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BUILDING SEISMIC SEPARATION AT TAIPEI CITY

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ABSTRACT

During an earthquake, adjacent buildings with insufficient separations often collide into each other. This 'collision' or 'seismic pounding' imposes unexpected impact loading on buildings and has lead to instant collapse of many tall buildings during the 1985 Mexico City Earthquake. In Taipei metropolitan area where maximum usage of high-priced land is sought, adjacent buildings with small or no separation are very common. A large amount of these buildings might suffer severe pounding damage during major earthquake; this paper present a study on this potential hazard.

First, a survey is conducted to reveal the status of building seismic separation. It is found that among 2398 tall buildings investigated: 708 (about 1/3) of them with separations less than the code requirement (1.5% of building height). Based on the study of the past pounding damage, adjacent buildings susceptible to pounding damage are highlighted: 356 cases with zero separations; 422 cases with different building height; 111 cases with different floor level; and 20 cases with large mass ratio (>3). Second, the analytical pounding response of adjacent buildings with different parameters, such as periods, height, and mass ratio, are studied. The results are used to identify the buildings susceptible to seismic pounding damage. It is estimated that 17% out of the total 2359 buildings surveyed at Taipei might suffer pounding damage during major earthquake.

KEYWORDS

Structural Pounding, Building Separation, Pounding Damage, Dynamic Analysis, Damage Evaluation

INTRODUCTION

During an earthquake, adjacent buildings with insufficient separations often collide into each other. This 'collision' or 'seismic pounding' imposes unexpected impact loading on buildings and has cause severe damage and even collapse of many tall buildings during the 1985 Mexico City Earthquake (Bertero 1986). A survey of the pounding damage in the San Francisco Bay area during the 1989 Loma Prieta Earthquake also reveals widespread pounding incidents (Kasai and Masion, 1990).

Taipei is located at the seismic active Pacific margin with a 0.32G (gravity acceleration, 9.8 m/(sec*sec)) effective peak acceleration for the 475 return year earthquake. Similar to the Mexico city, Taipei is resided on an ancient lake bed; the soft soil underneath the city has caused the official to endorse a long period seismic design spectra similar to the one for Mexico City (Fig. 1). In Taipei metropolitan area where maximum usage of high-priced land is sought, adjacent buildings with small or no separation are very common; many of these buildings might suffer severe pounding damage during a major earthquake. The author, therefore, conducted investigation on this building separations problem.

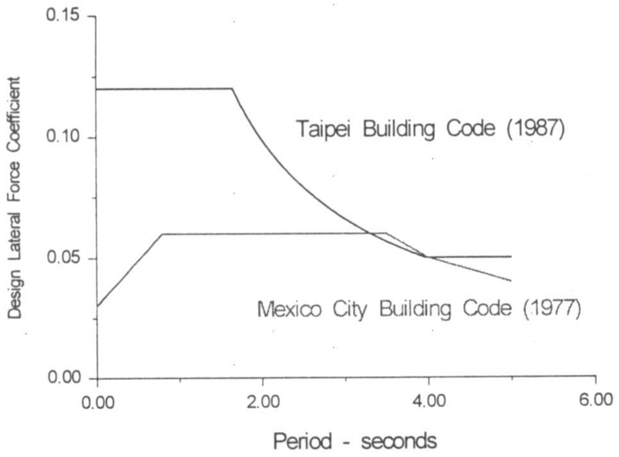

Fig. 1 Design Lateral Force Coefficient for Taipei and Mexico City

First, a survey is conducted to reveal the status of building seismic separations at Taipei; buildings susceptible to pounding damage are identified. Second, structural pounding analysis is performed to identify important parameters for evaluating pounding damage. Finally, the results of survey and analysis are combined to evaluate the seismic pounding damage of buildings. It is estimated that 17% out of the total 2359 buildings surveyed at Taipei might suffer pounding damage during major earthquake.

SURVEY OF BUILDING SEISMIC SEPARATION

Two districts with high building density, Da-Ann and Tzong-sun, out of twelve districts of Taipei are selected for the study. Tall buildings with more than seven stories are surveyed for their number of story, area of floor plan, separations with adjacent building, relative position with adjacent buildings, possible pounding location, year of build, and possible usage (commercial or residential). The survey was conducted on March, 1993.

The 1982 Building Code of Taipei required a separation of 1.5% of building height for each of the adjacent buildings; however, it is found that about one third (708) of total 2359 buildings surveyed has separation distance less than the code requirement (Fig. 2).

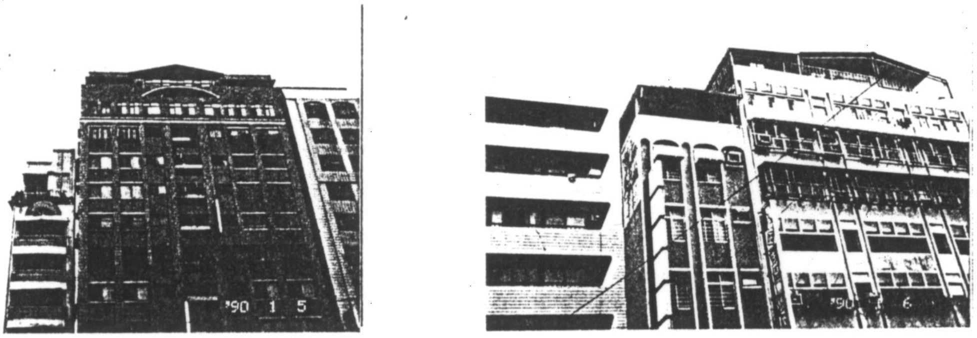

Fig. 2 Buildings with Insufficient Separations at Taipei City

The following are the finding among those 708 buildings:

(1) Distribution of the separations: Table 1 shows the number of buildings against the year of build and separation ratio (separation distance divided by the total height of two adjacent buildings). The number of buildings reach the peak at 1981, after the 1982 code revision, the number of building not complied drop immediately. Among the 708 buildings, 499 was built before 1982 and about half (356) of the 708 buildings are with ZERO separation.

(2) Adjacent buildings with floors at different level: there are 111 buildings of this kind. If seismic pounding occurred, it would be the floor of one building collide into the columns of the adjacent building and cause the column failure.

(3) Adjacent building with unequal floor mass: there are 20 buildings with heavy adjacent building(3 times floor mass or more). During seismic pounding, large momentum transferring into the light building could cause failure. However, the majority (651 or 92%) of the 708 building has similar floor mass as their adjacent buildings.

(4) Building in Series: there are 50 sets of buildings in series. For those at the corner, it has been found susceptible to pounding damage.

Table 1 Distribution of Building Separations

(Separation/Height)%	Year																																
	??	53	55	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Subtotal
0	7	1	3	0	3	1	2	4	3	4	15	10	11	6	1	47	32	16	27	31	37	54	18	4	7	6	2	2	1	0	1	0	356
0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	0	0	1	0	0	0	0	0	0	0	0	0	5
0.2	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	4	1	3	2	0	2	2	0	0	1	0	1	1	0	0	0	24
0.3	4	0	0	0	0	0	0	0	0	1	0	1	0	2	0	1	3	0	3	2	4	2	0	4	3	1	3	0	0	0	0	0	34
0.4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	2	2	2	1	5	2	0	1	1	2	1	0	0	0	0	21
0.5	1	0	0	0	0	0	0	1	0	0	1	2	0	0	0	1	2	0	2	3	1	2	1	7	0	1	1	3	2	4	0	0	35
0.6	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	3	1	3	4	3	2	1	3	2	3	1	2	5	1	0	0	37
0.7	5	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	3	1	0	2	11	2	3	1	2	2	1	0	0	36
0.8	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	2	0	1	2	0	3	3	3	3	2	0	2	1	1	1	2	0	29
0.9	2	0	0	0	0	0	0	0	0	0	2	1	1	1	0	3	3	1	1	2	0	2	2	4	2	3	2	1	2	1	0	0	36
1	3	0	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	1	0	2	2	0	1	2	4	0	1	1	2	0	0	1	24
1.1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	1	1	0	1	2	1	3	4	3	0	2	0	0	0	0	21
1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	2	0	1	1	2	0	0	0	0	0	12
1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	1	2	2	1	1	1	0	0	0	12
1.4	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	3	0	3	1	0	0	0	2	0	0	0	12
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	2	2	3	0	0	0	1	0	1	0	1	14
Subtotal	28	1	3	1	3	1	2	6	4	6	20	19	12	11	2	63	50	25	48	55	55	80	40	48	31	25	18	18	19	9	3	2	708

POUNDING ANALYSIS AND PARAMETER STUDY

A series of pounding analysis of adjacent buildings is conducted (Jeng and Tzeng 1994). Adjacent building's relative height ratio, relative period ratio, story mass ratio, and small enough separation for causing pounding are the most important parameters that influence the result of pounding. The purpose of this detailed pounding analysis is to supply the basic information for latter potential pounding damage evaluation.

The assumptions used are as following:
(1) Nine artificial earthquakes with peak ground acceleration of 0.4G, based on SEOAC (1990) response spectrum for three different soil types, are used as earthquake input.
(2) The computer program used is DRAIN-2DX (Parkash, Powell and Fillippou, 1992).
(3) The buildings are considered as elastic moment resistance frames with 5% damping ratio (Fig. 3).
(4) The numbers of stories of building studied are 12, 10, 7, and 4.

(5) The floor mass is assumed the same for each floor of that building.
(6) All buildings have the same story height, therefore, the pounding happen only at floor level.
(7) The ratio of story mass between the adjacent buildings studied are 1/8, 1/3, 1, 3, and 8.
(8) The periods of the buildings are adjusted to (0.040*building height)**0.75.
(9) The mean value of the analysis results of the nine artificial earthquake are then used for discussion.
(11) For pounding between buildings with the same height, one building's period is reduced to be 83% of the calculated period to simulate the variation of building period.
(12) The pounding mechanism is simulated by gap element of stiffness of 25000, 100000, and 400000 m/ton.

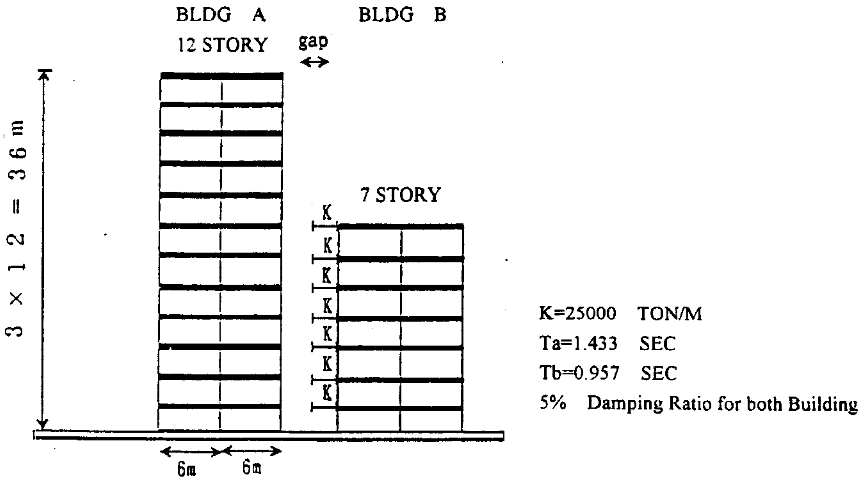

Fig. 3 Modeling of Adjacent Buildings for Pounding Analysis

The building story shear amplification, which is defined as the story shear result from pounding analysis divided by the story shear result from stand-alone analysis (no pounding), is used to demonstrate the pounding effect. Fig. 4 is the results of pounding analysis between building A (12 story) and building B (7 story) for various floor mass ratios (Mb/Ma=1/8, 1/3, 1, 3, and 8). For building A, the maximum story shear amplification are 1.0, 1.2, 1.9, 3.4, and 4.9 for mass ratio 1/8, 1/3, 1, 3, and 8. For building B the maximum story shear amplification are 2.3, 2.1, 1.9, 1.2, and 1.1 for mass ratio from 1/8 to 8. The lighter buildings will have higher story shear amplification, and the heavier building will only have smaller story shear amplification.

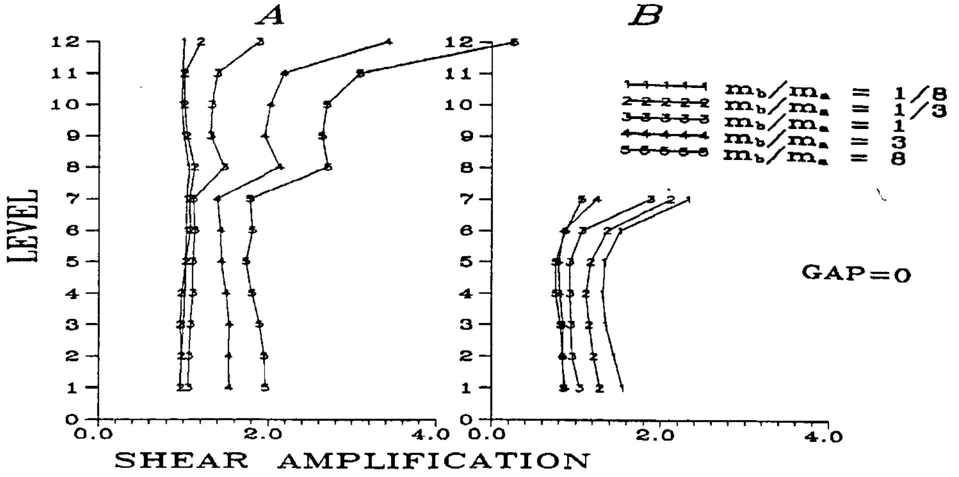

Fig. 4 Story Shear Amplification of Two Adjacent Buildings under Pounding

The resulted story shear amplification of adjacent buildings for different story mass ratios and building story ratios are summarized in Table 2.

Table 2 Story Shear Amplification for Adjacent Buildings

For Building A

Hb/Ha	Mb/Ma				
	1/8	1/3	1	3	8
12/4	1.1	1.4	2.4	3.3	3.6
10/4	1.1	1.3	2.4	3.2	3.6
12/7	1.1	1.2	1.9	2.1	2.3
12/10	1	1	1.2	1.6	1.7
1*	1	1	1.1	1.3	1.5

For Building B

Hb/Ha	Mb/Ma				
	1/8	1/3	1	3	8
12/4	2.9	2.1	1.4	1.1	1.1
10/4	2.8	2.1	1.5	1.1	1.1
12/7	4.9	3.4	1.9	1.2	1
10/12	3	2.5	1.7	1.2	1.1

Ma,Mb : Story Mass of Building A and B.
Ha,Hb : Number of Stories of Building A and B
* Hb/Ha=1 is the average of the results for hb/ha=12/12 & 7/7 ,period of build

DAMAGE EVALUATION METHOD

A damage index (DI), utilizing the results of survey and the pounding analysis, is proposed to evaluate the potential pounding damage at Taipei City. It is assumed that the pounding damage is independent to the other damage caused by earthquake.

Separation Distance Effect

The minimum separation distance to avoid pounding is calculated based on assumptions as following:

(1) The effective peak ground acceleration of the objective earthquake at Taipei is assumed to 0.32G with the normalized response spectra as in Fig. 5.
(2) The maximum spectral displacements for the adjacent buildings are calculated from the 5% damping response spectrum according to the fundamental periods of each building.
(3) The minimum separation distance, s, to avoid pounding is calculated according to the Spectral Difference Method (Jeng etc, 1992ab) with ductility ratio equal to 3.

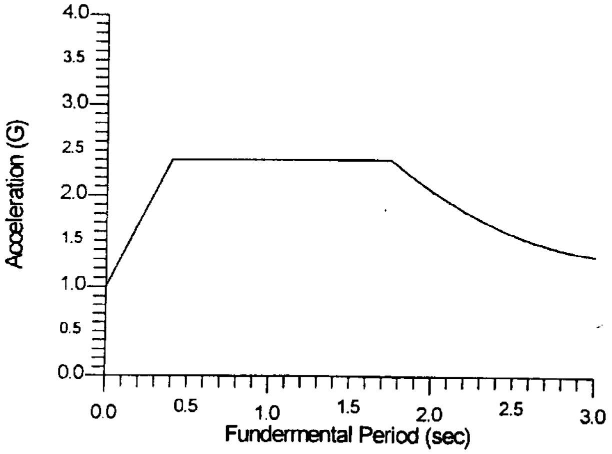

Fig. 5 Normalized Response Spectra for Taipei City (1G)

For each pair of adjacent buildings surveyed, the Gap factor is defined as following: Gap=1 for the case that separation < 8/9*s; Gap=0 for other cases.

Shape Effect

Shape effect, S, of each building is defined as follow:

S = 1.5	for mid-column pounding
S = 1.3	for corner building
S = 1.3	for building between taller and shorter buildings
S = 1.0	for all other cases

For buildings satisfied more than one case, the multiples of S's are used.

Damage Index (DI)

The damage index,DI, is defined as:

DI = S * Gap * V

V: story shear amplification as in Table 2.

Note that for adjacent buildings with same story height and zero separation, the damage index is the story shear amplification.

Damage Criteria

The potential pounding damage is then defined as

(1) Collapse (DI >= 2.4)

(2) Severe Damage (2.4 > DI >= 1.9)

(3) Medium Damage (1.9 > DI >= 1.5)

(4) Slight Damage (1.5 > DI >= 1.0)

(5) No Damage (DI = 0)

POTENTIAL POUNDING DAMAGE

Separation

Table 3 is the distribution of potential pounding damage among the 708 buildings surveyed with insufficient separation required by building code. 46 (6%) out of those 708 buildings will collapse; 76 (11%) will suffer severe damage; and 305 (43%) will suffer no damage. For buildings with separation ratio larger than 0.5%, there is no pounding damage. However, this should not be interpolated as a 0.5% separation ratio is safe from pounding damage, because a improperly designed building might have much larger permanent story drift and thus causing pounding even it has a larger separation.

Year of Build

For 499 buildings build before 1982, 356 (71%) will suffer pounding damage, and 44 (7.3%) might collapse. For 181 buildings build after 1982, 35 (19%) will suffer pounding damage, and 2 (1.1%) might collapse. The building build before 1982 are more likely to suffer pounding damage (Table 4).

Shape Factor

For the 111 buildings surveyed with different floor level comparing to their adjacent buildings, 39 (35%) buildings might collapse with mid-column pounding.

Table 3 Distribution of Pounding Damage per Separation

Separation Ratio	Collapse	Severe Damage	Medium Damage	Slight Damage	No Damage	Subtotal
0	41	69	85	146	5	**356**
0.1	0	0	1	4	0	**5**
0.2	1	3	5	14	1	**24**
0.3	3	3	5	14	9	**34**
0.4	1	1	5	0	14	**21**
0.5	0	0	1	0	34	**35**
0.6	0	0	0	0	37	**37**
0.7	0	0	0	0	36	**36**
0.8	0	0	0	0	29	**29**
0.9	0	0	0	0	36	**36**
1	0	0	0	0	24	**24**
1.1	0	0	0	0	21	**21**
1.2	0	0	0	0	12	**12**
1.3	0	0	0	0	12	**12**
1.4	0	0	0	0	12	**12**
1.5	0	0	0	0	14	**14**
Subtotal	**46**	**76**	**102**	**179**	**305**	**708**

Table 4 Distribution of Potential Pounding Damage

	Collapse	Severe Damage	Medium Damage	Slight Damage	No Damage	Subtotal
Year of built before 1982	44	65	86	161	143	**499**
after 1983	2	7	10	16	146	**181**

Comparison with Past Pounding Damage

The potential pounding damage at Taipei during a major earthquake is listed with the past pounding damage at Mexico City in the 1985 Mexico Earthquake and San Francisco area in the 1989 Loma Prieta Earthquake in Table 5. The pounding damages are comparable.

Table 5 Comparison of Potential Pounding Damage at Taipei to Pounding Damage at Other Cities

Earthquake	Mexico Earthquake, 1985	Loma-Prieta , 1989	Taipei Expected Major Earthquake
Pounding Survey Area	Mexico City	San Francisco Bay Area	Taipei City
Magnitude (M)	8.1	7.10	7.6 or 8.6
Distance to Epic Center (KM)	400	90	30 or 150
Maximum Ground Acceleration	~0.2G	~0.2G	~0.32G
Soil Condition	Soft	Soft	Soft
Survey Pounding Damage (or expected)	40% of 330 Severe Damaged Building Surveyed	More then 500 Buildings	17% of 2359 Buildings Surveyed for Separation Distance

CONCLUSION AND RECOMMENDATION

After the 1982 Building Code separation requirement was in act, the number of new building did not comply deceased. However, there are still a huge number of existing buildings not complied (708 (30%) out of the 2359 buildings surveyed) and they are vulnerable to pounding damage.

Based on the survey data and pounding analysis, the potential pounding damage on adjacent buildings under major earthquake is evaluated. For the 2359 surveyed building, 403(17%) will suffer pounding damage. Among them, 46 (1.9%) will collapse, 76 (3.2%) will suffer severe damage, 102 (4.3%) will suffer medium damage, and 179 will suffer slight damage.

This study reveal the status of existing building seismic separation at Taipei and the potential pounding damage hazard during a major earthquake; the seismic pounding mitigation is urgently needed for these existing buildings.

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