Structural Pounding between Adjacent Buildings Subjected to Near-Fault Strong Earthquakes

George Tsenis
Civil Engineer, M.Sc. / SST/ HOU
tseniskom@yahoo.gr

George Hatzigeorgiou
Assoc. Professor at SST/HOU
hatzigeorgiou@eap.gr

Abstract. **In this study, the structural pounding between adjacent buildings subjected to near-fault strong earthquakes is investigated. More specifically, two 5-storey and two 8-storey frames, regular or irregular along their height, are combined together to produce nine different pairs of adjacent RC structures. These adjacent structures are subjected to various near-fault strong ground motions and various parameters are examined such as maximum and permanent displacements, members' ductility and internal forces and interstorey drift ratios. It is found that the effect of collision of adjacent frames seems to be unfavorable for most of the cases and, therefore, the structural pounding phenomenon should be taken into account during the design process.**

Key-words: Structural pounding; Near-fault earthquakes

I. Introduction

Building structures are frequently constructed in close proximity to one another due to limited availability of areas, e.g. as shown in Fig. 1 in San Francisco, one of the most vulnerable area worldwide to strong earthquakes.

Figure 1. Example of continuous building systems - San Francisco, US.

Because of inadequate separations, collision can be occurred between adjacent buildings during strong ground motions. This phenomenon is commonly referred to as structural pounding. Many cases of structural damage due to pounding can be mentioned (Moehle & Mahin, 1991). Pounding may result in irregular response of buildings of different heights, local damage to columns as the floor of one building collides with columns of another, collapse of damaged floors, and collapse of entire structures (Anagnostopoulos & Karamaneas, 2008). Although the extensive research on this phenomenon during the last two decades, which is mainly referred above, the findings of many works have been refuted by other pertinent studies. According to Cole et al. (2010), this discrepancy has to do with the high level of complexity inherent in the problem.

In this study, four RC structures are examined, i.e., two five-storey and two eight-storey planar frames, which have been combined together to produce nine different pairs of adjacent RC structures. These pairs of buildings are subjected to various near-fault strong ground motions. The inelastic time-history responses of these concrete frames are evaluated by means of the structural analysis software Ruaumoko (Carr 2008). The most critical structural parameters, such as the maximum displacements and accelerations, structural damage, members' ductilities and interstorey drift ratios are examined for both collided and separated buildings in order to quantify the effect of structural pounding during near-fault earthquakes.

II. Description of Buildings

Four two-dimensional frames (F1–F4) are considered with the first two of them (F1 and F2) having 5 storeys and the other two (F3, F4) having 8 storeys. All buildings have three equal bays with total length equal to 18 m. Typical floor-to-floor height is equal to 3.0 m, but for the first floor of the eight-storey buildings, the height is equal to 4.0 m. For example, Figs 2) and 3) depict the geometry, sections and reinforcement of the frames F1 and F4, respectively. Pounding between the frames in every case took place between one 5-storey frame and one 8-storey frame to examine closely its effects to collision of structures with different floor levels.

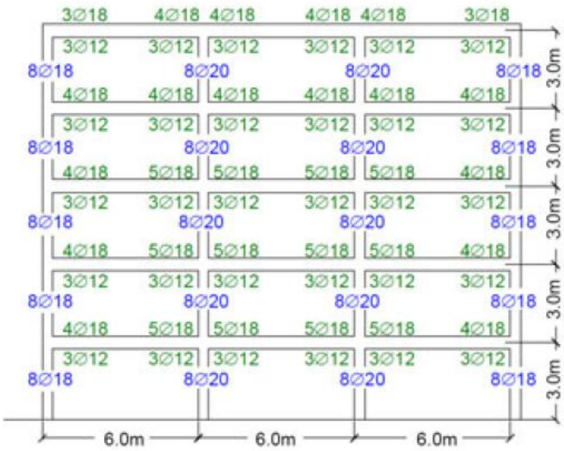

Figure 2. Five-storey regular building.

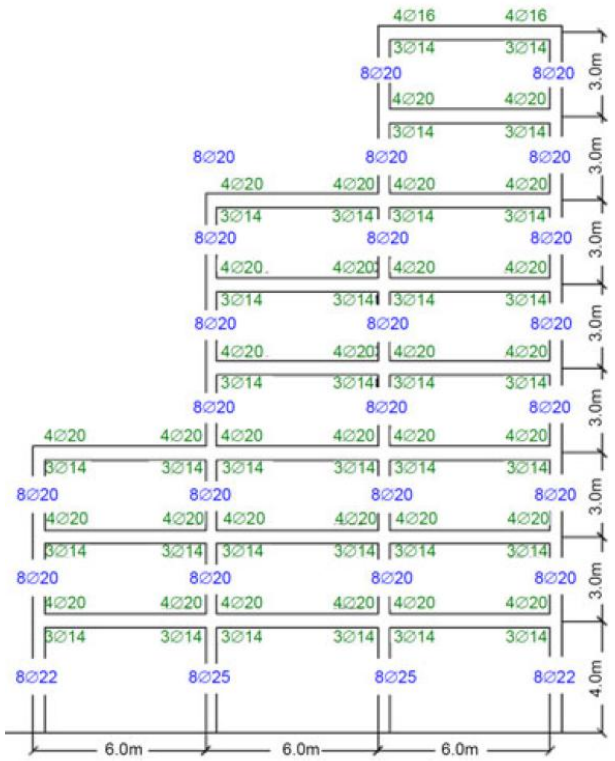

Figure 3. Eight-storey irregular building.

Material properties are assumed to be 20 MPa for the concrete compressive strength (C20) and 500 MPa for the yield strength of both longitudinal and transverse reinforcements (S500s). Figure 4 depicts the 9 different structures' configurations examined here.

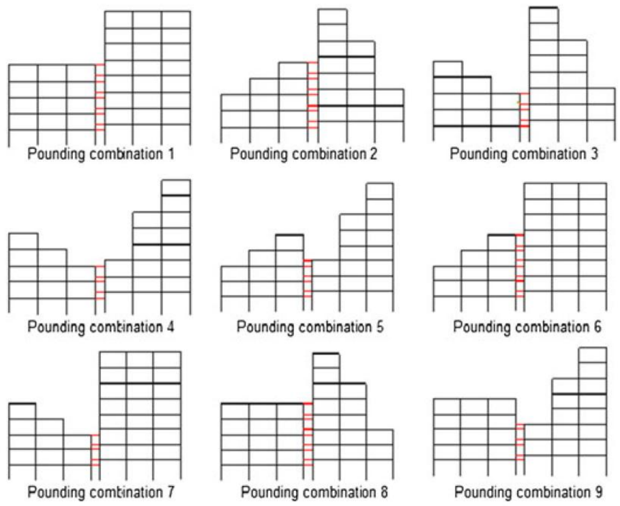

Figure 4. Buldings' configurations examined in this study.

III. DESCRIPTION OF GROUND MOTIONS

In this study, 60 strong ground motions that have been recorded near (up to 10km) to the corresponding fault of earthquake are examined. All the examined seismic records present, more or less, a pulse type of motion, which can be clearly shown in their velocity response spectra. The first 30 of the examined cases have been recorded near to Strike-Slip (SS) seismic faults while the other 30 ones near to earthquake sources with reverse or oblique-reverse (REV) fault mechanism. Table I and II show the examined Strike-Slip and Reverse near-fault earthquakes, respectively.

TABLE I
STRIKE-SLIP NEAR-FAULT EARTHQUAKES

No	Earthquake	Year	Station	Magnitude
1	CoyoteLake	1979	GilroyArray#6	5.74
2	ImperialValley-06	1979	Aerop.Mexicali	6.53
3	ImperialValley-06	1979	Agrarias	6.53
4	ImperialValley-06	1979	BrawleyAirport	6.53
5	ImperialValley-06	1979	ECMelolandOverp	6.53
6	ImperialValley-06	1979	ElCentroArray#10	6.53
7	ImperialValley-06	1979	ElCentroArray#6	6.53
8	ImperialValley-06	1979	ElCentroArray#8	6.53
9	ImperialValley-06	1979	HoltvillePostOf.	6.53
10	MammothLakes-06	1980	LongValleyDam	5.94
11	Westmorland	1981	ParachuteTestSite	5.90
12	Westmorland	1981	Westmorl.FireSt	5.90
13	MorganHill	1984	CoyoteLakeDam	6.19
14	MorganHill	1984	GilroyArray#6	6.19
15	SanSalvador	1986	GeotechInvestigCr	5.80
16	SanSalvador	1986	Nat.Geogr. Inst	5.80
17	SuperstitionHills-02	1987	ElCentroImp.Co.	6.54
18	SuperstitionHills-02	1987	KornbloomRoad	6.54
19	SuperstitionHills-02	1987	ParachuteTestSite	6.54
20	Erzican,Turkey	1992	Erzincan	6.69
21	Landers	1992	Lucerne	7.28
22	Landers	1992	YermoFireStation	7.28
23	Kobe,Japan	1995	KJMA	6.90
24	Kobe,Japan	1995	Takarazuka	6.90
25	Kobe,Japan	1995	Takatori	6.90
26	Kocaeli,Turkey	1999	Arcelik	7.51
27	Kocaeli,Turkey	1999	Yarimca	7.51
28	Duzce,Turkey	1999	Bolu	7.14
29	Duzce,Turkey	1999	Duzce	7.14
30	Yountville	2000	NapaFireStation#3	5.00

TABLE III
REVERSE OR OBLIQUE-REVERSE NEAR-FAULT EARTHQUAKES

No	Earthquake	Year	Station	Magnitude
1	SanFernando	1971	PacoimaDam	6.61
2	Coalinga-05	1983	OilCity	5.77
3	Coalinga-05	1983	TransmitterHill	5.77
4	Coalinga-07	1983	Coalinga- OldCHP	5.21
5	Nahanni,Canada	1985	Site2	6.76
6	N.PalmSprings	1986	NorthPalmSprings	6.06
7	WhittierNarrows	1987	LB — OrangeAve	5.99
8	LomaPrieta	1989	AlamedaNavalAir	6.93
9	LomaPrieta	1989	Gilroy — Gavilan.	6.93
10	LomaPrieta	1989	Gilroy - HistBldg.	6.93
11	LomaPrieta	1989	GilroyArray#2	6.93
12	LomaPrieta	1989	LGPC	6.93
13	LomaPrieta	1989	Oakland Harbor	6.93
14	LomaPrieta	1989	Oakland - T&T	6.93
15	CapeMendocino	1992	CapeMendocino	7.01
16	CapeMendocino	1992	Petrolia	7.01
17	Northridge-01	1994	WadswortHospital	6.69
18	Northridge-01	1994	LADam	6.69
19	Northridge-01	1994	Newhall - Fire Sta	6.69
20	Northridge-01	1994	PicoCanyonRd.	6.69
21	Northridge-01	1994	PacoimaDam	6.69
22	Northridge-01	1994	PacoimaDam	6.69
23	Northridge-01	1994	Rinaldi Rec.Stat	6.69
24	Northridge-01	1994	Sylmar 1	6.69
25	Northridge-01	1994	Sylmar 2	6.69
26	Chi-Chi,Taiwan	1999	CHY006	7.62
27	Chi-Chi,Taiwan	1999	CHY035	7.62
28	Chi-Chi,Taiwan	1999	TAP003	7.62
29	Chi-Chi,Taiwan	1999	TAP005	7.62
30	Chi-Chi,Taiwan	1999	TCU036	7.62

IV. SELECTED RESULTS

This section presents selected results that have mainly to do with the most critical response parameters such as maximum interstorey drift ratios (IDR_{max}) and maximum floor total accelerations. These parameters appear to be essential to evaluate, directly or indirectly, the structural and non-structural damage.

Figure 5 depicts the maximum floor accelerations for the case of REV earthquakes, examining collided and separated structures, and for the 1st and the 6th Buildings' Configurations (BC#1 and BC#6).

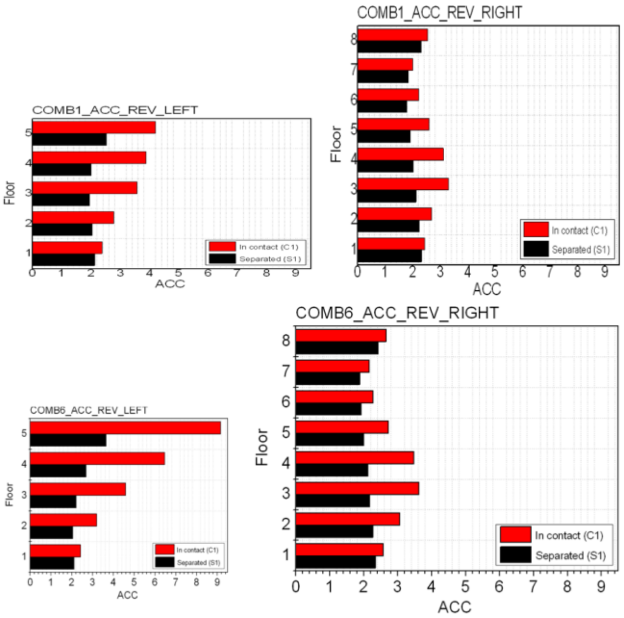

Figure 5. Max. floor accelerations: BC#1 - BC#6 and REV earthquakes.

Similarly, Fig. 6 depict the maximum floor accelerations for the case of S-S earthquakes, examining collided and separated structures, and for the 1st and the 6th Buildings' Configurations (BC#1 and BC#6).

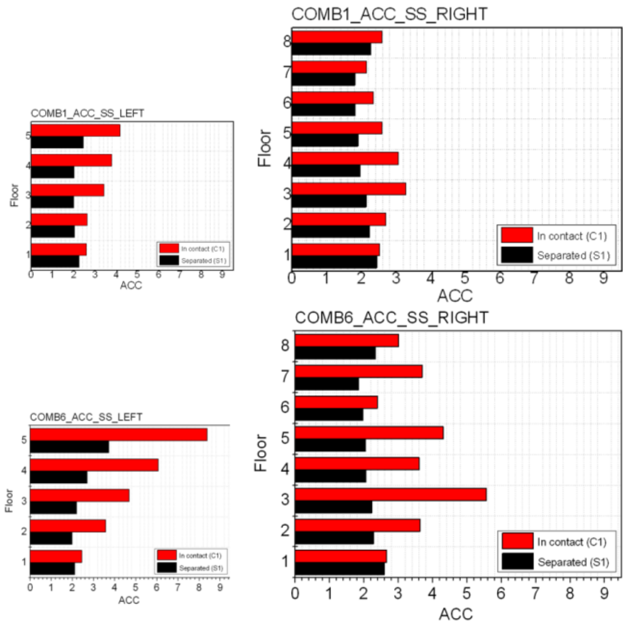

Figure 6. Max. floor accelerations: BC#1 - BC#6 and S-S earthquakes.

It is obvious that the collided structures have higher accelerations in comparison with the separated structures.

Figure 7 illustrates the maximum interstorey drift ratios for the case of REV earthquakes, examining collided and separated structures, and for the 1st and the 6th Buildings' Configurations (BC#1 and BC#6).

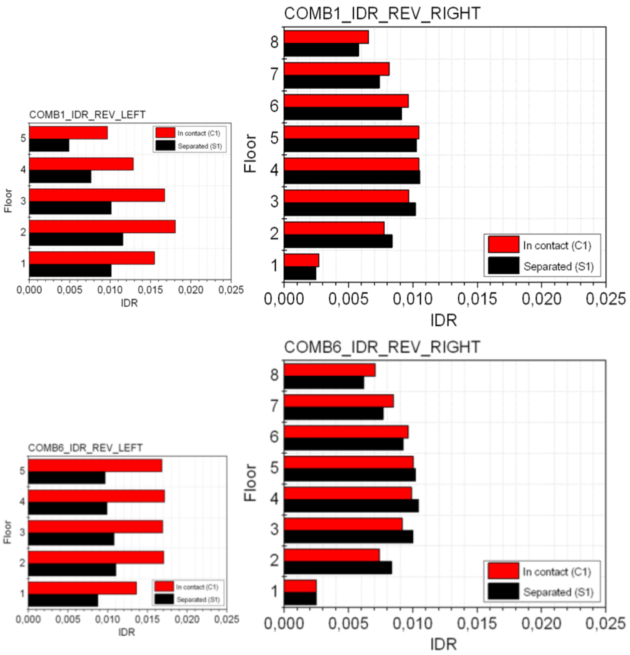

Figure 7. Max. interstorey drifts: BC#1 - BC#6 and REV earthquakes.

Similarly, Fig. 8 presents the maximum interstorey drifts for the case of S-S earthquakes, examining collided and separated structures, and for the 1st and the 6th Buildings' Configurations (BC#1 and BC#6).

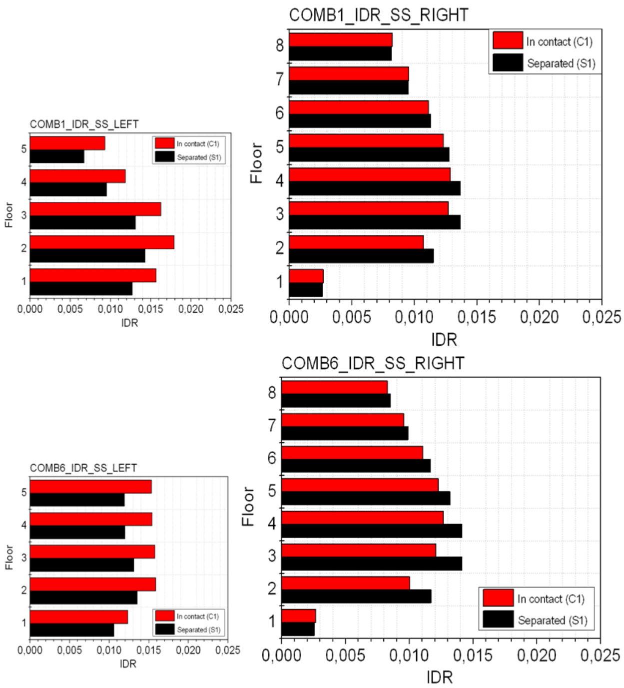

Figure 8. Max. interstorey drifts: BC#1 - BC#6 and S-S earthquakes.

It is obvious that the collided structures have higher interstorey drifts in comparison with the separated structures.

Therefore, the structural pounding should be taken into account in order to achieve a reliable seismic design.

V. Conclusions

In this study, four reinforced concrete structures are combined together to produce nine building configurations in order to examine the structural pounding phenomenon between adjacent structures. The study focused on the influence of near-fault earthquakes where strike-slip and reverse or reverse-oblique mechanisms are investigated.

Selected characteristic and total results have been provided in Section IV.

It is found that in most of the examined cases, the structural pounding phenomenon appears to be detrimental than beneficial. Therefore, although its complexity, this phenomenon should be taken into account since its ignorance will not lead to conservative results.

Furthermore, examining ground motions from near faults with different mechanism, it can be concluded that the strike-slip earthquakes seem to be more intense for the higher buildings examined here in comparison with the same structures subjected to earthquakes with reverse fault mechanism. On the other hand, earthquakes with reverse faults appear to be more intense for the lower structures examined here.

More investigation is needed to examine the behavior of three-dimensional reinforced concrete structures or to examine collided structures under near-fault earthquakes that have been made of other materials, i.e., steel buildings, masonry, etc.

ACKNOWLEDGEMENTS

The 2nd Member of Examination Committee, Prof. Dimitri E. Beskos, is gratefully acknowledged for his valuable comments during the writing and presentation of the corresponding Thesis.

REFERENCES

Anagnostopoulos, S. A., & Karamaneas, C. E. (2008). Use of collision shear walls to minimize seismic separation and to protect adjacent buildings from collapse due to earthquake-induced pounding. *Earthquake Engineering & Structural Dynamics*, 37(12), 1371-1388.

Carr, A. J. (2008). RUAUMOKO–Inelastic dynamic analysis program. Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand.

Cole, G., Dhakal, R. P., Carr, A. J., & Bull, D. (2010). Building pounding state of the art: Identifying structures vulnerable to pounding damage. *In New Zealand Society for Earthquake Engineering Annual Conference—NZSEE, Wellington*.

Moehle, J. P., & Mahin, S. A. (1991). *Observations on the behavior of reinforced concrete buildings during earthquakes*. ACI publication SP-127, Earthquake-Resistant Concrete Structures: Inelastic Response and Design, Ghosh, SK (ed.).