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Comparison Between The Dynamic Response of RC Building With Various Foundation Types

Susan Prajapati [a], Ramesh Karki [b]

[a, b] *Department of Civil Engineering, Thapathali Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] susanprajapati@thapathalicampus.edu.np, [b] rk.ioe.np@gmail.com

Abstract

In the conventional practice of analysis, buildings are assumed to be fixed at the base even though soil, which is a flexible support, is the boundary condition. Incorporating soil structure interaction (SSI) will significantly affect the performance of structures. Property line constructions are common construction practice in Nepal which will inhibit the eccentric condition of foundation and thus impact the performance of superstructure as well. Winkler's approach to model the foundation soil as spring is used in this study. Several buildings were modeled using finite element approach to incorporate the soil structure interaction effects and nonlinear time history analysis is carried out to analyze the performance. Roof displacement is considered as the performance parameter to evaluate the performance of structures. This study reports the influence of different types of foundations such as combined footing, strap footing, and eccentric isolated footing in dynamic characteristics of the RC-frame structure as natural time period, roof displacement, and base shear. SSI effect highlighted an increase in the roof displacement of the structure for all foundation types, meanwhile, the effect is more prominent in the case of eccentric isolated foundation.

Keywords

Soil Structure Interaction(SSI), Combined Footing, Strap Footing, Eccentric Isolated Footing, Spring Method, Nonlinear Time History Analysis

1. Introduction

In Nepal property line construction is inevitable in urban areas such as Kathmandu valley. Due to this reason condition of eccentric footing arises. The remedy for such condition is use of combined footing, strap footing or trapezoidal footing. Although mandatory rules are there for requirement of these types of foundation, there is still presence of false practice of using eccentric condition of foundation. This condition may cause change in performance of the superstructure. Past earthquakes has shown poor performance of buildings under the circumstances of improper foundation design.

The process in which the soil influences the motion of the structure and structure influences the motion of soil is known as Soil Structure Interaction (SSI). Winkler's idealization represent the soil model as discrete springs. Winkler hypothesis despite having limitations yields reasonable result and is easy to exercise. George Gazetas (1991) [1] has provided set of algebraic formulas for computing the spring stiffness (K) of soil . Halkude et al. (2014) [2] has used the approach as provided by George Gazetas (1991) [1] and concluded that the natural time period of structure increases with consideration of SSI and is more prominent in case of soft soil condition.Thusoo et al. (2015) [3] has drawn conclusion that deflection in cases where soil is hard and medium is significantly less as compared to the buildings on soft soils . Roopa et al. (2015) [4] has concluded that response of the tall building founded on clayey soil has significant increase compared to conventional approach of assuming fixed base. Kalyanshetti et al. (2015) [5] has drawn a conclusion that SSI effect can be controlled by providing strap beams so that base stiffness increases which ensures the stability and performance of structure. Pramod K. Shahi (2017) [6] has conducted thesis work considering SSI for different condition of soil for Isolated Foundation which is ideal case of foundation and is not applicable in most urban areas. Though previous research have considered the SSI effects for analyzing the performance of the structure, more ideal condition of foundation such as isolated and mat foundation are used. This leaves a gap for the performance of building with eccentric foundation condition which needs to addressed.

The objective of the study is to find the influence of eccentric foundation in the seismic performance of R.C. framed building. Seismic performance involves dynamic properties such as Natural Time Period, Roof Displacement and Base shear.The study is carried out by using Winkler's approach to model soil as discrete springs. Three different types of foundation such as Combined Footing, Strap Footing and Eccentric Footing are modeled and the performance analysis of these are carried out.

2. Methodology

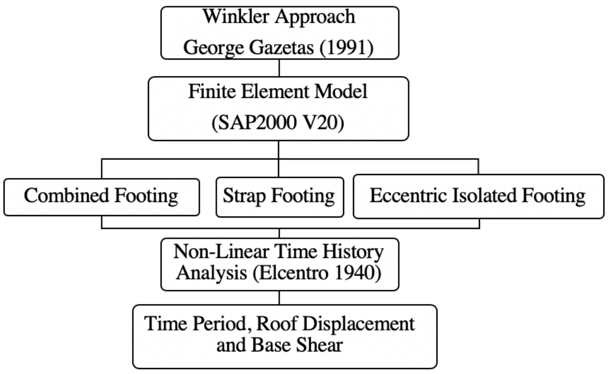

Figure 1: Flow Chart For Methodology

A three bay symmetrical frame of three storeys with bay width of 4m with property lines at two opposite faces of the building is taken. Conventional practice of foundation design is carried out to find the parameters of foundation. For the calculated foundation parameters soil springs are calculated and subsequently fem modeling of the structure is carried out. The overall process is represented in Fig. 1.

Idealization by Winkler approach

Effect of SSI is considered by generating springs having six degrees of freedom as shown in Fig. 2 . The Stiffness of the springs are calculated as per George Gazetas (1991) [1] and is shown in Table 1. All types of foundation is divided into 4x4 areas and spring stiffness is calculated for foundation type and divided for each nodes for all six degrees of freedom.

Table 1: Spring Stiffness Equations (Gazetas 1991)

Degree of Freedom	Stiffness of Equivalent Soil Spring
Vertical (K_z)	$\left[\frac{2GL}{1-v}\right](0.73 + 1.54\chi^{0.75})\ with\ \chi = A_b/4L^2$
Horizontal (Lateral Direction) (K_y)	$\left[\frac{2GL}{2-v}\right](2 + 2.5\chi^{0.85})\ with\ \chi = A_b/4L^2$
Horizontal (Longitudinal Direction) (K_x)	$[\{\frac{2GL}{2-v}\}(2 + 2.50\chi^{0.85})] - [\left\{\frac{0.2}{0.75-v}\right\} GL \left\{1 - \left\{\frac{B}{L}\right\}\right]$ $with\ \chi = A_b/4L^2$
Rocking (About Longitudinal) (K_{rx})	$[\frac{G}{1-v}]{I_{bx}}^{0.75}(L/B)^{0.25}[2.4+0.5(B/L)]$
Rocking (About Lateral) (K_{ry})	$[\frac{3G}{1-v}]{I_{by}}^{0.75}(L/B)^{0.15}$
Torsion (τ)	$3.5G{I_{bz}}^{0.75}(B/L)^{0.4}(I_{bz}/B^4)^{0.2}$

Where, A_b=Area of foundation considered, B and L = Half-width and Half-Length of rectangular foundation, I_{bx},I_{by},I_{bz} = Moment of Inertia of foundation area with respect to longitudinal, lateral and vertical axes respectively.

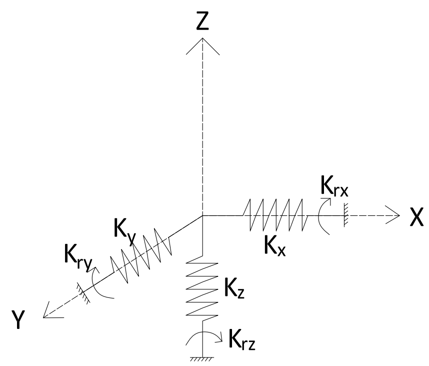

Figure 2: Soil Spring Stiffnes along 6 DOF

Finite Element Modeling

A three storey building with 3 bays of 4m in both direction is modeled on SAP2000 V20 software. Columns and beams are modeled as line elements, floor slab are modeled as area element and foundation as solid element with spring elements at foundation nodes.

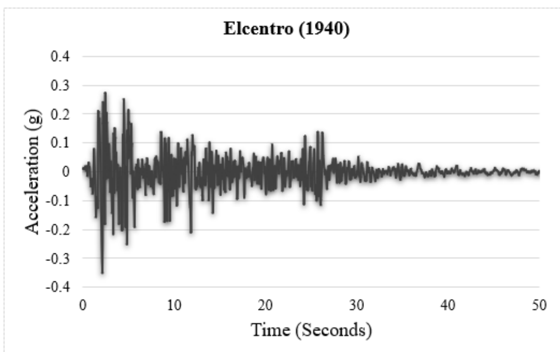

Figure 3: Elcentro (1940) Time History

The description of the building is provided in Table 2. The properties of soil are taken form Halkude et al. (2014) [2] and is shown in Table 3. Structure with four different condition as Combined footing, Strap Footing, Eccentric Isolated Footing and Fixed Base is modeled.

Table 2: Description of the Building

Description	Data (m)
Number of storey	3
Number of bays in X direction	3
Number of bays in Y direction	3
Storey height (m)	2.9
Bay width in X direction (m)	4
Bay width in Y direction (m)	4
Size of beam (m)	0.4x0.23
Size of column (m)	0.35x0.35
Thickness of slab (m)	0.125
Strap footing (Property Line) (m)	2.09x2.5
Strap footing (Middle) (m)	1.68x2.5
Strap beam (m)	0.65x0.55
Combined footing (m)	4.88x1.93
Eccentric footing (m)	2.5x2.5
Depth of footing (m)	0.65

Table 3: Material Properties

Material Properties	Value
Grade of concrete	M20
Modulus of elasticity of concrete	22360 N/mm^2
Unit weight of concrete	25 KN/m^3
Grade of rebar	500 N/mm^2
Modulus of elasticity of steel	2E+05 N/mm^2
Unit weight of steel	78.5 KN/m^3
Soil type	Soft soil
Modulus of elasticity of soil	15000 KN/m^2
Poisson's ratio of soil	0.4
Unit weight of soil	16 KN/m^3

Nonlinear Time History Analysis

Nonlinear Time History Analysis is conducted to analyze the dynamic performance of all types of model. Elcentro (1940) earthquake is utilized to conduct the analysis having PGA of 0.35g. Time history for the earthquake is shown in Fig. 3.

Parametric Study

For the parametric study three different types of soil condition are taken. The calculation of soil springs for respective foundation and soil condition is carried out for the study. Namely soft soil, medium soil and hard soil are considered and properties for soil are tabulated in Table 4.

Table 4: Properties of Soil

Soil Type	Modulus of Elasticity (KN/m^2)	Poisson's Ratio	Unit Weight (KN/m^3)
Hard Soil	65000	0.3	18
Medium Soil	35000	0.4	16
Soft Soil	15000	0.4	16

3. Result and Discussion

After the time history is conducted for various models, roof displacement and base shear response of the structures are plotted. The following section shows the response of structures for soft soil condition.

3.1 Combined Footing on Soft Soil

Finite element model of the structure with combined footing is shown in Fig. 4. Natural time period of the model was obtained as 0.873 seconds from modal analysis. Roof displacement and base shear response is represented in Fig. 5 and Fig. 6 respectively. Maximum and minimum roof displacement were 77.36 mm and -74.8 mm. Likewise maximum and minimum value of base shear was found to be 1513.5 KN and -1666.75 KN.

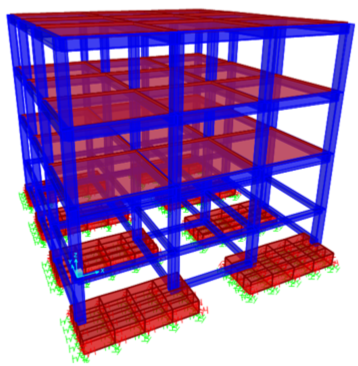

Figure 4: FEM model for Combined Footing

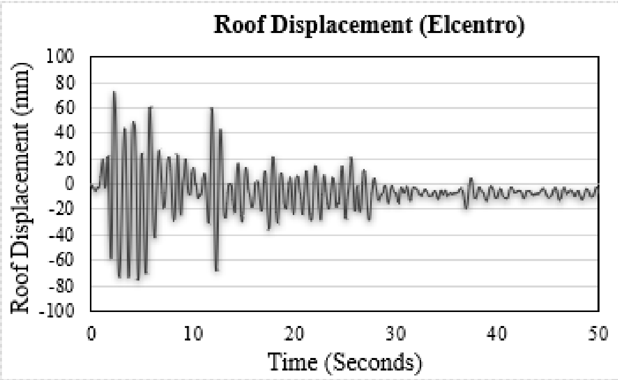

Figure 5: Roof Displacement for Combined footing

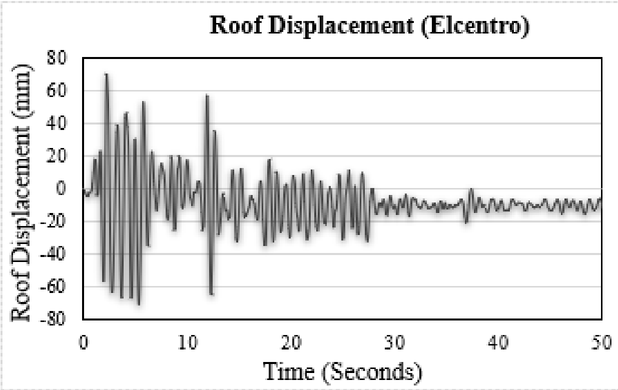

Figure 8: Roof Displacement for Strap footing

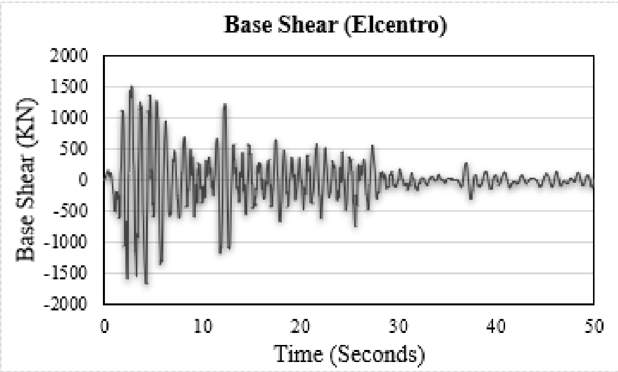

Figure 6: Base Shear for Combined footing

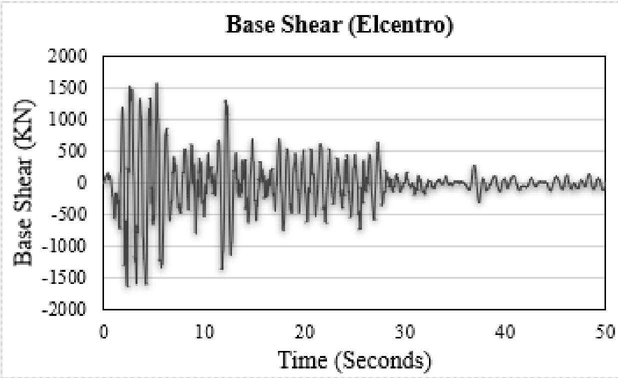

Figure 9: Base Shear for Strap Footing

3.2 Strap Footing on Soft Soil

Finite element model of the structure with strap footing is shown in Fig. 7. Natural time period of the model was obtained as 0.861 seconds from modal analysis. Roof displacement and base shear response is represented in Fig. 8 and Fig. 9 respectively. Maximum and minimum roof displacement were 69.89 mm and -71.44 mm. Likewise maximum and minimum value of base shear was found to be 1590.4 KN and -1618.3 KN.

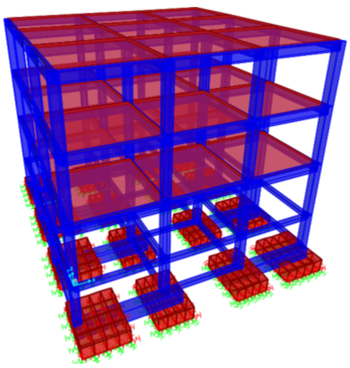

Figure 7: FEM model for Strap Footing

3.3 Eccentric Isolated Footing on Soft Soil

Finite element model of the structure with eccentric isolated footing is shown in Fig. 10. Natural time period of the model was obtained as 1.142 seconds from modal analysis. Roof displacement and base shear response is represented in Fig. 11 and Fig. 12 respectively. Maximum and minimum roof displacement were 76.85 mm and -101.15 mm. Likewise maximum and minimum value of base shear was found to be 1328.08 KN and -1358.5 KN.

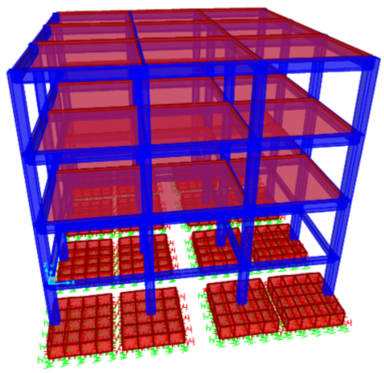

Figure 10: FEM model for Eccentric Isolated Footing Footing

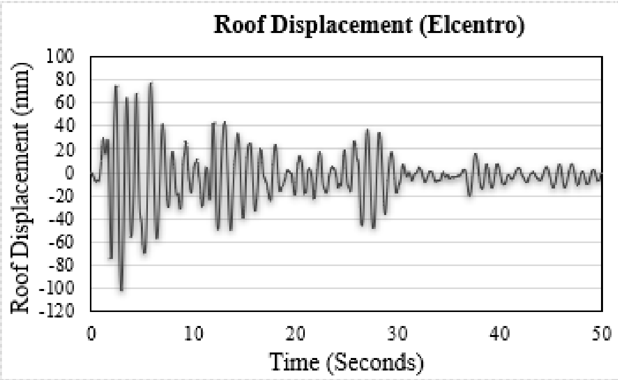

Figure 11: Roof Displacement for Eccentric Isolated Footing

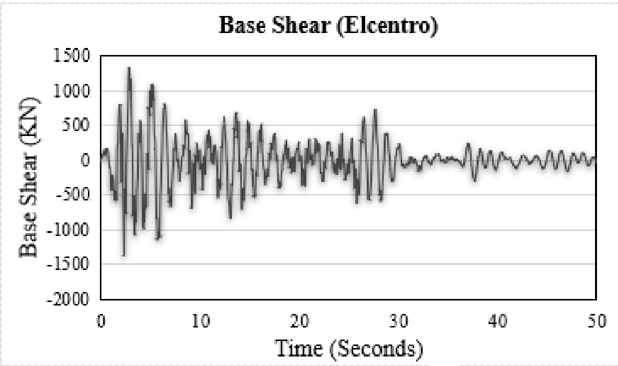

Figure 12: Base shear for Eccentric Isolated

3.4 Fixed Base Condition

Finite element model of the structure with fixed base condition is shown in Fig. 13 . Natural time period of the model was obtained as 0.693 seconds from modal analysis. Roof displacement and base shear response is represented in Fig. 14 and Fig. 15 respectively. Maximum and minimum roof displacement were 50.49 mm and -53.12 mm. Likewise maximum and minimum value of base shear was found to be 1572.2 KN and -1542.3 KN.

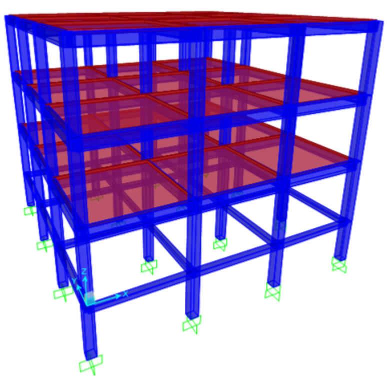

Figure 13: FEM model for Fixed Base Condition

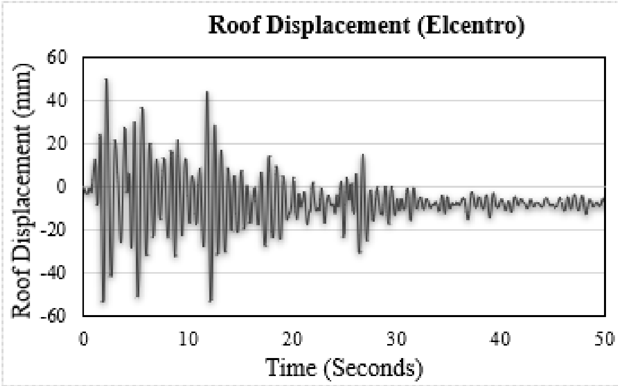

Figure 14: Roof Displacement for Fixed Base Condition

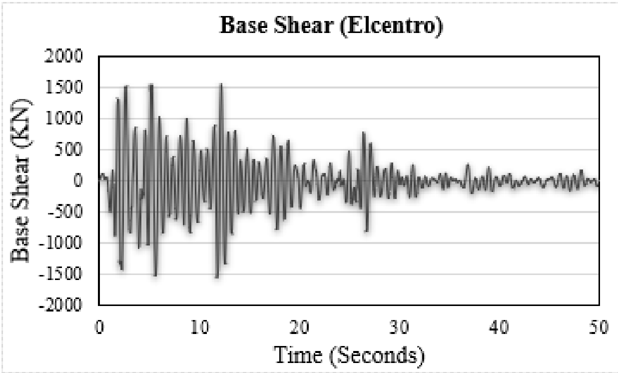

Figure 15: Base shear for Fixed Base Condition

3.5 Natural Time Period

The variation of natural time period for various types of support as well as soil condition is shown in Fig. 16. It was observed that the natural time period of the structure increases with consideration of SSI. It was found that the eccentric isolated condition found the highest increment in the natural time period after consideration of SSI. The SSI effect is more significant in soft soil.

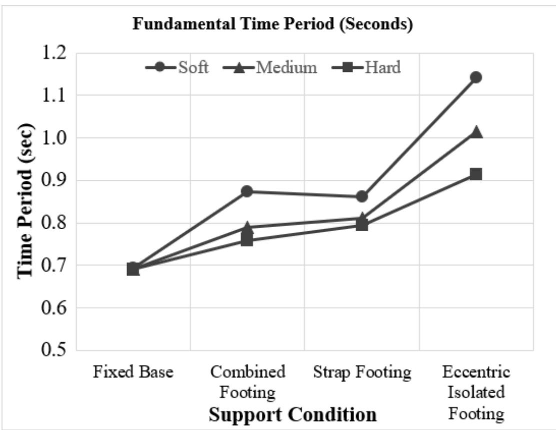

Figure 16: Time Period vs Support Condition

3.6 Roof Displacement

The variation of Roof Displacement for various types of support as well as soil condition is shown in Fig. 17. It was observed that the roof displacement of the structure increases with consideration of SSI. It was found that the eccentric isolated condition found the highest increment in the roof displacement after consideration of SSI. The roof displacement increases with increase in soil flexibility.

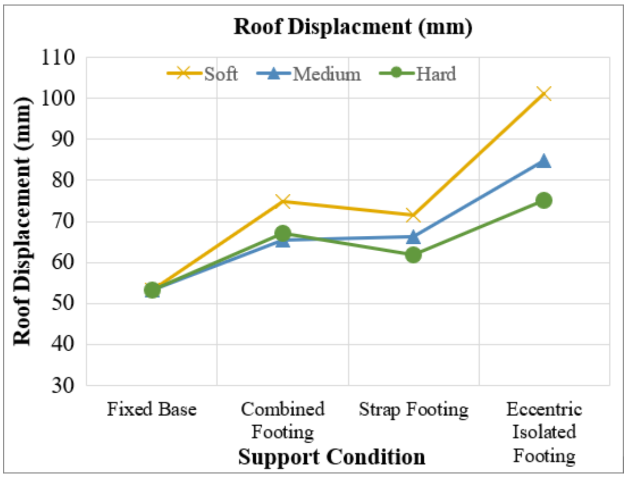

Figure 17: Roof Displacement vs Support Condition

3.7 Base Shear

The variation of base shear for various types of support as well as soil condition is shown in Fig. 18. It was observed that the base shear of the increasing for combined and strap footing for all soft condition with consideration of SSI but is reduced significantly for eccentric isolated footing. For medium and hard soil the base shear for strap footing and eccentric isolated footing is increased but it is slightly lower in case of combined footing.

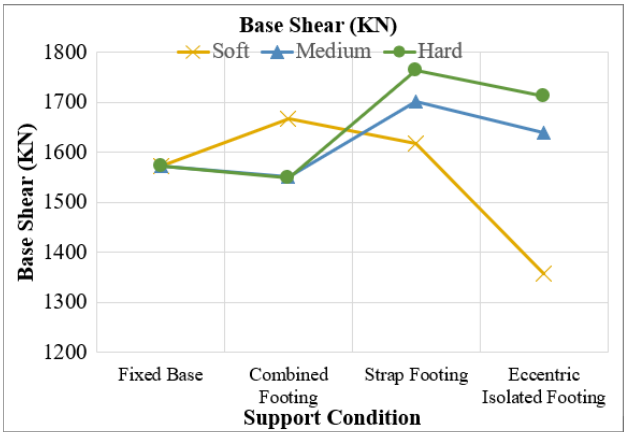

Figure 18: Base Shear vs Support Condition

4. Conclusions

A three storey building is analyzed for different types of foundation condition for three types of soil condition. Seismic Response in terms of Roof Displacement, Base Shear and Natural Time Period are compared between each type of foundation. The following conclusions may be drawn form results obtained.

- The natural time period of structure increase due to consideration of SSI effect. natural time period is primary parameter that relates to lateral response of framed structures. Evaluation of this parameter without considering SSI may result in misinterpretation in calculation of seismic design.
- SSI effect increases the roof displacement of the structure. The effect is significantly higher in case of eccentric isolated foundation and soft soil.
- Roof displacement is found to be slightly lower for strap foundation than combined foundation but both have similar performance. These two types of foundation can be used where property line construction is required as per suitability criteria.
- Eccentric isolated foundation shows poor performance and has significantly high roof displacement than other foundation types. It gets more critical with increase in soil flexibility.

In the study the analysis shows that, SSI effect during earthquake shows significant changes in response of building. To incorporate SSI in structural analysis it has been easier with development in FEM and computer technology. This evolution in field of engineering should be exploited in fullest to better our knowledge about structural behavior so that safe construction practices are adopted.

Future Enhancements

Winkler's approach to model the foundation as equivalent elastic springs are used in this research to conduct the study. More realistic results may be obtained by using elastic continuum method in future. Expanded studies may be carried out to find quantitative comparison of different types of foundation on structural member and sizes as well as contribution on construction cost and economy.

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References

[1] George Gazetas. Formulas and charts for impedances of surface and embedded foundations. *Journal of Geotechnical Engineering*, 1991.

[2] Halkude S. A, M.G. Kalyanshetti, and S.M. Barelikar. Seismic response of r.c. frames with raft footing considering soil structure interaction. *International Journal of Current Engineering and Technology*, 2014.

[3] Shreya Thusoo, Karna Modi, Rajesh Kumar, and Hitesh Madahar. Response of buildings with soil-structure interaction with varying soil types. *International Journal of Civil and Environmental Engineering*, 2015.

[4] M. Roopa, H.G. Naikar, and D.S. Prakash. Soil structure interaction analysis on a rc building with raft foundation under clayey soil condition. *International Journal of Engineering Research and Technology*, 2015.

[5] M. G. Kalyanshetti, S. A. Halkude, and Y. C. Mhamane. Seismic response of r.c building frames with strap footing considering soil structure interaction. *International Journal Of Research in Engineering and Technology*, 2015.

[6] Pramod K. Shahi. Study of response of rc framed building with lower tie beam and it's necessity in different soil condition. Master's thesis, Thapathali Campus, 2017.

[7] Koushik Bhattacharya and Sekhar Chandra Dutta. Assessing lateral period of building frames incorporating soil-flexibility. *Journal of Sound and Vibration*, 2004.

[8] Bureau of Indian Standards. *IS:1893(Part 1):2002 Criteria For Earthquake Resistant Design of Structure*. New Delhi, India.