Estimation of Secured Distance between Neighboring Buildings to Avoid Seismic Pounding

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Abstract

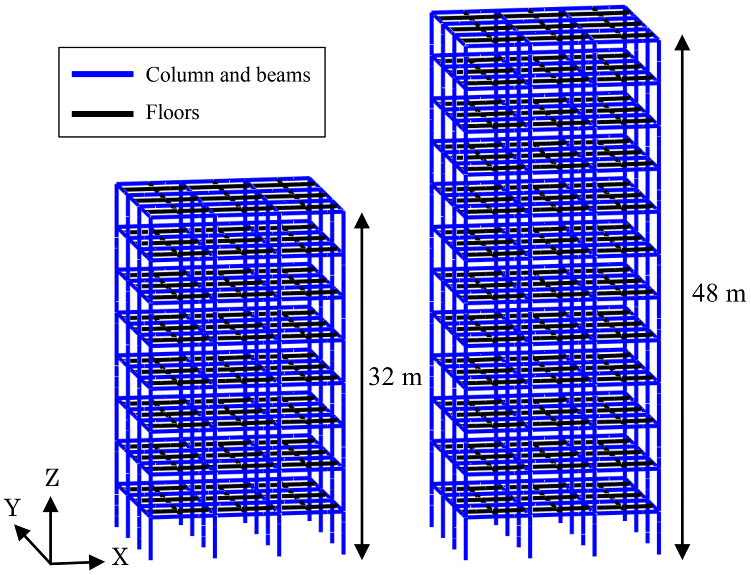
In this study, some seismic pounding analyses are performed on two neighboring buildings with different heights using a finite element code based on the adaptively shifted integration (ASI)-Gauss technique. Elastic limit distances of each building are estimated by applying various sine waves with different natural periods. Furthermore, a story drift angle of 1/100, which is an allowable plastic limit stated in the Building Standard Law, is added to each elastic limit distance to estimate the secured distance between the buildings. The secured distance between 8-story and 12-story steel frame buildings, for example, became 1,150 mm by summing both elastic and plastic limit distances. The numerical results clearly showed the effect of the secured distance compared to those of shorter distances.

Introduction

Seismic pounding phenomena, particularly the collision of neighboring buildings under long-period ground motion, are becoming a more significant issue. For example, the Nuevo Leon buildings in the Tlatelolco district of Mexico City, which consisted of three similar buildings built consecutively with narrow expansion joints between them, collapsed due to seismic pounding in the 1985 Mexican earthquake [1].

In this study, some seismic pounding analyses are performed on two neighboring buildings with different heights using a finite element code based on the adaptively shifted integration (ASI)-Gauss technique [2]. The numerical code provides a higher computational efficiency than the conventional code for this type of problem and enables us to address dynamic behavior with strong nonlinearities, including phenomena such as member fracture and elemental contact. Contact release and re-contact algorithms are implemented in the code to understand the complex behaviors of structural members during seismic pounding and the collapse sequence.

Elastic limit distances of each building are estimated by applying various sine waves with different natural periods. Furthermore, an allowable plastic limit stated in the Building Standard Law, which is a story drift angle of 1/100, is added to each elastic limit distance to estimate the secured distance between the buildings. Some numerical examples with various distances in between are performed under Atsuma wave, which was observed in 2003 Tokachi-oki Earthquake, to confirm the seismic pounding phenomena and the resulting damages of the buildings.



(a) 8-story model (b) 12-story model

Figure 1: Numerical models

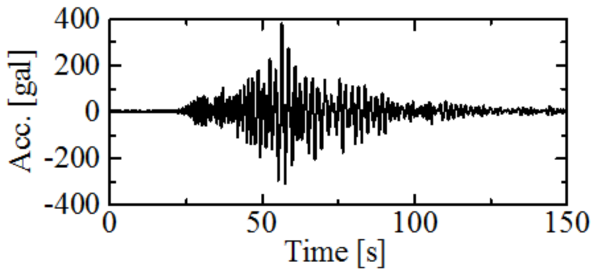
Numerical models and conditions

Two building models with different heights are constructed to perform some seismic pounding analyses. One of the models is an 8-story, 3-span steel building designed with a base shear coefficient of 0.232, and the other is a 12-story, 3-span steel building designed with a base shear coefficient of 0.167, as shown in Fig. 1. Their floor heights are 4 m and span lengths are 6 m. The columns and beams are made of SS400 steel and a floor load of 800 kgf/m^2 is applied on all floors. In both models, the members are modeled with four linear Timoshenko beam elements per member. The total number of elements are 1,856 for the former model and 2,784 for the latter model. The 12-story steel building models with their base shear coefficients of 0.083 (50 % of the original model), 0.125 (75 %), 0.210 (125 %), 0.250 (150 %), 0.330 (200 %) are also constructed. The natural periods to X-axis direction, elastic and plastic limit deformations are obtained as shown in Table 1. It is clear that the natural periods of 12-story models depend upon their base shear coefficients, however, there are no significant difference in elastic limit deformations between them.

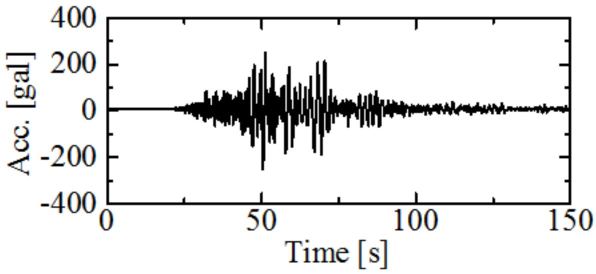
Table 1: Natural periods, elastic and plastic limit deformations of each model

	8-story model	12-story model					
Base shear coefficient	0.232	0.083	0.125	0.167	0.210	0.250	0.330
Natural period [s]	1.24	2.69	2.11	1.79	1.57	1.41	1.20
Elastic limit deformation [mm]	138	192	208	209	209	213	211
Plastic limit deformation [mm]	320	480					

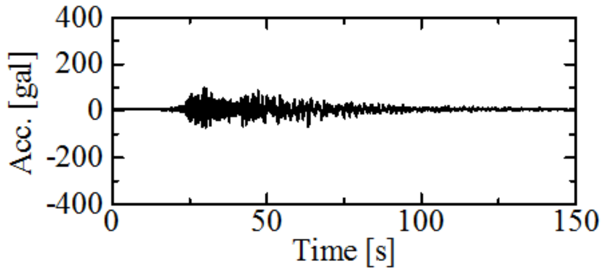
The acceleration record data of Atsuma wave, which is used as an input seismic wave, is shown in Fig. 2. Figure 3 shows its acceleration response spectrum, and Table 2 shows the maximum acceleration and predominant period of the seismic wave. The predominant period of the seismic wave in EW direction (which is X-axis direction in the models) nearly matches with the natural period of the 12-story model with a base shear coefficient of 0.167.



(a) EW



(b) NS



(c) UD

Figure 2: Input seismic wave (Atsuma wave)

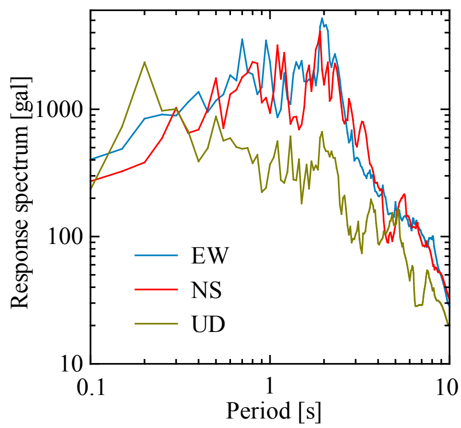


Figure 3: Acceleration response spectrum of Atsuma wave

Table 2: Maximum acceleration and predominant period of Atsuma wave

	EW	NS	UD
Max. acceleration [gal]	380.6	249.3	100.1
Predominant period [s]	1.95	1.90	0.20

We define the sum of elastic limit deformations of both models as the elastic limit distance, the sum of plastic limit deformations as the plastic limit distance, and the sum of both elastic and plastic limit distances as the elasto-plastic limit distance. In this case, the elastic limit distance can be estimated as 350 mm, the plastic limit distance as 800 mm, and the elasto-plastic limit distance as 1,150 mm, respectively, according to Table 1. The two models shown in Fig. 1 are placed with these distances between them as shown in Table 3. We applied a 17 % Atsuma wave to see the behaviors of two neighboring models which only deform elastically, when excited independently. Then we applied a 100 % Atsuma wave to see the effects of three limit distances between two models.

Table 3: Distance between two models for each input wave

Input seismic wave	Distance between two models [mm]
17 % Atsuma wave	100, 350
100 % Atsuma wave	350, 800, 1150

<u>Numerical results and summary</u>

There were no plastic deformations occurred or collisions between two models observed in the case when the distance between two models was set to its elastic limit distance, 350 mm, and 17% Atsuma wave was applied. However, the shorter distance 100 mm made the two models collide sequentially and many elements in both models yielded in the process.

For the 100 % Atsuma wave as an input, the rate of yielded elements in each case became as shown in Table 4. The rates of yielded elements in 8-story and 12-story models when excited independently were 30.5 % and 39.0 %, respectively. However, the rates became larger (and in greater rate in 8-strory model) as the distance between two models became shorter. Even a member fracture occurred in elastic and plastic limit distance cases. Figure 4 shows the behaviors of the models at moment of impact, when elastic limit distance is adopted as the distance between both models. f_y in the figure indicates yield function value and elements colored in red means that they are yielded. The 12-story model deformed largely as it nearly matches the predominant period of the input wave and many plastic elements could be observed. The 8-story model, on the other hand, deformed locally at the uppermost story, which indicates the occurrence of some local collisions near the location.

The numerical results indicate that the elasto-plastic limit distance should be taken as a clearance between two buildings to avoid any excessive, serious damages. However, further investigation should be taken to see the effects of building sizes, strengths, seismic waves and so on.

Table 4: Rate of yielded elements and presence of member fracture in each case

	8-story model		12-story model	
	Rate of yielded elements [%]	Member fracture	Rate of yielded elements [%]	Member fracture
Independent model	30.5	None	39.0	None
Elasto-plastic limit distance 1150 [mm]	35.5	None	39.7	None
Plastic limit distance 800 [mm]	38.3	None	41.3	Yes
Elastic limit distance 350 [mm]	46.7	Yes	42.6	None

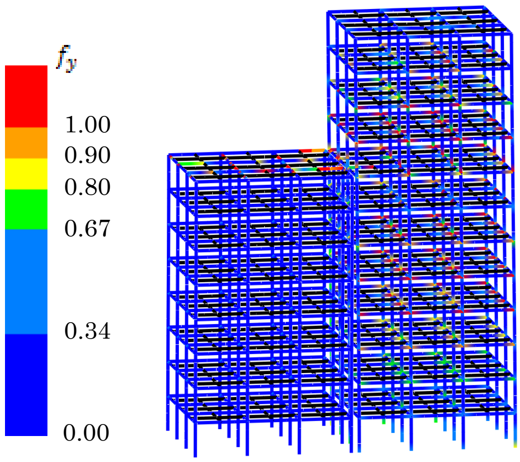


Figure 4: Moment of impact (49.1 s, 100% Atsuma wave, elastic limit distance 350 mm)

References
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