Seismic Pounding of Multistoried R.C. Framed Buildings with Effect of Shear Wall

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ABSTRACT

Pounding refers to collision of structures which occurs during earthquake when structures have different dynamic characteristics. In dense urban areas, the potential for closely spaced buildings to pound against each other exists.

In the present work, the pounding phenomenon has been thoroughly studied. The factors affecting pounding such as separation distance, characteristics of earthquake ground motion, type of pounding namely, slab to slab pounding have been investigated. The 12 storey and 8 storey buildings having symmetrical plan dimensions have been considered for pounding study. For analysis, the finite element software SAP2000 has been used and for impact force simulation the linear spring gap element is used. It was observed that, the member forces increased due to pounding. The axial force and bending moment were marginally on higher side in case of mid column pounding. However, the shear force was tremendously increased due to mid column pounding effect. The pounding forces in case of mid column pounding were observed to be less than the slab to slab pounding forces.

To mitigate pounding effects during earthquakes is to consider some pounding reduction techniques so as to enhance the seismic performance of structures without sufficient space in between. One of the methods is linking the buildings at certain locations which allow the forces to be transmitted between structural elements and thus eliminate collisions. In this study the reduction in pounding forces has been achieved by increasing the stiffness properties of buildings using shear walls, as the increase in stiffness of buildings reduces the displacement response of structures and thus less chance of impacts. The reduction in pounding forces has also been achieved by increasing the damping capacity of buildings with the help of shear walls.

***Keywords*- Seismic pounding, Separation Gap, Time history analysis, Shear Wall.**

I. INTRODUCTION

Structures are built very close to each other in metropolitan areas where the cost of land is very high. Due to closeness of the structures, they collide with each other when subjected to earthquake or any vibration. This collision of buildings or different parts of the building during any vibration is called pounding. Depending on the characteristics of the colliding buildings, pounding may cause either architectural and structural damage or even instant collapse of the whole structure. Further, even in those cases where it does not result in significant structural damage, pounding always induces higher floor accelerations in the form of large magnitude, short duration pulses, which in turn cause greater damage to building contents. This may happen not only in buildings but also in bridge decks and towers which are constructed close to each other. For these reasons, it is widely accepted that pounding is an undesirable phenomenon that should be prevented or mitigated. Although some modern codes have included seismic separation requirement for adjacent structures, large areas of cities in seismically active regions were built before such requirements were introduced. Many investigations have been carried out on pounding damage caused by previous earthquakes. Structural pounding damage in structures can arise in the following situations:-

(1) Adjacent buildings with the same heights and the same floor levels.
(2) Adjacent buildings with the same floor levels but with different heights.
(3) Adjacent structures with different total height and with different floor levels.
(4) Structures situated in a row.

(5) Adjacent units of the same buildings which are connected by one or more bridges or through expansion joints.
(6)Structures having different dynamic characteristics, which are separated by a distance small enough so that pounding can occur.
(7) The unsupported part (e.g. mid-height) of column or wall resulting in severe pounding damage.
(8)Majority of buildings constructed according to the earlier code that was vague on separation distance.
(9) Possible settlement and rocking of the structures located on soft soils leading to large lateral deflections.
(10) Buildings having irregular lateral load resisting systems in plan rotate during an earthquake, and due to the torsional rotations, pounding occurs near the building periphery against the adjacent buildings.
In these situations pounding effects can be catastrophic and dangerous than the effect of earthquake on standalone structure. Therefore its evaluation and mitigation is very essential.

II. FORMULATION OF THE PROBLEM

In this section, the pounding equations of Multi-Degree of Freedom (MDOF) system are introduced. On the contrary to the response for an independently vibrating single structure the pounding force response for pounding between two structures depend not only on damping ratios but also on masses and in-between gap size. Equation of motion can be written for the MDOF systems subjected to pounding under earthquake excitation as follows.

$$M\ddot{u}(t) + C\dot{u}(t) + Ku(t) + F_P(t) = M\ddot{u}_g(t)$$

Where, $F_P(t)$is a vector representing the pounding forces at the floor levels. The use of appropriate numerical model of pounding forces $F_P(t)$during collision between structures is essential for the precise determination of the pounding force response. Depending on the structural seismic response of the two adjacent buildings, pounding forces generated by collisions are applied and removed during a short interval of time initiating stress waves, which travel away from the region of contact. The process of energy transfer during impact is highly complicated which makes the mathematical analysis of this type of problem difficult. Several models have been used to simulate pounding force during collisions between structures namely, linear elastic model, linear viscoelastic model, modified linear viscoelastic model, hertz non-linear elastic model, hertz-damp non-linear model and non-linear viscoelastic model . Out of which, linear spring elastic model has been used for pounding study in this paper as displacement response of structure and impact forces of all impact force simulation models were found to be more or less same.

III. STUDY PROGRAM

There are many types of pounding but, slab to slab pounding and mid column pounding are most important and often observed in past earthquakes therefore, these two types of pounding has been studied and discussed in detail.
For analysis, 12 storey and 8 storey buildings having plan dimensions 24m × 24m and bay width 6m have considered and designed as per IS 456:2000. The other analysis details are below in Table II for slab to slab pounding and Table III for Mid Column Pounding.

(A)PROBLEM DEFINITION

To study slab to slab pounding, two shear frame buildings 12 storey and 8 storey are considered. The buildings have plan dimensions of 24 m × 24 m and bay width of 6 m as shown in Figure 4.3, The buildings have been designed as per IS 456 (2000). The other analysis details are presented in Table 4.5.

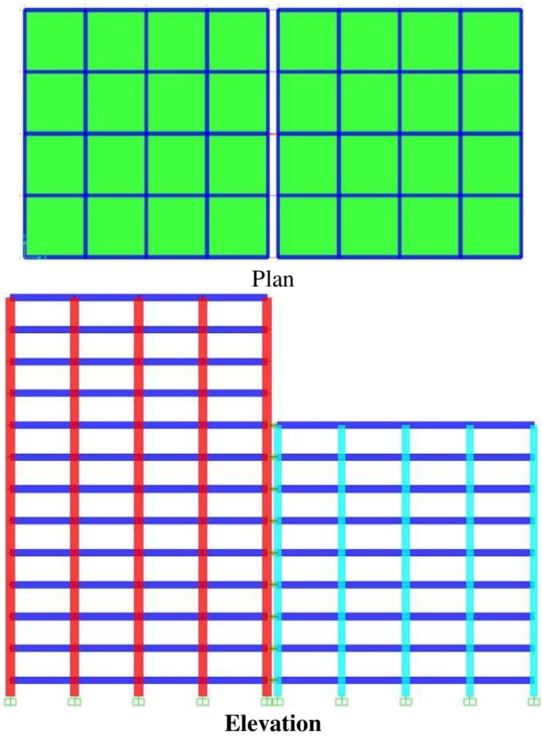


Fig. 1 Plan and elevation of buildings considered for slab to slab pounding

The details of two Indian and two foreign earthquakes used for time history analysis are given in Table I below.

Table I Particulars of earthquake time histories

Earthquake	Recording Station	Date	Duration (Sec)	PGA
Bhuj	Ahmedabad	Jan 26, 2001	26.04	0.10g
Uttarkashi	Uttarkashi	Oct 20,1991	40	0.31g
Elcentro	USGS (117)	May 18,1940	53.73	0.34g
Cape Mendocino	USGS(89005)	Apr 25, 1992	60	1.04g

Table II Properties of buildings considered for study of Slab to Slab Pounding.

Description	Building A	Building B
Storey height	3 m	3 m
Depth of	1.5 m	1.5 m

foundation		
Size of beams	300 mm x 600 mm	300 mm x 600 mm
Size of columns	750 mm x 750 mm	600 mm x 600 mm
Thickness of slab	150 mm	150 mm
Soil condition	Medium	Medium
Response reduction factor	3	3
Importance factor	1	1
Live load at floors	4 kN/m^2	4 kN/m^2
Floor finish load	1 kN/m^2	1 kN/m^2

Table III Properties of Buildings Considered for Study of Mid Column Pounding.

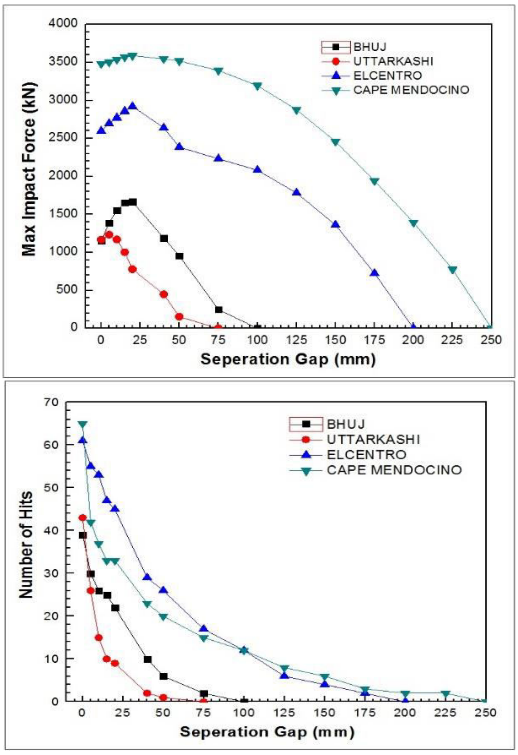
Description	Building A	Building B
Storey height	3 m	3 m
Depth of foundation	1.5 m	2 m
Size of beams	300 mm x 600 mm	300 mm x 600 mm
Size of columns	750 mm x 750 mm	600 mm x 600 mm
Thickness of slab	150 mm	150 mm
Soil condition	Medium	Medium
Response reduction factor	3	3
Importance factor	1	1
Live load at floors	4 kN/m^2	4 kN/m^2
Floor finish load	1 kN/m^2	1 kN/m^2

For study of these two types of pounding, pounding analysis of 12 storey and 8 storey buildings with varying separation distance (0mm, 5 mm, 10 mm, 15 mm, 20 mm, 40mm, 50 mm, 75 mm, 100 mm, 125 mm, 150 mm, 175 mm, 200 mm, 225 mm and 250 mm) for two Indian and two foreign earthquakes has been done. Therefore total no of models to be analysed and studied are 2 types of pounding study with 15 separation gaps for four earthquakes records i.e. 120 models.

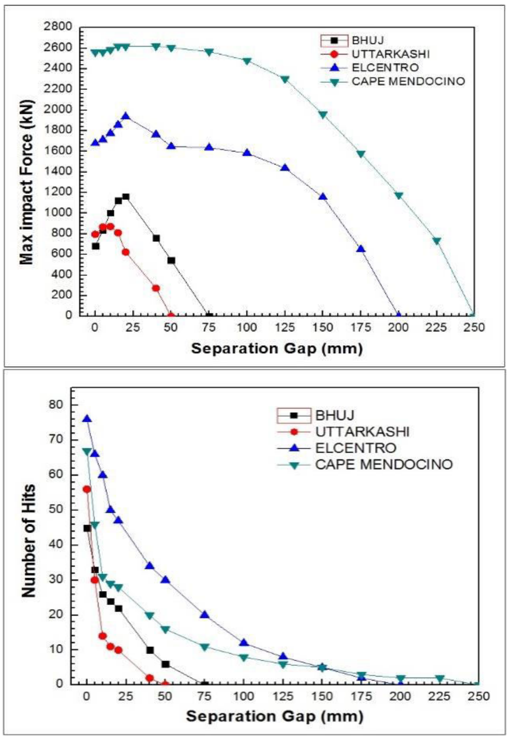
IV. RESULTS AND DISCUSSION

After having gone through the complete study of pounding, it has been observed that, the member forces (axial force, shear force and bending moment) amplify due to pounding of buildings. Therefore the member force amplification factor has been defined as the ratio of maximum axial force due to pounding to the minimum axial force of standalone structure.To have complete understanding about pounding effects, the pounding force, number of hits and three member force amplification factors defined above have been evaluated against separation gap for four earthquakes.

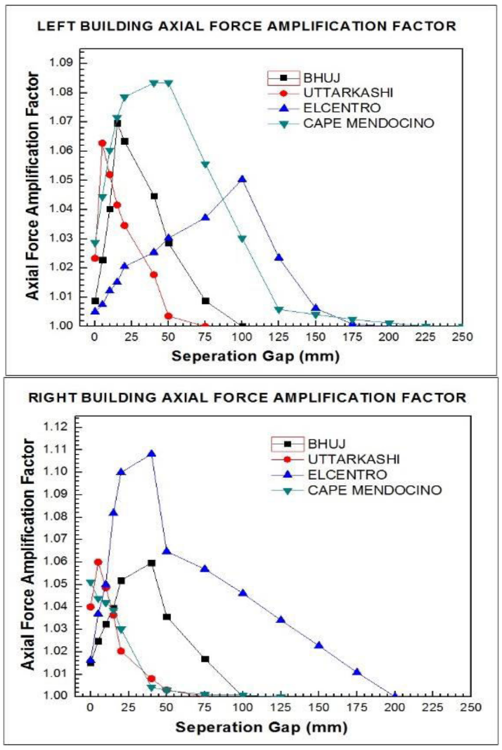
i. Pounding Force



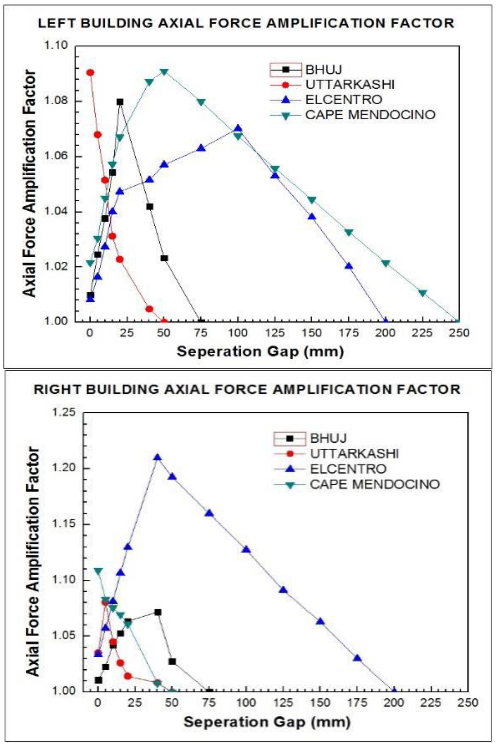
Graph 1- Maximum Pounding force and number of hits versus gap for slab to slab pounding



Graph 2- Maximum Pounding force and number of hits versus gap for mid column pounding



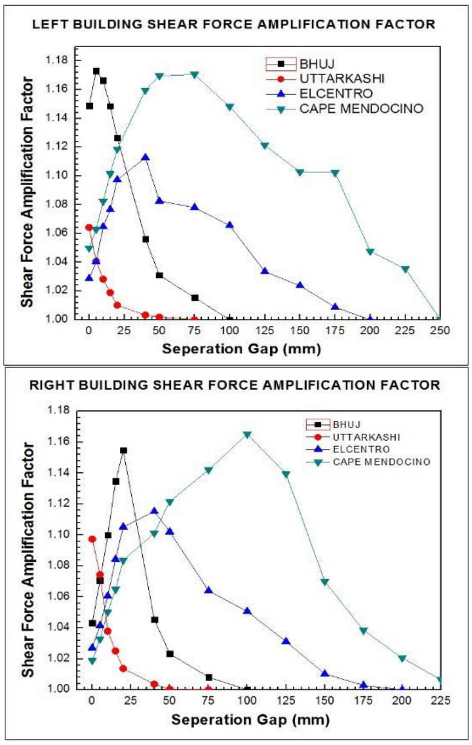
Graph 3-Axial force amplification factor versus gap for slab to slab pounding



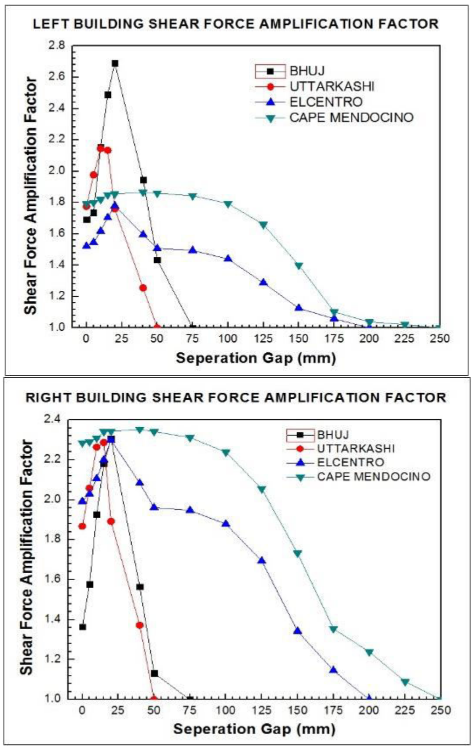
Graph 4- Axial force amplification factor versus gap for mid column pounding

From the Graph 1 and Graph 2, it is clear that, the pounding force increases with separation gap till; it reaches the peak value at critical separation gap and then after decreases with increase in separation gap and the number of hits is consistently decreases with separation gap for both types of pounding. In case of mid column pounding, maximum pounding force was reduced, but the number of hits increased compared to slab to slab pounding. Location of maximum pounding force for different earthquake records was observed to be varying substantially.

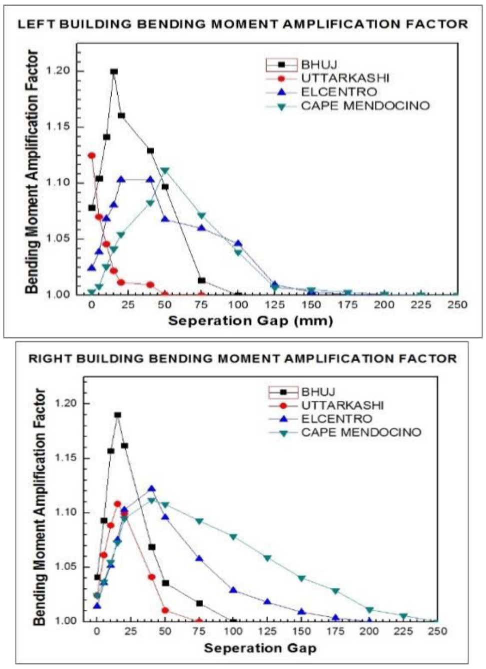
ii. Member Forces



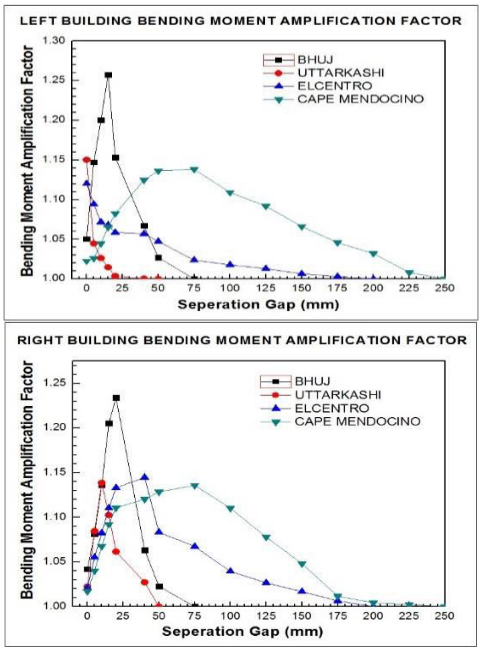
Graph 5- Shear force amplification factor versus gap for slab to slab pounding



Graph 6- Shear force amplification factor versus gap for mid column pounding



Graph 7- Bending moment amplification factor versus gap for slab to slab pounding



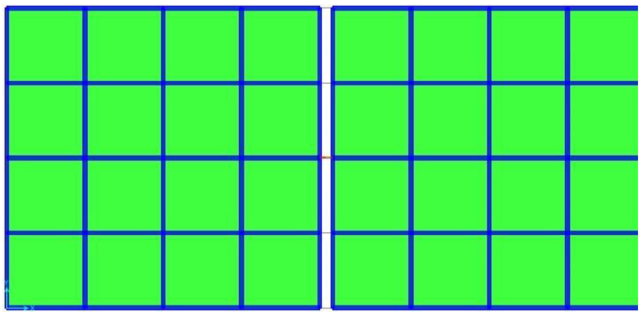
Graph 8- Bending moment amplification factor versus gap for mid column pounding

- From the Graph 3 to Graph .8 it is clear that, the member force amplification factor of both buildings due to both types of pounding increases with separation gap till it reaches the peak value at critical separation gap and then after it decreases for all four earthquake ground motions.
- From Graph 3, Graph 4, Graph 7 and Graph 8 it is clear that, the maximum axial force and bending moment were not considerably increased both due to slab to slab and mid column pounding. But as can be seen from Graph 5

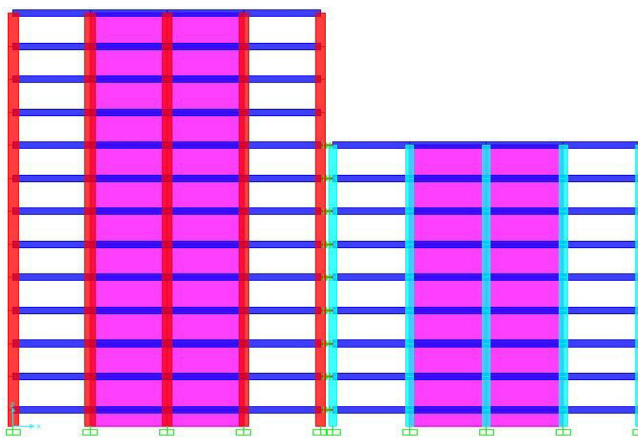
and Graph.6 the shear force was drastically increased due to mid column pounding than slab to slab pounding..

- It is clear from the Graph 3 to Graph 8 that**,** the left 12 storey building has got little higher amplification of member forces compared to the right 8 storey building.
- It is also observed from Graph 3 to Graph 8 that, the location of maximum member force amplification factor varies considerably for all four earthquake ground motions. Therefore the member force amplification factor depends substantially on the characteristics of ground motion and dynamic characteristics of buildings.

(B) Shear Wall as Pounding Mitigation Measures



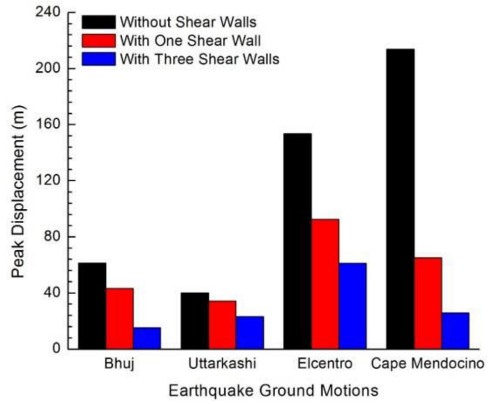
Plan



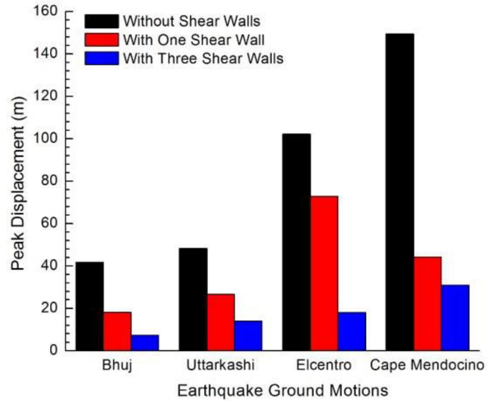
Elevation

Fig. 2 Location of shear wall shown in Plan and elevation of buildings

i. Peak Displacement



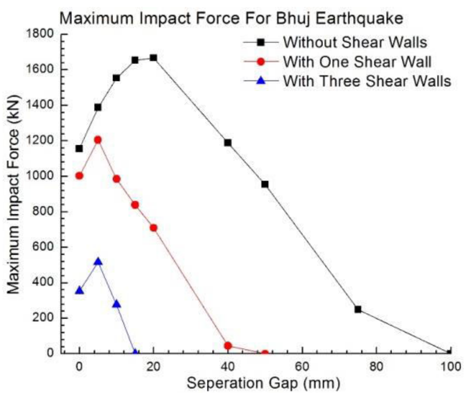
Graph 9- Peak Displacements of 12 storey buildings with different shear wall systems



Graph.10- Peak Displacements of 8 storey buildings with different shear wall systems

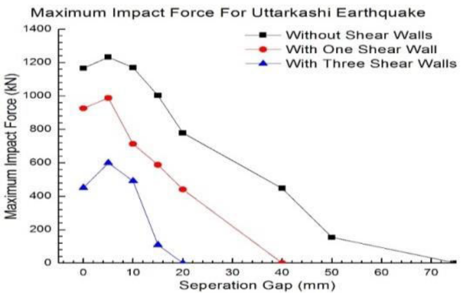
The peak values of displacements of 12 storey and 8 storey buildings are presented in Graph 9 and Graph 10 respectively for comparison as it is obvious that, though with incorporation of three shear walls in central three frames the buildings become stiff compared to one shear wall system, the displacements response of buildings were reduced 30% to 80% compared to the displacements for system without shear walls.

ii. Pounding Force



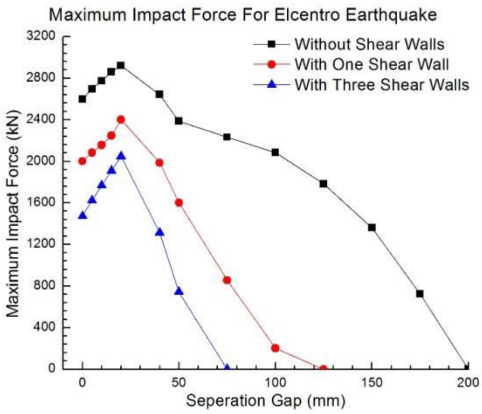
Graph 11 Maximum impact force(KN) vs. separation gap(mm) for Bhuj earthquake

It is clear from Graph 11, the maximum pounding force due to **Bhuj** earthquake has been reduced by 25% and 70% respectively for buildings with one shear wall in a central frame and with three shear walls in central three frames compared to the pounding forces for system without shear walls.



Graph 12 Maximum impact force (KN) vs. separation gap(mm) for Uttarkashi earthquake

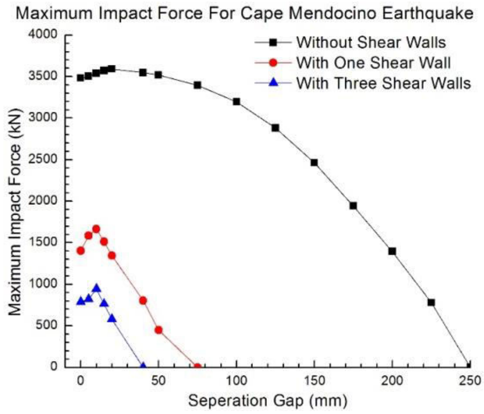
It is clear from Graph 12, the maximum pounding force due to **Uttarkashi** earthquake has been reduced by 20% and 50% respectively for buildings with one shear wall in a central frame and with three shear walls in central three frames compared to the pounding forces for system without shear walls.



Graph 13 Maximum impact force (KN) vs. separation gap(mm) for Elcentro earthquake

It is clear from Graph 13, the maximum pounding force due to **Elcentro** earthquake has been reduced by 18 % and 30 % respectively for buildings with one shear wall in a central

frame and with three shear walls in central three frames compared to the pounding forces for system without shear walls.



Graph 14 Maximum impact force (KN) vs. separation gap(mm) for Cape Mendocino earthquake

It is clear From Graph 13, the maximum pounding force due to **Cape Mendocino** earthquake has been reduced by 50 % and 70 % respectively for buildings with one shear wall in a central frame and with three shear walls in central three frames, compared to the pounding forces for system without shear walls.

V.CONCLUSION

Pounding is a very complex non-linear phenomenon which has been studied in detail considering all parameters affecting it such as type of pounding, separation gaps between buildings and characteristics of earthquake ground motion. The mitigation of pounding between buildings has also been investigated thoroughly with provision of shear walls.. After having gone through all the results above following conclusions are drawn:

1. The Member force amplification factor of buildings due to pounding increases with separation gap till, it reaches the peak value at critical separation gap and then it decreases with separation gap for all four earthquake ground motions in all types of pounding.
2. The critical separation gap at which the peak value of member force amplification factor occurs, varies substantially for different earthquake ground motions.
3. Maximum pounding force in case of slab to slab pounding is 37% more than mid column of pounding. Therefore it is obvious to say that, the pounding of buildings and its effects are very complex non-linear phenomenon which depends greatly on characteristics of earthquake ground motions and dynamic characteristics of building to be pounded against each other. The numbers of hits are more in case of mid column pounding compared to slab to slab pounding.
4. Regarding mid column pounding and slab to slab pounding, axial force amplification factor and bending moment amplification factor near about same. The shear force amplification factor was drastically increased 60% in left and right structure due to mid column pounding. It is because in case of mid column pounding the slab of one building (huge mass) impacts column of another building. Therefore it can be concluded that, the axial force amplification factor, shear force amplification factor and bending moment amplification factor depends very much on the characteristics of ground motion and dynamic characteristics of buildings.
5. The shear wall as a pounding mitigation measure proves very effective as it reduces the pounding forces about 20 % to 70 % for buildings with one shear wall in a central frame and with three shear walls in central three frames compared to the pounding forces for system without shear walls. From the results it is clear that, the pounding of buildings can be avoided by reducing the maximum separation Gap beyond which no pounding of buildings takes place, by increasing the stiffness of building with provision of shear wall
6. As it is obvious that, though with incorporation of three shear walls in central three frames the buildings become stiff compared to one shear wall system, the displacements response of buildings were reduced 30% to 80% compared to the displacements for system without shear walls.
7. The shear wall as a pounding mitigation measure can also avoid pounding altogether by reducing the maximum separation gap beyond which no pounding would occur.

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