Lateral Seismic Response of Building Frames Under the Influence of Soil–Structure Interaction

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ABSTRACT

This study deal with the elastic and inelastic structural responses of building frames under the influence of soil–structure interaction. Three give the types of moment-resisting building frames, including 5 storey, 10-storey and 15-storey buildings are selected. In addition, three soil types with the shear wave velocities less than 600m/s, representing soil classes C_e, D_e and E_e according to IBC-2006[3] , having three bedrock depths of 10m, 20m and 30m are adopted.

The structural sections are designed after conducting nonlinear time history analysis, on the basis of both elastic method and inelastic procedure considering elastic-perfectly plastic behavior of structural elements. The frame sections are modeled and analyzed, employing finite difference method adopting ANSYS software under two different boundary conditions: (a) fixed base (no soil–structure interaction) and (b) considering soil–structure interaction. Fully nonlinear dynamic analyses under the influence of different earthquake records are conducted. The results in terms of the maximum lateral displacements and base shears for the above mentioned boundary conditions for both elastic and inelastic behaviors of the structural models are obtained and compared, with the results. A comprehensive empirical relationship is proposed to determine the lateral displacements of the moment-resisting building frames under earthquake and the influence of soil– structure interaction.

Keywords: soil–structure interaction; seismic behavior; structural response; mid-rise moment-resisting frames.

الاستجابة الزلزالية الجانبية للابنية تحت تاثير تفاعل التربة

الخلاصة

في هذة الدراسة تم دراسة الاستجابة المرنة و الغير مرنة تحت تأثير التربة لثلاث انواع من الابنية (٥، ١٠، ١٥) متر مع استعمال ثلاث انواع من التربة حسب IBS (2005).

تم استخدام برنامج الانسس لتحليل الابنية باستخدام طريقة nonlinear time history analysis و اعتبار الاساس ثابت . و تم التحليل الدانميكي لهزات ارضية مختلفة و تم التحليل بالسلوك المرن و الامرنو المقارنة بين كل هذة المتغيراتون حيث التاثير الجانبي و قوى القص و لبعزوم المتولدةو تاثير التربة عليها.

INTRODUCTION

The seismic response of a civil structure is influenced by the medium on which the structure is founded. On solid rock, a 'fixed base' structural response occurs, which can be evaluated by subjecting the foundation to the 'free-field' ground motion occurring in the absence of the structure. However, on a deformable soil, a feedback loop exists. In other words, the structure responds to the dynamics of the soil, whereas the soil responds to the

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dynamics of the structure. The structural response is then governed by the interplay between the characteristics of the soil, the structure and the input motion.

The process, in which the response of the soil influences the motion of the structure and vice versa, is referred to as soil–structure interaction (SSI). As suggested by the name, SSI analysis aims at assessing the response of a structure resting on the ground and subjected to any stimulation, while taking into account coupling with the support medium and the soil, having its own deformation characteristics. It determines the actual loading experienced by the soil–structure system resulting from the free-field seismic ground motions [(1)]. Incomplete statement according to the available literature, generally when the shear wave velocity of the supporting soil is less than 600 m/s, the effects of SSI on the seismic response of structural systems, particularly for moment-resisting building frames [(2,3)]. These effects can be summarized as follows: (a) increase in the natural period and damping of the system, (b) increase in the lateral displacements of the structure and (c) change in the base shear force depending on the frequency content of the input motion and dynamic characteristics of the soil and the structure. During the recent decades, the importance of the dynamic SSI for several structures founded on soft soils has been well recognized. Thus, for ordinary building structures, a better insight into the physical phenomena involved in SSI problems has been recognized [(4)].

Over the past few years, the importance of SSI both for static and dynamic loads has been well established by several studies. Since 1990s, great effort has been made for substituting the classical methods of design by the new ones on the basis of the concept of performance-based seismic design. In addition, the necessity of estimating the vulnerability of existing structures and assessing reliable methods for their retrofit has greatly attracted the attention of engineering community in most seismic zones throughout the world [(5,6)].

During the past two decades, various analytical formulations have been developed to solve complex practical problems assuming linear and elastic SSI. However, effects of nonlinear behavior of the supporting soil and inelastic seismic response of structures have not been fully addressed in the literature. Thus, in this study, a state-of-the art soil–structure model has been developed adopting direct analysis method using ANSYS software to consider dynamic SSI as accurately and realistically as possible. By adopting the newly developed model, SSI effects have been investigated on the performance level of three structural models comprising 5-storey, 10-storey and 15-storey moment-resisting building frames constructed on various soil types including soil types C_e, D_e and E_e with varying shear wave velocities according to IBC in conjunction with three different bedrock depths of 10 m, 20m and 30 m. Finally, with the results of the investigation, an empirical relationship is proposed, which enables designers to determine lateral deflections of mid-rise moment-resisting building frames under the influence of SSI utilizing fixed base results as well as other basic site and structural characteristics[(7)].

Characteristics of Studied Building Frames

Mid-rise buildings are aggregation of dwelling buildings ranging from 5 to 15 stories. With respect to this definition, to cover this range, three structural models consisting of 5-storey, 10-storey and 15-storey models, representing conventional types of mid-rise reinforced concrete moment-resisting building frames, have been selected in this study as per specifications summarized in Table 1. The selected span width conforms to architectural norms and construction practices of the conventional buildings in mega cities.

For the structural concrete utilized in this analysis and design, specified compressive strength (f'_c) and mass density (ρ) are assumed to be 25 MPa and 2400 kg/m3 respectively, section coefficients are 0.4m beams and 0.7m for columns, slab thickness is o.15m, the dead load is 400 kg/m^2 and live load 600 kg/m^2 [(8)].

Table(1). Dimensional characteristics of the studied frames.

Reference name	Number of storeys	Number of bays	Bay height (m)	Bay width (m)	Total height (m)	Total width (m)
S5	5	3	3	4	15	12

S10	10	3	3	4	30	12
S15	15	3	3	4	45	12

In this study, structural sections of the models are designed on the basis of conventional elastic method and inelastic method assuming elastic- perfectly plastic behavior for the structural members. For this purpose, structural members of models S5, S10 and S15 (Table 1) are simulated, analyzed and designed using ANSYS V11 software.

Then, nonlinear time history dynamic analyses under the influence of four earthquake ground motions, shown in Table 2, are performed on the structural models. In the dynamic analyses, geometric nonlinearity and P-delta effects are considered according to IBC 2006[3]. In addition, cracked sections for the reinforced concrete sections are taken into consideration by multiplying cracked section coefficients by stiffness values of the structural members (EI) according to ACI 318 (2002).

With this standard, cracked section coefficients are 0.35 for beams and 0.7 for columns.

Table (2). Earthquake ground motions used in this study [9].

Earthquake	Country	Year	PGA(g)	Mw (R)	T(s) Duration	Type
Northridge	USA	1994	0.843	6.7	30.0	Near field
Kobe	Japan	1995	0.833	6.8	56.0	Near field
El Centro	USA	1940	0.349	6.9	56.5	Far field
Hachinohe	Japan	1968	0.229	7.5	36.0	Far field

Finite Element Idealization and Material Properties

1. Concrete idealization

2. Three dimensional brick element (Solid 65) is used to model the concrete with or without reinforcing bars (rebar). The element is capable of cracking in tension and crushing in compression.

3. Steel idealization

The steel reinforcing bars (tensile, compressive, and stirrups) are represented by using 2-nodediscrete representation (Link8 in ANSYS) and included within the properties of 8-node brick elements.

4. Soil idealization

The Solid 45 is used for the 3-D modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain.

Soil–Structure system

The governing equations of motion for the structure incorporating foundation interaction and the method of solving these equations are relatively system is modeled in a single step, is employed in this study. The complex. Therefore, direct method, the method in which the entire soil–structure use of direct method requires a computer program that can treat the behavior of both soil and structure with equal rigour simultaneously. Thus, the finite difference software, ANSYS, is utilized to model the soil– structure system and to solve the governing equations for the complex geometries and boundary conditions [6].

To model soil–structure system in direct method, a novel and enhanced soil–structure model is developed in ANSYS to simulate various aspects of complex dynamic SSI in a realistic and rigorous manner. In the soil–structure model (Figure 1), structural elements of building frames including beams, columns and foundation slabs are modeled using beam structural elements. Beam structural elements are two-nodded and straight elements with six degrees of freedom per node comprising three translational and three rotational components. Soil medium beneath the structure is simulated employed by many researchers in SSI simulation to model the soil medium and the interface elements. Elastic and inelastic dynamic analyses were carried out for structural models S5 (5-storey), S10 (10-storey) and S15 (15-storey) conjunction with three soil types representing soil classes C_e, D_e and E_e with geotechnical properties presented in Table 3.for two different systems: (a) fixed base structure on the rigid ground (Figure 4(a, b)) flexible base structure [(8)].

Table(3). Geotechnical ch1aracteristics of the adopted soils in this study.

Soil type (AS1170)	Shear wave velocity Vs (m/s)	Unified Classification (USCS)	Maximum shear modulus G_{max} (MPa)	Soil density ρ(kg/m^3)	Poisson ratio	SPT	Plasticity index (PI)
Ce	600	GM	623.4	1730	0.28	N>50	-
D_e	320	CL	177.3	1730	0.39	30	20
Ee	150	CL	33.1	1470	0.40	6	15

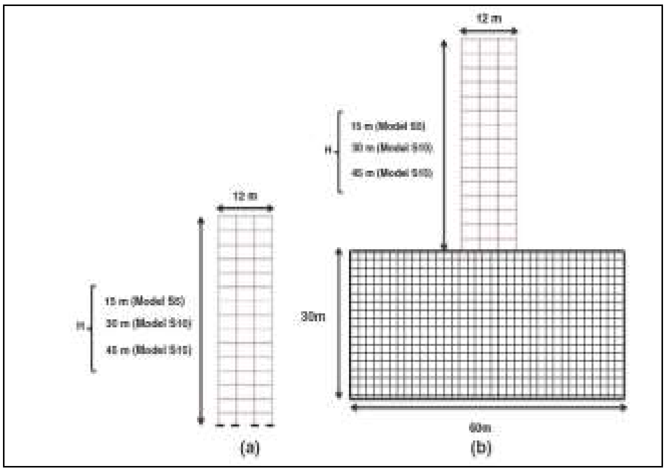


Figure (1). Numerical models: (a) fixed base model; (b) flexible base model.

Dynamic analyses for fixed base and flexible base cases have been performed on the basis of both conventional elastic analysis procedure and inelastic analysis method assuming elastic-perfectly plastic behavior for the structural models.

To perform a comprehensive investigation on the seismic response of structural models, two near field earthquake acceleration records including Northridge, 1994 (Figure 2) and Kobe, 1995 (Figure 3) and two far field earthquake acceleration records comprising El Centro, 1940 (Figure 4) and Hachinohe, 1968 (Figure 5) are selected and utilized in time history analyses. These earthquakes have been chosen by

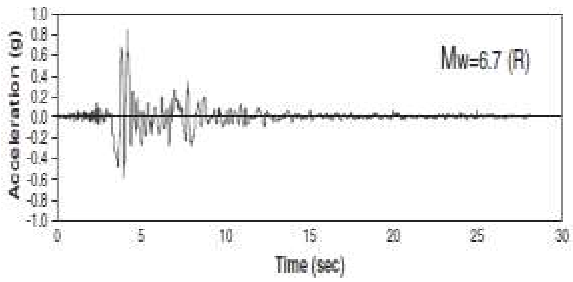


Figure (2). Near field acceleration record of Northridge earthquake (1994).

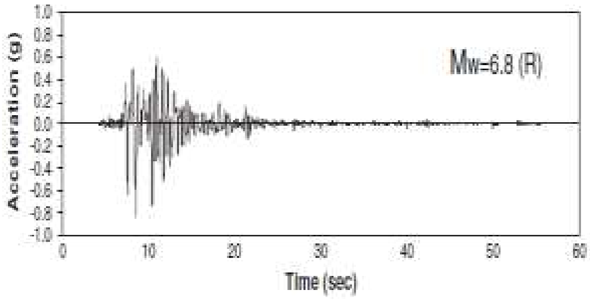
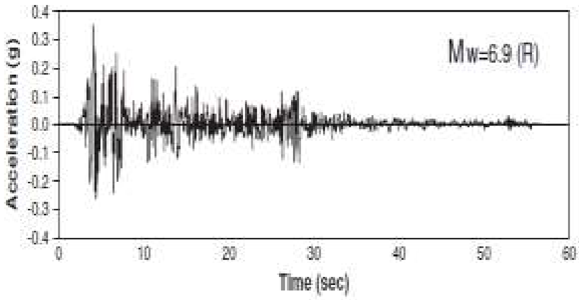


Figure (3). Near field acceleration record of Kobe earthquake (1995).



Figure(4). Far field acceleration record of El Centro earthquake (1940).

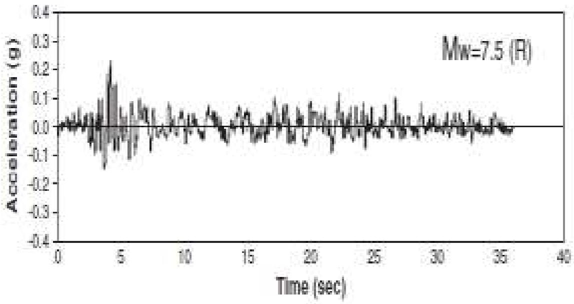


Figure (5). Far field acceleration record of Hachinohe earthquake (1968).

Results

The results of the elastic and inelastic analyses including base shears and lateral deflections are derived from ANSYS history records for fixed base and flexible base models resting on three different soil types, having three bedrock depths of 10 m, 20m and 30 m. To have a comprehensive comparison between the results and draw a clear conclusion about the effects of structural height variations, subsoil stiffness and bedrock depth on elastic and inelastic seismic response of moment-resisting frames under the influence of dynamic SSI, average values of the elastic and inelastic base shears and the maximum lateral deflections under the influence of four mentioned earthquake records (Table 2) are determined and compared. To ease the discussion of the obtained results, in this study, the structures that are analyzed and designed on the basis of elastic procedure are named 'elastic analysis case', whereas the term 'inelastic analysis case' is used to refer to the structures analyzed and designed according to inelastic method.

1. Base Shear

According to average base shear ratios of flexible base models (V') to fixed base models (V) for elastic and inelastic analysis cases, summarized in Tables 4 and 6, it is observed that the base shear ratios (V'/V) in all the studied models are less than one for both elastic and inelastic analysis cases. However, these ratios are fairly higher and closer to unity for inelastic analysis case in comparison with elastic analysis case. Thus, base shear of the structures modeled with soil as flexible base are always less than base shear of structures modeled as fixed base. As shown in Tables 4 and 5, by decreasing shear wave velocity (V_s) and shear modulus (G_{max}), base shear of flexible base models decrease relatively. In addition, it is observed that, by decreasing the bedrock depths from 30m to 10 m, the base shear ratios of flexible base (V'/V) increase. This ratio is very close to unity for the models on soil class C_e; nevertheless, by reducing the shear wave velocity (V_s) and shear modulus (G_{max}) of the subsoil in soil classes D_e and E_e, and increasing bedrock depths for both elastic and inelastic analysis cases, the base shear ratio (V'/V) decreases. This ratio is slightly higher in inelastic analysis cases in comparison with elastic analysis cases.

Table (4). Elastic base shear ratios of flexible base to fixed base models (V'/V).

Soil classification	Soil class C_e			Soil class D_e			Soil class E_e		
Bedrock depth	H=30 (m)	H=20 (m)	H=10 (m)	H=30 (m)	H=20 (m)	H=10 (m)	H=30 (m)	H=20 (m)	H=10 (m)
Model S5	0.94	0.98	1.00	0.76	0.93	0.99	0.55	0.77	0.98
Model S10	0.92	0.93	1.00	0.62	0.83	0.99	0.43	0.61	0.95
Model S15	0.92	0.95	0.99	0.58	0.72	0.98	0.33	0.53	0.83

Table (5). Inelastic Base Shear Ratios Of Flexible Base To Fixed Base Models (V'/V).

Soil classification	Soil class C_e			Soil class D_e			Soil class E_e		
Bedrock depth	H=30 (m)	H=20 (m)	H=10 (m)	H=30 (m)	H=20 (m)	H=10 (m)	H=30 (m)	H=20 (m)	H=10 (m)
Model S5	0.98	1.00	1.00	0.79	0.95	1.00	0.62	0.84	0.99
Model S10	0.95	1.00	1.00	0.74	0.88	1.00	0.52	0.68	0.97
Model S15	0.95	0.99	1.00	0.71	0.80	0.95	0.42	0.54	0.88

2. Lateral deflections and inter-storey drifts

The maximum lateral deflection ratios (δ'/δ) for elastic and inelastic analysis cases resting on soil classes C_e, D_e and E_e with bedrock depth of 30m can be compared from Tables 6 and 7. Comparing those values, it becomes apparent that in elastic analysis case, lateral deflections of flexible base models resting on soil class C_e have increased only by 1%, 3% and 7% in comparison with fixed base S5, S10 and S15 models, respectively. For inelastic analysis case, lateral deflections of flexible base models resting on the same soil class have been amplified by 2% and 4% in comparison with fixed base models for models S10 and S15, respectively, whereas model S5 experiences insignificant changes in lateral deflections. Thus, performance level of studied mid-rise moment-resisting building frames resting on soil class C_e remains in life safe level, and SSI effects can be neglected in both elastic and inelastic cases. However, lateral deflections of flexible base models resting on soil class D_e amplify by 3%, 10% and 19% in elastic analysis case and 2%, 7%and 15%in inelastic analysis case, respectively, in comparison with fixed base S5, S10 and S15 models. Figures 6–9 illustrate examples for amplification of lateral deflections and consequently corresponding inter-storey drifts of model S15 resting on soil class D_e in elastic and inelastic analysis cases. Those amplifications could be potentially safety threatening for models S10 and S15 as performance level of the mentioned building frames may change from life safe to near collapse.

For the models on soil class E_e, lateral deflections and consequently, corresponding inter-storey drifts of flexible base models have increased by 11%, 40% and 89% in elastic analysis case (Table 6) and 7%, 31% and 67% in inelastic analysis case (Table 7) in comparison with fixed base S5, S10 and

Table(6). Maximum elastic lateral deflection ratios of flexible base to fixed base models (δ'/δ).

soil classification	Soil class Ce			Soil class De			Soil class Ee		
Bedrock depth	H=30 (m)	H=20 (m)	H=10 (m)	H=30 (m)	H=20 (m)	H=10 (m)	H=30 (m)	H=20 (m)	H=10 (m)
Model S5	1.01	1.01	1.00	1.03	1.01	1.01	1.11	1.07	1.04
Model S10	1.03	1.02	1.01	1.10	1.03	1.06	1.40	1.27	1.14
Model S15	1.07	1.04	1.02	1.19	1.13	1.07	1.89	1.60	1.30

Table (7). Maximum inelastic lateral deflection ratios of flexible base to fixed base models (δ'/δ).

soil classification	Soil class Ce			Soil class De			Soil class Ee		
Bedrock depth	H=30 (m)	H=20 (m)	H=10 (m)	H=30 (m)	H=20 (m)	H=10 (m)	H=30 (m)	H=20 (m)	H=10 (m)
Model S5	1.00	1.00	1.00	1.02	1.00	1.00	1.07	1.06	1.02
Model S10	1.03	1.01	1.00	1.07	1.03	1.06	1.40	1.27	1.11
Model S15	1.04	1.03	1.01	1.15	1.13	1.07	1.70	1.30	1.23

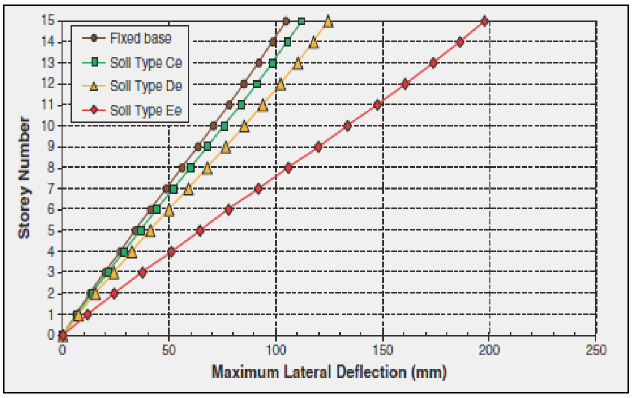


Figure (6). Elastic storey deflections for model S15 resting on soil classes C_e, D_e and E_e with bedrock depth of 30 m.

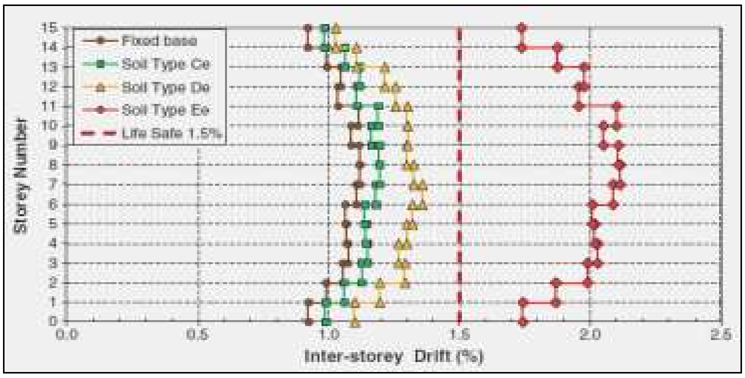


Figure 7. Elastic inter-storey drifts for model S15 resting on soil classes C_e, D_e and E_e with bedrock depth of 30 m.

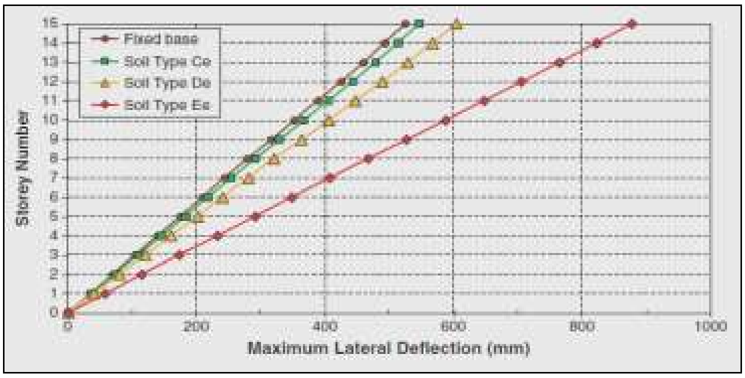


Figure 8. Inelastic storey deflections for model S15 resting on soil classes C_e, D_e and E_e with bedrock depth of 30 m.

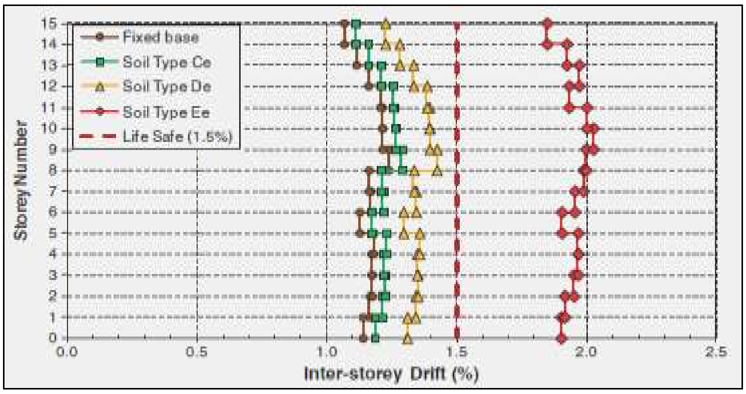


Figure 9. Inelastic inter-storey drifts for model S15 resting on soil classes C_e, D_e and E_e with bedrock depth of 30 m.

S15 models, respectively. For elastic and inelastic lateral deflection and inter-storey increments of models S15 on soil class E_e are presented in Figures 6–9. Accordingly, performance levels of S10 and S15 models change from life safe to near collapse level. Such a significant change in performance levels of 10-storey and 15-storey models resting on soil class E_e is absolutely dangerous and safety threatening for both elastic and inelastic analysis cases. Thus, it can be concluded that as shear wave velocity (V_s) and shear modulus (G_{max}) of the subsoil decrease, the maximum lateral deflections and consequently, corresponding inter-storey drifts of mid-rise moment-resisting building frames increase significantly. It can be noted that by decreasing the shear wave velocity and consequently stiffness of the subsoil, the difference between the vibration period of the flexible and the fixed base models increases for both elastic and inelastic analysis cases. Therefore, the effects of SSI for soil classes D_e and E_e are quite significant, whereas for relatively

rigid grounds (soil class C_e), it is negligible. By taking SSI effects into account, the spectral displacement, (S_d), increases considerably due to lengthening of the natural period. Therefore, such increase in the natural period dominantly alters the response of the building frames under the seismic excitation. In the case of adopted mid-rise moment-resisting building frames resting on soft soil deposits, natural period lies in the long period region of the response spectrum curve due to the natural period lengthening for such systems. Hence, the displacement response tends to increase, and eventually performance level of the structures may change from life safe to near collapse or total collapse. Generally, by decreasing the dynamic properties of the subsoil such as shear wave velocity and shear modulus, base shear ratios decrease, whereas lateral deflections and consequently, corresponding inter-storey drifts of the moment-resisting building frames increase relatively.

By observing the effects of bedrock depth variations on the maximum lateral deflections of the models resting on soil classes C_e, D_e and E_e for elastic and inelastic analysis cases (Table 8 and 9), it can be noted that as the bedrock depth varies from 30m to 10m, ~ d=d becomes closer to unity for both elastic and inelastic analysis cases resting on soil class Ce. For the models resting on soil class De, it is observed that elastic and inelastic lateral deflections and corresponding inter- storey drifts of models S5, S10 and S15 with 10m of soil depth underneath as well as models S5 and S10 with 20m bedrock depth do not differ much from fixed base models. Thus, the amplification of lateral deflections and inter-storey drifts due to SSI effects for those models are negligible, whereas for model S15 with 20m bedrock depth, lateral deflections and inter-storey drifts noticeably increase in comparison with fixed base model. Distinctly, for models S10 and S15 resting on soil class Ee, the maximum lateral deflections and inter-storey drifts of flexible base models in comparison with fixed base models increase substantially in both elastic and inelastic analysis cases. Obviously, performance level of these building frames change from life safe to near collapse when SSI is considered in the analysis, which is dangerous and safety threatening. Examples for elastic and inelastic lateral deflection and inter-storey drift amplifications and corresponding change in performance level of model S15 on soil class Ee with variable bedrock depths are presented in Figures 10–12.

It is noticeable that by increasing the bedrock depth, the natural period of the subsoil increases and consequently the difference between the period of vibration in two cases (i.e. structures modeled on flexible soils and structures modeled as fixed base) increase. Thus, the effects of dynamic SSI for Figure 13. Elastic storey deflections for model S15 resting on soil class Ee with variable bedrock depths.

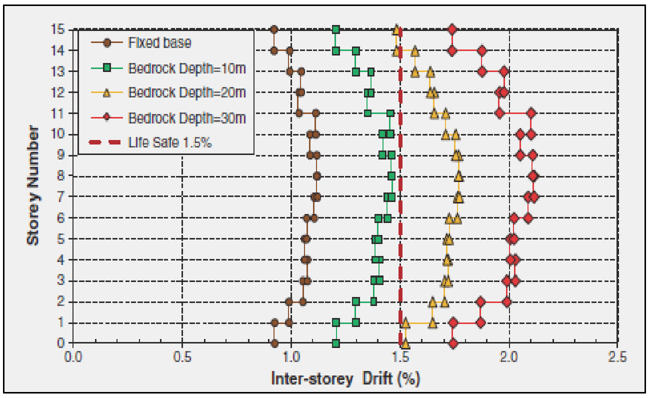


Figure (10). Elastic inter-storey drifts for model S15 resting on soil class Ee with variable bedrock depths.

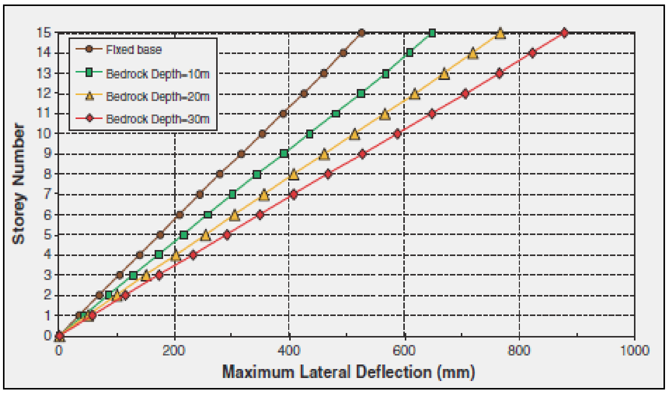


Figure (11). Inelastic storey deflections for model S15 resting on soil class Ee with variable bedrockdepths.

Deeper bedrock depths are more considerable. In the case of deeper bedrock depth, natural period lies in the long period region of the response spectrum curve due to the natural period lengthening for such systems. Consequently, the displacement response tends to increase, and the performance level of the structures may be changed from life safe to near collapse or even total collapse.

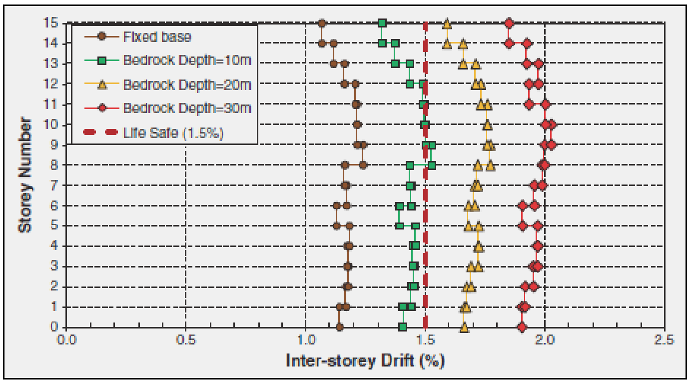


Figure (12). Inelastic inter-storey drifts for model S15 resting on soil class Ee with variable bedrock depths.

From the above observations, it can be concluded that considering SSI effects in seismic design of mid-rise moment-resisting building frames resting on soil classes De and Ee is essential, particularly for the following:

• 10-storey building frames or higher resting on more than 20m of soil class De and Building frames higher than 5-storey resting on soil class Ee irrespective of the bedrock depth. Thus, the conventional elastic and inelastic design procedures excluding SSI may not be adequate to guarantee the structural safety of mid-rise moment-resisting building frames resting on soft soil deposits. It is recommended to practicing engineers and engineering companies working in regions located in high earthquake risk zones to consider dynamic SSI effects in the analysis and design of mid-rise moment-resisting building frames resting on soft soils to ensure safety of the design.

CONCLUSIONS

In this study, to have a comprehensive comparison between the results and draw a clear conclusion about the effects of structural height, subsoil stiffness and bedrock depth on elastic and inelastic seismic response of mid-rise moment-resisting building frames under the influence of SSI, numerical investigations have been performed utilizing 5-storey, 10-storey and 15-storey structural models resting on soil classes C_e, D_e and E_e, having three bedrock depths of 10 m, 20m and 30 m.

According to the results, it is observed that base shear of the structures modelled with soil as flexible base is generally less than the base shear of the structures modelled as fixed base for both elastic and inelastic cases. In addition, it is observed that lateral deflections and corresponding inter-storey drifts of flexible base models resting on soil class C_e do not differ much from fixed base models for both elastic and inelastic analysis cases. Thus, performance level of mid-rise moment-resisting building frames resting on soil class C_e remains in life safe level, and SSI effects are insignificant in both elastic and inelastic analysis cases. However, lateral deflections and inter-storey drifts of flexible base models resting on soil classes D_e and E_e (in particular for 10-storey building frames or higher resting on more than 20m of soil class D_e and building frames higher than 5-storey resting on soil class Ee irrespective of the bedrock depth) significantly increase in comparison with fixed base models. In general, as shear wave velocity (V_s) and shear modulus (G_{max}) of the subsoil decrease and bedrock depth (hs) increases, the base shear of flexible base models in comparison with fixed base models decreases, whereas lateral deflections and consequently, corresponding inter-storey drifts increase relatively.

The amplification of the lateral deflections and corresponding inter-storey drifts of flexible base models resting on soil classes D_e and E_e can change the performance level of the structures from life safe to near collapse or total collapse, which is absolutely dangerous and safety threatening for both elastic and inelastic analysis cases. As a result, SSI has considerable effects on the elastic and inelastic seismic response of mid-rise moment-resisting building frames resting on soil classes D_e and E_e. It can be concluded that the conventional elastic and inelastic design procedures excluding SSI may not be adequate to guarantee the structural safety of mid-rise moment-resisting building frames resting on soft soil deposits.

To consider the amplification of lateral deflections and corresponding inter-storey drifts under the influence of SSI in seismic design of mid-rise moment-resisting building frames, a simplified design procedure has been proposed. The proposed design procedure enables structural engineers to determine inter-storey drifts under the influence of SSI for each two adjacent storeys and check those drifts against the limiting value of 1.5% for life safe performance level. Thus, detrimental effects of SSI can be captured more precisely in the seismic design procedure of mid-rise moment-resisting building frames to ensure the design safety and reliability.

REFERENCES

[1].Vision 2000 Committee. 1995. Performance Based Seismic Engineering of Buildings. Structural Engineers Association of California (SEAOC), Sacramento, CA.

[2]. ACI318. 2002. Building Code Requirements for Reinforced Concrete, American Concrete. Institute, Detroit, Michigan.

[3].Dr. Alaa K. Abdal Karim.The Seismic Analysis for a multi-story Building due to UBC 1997 & IBC 2006 Codes . Eng.&Tech. Journal Vol.29 No. 7, 2011: 1360–1371.

[4].Mohammed Ahmed A. Al-Hamdany.Seismic Analysis Using Three Dimensional Modeling . Eng.&Tech. Journal Vol. 28 No. 7, 2010: 1454–1463.

[5]. Lu X, Li P, Chen B, Chen Y. 2005. Computer simulation of the dynamic layered soil–pile–structure interaction system. Canadian Geotechnical Journal 42(3): 742–751.

[6]. Mirhashemian1 P, Khaji, N, Shakib, H. 2009. Soil-structure interaction (SSI) analysis using a hybrid spectral element/finite element (SE/FE) approach. Journal of Seismology and Earthquake Engineering 11(2).

[7]. Tabatabaiefar HR, Massumi A. 2010. A simplified method to determine seismic responses of reinforced concrete moment resisting building frames under influence of soil–structure interaction. Soil Dynamics and Earthquake Engineering 30(11): 1259–1267, Elsevier Ltd.

[8]. Tabatabaiefar HR, Fatahi B, Samali B. 2012. Seismic behaviour of building frames considering dynamic soil-structure interaction. International Journal of Geomechanics, Doi: 10.1061/(ASCE)GM.1943-5622.0000231.
[9]. Tavakoli HR, Naeej M, Salari A. 2011. Response of RC structures subjected to near fault and far fault earthquake motions considering soil-structure interaction. International Journal of Civil and Structural Engineering 1(4): 881–896.