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A numerical study on seismic characteristics of stepback buildings considering SSI effect

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ABSTRACT :*From previous studies it is observed that seismic forces are affecting the behaviour of vertical irregular buildings. Stepback buildings are subset of these vertical irregular buildings. Many of these stepback buildings are constructed due to scarcity of level ground. Past studies reveal that, the stepback buildings failed vulnerably due to seismic effect. Further the effect of soil where these buildings founded also influences the failure of the buildings. Hence in this present study an attempt has been made to observe the behaviour of stepback buildings considering soil structure interaction (SSI) effect using Finite element analysis. Continuum modelling approach has been adopted to analyse these buildings resting on 20°, 25°and 30°ground slopes. Results such as resonance frequency and storey displacements are presented adopting time history analysis for both fixed base and flexible base conditions*

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I. INTRODUCTION

Buildings are built on the sloping ground due to deficiency of level ground. These buildings which are built on sloping ground fail vulnerably when subjected to seismic forces because they are irregular horizontally as well as vertically. The chances of failure further increase with the effect of soil where the buildings are founded. Figure 1 depicts the typical type of building resting on sloping ground called as stepback building.

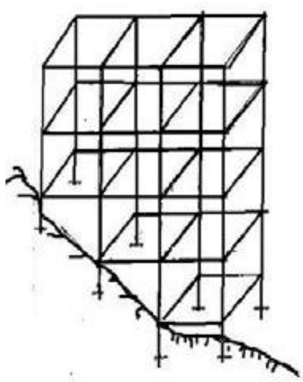


Fig.1. Stepback building configuration

Most of the buildings are in directly contact with the soil. In the seismic analysis of a buildings founded on ground, the ground motion passes to the base of buildings and then loads on buildings. The response of the foundation system affects the response of the structure and vice versa, which is called dynamical soil-structure interaction (SSI). Soil structure interaction plays an important role in seismic response of the structure by altering the dynamic properties of the system. Figure 2 shows the SSI effect on the sloping ground.

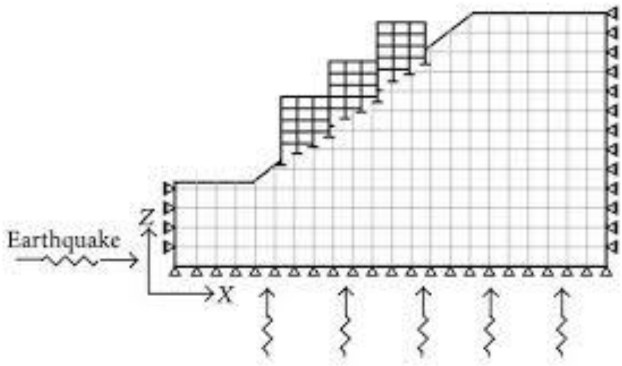


Fig.2. SSI effect on sloped building

II. GEOMETRICAL DETAILS

In this study a medium rise stepback RC buildings are considered to observe their behaviour considering SSI numerically. A continuum model approach has been adopted, because very few studies have been carried out using this approach previously. Figure 3 shows the plan at the base of the building and Figure 4 shows the geometries considered in the present study. These irregular buildings have a uniform storey height of 3m, they are denoted as STB -1, STB -2 and STB -3 for buildings resting on ground at an inclination of 20°, 25°and 30° respectively.

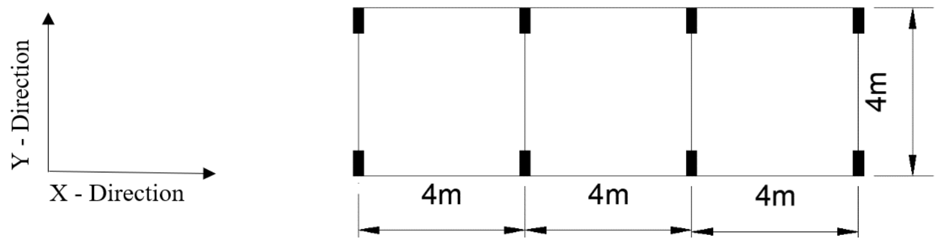
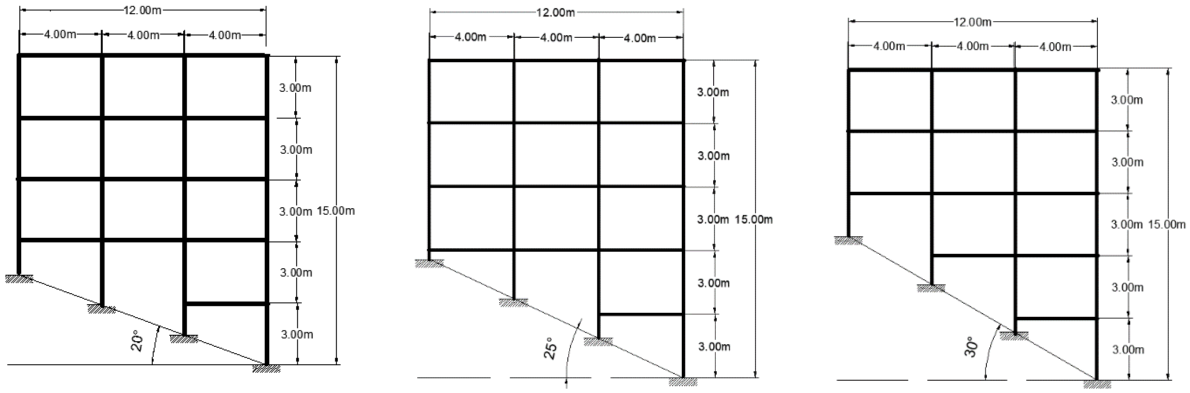


Fig 3. Plan of the building



(a) STB-1 **(a) STB-2** **(a) STB-3**

Fig.4. Elevation of the buildings

The RC buildings shown in Fig.4 are designed according to IS: 1893(Part 1)-2016 and IS: 456-2000. While designing it has been considered that the first mode of vibration is obtained along longitudinal direction (X-axis). Live load of 3kN/m^2 and floor finish of 1 kN/m^2 is considered at each floor. At roof, live load of 1.5kN/m^2 and floor finish of 2kN/m^2 is considered for design of these buildings. Table 1 shows the dynamic details of the buildings considered for the present study. Table 2 shows the details of the designed structural elements of the buildings.

Table 1. Dynamic Properties of The Building

Sl. No.	Contents	Description
1	Structure	SMRF
2	Seismic Zone	V
3	Importance factor	1
4	Type of soil	I

Table 2. Details of Structural Elements of the Building

Sl. No.	Contents	Description
1	Slab thickness	150mm
2	Beams dimension	300mm X 400mm
3	Columns dimension	250mm X 600mm

III. NUMERICAL STUDY

The effect of under-laying soil can be neglected while performing seismic analysis of a structure if the ground is stiff, and structure can be analyzed considering fixed base conditions. But when the same structure is constructed on soft soil it behaves differently. Hence in this present study, to observe the effect of soil on the structures resting on sloping ground both fixed base and soil structure interaction study has been carried out using Finite element method-based software, SAP 2000. Figure 5 shows the numerical fixed base (FB) model.

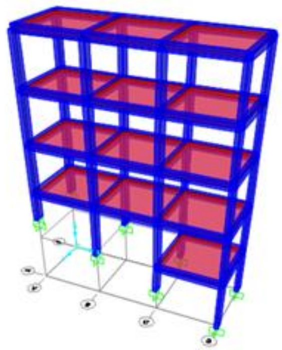


Fig. 5. Three-dimensional View of 20^0 FB model

The soil medium beneath the structures is a clayey soil as shown in Table 3. The peak load that can be carried by the pile or at which the pile continues to sink without further increase in load is known to be as ultimate bearing capacity of pile or ultimate bearing resistance of pile. Safe load that can be carried by the pile is called as its allowable load and it is obtained by dividing ultimate bearing capacity of pile by factor of safety of 2.5.

Table 3. Properties of the soil

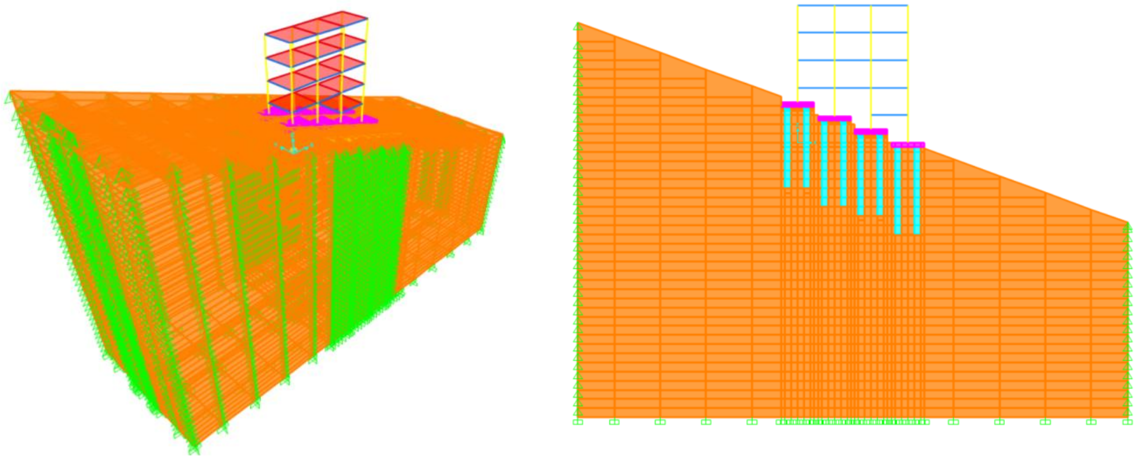
Sl. No.	Contents	Description
1	Young's modulus	25MPa
2	Poisson's ratio	0.4
3	Density of soil	1470kg/m³
4	Shear wave velocity	200m/sec

A friction type of pile group is adopted in this study which is having a pile group of 1 x 2. A square pile foundation of M25 grade concrete has been designed according to IS:456-2000 and BS: 8110 (part 1). Table 4 shows the dimensions of the piles and pile cap.

Table 4. Size of pile and pile cap

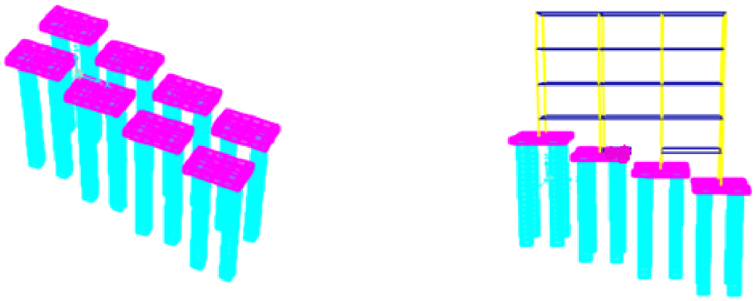
Sl. No,	Contents	Description
1	Pile size	0.7m x 0.7m
2	Pile length	9.6m
3	Pile spacing	3 times the pile size
4	Pile cap size	1.4m X 3.5m X 0.7m

Finite element method-based software SAP 2000 is used for modelling and analysing. A soil profile of width 20m, length 60m and height 41.84m to 54.64m from smaller end to the larger end for 20^0 to 30^0 respectively, are considered for modelling which is five times the width and length of the building. Figure 6 shows the three-dimensional view of a numerical model considering soil structure interaction effect (SSI) and Fig.7 shows the three-dimensional view of pile and pile cap along with elevational view.



(a) Three-dimensional view (b) Elevation

Fig. 6. View of 20^0 SSI model



(a) Three-dimensional view (b) Elevation

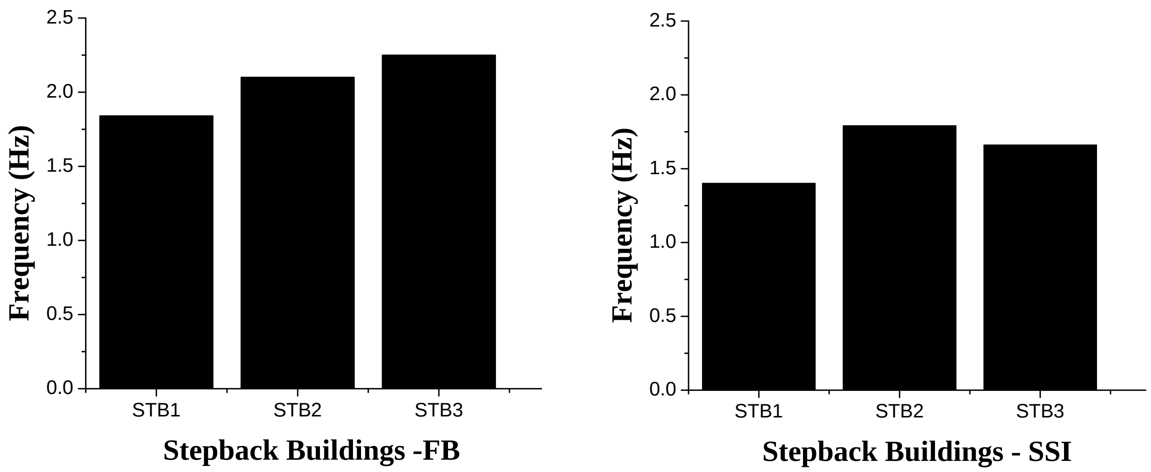
Fig. 7. View of Pile and Pile cap

IV. RESULTS AND DISCUSSION

Results such as resonant frequency and storey displacements are presented for both fixed base and flexible base buildings. Modal analysis has been carried out and resonant frequency (Hz) of buildings STB 1, STB 2 and STB 3 for buildings considering both fixed base and SSI effect are presented in Table 5, Figure 8 shows the graphical representation of the same.

Table 5. Resonant frequency (Hz)

Type	FB	SSI
STB1	1.84	1.40
STB2	2.1	1.79
STB3	2.25	1.66



(a)FB Buildings **(b) SSI Buildings**

Fig. 8. Variation of frequency (Hz)

From Table 5 and Fig.8 it is observed that resonant frequency of fixed base buildings are found to be more compared to SSI buildings. In case of fixed base buildings Resonant frequency is found to increase with increase in sloping angle,but in case of SSI condition, STB 2 building has higher resonant frequency compared to STB 1 and STB 3.

Time history analysis has been carried out for stepback buildings using 2001 Bhuj earthquake(N-E) ground motion data with Peak acceleration 1.0382 m/s^2. The Bhuj earthquake ground motion is as shown in Fig. 9. Storey displacements for the considered buildings when subjected to Bhuj earthquake(N-E) are presented in Table 6 and Table 7, along with graphical representation as shown in Fig.10 and Fig. 11.

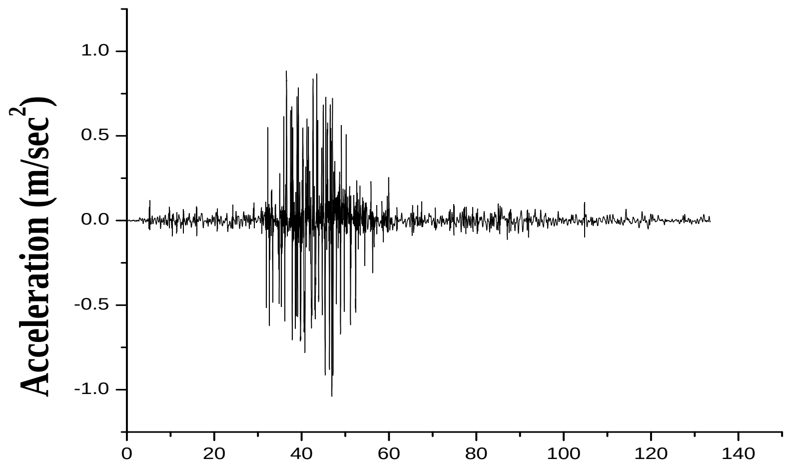


Fig. 9. Time History of Bhuj Earthquake(N-E)

Table 6. Storey displacements of the fixed base Stepback buildings(mm)

Storey No's.	SB4	SB5	SB6
1	0.98	0.13	0.03
2	4.65	0.24	0.7
3	12.78	4.88	3.4
4	18.98	8.97	7.1
5	22.21	11.43	9.4

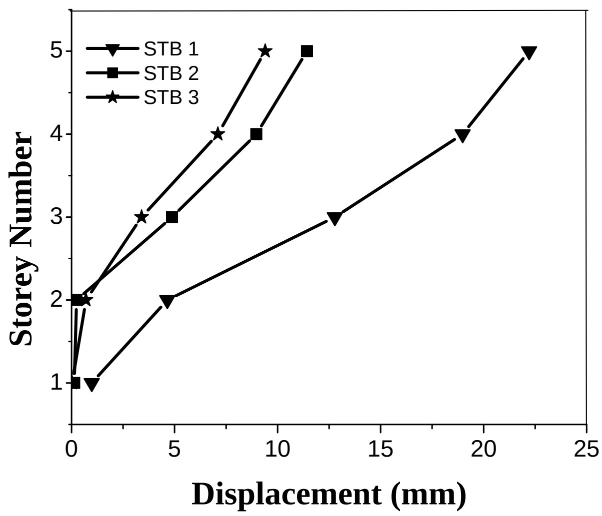


Fig.10. Storey displacement of stepback buildings (FB)

From Table 6 and Fig. 10 it is observed that STB 1 has found to have higher displacement compared to STB 2 and STB 3.

Table 7. Storey displacements of the flexible base Stepback buildings(mm)

Storey No's.	STB 1	STB 2	STB 3
1	17.79	14.51	12.35
2	25.40	18.39	16.21
3	42.10	35.39	28.49
4	54.47	48.23	41.19
5	61.27	57.76	48.03

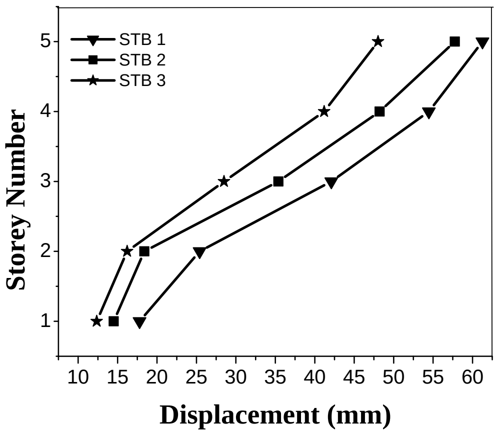


Fig. 11. Storey displacement of stepbackbuildings(SSI)

From Table 7 and Fig.11 it is observed that STB 1 has found to have higher displacement compared to STB 2 and STB 3.

V. CONCLUSIONS

Comparing buildings resting on both fixed base and soil structure interaction conditions when subjected to seismic action, it is observed that storey displacements reduces with increase in angle of inclination of buildings resting on ground in both fixed base and SSI conditions. Buildings resting on soft soil (SSI condition) have found to be more vulnerable when compared to buildings resting on fixed base conditions, as the storey displacements increased 3 times more in all types of building variants such as STB 1, STB 2 and STB3.

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