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RESEARCH ARTICLE / НАУЧНАЯ СТАТЬЯ

Evaluation of Soil Structure Interaction Effects on Seismic Response of RC Framed Buildings Using Simplified Method

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Conflicts of interest

The authors declare that there is no conflict of interest.

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Abstract. In the current practice for the design of the building structure is done by considering the footing as fixed based. The mid-rise buildings having variation in storey height from 3- to 10-storey were selected for the research. In this research, analysis was done to study into the interaction between the seismic response of RC-framed buildings and the soil-structure for various soil types. To study the linear responses of the structures, the model was developed in FEM software SAP2000. The underneath soil was modelled by using direct method, where the soil is considered as solid element. The considered depth of soil was considered 30 m and the viscous spring dashpot were applied to avoid the reflection of seismic waves in soil medium along the effective horizontal soil boundaries. The seismic response variables such as maximum lateral deflection, inter-storey drift and fundamental time periods have been studied. SSI amplified the lateral deflection, inter-storey drift and time period of structure shifting the performance level from life safety to near collapse level. Fundamental time period of the first mode was increased by 23 % for very soft soil. The maximum lateral deflection of 10-storey building for very soft soil was amplified up to 282 % for Kobe and the performance level was shifted from life safety (1.5 %) to collapse level for all the considered model for soil type *D*. The performance level of structure was checked against the different soil types on varying storey height and finally a simplified method has been proposed to incorporate the effects of SSI in fixed base structures.

Keywords: Soil structure interaction, Simplified method, Seismic response, Linear dynamic analysis, Inter-storey drift

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Оценка влияния взаимодействия грунтовых структур на сейсмический отклик зданий с железобетонным каркасом с использованием упрощенного метода

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Аннотация. Существующая практика проектирования конструкции здания основывается на рассмотрении фундамента как неподвижно закрепленного. Для исследования были выбраны здания средней этажности, высота которых варьируется от 3 до 10 этажей. Проведен анализ взаимодействия между сейсмическим откликом зданий с радиоуправляемым каркасом и структурой грунта для различных типов грунтов. Для изучения линейных откликов конструкций разработана модель в программном обеспечении FEM SAP2000. Грунт под землей был смоделирован с использованием прямого метода, где грунт рассматривается как твердый элемент. Глубина залегания грунта считалась равной 30 м, и для предотвращения отражения сейсмических волн в грунтовой среде вдоль эффективных горизонтальных границ грунта были применены вязкие пружинные амортизаторы. Были изучены такие переменные сейсмического отклика, как максимальное боковое отклонение, смещение между этажами и основные периоды времени. SSI увеличил поперечный прогиб, смещение между этажами и временной промежуток конструкции, повысив уровень эксплуатационных характеристик с уровня безопасности жизнедеятельности до уровня, близкого к обрушению. Основной период первого режима был увеличен на 23 % для очень мягкого грунта. Максимальное боковое отклонение 10-этажного здания для очень мягкого грунта было увеличено до 282 % для Кобе, а уровень производительности был изменен с уровня безопасности для жизни (1,5 %) на уровень обрушения для всех рассмотренных моделей для грунта типа *D*. Уровень эксплуатационных характеристик конструкции был проверен с учетом различных типов грунта на разной высоте этажа, и, наконец, был предложен упрощенный метод для учета эффектов SSI в конструкциях с фиксированным основанием.

Ключевые слова: взаимодействие грунта и конструкции, упрощенный метод, сейсмический отклик, линейный динамический анализ, перекос этажа

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1. Introduction

Since it might be essential to develop structures at places with less favorable site conditions in areas that are earthquake-prone, the issue of soil-structure interaction (SSI) in seismic analysis and structure design has become more crucial. These factors make Nepal extremely earthquake susceptible. Some of the past large earthquakes are Nepal-Bihar Earthquake (1833), Nepal-TibetEarthquake (1916), Kathmandu Earthquake (1988) and Gorkha Earthquake (2015) [1]. The features of earthquakes, their travel paths, local sites, and interactions between soil and structures influence the structures' seismic sensitivity [2]. The combination of the first three of

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these components results in free-field seismic activity [3]. SSI influences the structural responses to the free-field motion. The process by which the motion of the system is affected by the response of the ground under structure and the response of the ground is affected by the motion of the building is known as SSI [4]. FEM or FDM is used for most complicated study of interface behavior of soil and structure rather than analytical approaches [5]. The support configuration of structure is crucial for determining a building's dynamic behavior. The footing condition is different for various soil types, on stiff soil, a rigid footing might be considered, and i.e. a rigid footing might be considered for stiff soil and a flexible base footing for soft soil [6]. On considering SSI effects the fundamental period of building is increased, and a result structural response such as displacement, drift, base shear may differ from the rigid base structures (Figure 1). To predict the actual behaviour, the designer should consider the SSI effects. Generally, there are two methods to consider the effects of SSI in analysis i.e., Substructure and Direct approaches [7]. Two independent media are considered in the substructure technique, and the principle of superposition is used to determine the final seismic results [8; 9], where as in direct-method soil and building are modeled as a unified system [10].

a *b*

Figure 1. Observed damage due to foundation settlement:
a — Differential settlement caused by foundation rotation; *b* — Vertical settlement [1]

Damage on buildings occured due to foundation settlements in Kathmandu valley, this was due to basin effects caused during Gorkha Earthquake 2015 [1]. A considerable effect of SSI should be considered for soil having shear-wave velocity below 600 m/s [4; 9; 5]. The properties of soil deposited at different place of Kathmandu city has shear-wave velocity less than 150 m/s [11; 12]. The SSI effects on midrise buildings for very soft soil (<150 m/s) has not been yet carried out. The lower the value of shear-wave velocity of soil increases the flexibility of medium, which may affect on performance level of structures. IS 1893:2016 / NBC 105:2020 ignore the effects of SSI on period of buildings. Not only building height but SSI also influence the fundamental period of structures [13]. The main aim of this research is to propose the maximum lateral deflection increment factor for fixed based RC structure to simplify the design method considering SSI effects.

Description of buildings. According to NBC 206:2015 a mid-rise building is considered to be 16–25 m in height, and similarly IS code classifies 4–10 stories buildings as mid-rise ones. Here, 3, 5, 7 and 10 stories building are taken into consideration, as this thesis examined the seismic response of mid-rise structures up to 10 storey high. The details of model used in this study are shown in Table 1. Because a finite-element program SAP2000 can simulate complicated issues requiring massive computational resources through a direct technique of analysis, it was used to simulate soil-structure systems numerically. The damping in the models was considered to be 5 %. Concrete of grade M25 and steel of grade Fe500 were assigned as materials for beams, columns, and slabs. Each building was modeled and analyzed as per IS 1893:2016 and NBC 105:2020 for dynamic analysis. The loading on structure was taken in accordance with IS 1893:2016 (Table 2).

Live load intensity applied on selected structures was 1.5 KN/m^2 for roof and 3 KN/m^2 for other slabs, and similarly floor finish of intensity 1.2 KN/m^2 was also applied. Wall loads were converted into uniformly distributed load. For dynamic analysis seismic load was applied in accordance with NBC 105:2020.

Table 1

Major features of building

Storey No.	Storey height, mm	No of bays in *X*- & *Y*-direction	Bay width in *X*-direction, mm	Bay width in *Y*-direction, mm	Depth of MAT, mm	Column Size, mm	Beam Size, mm	Slab thickness, mm
3	3000	2	4000	4000	500	300×300	300×250	125
5	3000	2	4000	4000	500	380×380	300×250	150
7	3000	3	4000	4000	1000	550×550	500×450	200
10	3000	3	4000	4000	1000	650×650	600×550	200

Table 2

Seismic parameters of building (IS 1893:2016)

Parameters	General Description
Structural System	Special Moment Resisting Frame
No. of Floors	3,5,7 and 10 storey
Concrete Grade	M25
Reinforcements	Fe 500
Response Reduction Factor	5 %
Seismic Zone Factor	0.36
Importance Factor	1.5

2. Methods

The 3D model was simulated by applying frame components for the columns and beams, shell components for the slabs, MAT foundation, and viscous spring elements for the soil boundaries; the structure was represented as a three-dimensional frame. The MAT foundation and soil elements (continuum elements) are simulated using solid components (Figure 2).

Direct method of approach was used for modeling of system as it can show the real behaviour of structure. Viscous spring absorbing boundaries were used to avoid reflective nature of waves propagation. The effects of the reflective waves were minimal if the gap between the building's center and the soil FEM margin was within three/four times in horizontal and two/three times along the depth of soil layers [14]. In this study the boundary was considered 5–6 times the foundation radius, and depth was considered as a rigid base after 30 m below (Tables 3, 4).

Table 3

Properties of soil layers

Model Parameters	Unit	Soil class B	Soil class C	Soil class D
Mass density **ρ**	kg/m^3	1,700	1,698	1,164
Bulk modulus *K*	kPa	1,209,036	746,826	27,522
Shear modulus *G*	kPa	623,409	177,304	3321
Poisson's ratio $\boldsymbol{\nu}$		0.28	0.39	0.442
Elastic modulus *E*	kPa	1,595,927	492,905	9,577
Shear strength *C*	kPa	5	20	20
Friction angle **φ**	° (deg)	40	19	12

Table 4

Soil parameters

Soil Type	S-wave velocity, m/s	P-wave wave velocity, m/s
Soil class B	600	1318
Soil class C	320	753
Soil class D	52.9	164

The soil parameters for soil modeling were taken from the (Rahvar 2005) and (Rahvar 2006a) for soil class *B* and *C* respectively, and soil parameters of Kathmandu valley were taken into consideration for soil class *D* as soil parameter classified by [11]. The above soil are taken under the consideration of soil profiles classified by (ATC, 1996; FEMA356, 2000) [15]. The shear-wave velocity of soil in different places of Kathmandu valley was less than 180 m/s [12; 11]. For soil type *D*, the soil having minimum value of shear velocity was taken for this study. For soil having shear-wave less than 600 m/s, there were significant effects of SSI for RC framed building [9]. The soil was modeled as one homogeneous layer of 30 m depth. The maximum grid spacing (Δh) was limited in accordance with formula given by [16].

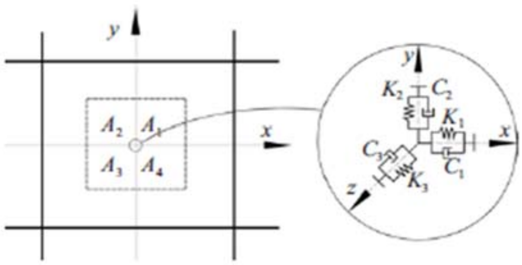


Figure 2. Sketch of 3D Viscous Spring Artificial Boundary (VSAB) [17]

$$\Delta h \leq \frac{V_S}{10 f_{max}}, \quad (1)$$

where f_{max} — is the maximum frequency of relevant structures; V_s — is shear wave velocity of medium (Figure 2).

$$K_1 = K_2 = \frac{2G}{R} A, \quad (2)$$

$$C_1 = C_2 = \rho c_s A, \quad (3)$$

$$K_3 = \frac{4G}{R} A, \quad (4)$$

$$C_3 = \rho c_p A, \quad (5)$$

where, C_1, C_2, and C_3 are viscous damping coefficients and K_1, K_2, and K_3 are spring stiffness coefficient along *x*-, *y*- and *z*-axis respectively. *G* is the shear modulus, ρ is the mass density, *A* is the area of soil continuum grid, c_s and c_p are *s*- and ρ-wave velocities respectively.

In computational models, the facing zone was divided from the neighboring soil region by interface components. Here, two shear springs along two orthogonal direction and one spring along the vertical direction were modeled for frictional contact between the two planes of soil layer and MAT foundation in order to prevent from sliding of MAT and soil layers during seismic loading. The shear strength of soil and footing elements was determined as Mohr–Coulomb failure criterion, and the interconnection between structural base and soil layers were given as spring-slider systems [18; 19].

$$K_{n(max)} = K_{s(max)} = 10_{x(max)} \left[\frac{k + \frac{4}{3}G}{(\Delta z)_{min}}\right], \quad (6)$$

where $(\Delta z)_{\min}$ is the smallest continuum zone dimension next to the normal direction of the interface. The direct method of modeling of building and soil along with its boundary elements along the periphery of soil layer is shown on Figure 3. Selection of representative ground motion for seismic performance evaluation should be done in such a way, that they account for the uncertainties and difference in frequency, severity and the duration characteristics. Ground motion parameters can be displacement, velocity and acceleration or combination of them. Among these parameters, acceleration is measured quantity and other are derived quantity. So, acceleration time histories are generally used in the analysis.

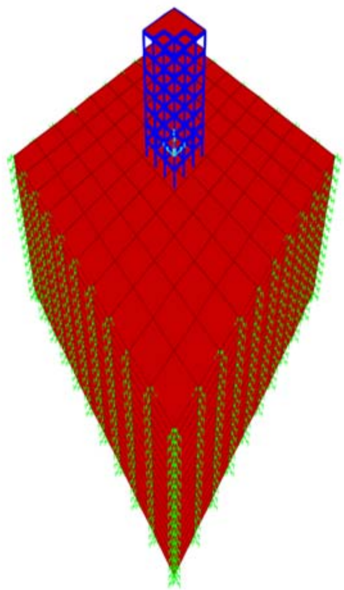


Figure 3. Model of 7-storey building using direct approaches
S o u r c e : made by authors

At least three pairs of synthetic earthquake recordings with two orthogonal components i.e., in both x- and y-direction are used. The acceleration histories of given earthquake are downloaded from PEER. The ground motion data are selected according with codal provisions. Response of different ground motion differ depending on their origin, the types of earthquakes and local site response.

SeismoMatch 2022 is used for matching of earthquake data. Kobe, Gorkha and El Centro are input source accelerogram. Code based spectrum IS 1893 (Part 1):2016 is set as a targeted spectrum. The earthquake data are matched differing the soil type with damping value of 5 % (Figure 4,Table 5).

Table 5

Selected ground motion with Original and Matched PGA (g)

S.No	Earthquake	PGA(g)-Original		PGA(g)-Matched	
		x	*y*	*x*	*y*
1	Kobe, Japan	0.21924	0.28977	0.154	0.23153
2	El Centro	0.25409	0.15024	0.19777	0.1696
3	Gorkha, Nepal	0.44942	0.4081	0.2308	0.22572

Linear dynamic. To compute earthquake forces, their dispersion over the height of the structure, and the associated internal forces and structural deflections for the Linear Dynamic Procedure (LDP), a linearly elastic, dynamic analysis is applied. Using the codal response spectra provided by the seismic code (IS 1893:2016), the dynamic analysis of the building model has been performed. When a structure is exposed to earthquake excitations [20], the equation of motion in a structural system can be expressed as

$$[M]\ddot{u} + [C]\dot{u} + [K]u = F(t). \quad (7)$$

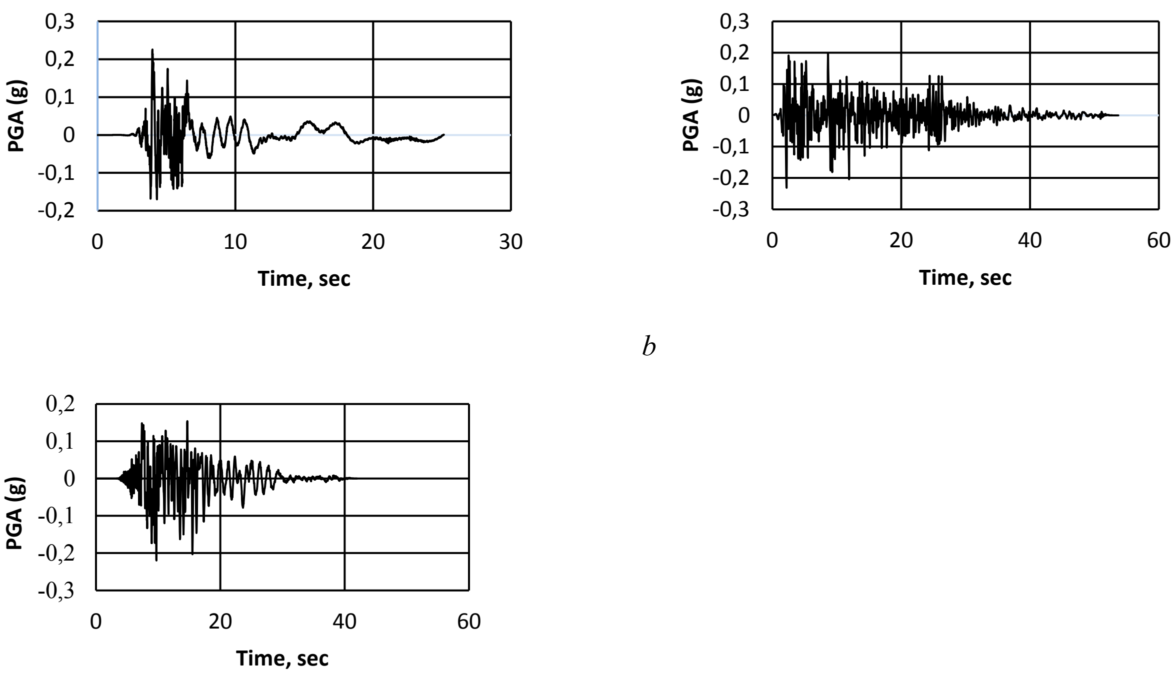


Figure 4. Seismic records along X-direction:
a — Gorkha Earthquake 2015; *b* — El Centro; *c* — Kobe
Source: made by authors

3. Result and discussion

3.1. Maximum lateral deflection

Figure 5–7, *a, b, c a, d* show the maximum lateral deflection of 3-storey, 5-storey, 7-storey and 10-storey RC framed structures with different soil type *B*, *C*, *D* and considering fixed based respectively. Compared to rigid base structure lateral deflection of flexible-base structure for all cases was been increased, despite of the height of buildings, footing and soil type. This was because of the soil-structure system's degree of freedom increased once SSI was taken into account; the natural period was lengthened [21]. So, the amplification of displacement was seen in the structure when considering SSI. This indicates that with the changing soil from *B* to *C* to *D*, the maximum lateral deformation also increased gradually. With increase in width of buildings the stability increased and effects of footing rotation decreased. Also, it should be noted that increase in buildings bays distance (spacing between two columns) increase in overall mass of structure resulting in the increments of inertial force. Hence, the nature lateral deflection follows different pattern on change in height and width of structure. Soil having shear-wave velocity less than 180 m/s (very soft soil), the structure can deform considerable amplification ranging up to 300 % as compared to rigid-base structure [6]. The displacement of structure increases nonlinearly over the storey height.

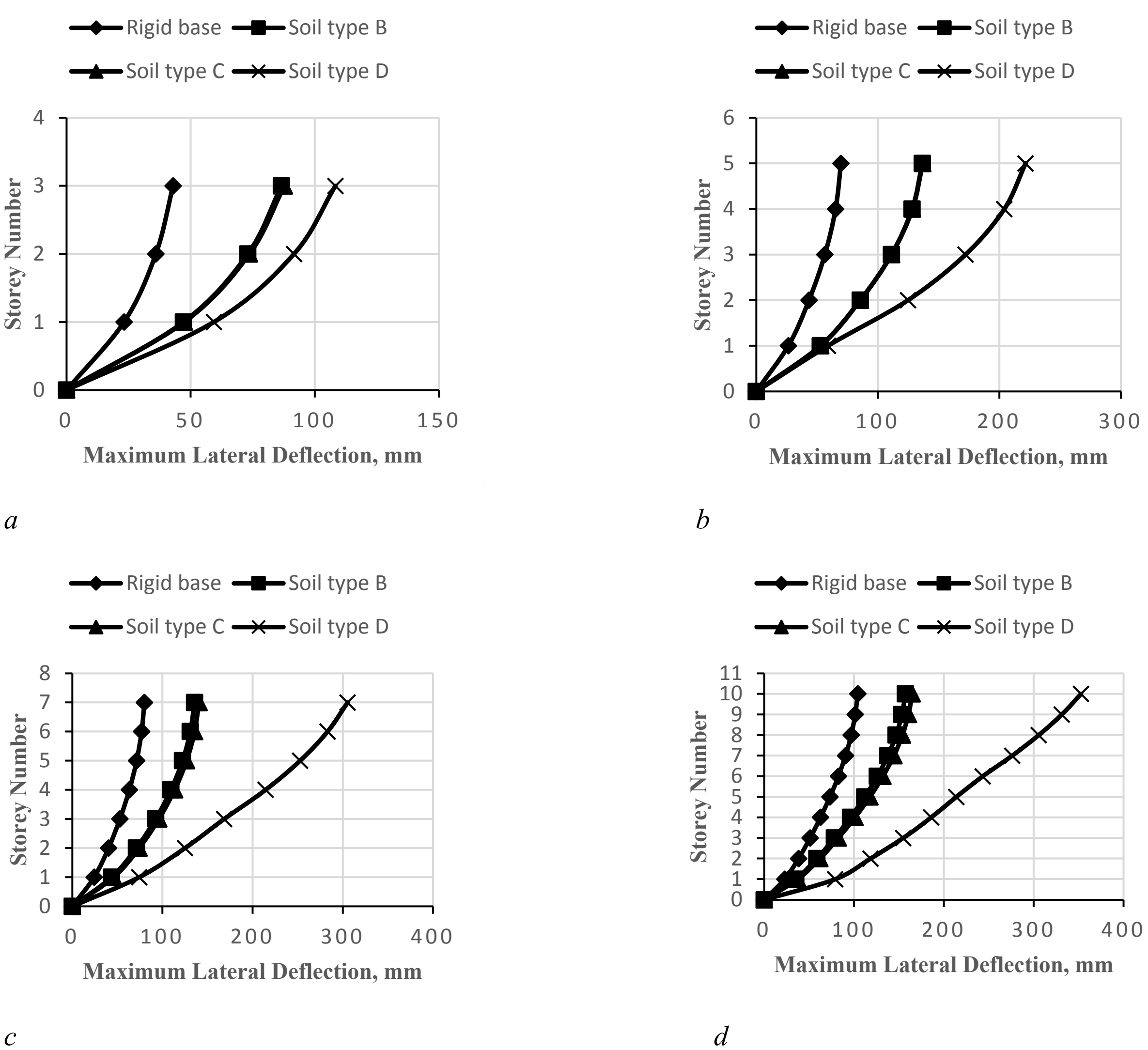
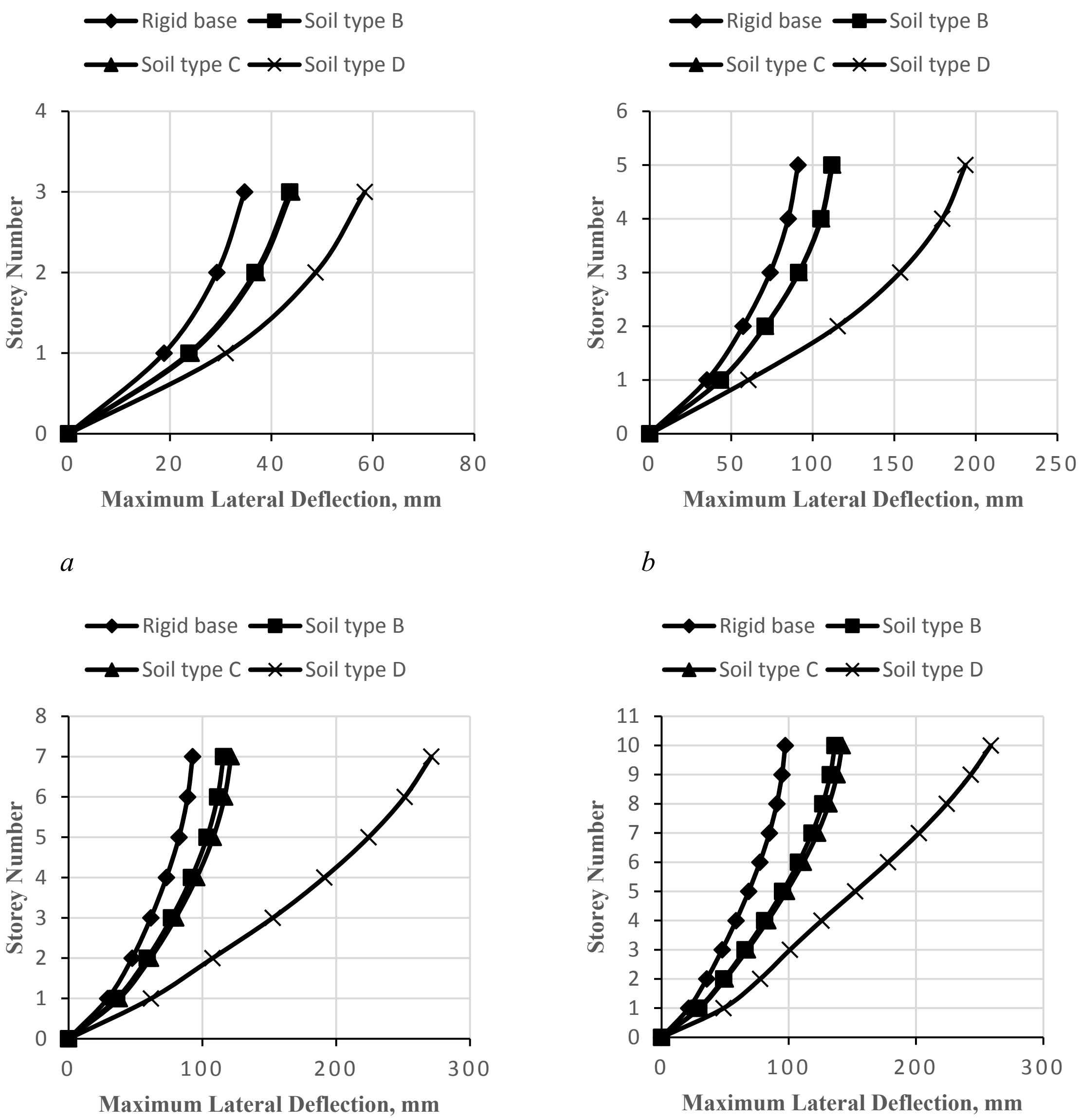


Figure 5. Lateral deflection with various types of subsoil:
a — M-3; *b* — M-5; *c* — M-7; *d* — M-10 structures (Kobe earthquake)
S o u r c e : made by authors

Figure 5 shows the maximum lateral deflection of 3-, 5-, 7-, and 10-storey buildings for Kobe earthquake. In this section, the results are presented and analyzed in terms of the maximum storey displacements. The top of the structure was amplified 101.5, 104.2 and 152.2 % for soil classes *B, C* and *D* respectively for a 3-storey building. The deformation of 5-storey was amplified by 69.5, 75.8 and 207.6 % for Kobe earthquake. It can be seen that lateral deflection of a 7-storey building was amplified by 69.5, 76 and 282 % for soil classes *B*, *C* and *D* respectively. Similarly, 51, 58.3 and 238.7 % were the lateral displacement amplification values for a 10-storey structure.

Figure 6 shows the maximum lateral deflection of 3-, 5-, 7-, and 10-storey building for El Centro earthquake. The maximum top deflections for 3-storey regular building were been amplified as 74.8, 83.5 and 105.8 % respectively for soil type *B*, *C* and *D* with respect to the rigid base. Top deflection for 5-storey regular building has been amplified as 65.5, 86 and 149 %. Top deflection for a 7-storey regular building was been amplified as 49, 79.2 and 285 %. Similarly, top displacement for 10-storey building along *X*-direction was amplified as 61.7, 86.5 and 281.9 % for soil type *B*, *C* and *D* respectively.



a *b* *c* *d*

Figure 6. Lateral deflection with various types of subsoil:
a — M-3; *b* — M-5; *c* — M-7; *d* — M-10 structures (Gorkha earthquake)
S o u r c e : made by authors

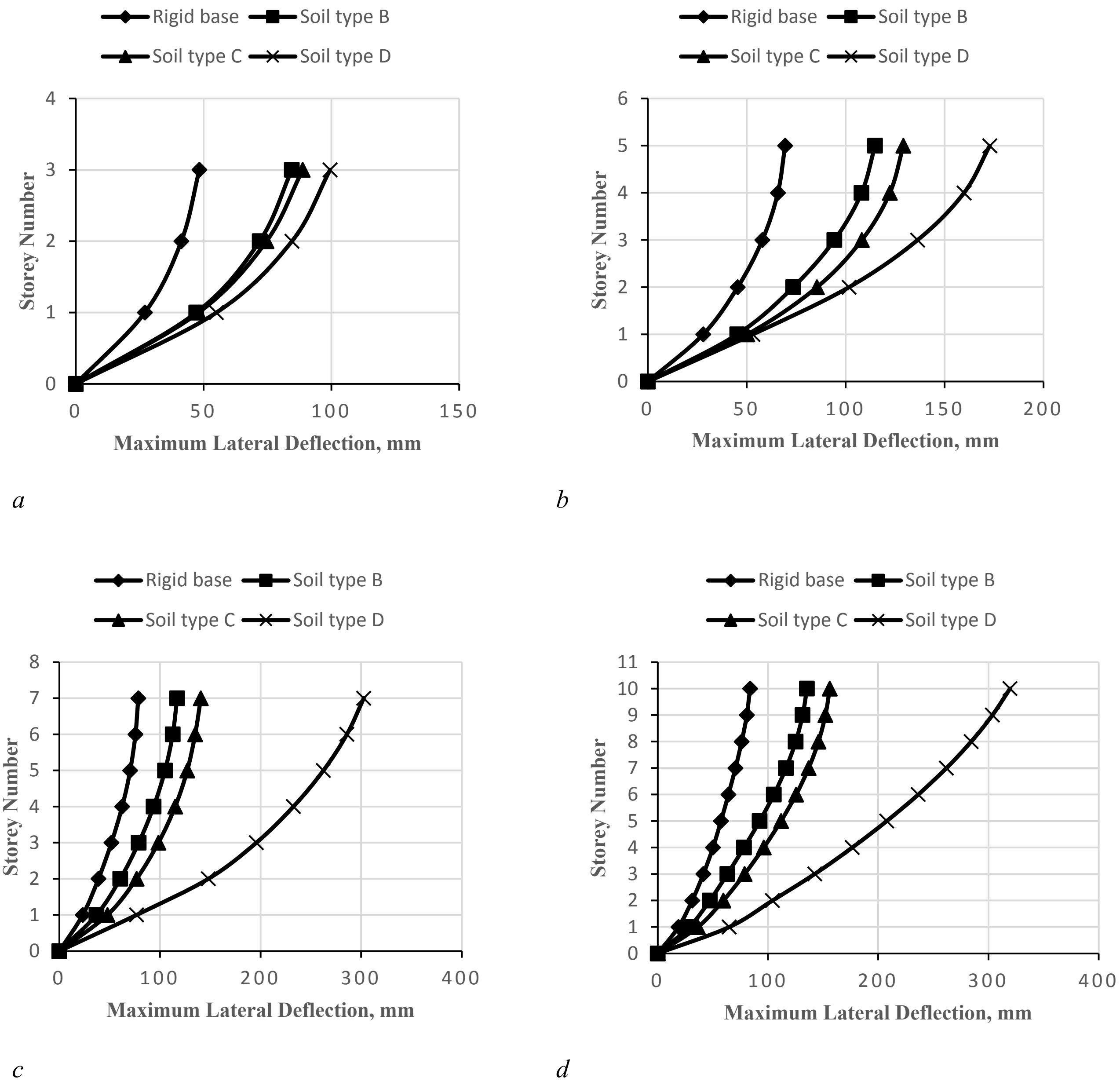


Figure 7. Lateral deflection with various types of subsoil:
a — M-3; *b* — M-5; *c* — M-7; *d* — M-10 structures (El Centro earthquake)
S o u r c e : made by authors

Figure 7 shows the maximum lateral deflection of 3-, 5-, 7-, and 10-storey building for Gorkha earthquake. The maximum top deflection for 3-storey regular building has been amplified as 34.5, 35.45 and 68.3 % respectively for soil type *B*, *C* and *D* with respect to rigid base. Top deflection for 5-storey regular building has been amplified as 36.2, 37 and 113 %. Top deflection for 7-storey regular building along *X*-direction has been amplified as 25, 31.1 and 192.5 %. Similarly, top displacement for 10-storey building has amplified as 40.2, 46.1 and 175.2 % for soil type *B*, *C* and *D* respectively.

The one of most important design parameters is inter-storey drift. This variable displays the appropriate displacement between the top and bottom of a storey. The storey drift ratio is calculated for different types of soil types ranging from *B* to *D* according to Nepalese code. The drift values reach maximum at first storey for all the considered models. If the stiffness decreases the drift ratio increases [13]. Mainly the top and the bottom stories drift ratio values are affected by SSI than the middle stories. The below statement illustrates the inter-storey drift ratio's governing equation:

$$drift = \frac{\Delta_{i+1} - \Delta_i}{h}. \quad (7)$$

Figures 8–10, *a, b, c* and *d,* show the inter-storey drift of 3-storey, 5-srorey, 7-storey and 10-storey RC framed structures with different soil type *B*, *C*, *D* and considering fixed based respectively for different earthquake (Kobe, El Centro, Gorkha). Similar to lateral deflection, inter-storey drifts were also found to be increased in all flexible cases and the maximum value in many cases has exceeded 1.5 %. This indicates, after accounting for SSI, the performance level was shifted from life safety to near collapse (2.5 %)[1]. In a fixed base foundation system, the inter-storey drift lies at the life safety level. The different performance level according to FEMA-356 are tabulated below:

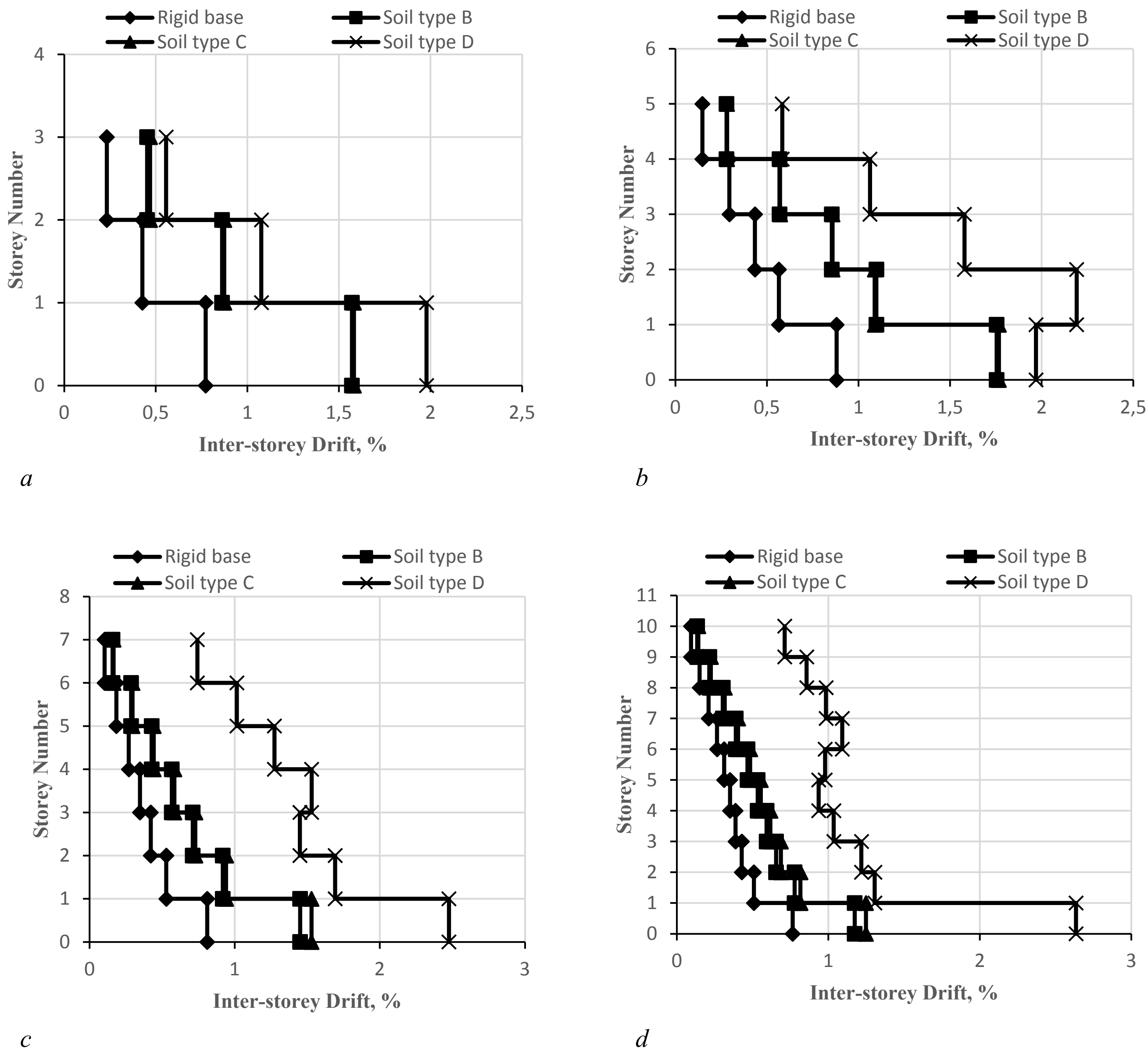


Figure 8. Inter-storey drift (%) of various buildings types and subsoil types (THx):
a — M-3; *b* — M-5; *c* — M-7; *d* — M-10 structures (Kobe earthquake)
S o u r c e : made by authors

[1] Building Seismic Safety Council (BSSC) NEHRP guidelines for the seismic rehabilitation of building. Washington, DC, FEMA 273/274, FEMA, 1997.

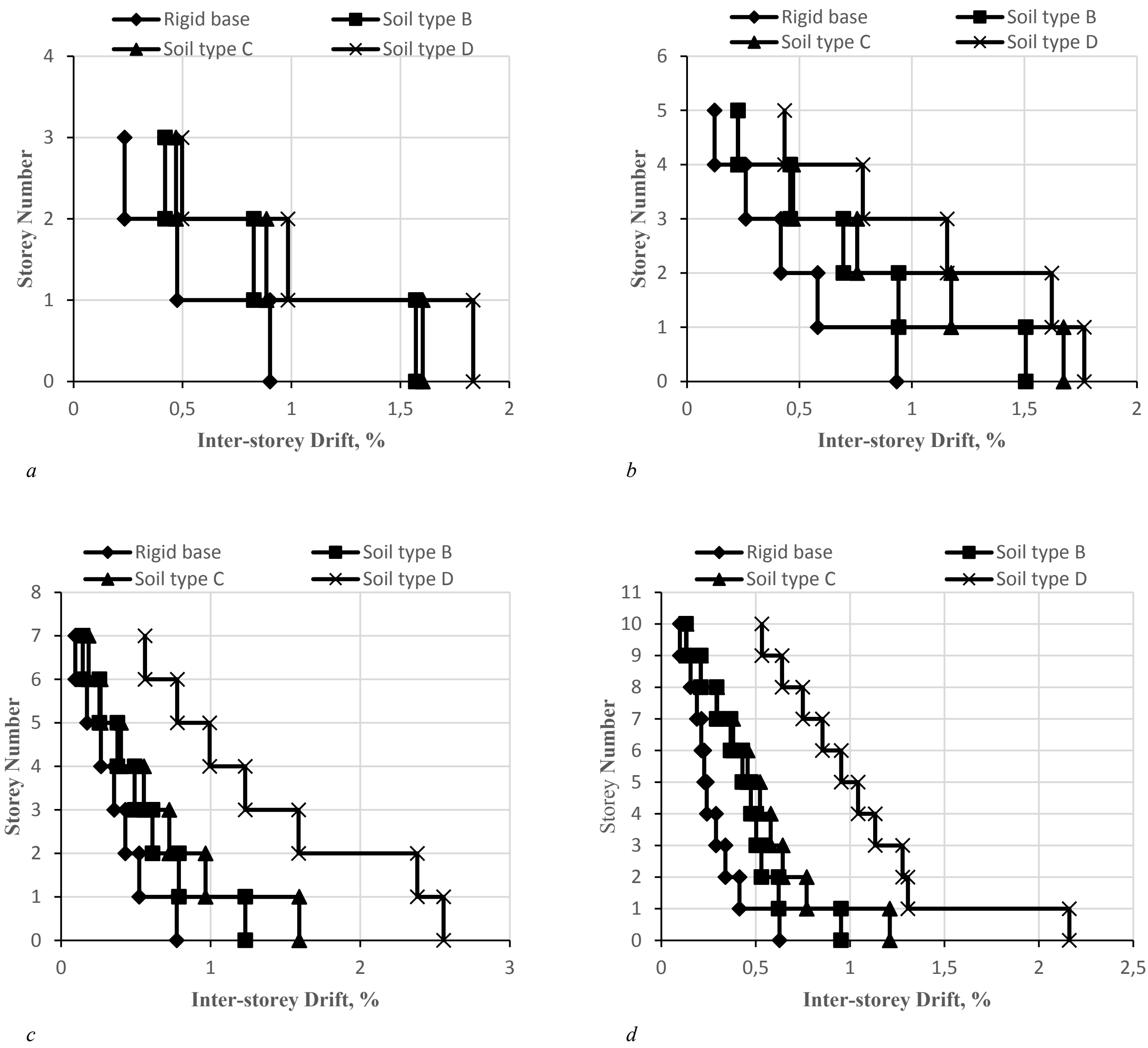


Figure 9. Inter-storey drift (%) of various buildings types and subsoil types (THx):
a — M-3; *b* — M-5; *c* — M-7; *d* — M-10 structures (El Centro earthquake)
S o u r c e : made by authors

The different performance according to FEMA-356 are shown in Table 6.

Table 6

Performance level

Performance level	Drift % (FEMA-356, BSSC-1997)
Slight damage	0.2
Moderate damage	0.5
Extensive damage	1.5
Near collapse	2.5
Collapse Prevention	4

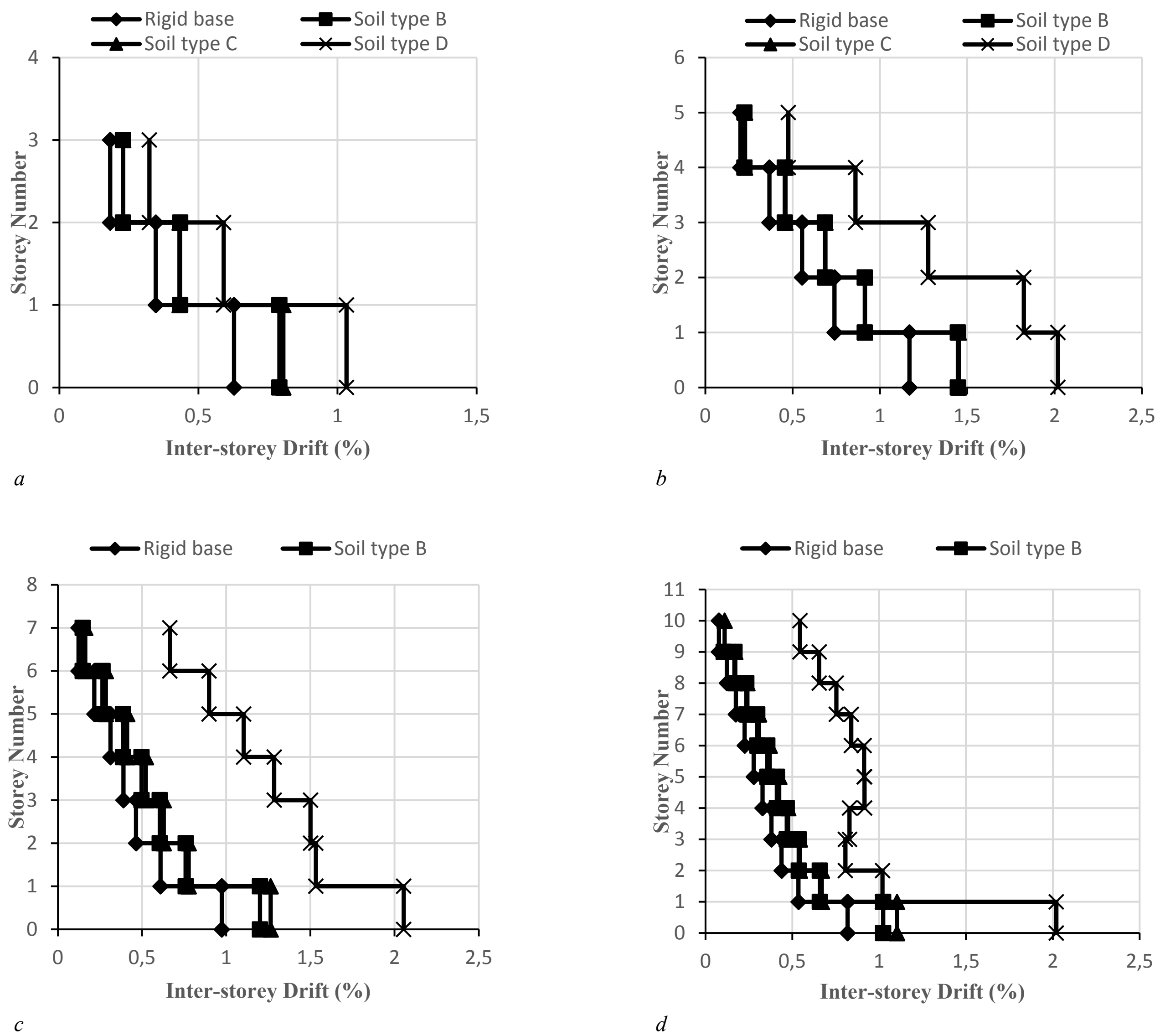


Figure 10. Lateral deflection with various types of subsoil:
a — M-3; *b* — M-5; *c* — M-7; *d* — M-10 structures (Gorkha earthquake)
S o u r c e : made by authors

The higher value of the interstorey drift occurred for the building located in Soil-*D* for all three ground records used in this study. As the soil class changes from *B* to *C* and *C* to *D*, the storey drift ratios was also shifted from life safety levels to the near collapse level. It can be seen from Figures 8–10 that the lower stories were found to be affected more by SSI than other stories. The maximum value of IS-drift % value were seen in Kobe earthquake among the selected three pairs of ground motion data.

The maximum IS-drift value for M-3 fixed base structure is 0.78 % whereas corresponding values for soil type *B*, *C* and *D* is 1.50, 1.52 and 1.70 % respectively for Kobe earthquake. The maximum IS-drift value for M-5 fixed base structure is 0.87 % whereas corresponding values for soil type *B*, *C* and *D* is 1.75, 1.76 and 2.19 % respectively. The maximum IS-drift value for M-7 fixed base structure is 0.81 % whereas corresponding values for soil type *B*, *C* and *D* is 1.45, 1.52 and 2.47 % respectively.

The maximum IS-drift value for M-10 fixed base structure was 0.76 % whereas corresponding values for soil type *B*, *C* and *D* is 1.17, 1.24 and 2.63 % respectively. The study finds that, for nearly all the models pertaining to soil class D, there is a substantial amplification in building performance — from ensuring life safety to reaching the critical points of near-collapse or complete collapse. Hence, to enhance the safety and serviceability of building SSI should be account in order to design the buildings.

3.2. Time period

Seismic demands of the structure depend upon the fundamental time of the building (Figure 11). According to NBC 105:2020, the fundamental time period for moment resisting concrete frame building was a function of overall height of the building i.e.

$$T_a = 0.075h^{0.75} \quad (8)$$

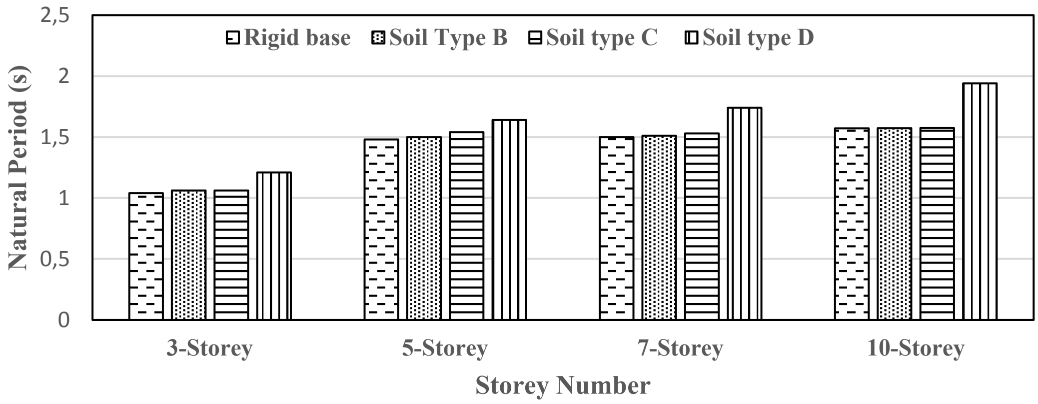


Figure 11. Time chart for rigid base and flexible base considering different soil type
Source: made by authors

According to [22] the time period of 12-storey building has been amplifying up to 100 % considering SSI effects. Result obtained from the structural analysis, the fundamental time period of first mode is increased only within 2 % for soil type B and C. But fundamental time period of soil type D is increased by 16, 11, 16 and 23 % for 3- , 5- , 7- and 10-storey building respectively.

3.3. Simplified procedure

Criteria for consideration of SSI effects. Criteria to consider SSI effects on the building is given by [9], which is as follow:

$$\frac{V_s}{fh} < 20, \quad (9)$$

where, f is the frequency of rigid base buildings using empirical code basis formula and h is the overall height of the structure. The above criteria were applied for all lateral force resisting system including both rigid and ductile structures [9]. The main factor for considering the SSI effects was rigidity of the structure against the soil-layers considered within the boundary area. The natural frequency of the structure considering soil-structure interaction was obtained only after analyzing the soil-structure model. Therefore, a formula based on a conventional code was proposed for the criteria given by Veletsos and Meek [23].

Table 7

Derivation of Criteria given by Veletsos and Meek

Soil Type	Storey Number	Storey Height, m	Natural Frequency of Structure Hz	$\frac{V_s}{fh}$
Type *B* (V_s = 600 m/s)	3	9	2.566	25.98077
	5	15	1.749	22.87021
	7	21	1.359	21.02386
	10	30	1.04	19.23077

Ending of the Table 7

Soil Type	Storey Number	Storey Height, m	Natural Frequencyof Structure Hz	$\frac{V_s}{fh}$
Type *C* **(V_s = 320 m/s)**	3	9	2.566	13.85641
	5	15	1.749	12.19745
	7	21	1.359	11.21273
	10	30	1.04	10.25641
Type *D* **(V_s = 52.9 m/s)**	3	9	2.566	2.290638
	5	15	1.749	2.01639
	7	21	1.359	1.853604
	10	30	1.04	1.695513

The Table 7 above shows that the specified criteria are not fulfilled for soil type *B*, so there is no need to consider SSI effects in the seismic analysis of the structure. The ratio of the maximum lateral deflection of the considering soil to the rigid base is known as the maximum lateral deflection increment factor (β) which is given as:

$$\beta = \frac{\delta'}{\delta}, \tag{10}$$

where δ' is the maximum lateral deflection of structure considering soil-structure interaction and δ is the maximum lateral deflection of structure considering as rigid base. Tabatabaiefar and Massumi gave the relation between maximum lateral deflection ratio and the number of stories [2].

For soft soil sites (soil type *C*)

$$\beta = a + bs^3. \tag{11}$$

For very soft soil sites (soil type *D*)

$$\beta^2 = a + \frac{b}{S^2}. \tag{12}$$

The above equations were solved by curve fitting techniques, and the values can be presented in graphical form (Figures 12–14):

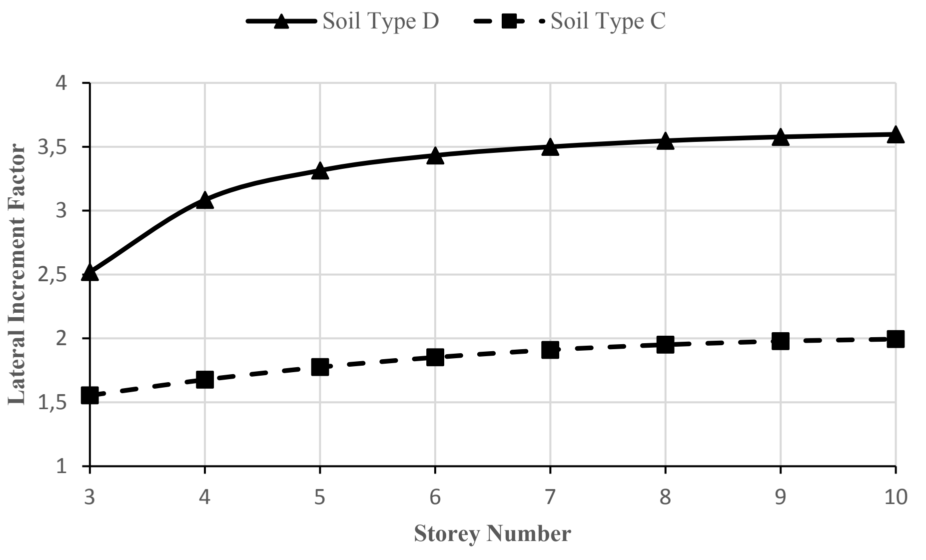


Figure 12. Maximum lateral deflection factor vs Storey number for Kobe earthquake
Source: made by authors

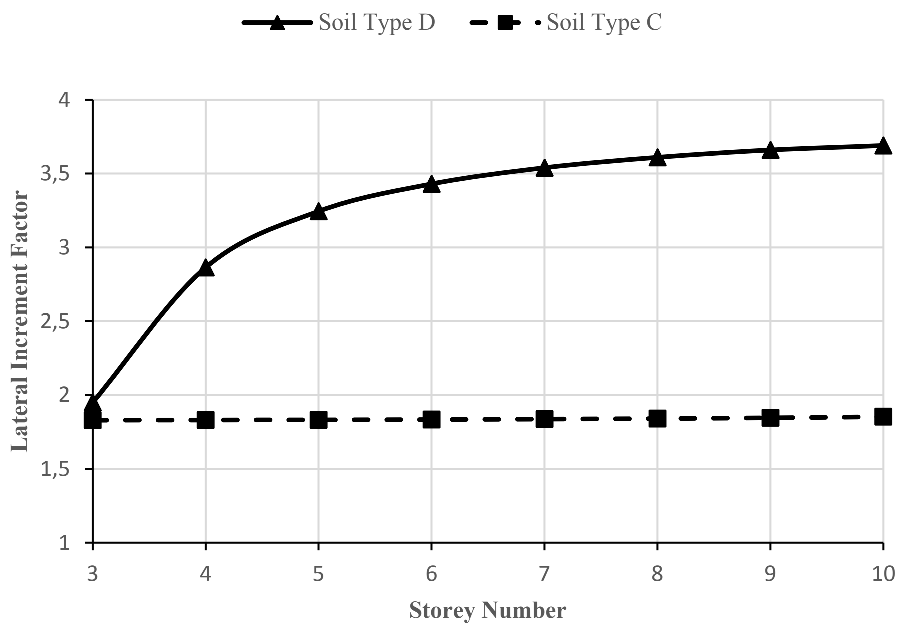


Figure 13. Maximum lateral deflection factor vs Storey number for El Centro earthquake
Source: made by authors

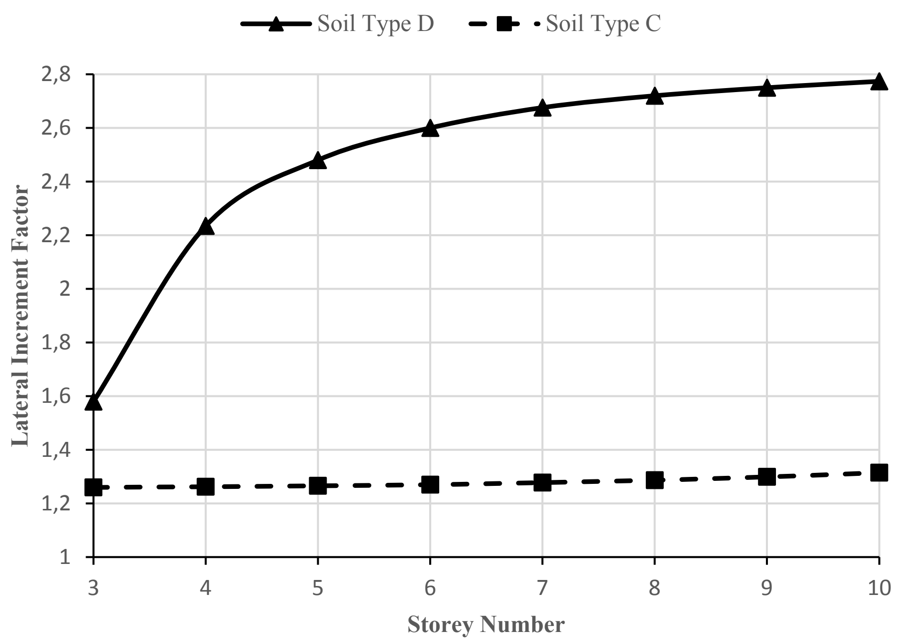


Figure 14. Maximum lateral deflection factor vs Storey number for Gorkha earthquake
Source: made by authors

From Eqs. (10) the lateral increment factor can be derived. Among the considered three pairs of ground acceleration data, the maximum value of the lateral increment factor was obtained for Kobe.

The top deflection of each model was used to calculate the lateral increment factor by curve fitting techniques. The calculated β values along *X*-direction is greater than that of *Y*-direction. The maximum response value of selected earthquake pairs was incorporated, hence the values along *X*-direction are recommended in the simplified procedure. The incremental factor increased nonlinearly with storey height.

4. Conclusion

This study aims to assess the influence of soil-structure interaction on the seismic behavior of reinforced concrete frame buildings. A set of forty-eight mid-rise building models with varying heights (ranging from 3 to 10 stories) were analyzed using linear dynamic analysis. These models were located on soft, medium, and hard soil conditions.

The structural response with and without considering soil-structure interaction was evaluated in terms of fundamental time period, stiffness, base shear, storey drift, and storey displacement. The findings from the analysis led to the following conclusions:

1. Incorporating soil flexibility led to a decrease in the base shear. This decrease was attributed to an increase in the structure's effective damping ratio and natural time period. Consequently, buildings with fixed bases exhibited higher base shear, while those situated on soft soil displayed the least base shear.

2. The fundamental time period of the structures decreased with higher soil spring stiffness. Soil-structure interaction significantly influenced the lateral stiffness of the structural system. Buildings with fixed base systems demonstrated longer time periods compared to those on soft soil.

3. Structures with flexible bases exhibited greater displacement compared to fixed base systems. This trend was consistent for inter-storey drift ratios across various building models. Inter-storey drift ratios were higher on soft soil and lowest for buildings with fixed bases. This effect was attributed to lower stiffness in soft soil conditions.

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