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3-D ANALYSIS OF TORSIONAL POUNDING BETWEEN TWO ADJACENT BUILDINGS

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ملخص البحث

تتعرض المبانى عند حدوث زلزال الى حركه جانبيه يتم اخذها فى الاعتبار اثناء التصميم تبعا لما يقرره الكود المستخدم فى التصميم, و لكن نجد فى اماكن متتعدده - غالبا فى المدن الرئيسيه - انه يتم انشاء المبانى ملاصقه لبعضها البعض لاسباب عديده اهمها الازدحام و زياده عدد السكان و غلو سعر الاراضى, وعندما تتعرض هذه المبانى فى هذه الحاله للزلزال فيحدث تصادم بينها و بين المبانى الملاصقه لها لم تكن مصممه علي تحمله و بالتالى تحدث مضاعفات فى المبانى, قد تصل الى الانهيار التام. و بالرغم من ان معظم الاكواد تنص على وضع طريقه لحساب المسافه الصغرى المسموح بها بين المبانى و التى ان قلت المسافه بين المبانى عنها حدث التصادم, الا انه فى واقع البناء الفعلى لا يتم حساب هذه المسافه فى كثير من الاحيان للاسباب الموضحه سابقا.

يركز هذا البحث على دراسه التصادم بين المبانى فى حاله حركه المبانى حركه جانبيه فقط و ايضا فى حاله حركتهم حركه حانبيه والتوائيه معا, و تم تمثيل المبانى تمثيل ثلاثى الابعاد باستخدام برنامج SAP2000, وو جد ان فى حاله الحركه الالتوائيه يظهر تاثير التصادم بشكل اوضح و اكبر على المبانى عن حاله الحركه الجانبيه فقط.

ABSTRACT

Pounding between adjacent structures is commonly observed phenomenon during earthquakes. In metropolitan areas, due to increasing population and land values buildings have been constructed very close to each other. Although seismic pounding between adjacent structures is considered in codal provisions, the practice of construction is still a problem in developing countries resulting more vulnerable during earthquakes.

The main aim of this paper is to analyze and study the seismic response due to lateral and torsional pounding between the buildings which are constructed without sufficient seismic gap especially the case of zero gap distance.

To study the effect of structural pounding, a 3-D model of two adjacent buildings was built using SAP2000 software, where the left building suffers from torsional rotations prior to the occurrence of pounding, as well as having double the mass of the right building.

The pounding responses of the two structures were calculated, and it was found that the effect of collision is more prominent when the structures suffer from torsional rotations while pounding each other, also that the heavier structure resist the motion of the adjacent lighter building.

Keywords: Pounding, Torsion, SAP2000, 3-D, Mass, Adjacent buildings, Gap

1 Introduction

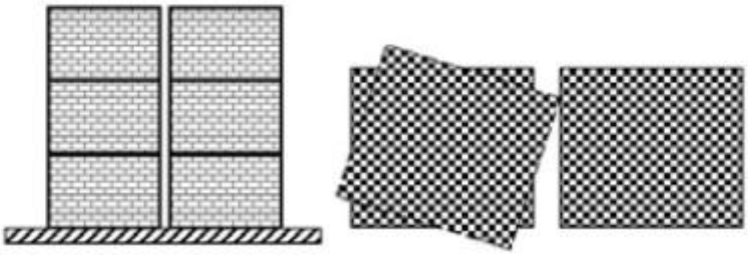
In past earthquakes (Northridge 1994, Kobe 1995, Sichuan 2008, and Lomaprieta 1989 [7], many buildings suffered from damaged in their structural and nonstructural elements, one of the main reasons of that damage is seismic pounding.

Seismic pounding (i.e. collisions between adjacent structures due to earthquakes) was frequently observed in past and recent earthquakes, and during 2007 Niigata Chuetsu-Oki Japan (M6.8, 2007) Earthquake [5] pounding damage was observed to school buildings. This type of damage had occurred when slab levels of adjacent structures were located at different elevations. From figure 1 pounding occurred between two – three story structures during Wenchuan earthquake in 2008. Due to insufficient separation distance, two story structure was colliding with existing three story structure having a setback of 3 m (approximately). (Figure 1) illustrated that pounding occurred between an old and new buildings during L'Aquila earthquake in 2009. There would be slight damage to new structure [12].

Figure 1: Pounding occurred during 12 Dec 2008, Wenchuan Earthquake, the two structures collided due to torsional vibration.

Structural pounding damage in structures can arise from the following: (1) Adjacent structures with same height and same slab levels (Figure 2a). (2) Same slab levels but with different heights (Figure 2b). (3) Structures having different dynamic properties and characteristics. (4) Buildings that have a lateral load resisting systems that is irregular in plan suffer from torsional rotation during an earthquake, and due to this rotation, pounding happens near the building edges against the adjacent buildings (Figure 2c) [12].

Mitigating pounding and reducing the damage it produces is very important, and the most effective way of mitigation of pounding is to provide sufficient separation distance between the adjacent buildings. So, it is essentially very important to study the pounding of buildings during earthquakes not only for safety but also to establish appropriate design guidelines [12].



(a) (b)

Figure 2: Presenting different cases in which pounding may occur

Large number of studies has been conducted on seismic pounding between adjacent structures to study the behavior of structures. Among them, Anagnostopoulos S A examined the case of several adjacent buildings in a row subjected to pounding [1]. Leibovich et al. studied the effect of impact eccentricity on two sets of symmetric and asymmetric models aligned with respect to each other for several gap widths [8]. Papadrakakis et al. developed a three-dimensional finite element model to simulate pounding between adjacent buildings [10]. Gong and Hao studied the torsional pounding between an asymmetric and a symmetric one-story structure subjected to bi-directional ground motion [6]. Mouzakis and Papadrakakis investigated the three-dimensional pounding between two adjacent buildings based on the impulse-momentum relation [9]. Chau and Wei considered the torsional pounding between two adjacent asymmetrical single-story structures using the nonlinear Hertz contact law [2].

2 Modeling of pounding in SAP2000

Most of the research work in last decades concentrated on modeling the pounding phenomenon using 2-D models, because it is easier, taking fewer time, and the behavior of the modeled structures are more obvious than 3-D models. In the last years, few of researchers began to focus on modeling pounding phenomena using 3-D models, but these models were simple and didn’t have many different dynamic characteristics.

The following characteristics were chosen when using Sap2000 for the analysis:

1- A separate horizontal diaphragm has been assigned for each floor for each building.

2- The mass was lumped for each story in a single joint, with an eccentricity of 0.15 L to introduce torsion.

3- Two ground motions were selected for this paper, namely Northridge earthquake and Corralitos earthquake, where the peak ground accelerations of the chosen earthquakes were normalized to 0.15g, which was selected based on Egyptian Code recommendation that assigns such PGA value to Cairo zone.

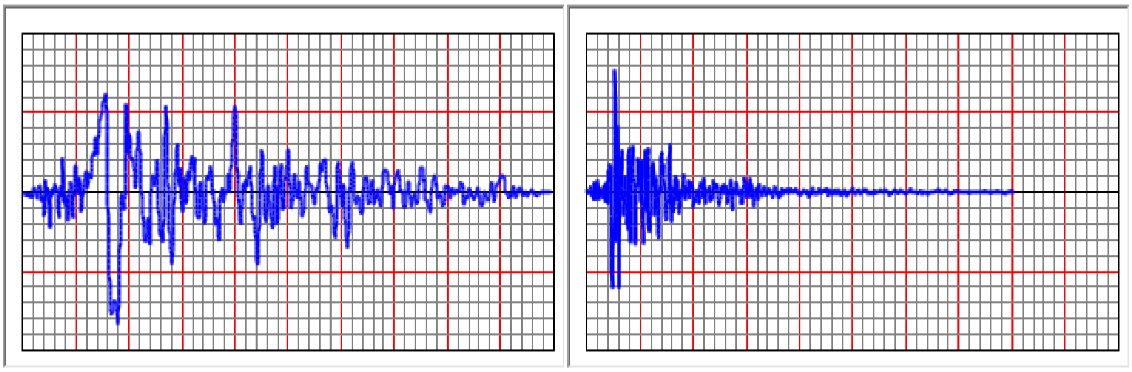


Figure 3: The ground motions used: to the left is the Northridge earthquake, and to the right is the Corralitos earthquake, both with normalized peak ground acceleration to 0.15g

4- Gap joint element is an element which connects two adjacent nodes to model the contact. In SAP2000 modeling for each deformational degree of freedom, independent gap ("compression only") properties may be specified. All internal deformations are independent. The opening or closing of a gap for one deformation does not affect the behavior of the other de formations. The non-linear force- deformation relationship is given by:

$$F = \begin{cases} k(d + open), & \text{if } (\mathrm{d} + \mathrm{open}) < 0 \\ 0, & \text{Otherwise} \end{cases} \tag{3.1}$$

Where (*k***)** is the spring constant, (open) is the initial gap opening, which must be zero or positive, (d) is the displacement in the gap element which has negative value.

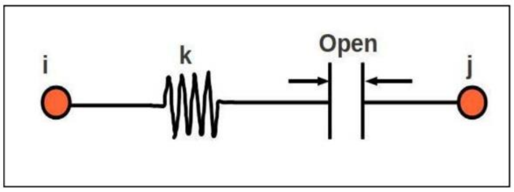


Figure 4: Gap joint used in SAP2000

5- Non-linear Time History Analysis was used on a 50 seconds' duration for the earthquake.

3 Description of building properties

Two buildings were used in this study, were both buildings consist of 10 floors, the height of the first floor is 5 meters from foundation's level and the height of the other floors is 3 meters, the right building has half the mass of the left building.

The columns had been designed per the ECCS 2001 under vertical loads only, and the dimensions of shear walls had been assumed as (4m * 0.3m).

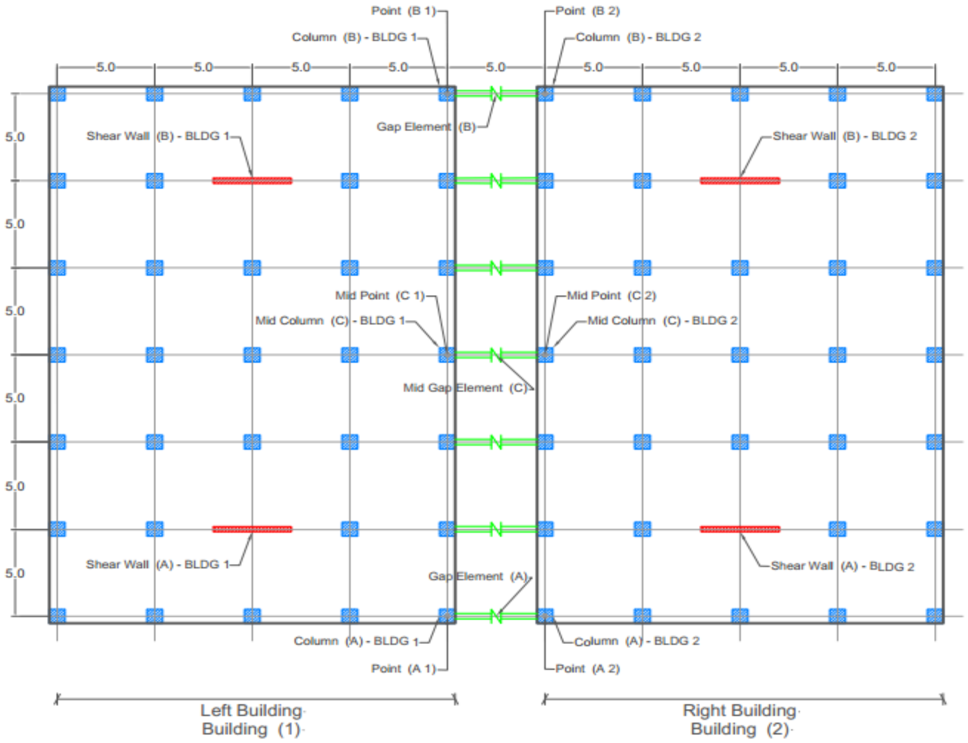


Figure 5: Typical floor plan for illustrating studied points, columns, shear walls, and gap elements.

4 Description of models and results created

Models used are as follows:

1. Lateral Model (M – Lateral): considers that the two buildings have only lateral (translational) movements before pounding occurs.
2. Torsion Model 1 (M.1 - Torsion): considers that the left building has torsional movement before pounding occurs, while the right building doesn’t have torsional movement.

The following figures show the results obtained from the research concerning displacements, shear forces, and moments for the studied buildings.

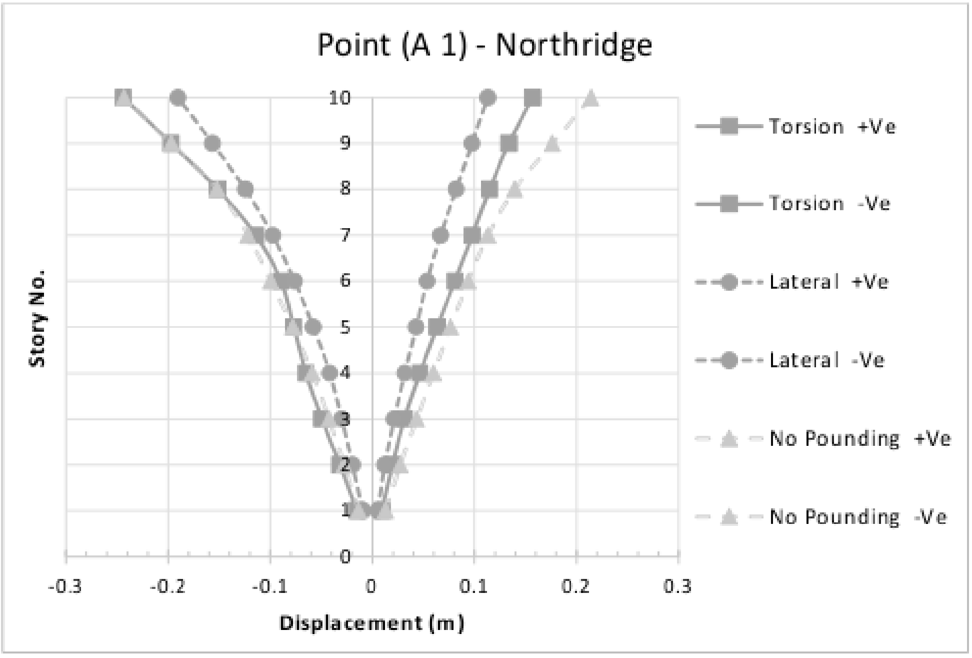


Figure 6: Maximum lateral Displacement for all stories for point (A) in building (1) for all studied models for Northridge earthquake

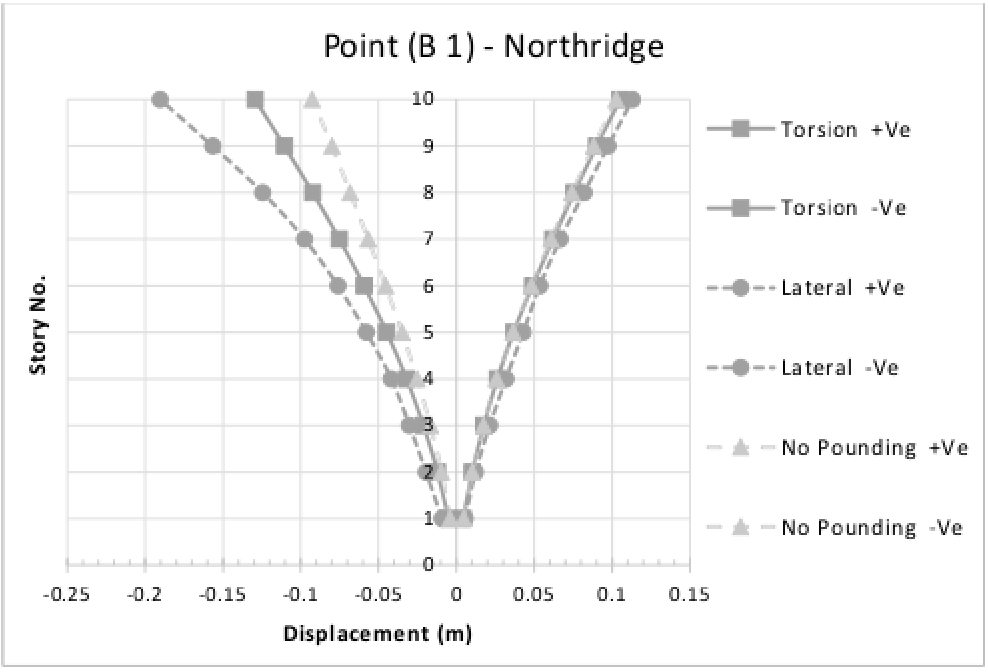


Figure 7: Maximum lateral Displacement for all stories for point (B) in building (1) for all studied models for Northridge earthquake

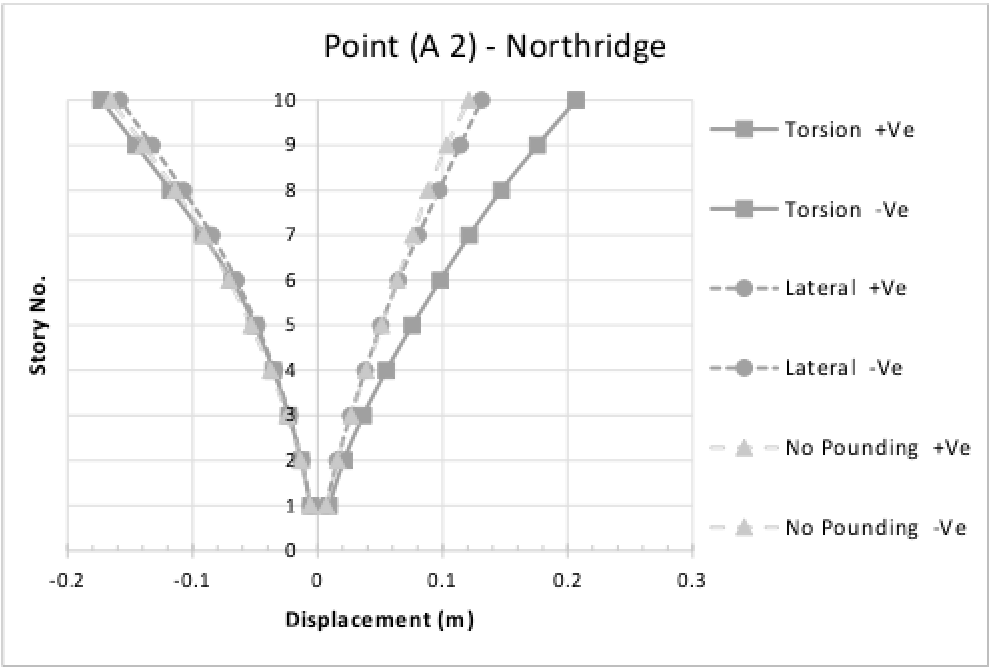


Figure 8: Maximum lateral Displacement for all stories for point (A) in building (2) for all studied models for Northridge earthquake

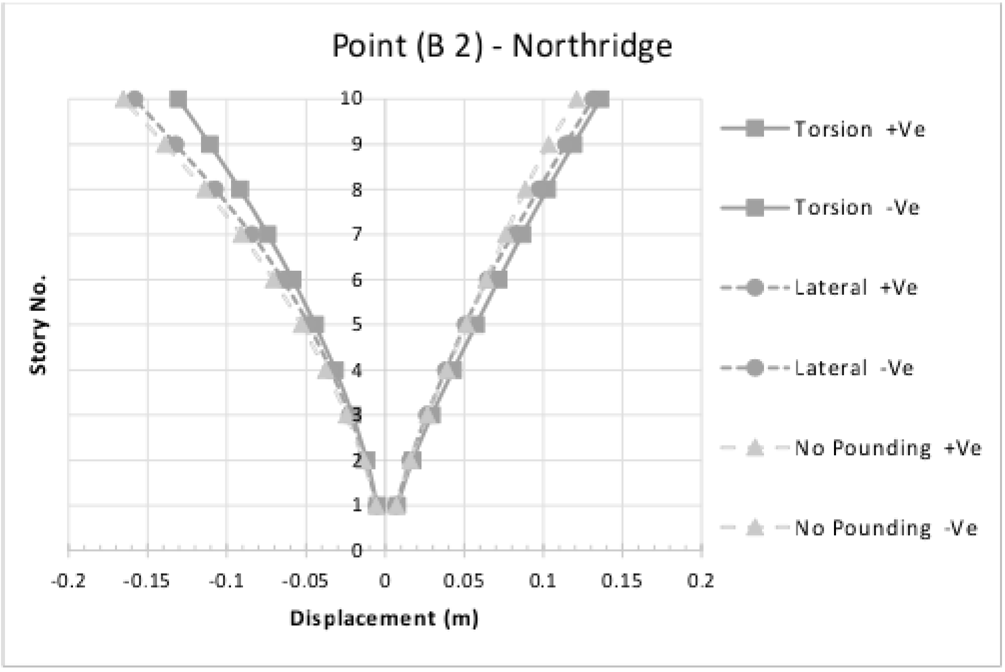


Figure 9: Maximum lateral Displacement for all stories for point (B) in building (2) for all studied models for Northridge earthquake

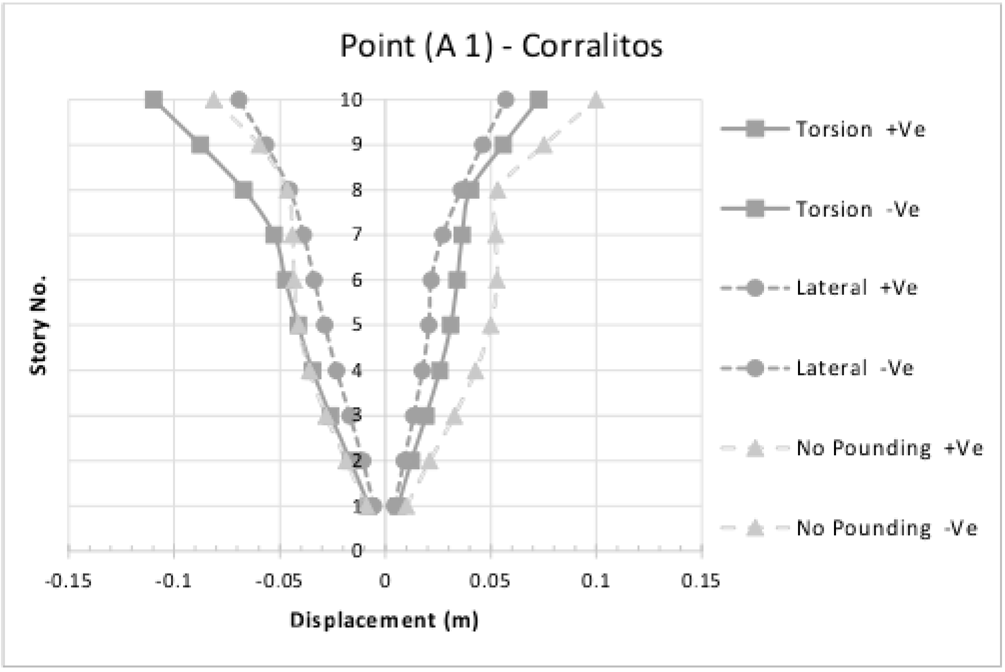


Figure 10: Maximum lateral Displacement for all stories for point (A) in building (1) for all studied models for Corralitos earthquake

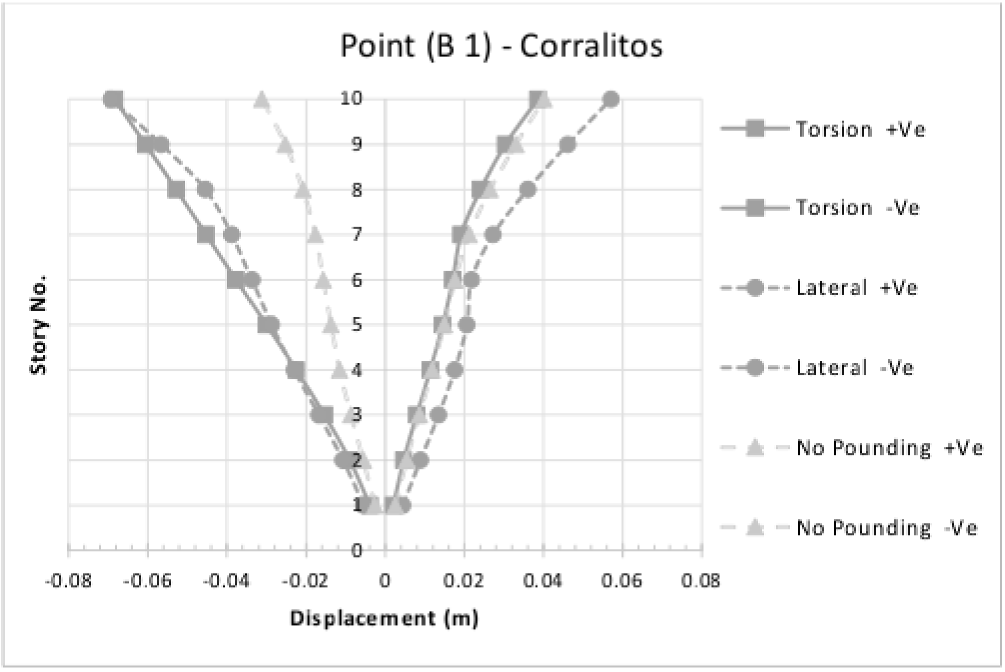


Figure 11: Maximum lateral Displacement for all stories for point (B) in building (1) for all studied models for Corralitos earthquake

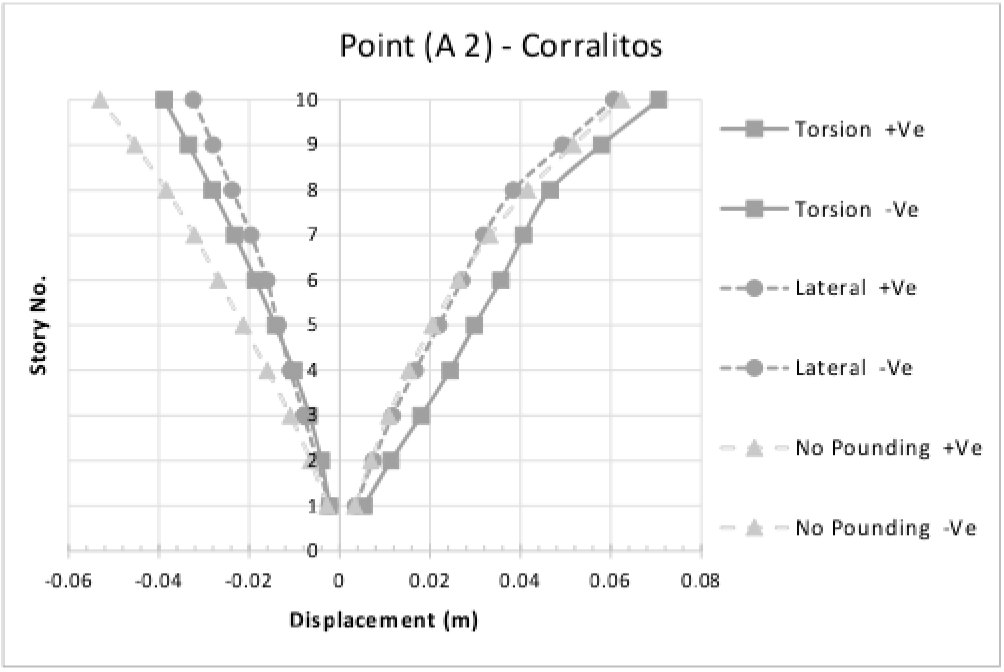


Figure 12: Maximum lateral Displacement for all stories for point (A) in building (2) for all studied models for Corralitos earthquake

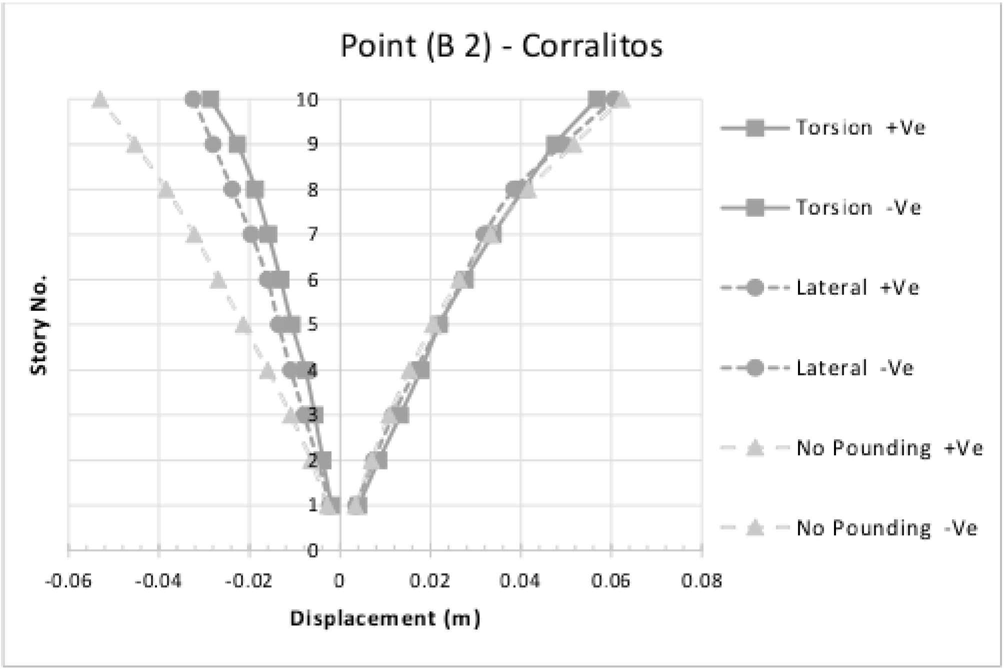


Figure 13: Maximum lateral Displacement for all stories for point (B) in building (2) for all studied models for Corralitos earthquake

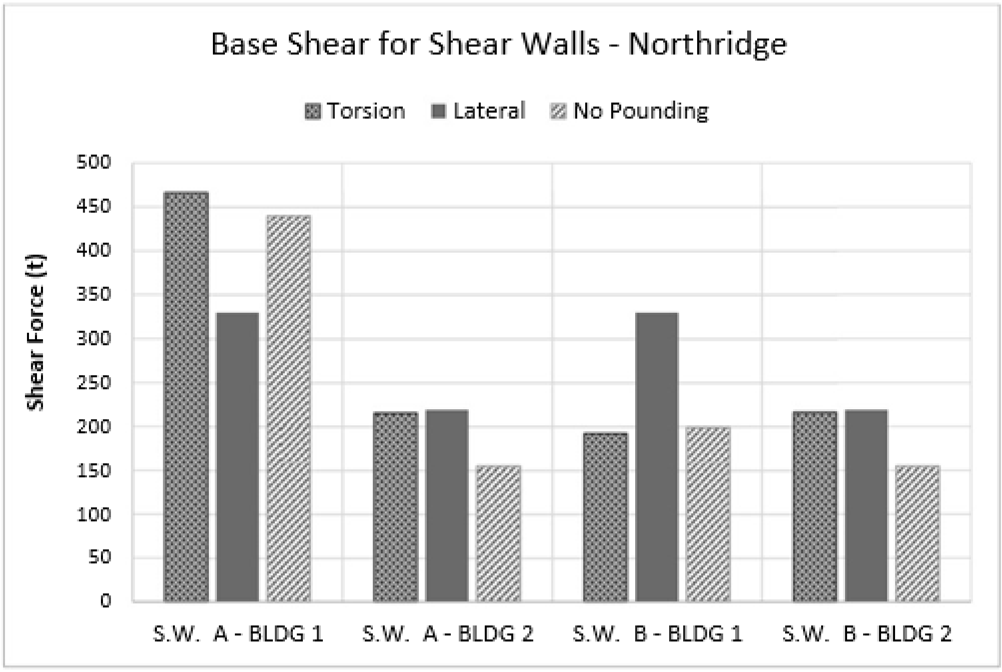


Figure 14: Maximum Absolute Base Shear for Shear Walls (A & B) for BLDGs (1 & 2) for all studied models for Northridge earthquake

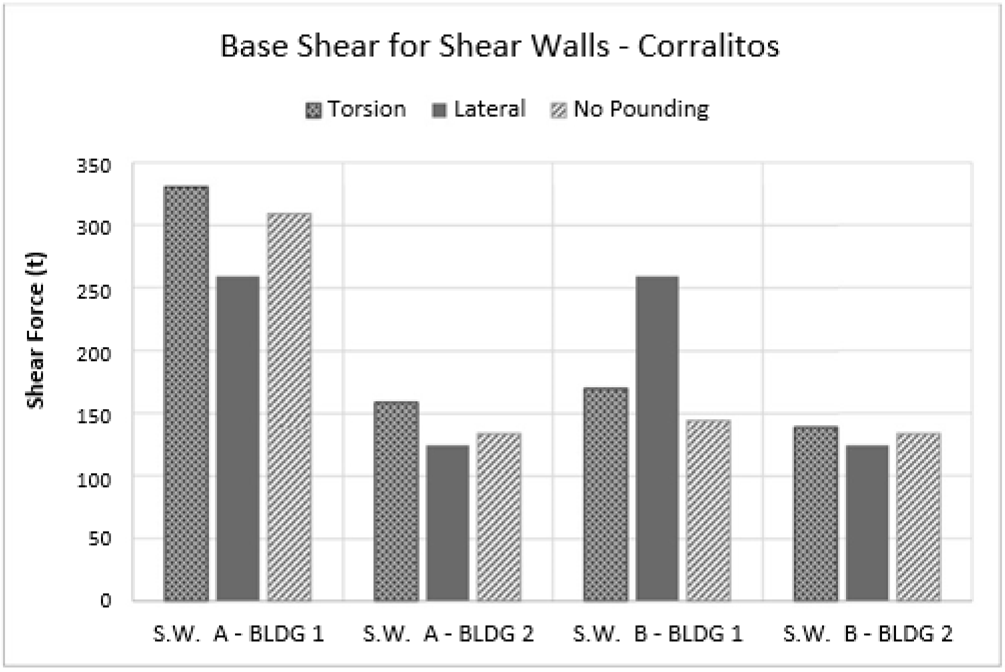


Figure 15: Maximum Absolute Base Shear for Shear Walls (A & B) for BLDGs (1 & 2) for all studied models for Corralitos earthquake

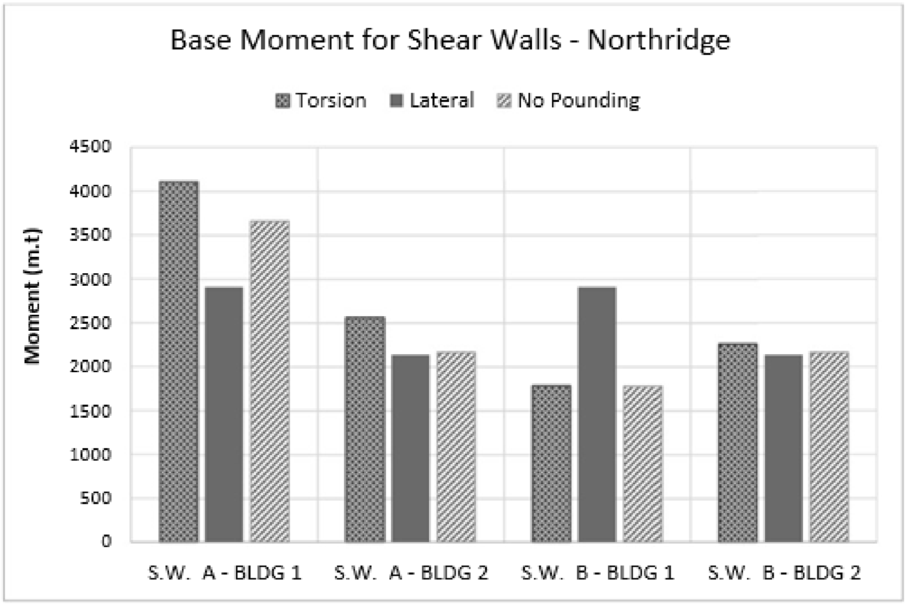


Figure 16: Maximum Absolute Base Moment for Shear Walls (A & B) for BLDGs (1 & 2) for all studied models for Northridge earthquake

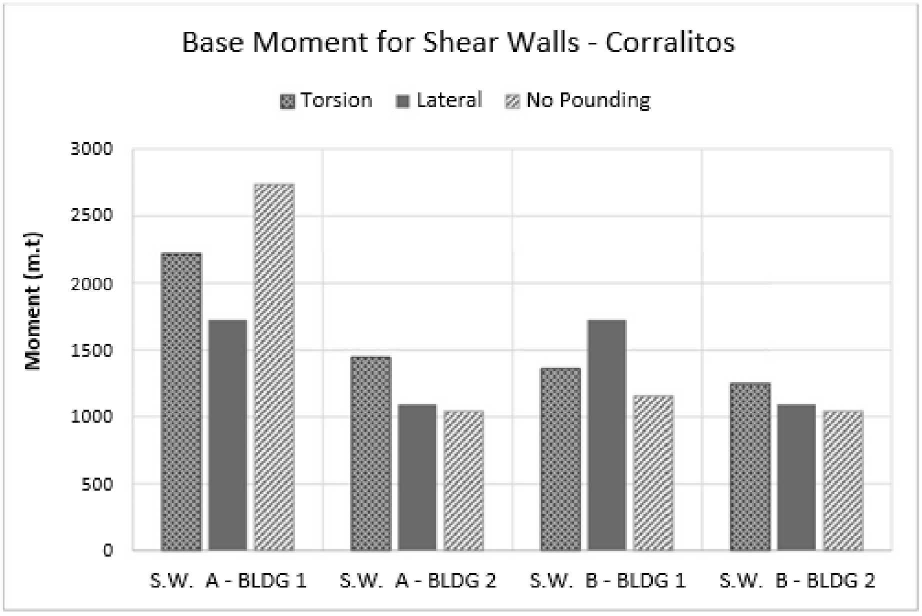


Figure 17: Maximum Absolute Base Moment for Shear Walls (A & B) for BLDGs (1 & 2) for all studied models for Corralitos earthquake

5 Summary and Conclusions

The analysis considered two adjacent buildings suffering from pounding due to recorded earthquake, using 3-D models and time history analysis through a software using the finite element method time history analysis.

The following was concluded:

1. Buildings with heavy masses resist the motion of the adjacent lighter buildings, which results in mitigating displacements and straining actions of those lighter buildings.
2. It was found that, points (A & B) for the left building are mostly higher than their relatives in the right building before and after pounding, which indicates that the left building with its higher mass had higher responses than the one with smaller mass even before pounding.
3. The effect of building torsional movement was found to have a highly significant effect on the pounding response of the adjacent buildings.
4. Both the heavy and light buildings had their responses increase after pounding.

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