Lowland Technology International 2020; 22 (1): 064-074
International Association of Lowland Technology (IALT): ISSN 1344-9656
Special Issue on: Engineering Geology and Geotechniques for Developing Countries

Research Paper

Effects of Soil Structure Interaction on Reinforced Concrete Framed Structures

N. Dongol [1], S. Manandhar *[2], and P.M. Pradhan [3]

ARTICLE INFORMATION

Article history:

Received: 30 September, 2019
Received in revised form: 01 March, 2020
Accepted: 03 March, 2020
Publish on: 06 June, 2020

Keywords:

Direct modelling
Time history analysis (THA)
Soil structure interaction (SSI)
Standard penetration test (SPT)
Stiffness

ABSTRACT

This study proposes to highlight effects of soil structure interaction on the Reinforced Concrete (RC) framed structures. In this study, the seismic responses of the structures are observed considering soil structure interaction (SSI) from its actual soil condition. Here, two preexisting structures are taken for the study. One is residential building and the other is hospital building with two basements. Taking into account the actual soil condition of each building site, this study provides idea on the soil structure interaction on different kinds of buildings. Direct and substructure approaches are used to incorporate soil structure interaction in the analysis. The properties of springs are calculated for different standard penetration test (SPT) values and springs are assigned for footing for the substructure approach. Entire soil-foundation-structure system is modelled and analyzed in single step for direct approach. Static analysis, response spectrum analysis and time history analysis (THA) are done in order to find the variations in natural periods, base shears and deflections of the structures by incorporating soil flexibility as compared to structures with conventional fixed base.

1. Introduction

The usual method of analyzing structures is by incorporating the soil as rigid support, however the soil actually exhibits flexibility to the vertical and horizontal forces acting on it. 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 (SSI). The flexibility of soil mass causes the differential settlement and rotation of footings under the application of load. Neglecting the soil structure interaction is reasonable only for light weight structures, low rise buildings and rigid retaining walls (Baragani and Dyavanal, 2014). The soil structure interaction effects are needed to be considered for the tall buildings and buildings resting over soft soils. The lack of implementation of SSI analysis can be mainly attributed to the misconception of the conservative approach of using fixed base supports for all types of soil conditions. Soil plays an important role is the response of the structure however, it is neglected due to computational tediousness. Ignoring soil conditions eliminates many significant factors that influences the building in many ways and therefore results arenot reliable. Hence, this study is aimed to study the soil-structure-interaction for multi-story buildings.

---

[1] Student of Masters in Structural Engineering, Kathmandu University, Dhulikhel, NEPAL, trishnadongol123@gmail.com
[*2] Corresponding Author and Research Fellow of Global Institute of Interdisciplinary Studies (GIIS), 44600, Kathmandu, NEPAL, geosuman27@gmail.com
[3] Associate Professor and Head of Department, Department of Civil Engineering, Kathmandu University, Dhulikhel, NEPAL, prachand@ku.edu.np, prachand.pradhan@gmail.com
Note: Discussion on this paper is open until 01, December, 2020

2. Research Hypothesis

In this study, two building are chosen. One is the residential building whereas other is hospital building with two basements. The main objective of the study is to compare the study of buildings where one has no basement and other with two basements considered as soil penetration factor for the study. Each building structure is modelled with rigid base, spring base and direct soil modelling (Dongol et al., 2019). Soil is modelled from its N-value up to certain depth. The top 30 m of surface soil stratum is considered key influence on the structure and its respectively ground motions (Kiku, 2001).

For determination of seismic responses, it is necessary to carry out seismic analysis of the structure using different available methods (Duggal, 2010). In this study, three approaches are used for the analysis. The first one is the equivalent static analysis. In the preliminary design process, equivalent static seismic forces are used to determine the design internal forces of structural members using linear elastic analyses of structure. The second one is response spectrum analysis or dynamic analysis. Analysis that considers mode shapes and modal mass participation of the structures for different building frequencies is called dynamic analysis. Every building has different frequency of vibration, not just one frequency and when an earthquake occurs, the response of the building is a combination of different natural frequencies of the building (Kabtamu et al., 2018). Time history analysis is the most comprehensive method for seismic analysis. The earthquake record in the form of acceleration time history is input at the base of the structure (Raheem, et al., 2014). The response of the structure is computed at any time within the entire duration of an earthquake. This method differs from response spectrum analysis because the effect of “time” is considered in THA.

In sub structure modelling, spring stiffness is used to account for frequency dependency of interaction. It is the simplest way to consider the SSI effects. Gazetas base condition gives better result for dense, FEMA 356 for stiff soil and FEMA 273 for soft soil (Rajak and Debbarma, 2017). In the residential building having isolated footing, FEMA 356 is used for the consideration of soil stiffness on the structure while formula of Gazetas is used in case of hospital building having raft foundation. Gazetas is referred for development of spring stiffness solutions that are applicable to any solid basement shape (FEMA 356). In direct modelling, the equations of motion are solved directly in their coupled form and in one step. It is recommended that location of transmitting boundary to be selected 8 to 10 times of the foundation base width of the direct modelling of soil (Rosset and Kausel, 1976). The base shear can increase by 42% in case of SSI of adjacent buildings and in single building, it can increase by 18% (Suhas and Prakash, 2017).

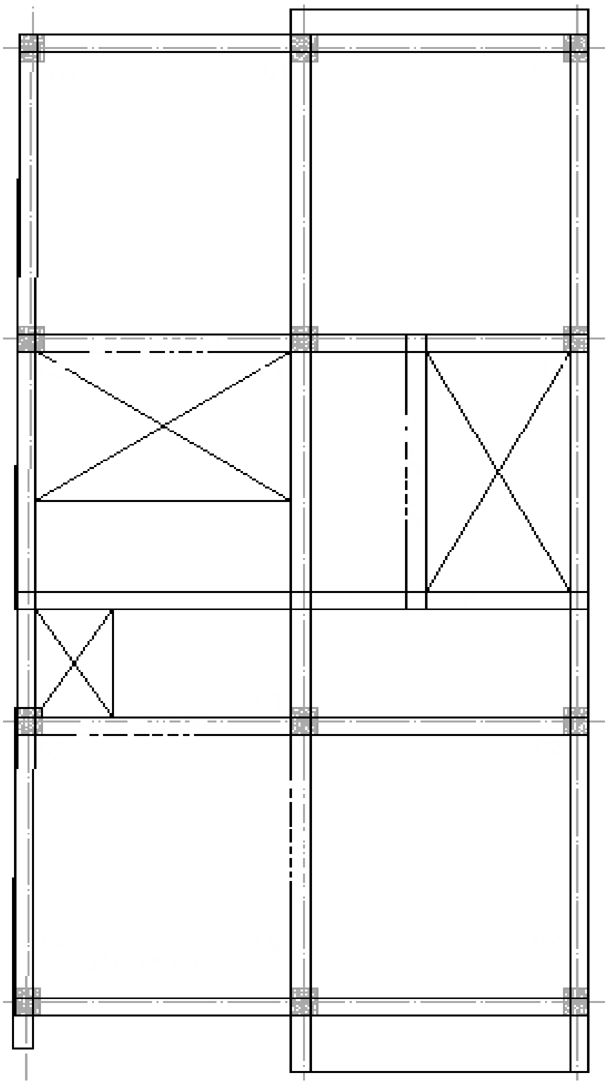

Fig. 1. Plan of the residential building.

SAP2000 software is used for the modelling and analysis of the buildings and the code referred for the study is Indian standard code i.e. IS 456: 2000 and IS 1893: (Part 1) 2002.

3. Structure Modelling and Analysis

In this paper, plans of two buildings are taken where one is residential building and other is hospital building with two basements. The two types of buildings are chosen so as to compare the results between soil penetrated one to non-penetrated one.

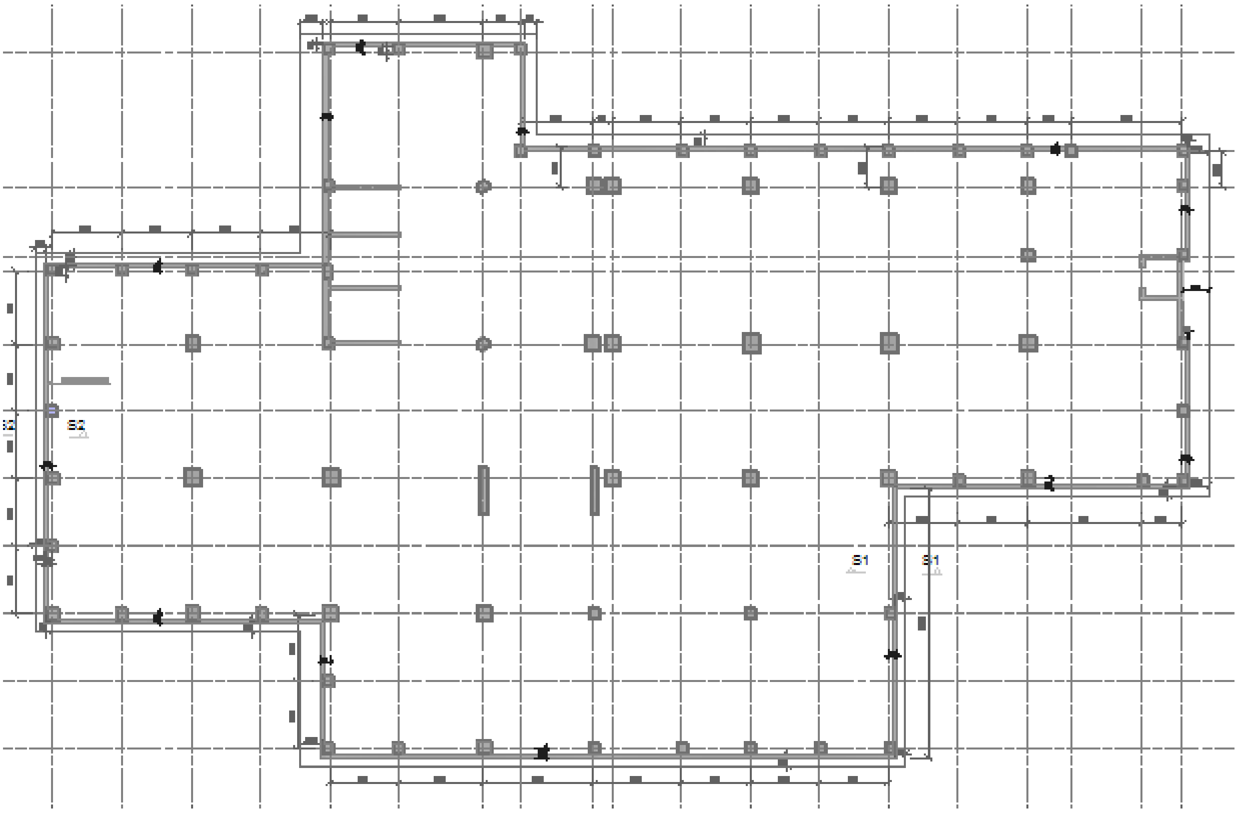

Fig. 2. Plan of the hospital building.

3.1 Residential Building

The followings are the general properties for the study of residential building as shown in **Fig. 1**.

- Beam: 230 mm x 430 mm
- Column: 300 mm x 350 mm
- Depth of slab: 125 mm
- No. of storey: 5
- Height of storey: 3 m
- Total height of building: 17 m
- Live Load: 3 kN/m^2
- Plinth area of the building: 89.466 sqm
- Type of foundation: Isolated Footing
- Importance factor (I): 1
- Zone factor (Z): 0.36
- Concrete Strength: M20 (beam and slab) and M25 (column)
- Rebar Strength: Fe500

For the spring modelling, the stiffness of soil is calculated using the equations as per **Tables 1** and **2** referring the FEMA 356 (FEMA 2000).

3.2 Hospital building

The followings are the properties of hospital building with two basements used for the study as shown in **Fig. 2**.

- Beam: 350 mm x 600 mm
- Secondary Beam: 230 mm x 300 mm
- Column: 750 mm x 750 mm (Maximum size)
- Depth of slab:125 mm
- Thickness of Lift wall: 200 mm
- Thickness of retaining wall: 200 mm
- Thickness of Shear wall: 350 mm
- No. of storey: 9
- Total height of building: 32.4 m
- Height below GL: 7.2 m
- Height of storey: 3.6 m
- Live Load: 5 kN/m^2
- Stair Load: 5 kN/m^2
- Terrace Load: 2 kN/m^2
- Floor Finish Load: 1.5 kN/m^2
- Plinth area of the building: 1161.48 m^2
- Type of foundation: Raft Footing
- Depth of raft foundation: 700 mm
- Importance factor (I):1.5
- Zone factor (Z): 0.36
- Response reduction factor (R): 5
- Concrete Strength: M25 (beam, slab, shear wall and lift wall) and M30 (column)
- Rebar Strength: Fe500

For the spring modelling, the stiffness of soil is calculated using the equations of Gazetas as shown in

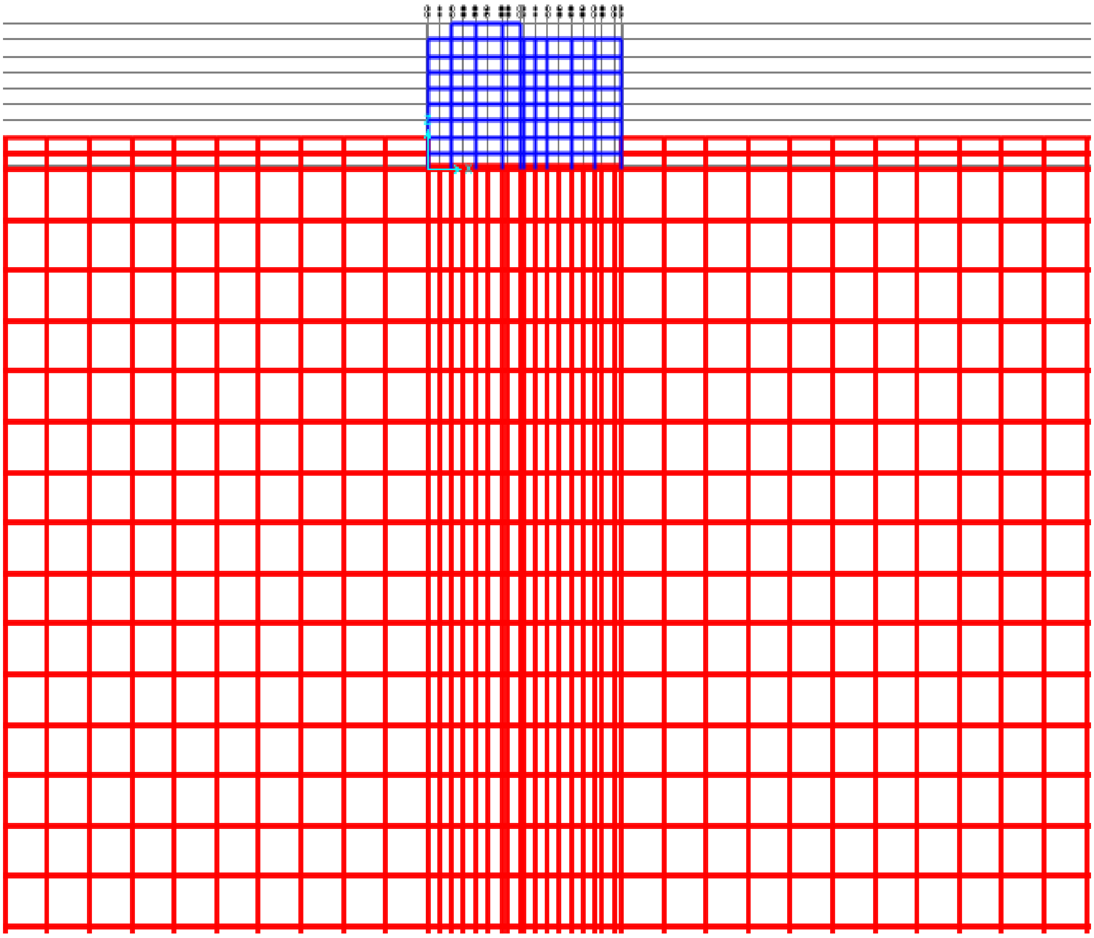

Fig. 3. Direct modelling of hospital building.

Tables 4 and **5** (Gazetas,1991). Here surface and embedded stiffness are calculated separately for the soil stiffness at certain depth of the soil condition and at ground surface condition.

In direct modelling approach, soil is modelled as a finite element as shown in **Fig. 3**. Hence, it is needed to estimate the properties of soil. For direct modelling, Kiku *et al*. is used to compute the value of the soil properties from the N-value available for the certain depth of the soil using as shown in **Table 6**.

The time history analysis is conducted using earthquake of different varying PGA values and the results are computed. The effect of earthquake will not always be more for the one having larger value of PGA. To understand these variation, governing factors needs to be considered like amplitude, duration of shaking, bracketed duration etc. **Table 7** shows the chosen earthquakes and their PGA for the THA.

The graph of time histories of each earthquake are shown in **Figs. 4, 5, 6, 7** and **8** respectively. Here, Miyagi earthquake have the highest PGA but lesser number of similar amplitudes in comparison to other earthquakes as shown in **Fig. 8**. Kobe earthquake shows larger number of similar amplitudes among them as shown in **Fig. 7**. Hokota earthquake has the largest bracketed duration among the five chosen earthquake data as shown in **Fig. 6**. Nepal earthquake has the smallest PGA value as shown in **Fig. 4**. Chamouli earthquake has the smallest duration of earthquake as shown in **Fig. 5**.

4. Results and discussions

4.1 For residential Building

Residential Building is analyzed for fixed base, spring base and direct modelling and results are computed from static, dynamic and time history analysis.

As shown in **Table 8**, the residential building shows increase in time period up to 3.22% with the consideration of SSI in form of spring and 9% with the considering of SSI in direct modelling which causes decrease in base shear up to 7% as shown in **Table 9**. Likewise, maximum storey displacement also increases

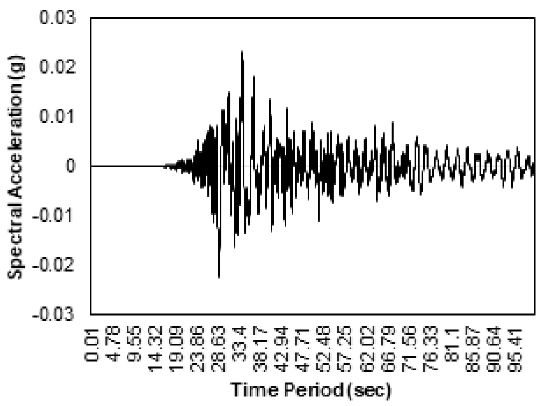

Fig. 4. Time history of Nepal earthquake (PGA = 0.233 g)

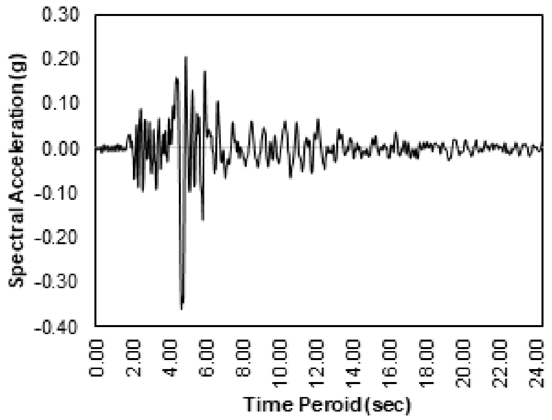

Fig. 5. Time history of Chamouli earthquake (PGA= 0.36 g).

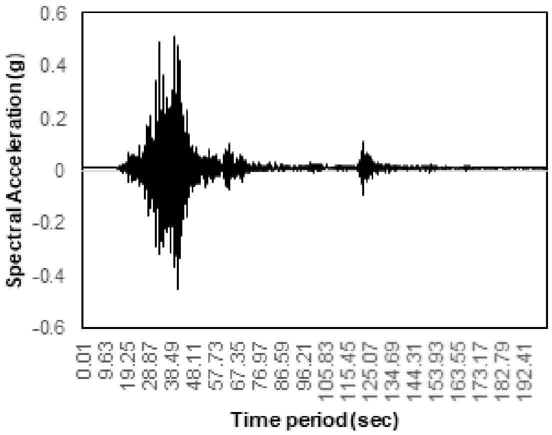

Fig. 6. Time history of Hokota earthquake (PGA= 0.547 g).

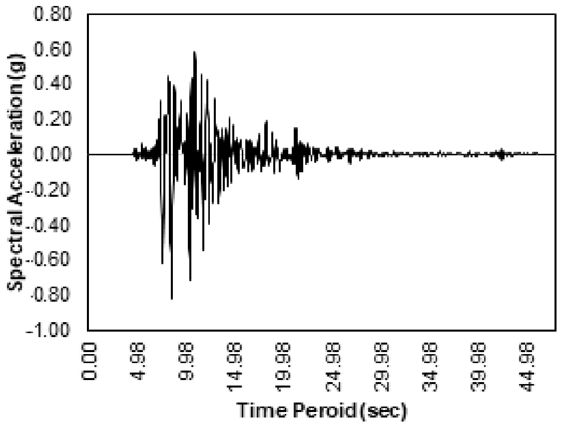

Fig. 7. Time history of Kobe earthquake (PGA= 0.82 g).

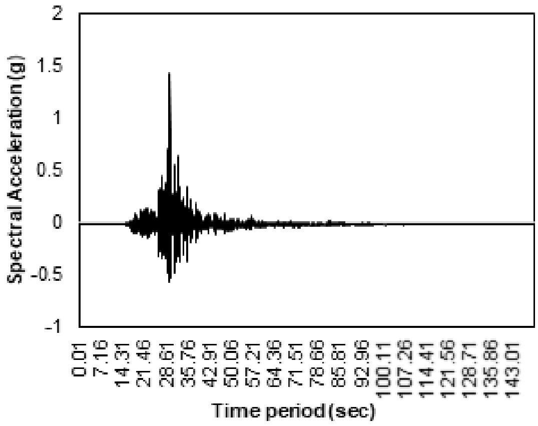

Fig. 8. Time history of Miyagi earthquake (PGA= 1.47g).

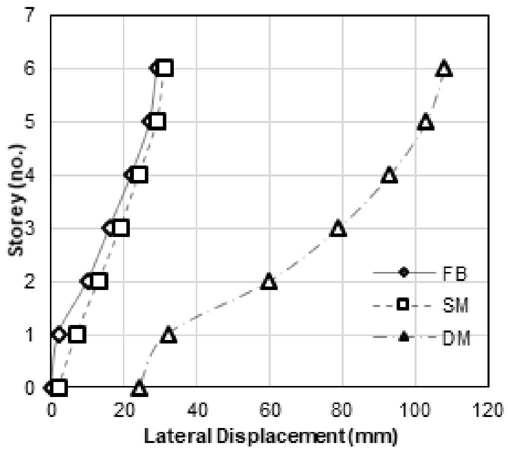

Fig. 9. Storey displacement of static analysis in x-direction.

up to 7% while considering SSI effect in form of spring as shown in **Figs. 9, 10, 11** and **12**. In direct modelling, roof displacement is affected by base displacement of 24 mm and 48 mm under static analysis along x and y direction respectively whereas the value increases to 17% under dynamic analysis. In THA, the building shows greater lateral displacement for Kobe earthquake in SSI and lowest for Hokota earthquake rigid base condition as shown in **Figs. 13** to **18**. The increase in lateral displacement is up to 5% in spring base system as shown in **Figs. 15** and **16**. The value increases further more in direct modelling because direct modelling considers the base displacement too. Here, maximum base displacement up to 230 mm in x-direction and 290

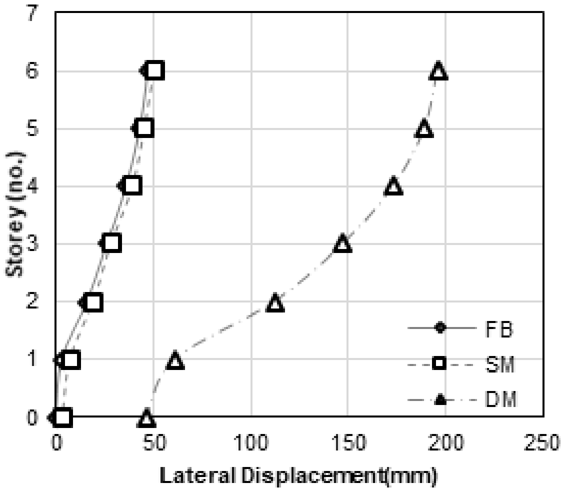

Fig. 10. Storey displacement of static analysis in y-direction.

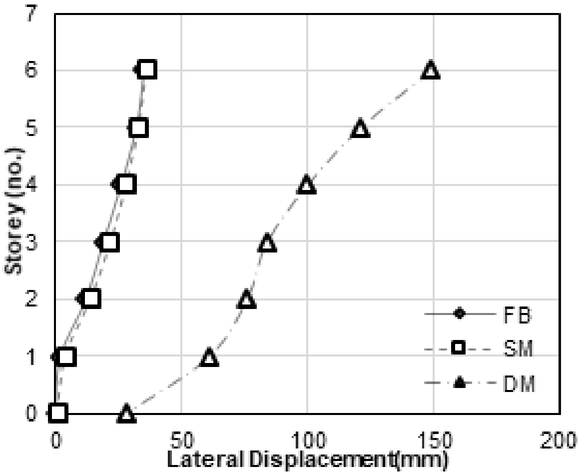

Fig. 11. Storey displacement of dynamic analysis in x-direction.

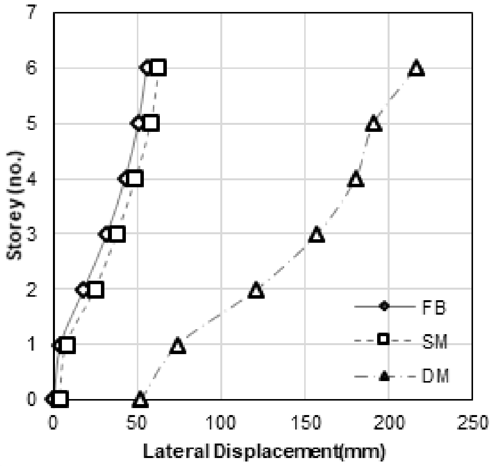

Fig. 12. Storey displacement of dynamic analysis in y-direction.

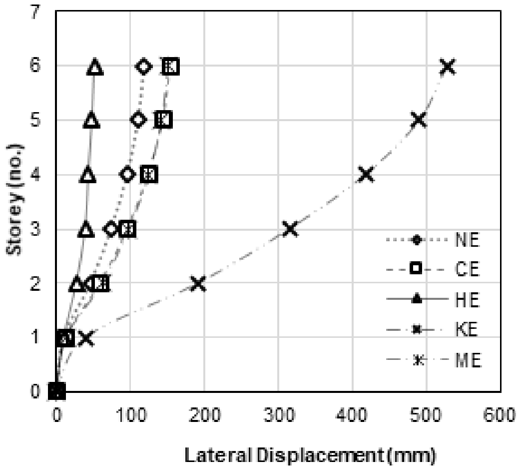

Fig. 13. Time history analysis on fixed base along x-direction.

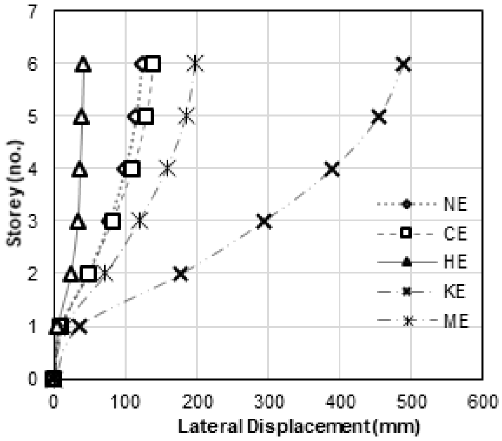

Fig. 14. Time history analysis on fixed base along y-direction.

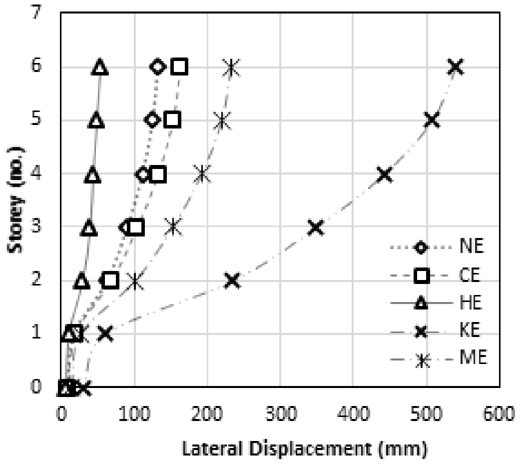

Fig. 15. Time history analysis on spring base modelling along x-direction.

Table 1. Embedment factor according to FEMA 356.

Description	Embedment Factor
β_x	$\left[1+0.21\sqrt{\frac{D}{B}}\right]x\left[1+1.6\left(\frac{h}{B}\frac{d(B+L)}{L^2}\right)^{0.4}\right]$
β_y	$\left[1+0.21\sqrt{\frac{D}{B}}\right]x\left[1+1.6\left(\frac{h}{B}\frac{d(B+L)}{L^2}\right)^{0.4}\right]$
β_z	$\left[1+\frac{D}{21B}\left(2+2.6\frac{B}{L}\right)\right]\left[1+0.32\left(\frac{1}{B}\frac{d(B+L)}{L}\right)^{0.67}\right]$
β_{xx}	$\left[1+2.56\frac{d}{B}\left[1+\frac{2d}{B}\left(\frac{d}{D}\right)^{-0.2}\sqrt{\frac{B}{L}}\right]\right]$
β_W	$\left[1+1.4\left(\frac{d}{L}\right)^{0.6}\right]\left[1.5+3.7\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}\right]$
β_{zz}	$1+2.6\left[\left(1+\frac{B}{L}\right)\left(\frac{d}{B}\right)^{0.9}\right]$

Table 2. Surface Stiffness according to FEMA 356.

Description	Surface Stiffness
Translation Stiffness, K_{xsur}	$\frac{GB}{(2-v)}\left[3.4\left(\frac{L}{B}\right)^{0.65}+1.2\right]$
Translation Stiffness, K_{ysur}	$\frac{GB}{(2-v)}\left[3.4\left(\frac{L}{B}\right)^{0.65}+0.4\frac{L}{B}+1.2\right]$
Translation Stiffness, K_{zsur}	$\frac{GB}{(1-v)}\left[1.55\left(\frac{L}{B}\right)^{0.75}+0.8\right]$
Rocking Stiffness, K_{rxsur}	$\frac{GB^3}{(1-v)}\left[0.4\left(\frac{L}{B}\right)^{1}+0.1\right]$
Rocking Stiffness, K_{rysur}	$\frac{GB^3}{(1-v)}\left[0.47\left(\frac{L}{B}\right)^{2.4}+0.034\right]$
Rocking Stiffness, K_{rzsur}	$GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45}+0.51\right]$

Table 3. Soil Properties at Residential Building site.

Depth (m)	N-value	Vs (m/s)	Vp (m/s)	G (MPa)	E (MPa)
3	80	245.54	613.85	126.39	355.09
6	72	238.10	595.25	109.67	308.12
9	67	233.15	582.87	105.38	296.08
12	13	144.44	361.10	36.03	101.22
>15	21	166.15	415.38	47.62	133.78

Table 4. Surface Stiffness according to Gazetas.

Description	Surface Stiffness
Translation Stiffness, K_{xsur}	$\frac{2GL}{(1-v)}[2+2.5x^{0.85}]-\left[\frac{0.2}{(0.75-v)}\right]GL\left(1-\frac{L}{B}\right)$
Rocking Stiffness, K_{rxsur}	$\frac{G}{(1-v)}Ix^{0\cdot 75}\left(\frac{L}{B}\right)0\cdot 25\left(2.4+0.5\left(\frac{B}{L}\right)\right)$
Translation Stiffness, K_{ysur}	$\frac{2GL}{(1-v)}[2+2.5x^{0.85}]$
Rocking Stiffness, K_{rysur}	$\frac{3G}{(1-v)}Iy^{0\cdot 75}\left(\frac{L}{B}\right)0\cdot 1$
Translation Stiffness, K_{zsur}	$\frac{2GL}{(1-v)}[0.73+1.54x^{0.75}]$
Rocking Stiffness, K_{rzsur}	$GJb^{0\cdot 75}\left[4+11\left(1-\frac{B}{L}\right)10\right]$

Table 5. Embedment Stiffness according to Gazetas.

Description	Embedment Stiffness
Translation Stiffness, K_{xemb}	
Rocking Stiffness, K_{rxemb}	$Kx,sur\left\|1+0.15\sqrt{\frac{D}{B}}\right\|x\left\|1+0.52\left(\frac{h}{B}\frac{Aw}{L^2}\right)^{0.4}\right\|$
Translation Stiffness, K_{yemb}	$Krx,sur\left\|1+1.26\frac{d}{B}\left\|1+\frac{d}{B}\left(\frac{d}{D}\right)^{-0.2}\sqrt{\frac{B}{L}}\right\|\right\|$
Rocking Stiffness, K_{ryemb}	$Ky,sur\left\|1+0.15\sqrt{\frac{D}{B}}\right\|\left\|1+0.52\left(\frac{h}{B}\frac{Aw}{L^2}\right)^{0.4}\right\|$ $Kry,sur\left\|1+0.92\left(\frac{d}{L}\right)^{0.5}\left\|1.5+\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}\right\|\right\|$
Translation Stiffness, K_{zemb}	$Kz,sur\left\|1+\frac{1}{21}\frac{D}{B}(1+1.3x)\right\|\left\|1+0.2\left(\frac{Aw}{Ab}\right)^{2/3}\right\|$
Rocking Stiffness, K_{rzemb}	$Krz,sur\left\|1+1.4\left(1+\frac{B}{L}\right)\left(\frac{d}{B}\right)^{0.9}\right\|$

Table 6. Soil Properties Commercial Building site.

Depth (m)	N-value	Vs (m/s)	Vp (m/s)	G (MPa)	E (MPa)
3	18	158.84	397.10	29.03	81.56
6	13	144.44	361.10	33.19	93.24
> 9	15	150.60	376.51	34.90	98.06

Table 7. Soil Properties Commercial Building site.

Earthquake	PGA
Nepal Earthquake (2015)	0.233g
Chamouli Earthquake (1999)	0.360g
Hokota Earthquake (2011)	0.547g
Kobe Earthquake (1995)	0.820g
Miyagi Earthquake (2011)	1.470g

mm in y-direction is seen in Kobe earthquake as shown in **Figs**. **17** and **18** respectively.

4.2 For hospital building

Hospital building carries heavier load in comparison to the residential building and it is further more penetrated in its soil condition as there are two basement system in the building. The analysis is carried out in fixed base, spring base modelling, direct modelling and results are computed from static, dynamic and time history analysis.

Table 10 shows that time period decreases while considering SSI in spring system. This is due to penetration effect of the two basements. Decrease in

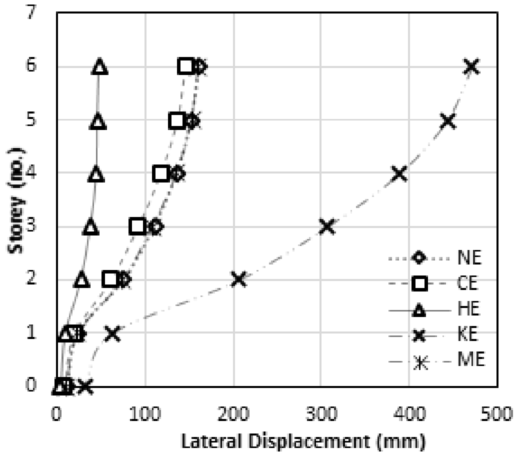

Fig. 16. Time history analysis on spring base modelling along y-direction.

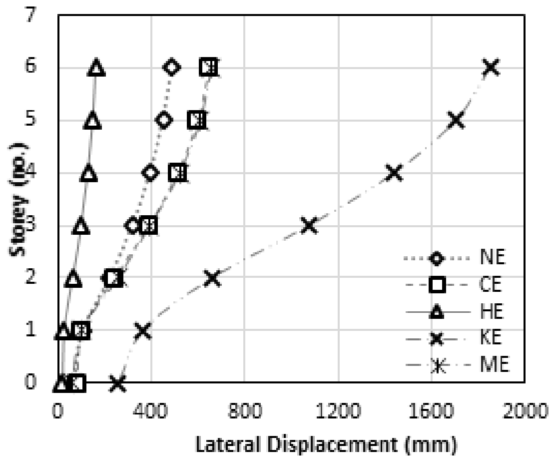

Fig. 17. Time history analysis on direct modelling along x-direction.

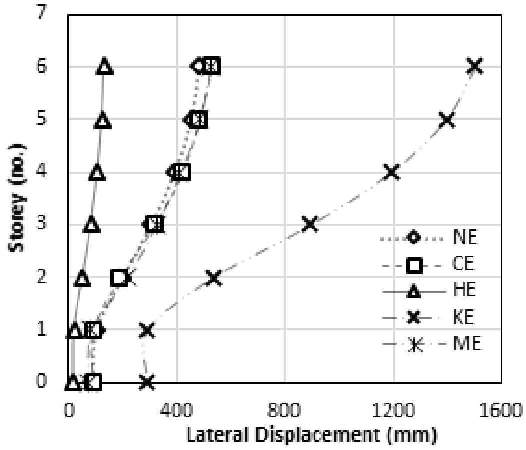

Fig. 18. Time history analysis on direct modelling along y-direction.

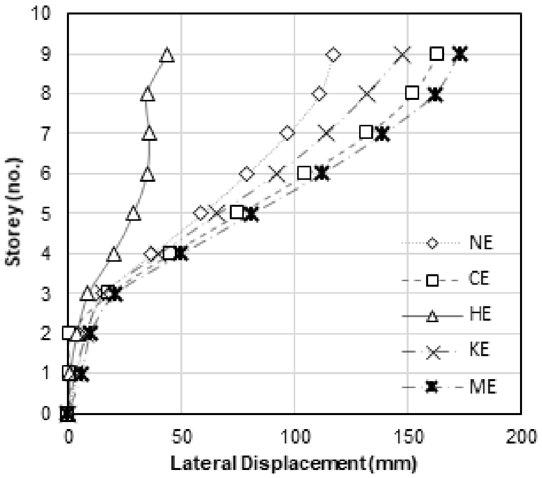

Fig. 19. Time history analysis on fixed base condition along x-direction.

time period causes increase in base reaction by 3% to 5% as shown in **Table 11**. However, Direct modelling shows that time period increases while considering SSI effect. The roof displacement is not affected by time period and it increases as we consider SSI effect on the structure as shown in **Table 12**. The effect of earthquake from time history analysis shows that lateral displacement is more while considering SSI effect. As shown in **Fig. 19**, maximum deflection is shown by ME at top floor with the value of 173 mm along X-direction however, if we consider SSI as shown in **Fig. 21**, critical floor for ME was found in 8th floor with the deflection of 183 mm along x-direction i.e. 5% more deflection in comparison to the one obtained from fixed base condition. Along y-direction, the value of displacement increases up to 17% if SSI is considered in THA as shown in **Figs. 20** and **22**. Hence, earthquake with the maximum PGA affects the structure the most with the increase in lateral displacement 5% to 17% in the consideration of SSI.

5. Conclusions

This study clearly shows that base support condition has an impact on the behavior of structure which can be clearly observed from static analysis, dynamic analysis and time history analysis done on fixed, spring base and direct modelling base. For residential building with no basement which means less soil penetration, considering SSI may be beneficial in terms of less base shear and more time period. However, the storey displacement increases and structure members get affected vigorously. This shows that base shear reduction due to SSI may not

Table 8. Time period in static analysis for the residential building.

Base Condition	X	Y
Fixed Base (sec)	0.899	0.467
Spring Base (sec)	0.971	0.470
Direct Modelling (sec)	0.982	0.467

Table 9. Base reaction in static analysis for the residential building.

Base Condition	X	Y
Fixed Base (kN)	292.670	483.554
Spring Base (kN)	272.125	485.785
Difference (%)	7.020	0.461

Table 10. Time period in static analysis for the hospital building.

Base Condition	**X**	**Y**
Fixed Base (sec)	0.893	0.682
Spring Base (sec)	0.871	0.657
Direct Modelling (sec)	1.657	1.342

Table 11. Base reaction in static analysis for the hospital building.

Base Condition	**X**	**Y**
Fixed Base (kN)	6315.587	8266.365
Spring Base (kN)	6555.452	8691.798
Difference (%)	3.798	5.147

Table 12. Maximum roof displacement for the hospital building.

Base Condition	**Static**		**Dynamic**	
	X	**Y**	**X**	**Y**
Fixed base (mm)	46	70	50	77
Spring base (mm)	50	77	55	79
Direct Modelling (mm)	86	117	95	120

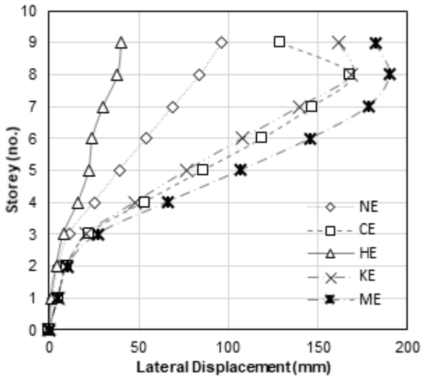

Fig. 20. Time history analysis on fixed base condition along y-direction.

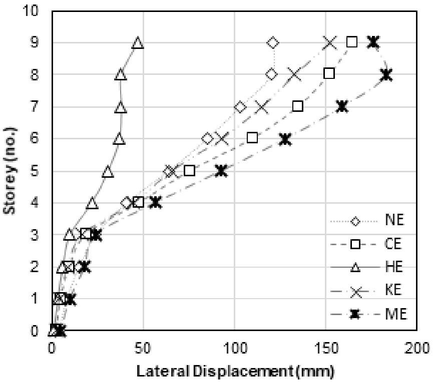

Fig. 21. Time history analysis on spring base condition along x-direction.

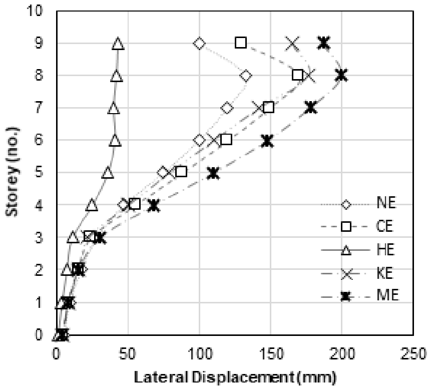

Fig. 22. Time history analysis on fixed base condition along y-direction.

be always beneficial. For hospital building which penetrates on soil with two basements, the time period and base shear are affected by the penetration of the structure in the soil and results are directly affected by the soil conditions. Here, storey deflects less and time period is slightly decreased while considering SSI even though structure is larger in comparison to the residential one because of the soil penetration up to 6 m with two basements while residential building does not undergo much penetration. In direct modelling, base displacement is also vividly observed which is neglected by rigid and spring base analysis. Time history analysis shows that residential building is more vulnerable to earthquake with a greater number of peaks of similar amplitudes whereas building with basements is more vulnerable to earthquake with maximum PGA. If there is change in building height, its use, its plinth area, load carried by it, soil condition and presence of underground structures, we will observe difference in various parameters of the building such as time period, roof displacement and base shear that means soil structure interaction is necessary.

References

Abdel Raheem, S., Ahmed, M. and Alazrak, T, 2014. Evaluation of soil–foundation–structure interaction effects on seismic response demands of multi-story MRF buildings on raft foundations. International Journal of Advanced Structural Engineering, **7** (1): 11-30.

Baragani, R. and Dyavanal, D., 2014. Performance Based Seismic Evaluation of G+6 RC Buildings Considering Soil Structure Interaction. International Journal of Engineering Trends and Technology, **14** (3):119-127.

Dangol, N., Manandhar, S. and Pradhan, P.M., 2019. Effects of Soil-Structure Interaction on the Seismic Response of Ordinary RC-Framed Structures. Civil Insight: A technical Magazine, **III**: 37-44.

Duggal S.K., 2010. Earthquake Resistance Design of Structure, Fourth Edition, Oxford University Press, New Delhi, ISBN:9780198083528: 528p.

FEMA.NEHRP, 2000. Guidelines for the seismic Rehabilitation of Buildings, FEMA-356, Federal Emergency Management Agency, Washington, D.C.

Gazetas, G., 1991. Formulas and Charts for Impedances of Surface and Embedded Foundations. Journal of Geotechnical Engineering, **117** (9):1363-1381.

Indian Standard Criteria for Earthquake Resistant Design of Structures, IS 1893: (Part 1) 2002, Part 1 General Provisions and Buildings (Fifth Revision), Bureau of Indian Standards, New Delhi, India.

Indian Standard Code of Practice for Plain and Reinforced Concrete (Fourth Revision), IS 456: 2000, Bureau of Indian Standards, New Delhi, India.

Kabtamu, H.G., Peng, G., and Chen, D., 2018. Dynamic Analysis of Soil Structure Interaction Effect on Multi Story RC Frame. Open Journal of Civil Engineering, **8**: 426-446.

Kiku, H., Yoshida, N., Yasuda, S., Irisawa, T., Nakazawa, H., Shimizu, Y., Ansal, A., and Erkan, A., 2001. In-situ Penetration Tests and Soil Profiling in Adapazari, Turkey, Proceedings of the ICSMGE/TC4 satellite conference on lessons learned from recent strong earthquakes: 259-265.

Rajak, P., and Debbarma, R., 2017. Effect of Soil Structure Interaction on RC Building under Earthquake Load. International Journal of Advances in Mechanical and Civil Engineering, ISSN 2394-2827, **4** (2): 82-87.

Rosset, J. M. and Kausel E.,1976. Dynamic Soil-Structure Interaction. Proc. Second International Conference on Numerical Methods in Geomechanics, Blacksburg, Virginia, **2**, 3-19.

Strongmotioncenter.org. (2020). Center for Engineering Strong Motion Data. [online] Available at: https://strongmotioncenter.org [Accessed 29 May 2019].

Suhas, K.S. and Prakash, D.S., 2017. Effect of Structure-Soil-Structure Interaction on Seismic Response of Adjacent Buildings. International Journal of Engineering Research & Technology (IJERT), ISSN 2278-0181, **6** (1):120-124.

Symbols and abbreviations

A_b	Base foundation area
A_w	Soil contact area
B	Width of foundation
CE	Chamouli Earthquake
D	Depth of foundation
d	Height of effective sidewall contact
DM	Direct Modelling
E	Modulus of elasticity
FB	Fixed Base
FEMA	Federal Emergency Management Agency
G	Shear modulus of elasticity
GL	Ground Level
HE	Hokota Earthquake
h	Depth of centroid of effective sidewall contact
I	Importance factor
IS	Indian Standard
I_{bx}	Moment of inertia about x-axis
I_{by}	Moment of inertia about y-axis
J_b	Polar moment
K_{xemb}	Embedded stiffness value along x-axis
K_{yemb}	Embedded stiffness value along y-axis
K_{zemb}	Embedded stiffness value along z-axis
K_{xsur}	Surface stiffness value along x-axis
K_{ysur}	Surface stiffness value along y-axis
K_{sur}	Surface stiffness value along z-axis
Kr	Rocking stiffness
KE	Kobe Earthquake
L	Length of foundation
ME	Miyagi Earthquake
N	Standard penetration value
NE	Nepal Earthquake
PGA	Peak Ground Acceleration
R	Response reduction factor
RC	Reinforced Concrete

RS	Response Spectrum
SAP2000	Structure Analysis Software Manufactured by Computers and Structures Incorporated
SM	Spring Modelling
SPT	Standard Penetration Test
SSI	Soil Structure Interaction
THA	Time History Analysis

Vp	Compressional wave velocity
Vs	Shear wave velocity
Z	Zone factor
ν	Poisson’s ratio
β	Embedment factor