26 May 2010, 4:45 pm - 6:45 pm

Effects of Recorded Free-Field Motion on the Response of Buildings Considering Soil-Structure Interaction Effects

Fereidoun Amini
Iran University of Science and Technology, Iran

Masoud Shadlou
Iran University of Science and Technology, Iran

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

EFFECTS OF RECORDED FREE-FIELD MOTION ON THE RESPONSE OF BUILDINGS CONSIDERING SOIL-STRUCTURE INTERACTION EFFECTS

Fereidoun Amini
School of Civil Engineering, Iran University of Science and Technology. Tehran, Iran,
P.O. Box 16846-13114

Masoud Shadlou
School of Civil Engineering, Iran University of Science and Technology. Tehran, Iran,
P.O. Box 16846-13114

ABSTRACT

One of the intents of this study is to demonstrate some lacking accurate results of seismic code for considering soil-foundation-structure interaction (SFSI) effects. The other objective of this study is to evaluate the effects of type of recorded motion on the response of moderately flexible building considering SFSI effects. The effects of SFSI, under plane-strain conditions, have been studied by substructure approach for buildings supported by rigid foundations on a homogeneous, isotropic and elastic half-space. 32 data motions recorded in Imperial Valley-06 (1979) earthquake are used to demonstrate some intents of this study. It can be concluded that if it is required for an analysis, research, or study to consider SFSI effects on structural response, first of all, identical recorded earthquake motions should be selected on assumed site's soil. As shown in this study, soil shear wave velocity of site that earthquake recorded on it and the component of earthquake motion can affect structural response and damage induced by soil-structure system. To obtain as another result in this study, considering equivalent one-storey model that usually proposed by design codes or rehabilitation provisions may not have an adequately accurate result and in some cases underestimates the induced demand by earthquake motion rather than full building. In some data motions, this incoherency effect can be resulted sensible difference of base shear index. It is concluded that number of building-story, and frequency content of earthquake motion have intense role on influenced demand for buildings considering SFSI effects.
Key words: SFSI, Equivalent One storey Model, Induced Damage

INTRODUCTION

For the purpose of development of seismic safety for buildings, it is necessary to understand the characteristics of earthquake ground motions and the behavior of buildings during earthquakes. Soil-foundation-structure interaction (SFSI) can significantly affect the seismic performance of building. Engineering models of these effects are required for rational evaluations of seismic demand placed on the soil-foundation-structure system, and for evaluations of the deformation capacity of such systems. These effects can be quantified by flexible natural period ($\tilde{T}$) and by the damping ratio ($\tilde{\zeta}$) of the complete structure-foundation-soil system (Jennings and Bielak, 1973). Trifunac (1972) and Wong and Trifunac (1975) show superstructures produce modification of the free-field motion by scattering of incident seismic waves from their foundations. The embedded foundations experience a reduction in base-slab translational motion relative to free-field while introduce the base-slab rocking motions [Bielak (1978)0, Pais and Kausel (1985)]. On the other hand, the static stiffness of embedded foundations is increased from that of surface-supported foundations [Beredugo and Novak (1972), Elsabee *et al.,* (1977)] and embedded foundations can produce much larger damping due to the larger soil-foundation contact area (Srewart *et al.,* (1999)). Bielak 0(1978) also pointed to the importance of rocking input motion for structures with deep embedded foundations. Kim and Stewart (2003) separated kinematic effects of SFSI on base slab averaging and embedment effects. The complexity of seismic focus, finite velocity of wave propagation, and geological and geometrical heterogeneities of the ground are main sources to be attributed to spatial seismic effects of free-field motion and thereupon base slab averaging effects.

Mylonakis and Gazetas (2000) reported three cases of earthquakes (Bucharest 1977, Mexico City 1985 and Kobe 1995) where SFSI caused an increase in the seismic-induced of structures despite a possible increase in damping. In this research, it was concluded, in certain seismic and soil environments, an increase in the fundamental natural period of a moderately flexible structure due to the SFSI may have a detrimental effect on the imposed seismic demand. Kashima *et. al*. (2004), Jie *et. al.* (2007) were shown some of the damaging effects of Soil-Structure systems affected by different earthquake motions. Takewaki (2005) showed notable effects of SFSI in the stiff structures on flexible foundations.

It is common in the design code and rehabilitation provision to consider SFSI effects by modifying base shear and design spectrum as flexible-base first mode period and foundation damping (ASCE 7-05, and FEMA 440). In this condition, seismic demand is always reduced. One of the intents of this study is to demonstrate some lacking accurate results of seismic code for considering SFSI effects.

Earthquake motions generally record on the sites that is categorized by design Codes. There are broad ranges as shear wave velocity of soil for each part of soil classification. According to the codes for the time history dynamic analysis of structures which is believed to be the most reliable prediction method, it is essential to choose some ground motion records which represent the hazard at the site planed to be built the structure (ASCE 7-05). On the other hand, earthquake free-field motions for evaluating a research project is used, and it seems to have to be indicated accordance between earthquake ground motion in seismically active regions and the site of structure considering SFSI effects. So, the other objective of this study is to evaluate the effects of type of recorded motion on the response of moderately flexible building considering soil-structure interaction (SSI) effects.

A 12-storey building is modeled to demonstrate moderately flexible building and a one story building is considered to illustrate first mode of vibration of 12-story building. 32 data motions recorded in Imperial Valley-06 (1979) earthquake are used to demonstrate some intents of this study. Past significant earthquakes have seriously damaged many engineering structures, and field studies have reported that the degree of damage to each structure varied significantly from one location to another, even if the two structures were similar and the distance between them was small. This variation in structural damage, according to the reliability theory, is due to the differences in structural strength and the ground motion amplitude at these two separate locations. So, in this study, spatial effects of earthquake ground motion are comprised in recorded data motions.

SOIL-STRUCTURE INTERACTION SYSTEM

A typical example of a structure embedded in soil is shown in Figure 1. As the supporting soil is much larger in size than the structure itself it is considered as being unbounded, i.e. infinite in dimension. In a dynamic SFSI analysis, the soil is divided into an irregular bounded soil that can exhibit nonlinear behavior and a regular unbounded soil that extends to infinity. Regular unbounded soil is thus assumed to behave linearly 0(Wolf, 1985). The bounded domain in a dynamic SFSI analysis can be modeled using the well developed finite-element method. To model the unbounded domain, a radiation condition at infinity has to be satisfied. A common practice in seismic SFSI analysis is to introduce the artificial boundaries enclosing the structure at a finite distance. These boundary conditions are coupled with the equation of motion for the bounded domain to be modeled by finite elements. For this purpose substructure and direct approaches can be employed.

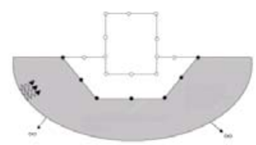


Fig 1. A structure embedded in soil

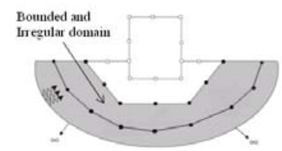


Fig. 2. Direct method

In the direct method, the artificial boundary is constructed far away from the foundation-soil interface (Figure 2). Because assumptions of superposition are not required, true nonlinear analyses are possible. Hence, the direct approach is rarely used in practice. In the second approach (referred to as the substructure approach), the artificial boundary can be chosen to coincide with the foundation-soil interface as shown in Fig. 3. The two substructures, a bounded (Fig. 3-a) and an unbounded domain (Fig. 3-b), are modeled independently. In order to clarify the interaction effects between the embedded foundation and soil, it is required to analyze the two basic problems that may be evaluated independently by different analytical or experimental methods; (1) The force-displacement relationships for the massless embedded foundation and (2) response of the massless foundation to incoming seismic waves in the absence of external excitations. The relationships obtained in the first stage are generally expressed in terms of impedance matrix. On the other hand, the seismic response in the second stage is referred to here as the FIM.

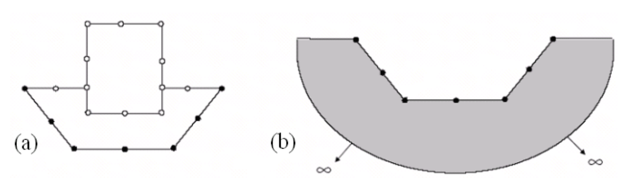


Fig. 3. Modeling the SFSI by substructure method: (a) substructure of bounded domain; (b) substructure of unbounded domain

In practice, seismic environments are usually to be composed exclusively of vertically propagating body waves (Gomez-Masso *et al*., 01985). In this research, the seismic excitation is given under vertically incident coherence SH waves, with particle motion along the x-axis. So the free-field ground motion is, (Roesset, 1977)

$$u = X_g \exp[i\omega(t - \frac{z}{V_S^*})] \quad (1)$$

where X_g is the amplitude of the free-field motion at the ground surface and ω is the exciting frequency. V_S^* is the complex shear-wave velocity,

$$V_S^* = \sqrt{\frac{G(1+2\zeta i)}{\rho}} \quad (2)$$

G, ρ are the shear modulus and mass density. ζ denotes the ratio of the linear hysteretic damping.

The effects of both filtering of the character of ground shaking transmitted to the foundation (kinematic interaction) and flexible foundation effects (inertia interaction) are evaluated by using the soil-foundation-structure system shown in Fig. 4.
The governing equations of motion in the frequency-domain for the case that soil and structure behave linearly are given by,

$$\{-\omega^2 M + j\omega C + K\} X_{(\omega)} = -M\{\Gamma.H_{U(\omega)} + \Upsilon.H_{\Phi(\omega)}\}\ddot{X}_{g(\omega)} \quad (3)$$

where the symbol $j=\sqrt{-1}$ and ω indicates the excitation frequency and $X=\{X_S \;\; X_0 \;\; \Phi_0\}^T$ is the vector of displacement amplitudes of the system that consists of structure displacement (X_S) and translation and rocking motions of foundation (X_0, Φ_0), and

$$M = \begin{pmatrix} M_S & M_S\Psi & M_S\Lambda \\ \Psi^T M_S & M_T & E_T \\ \Lambda^T M_S & E_T & I_T \end{pmatrix} \quad (4)$$

$$C = \begin{pmatrix} C_S & 0 & 0 \\ 0 & C_{HH} & C_{HM} \\ 0 & C_{MH} & C_{MM} \end{pmatrix} \quad , \quad K = \begin{pmatrix} K_S & 0 & 0 \\ 0 & K_{HH} & K_{HM} \\ 0 & K_{MH} & K_{MM} \end{pmatrix} \quad (5)$$

$$\Gamma = \{0_{n\times1} \;\; 1 \;\; 0\}^T \quad , \quad \Upsilon = \{0_{n\times1} \;\; 0 \;\; 1\}^T \quad (6)$$

Where

$$M_T = m_0 + \sum_{i=1}^{n} M_{S_{ii}} \quad \text{(a-7)}$$

$$E_T = m_0.(\frac{e}{2}) + \sum_{i=1}^{n} [M_{S_{ii}}(\Lambda_i)] \quad \text{(b-7)}$$

$$I_T = m_0.(\frac{e}{2})^2 + I_0 + \sum_{i=1}^{n} [M_{S_{ii}}(\Lambda_i)^2 + I_i] \quad \text{(c-7)}$$

Ψ is the column vector where each element is unity and $\Lambda=\{\Lambda_i\}$ is the column vector of bottom foundation-to-storey heights. M_S, C_S and K_S are the mass, damping and stiffness matrices of the fixed-base system, respectively. I_i is mass moment of inertia for ith story level. The foundation is treated as a rigid cylindrical of radius r , embedded depth e, mass m_0 and mass moment of inertia I_0 . The coefficients K_{HH}, K_{HM}, K_{MM} are the frequency dependent foundation stiffness and C_{HH}, C_{HM}, C_{MM} are the frequency dependent foundation radiation damping coefficient. The ratio $H_U = \ddot{X}_{FIM} / \ddot{X}_g$ and $H_\Phi = \ddot{\Phi}_{FIM} / \ddot{X}_g$ present the transfer functions of the translational and rocking components of the foundation input motion. X_{FIM} and Φ_{FIM} are the foundation input motions in the frequency domain for horizontal and rotational components, respectively. Let X_0 and Φ_0 denote the Fourier transform of the horizontal displacement of the foundation relative to X_{FIM} and the angle of rotation of the foundation relative to Φ_{FIM} , respectively.

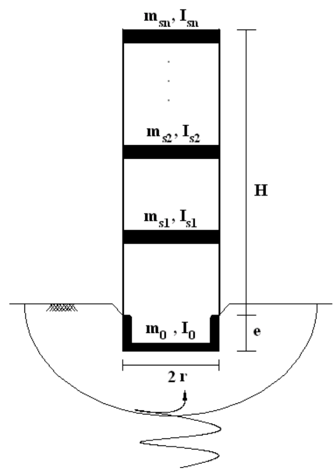
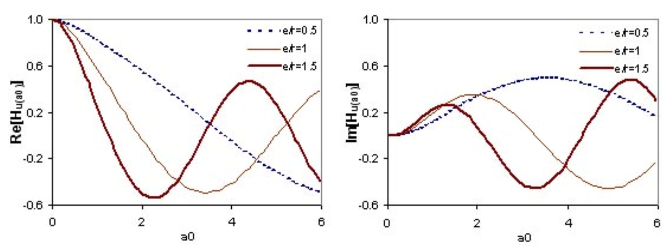
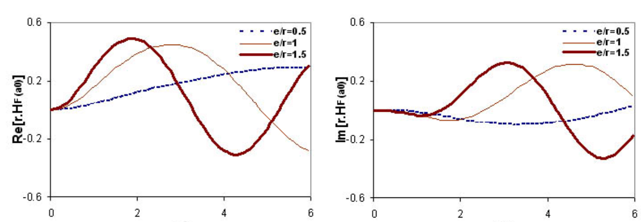


Fig. 4. Soil-Foundation-Structure system in substructure method



(a) (b)

Fig. 5. Horizontal component of effective foundation input motion for various depth of embedment; (a) real part, (b) imaginary part.



(a) (b)

Fig. 6. Rocking component of effective foundation input motion for various depth of embedment; (a) real part, (b) imaginary part

Cone models have been proposed by Meek and Wolf (1994) and Wolf and Deeks 0(2004) for evaluating the impedance functions and the effective input motions of foundation. The cone model is based on an assumption that the force transmitting mechanism of a foundation subjected to seismic disturbances can be represented approximately by a cone chopped by the foundation. In this method, the foundation is represented by a stack of disks in that part of the layered half-space which will be excavated. Figure 5 shows the effective FIM for horizontal component and Figure 6 illustrates that for the rotational component. The abscissa in Figures 5 and 6 is the dimensionless frequency ($a_0 = \omega r / V_S$). Generally, the amplitude of the horizontal component of FIM is less than that of the free-field motion and their difference becomes larger by increasing the embedment ratio. However, the amplitude of the additional rocking component of FIM starts from zero in case of surface foundation and increase for deeper embedded foundations.

NUMERICAL EXAMPLES

System Considered and Parameters

In this research, three range of soil-shear wave velocity of category C ($180 < V_S < 360 m/\sec$) are considered to demonstrate effects of SFSI on moderately flexible building rested in or on different soils as shear wave velocity. First range is $195 < V_S < 210 m/\sec$. Second range is $260 < V_S < 280 m/\sec$ as middle shear wave velocity of site category, and third range is $330 < V_S < 360 m/\sec$ as latest range of site category. Because source characterization and path affect seismic motion, one earthquake was considered to demonstrate an explicit result. Imperial Valley-06 earthquake on October 1979 (M = 6.53) is regarded ground motion in this research.

Fig. 7. Station’s position vs. epicenter for first rage of soil-shear wave velocity.

Figure 7 shows the position of different stations included in the first range of shear wave velocity of soil (Provided by Pacific Earthquake Engineering Research Center: NGA Database). As shown in Figure 7, Figures 8, and 9 show second and third ranges of station’s position, respectively. Details of the selected free-field ground motions are listed in Tables 1, 2, and 3. The numbers in Figures 7, 8, and 9 demonstrate the number of stations recorded ground motions.

Fig. 8. Station’s position vs. epicenter for second rage of soil-shear wave velocity.

Fig. 9. Station’s position vs. epicenter for third rage of soil-shear wave velocity.

Two building model are evaluated in this study. A 12-storey building is modeled to demonstrate moderately flexible building (Table 4), and a one-storey building is considered to illustrate first mode of vibration of 12-story building. 12-storey model ($H/r=3$) designed by ASCE 7-05 0 rested on site class C was chosen for the analyses. It is assumed the structure rested on (surface foundation) a homogenous elastic soil with material damping $\beta_S = 0.05$, Poisson’s ration 1/3 and mass density $\rho = 1700 kg/m^3$. For considering SFSI effects, it is assumed the structure founded up on circular-rigid foundation with radius of 8 meter. Table IV shows structural properties. Mass of stories are 120.68 (ton). Structural damping is calculated by proportional damped system as Rayleigh damping;

$$C_S = 0.004 K_S + 0.001 M_S \tag{8}$$

Table 1. Selected Free-field Ground Motions for First Range

Station No.	Vs30 (m/sec)	Station's Distance To Epicenter	Station's Name as NGA Database	Components
1	208.7	43.15	USGS 5060 Brawley Airport	225, 315
2	205.8	57.14	USGS 5061 Calipatria Fire Station	225, 315
3	202.9	26.31	USGS 412 El Centro Array #10	50, 320
4	196.3	29.44	USGS 5058 El Centro Array #11	140, 230
5	206.1	28.09	USGS 958 El Centro Array #8	140, 230
6	202.9	19.81	USGS 5055 Holtville Post Office	225, 315
7	207.5	68.92	CDMG 11023 Niland Fire Station	90, 360
8	196.9	31.99	USGS 931 El Centro Array #12	140, 230
9	202.3	27.23	USGS 5165 El Centro Differential Array	270, 360
10	208.9	27.13	USGS 955 El Centro Array #4	140
11	205.6	27.8	USGS 952 El Centro Array #5	140
12	203.2	27.47	CDMG 5158 El Centro Array #6	140, 230

Table 2. Selected Free-field Ground Motions for Second Range

Station No.	Vs30 (m/sec)	Station's Distance To Epicenter	Station's Name as NGA Database	Components
1	274.5	2.47	UNAMUCSD 6616 Aeropuerto Mexicali	45, 315
2	274.5	18.88	UNAMUCSD 6621 Chihuahua	12, 282
3	274.5	22.43	UNAMUCSD 6622 Compuertas	15, 285
4	274.5	12.92	UNAMUCSD 6617 Cucapah	85
5	274.5	33.73	UNAMUCSD 6605 Delta	262, 352
6	274.5	43.9	UNAMUCSD 6610 Victoria	75, 345
7	274.5	2.62	UNAMUCSD 6618 Agrarias	03, 273

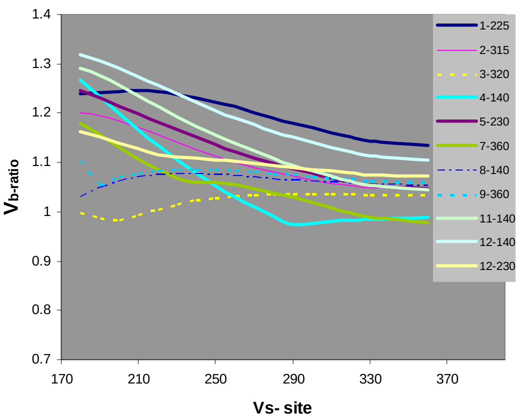
Table 3. Selected Free-field Ground Motions for Third Range

Station No.	Vs30 (m/sec)	Station's Distance To Epicenter	Station's Name as NGA Database	Components
1	338.6	12.43	UNAMUCSD 6619 SAHOP Casa Flores	00, 270
2	348.7	48.62	USGS 5051 Parachute Test Site	225, 315
3	345.4	54.26	USGS 5052 Plaster City	45, 135
4	345.4	83.94	USGS 5066 Coachella Canal #4	45, 135

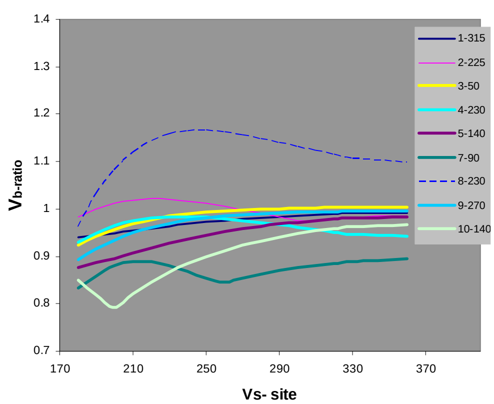
Evaluation of base shear index for full 12-storey building and equivalent one storey model

To consider SFSI effects in design codes, it is usually exhibited by reduced-design base shear as increasing natural period and damping of system. Base shear can be an index for damage induced by an earthquake. In this study, ratio of base shear between flexible-based and fixed-based systems is calculated for different assumed soil-shear wave velocity of site included in the site category of C. Because there were too number of earthquakes in first range data motions, figures 10-a, 10-b, 11-a, and 11-b show base shear index or base shear ratio for comprised range in two label to be better displayed. Figures 10-a, and 10-b are for full 12-storey building, and figures 11-a, and 11-b demonstrate damage indices for one-storey building presenting first mode of vibration of system. Figure 10-a, and 10-b show multiplier-affected components and reducer affected components of data motions on base shear index, respectively. For data motions producing figure 10-a, identical data motions are comprised by figure 11-a. This condition is same for figures 10-b and 11-b. Among 43 earthquakes recorded in site class C of Imperial Valley-06 earthquake, authors evaluated only motions that have distances greater than 20 km from Epicenter. 32 recorded motions possessed this condition and evaluated in this study.

Figure 10-a shows that all the included earthquake motions recorded on first range of data motions increased the base shear for different assumed soil-shear wave velocity. Figures 10-a presents the high difference between full 12-storey building and one-storey building in comparison with figures 11-a. Due to the figure 10-a, full 12-storey building model induced major base shear rather than equivalent one-storey model. Figure 10-b shows that most of the other components of earthquake motions recorded on first range of data motions decreased the base shear for different assumed soil-shear wave velocity. Figure 10-b demonstrates almost difference pattern of base shear index for distributed soil-shear wave velocity rather than equivalent one-story model and figure 11-b. Figures 10, and 11 demonstrate lacking accurate results of base shear of full 12-storey building to be modeled by equivalent one storey as first mode of vibration for selected ground motions in first range of data motions.



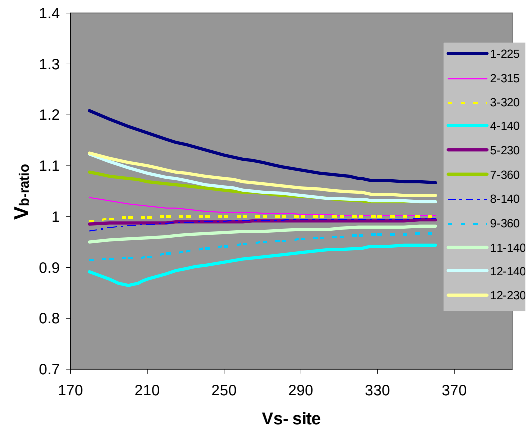
(a)



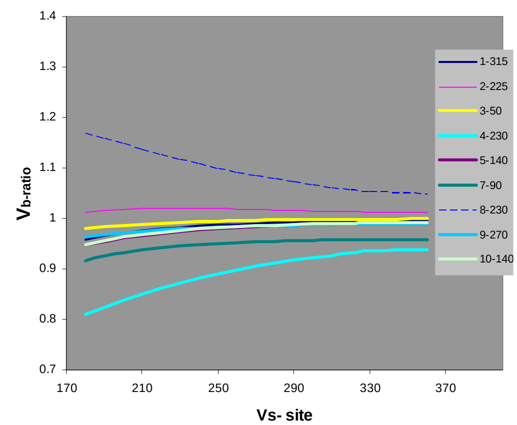
(b)

Fig. 10. Variations of distributed shear wave velocity of soils included in site class C versus base shear index for first range data motions and full 12-storey building.

Figure 12, and 13 shows base-shear index obtained by second range of data motions for different shear wave velocity of site's soil. Due to the figure 12, it can be derived that if earthquake motions recorded on second range of data motions are used in an identical system, lower base shear ratio is expected by decreasing shear wave velocity of site's soil. The different patterns and values between base shear index of full 12-storey model and equivalent one-storey model demonstrate lacking identical result between full building and equivalent model. In some data motions, this incoherency effect can be resulted sensible difference of base shear index.



(a)



(b)

Fig. 11. Variations of distributed shear wave velocity of soils included in site class C versus base shear index for first range data motions and equivalent one-storey building.

As shown in figure 10, earthquake motions in first range caused an increase or decrease in base shear index for different-assumed soil-shear wave velocity of site; some components induced an increase and other components induced decrease of base shear index. As a component of earthquake motion for first range induced an increase or decrease in base shear index for $195 < V_S < 210\,m/\sec$, intensification or reduction of base shear can be extracted for other shear wave velocity of soils included in site class C. This result can not be derived by equivalent one-storey building model as figure 11.

Table 4. Characteristics of Structure

Storey	12 Storey	
	Stiffness (MN/m)	**Period** in each mode (sec)
1	537.118	0.898
2	473.67	0.346
3	435.72	0.212
4	408.28	0.152
5	404.75	0.122
6	320.62	0.104
7	298.5917	0.093
8	289.4142	0.082
9	244.586	0.073
10	191.456	0.067
11	155.729	0.060
12	155.729	0.054

Figure 14, and 15 shows base-shear index obtained by third range of data motions for different shear wave velocity of site's soil. There are few data motions (4 data) used in this range. Due to the figure 14, it can be derived that if recorded earthquake motions on third range of data motions are used in an identical system, it can be seen greater base shear ratio is by decreasing shear wave velocity of site's soil. The different patterns and values between base shear index of full 12-storey model and equivalent one-storey model demonstrate lacking identical result between full building and equivalent model in this range.

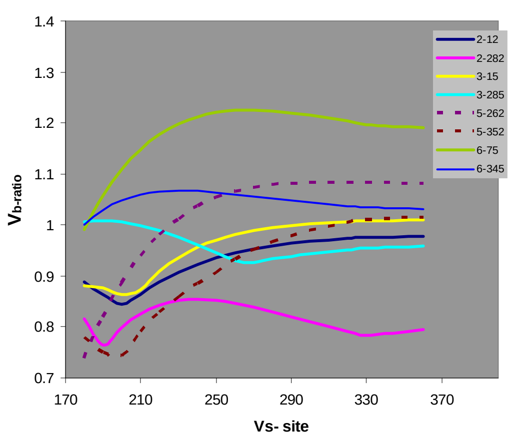


Fig. 12. Variations of distributed shear wave velocity of soils included in site class C versus base shear index for second range data motions and full 12-storey building.

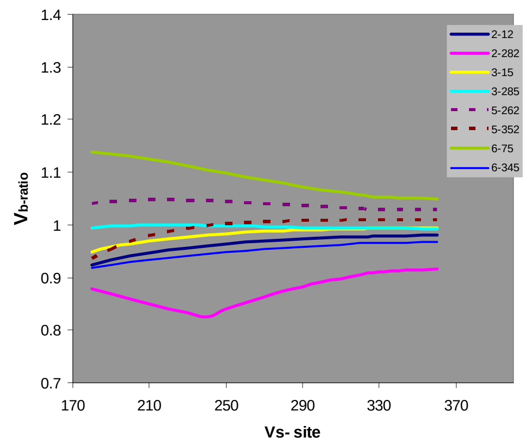


Fig. 13. Variations of distributed shear wave velocity of soils included in site class C versus base shear index for second range data motions and equivalent one-storey building.

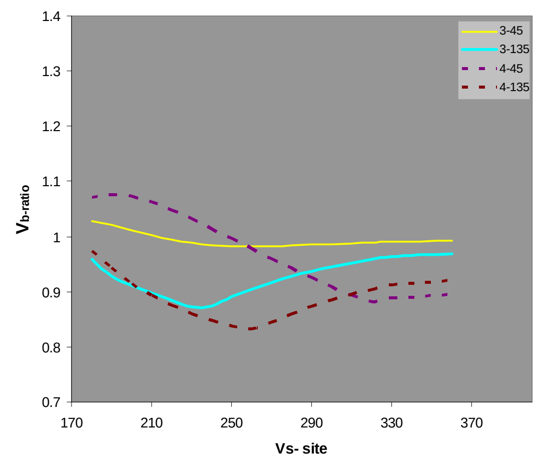


Fig. 14. Variations of distributed shear wave velocity of soils included in site class C versus base shear index for third range data motions and full 12-storey building.

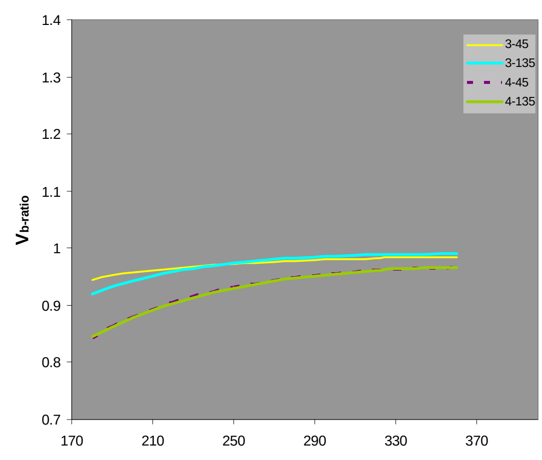


Fig. 15. Variations of distributed shear wave velocity of soils included in site class C versus base shear index for third range data motions and equivalent one-storey building.

CONCLUSION

It is common in the design code and rehabilitation provision to consider SFSI effects by modifying base shear and design spectrum as flexible-base first mode period and foundation damping (ASCE 7-05, and FEMA 440). In this condition, seismic demand is always reduced. Earthquake motions generally record on the sites that is categorized by design Codes. There are broad ranges as shear wave velocity of soil for each part of soil classification. According to the codes for the time history dynamic analysis of structures which is believed to be the most reliable prediction method, it is essential to choose some ground motion records which represent the hazard at the site planed to be built the structure. On the other hand, earthquake free-field motions for evaluating a research project is used, and it seems to have to be indicated accordance between earthquake ground motion in seismically active regions and the site of structure considering SFSI effects. So, one of the intents of this study was to demonstrate some lacking accurate results of seismic code for considering SFSI effects.

The other objective of this study was to evaluate the effects of type of recorded motion on the response of moderately flexible building considering soil-structure interaction (SSI) effects. 32 data motions recorded in Imperial Valley-06 (1979) earthquake are used to demonstrate some intents of this study.
It can be concluded that if it is required for an analysis, research, or study to consider SFSI effects on structural response, first of all, identical recorded earthquake motions should be selected on assumed site's soil. As shown in this study, soil shear wave velocity of site that earthquake recorded on it and the component of earthquake motion can affect structural response and damage induced by soil-structure system.

To obtain as another result in this study, considering equivalent one-storey model that usually proposed by design codes or rehabilitation provisions may not have an adequately accurate result and in some cases underestimates the induced demand by earthquake motion rather than full building. In some data motions, this incoherency effect can be resulted sensible difference of base shear index.

It is concluded that number of building-story, and frequency content of earthquake motion have intense role on influenced demand for buildings considering SFSI effects.

REFERENCES

Beredugo YO, Novak M. [1972]. "Coupled horizontal and rocking vibration of embedded footings". *Canadian Geotechnical Journal*. 9(4): 477-497.

Bielak J.[1978]. "Dynamic response of nonlinear building-foundation systems". *Earthquake Engineering and Structural Dynamics*. 6(1): 17-30.

Elsabee F, Kausel E, Roesset JM. [1977]. "Dynamic stiffness of embedded foundations". *Proceeding of the ASCE Second Annual Engineeering Mechanics Division Specialty Conference*, North Carolina, 23-25 May, 40-43.

FEMA 440, [2004]. Improvement of nonlinear static seismic analysis procedures , prepared by the American Society of Civil Engineers for the Federal Emergency Management Agency, Washington, D.C.

Gomez-Masso A., Lysmer J., Chen J. CH., Seed H. B. [1985]. "Soil-Structure Interaction With Rayleigh Waves", *Earthquake Engineering and Structural Dynamics*. 11: 567-583.

Jennings P. C. and Bielak J. [1973] . "Dynamic of building –soil interaction". *Bulletin of the Seismological Society of America*. **63**: 9-48.

Jie G., Preising M., Jeremic B., [2007] "Benefits and Detriments of Soil Foundation Structure Interaction". *Proceedings of Sessions of Geo-Denver 2007*.

Kashima T., Itou A., Fujita H., [2004], "Evaluated Dynamic Behavior of 9-storey Base Isolated Building During the 2003 off Tokachi Earthquake, Japan". *Proceedings Third UJNR Workshop on Soil-Structure Interaction. March 29-30, 2004,* Menlo Park, California, USA.

Kim A., Stewart J. P. [2003]. "Kinematic Soil-Structure Interaction from Strong Motion Recordings". *Journal of Geotech. and Geoenv. Engineering*. 129: 323-335.

Minimum Design Loads for Buildings and Other Structures, 2005, American Society of Civil Engineering, ASCE 7-05.

Mylonakis G, Gazetas G., [2000]. "Seismic soil-structure interaction: beneficial or detrimental?", *J. Earthquake Engng*., 4, 277-301.

Pais A, Kausel E. [1985]. "Stochastic response of foundations". *Report No. R8509, Massachusetts Institute of Technology,* MA, USA.

Roesset J.M. [1977]. "Soil Amplification of Earthquakes, in Numerical Methods in Geotechnical Engineering". McGraw-Hill, New York.

Stewart JP, Seed RB, Fenves GL. [1999]. "Seismic soil-structure interaction in buildings. II: Empirical findings". *Journal of Geotech. and Geoenv. Engineering.* 125: 38-48.

Takewaki I., [2005]. "Bound of Earthquake input Energy to Soil-Structure Interaction Systems", *Soil Dyn. Earthquake Engng.* 25, 741-752.

Trifunac, M. D., [1972]. "Interaction of a Shear Wall with the Soil for Incident plane SH Waves". *Bull. Seism. Soc. Am*., 62: 63-83.

Wolf J. P. [1985]. "Dynamic Soil-Structure Interaction", Englewood Cliffs, NJ: Prentice-Hall.

Wolf J. P, Meek J.W., [1994], Cone Models For Embedded Foundation, Journal of Geotechnical Engineering Division, ASCE. 120(1): 60-80.

Wolf J. P. and Deeks A. J. [2004]. "Foundation vibration analysis: a strength-of-materials approach". Elsevier Publication. 2004.

Wong, H. H. and Trifunac, M. D.[1975]. "Two dimensional, Antiplane, Building-Soil-Building Interaction for Two or More Buildings and for Incident Plane SH Waves". *Bull. Seism. Soc. Am.* 65: 1863-1885.