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Soil structure interaction effect for a building resting on sloping ground including infiill subjected to seismic analysis.

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Abstract- *The scope of this study is carry out seismic analysis for a building resting on sloping ground with sloping angles 16, 20 and 24 degrees under the effect of soil structure interaction. The infill effect for the building is included for the analysis. Hard, medium and soft soils are used for soil structure interaction effect.*

Linear seismic analysis is carried out using IS-1893:2002 using ETAB2003 software and the response parameters such as base shear, fundamental time period, storey displacement and axial force are compared for buildings with fixed and flexible base. It is observed that the soil structure interaction effect leads to effective reduction of base shear. However the fundamental time period, storey displacement and axial force values are magnified due to soil structure interaction effect.

***Keywords*: RCC building, Sloping ground, Stepback, Stepback-setback, Infill stiffness, Compressive Diagonal strut, Soil structure interaction (SSI).**

1. INTRODUCTION

The fast growing economy and rapidly growing urbanity in hilly regions has catalysed the real estate business, as a result of which is attracting more people to settle in hilly regions. Therefore construction of multistoried buildings has become the need of the hour. Hilly regions have sloping ground, therefore construction of buildings in such areas is completely different from the usual building construction on plain grounds. This is because the ground in hilly regions is inclined at a certain angle from the regular ground level, which leads to different heights of the columns in the same storey. Therefore the columns of the same storey retain different stiffness values.

1.1 EARTHQUAKE EFFECT ON BUILDINGS RESTING ON SLOPING GROUND

One of the most dangerous natural calamity is earthquake. It is very important to carry out seismic analysis on buildings situated in severe earthquake zones. As per the past earthquake records RCC building which, consists of columns of different heights within the same storey has shown more damage in the short column of that storey, when compared with the tall column of the same storey. Due to inclination of the ground we have short column on uphill side, which is subjected to greater lateral forces and is liable to damage first as, compared to the long columns down the hill. This is because the short column possess more stiffness than the tall column, due which it attracts larger earthquake forces. This phenomena is called “Short Column Effect”. The damage is seen in the form of X-shaped cracks and the short column is subjected to shear failure.

The buildings in hilly regions show irregularity in mass and stiffness about longitudinal and transverse planes. These buildings are unsymmetric about longitudinal and transverse planes. The irregular distribution of mass and stiffness in each storey leads to centre of mass and centre of stiffness not coinciding with each other, which in turn inhibits the torsion to act on the building. Therefore the buildings on sloping ground need to analysed for torsion also. We have static and dyanamic method of seismic analysis. The objective of my study is conduct a linear seismic analysis i.e (Equivalent static method and Response spectrum method) under the effect of soil structure interaction, considering three types of soil on RC Building with infill, resting on sloping ground and to determine the behavior of building under soil structure interaction in terms of base shear, fundamental time period, maximum storey displacement and axial force. The infill effect is included by modeling the wall as equivalent compressive diagonal strut using Demri and Servi’s formula. Presence of infill walls increases the overall stiffness of the building. As the stiffness of the building increases the time period shortens, this in turn increases the seismic force on the building.

1.2 Soil structure interaction effect on buildings subjected to seismic analysis

Seismic response of a building usually depends on the behaviour of the soil, on which the building is laid. The response of the building varies as the soil type changes and also this dynamic response, depends upon the state of one type of soil at a particular instant. The response values of the building subjected to seismic analysis, under the effect of soil structure interaction are greater than the response values obtained from seismic analysis of building, with fixed base. Therefore it very important to consider the effect of soil

structure interaction, to get more appropriate values of response of the building subjected to seismic forces.
Soil structure interaction is defined as a process, in which the response of soil for seismic force affects the motion of the structure and the motion of the structure, in turn affects the response of the soil. Soil structure interaction depends, on the footing size and elastic properties such as poisson's ratio, shear modulus and young's modulus of footing soil. There is significant effect of soil structure interaction on the response of building, which is resting on soft soil as compared to building resting on hard and medium soil.

2. MODELING

Eight storey Stepback-setback buildings are modeled on sloping ground. The angles of sloping ground taken are 16°, 20° and 24°. Bay configuration of 5x5 is adopted for all buildings. Size of each bay is 5m in x-direction and 5m in y-direction. Infill wall is considered and modeled as equivalent compressive diagonal strut. Seismic analysis is carried out using equivalent static method and response spectrum method in ETABS 2013. The analysis is carried out as per IS1893-2002. The effect of soil structure interaction is considered taking hard soil, medium soil and soft soil. The foundation soil is modeled by replacing the support by equivalent spring, with six degrees of freedom. The spring constants are calculated using stiffness equations.

Building configuration

-Size Of Building : 25m x 25m
-Bay Configuration : 5x5
-Bay Size : 5m x 5m
-Storey Height : 3.2m
-Depth Of Foundation Below Ground Level : 2m
-Slab Thickness : 120mm
-Wall Thickness : 230mm
-Beam Size : 230mm x300mm
-Column Size : 450mm x450mm
-Sloping Ground Angles : 16°, 20°, 24°

Material Properties

- Grade of Concrete : M25
- Grade of steel reinforcement : Fe415

Loading Data

- Floor finish : 1.0 KN/m^2
- Live load on floor : 3 KN/m^2
- Earthquake zone : 5
- Importance factor : 1
- Soil type : Medium
- Frame system : Special moment resisting system (SMRF)

2.1 : Modelling Of Infill Wall

In order to establish the effect of infill characteristics, such as strength and stiffness in the analysis we need to model the infill. For this Demir and Sirvi's method is adopted. In this method, we calculate equivalent diagonal width of infill and provide infill as equivalent compressive diagonal strut in the structural model to account for infill stiffness,for analysis of structure.

2.2 : Database For Soil Structure interaction

Three types of soils are used for soil structure interaction i.e hard, medium, and soft soil. The foundation soil is modelled with spring having six degrees of freedom. The spring constants are calculated using stiffness equations from FEMA 356. Shear modulus and poisson's ratio values of hard, medium and soft are refered from Pandey A.D, Prabhat Kumar and Sharad Sharma paper. The values of shear modulus and poisson's ratio are listed in the table below.

Soil type	Shear Modulus (G) in kN/m^2	Poisson's Ratio (µ)
Hard Soil	2700	0.25
Medium Soil	451.1	0.33
Soft Soil	84.5	0.48

Table No2.2.1 : Properties of the soil

The stiffness equations refered from FEMA 376 are as follows:

Translation along x-axis $K_{x,sur} = GB/2\text{-}\mu\ [3.4(L/B)^{0.65} + 1.2]$
Translation along y-axis $K_{y,sur} = GB/2\text{-}\ \mu\ [3.4(L/B)^{0.65} + 0.4(L/B) + 0.8]$
Translation along z-axis $K_{z,sur} = GB/1\text{-}\ \mu\ [1.55(L/B)^{0.75} + 0.8]$
Rocking about x-axis $K_{xx,sur} = GB^3/1\text{-}\ \mu\ [0.4(L/B) + 0.1]$
Rocking about y-axis $K_{yy,sur} = GB^3/1\text{-}\ \mu\ [0.47(L/B)^{2.4} + 0.034]$
Torsion about z-axis $K_{zz,sur} = GB^3\ [0.53(L/B)^{2.45} + 0.51]$
Where,

G = Shear modulus of the soil
µ = Poisson's ratio of the soil
L = Length of the footing
B = Width of the footing

Using the input of footing size as 3.5m x3.5m, shear modulus and poisson's as specified in Table 2.2.1, the spring constants are calculated using stiffness equations and listed in the table below

SPRING CONSTANTS	TYPE OF SOIL		
	HARD SOIL	MEDIUM SOIL	SOFT SOIL
Kx	48487.7	8489.11	1747.1
Ky	48487.7	8489.11	1747.1
Kz	37515.9	7016.34	1693.42
Kxx	117074	21895.6	5284.61
Kyy	136214	25475.2	6148.54
Kzz	233803	39062.5	7317.17

Table No 2.2.2 : Spring constants for SSI

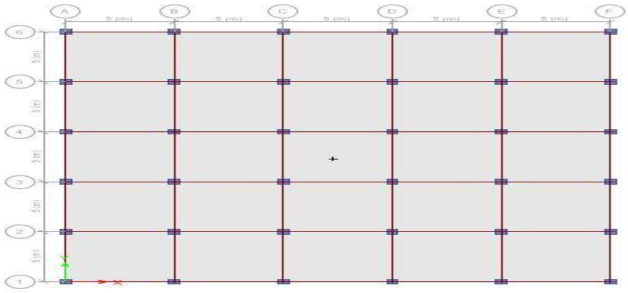

Fig 2.1 : Plan of building

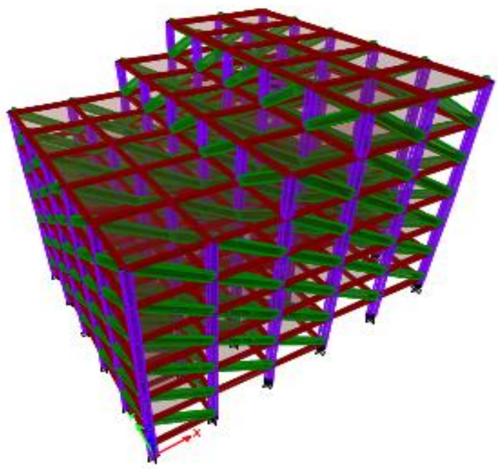

Fig 2.2 : Building with sloping angle 16°

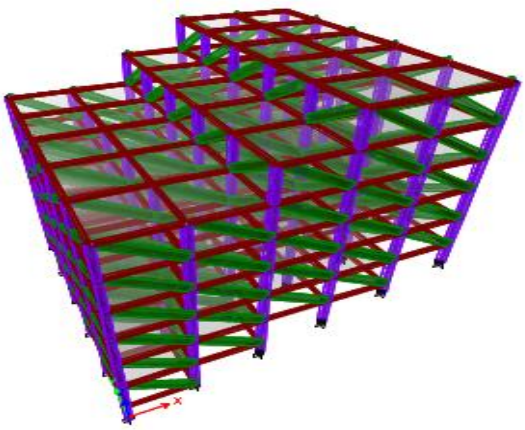

Fig 2.3 : Building with sloping angle 20°

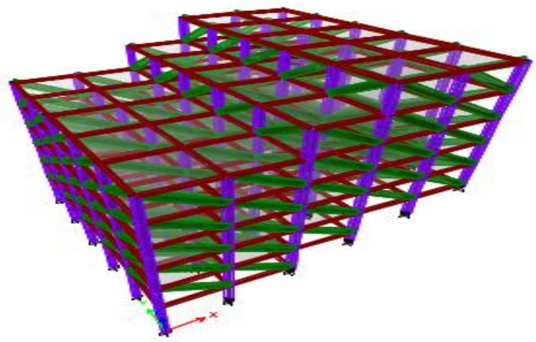

Fig 2.3 : Building with sloping angle 24°

3. RESULTS AND DISCUSSION

The objective of the study is to observe the variation of response parameters i.e base shear, fundamental time period, maximum story displacement and axial force of the buildings on sloping ground with 16°, 20 °and 24 °sloping angles. The main scope of the study is to compare the response parameters of buildings with infill with and without soil structure interaction.

1. Base shear (kN):

The base shear values for eight storey stepback-setback building resting on sloping ground with sloping angles 16°, 20° and 24° are listed in the table below.

Table 3.1 :Base shear of the building on sloping ground with and without soil structure interaction

BUILDING TYPE	BASE SHEAR (kN)			
	FIXED BASE	FLEXIBLE BASE		
		HARD SOIL	MEDIUM SOIL	SOFT SOIL
8S, 16°	2926.25	2632.66	1238.37	608.81
8S, 20°	2742.1	2554.04	1228.37	610.09
8S, 24°	2543.02	2475.27	1258.04	615.29

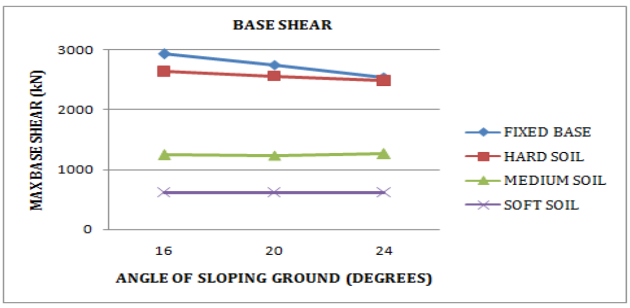

Fig. 3.1 Base shear of the building on sloping ground with and without soil structure interaction

From table 3.1 and Fig. 3.1, it can be seen that soil structure interaction effect on the building is observed in the form of reduction of base shear of the building. It is observed that as the flexibility soil increases the base shear value decreases. Hence the soft soil gives the least base shear value as compared to medium and hard soil for all three sloping angles.

2. Maximum storey displacement (mm)

The storey displacement values for eight storey stepback-setback building resting on sloping ground in x and y directions are listed in the table below

Table 3.2 Maximum storey displacement for building on sloping ground with and without soil structure interaction.

MAX STOREY DISPLACEMENT(mm)	BUILDING TYPE		
	8S,16°	8S,20°	8S,24°
1. FIXED BASE	X = 6.7 Y = 5.8	X = 6.9 Y = 5.8	X = 4.8 Y = 3.7
2. FLEXIBLE BASE(hard soil)	X = 21.9 Y = 22	X = 23.9 Y = 20.4	X = 18.8 Y = 17
3. FLEXIBLE BASE (medium soil)	X = 39.2 Y = 45.4	X = 52.7 Y = 41.5	X = 40.3 Y = 35.8
4. FLEXIBLE BASE (soft soil)	X = 60.7 Y = 89.9	X = 123.6 Y = 81.7	X = 84.3 Y = 71.8

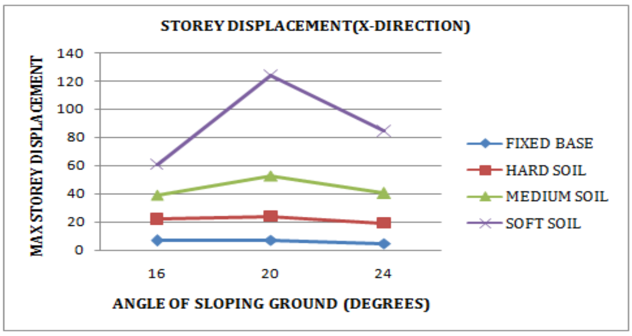

Fig 3.2.1 Maximum storey displacement for building on sloping ground with and without soil structure interaction in x-direction.

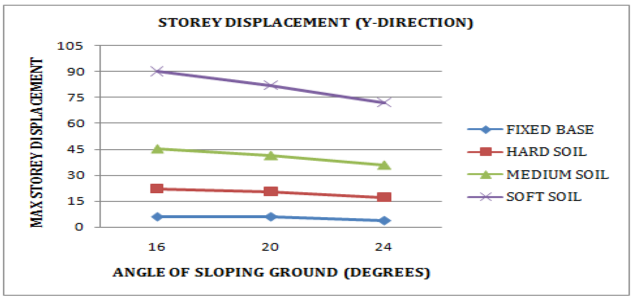

Fig 3.2.2 Maximum storey displacement for building on sloping ground with and without soil structure interaction in y-direction.

From the table 3.2 and figures 3.2.1 and 3.2.2 we can interprete that the effect of soil structure interaction magnifies the storey displacement. The building experiences larger displacement as the flexibility of soil increases in both x and y directions. Hence it is observed that the soft soil gives larger displacement values as compared to medium and hard soils. However it is seen that the building without soil structure interaction gives lesser values of storey displacement. Hence it becomes important to consider soil structure interaction effect to get appropriate response of building.

3. Fundamental time period (sec)

In the table below the values of time period are listed for 8-storey stepback-setback buildings with sloping angles 16°, 20° and 24° with and without soil structure interaction.

Table 3.3 Fundamental time period for building on sloping ground with and without soil structure interaction.

BUILDING TYPE	FUNDAMENTAL TIME PERIOD (sec)			
	FIXED BASE	FLEXIBLE BASE		
		HARD SOIL	MEDIUM SOIL	SOFT SOIL
8S, 16°	0.252	0.612	1.301	2.643
8S, 20°	0.262	0.590	1.231	2.485
8S, 24°	0.225	0.559	1.157	2.328

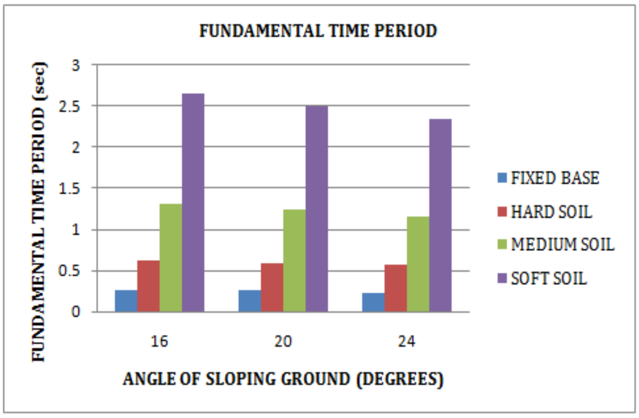

Fig 3.3 Fundamental time period for building on sloping ground with and without soil structure interaction.

The effect of soil structure interaction on the building eventually lengthens the time period by greater magnitude. Flexibility of the soil is directly proportional to the time period. Therefore it is seen that the soft soil gives longer time period as compared to medium and hard soils.

4. Axial force on column (kN)

he axial force on the outer column is listed in the table below for buildings on sloping ground with and without soil structure interaction effect.

Table 3.4 Axial force for building on sloping ground with and without soil structure interaction

BUILDING TYPE	AXIAL FORCE (kN)			
	FIXED BASE	FLEXIBLE BASE		
		HARD SOIL	MEDIUM SOIL	SOFT SOIL
8S, 16°	1514.54	1671.27	1678.79	1680.45
8S, 20°	1438.18	1647.73	1656.26	1657.69
8S, 24°	1291.85	1488.60	1500.87	1502.62

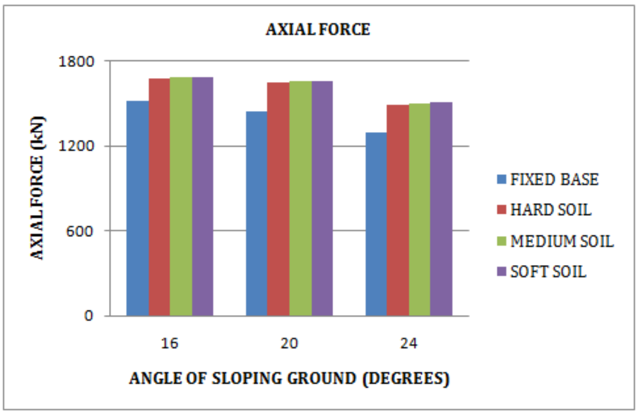

Fig 3.4 Axial force for building on sloping ground with and without soil structure interaction

Soil structure interaction usually amplifies the axial force of column in a building. From the fig 3.4 it is observed that the building under soil structure interaction experiences larger axial force as compared to building without soil structure interaction.

5. CONCLUSIONS

The following conclusion is framed from the above results and observations:

1. The base shear for the building on sloping ground is inversely proportional to the sloping angle. The base shear increases with the decrease in the sloping angle.
2. The response parameters such as storey displacement, fundamental time period and axial force values increases with decrease in sloping angle.
3. Soil structure interaction effect leads to reduction of base shear of the building.
4. Soft soil shows greater reduction of base shear as compared to medium and hard soils.
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 these 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 becomes mandatory to consider the effect of soil structure interaction on the building to get appropriate response of the building.

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