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Seismic Response of Reinforced Concrete Frames on Sloping Ground considering Soil Structure Interaction

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Abstract: Due to local topography the construction in hilly areas is usually limited to adoption of either a step-back or step back-setback buildings. These irregular configurations permit columns of varying heights to rest at different foundation levels on sloping ground leading to greater torsion and shear during earthquakes. As a result soil structure interaction must be suitably considered from design point of view. This paper investigates the seismic behaviour of multi storey buildings on sloping ground considering soil-structure interaction. A ten storey reinforced concrete structure with and without elevation irregularities are analyzed for different soil conditions using finite element software SAP2000 and results are compared with respect to top storey displacement, time period and base shear. Equivalent static analysis is adopted in the study and results indicate that model M-3 is the most preferred configuration in hilly regions.

Keywords: *Soil-structure interaction, Top storey displacement, Base shear*

1. Introduction

Now a days, rapid construction is taking place in hilly areas due to scarcity of plain ground. As a result the hilly areas have marked effect on the buildings in terms of style, material and method of construction leading to popularity of multi-storeyed structures in hilly regions. Due to sloping profile, the various levels of such structures step back towards the hill slope and may also have setback also at the same time. The step-back structures usually have the number of storeys decreasing successively at the bottom in each bay, in the direction of the slope maintaining same roof level, whereas setback-step-back buildings do not have same roof level. These structures become highly uneven and asymmetric, due to variation in mass and stiffness distributions on different vertical axis at each floor. Such construction in earthquake prone areas makes them to attract greater shear forces and torsion compared to normal construction.

Vibrations which causes disturbance in the earth's surface induced by waves generated inside the earth are termed as earthquakes. It is well known that earthquake ground motions results primarily from the three factors, namely, source characteristics, propagation of waves and local site conditions. When an earthquake of certain magnitude strikes a structure, they induce motions in the structure which depends upon the structure's vibrational characteristics and the location of structure. If a lightweight flexible building is constructed on a foundation which is very stiff, assumption is that the input motion at the base of the structure is same as free-field motion. If a huge and rigid structure rests on a relatively soft foundation, the motion at the base of the structure will be different from free-field motion. The process in which behaviour of soil affects the motion of the structure and motion of the structure affects the behaviour of soil is termed as soil-structure interaction (SSI). Pandey et al. (2011) performed static pushover analysis and response spectrum analysis on three step back buildings and two step back-set back buildings for different support conditions on sloping ground. Buildings were analyzed for different soil conditions using SAP2000 software idealized by equivalent springs. It was found that as time period increases, response reduction factor decreases but was found to be the same after certain time period [1]. Shiji PV, et al. (2013) studied soil-structure interaction effects on response of framed structures by considering frames of 5, 10, 20 and 40 storeys with fixed and flexible base conditions. The period of vibration was more when considering soil as elastic continuum models than as nonlinear spring model and the influence of soil structure interaction on base shear was observed to be significant on frames more than 10 storeys [2]. Priyanka, et al. (2014**)** studied the effect of lateral deflection on the regular and vertically irregular RC framed buildings with fixed support for different soil conditions for 4m and 5m column spacing respectively. Models were analysed in STAAD Pro V8i. Study concluded that the lateral deflection for regular building was greater for 5m column spacing along the width with respect to soft soil [3]. Prabhat Kumar, et al. (2014) carried out dynamic analysis taking into account of ground profile; the structural forms, .i.e., two step-back and two step-back-set-back buildings were compared to get the better configuration for the sloping topography. The four different buildings were modelled and analysed in SAP2000.Results showed that the step-back-set-back configuration was found to be more appropriate for topography having sloped profile from a design point of view as compared to step-back configuration [9].

2. Description of Models

A total of three ten storeyed building frame models represented as M-1, M-2 and M-3 are considered in the present study. Model M-1 is generally a step back building i.e. without irregularity on sloping ground; whereas M-2 and M-3 are models with elevation irregularities on sloping ground, M-3 is considered as a step back-setback building. These models are modelled and analyzed in SAP2000 for different soils such as soft clay (SC), dense sand (DS), hard clay (HC), and rock (RCK). Properties of different soil considered are mentioned in Table 1. Plan and elevation of these models are shown in Figures 3, 4, 5 and 6 respectively. The slope of the ground profile considered is 27 degree with respect to horizontal [10]. Properties of considered building configurations are summarized as follows: Total number of storeys-10, Height of each storey is 3.5m. Length along X direction is 45m. Length along Y direction is 30m. Plan dimension of each block is 4.5x5m, Slab thickness is 0.15m. Wall thickness is 0.23m. Live load on floor is taken as 3kN/m^2 and on roof is 1.5kN/m^2.Seismic zone-5, Response reduction factor-5, Importance factor-1. The density of concrete and masonry are taken as 25kN/m^3 and 20kN/m^3. Size of beams and columns considered are 0.23x0.5m and 0.6x0.6m respectively. Beams and columns are modelled using frame element. Joints between building elements are modelled by using diaphragm as constraints.

3. Modelling of Soil and Foundation

Direct method is adopted in the current study in which the response of the soil and structure is determined simultaneously by analyzing the idealized soil- structure system in a single step. Soil stratum is idealized by elastic continuum theory in which physical representation of the infinite soil generates an elastic continuum model. The set of parameters adopted to represent the soil are young's modulus and poisson's ratio. The soil is modelled using solid element. Foundation is designed using spread sheets and modelled using shell element. Soil is assumed to be linear, elastic and isotropic material. Width of soil mass beyond the foundation is considered as 5B and depth as 6B, where B is the width of foundation. The dimensions are taken in order to get a considerable stress distribution.The lateral movement at the soil boundaries are restrained at side faces and fixed at base of soil. Equivalent static analysis has been carried out for fixed base and flexible base conditions.

Table 1: *Properties of soil (Joseph E Bowles, 1995)*

Soil properties	Type of soil			
	SC	DS	HC	RCK
Modulus of elasticity E(kN/m²)x1000	25	50	100	14400
Poisson's ratio μ	0.25	0.3	0.1	0.4
Density (kN/m³)	17	21	20	26.5

SC- Soft clay HC-Hard clay
DS-Dense sand RCK- Rock

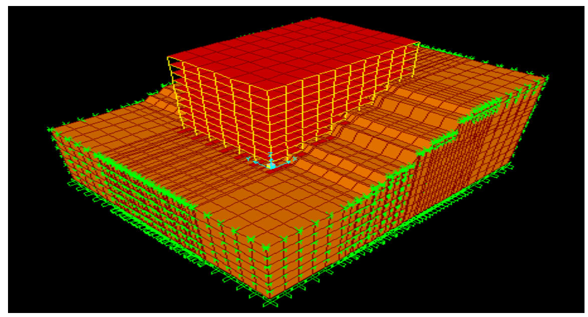

Figure 1 *3D model of soil and structure in SAP2000*

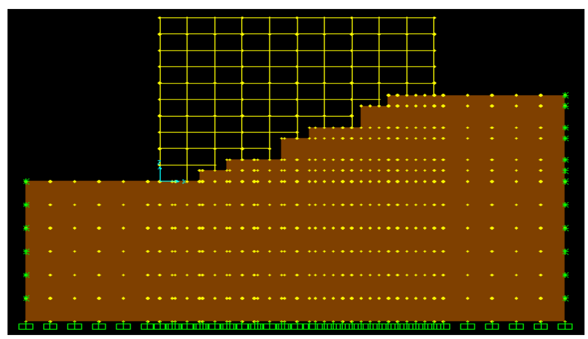

Figure 2 *Elevation of model M-1 with soil in SAP2000*

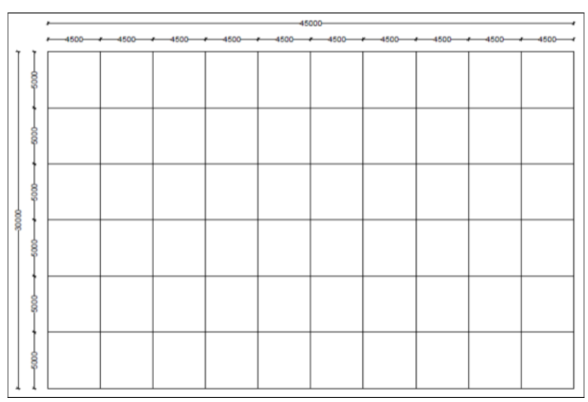

Figure 3 *Typical plan*

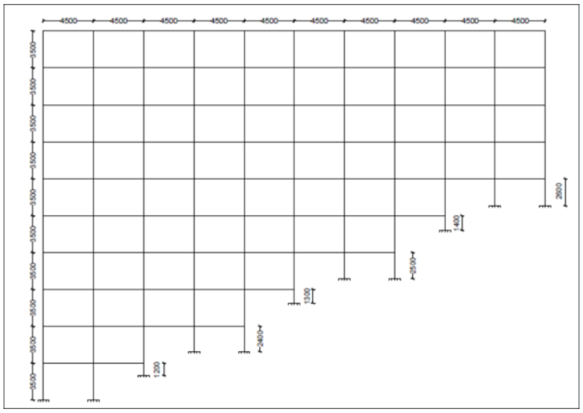

Figure 4 *Elevation of model M-1.(Note: All dimensions in mm)*

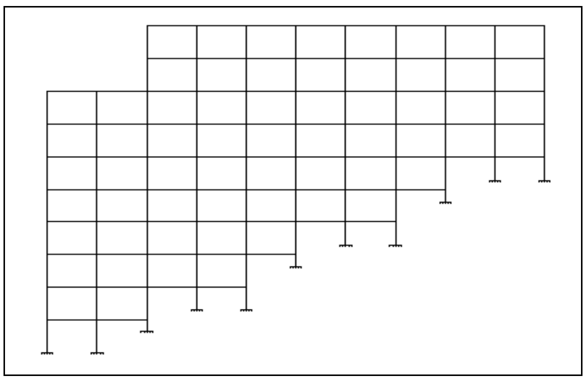

Figure 5 *Elevation of model M-2*

4. Results and Discussion

Equivalent static analysis is performed on all the models for different soils and their responses are studied in terms of top storey displacement, time period and base shear. Figures 7,8 and 9 represent the variation of maximum top storey displacement along X direction for different models where the percentage reduction in maximum top storey displacement for model M-1 were found to be 43.5%, 66.22% and 94.47% for dense sand (DS), hard clay (HC) and rock (RCK) respectively with respect to soft clay (SC) whereas percentage reduction in top storey displacement for model M-2 were found to be 43.81%, 64.63% and 93.75% for dense sand, hard clay and rock respectively with respect to soft clay and percentage reduction in top storey displacement for model M-3 were found to be 50.15%, 67.93% and 89.83% respectively for dense sand, hard clay and rock with respect to soft clay. It indicates that as stiffness of soil increases, top storey displacement decreases. As seismic weight of model M-3 is less compared to other two models percentage reduction in top storey displacement were found to be 51.37%, 57.09%, 53.83% and 10.54% respectively for soft clay, dense sand, hard clay and rock with respect to M1. Table 2 represents the time period for fundamental mode shape of all models under different soil conditions in which flexibility of soil medium below the foundation decreases the overall stiffness of the structure resulting in subsequent decrease in time period of the system. Figure 10 indicates considering the effect of SSI increased the base shear and percentage increase were found to be 33%, 51% and 46% respectively for models M1, M2 and M3 with respect to fixed base conditions; however it depends on stiffness of soil and building configuration.

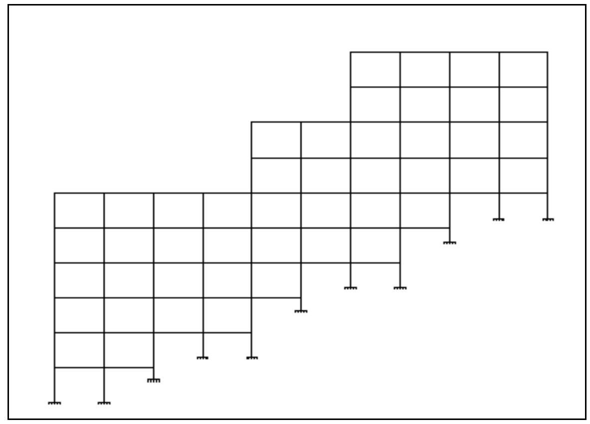

Figure 6 *Elevation of model M-3*

5. Conclusions

The following are the conclusions drawn from the present study.

1) Maximum top storey displacement for M-3 obtained from equivalent static analysis decreased by 51.37%, 57.09%, 53.83% and 10.54% respectively for soft clay (SC), dense sand (DS), hard clay (HC) and rock (RCK) with respect to model M1. Thus as stiffness of soil increases top storey displacement decreases.
2) For all models considered for analysis, effect of soil below foundation decreased the time period of the whole system with corresponding increase in frequency.
3) Also base shear was found to be minimum for model M-3 under different soil conditions compared to other models M1 and M2. Hence of all the models considered for analysis, model M-3 is the most suitable configuration preferred for a particular sloping ground considered in the study.

Table 2: *Time period for first mode shape of different models under different soil conditions*

Model Number	Type of soil				Fixed
	SC	DS	HC	RCK	
M1	1.493	1.201	1.105	0.982	0.869
M2	2.714	1.297	0.869	0.78	0.756
M3	1.285	1.024	0.777	0.653	0.638

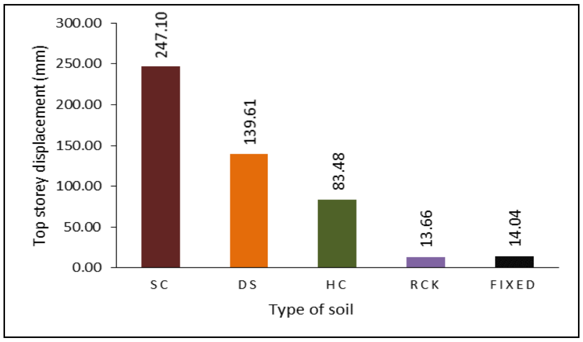

Figure 7 *Variation of maximum top storey displacement along X direction in M1 for different soils*

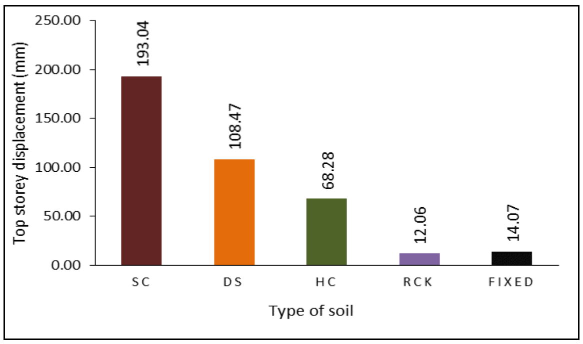

Figure 8 *Variation of maximum top storey displacement along X direction in M2 for different soils*

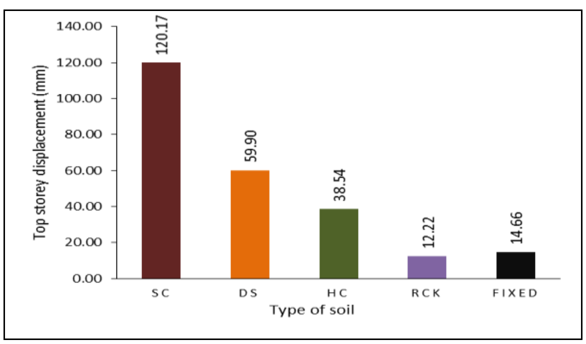

Figure 9 *Variation of maximum top storey displacement along X direction in M3 for different soils*

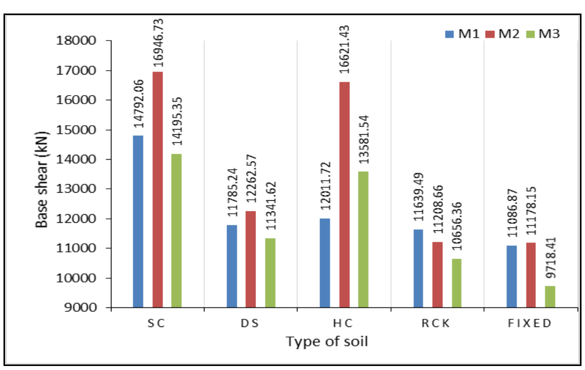

Figure 10 *Variation of maximum top storey displacement along X direction in M3 for different soils*

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