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DESIGN VALIDATION OF MASS ACCOMMODATION STRUCTURES DURING THE Mw 7.8 GORKHA EARTHQUAKE (2015) FROM A SOIL-STRUCTURE INTERACTION PERSPECTIVE

Sujal Maharjan[1]*, Ram Chandra Tiwari[2], Aanchal Tiwari [2], Sandeep Sapkota [3]

[1] Department of Civil Engineering, IOE, Thapathali Campus, Tribhuvan University, Nepal
[2] Department of Civil Engineering, IOE, Pulchowk Campus, Tribhuvan University, Pulchowk Lalitpur, Nepal
[3] Department of Civil Engineering, Universal Engineering & Science College, Pokhara University, Nepal

Abstract

The seismic response of the structure with underground stories is observed with the consideration of soil structure interaction (SSI). The soil is replaced by springs assigned at the joints. The spring parameters are calculated from ASCE and contemporary literature. The study is conducted on three sets of building with three stories. Two input motions, i.e. Gorkha-Barpak (2015) earthquake time history and time history matched with response spectrum for medium soil from IS 1893 (Part 1): 2002 is used for the analysis. The response of the structure is compared in terms of the time period, roof displacement and shear force demand at ground floor level. The study reveals that on considering SSI, there is an increase in the lateral time period of the building, resulting in a decrease in shear force demand and an increase in lateral displacement. However, the change in the demand is observed to be low and would rarely alter the design of the structure.

Keywords: Seismic response, Soil structure interaction (SSI), Mass accommodation structure, Finite element method (FEM)

1. Introduction

The extent of damage caused by an earthquake largely depends on the characteristics of the strong ground motion. It is well established that earthquake ground motion is primarily governed by three factors: (i) source characteristics, (ii) the propagation path of seismic waves, and (iii) local site conditions (Aki and Richards, 2002,Kramer, 1996). However, current structural design practices often overlook the significance of Soil–Structure Interaction (SSI), which can considerably influence the overall seismic response of a structure. SSI affects not only the relative building response but also the motion of the foundation and surrounding soil (Gazetas and Stokoe, 1991,Wolf, 1985).

In general, building–soil interaction consists of two main components: kinematic interaction and dynamic (inertial) interaction. Kinematic interaction arises from the wave nature of seismic excitation and is manifested through the scattering and diffraction of incident waves by the building foundation. In contrast, dynamic interaction results from the inertia forces of the structure and its foundation acting on the underlying soil due to the contact area between them (Mylonakis and Gazetas, 2000, Stewart et al., 1999). The extent of dynamic interaction depends on several parameters, including the mass and height of the building, the mass and embedment depth of the foundation, the relative stiffness between the soil and the structure, and the foundation geometry (Veletsos and Meek, 1974, Gazetas, 1991).

The present study aims to evaluate the seismic response of a typical low-rise building in Nepal considering inertial SSI effects, and to compare it with the conventional fixed-base model. The study focuses exclusively on the inertial component of SSI for the considered cases.

Soil–structure interaction is a complex phenomenon because the soil medium is generally semi-infinite and nonlinear in its material behavior (Wolf, 1985, Kramer,

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*Corresponding author: Sujal Maharjan
Department of Civil Engineering,
IOE, Thapathali Campus, TU, Nepal
Email: er.sujalmaharjan@gmail.com

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1996). The inclusion of SSI can have a significant impact on the structural demand during the design process, especially at sites characterized by low shear wave velocity, where the amplification of ground motion becomes more pronounced a condition often encountered in Nepal (Bhattarai et al., 2017, Gautam et al., 2017).

Since no site-specific dynamic soil tests have been conducted for the selected study area, the dynamic soil properties have been estimated based on published literature and representative data for similar local conditions (Idriss and Boulanger, 2008, Hashash et al., 2017). Furthermore, there exists a lack of comprehensive studies addressing SSI effects in low-rise buildings under Nepalese soil conditions, highlighting the need for this investigation.

The objectives of this research are as follows: 1) To determine the seismic response of a low-rise building considering soil–structure interaction, 2) To compare the response of the structure with a fixed-base model and a model incorporating SSI through a spring system.

The scope of the present study includes: 1) Modeling a three-story low-rise building for dynamic analysis, 2) Obtaining dynamic soil properties from the literature corresponding to local site conditions, 3) Representing the soil using the Winkler foundation approach, modeled through discrete springs (Gazetas and Stokoe, 1991, Wolf, 1985), and 4) Employing two earthquake time histories for analysis—an Indian code-based compatible time history (for soil type II, as per IS 1893:2016) ("Criteria for Earthquake Resistant Design of Structures – General Provisions and Buildings", 2002) and the 2015 Gorkha–Barpak Earthquake record.

The 2015 Gorkha–Barpak earthquake has been selected as a representative seismic event for Nepal, though it exhibits a relatively low peak ground acceleration (PGA) compared to design-level ground motions (Dixit et al., 2017, Gautam and Chamlagain, 2016).

2. Method and Materials

During an earthquake, the response of the structure highly depends upon SSI. The degree of the Influence of SSI on response of structure depends on the Stiffness of soil, dynamic characteristics of the structure itself, i.e. natural period and damping factor and Stiffness and mass of the structure.

Stewart et al. (1999), observed that the single most important parameter controlling the significance of the inertial soil structure interaction is , and that inertial SSI effects are generally negligible for <0.1, which occur in flexible structures (e.g. moment frame buildings) located on competent soil or rock. Conversely, inertial SSI effects tend to be significant for stiff structures, such as shear wall or braced frame buildings, located on softer soils.

Gazetas and Stokoe (1991) developed simple algebraic formulas and charts for estimating the dynamic spring and dashpot parameters of foundations. The formula is valid for constant embedment depth and for solid basement shape. However, the basemat may be practically of any shape and the vertical sidewalls may have any degree of contact with the surrounding soils. The charts and formulas are used for all the significant translation and rotational modes of vibration. Later, ASCE 41-06 incorporated the procedures for incorporating the effects of SSI.

Dutta and Roy (2002) compared the different modeling approach of soil media. He concluded that Winkler hypothesis, despite its obvious limitations, yields reasonable performance and it is very easy to exercise. So for practical purposes, this idealization should, at least, be employed, instead of carrying out an analysis with the fixed base idealization of structures.

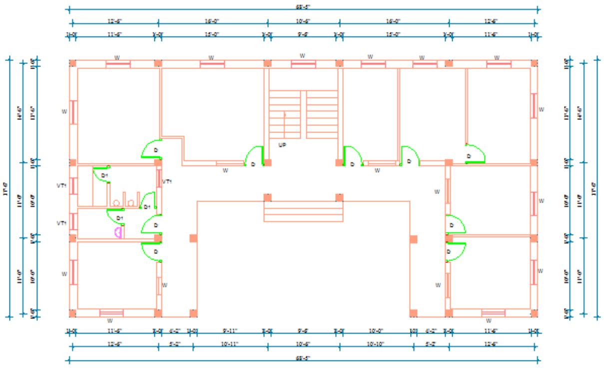

Figure 1. Typical plan of Building 1

Table 1. Properties of elements in the model

Properties of elements	Value
Concrete Grade	M20
Rebar Grade	500
Column Size	300×300 mm^2
Beam Size	230×355 mm^2
Slab Thickness	125 mm

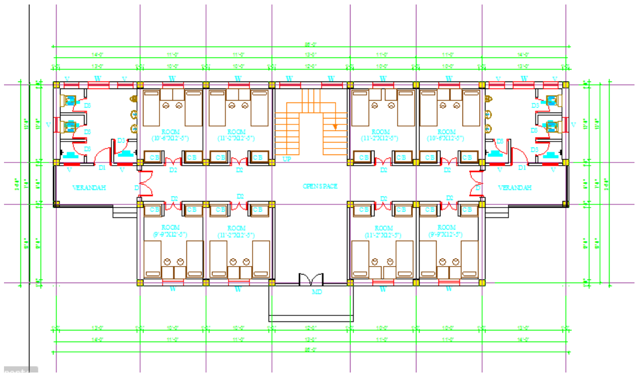

Figure 2. Typical plan of Building 2

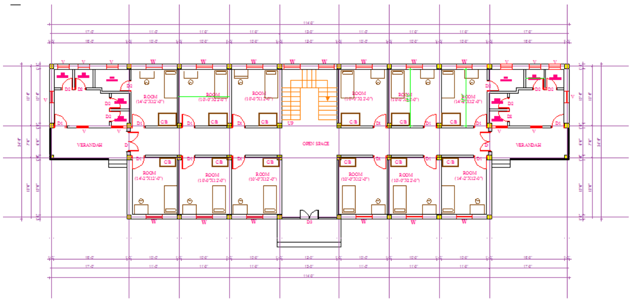

Figure 3. Typical plan of Building 3

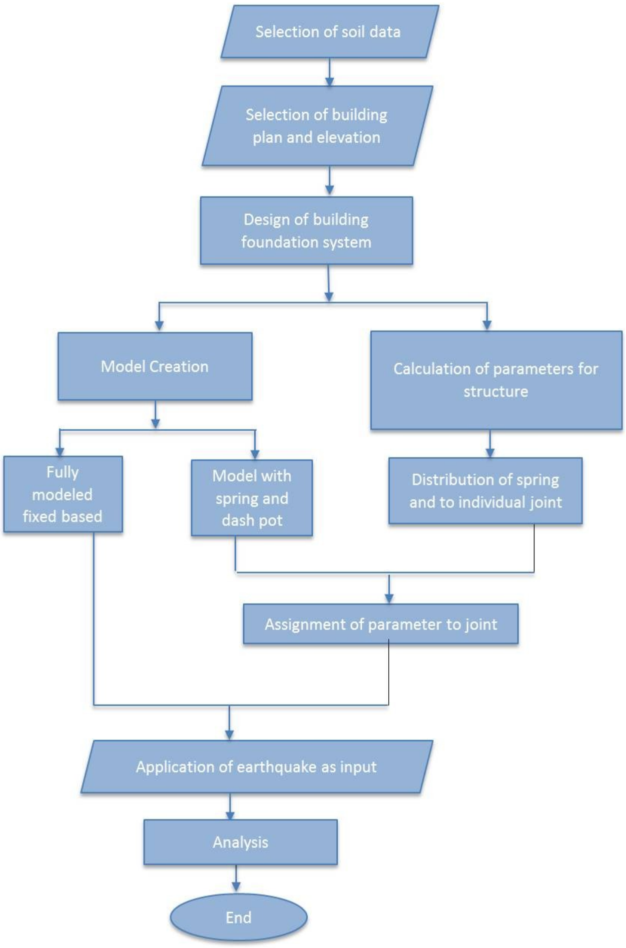

Figure 4. Flowchart of the step followed

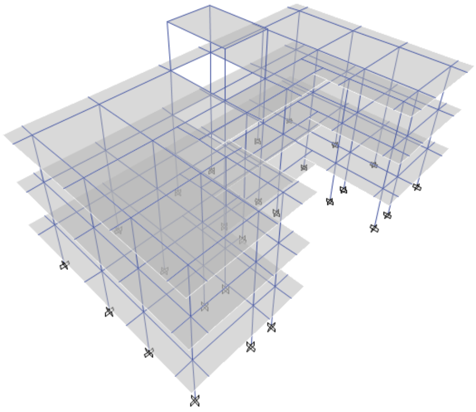

Figure 5. Typical Model of building with fixed base

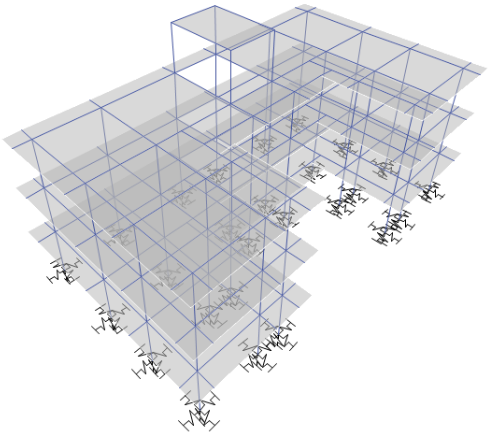

Figure 6. Typical Model of building with SSI model

Dynamic properties of the soil highly influence the values of springs used in the analysis. As dynamic soil properties are not available, we referred literature for the most appropriate value. The average shear wave velocity assumed is 182.14 m/s, as per correlation with similar site. The density of the soil is assumed to be 1.36g/cm3. Thus the obtained value of the average shear modulus is 45 mPa.

Three sets of building models are created. The buildings selected are the representative of common building practice in Nepal. The properties used for modeling of the building are given in Table 1. The plans of the considered building are shown in Figure 2.

A Finite Element method based program ETABS2015 v15.0.0 is employed for the analysis. Dynamic Analysis of the structure is done by time history Analysis. Synthetic Ground motion generated for the Indian code based response spectra for medium soil is used. In addition, Time History of Gorkha Earthquake (April 25, 2015) is also used. The selection of these two categories of records is done for the reason that Indian Code method is widely followed method of design in Nepal and Gorkha Earthquake is the most significant and recent earthquake in Nepal with its peculiar nature of increase in demand to increase in time period. Results are obtained for each set of models. The comparison of results would be based on: 1) Base Shear, Story Shear, 2) Maximum Story Deflection and 3) Shifting of the building time period.

Table 2. Equivalent soil-springs stiffness as per ASCE 41-06

K_x (kN/m)	K_y (kN/m)	K_z (kN/m)	K_{rx} (kN-rad)	K_{ry} (kN-m/rad)	K_{rz} (kN-m/rad)
6140.45	6104.52	44135.62	4471.34	78740.27	57276.42

Table 3. Change in the Time Period

	X-dir		Y-dir	
	No SSI	SSI	No SSI	SSI
Building 1	0.707	0.717	0.683	0.696
Building 2	0.672	0.684	0.663	0.669
Building 3	0.672	0.684	0.663	0.669

2.1. Spring Model

The soil is represented with the help of spring assigned at the base of the building replacing the foundation. The value of the spring is influenced by the dimension of the foundation system and the dynamic properties of the soil. Thus, initially the foundation system is designed according to the static condition. Then the values of springs are obtained as prescribed in ASCE 41-06.

The Poisson's ratio was assumed to be 0.33 for the soil. The values of soil-spring stiffness is given in Table 2.

The spring is assigned to the base of the column and analyzed.

3. Results

Static and response spectrum analysis of the models are performed using ETABS 2015. Effect of SSI on different parameters of seismic analysis, i.e. the natural time period, roof displacement and base shear are studied.

3.1. Time Period

Time period comparison of conventional fixed base building and building with SSI effect is tabulated and shown in Table 3. As discussed earlier due to the SSI effect time period of flexibility of the building increases with an increase in a time period which results into larger relative displacements. Results show that effect of soil structure interaction is more significant for low stiff soils.

3.2. Displacement

Roof displacement results are shown in Table 4, in which it is observed that on considering SSI effect roof displacement of the building increased. However, in the case of low rise structure, it is observed that the change in displacement is relatively low.

3.3. Base Shear

The variation in the base shear demand is similar to that of the displacement demand. The demand is reduced when considering SSI; but, the reduction is relatively low. The time period of the building lies in the similar range, thus the change in demand is similar and relatively low in all cases (Table 5).

4. Conclusion

The consideration of SSI increases the time period of the structure causing it to be more flexible, hence increasing the displacement demand and reducing the shear force demand. However, the change in the response of the structure due to the consideration of SSI is very low and does not carry much significance while designing the structures.

References

Aki, K., & Richards, P. G. (2002). *Quantitative seismology*. University Science Books.

Bhattarai, M., Adhikari, L. B., Gautam, D., & Koirala, R. (2017). Site effects and damage patterns of the 2015 gorkha earthquake. *Soil Dynamics and Earthquake Engineering*, *100*, 97–110.

Criteria for earthquake resistant design of structures – general provisions and buildings. (2002). Bureau of Indian Standards.

Dixit, A. M., Yatabe, R., Dahal, R. K., & Bhandary, N. P. (2017). Initiatives for earthquake disaster risk management in nepal. *Natural Hazards*, *43*(3), 477–500.

Dutta, S., & Roy, R. (2002). A critical review on idealization and modeling for interaction among soil foundation–structure system. *Computers and Structures*, *80*, 1579–1594.

Gautam, D., Bhattarai, M., & Adhikari, L. B. (2017). Performance of buildings during the 2015 gorkha earthquake: Lessons learned. *Earthquake Spectra*, *33*(S1), S381–S402.

Gautam, D., & Chamlagain, D. (2016). Seismic response of low-rise buildings considering site effects: Lessons from the 2015 gorkha earthquake. *Engineering Structures*, *124*, 432–443.

Gazetas, G. (1991). Formulas and charts for impedances of surface and embedded foundations. *Journal of Geotechnical Engineering*, *117*(9), 1363–1381.

Gazetas, G., & Stokoe, K. H. I. (1991). Free vibration of embedded foundations: Theory versus experiment. *Journal of Geotechnical Engineering*, *117*(9), 1382–1401.

Hashash, Y. M. A., Musgrove, M. I., Harmon, J. A., Groholski, D. R., Phillips, C. A., & Park, D. (2017).

Table 4. Change in Displacement

Building	Gorkha EQ (x-dim)		Gorkha EQ (y-dim)		IS EQ (x-dim)		IS EQ (y-dim)	
	No SSI	SSI	No SSI	SSI	No SSI	SSI	No SSI	SSI
Building 1	5.34	5.43	4.48	5.25	13.34	13.3	13.23	14.177
Building 2	3.3	3.61	3.76	4.51	12.6	12.52	12.52	13.16
Building 3	2.98	2.97	3.04	3.09	12.59	12.59	12.9	12.93

Table 5. Change in Base Shear

Building	Gorkha EQ (x-dim) (kN)		Gorkha EQ (y-dim) (kN)		IS EQ (x-dim) (kN)		IS EQ (y-dim) (kN)	
	No SSI	SSI	No SSI	SSI	No SSI	SSI	No SSI	SSI
Building 1	195.45	189.83	205.163	209.77	471.7	456.72	561.51	539.52
Building 2	218.65	221.92	223.76	232.23	615.04	603.63	630.37	634.81
Building 3	278.38	277.18	272.12	264.47	801.76	795.08	779.74	753.93

Table 6. Change in Displacement

Building	Gorkha EQ (x-dim)		Gorkha EQ (y-dim)		IS EQ (x-dim)		IS EQ (y-dim)	
	No SSI	SSI	No SSI	SSI	No SSI	SSI	No SSI	SSI
Building 1	5.34	5.43	4.48	5.25	13.34	13.3	13.23	14.177
Building 2	3.3	3.61	3.76	4.51	12.6	12.52	12.52	13.16
Building 3	2.98	2.97	3.04	3.09	12.59	12.59	12.9	12.93

Table 7. Change in Base Shear

Building	Gorkha EQ (x-dim) (kN)		Gorkha EQ (y-dim) (kN)		IS EQ (x-dim) (kN)		IS EQ (y-dim) (kN)	
	No SSI	SSI	No SSI	SSI	No SSI	SSI	No SSI	SSI
Building 1	195.45	189.83	205.163	209.77	471.7	456.72	561.51	539.52
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Deepsoil 7.0 user manual. University of Illinois at Urbana-Champaign.

Idriss, I. M., & Boulanger, R. W. (2008). *Soil liquefaction during earthquakes*. Earthquake Engineering Research Institute.

Kramer, S. L. (1996). *Geotechnical earthquake engineering*. Prentice Hall.

Mylonakis, G., & Gazetas, G. (2000). Seismic soil–structure interaction: Beneficial or detrimental? *Journal of Earthquake Engineering*, *4*(3), 277–301.

Stewart, J. P., Seed, R. B., & Fenves, G. L. (1999). Seismic soil-structure interaction in buildings. i: Analytical aspects. *Journal of Geotechnical and Geoenvironmental Engineering*, *125*(1), 26–37.

Veletsos, A. S., & Meek, J. W. (1974). Dynamic behavior of building–foundation systems. *Earthquake Engineering and Structural Dynamics*, *3*(2), 121–138.

Wolf, J. P. (1985). *Dynamic soil–structure interaction*. Prentice Hall.

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