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Soil Structure Interaction of Soft Storey Building in Kathmandu Valley

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Abstract
Nepal geography is susceptible to frequently reoccurring earthquakes. Major thrusts run parallel in the east-west direction throughout the country, where special seismic designs for infrastructures are necessary. Also, heavy structures like high rise building, Hydropower plant, Bridges etc., on different types of soil strata is in rapid progress. Seismic force is being analysed considering the fixed base as per the seismic code IS 1893 (Part 1): 2016 [1]. Thus, to apply the appropriate site condition, the site soil type must be taken in consideration for the structural analysis. With rapid urbanization and rising land prices, there has been a growing tendency in the construction of open floor spaces to meet the practical needs of parking, shopping malls, car park etc. The conventional practice for design treats the infill wall as a non-structural member and is therefore overlooked. However, the latest IS Code has recognized the need of infill wall in modelling. Consideration of infill walls in the frames of a building changes its behavior under lateral loads. A Reinforced Concrete (RC) framed Building (G+3) has been considered to evaluate the result. So, nine models of the building (Bare Frame Model, Open Ground Storey Model and Fully Infilled Model with and without considering Soil Structure Interaction (SSI) are prepared and analysed in SAP 2000. As a result, it is concluded that design of building without considering SSI may lead to unsafe design.

Keywords
Infill Wall, Diagonal Strut, Soft Storey, Soil Structure Interaction

1. Introduction

Almost all the civil engineering structures are directly or indirectly founded on ground. During the external forces, such as earthquake, acts on these systems, neither the structural displacements nor the ground displacements, are independent of each other. The response of the structure to earthquake shaking is affected by interaction between three linked systems; the structure, the foundation and the soil underlying and surrounding the foundation [2]. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as Soil-Structure Interaction.

Since, the presence of a soft storey which has less rigidity than other storeys and if this fact is not taken into consideration it causes the construction to be affected by the earthquake. The columns in this part are forced by the earthquake more than the ones in the other parts of the building. Studies conducted suggest that walls increase the rigidity at a certain degree in the construction [3].

Reinforced concrete frame buildings have become common form of construction with masonry infills in every area in the world. The term infilled frame denotes a composite structure formed by the combination of a moment resisting plane frame and infill walls [4]. The infill masonry may be of brick, concrete blocks, or stones. Ideally, in present time the reinforced concrete frame is filled with bricks as non-structural wall for partition of rooms because of its advantages such as, thermal insulation, durability, cost and simple construction technique.

Kathmandu valley underlain by soft soil deposit of varying thickness from two hundred meters to eight hundred meters [5]. In reality, considering the SSI the fundamental time period of building is increased. The natural period of a building structure with that of a surface soil causes significant amplification which result in the increasing of inertial forces acting on the structure (resonance) with a considerable damage [6].

The main objective of this research is to evaluate the behaviour of masonry infill walls in reinforced concrete framed structures with and without considering SSI of Kathmandu Valley. Thus, to attain the objective of this research two location of the Kathmandu valley (Budhanilkhantha and Jawalakhel) are selected. Also, lateral natural period, seismic base shear and storey drift of masonry infilled reinforced concrete framed buildings for different configuration of infill walls with and without considering SSI of Kathmandu Valley has been studied.

2. Methodology

At present, there are two approaches to solve the problem based on SSI. The first direct approach discretizes the soil-structure system into several small grids and analyses the whole system after imposing appropriate boundary conditions. The other approach is called three- step approach, first the foundation stiffness is obtained, then the consistent motion at the foundation base accounting for excavation due to waves propagating in the free field and causing a specified motion at the ground surface is calculated. Finally, the structural response due to the consistent motions is obtained with the foundation replaced by a dynamic stiffness calculated in the first step. The second step is called the kinematic interaction and the third the inertial interaction, the combined effect being the soil-structure interaction [7]. Direct approach has been used in this research.

For understanding the seismic response of RC frame buildings with soft storey, three models: bare frame model, open ground storey model and fully infilled model with opening with same plan and same storey i.e., four storey building was selected and analyzed. To study the response of the structure, the model was developed in SAP 2000 software. The storey height was chosen as 4m for ground storey and 2.85 m for other stories. The length of each bay of the building frame was selected as 5 m. Three bays in transverse and longitudinal direction was considered as shown in figure 1.

Material used in modeling was M25 grade of concrete for slab, beam and column and Fe 500 grade of rebar material for longitudinal bars and Fe 415 grade of rebars material for confinement bars. The thickness of the floor slab and roof slab was taken as 125 mm. Size of beam and column was taken as 300*450 mm and 400*400 mm respectively. These dimensions were arrived on the basis of the design following the respective Indian Standard Code IS 456: 2000 for design of reinforced concrete structures. Static Live Load of intensity 1.5 kN/m2 on roof slab and 3 kN/m2 on all other slabs is applied to all models in gravity direction. Floor Finish of 1.125 kN/m2 is applied. Wall Loads, Partition wall Loads and staircase loads were converted to uniformly distributed load and assigned to beam members. The dead load of beam, column and slab was calculated by program itself. To find out the effect of masonry infill walls on seismic performance of RC frame building, equivalent single diagonal strut method based on IS 1893 (Part 1): 2016 [1] was adopted.

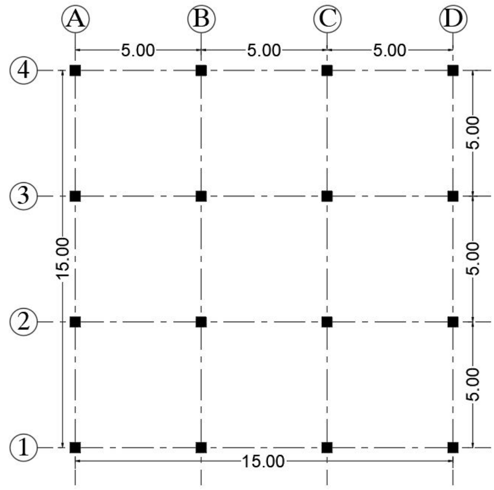

Figure 1: Plan of the Building

Table 1: Soil properties of Jawalakhel Site

Depth (m)	Modulus of Elasticity, E (KN/m^2)	Bulk Unit Weight (KN/m^3)	Poisson's Ratio
1.5	44000.00	19.00	0.30
3.0	48800.00	19.00	0.30
4.5	34000.00	19.00	0.30
6.0	11017.00	18.00	0.35
7.5	10857.33	18.00	0.35
9.0	11176.67	18.00	0.35
10.5	9464.00	18.00	0.35
12.0	10816.67	18.00	0.35
13.5	10457.00	18.00	0.35
15	11434.33	18.00	0.35

Soil samples for 15m depth of each bore hole from three bore holes in each sites have been collected. Then, the soil samples were tested in lab. The value for Modulus of Elasticity, Bulk Unit Weight and Poisson's Ratio provided for Jawalakhel site and Budhanilkantha site are shown in Table 1 and Table 2 respectively.

Table 2: Soil properties of Budhanilkantha Site

Depth (m)	Modulus of Elasticity, E (KN/m^2)	Bulk Unit Weight (KN/m^3)	Poisson's Ratio
1.5	20118.00	18.00	0.30
3.0	25546.67	18.00	0.30
4.5	43211.33	18.67	0.29
6.0	46800.00	19.00	0.28
7.5	55600.00	19.00	0.28
9.0	56800.00	19.00	0.28
10.5	56800.00	19.00	0.28
12.0	56000.00	19.00	0.28
13.5	56800.00	19.00	0.28
15	54800.00	19.00	0.28

3. Analysis and Results

After modeling of the structure for fixed support condition and considering Jawalakhel site soil and Budhanilkantha site soil, the analysis of models was carried out using SAP 2000 software and the results are obtained and compared in terms of lateral natural period, base shear and storey drift.

3.1 Lateral Natural Period

Natural period of a structure is its time period of undamped free vibration. Fundamental natural period of a structure is the longest modal time period of vibration [8]. The variation in fundamental time period for fixed base condition and considering SSI at Jawalakhel and Budhanilkantha for bare frame, open ground storey model and fully infilled model of four storey is shown in Table 3.

It is observed that the time period of bare frame model is highest among the models whereas time period is minimum for fully infilled model. Also, time period for the models considering SSI of Jawalakhel site and Budhanilkantha Site were found out and is observed that time period is increased considering the flexibility of the soil. This means fundamental time period of the building considering fixed base condition is shorter than the flexible base condition.

Table 3: Fundamental Time Period for four storey model (sec)

Support Condition	Fixed Base	Budhanilkantha Site with SSI	Jawalakhel Site with SSI
Bare Frame	0.97653	1.65785	1.72564
Soft Storey	0.76758	1.50683	1.58481
Fully Infilled	0.46483	0.72231	1.10935

3.2 Base Shear

Base shear reflects the seismic lateral vulnerability of the structures and is considered as very important parameter for seismic evaluation of buildings. The variation in base shear for fixed base condition and considering SSI at Jawalakhel for bare frame, open ground storey model and fully infilled model of four storey is shown in Table 4. The study shows that the presence of infill walls affects the base shear of the structure i.e., infill walls increases the base shear of the structure. Base shear is maximum for fully infilled model and minimum for bare frame model. Base shear is intermediate for open ground storey model. This is valid in all the cases i.e., considering fixed base condition and considering SSI at Jawalakhel site and Budhanilkantha site.

It is observed that base shear decreases considering the flexibility of soil. Base shear is found maximum for fixed base condition. Base Shear of the building decreases due to SSI consideration. Base shear in the building considering Budhanilkantha site with SSI is about 90% of base shear in fixed base condition and base shear for Jawalakhel site with SSI is about 95% of base shear in building with fixed base.

Table 4: Base Shear for four storey model (kN)

Support Condition	Fixed Base	Budhanilkantha Site with SSI	Jawalakhel Site with SSI
Bare Frame	899.516	863.535	829.055
Soft Storey	1168.775	1040.21	968.456
Fully Infilled	1387.401	1109.921	1048.461

3.3 Storey Drift

Storey drift is the displacement of one level relative to the other level above or below. It is the maximum relative displacement of each floor divided by the height of the same floor. The variation in storey drift along both the longitudinal and transverse direction for three different models; bare frame model, open ground storey model and fully infilled model of four storey building for fixed base condition and considering SSI at Jawalakhel site and Budhanilkantha site are shown in Table 5, 6, 7 and 8 and graphical representation is shown in Figure 2, 3, 4 and 5.

Table 5: Storey Drift for four storey bare frame model along longitudinal and transverse direction

Support Condition	Fixed Base	Budhanilkantha Site with SSI	Jawalakhel Site with SSI
4th Storey	0.000993	0.007335	0.009155
3rd Storey	0.001653	0.012492	0.014298
2nd Storey	0.002091	0.021064	0.022792
1st Storey	0.002215	0.067458	0.06822
Base	0.000	0.000	0.000

Table 6: Storey Drift for four storey soft storey frame model along longitudinal and transverse direction

Support Condition	Fixed Base	Budhanilkantha Site with SSI	Jawalakhel Site with SSI
4th Storey	0.000321	0.003173	0.005053
3rd Storey	0.000505	0.004166	0.00604
2nd Storey	0.000756	0.007488	0.009333
1st Storey	0.002467	0.063168	0.063933
Base	0.000	0.000	0.000

Table 7: Storey Drift for four storey fully infilled frame model along longitudinal and transverse direction

Support Condition	Fixed Base	Budhanilkantha Site with SSI	Jawalakhel Site with SSI
4th Storey	0.000378	0.003082	0.005037
3rd Storey	0.000607	0.004218	0.006167
2nd Storey	0.000723	0.005031	0.006974
1st Storey	0.000682	0.006146	0.008076
Base	0.000	0.000	0.000

The drift due to static method is taken into consideration. The inter- storey drift in first storey are large for open ground storey model compared to bare frame model and fully infilled model which shows the sudden change in slope of drift, this is due to abrupt change in storey stiffness, whereas the bare frame model and fully infilled model shows a smooth profile. Storey drift is higher at each floor for bare fame model compared to fully infilled model.

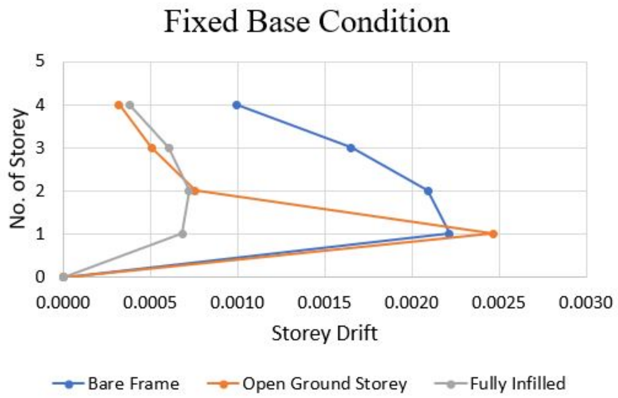

Figure 2: Variation in storey drift for four storey fixed base model

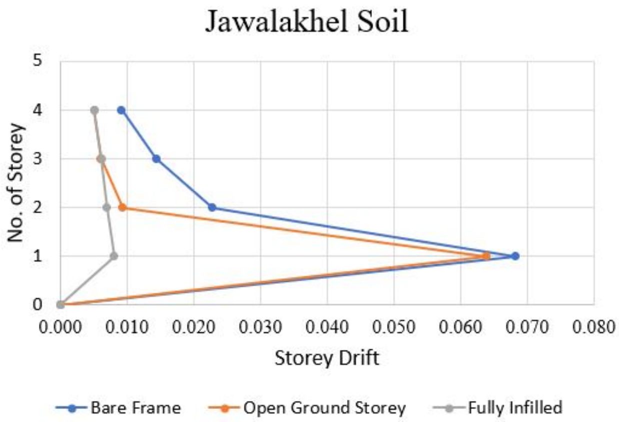

Figure 3: Variation in storey drift for considering SSI at Jawalakhel

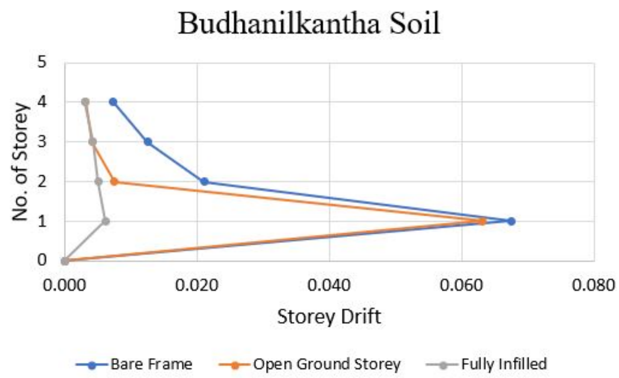

Figure 4: Variation in storey drift considering SSI at Budhanilkantha

4. Conclusions

The study is based on different base condition of three models of building: bare frame model, open ground storey model and fully infilled model of RC framed building (G+3) with and without considering SSI. Soil properties of Budhanilkantha and Jawalakhel area has been adopted. In general, nature of soil at Jawalakhel site is softer as compared to the nature of soil at Budhanilkantha site. The study shows that the presence of infill walls and the SSI affects the time period of structure. The presence of infill walls reduces the fundamental time period of the structure while SSI extends the fundamental time period of the building. It is also seen that time period for the bare frame model is maximum and time period is minimum for fully infilled model. It is also evident that the time period of a building on weak ground is greater than the relative structure found in the harder soil. Base Shear of the building increases as a result of the presence of infill walls and decreases due to SSI considerations.

The research can be further extended to evaluate the capacity of the building with SSI. Also, the effect of SSI on the response of the structure can be studied by increasing height of the building. Further, the role of earthquake input parameter like acceleration, duration and frequency content on the structure due to the soil structure interaction behavior can be studied.

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