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SEISMIC ANALYSIS OF ADJACENT BUILDINGS WITH POUNDING EFFECT

S. PRAGADEESWARAN, S. PRADEEP

Department of Civil Engineering, SRM University, Kattankulathur, Kanchipuram District, Tamil Nadu, India. Email: pragadees.in@gmail.com

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ABSTRACT

During major earthquakes, pounding between two adjacent structures will be an important phenomenon which may cause severe damages to the structures. Structural components of those pounded structures will be greatly damaged during earthquake excitation. Insufficient distances between the structures are the main reason for the pounding effect. To mitigate the effect of the pounding the simplest form is to provide maximum separation distance to the structures. Thus, it is very important to find out the pounding effect of two closely spaced structures during an earthquake excitation. Non-linear seismic analysis has been done to investigate the effect of pounding damage between the two MDOF adjacent buildings subjected to ground motion and the time history analysis has been used for this paper. The results are observed in the form of story shear, story drift and displacement which are helpful to find the occurrence of pounding between the two structures.

Keywords – Non-Linear analysis, Time History analysis, Pounding, Separation distance, Adjacent Structures.

INTRODUCTION

It is expected that when two buildings are very close to one another, they may pound each other. Nowadays, due to increase in population, high rise buildings with minimum separation gap became predominant structures and during an earthquake these structures may affect due to pounding damage. As the separation distances of these adjacent structures are very less, during an earthquake excitation they cannot vibrate out of phase and hit one another and cause pounding damage. Pounding of adjacent structures increases the damage of the structural components in the form of infill wall damage, column shear failure. To avoid these damages which are caused by pounding seismic codes didn't give any pro-per guidelines. Because of these reasons and due to very less land availability in highly populated cities widely all buildings are built extremely close to each other which may tend to damage due to pounding. For the above reason, it is accepted that pounding effect will be an undesirable phenomenon which must be prevented or mitigated. Providing enough gap between the structures will be the most effective and simplest way to reduce the pounding effect. But it is very difficult to execute due to the above reasons. an alternative way which can be used is decreasing the lateral motion [Ruangrassamee and Kawashima, 2001] means, increasing the stiffness of the structure so that the motion of the structures would be in phase. This can be achieved by joining adjacent structures at critical locations or by increasing the damping capacity of the structure by retrofitting the critical elements. In 1985, the Mexico City damaged by a earthquake, revealed that 40% of damaged structures were due to pounding effect.

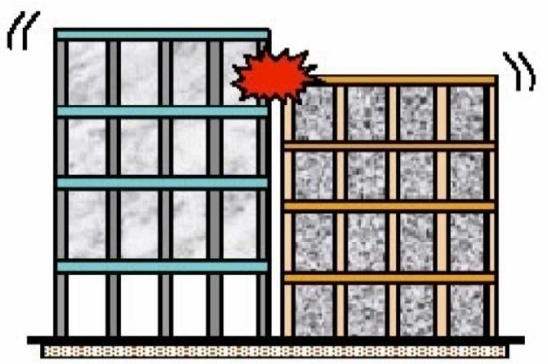


Fig. 1: Occurrence of Pounding

Several researches have been covered the pounding effect for different separation distance with equal and unequal floor heights. It has been said that, two structures which have equal floor heights reduces the pounding effect considerably. Loma Prieta earthquake has been investigated by Maison and Kasai [1992] was the first simplest model which consist of linear spring which did not take energy loss during contact between two structures. The linear visco-elastic model was the second model used by Anagnostopoulos and Spiliopoulos [1992], which was more precise model in considering the energy loss during collision. Non-linear visco-elastic model as a powerful tool has been used recently for simulating pounding effect during an earthquake [Jankowski 2006a]. This model was used for deriving of the impact pounding force spectrum between two structures which have been modeled as two SDOF systems [Jankowski, 2006b]. In fact, this research has completed the studies by Ruangrassamee and Kawashima [2001] concerning relative displacement response spectra. The pounding effect with different mass ratio was also conducted by Jankowski [2010]. He also performed non-linear analysis for two equal heights [Jankowski, 2006a]. Structures with different dynamic properties results that, collisions leds to significant influence on the lighter structures. Maison and Kasai [1990, 1992] considered two structures with non-equal heights in order to simulate pounding effect in MDOF systems. The inter-story pounding effect between two unequal story heights were examined, where several springs with infinite stiffness were used at different places in the pounding modeling process [Karayannis and Favvata, 2005]. Hertz law of contact for a non-linear elastic model which was modeled more realistically [Davis, 1992]. Linking building beams [Westermo, 1989] which can transmit the forces developed between the structures and thus eliminating the collisions. The seismic responses of two adjacent buildings in city areas to several strong earthquakes were analyzed by Anagnostopoulos and Spiliospolos [1992], taking into account of the mutual collisions, resulting from insufficient or non-existing separation distances [Papadrakakis and Mouzakis,1995, Chau, et al., 2003]. A shaking table test considering different cases for pounding analysis [Papadrakakis and Mouzakis,1995, Chau, et al., 2003]. As a new attempt was made by Jankowski [2010] determined the coefficient of restitution (e), for different materials based on the experimental analysis.

MODELLING and SPECIFICATION

Two adjacent structures which have different heights were modeled in this paper. The buildings are 15 and 10 stories with 45m and 30m total heights respectively. The height of each story is assumed to be 3m. The structures are modeled for reinforced concrete frames which consist of four bays in both X-direction and in Y-direction each of 5 m and square columns of dimension 400x400 mm size, the buildings were assumed to be fixed at the base and the floors act as rigid diaphragms. All beams are of dimension 300x400 mm. The sections are selected from IS 13920-1993 [Ramadevi and Shri, 2015]. Moreover, 150mm slab thic-kness has been assumed for the selected frame. The grade of the concrete was assumed to be M30 grade. The two structures have been analyzed to be separated with 3 m and 25 mm gap separation. The built-up area of each floor is 400 Sq.m. the lan view if the model been shown in fig. 2 and lan view if the model been shown in fig. 2 and 3.

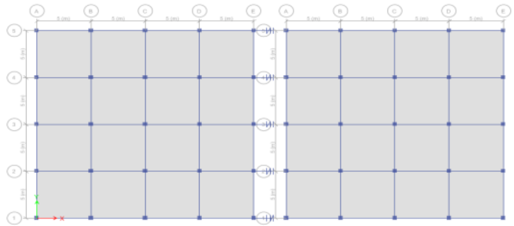


Fig. 2: Plan view of two adjacent structures with 3 m separation gap

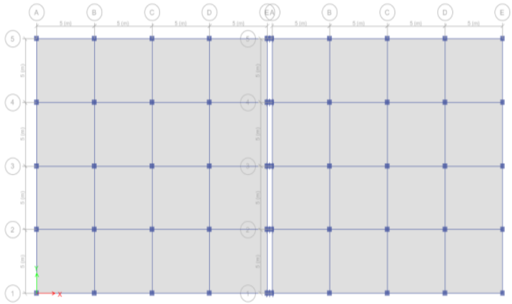


Fig. 3: Plan view of two adjacent structures with 25 mm separation gap

All levels of stories from 10th story were linked with gap elements at 5 nodes between the structures of the model as shown in fig 4. To simulate at which story the contact occurs and to determine the pounding force during the two structures approach each other after pounding. The gap element is introduced because it is only a compression element which will be used to assess the force developed due to pounding. The main purpose of these gap elements is when two structures come in contact with each other they transmit the force through the gap links.

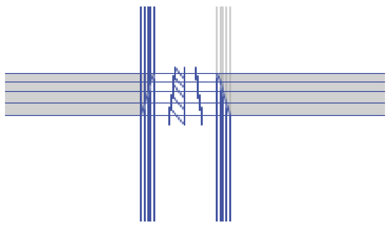


Fig. 4 Gap element linked with two structures

TIME HISTORY ANALYSIS

This type of analysis is the most used dynamic analysis used to find the dynamic response of the structures which is subjected to earthquake loading. In this method of analysis, a mathematical model of the previous earthquake data were used to analyze the structure. In this paper time history analysis are performed by considering El Centro earthquake loading as seismic time history functions which have magnitude of 7.1 in the year

1941. The graph of the function has been illustrated in fig. 5.

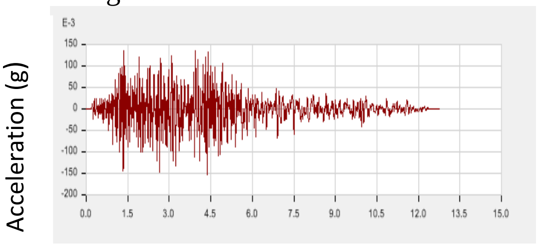
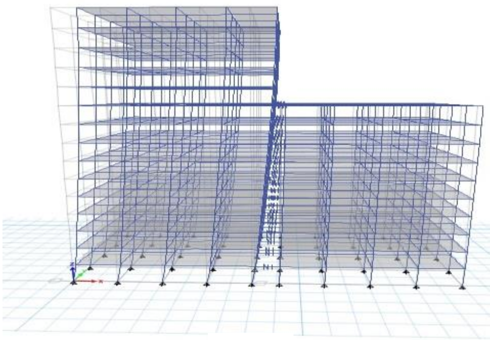
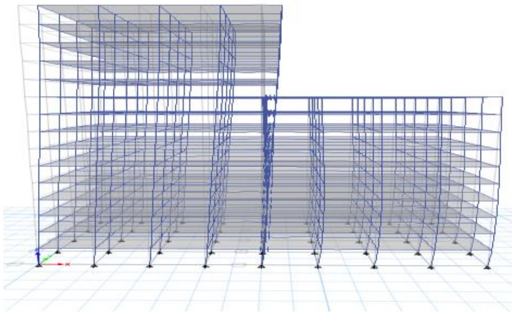


Fig. 5: Time History of El Cento earthquake

Fast nonlinear analysis technique has been considered to analyze the models [Thenmozhi and Shri, 2012]. The method of analysis is very efficient because it is developed for structural systems that are primarily linearly elastic, but the nonlinear elements are limited to a predefined number. All nonlinearities in this method are restricted to gap link elements. A specific time history load is applied in this method quasi-statically with high damping. This time history function has been considered as a ramp type function by the FNA method. Over a certain period of time this time history function increases linearly from zero to one. The nonlinear equations were solved automatically and iteratively in each and every time step of the time history function. During each and every time step the program considers that the analysis results varies from one another. The iterations will be carried out until the solution converges. The program divides the time step to more-smaller sub-steps and tries again and again automatically if convergence is not achieved. Fig. 6 shows the maximum deformed positions of two adjacent structures after the El Centro earthquake loading given to the structures.



(a)



(b)

Fig 6. Seismic Response of buildings with (a) 3 m gap distance (b) 25 mm gap distance

RESULTS AND DISCUSSIONS

The analysis result in terms of story drift, story displacement and story shear and are presented as follows,

STOREY DISPLACEMENT

The displacement of the structures separa-ted with 25 mm gap distance are shown in the table 1 which shows that the maximum displacement between the structures varies gradually as the height of the structure increases. It is also shown that there is a large-difference between the maximum story displacements between the 10th and 11th stories of the structures which is due to the impact force induced due the occurrence of the pounding when the taller structure hits the smaller structure.

Table 1: Max. Story displacement for 25 mm separation gap

Max. Storey displacement for 25mm separation gap		
storey	X-Dir Max	X-Dir Min
	mm	mm
storey15	0.0003388	-0.001
storey14	0.0003396	-0.001
storey13	0.0003451	-0.001
storey12	0.0003518	-0.001
storey11	0.0003584	-0.001
storey10	0.000422	-0.001
storey9	0.0003801	-0.001
storey8	0.0003613	-0.001
storey7	0.0003514	-0.0004847
storey6	0.0003342	-0.0004566
storey5	0.0003437	-0.0004194
storey4	0.0003424	-0.0004078
storey3	0.0003174	-0.0003984
storey2	0.0002656	-0.0003445
storey1	0.0001826	-0.0002353
Base	0	0

Fig. 7 shows a large displacement in minimum direction which shows that pounding effect will be more for shorter structure due to the displacement of the larger structure at pounding level which is at the 10th story level. The effect of pounding may also cause damage to 8th and 9th story levels.

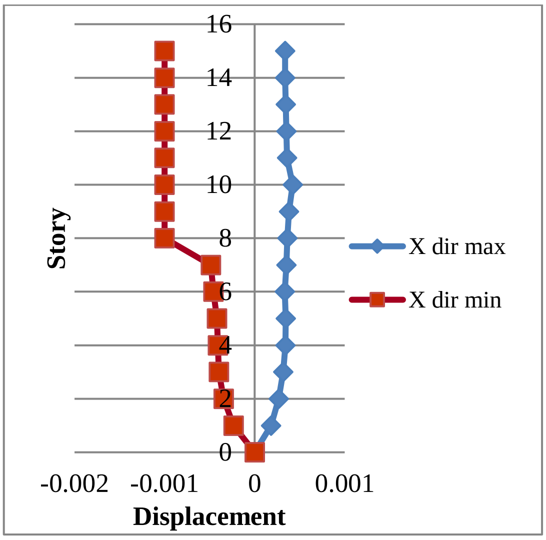


Fig 7. Story displacement for 25 mm

Table 3 shows the results of the displacement of the two structures with 3m separation distance where there is only gradual increase throughout the structure while the minimum displacement also increases from base since there is no effect of pounding between the structures.

Table 2: Max. Story displacement for 3 m separation gap

storey	X-Dir Max	X-Dir Min
	Mm	Mm
Story15	0.439	-0.439
Story14	0.433	-0.433
Storey13	0.425	-0.425
Story12	0.414	-0.413
Story11	0.399	-0.399
Story10	0.382	-0.183
Story9	0.361	-0.180
Story8	0.337	-0.174
Story7	0.31	-0.165
Story6	0.28	-0.153
Story5	0.247	-0.139
Story4	0.211	-0.122
Story3	0.174	-0.102
Story2	0.133	-0.079
Story1	0.085	-0.051
Base	0	0

STORY DRIFT

The story drift in each floor level of the adjacent structures were shown in table 4. Only a negligible amount influence in story drift can be seen during pounding effect. A study by Jankowski [2010] also shows that pounding effect between the main building and stairway tower with larger mass and stiffness may response similarly for pounding effect. This is because the interaction between the adjacent structures is mainly at direction of pounding. So, during pounding effect there will be only friction force takes place between the structures. Thus, from the results it is shown that the story drift will response identically for the structures affected by pounding damage.

Table 3 Storey drift for 3 m and 25 mm separation gap

Storey	3m separation gap	25mm separation gap
	X-Dir	X-Dir
Storey15	0.000239	0.000666
Storey14	0.000373	0.000986
Storey13	0.000499	0.001279
Storey12	0.000608	0.001531
Storey11	0.0007	0.001741
Storey10	0.000774	0.001912
Storey9	0.000834	0.002048
Storey8	0.000879	0.002153
Storey7	0.000913	0.002229
Storey6	0.000936	0.00228
Storey5	0.00095	0.002311
Storey4	0.000959	0.002332
Storey3	0.000982	0.002386
Storey2	0.001121	0.002723
Storey1	0.001947	0.00473
Base	0	0

Fig. 8 shows a large drift in at 1st storey level for the ground acceleration. Since, there is only friction force which is taking place between the structures, the story drift would response same for pounding affected structures.

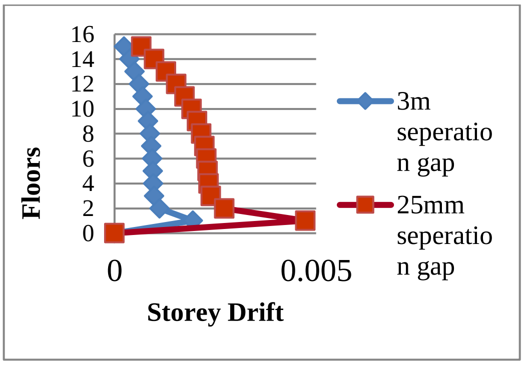


Fig. 8: Storey drift for both 3 m and 25 mm separation gap models

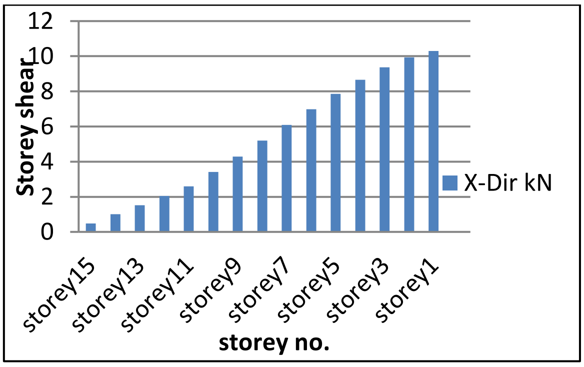
STORY SHEAR

Story shear amplification for each floor level with different gap distances are shown in table 5. The effect of pounding can be said to be occurred since there is sudden increase of story shear at 10th story of the structure comparing to the 11th story level. It can also be said that pounding effect may cause damage at 6th story level as the story shear is maximum at that level. Another important factor can be observed is that the story shear is reduced in consistent manner as the gap distance increases. From the table 5, it is observed that, at 10th floor level, the story shear amplification for the structures separated with 25 mm gap is 0.0131 kN and for 3 m gap is 3.406 kN. This is because increase in gap size reduces the effect of pounding damage can be minimized.

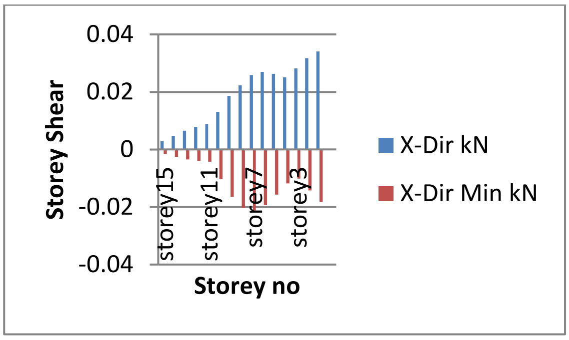
Table 4 Storey shear for 3 m and 25 mm separation gap

	25 mm separation gap		3 m separation gap
	X-Dir min kN	X-Dir max kN	X-Dir max kN
Storey15	-0.0016	0.0028	0.4834
Storey14	-0.0026	0.0047	1.0018
Storey13	-0.0035	0.0065	1.5244
Storey12	-0.004	0.0078	2.0524
Storey11	-0.0042	0.0088	2.585
Storey10	-0.0104	0.0131	3.4069
Storey9	-0.0165	0.0186	4.2905
Storey8	-0.0202	0.0223	5.1898
Storey7	-0.0213	0.0258	6.0912
Storey6	-0.0194	0.0269	6.9801
Storey5	-0.0157	0.0263	7.8537
Storey4	-0.0118	0.0251	8.6617
Storey3	-0.0101	0.0282	9.3679
Storey2	-0.0142	0.0317	9.935
Storey1	-0.0182	0.0341	10.3076
Base	0	0	0

Fig 9a and b shows story shear of the structures with 3m and 25mm gap distance respectively. It is clearly seen that the story shear is gradually decreased from the bottom story for the 3m separation gap because of ground acceleration and shows that there is no pounding effect between the structures. Whereas, for the 25mm gap distance it is clearly seen that the story shear does not reduces gradually and thus results that effect pounding damage between the structures.



(a)



(b)

Figure 9 Storey shear response of (a) 3m separation gap and (b) 25mm separation gap

CONCLUSION

The time history analysis for two models with two adjacent buildings with 15 and 10stories separated by 3m and 25mm separation gap distances results that, the pounding effect will be more for the top story of the shorter building since the displacement of the structure at the pounding level is more and even cause some damages to stories below the pounding level. The story drift tends to be reduced above the pounding state as the displacement of the stories will be reduced above the pounding state. As the two buildings come in contact with each other frictional force will be developed and thus the story shear at the pounding level will be more. From these results, it is shown that the occurrence of the effect of the pounding is maximum if the two structures are very close to each other.

REFERENCES

Anagnostopoulos, S. and K. Spiliopoulos, An Investigation of Earthquake Induced Pounding between Adjacent Buildings. Earthquake Enginee-ring and Structural Dynamics 21: 228-302 (1992).

Chau, K.T., X.X. Wei, X. Guo and C.Y. Shen, Experimental and theoretical simulations of seismic poundings between two adjacent structures. Earthquake Engineering and Structural Dynamics 32: 537–554 (2003).

Davis, R.O., Pounding of buildings modelled by an impact oscillator. Earthquake Engineering and Structural Dynamics 21: 253–274 (1992).

Jankowski, R., Analytical expression between the impact damping ratio and the coefficient of restitution in the non-linear viscoelastic model of structural pounding. Earthquake Engineering and Structural Dynamics 35: 517–524 (2006a).

Jankowski, R., Experimental study on earthquake-induced pounding between structural elements made of different building materials. Earthquake Engineering and Structural Dynamics, 39: 343–354 (2010).

Jankowski, R., Pounding force response spectrum under earthquake excitation. Engineering Structures 28: 1149–1161 (2006b).

Karayannis, C.G. and M.J. Favvata, Earthquake induced interaction between adjacent reinforced concrete structures with non-equal heights. Earthquake Engineering and Structural Dynamics 34: 1–20 (2005).

Maison, B.F. and K. Kasai, Analysis for type of structural pounding. Journal of Structural Engineering 116: 957–977 (1990).

Maison, B.F. and K. Kasai, Dynamics of pounding when two buildings collide. Earthquake Engineering and Structural Dynamics 21: 771–786 (1992).

Papadrakakis, M. and H.P. Mouzakis, Earth quake simulator testing of pounding between adjacent buildings. Earthquake Engineering and Structural Dynamics 24: 811–834 (1995).

Ramadevi, K. and S.D. Shri. Flexural Behaviour of Hemp Fiber Reinforced Concrete Beams. ARPN Journal of Engineering and Applied Sciences 10: 1819-6608 (2015).

Ruangrassamee, A. and K. Kawashima, Relative displacement response spectra with pounding effect. Earthquake Engineering and Structural Dynamics 30: 1511–1538 (2001).

Shri, S. Deepa and R. Thenmozhi, Flexural behavior of hybrid ferrocement slabs with microconcrete and fibers. Int. J. Emerg. Trends. Eng. Dev. 4(2): 165-177 (2012).

Thenmozhi, R. and S.D., Shri, An Experimental investigation on the flexural behavior of scc ferrocement slabs incorporating fibers. International Journal of Engineering Science and Technology 4(5): 2146–2158 (2012)

Westermo, B.D., The dynamics of inter-structural connection to prevent pounding. Earthquake Engineering and Structural Dynamics 18: 687–699 (1989).