

# Seismic pounding of buildings in a row considering soil-foundation interaction represented by discrete model

K. Shakya and A. C. Wijeyewickrema

Department of Civil Engineering, Tokyo Institute of Technology, Japan  
 shakya.k.aa@m.titech.ac.jp, wijeyewickrema.a.aa@m.titech.ac.jp

**ABSTRACT:** Structural pounding between three buildings in a row, where a 8-story building is located between two 6-story exterior buildings which are identical, are investigated using the finite element analysis software SAP2000. Soil-structure interaction is incorporated by including appropriate mass-spring-damper systems at the foundation level. Energy dissipation during collisions is considered by using a gap element together with a link element with both stiffness and viscous damping properties. Two near field earthquakes and two far field earthquakes are considered for input motions. For the earthquake inputs used in this study, results obtained indicate that buildings are more vulnerable to near field earthquakes. The taller building has relatively large shear amplification factors.

## 1 INTRODUCTION

To find out the effect of underlying soil on structural pounding during earthquakes, Rahman et al. (2001) performed an analysis on multi-story buildings of different total heights using 2-D structural analysis software, RUAUMOKO.

The present paper deals with the response of three reinforced concrete moment resisting frame buildings in a row where a 8-story building is located between two identical 6-story buildings (Fig. 1). Translational and rotational frequency independent mass-spring-damper systems have been used to incorporate soil effects. The mass-spring-damper properties can be obtained from Rahman et al. (2001) and Wolf (1988).

## 2 PROBLEM STATEMENT

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 318-02 and earthquake loads are considered as per IBC 2003. The gaps between the buildings are considered as 1 cm. For analysis and design, M25 grade concrete with unit weight,  $\gamma_c = 24 \text{ kN/m}^3$ , modulus of elasticity  $E_c = 25,866 \text{ N/mm}^2$ , and Poisson's ratio  $\nu_c = 0.2$  is considered. Slab thicknesses of 130 mm and 150 mm are provided for the 6-story buildings and the 8-story building, respectively. For all the buildings 300 mm x 500 mm beams are provided. Two near field earthquakes, 1994 Northridge and 1995 Kobe and two far field earthquakes, 1940 El Centro and 1968 Hachinohe 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. The mass-spring-damper 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  $G_s = 18.75 \text{ MPa}$ .

## 3 RESULTS AND CONCLUSIONS

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

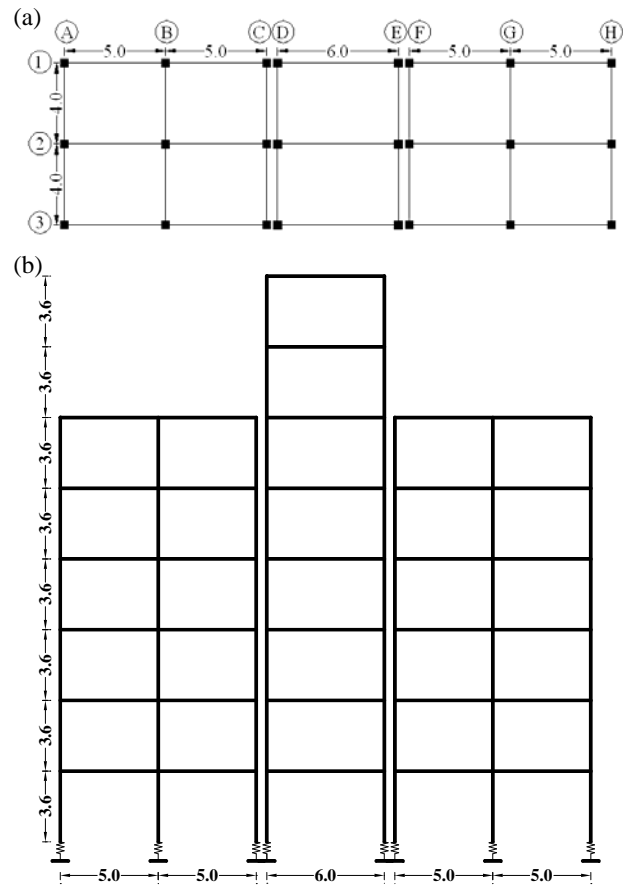


Fig. 1. (a) Building plan; (b) Building elevation

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

Figure 2 shows the impact force time history at the 6<sup>th</sup> floor column C2 of the left building. It shows that the collision between the buildings occur at different time and with different magnitudes. The magnitudes of impact forces in the case of flexible (soil) foundation are lesser than those of fixed foundation case. Kobe earthquake has the most dominant effects on the buildings as the impact forces due to this earthquake are the largest. Shear amplification factors, defined

as the ratio of maximum shear resulting from pounding to that of no pounding case, are shown in Fig. 3, where it can be observed that except for left 6-story building and 8-story building under Northridge earthquake (Figs. 3(a), 3(b)), the shear amplification factors of the building with fixed foundations are in general larger than those of foundation with soil flexibility. Although the natural frequency of 8-story building with foundation with soil flexibility is close to the dominant frequency of Northridge earthquake, the shear amplification factors of 8-story buildings with fixed foundation and foundation with soil flexibility are almost same (Fig. 3(b)). Pounding of buildings does not always amplify the shear forces (Figs. 3(a), 3(c)) but also reduces shear forces in some cases (Figs. 3(i), 3(j), 3(l)). In most of the cases, combination of reduction and amplification of shear forces at different floor levels are common. Since, 8-story building is flexible compared to 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<sup>th</sup> floor, significant increment in shear amplification factors occurred at

7<sup>th</sup> and 8<sup>th</sup> floor of the 8-story building under all earthquake inputs (Figs. 3(b), 3(e), 3(h), 3(k)). In particular, from Fig. 3 it can be said that the buildings under consideration are less vulnerable to far field earthquake in comparison to near field earthquakes. The 6-story buildings are less vulnerable to the Hachinohe and El Centro earthquakes and highly vulnerable to the Northridge earthquake, whereas 8-story building is highly vulnerable to the Kobe earthquake.

## REFERENCES

- Rahman, A. M., Carr A. J., Moss P. J. 2001. Seismic pounding of a case of adjacent multiple-storey buildings of differing total heights considering soil flexibility effects. *Bulletin of the New Zealand Society for Earthquake Engineering*, 34(1), 40-59.
- Wolf, J. P. 1988. *Soil-structure-interaction analysis in time domain*. Prentice Hall Inc.

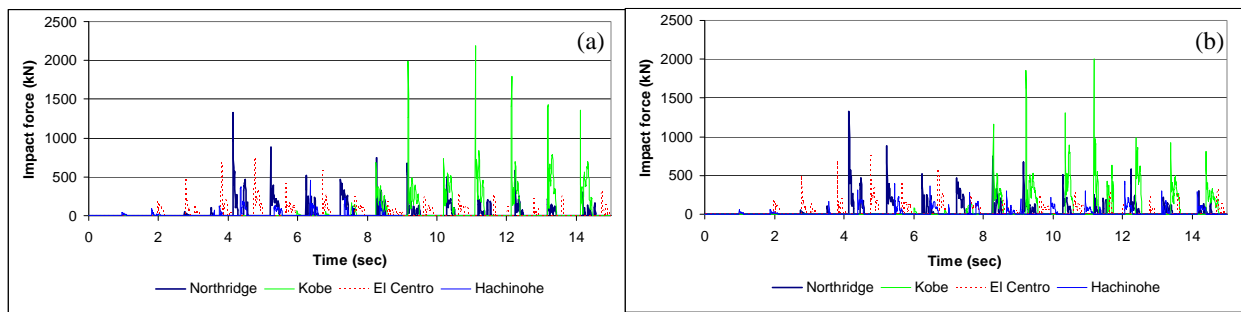


Fig. 2. Impact force time history at 6<sup>th</sup> floor column C2 of left building: (a) Fixed foundation; (b) Foundation with soil flexibility.

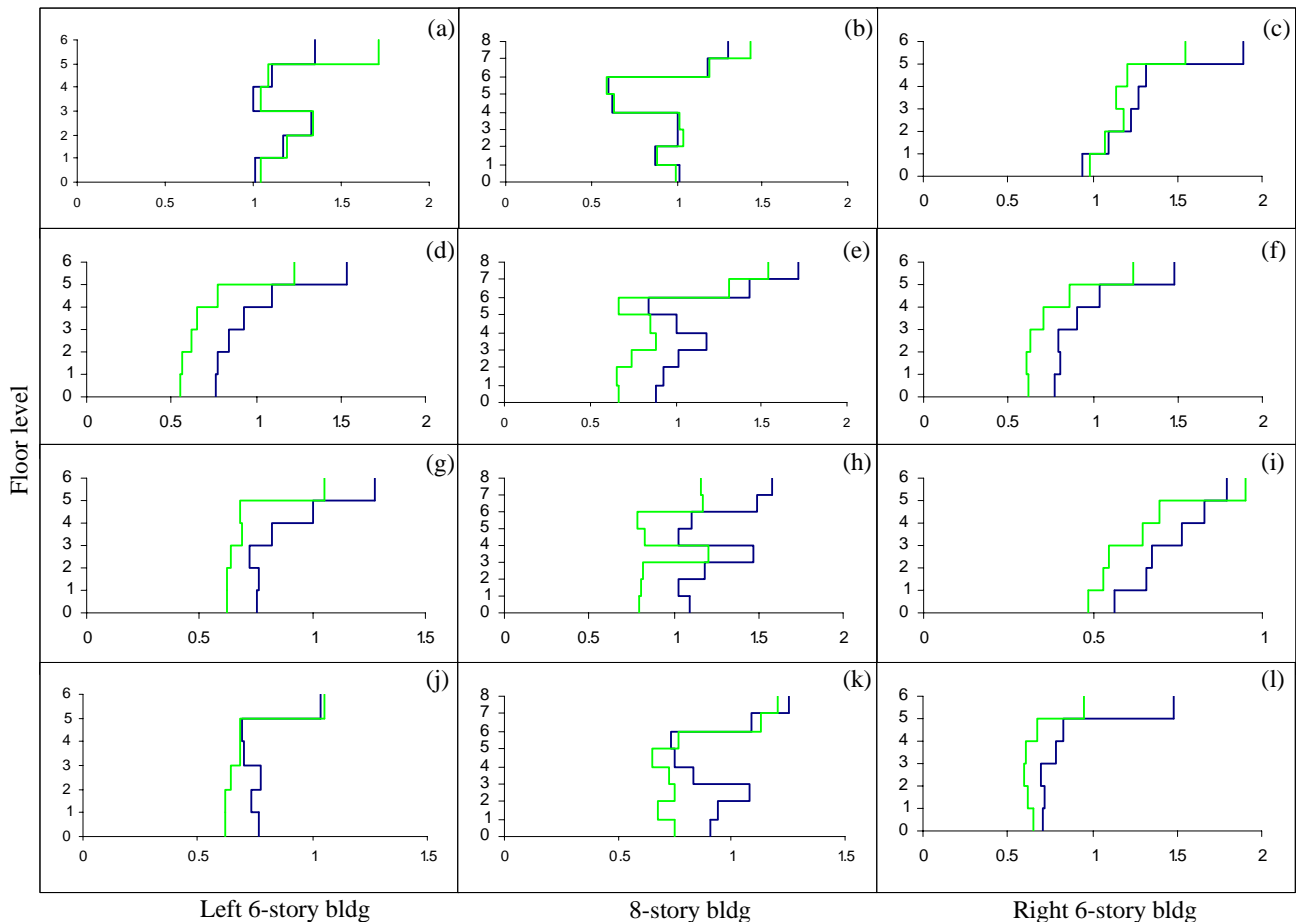


Fig. 3. Shear amplification factor: (a)-(c) Northridge; (d)-(f) Kobe; (g)-(i) El Centro; and (j)-(l) Hachinohe;

Fixed foundation ————, Foundation with soil flexibility ————.