Effects of underlying soil on structural pounding between adjacent multi-story buildings in a row

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1. Introduction

Structural pounding between adjacent buildings having different dynamic properties cannot be avoided during earthquakes, if the gap between them is insufficient. The magnitude and location of impact depends on the characteristics of input ground motion, soil parameters, dynamic characteristics of the buildings and the gap between adjacent buildings. Considering simplified single degree of freedom systems (SDOFs), Anagnostopoulos (1988) investigated the pounding of buildings in series during earthquakes and reported that the end structures almost always experience a substantial increase in their response, while for interior structures the opposite often happens. Rahman et al. (2001) performed an analysis on multi-story buildings of different total heights using 2-D structural analysis software, RUAUMOKO, to find out the effect of underlying soil on the pounding of structures.

In this paper, the response of three reinforced concrete moment resisting frame buildings constructed in a row where a 8-story building is located between two identical 6-story buildings, considering underlying soil effects is presented (Fig. 1). Underlying soil effects are modeled through translational and rotational frequency independent mass-spring-damper systems and their properties can be obtained from Rahman et al. (2001) and Wolf (1988). Two far field earthquakes and two near field earthquakes are considered for input motions. For the earthquake inputs used in this study, results obtained indicate that buildings considered are more vulnerable to near field earthquakes and the taller building has relatively large shear amplification factors.

2. Problem statement

Considering earthquake loads according to IBC 2003, the two 6-story and the 8-story moment resisting frame buildings with 5% damping ratio are analyzed using SAP2000 and designed according to ACI 318-05. The gaps between the buildings are assumed to be 1 cm. For analysis and design, M25 grade concrete is used. Unit weight $\gamma_c = 24\ \text{kN/m}^3$, modulus of elasticity $E_c = 25866\ \text{N/mm}^2$, and Poisson's ratio $\nu_c = 0.2$ are assumed for concrete. The 6-story buildings and the 8-story building are provided with 130 mm and 150 mm thick slabs, respectively. For all the buildings 300 mm x 500 mm beams are provided. Two far field earthquakes, 1940 El Centro and 1968 Hachinohe and two near field earthquakes, 1994 Northridge and 1995 Kobe are used as earthquake inputs along *x*-direction. Newmark method with $\beta = 0.25$, $\gamma = 0.5$ and time step $\Delta t = 0.005$ sec is adopted for time history analysis of buildings. Contacts of buildings and pounding forces are simulated by link element systems consist of a gap property and linear spring-damper element. The underlying soil is modeled through the mass-spring-damper systems and their coefficients are calculated using the soil properties: density $\rho_s = 16.5\ \text{kN/m}^3$, Poisson's ratio $\nu_s = 1/3$ and shear modulus $G_s = 18.75$ MPa.

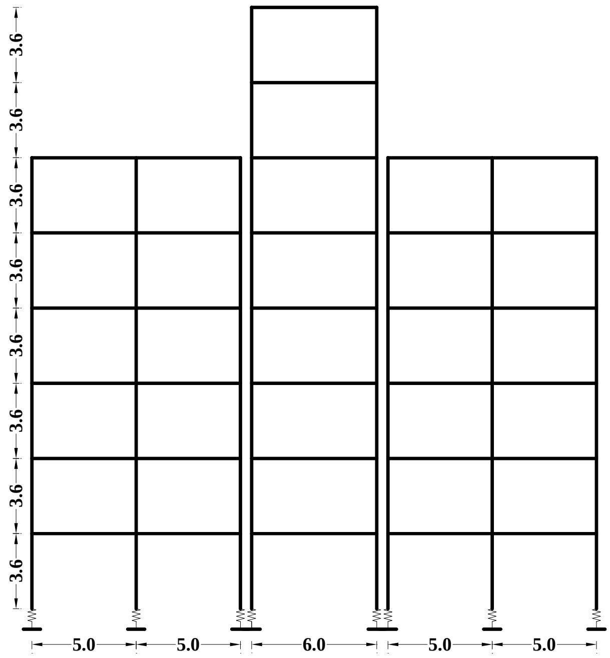

Figure 1. Building elevation.

3. Results and conclusions

Using Fourier spectrum, the dominant frequencies of El Centro, Hachinohe, Northridge, and Kobe earthquakes are found to be 2.151 Hz, 0.361 Hz, 0.633 Hz, and 1.417 Hz, respectively and the dominant frequency of Northridge earthquake is observed to be quite close to the natural frequency of 8-story building with flexible foundation (Table 1). The fundamental time periods of the buildings are increased when underlying soil is taken into consideration.

Table 1. Dynamic properties of buildings.

Foundation Type	Fundamental Time Period (sec)		Natural Frequency (Hz)	
	6-Story	8-Story	6-Story	8-Story
Fixed	0.8955	1.2249	1.1167	0.8165
Flexible (Soil)	0.9368	1.3303	1.0674	0.7517

Shear amplification factors, defined as the ratio of maximum shear resulting from pounding to that of no pounding case, are used to express the response of the buildings and are shown in Fig. 2, where it can be observed that except for the left 6-story building and the 8-story building under Northridge earthquake (Figs. 2(g), 2(h)), the shear amplification factors of the building with fixed foundations are in general more than that of flexible foundations. This result shows that the consideration of soil is beneficial when pounding occurs between adjacent buildings. In most of the cases, buildings with natural

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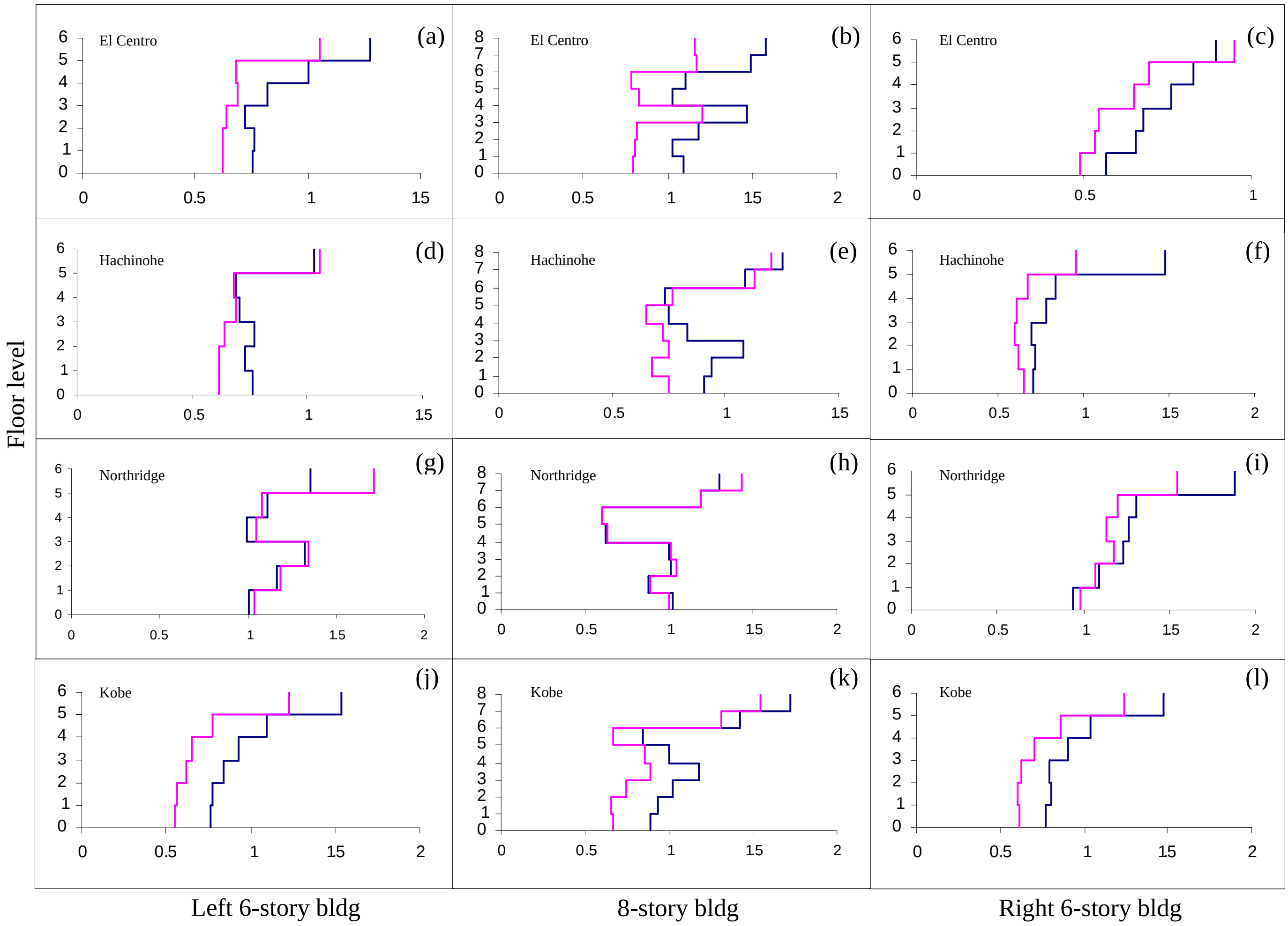

Figure 2. Shear amplification factor: (a)-(c) El Centro; (d)-(f) Hachinohe; (g)-(i) Northridge; and (j)-(l) Kobe earthquakes; Fixed foundation ——————, Flexible foundation —————— .

frequency closer to the dominant frequency of earthquakes are most affected when structural pounding is not considered. But the case may be different when pounding occurs. Although the natural frequency of 8-story building with flexible foundation is close to the dominant frequency of Northridge earthquake, the shear amplification factors of 8-story buildings with fixed foundation and flexible foundation are almost same. Hence, an individual building does not govern the global response but the system of all buildings does. Pounding of buildings does not always amplify the shear forces (Figs. 2(g), 2(i)) but also reduces shear forces in some cases (Figs. 2(c), 2(d), 2(f)). Since the 8-story building is more flexible than the 6-story buildings, big changes of shear amplification factors at different floor levels are observed. As 8-story building is restricted in free movement up to 6^{th} floor, significant increment in shear amplification factors occurred at 7^{th} and 8^{th} floor of the 8-story building under all earthquake inputs. In particular, from Fig. 2 it can be said that the buildings under consideration are less vulnerable to far field earthquake in comparison to near field earthquakes. The 8-story building is highly vulnerable for the Kobe earthquake, whereas 6-story buildings are least vulnerable for the Hachinohe and El Centro earthquakes and highly vulnerable for the Northridge earthquake.

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