) as per IS: 1893 (I)-2002, are evaluated and are presented in the same table. A linear increase in the top storey displacement value and the time period is observed if there is increase in the step back building height. The fundamental time period value 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

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. 54 kN and 142.3 kN for 4 and 11 step back building respectively.

In the case of Step Back building that have spring models support for the soft rock, the variation of time period in the direction of X varies from 2.67 to 6.09 sec. The shear force ratio is observed to vary from the value 0.97 to 1.048 for the case of Frame 1 and from the value of 0.946 to 1.07 in the direction of X for the other frames that are exterior. The displacement ratio in the direction of X varies from 1.22 to 1.28.

In the favor of soft soil, the time period in the direction of X is observed to vary from 2.80 to 6.58 sec. The shear force ratio varies from a value of 1.103 to 2.32 in X-direction for frames that are exterior. In the same direction of X, the values range from 1.326 to 2.3. The displacement range ratio varies from 2.196 to 2.713 in direction of X.

4.4 DYNAMIC ANALYSIS OF STEPBACK-SETBACK BUILDINGS

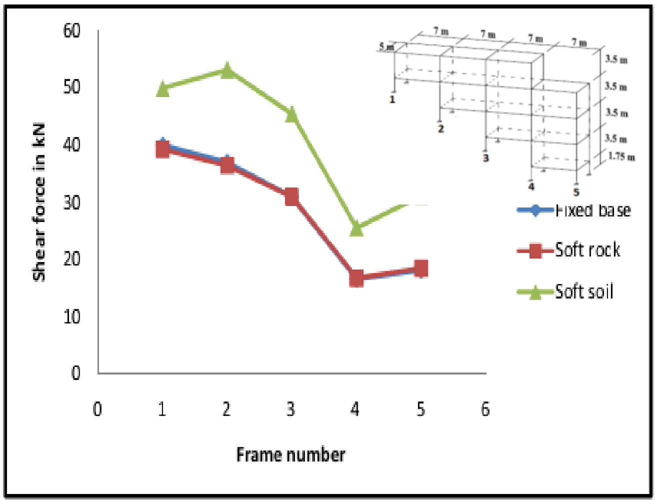

Fig 4.4 (a)

For the step back set back buildings the obtained results from the dynamic analysis are listed in the Fig 4.4 The results of dynamic analysis of step back set back buildings are presented in Fig 4.4 with an observation of the following points.

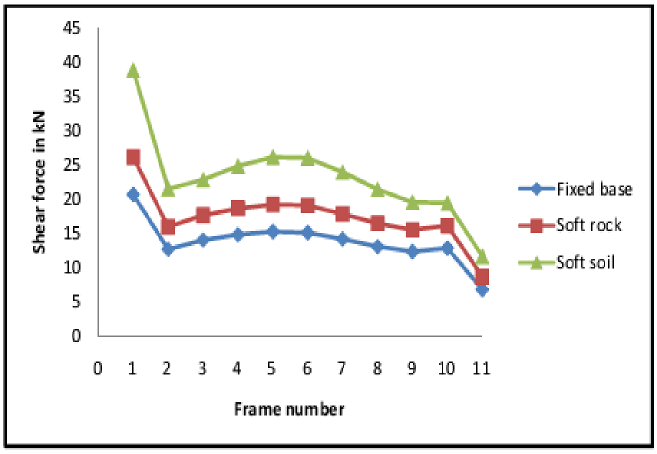

Fig 4.4 (b)

Normalised shear force in columns at ground level (kN) in x-direction (a) 4-stepback-setback building (b) 11- step-back-setback building.

- Less significant variation of shear force is observed in all frames.
- Extreme left frame 1 is not severely stressed, indicating the lateral forces in X direction cause insignificant effect due to torsion.

Moreover, the top storey displacement is comparatively higher in X direction than the corresponding values in Y direction, under the seismic action.

In the case of Step Back building that have spring models support for the soft rock, the variation of time period in the direction of X varies from 1.66 to 1.88 sec. The shear force ratio is observed to vary from the value 0.997 to 1.063 for the exterior frames and from the value of 0.992 to 1.127 in the direction of X for the interior frames. The displacement ratio in the X direction varies from 1.02 to 1.096.

In the favor of soft soil, the value of the time period in the direction of X is observed to vary from 2.195 to 2.336 sec. The shear force ratio varies from a value of 1.24 to 2.70 in X-direction for frames that are exterior. In the same direction of X, the values range from 1.280 to 1.716 for the frames that are interior. The ratio of displacement ranges from a value of 2.51 to 2.67 in X-direction. The value of displacement is seen to be increased with decrease in shear wave velocity of soil.

5. CONCLUSIONS

Based on the proposed work we draw the conclusions as mentioned below.

1. On the basis of static analysis, there is an observation that there is maximum shear force at the shorter exterior column. The values of shear force in the columns decreases along the slope. Observation of the shear force reduction with the decreasing shear wave velocity of soil is made.

2. A contradictory trend is indicated for the dynamic shear ratios and the ratios of static analysis in the direction of X and Y .In dynamic analysis the ratio of shear force in columns at ground level shows increasing trend for all type of soils.

3. The static displacement on the vertical side and the dynamic displacements o the horizontal in the direction of X and Y increases in accordance with the foundation flexibility in relation to the fixed base displacements. The displacements ratio indicates that the foundation cannot be designed assuming fixed base condition.

4. The maximum variation in the fundamental natural period in comparison to fixed base model, 22 % for 4-stepback building, 35% for 4-stepback-setback building, 20% For 11-stepback building, 25% for 11-stepback-setback building on soil with least shear modulus also we can observe natural period increases with the decrease in value of shear modulus of soil and higher modes are also influenced by soil structure interaction.

5. The maximum value of base shear with soil flexibility effect is observed for Soft soil support in 11 storey buildings. There is an observation of increase in the base shear as the shear modulus of soil is decreased.

6. For the load combination of DL+LL+EQ at the corner column for step back and step back-setback building, the axial load gradually increases with decrease in shear modulus of soil.

7. 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. Particular attention should be given to these columns in their design and detailing

8. Comparison of the performance of both the configuration of buildings during seismic excitation yields the result of step back building being more vulnerable as compared to the step back-set back building configuration. The torsional moment development in the case of Step back buildings is observed to be higher as compared to the Step back set back buildings. Thus we conclude with the Step back Set back buildings being less vulnerable as compared to the Step back building against the seismic ground motion.

9. Step back-setback type buildings are best suited configuration of buildings to be adopted on hill slopes.

5.1 SCOPE FOR FUTURE STUDY

The study presented here can be improved further by considering other aspects of analysis, some of which are listed below.

1. In the present study, response spectrum analysis has been done. Non linear Push over analysis of a building considering soil structure interaction can be done.

2. The Building is considered to have only a single block along Y direction, further study for two or more directions along Y axis can be studied

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BIOGRAPHY

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Worked as QS & planning engineer after complete his engineering and decided to be a post graduate in the field of construction technology. He admires to work as a consulting engineer at different projects. And looks forward to own an office space.