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Effects of Plan Irregularities of Multi-Storeyed Structure Resting on Sloping Terrain with Soil Structure Interaction

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Abstract: Structures resting on sloping ground are highly vulnerable to earthquakes due to irregularities in plan and elevation. Structures are often analysed under earthquake loadings, without considering the effect of soil–structure interaction (SSI).In the present study the irregular G+4 storey structure has resting on sloping terrain. The influence of the soil structure interaction in the dynamic behaviour of the structure is reflected in an increase in the vibration period as well as increase in the system damping in comparison with the fixed-base model, which does not consider the supporting soil. 4 types of sloping angles are considered in the present study. The considered structure have been modelled and analysed in ETAB2016 software. The considered building has been subjected to earthquake forces. Non linear time history method is considered to perform on structures models. Performing soil structure interaction for all three types of soil Hard, Medium and Soft by applying point spring at the footing. The design and analysis of structure is carried out in ETABS2016 and calculation of spring constants are carried out manually with standard data of it.
Keywords: Multi storied RC structures, Plan irregularities, Sloping Terrain, Soil Structure Interaction(SSI), Non linear Time History Method(NLTHM)

I. INTRODUCTION

This paper presents the Multi storied RC structure resting on different sloping angle with two way slopes. The structure is rested on two different planes slope i.e. XZ and YZ plane. The structure having 0°,10°,20°,40° degree of slopes. The soil structure interaction is carried out for the analysis of structure. Non linear time history would be applied for the results of base shear and storey drift.

First, a brief literature review on the topic is presented. Then models of G+4 L shape and G+4 Z shape structures are designed and analyzed in ETABS2016 software. Considering the two different plan irregularities of the structure gives the accurate results. Structure with different sloping angles i.e. 0°, 10°, 20°, 40°have different properties. The analytical process have been conducted by applying different loads i.e. earthquake loads and non linear time history method (NLTHM).considering the Soft, Medium and hard soil for soil structure interaction (SSI). Structures resting on sloping ground are highly vulnerable to earthquakes due to irregularities in plan and elevation. Structures are often analyzed under earthquake loadings, without considering the effect of soil–structure interaction (SSI).

Due to the scarcity of flat ground in developed cities, most of structures are constructed on the hill slopes with irregular arrangement of foundation at different levels. Cities that are lying in severe earthquake zones, building structures resting on hill slopes are more prone to the impact of an earthquake. Such structures may fail if they are not designed considering dynamic characteristics affecting for structures on hill slopes. Hence construction of multistory R.C. frames buildings on hill slope is the only feasible choice to accommodate increasing demand for residential and commercial activities. Three major earthquakes of magnitude greater than 8, Kangra (1905) have occurred in this hilly track in the last century.

The hilly seismic region of our country ranges from Jammu Kashmir, Himachal Pradesh, North Uttar Pradesh, North Bihar, Sikkim, North Bengal, Assam, Meghalaya, Nagaland, Arunachal Pradesh, Manipur, and Tripura and Mizoram.

It is observed from the past earthquakes, buildings in hilly regions have experienced high degree of damage leading of collapsed though they have been designed for safety of the occupants against natural hazards. Hence while adopting practice of multi-storey buildings in these hilly and seismically active areas, utmost care should be taken making these buildings earthquake resistant.

II. LITERATURE REVIEW

Mitesh Surana, Yogendra Singh and Dominik H. Lang has studied the Seismic Characterization and Vulnerability of Building Stock in Hilly Regions. This paper presents the extensive field surveys in two test bed cities, Missouri and Nainital, situated in the Himalayan state of Uttarakhand in India, in order to develop a comprehensive building stock inventory. They have been studied and analyzed by Nonlinear Modeling and Analysis in ETABS2016 software. They evaluate with a limited number of structural models and configurations of RC buildings with low-rise and midrise buildings considering representative plan. They have concluded that hill building configuration is more susceptible to damage as compared to regular buildings on flat terrain.

Julio A. Garcia have studied the soil structure interaction in the analysis and seismic design of reinforced concrete frame buildings. This paper presents the investigation of the influence of soil-structure interaction in the analysis and design under the action of gravitational and seismic loads of an office building consisting of 6-storey and basement and structured as reinforced concrete frames. The analysis carried out by using the computer program ANSYS. Model is generated to simulate seismic soil-structure interaction and includes the structure, foundation and subsurface conditions. The study conclude that soil-structure interaction in the dynamic behavior of the structure is reflected in an increase in the vibration period as well as an increase in system damping compared to the fixed base model.

Pranab Kumar Das Sekhar Chandra Dutta and Tushar Kumar Datta have studied Seismic Behavior of Plan and Vertically Irregular Structures: State of Art and Future Challenges. This paper presents the current state of the art on increased vulnerability of structures with asymmetry and irregularity. They have been studied and analyzed by nonlinear static analyses(pushover analysis) in Open Sees software. They have conclude that large number of research studies have been conducted on buildings with asymmetry. Due to the diverse nature of results, the guidelines are still not well developed. differences in results observed even in the behavior of a single-story asymmetric system, particularly for regulating inelastic range behavior, are a major bottleneck to forming guidelines covering all aspects, and acceptable from all points of view.

Sahil Abbas Zaidi , Tabassum Naqvi and Syed Muhammad Ibrahim have studied on the effects of seismic soil structure interaction of concrete buildings resting on hill slopes. This paper presents the soil structure interaction of structure resting on hill slopes by measuring the the behavior of a building subjected to seismic loading. The sloping conditions of the considered building are changed as 0^{o},15^{o} and 27^{o}. The effect of soil-structure interaction is considered by replacing the fixed base of foundation by equivalent static springs. The analysis is carried out by performing non-linear static Pushover analysis SAP 2000. The study conclude that as the slope of ground increases, the value of base force increases around 21% in case of buildings with fixed base and around 37% in case of buildings with flexible base and for soft soil condition since the building becomes more and more irregular as the slope of ground increases and hence attracts greater shear and torsion.

Rahul Ghosh & Debbarma have studied on Structure on sloping ground are highly susceptible to earthquakes because of irregularities in plan and elevation. Structure considered Soil-Structure Interaction (SSI) and without SSI considering.G+4 storey plan-regular and bare frame model building models on sloping ground angles 0˚,15˚,30˚ and 45˚ with and without SSI were analyzed in ETABS software using, equivalent static force method (ESFM), response spectrum method (RSM), time history method(THM), non-linear static method (NLSM). Comparison was done between augment of slope angle with and without soil structure interaction. Structures on the sloping ground are found as more vulnerable than the structures on the flat ground, and therefore the degree of vulnerability augment with the increment of slope angle. They have concluded that structure without SSI consideration over estimate the forces (base shear and bending moment) and underestimate the responses (time period, displacement, torsion). This improper estimation of forces and responses can affect the structure very badly.

III.SOIL STRUCTURE INTERACTION

Three main soil types are considered for this analysis procedure. The soil types are Soft, Medium, Hard. Poison's ratio(ϑ) and shear modulus(G) are varies for all types of soil. For the soil structure interaction (SSI) the spring stiffness(K) is calculated as per Gazeta's formula of point spring. The Gazeta's equations are:

The stiffness equations referred from Gazeta's formula are:

1. Kz = 2GL / (1-ϑ) [0.73+1.54X^0.75]

2. Ky = 2GL / (2-ϑ) [2+2.5X^0.85]

3. Kx = Ky- 0.2GL / (0.75-ϑ) [1- B/L]

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Where

$X = Ab/4L^2$

A_b = area of foundation,

I_{bx} = moment of inertia about longitudinal axis,

I_{by}= moment of inertia about lateral axis,

I_{bz} = moment of inertia about vertical axis,

B = half of the width of foundation,

L = half of the length of foundation,

K_Z = translational stiffness in vertical direction,

K_y = translational stiffness in lateral direction,

K_x = translational stiffness in longitudinal direction

A. Objectives

1) To carry out Non Linear Time History Analysis of Multi storey Structure With plan irregularity with Soil Structure Interaction (SSI) using ETABS.
2) Seismic analysis of multi-storeyed structure measure with SSI and without SSI at various sloping angle.
3) Input parameters under study are: Zone factor , Plan irregularities , Soil type, Slope Angle
4) Time history under study are: Kobe Earthquake
5) Output parameters under study are: Storey shear, storey displacement, storey drift.
6) To study variation of time period with respect to various slope angle and soil type.

B. Scope Of Work

1) To study ETABS software and perform validation procedure.
2) Parameter such as zone factor, plan configuration, soil type will be carried out for non linear analysis.
3) Non Linear Time History of Kobe Earthquake (1994) will apply for Seismic Analysis.
4) G+4 L Shape and G+4 Z shape building will be consider under study.
5) Soil for Soil Structure Interaction(SSI) : Soft, Medium, Hard

Multistoried RC structure with G+4 L shape and G+4 Z shape having 0°,10°,20°,40° degree of sloping angles are modeled in ETABS 2016.Structure with different sloping angles are shown in Fig. properties of soil structure interaction take as per IS1893(part1). In this study for the reference purpose A G+4 multistoried Rectangular building have been taken .Multistoried structures details such as material properties, section properties of various structure elements, details and geometric properties are described in following table given below:

Sr.No.	Description	Dimensions
1.	Size of Beam	250x300mm
2.	Size of Column	350x350mm
3.	Slab thickness	200mm
4.	Bay Width	3m each
5.	Wall thickness	150mm
6.	Storey Height	3m each
7.	Strength of concrete	25kN/m
8.	Slope Angles	0°,10°,20°,40°
9.	Modulus of elasticity	25000Mpa
10.	Damping coefficient	0.005
11.	Response reduction factor(R)	5
12.	Importance factor(I)	1
13.	Yield strength of concrete	250Mpa
14.	Seismic Zone	V

Model Description

Sr. No.	Name of Models	Description of models
1	REC0FB	Rectangular section with fixed base
2	REC0SSI	Rectangular section with point spring at base
3	L0FB	L shape model with 0° slope with fixed base
4	L20,10FB	L shape model with 20°[XZ] slope 10°[YZ] slope with fixed base
5	L40,10FB	L shape model with 40°[XZ] slope 10°[YZ] slope with fixed base
6	L0SSI	L shape model with 0° slope with point spring at base
7	L20,10SSI	L shape model with 20°[XZ] slope 10°[YZ] slope with point spring
8	L40,10SSI	L shape model with 40°[XZ] slope 10°[YZ] slope with point spring
9	Z0FB	Z shape model with 0° slope with fixed base
10	Z20,10FB	Z shape model with 20°[XZ] slope 10°[YZ] slope with fixed base
11	Z40,10FB	Z shape model with 40°[XZ] slope 10°[YZ] slope with fixed base
12	Z0SSI	Z shape model with 0° slope with point spring at base
13	Z20,10SSI	Z shape model with 20°[XZ] slope 10°[YZ] slope with point spring
14	Z40,10SSI	Z shape model with 40°[XZ] slope 10°[YZ] slope with point spring

C. *Figures and Table*

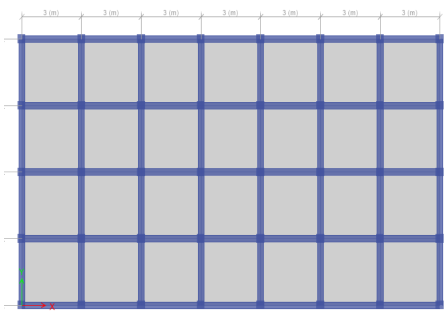
Figure 1 plan REC

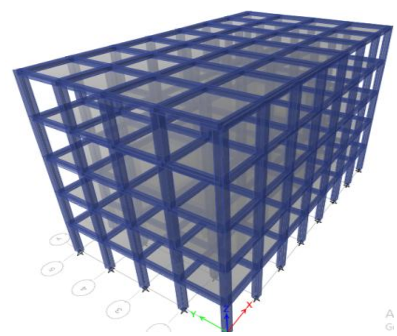
Figure 2 3D model

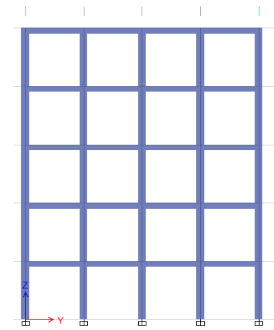
Figure 3 Elevation

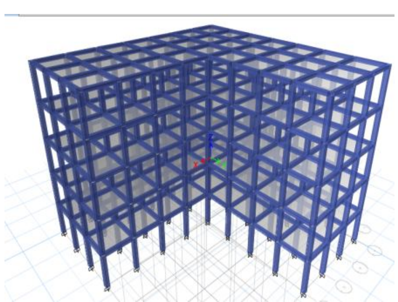
Figure 4 L 0 3D Model

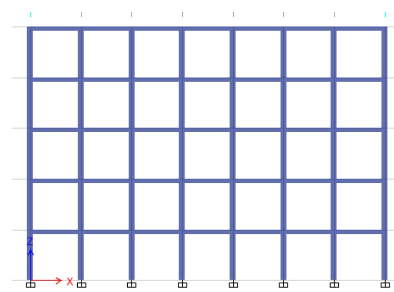
Figure 5 Elevation [XZ]

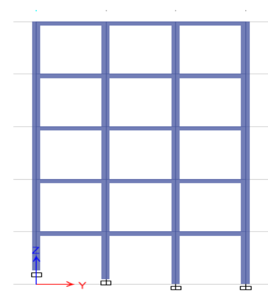
Figure 6Elevation [YZ]

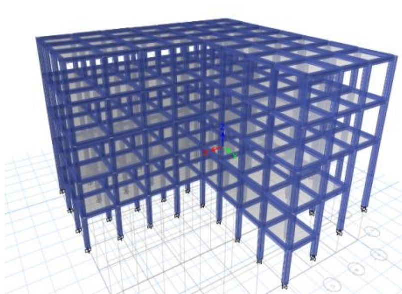
Figure 7 L20 3D model

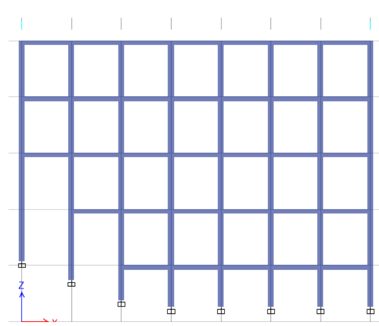
Figure 8 Elevation [XZ]

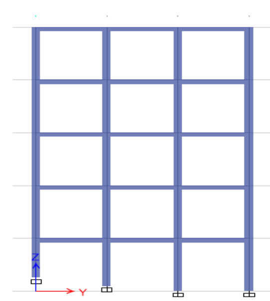
Figure 9 Elevation [YZ]

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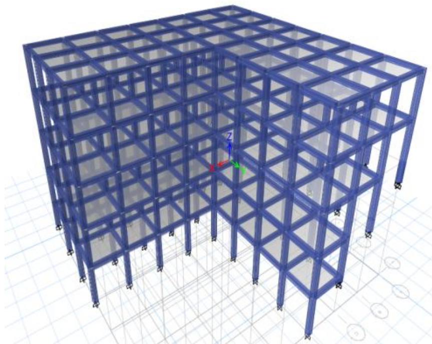
Figure 10 L 40 3D model

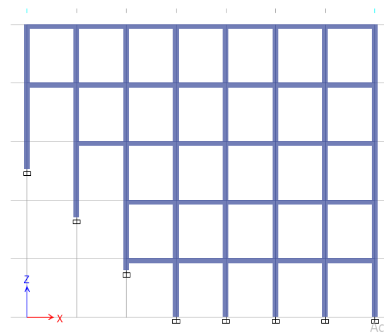
Figure 11 Elevation [XZ]

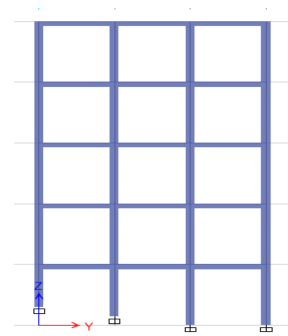
Figure 12 Elevation [YZ]

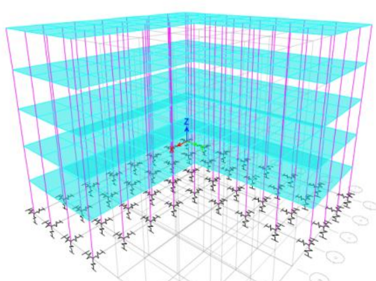
Figure 13 l 0 point spring

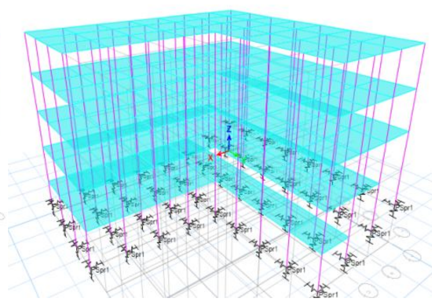
Figure 14 L 20 point spring

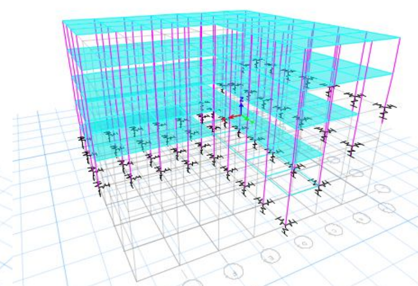
Figure 15L 40 point spring

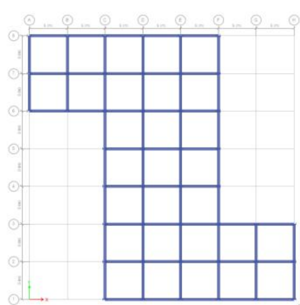
Figure 16 Z shape plan

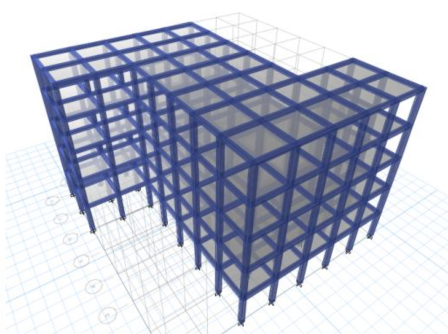
Figure 17 Z 0 3D model

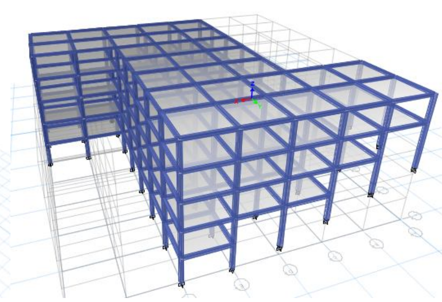
Figure 18 Z 20 3D model

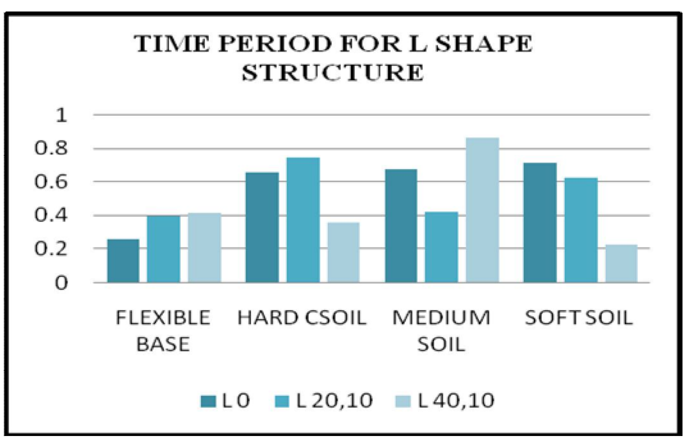

Figure 19 Time period for L shape structure

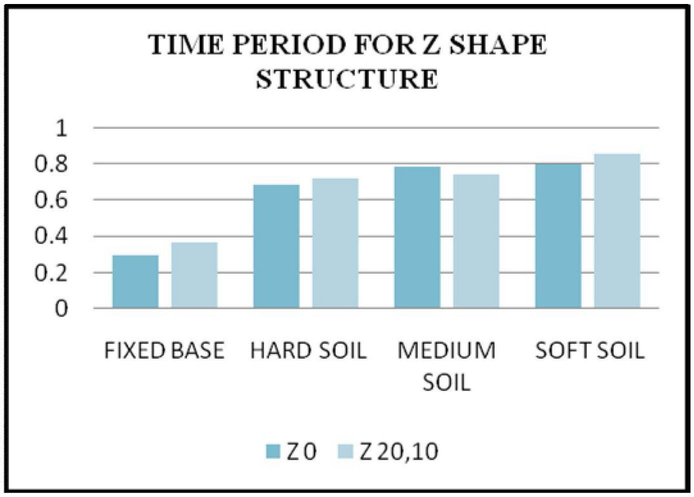

Figure 20 Time period for Z shape structure

Comparison of base shear with REC structures

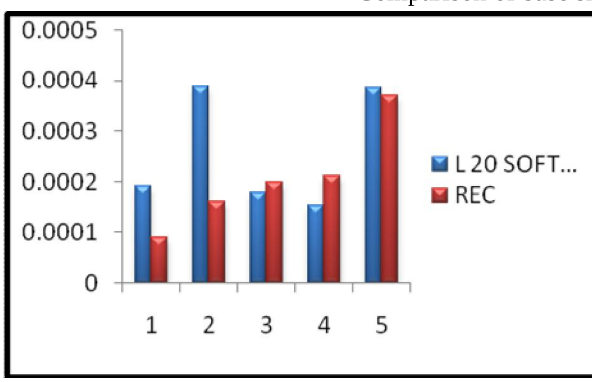

Figure 21 L20 soft with REC

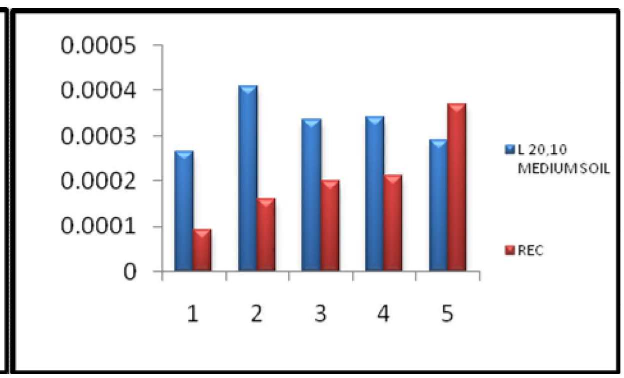

Figure 22 L 20 medium with REC

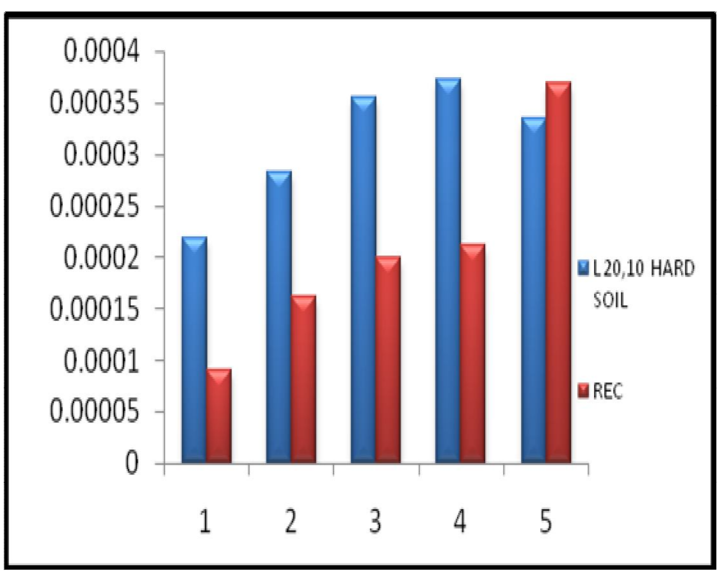

Figure 23L20 hard with REC

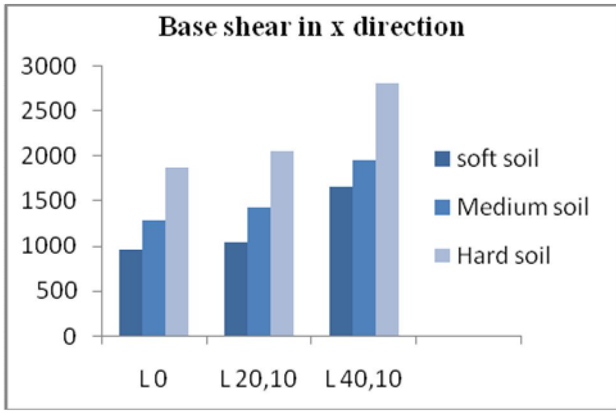

Figure 24Base shear [X]

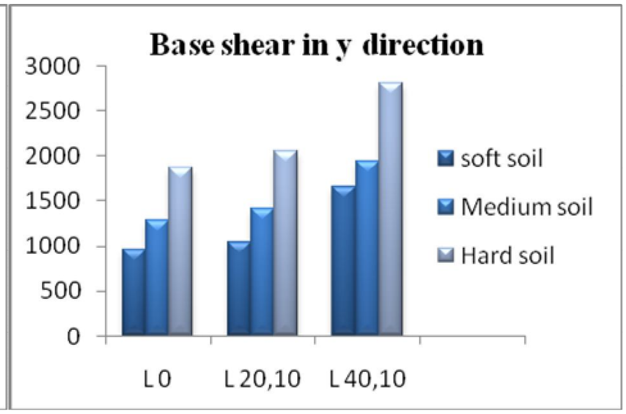

Figure 25 Base shear [Y]

IV. RESULTS AND DISCUSSION

The results of non linear time history analysis for different models, considering different parameters are initially compared and effect of slope angle variation along with SSI consideration is explored. Time history analysis results and results of soil structure are presented thereafter. A Structure resting on two way slopes is very rare in this time .There is lots of work to do in the two way slopes. It is found that the major changes in base shear and storey drifts are at the 40° slopes.

A. Time Period

Fundamental time period of the models are presented in Fig. Percentage variations of time periods due to implementation of SSI are given, according to different slope angles.

It is noticed that with the increment of the slope, the fundamental time period of the models gets reduced. The reduction of column length increases the structural stiffness; as a result, the time period reduces. Models on 40° slope show marginal increase of time period compared to the models on 20° slope (with and without SSI). The models on 10° slope (with and without SSI) and 20° (with and without SSI) slope have intermediate column length (in between 0 and 3 m) in different storey levels along the height, which does not allow the storey's to vibrate freely as a complete storey. These intermediate columns provide additional stiffness to those storey's and reduce the time period of the models, but the models on 40° slope (with and without SSI)also not get a complete storey on each level, which results in a minor increase in flexibility as well as in time period.

All the models, where SSI has been considered, exhibit a larger time period compared to the fixed base models, due to increased flexibility of the base of the structures. Interestingly, the percentage increment of time period due to SSI implementation has also increased with the increase in slope angle.

B. NLTHM

Nonlinear time history analysis, which explores more accurate responses of structure, is performed for all the models by direct integration technique, using the real ground motion data of Kobe earthquake. Non-recoverable permanent deformation is noticed in most of the models by nonlinear time history analysis. After reaching the maximum responses corresponding to input acceleration, the models deform permanently and fail to regain their original phase. The variations of maximum responses for all models are extracted from nonlinear time history results and shown in Figs.. Extracted results from nonlinear time history imply that with the increment of slope angle, displacement in the direction of force (*X* direction) reduces for both fixed and flexible base. But displacement in the transverse direction of force (*Y* direction) goes on increasing with the increment of slope. Similar nature is noticeable in the case of maximum inter-storey drift at *X* and *Y* directions. Maximum torsion response also increases with the increment of slope angle.

V. CONCLUSION

1) Base shear for the building is inversely proportional to the sloping angle. The base shear increases with the decreases in the sloping angle.
2) Considering the two way slope with more than 15° slope it is necessary to apply soil structure interaction (SSI). The response parameters such as time period values increases with increase in sloping angle but at 40° slope it is decrease.
3) Soil structure interaction (SSI) affects leads to reduction of base shear of the building.

4) Soft soil shows the higher reduction of base shear as compared to medium and hard soils. Therefore for Medium and Hard soil it is not necessary to apply soil structure interaction.
5) Storey displacement, time period and axial force values are magnified due to effect of soil structure interaction. Soft soil gives the highest values of response parameters.
6) Hence it is concluded that fixed base building gives lesser values of response parameters as compared to flexible base building. Therefore It is mandatory to consider the effect of soil structure interaction on the building to get appropriate response of the building.

VI. FUTURE SCOPE OF WORK

A. Structure with plan irregularities are considered in this study, torsional irregularities or mass irregularities should be m
B. In this study two way slope in two different planes have been taken so in future 3 way slopes should be considered.
C. Soil structure interaction with area spring would be considered for future work.

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