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Pounding effectsin RC Frame structures

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Abstract: *Pounding between neighboring buildings is a common phenomenon which can be observed during strong ground motions. It can damage the buildings and also can cause loss of life and property. It is an important phenomenon and therefore, shall be considered in modeling of buildings for structural analysis. In this study, the pounding has been considered in the modeling of two hypothetical case study buildings for seismic Zone 2B as per BCP-SP07 building code of Pakistan. Etabs has been used for the said purpose. The buildings are analyzed using Non-linear modal time histories as per BCP-SP07. Various analysis results have been compared. The analysis results show that pounding increase displacement up to 2 times as compared to without pounding case. Pounding increase, the axial forces up to 230 times and bending moment up to 3 time in the beams being collided. Similarly, the shear forces are also significantly increased in case of pounding as compared to without pounding case.*

Keywords: *Pounding Phenomenon, BCP-SP07, Non-linear Modal Time Histories.*

"I. INTRODUCTION"

Due to the difference in dynamic properties, the relatively tall neighboring buildings can collide during ground shaking of moderate to high intensity. This phenomenon is known as structural pounding. Pounding induces additional forces in structural members at diaphragm level, which results in local crushing or even can cause collapse and ultimately loss of life. Therefore, it is necessary to consider pounding in structural analysis and design [1,2,3,4].
In an extreme event, pounding can even lead to the collapse of structure [5]. In figure 1 & 2 typical cases of ponding are shown [5].

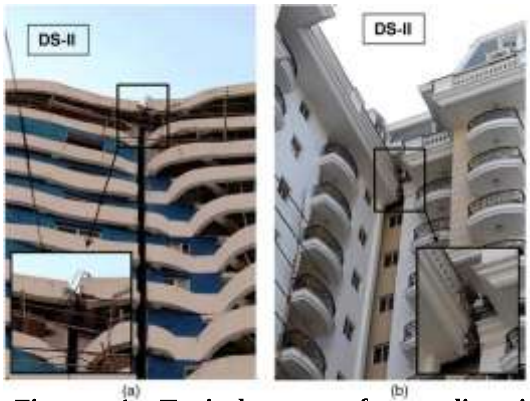

Figure. 1. Typical cases of pounding in apartment buildings with wide separation: (a) Pounding between two blocks (b) Pounding of projected roof cornices.

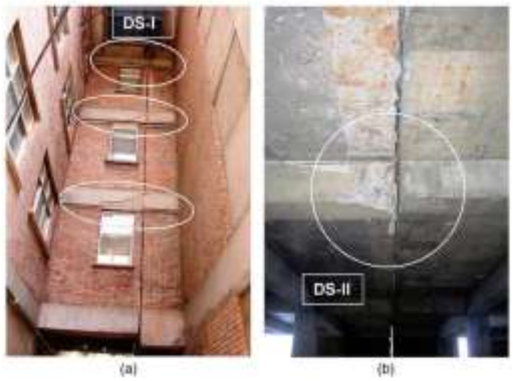

Figure. 2. Typical cases of pounding in building with insufficient separation: (a) Pounding between two blocks (b) Pounding damage at beam.

Deepak R. Pant and Anil C. Wijeyewwickrema conducted ponding studies on a typical four storey base isolated RC building. Three-dimensional finite element analyses were conducted considering geometric and material non-linearities. It was concluded that the performance of the base isolated building is significantly influenced by the pounding. The base isolated building showed good performance against shear failure [6]. Sofia Efraimiadou et all investigated the effect different structural configurations on the collisions between RC building frames subjected to strong ground motions. Nine different arrangements were made from 5-storey and 8-storey frames. The pair of building the subjected to six ground motions compatible with design process. Various parameters were investigated such as ductility, internal forces, storey displacements and interstorey drifts. From the results, it was concluded that collision is unfavorable for most of the cases [7]. Harris P. Mouzakis and ManolisPapadrakakis investigated two adjacent buildings having aligned rigid horizontal diaphragms for linear and non-linear structural response of pounding phenomenon. The three-dimensional dynamic contact conditions for the velocity and acceleration were considered. The results were compared with the lagrange multipliers approach. The elastic and inelastic structural response was also taken into account. From this study it was concluded that the formulation presented as compared to the Lagrange multipliers approach, is computationally more efficient as it can easily incorporated into existing computer codes for elastic and inelastic dynamic analysis of buildings [8].

"II. METHODOLOGY"

The current study is conducted in order to determine the effect of phenomenon in RC buildingsfor seismic Zone 2B as per BCP-SP07. Two case study buildings are condidered. These buildings are analyzed using usingEtabs. One ground acceleration history is considered. The analysis results such maximum displacement, pounding forces and its effects on bending moment and axial forces are compared.
Two buildings of unequal heights have been taken and named as taller building and shorter building. The taller building has 14 storeys (Height=168 ft) and 4 bays in x and y-direction.The column size is 33-inch x 33-inch and beam size is 12-inch x 21-inch. Slab thickness is taken as 7.0 inches. The shorter building has 10 storeys (Height = 120 ft) and 4 bays in x and y-direction. The column size is 27-inch x 27-inch and beam size is 12-inch x 21-inch. Slab thickness is taken as 7.0 inches. The plan of taller and shorter building is shown in figure below. The material properties for both buildings have been shown in Table-1.
Gap element of Etabs is used in the current study. Pounding can be simulated by gap element. It is a compression member only. The separation between the buildings is defined as a gap. The gap element gives axial force when the gap is closed. The gap uses non-linear force deformation relationship as shown in equation 1.

$$f = \begin{cases} K(d - open) & if\ d - open < 0 \\ 0 & otherwise \end{cases} \qquad (1)$$

Where d denotes displacement, open is the initial gap opening which must be zero or positive and k is the stiffness of the element. The stiffness of the gap element should be 100 times greater than the axial stiffness of the connected members.

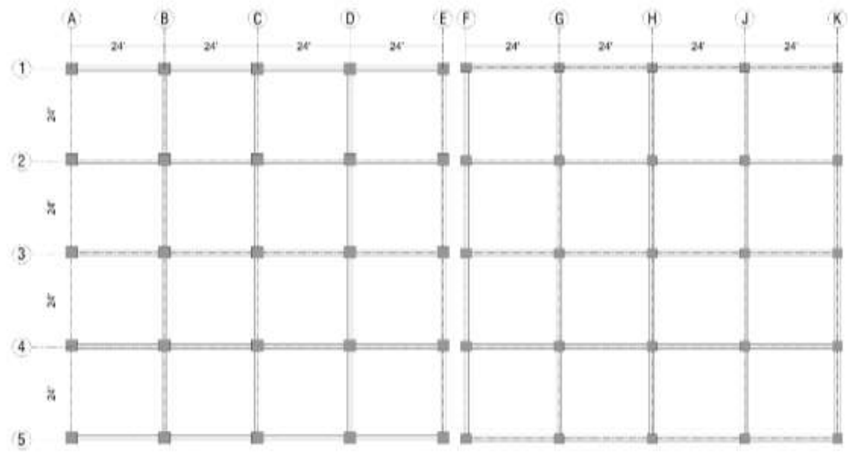

Figure3: Plan view of taller building (left side) &shorter building (right side)

Table-1: Material Properties			
S.No.	Material Description	Material Property	ASTM Designation
1.	Concrete used in Reinforced Concrete Members	Compressive Strength = 4000 psi in columns & 3000 psi in other Structural Members	28-days compressive cylinder strength
2.	Reinforcement Steel used in Reinforced Concrete Members	Yield Strength = 60,000 psi	Grade-60 deformed round bars conforming to ASTM A615

"IV. Results"

The analysis results for both pounding and without pounding cases are discussed under this section. The effect of pounding on pounding forces & spectral displacements are discussed. After this effect on bending moments and axial forces are discussed.
The pounding induces forces at storey levels. Figure 4 shows that maximum pounding force occurs at 12th storey floor level and it decreases from top to bottom.

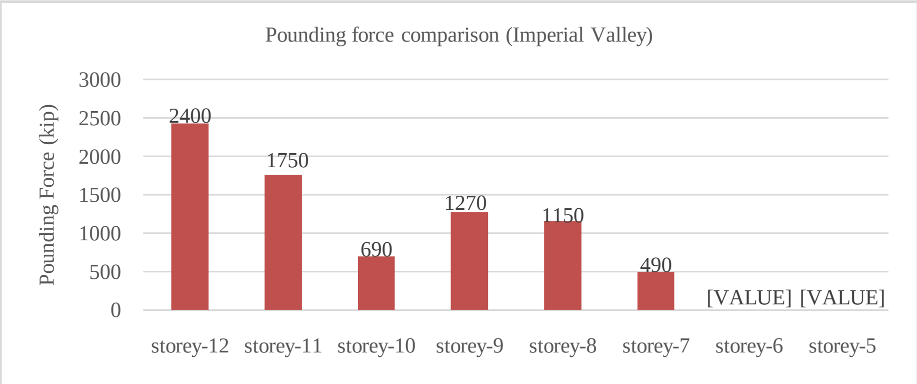

Figure 4: Imperial Valley

The displacement response histories for taller & taller buildings at pounding level are shown in figure 5 & 6, for both pounding and without pounding case corresponding to Imperial Valley ground motion. The displacement response of the taller building is same for both cases before pounding. After the pounding, which happens from 9 to 14 seconds, there is a difference in the displacement response histories for both pounding and without pounding cases. The difference is considerable.

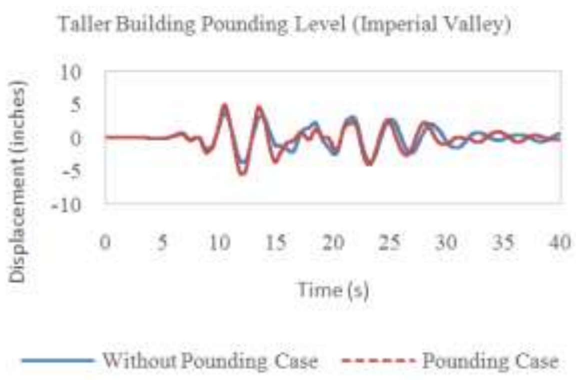

Figure 5: Displacement history of taller building at pounding level

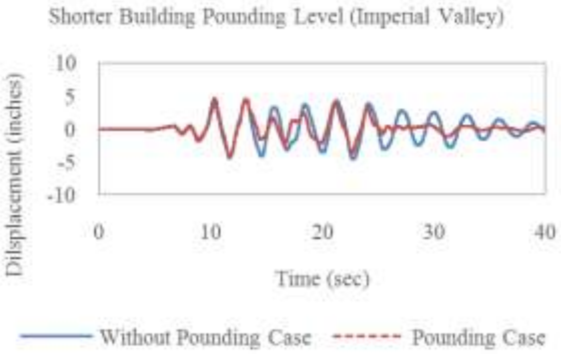

Figure 6: Displacement history of shorter building at pounding level

Figure 7 shows typical beam-column plan of the buildings. Beams named as B-1, B-2, B-3 and B-4 are marked on the plan for which the values of bending moment, axial force & shear force are compared in tables 2, 3 & 4. Table 2 shows that bending moments in pounding case increase up to 2 times as compared to without pounding case. Table 3 shows a tremendous increase in the axial forces for the pounding case as the impact forces developed are directly carried by these beams. Similarly, table 4 shows that the shear forces are doubled in case of pounding as compared to without pounding case.

B-2 B-1

B-4 B-3

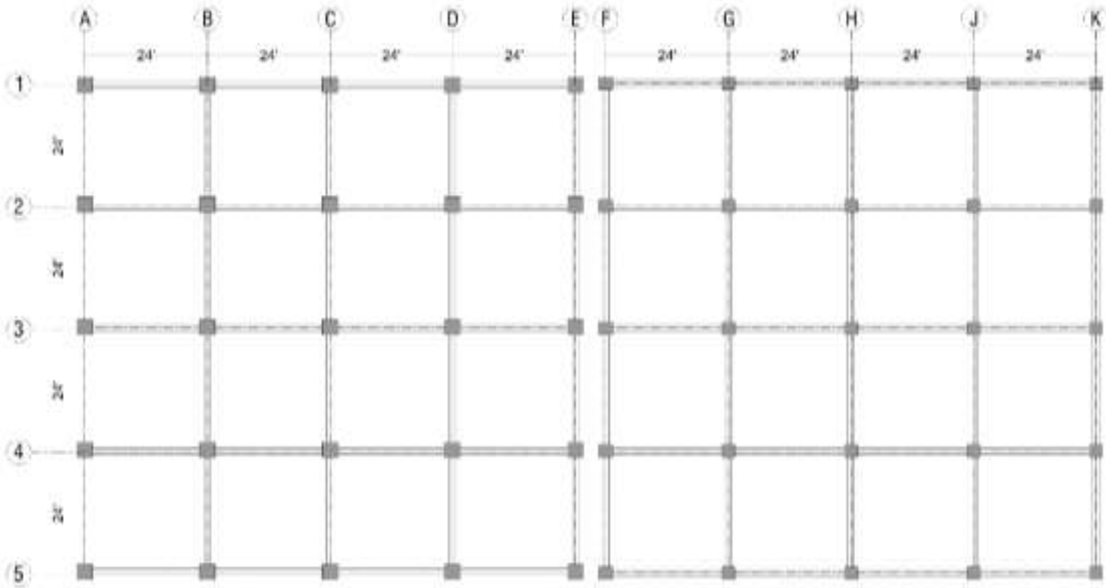

Figure 7:Plan view of taller building (left side) &shorter building (right side)

Table 2Comparison of Maximum Bending Moments (kip-ft) for pounding and without pounding cases			
S. No.	Beam	Without pounding case	Pounding case
1	B-1	56	112
2	B-2	94	148
3	B-3	58	122
4	B-4	98	156

Table 3Comparison of Axial force (kip) for pounding and without pounding cases			
S. No.	Beam	Without pounding case (compression)	Pounding case (compression)
1	B-1	3.5	250
2	B-2	1.5	198
3	B-3	1.0	212
4	B-4	1.2	190

Table 4Comparison of Shear force (kip) for pounding and without pounding cases			
Beam	Beam	Without pounding case	Pounding case
B1	B-1	6.8	13
B2	B-2	14.5	18
B3	B-3	9.2	19
B4	B-4	20.3	26

"IV. Conclusions"

Based on the results of this study following conclusions are drawn.

- Displacement response changes substantially due to the pounding of buildings.
- Pounding increase shear force and bending moment and a tremendous increase up to 230 times in the axial forces.
- The induced pounding forces have large magnitudes which can damage the structural members especially can cause crushing at slab level.
- The pounding forces are significant at top storeys and decreases from top to bottom.

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