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Mitigation of Seismic Pounding

Ravindranatha¹, Pradeep Karanth², Shivananda S.M³, Suresh H.L⁴

Assistant Professor (Selection Grade), Dept. of Civil Engineering, Manipal Institute of Technology, Karnataka, India¹

Post Graduate Student, Dept. of Structural Engineering, Manipal Institute of Technology, Karnataka, India²

Structural Engineer, Atkins India Pvt. Ltd, Bangalore, Karnataka, India³

Director, Structural Engineer, CIVIL Technologies (India) Pvt. Ltd, Bangalore, Karnataka, India⁴

ABSTRACT: Collision of two buildings which are of different dynamics characteristic is called as seismic pounding, the main reason for the seismic pounding is lack of separation gap between the buildings. This study covers the effect of structural pounding on conventional beam column system adjacent to flat slab system, in order to observe seismic pounding Time History analysis is carried out by using Elcentro earthquake data. This study also covers the mitigation techniques of pounding by introducing new Reinforced Concrete (RC) wall and Combined RC wall with steel bracings are proposed as possible mitigation techniques for pounding.

KEYWORDS: Seismic Pounding, Earthquake, SAP 2000, Flat slab, Reinforced Concrete (RC) wall, Steel Bracings.

I. INTRODUCTION

The Seismic pounding is simply known as collision or hammering of two buildings which are adjacent to each other having different dynamic characteristics. The main reason for the seismic pounding is a lack of separation gap in between the adjacent buildings. Most of the time pounding between the structures is commonly observed in the old buildings that were constructed before the earthquake resistant design principles came into the picture. Even though many present codes specify a minimum seismic gap, it still fails to include the effect of all other parameters that affect the structural deformation. The simplest and effective way for pounding mitigation and reducing damage due to pounding is to provide enough separation gap, but it is sometimes difficult to be implemented due to the high cost of land.

Pounding damage was assessed during the 1985 Mexico earthquake, the 1988 Sequenay earthquake in Canada, the 1992 Cairo earthquake, and 1944 Elcentro earthquake. Pounding of adjacent buildings could have worse damage as adjacent buildings with different dynamic characteristics which vibrate out of phase and there is insufficient separation distance (Abdel and Shehata, 2006 [1]). Previous seismic codes couldn't give fixed guidelines to prevent pounding, due to economic considerations especially in the metropolitan cities; there are many buildings worldwide which are already built extremely close to each another, that could suffer pounding damage in forthcoming earthquakes. A large separation is not feasible from both technical and economical point of views (A Hameed et.al, 2012 [2]). The highly congested building system in many metropolitan cities constitutes a major apprehension for seismic pounding damage.

The simplest and most appropriate way for pounding mitigation is to provide safe separation gap, but it is sometimes difficult to fulfil due to the high cost of land. An alternative to the seismic separation gap provision in the structure design is to reduce the effect of pounding through decreasing lateral displacement by introducing the stiffeners like RC walls, Bracings, dampers etc. The main objective and scope of the study are to evaluate the effects of structural pounding on the global response of building, to determine the lateral peak displacement during the earthquake ground motion, evaluating the minimum seismic gap between buildings and provide engineers with practical tool to mitigate the seismic pounding.

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II. RELATED WORK

2. a) Robert Jankowski -*“Earthquake Induced pounding between equal heights buildings with Substantially different dynamic properties (2008)”*

Carried out analysis of two equal height buildings with different dynamic properties, the non-linear effects are considered in the analysis and structures was modelled as elastoplastic multi-degree-freedom lumped mass systems structural behaviour due to the ground motion excitation is studied. The results of the study clearly shows that special attention should be given while designing weaker building, for which earthquake-induced structural pounding can be catastrophic. In order to mitigate destructive collisions of the building the natural vibration period of the lighter building should be tuned with the period of a stronger building, so as to induce in-phase vibrations during the earthquake, or a sufficiently large separation gap between both structures should be provided.

2. b) Tauseef M honnyal et.al -*“A study of seismic pounding between adjacent buildings(2014)”*

Studied Preventive measures of pounding between adjacent buildings. Different mitigation technique like Construction of new RC walls, cross bracing system and combined RC wall & bracing, dampers, combined system of RC wall and dampers and combined system of bracing and dampers with proper placement are proposed as possible prevention techniques for pounding between adjacent buildings . Stiffness of the buildings can be increased by adopting all this methods and all the prevention methods that are used in this study was found effective to counter act pounding between adjacent buildings.

III.METHODOLOGY

To observe pounding, a three-dimensional reinforced concrete moment resisting frame buildings is taken and analysed in SAP2000. For the analysis, eight (G+ 8) storey buildings consist of conventional beam column structural system adjacent to the six (G+6) storey building consists of flat slab system. All columns in the models are assumed to be fixed at the base. The height of all floors is 3.2 m. A slab of eight(G+8) storey are modelled as rigid diaphragm floor element of 150mm thickness and slab of six (G+6) storey are modelled as rigid diaphragm floor element of 150mm thickness and drop thickness is 200 mm and is designed as per to IS 456-2000. Live load on the floor is taken as 3kN/m^2 and on the roof is 1.5kN/m^2 . Floor finish on the floor and weathering course on the roof is taken as 1kN/m^2 respectively for the both the building. The seismic weight is calculated according to IS 1893-2002. The unit weight of concrete is taken as 25kN/m^3 . The grade of concrete for columns is M-25 and that of beams and slab is M-20. The building is analysed as special moment resisting frame considered to be situated in seismic zone IV having medium soil and proposed for residential use. These buildings are separated by expansion joint of 100mm. Both buildings are analysed in SAP2000 and are designed as per IS 456-2000. Both buildings are subjected to gravity and dynamic loads. To observe pounding, Time History Analysis is carried out by taking the data of Elcentro earthquake.

Building-A, Beam- column system consist of eight (G+8) storey has 4 bays in X and Y directions, having external columns size of $0.4\times 0.8\text{ m}^2$, whereas all internal column size of $0.55\times 1.0\text{ m}^2$ and beam size is $0.35\times 0.6\text{ m}^2$ in both the direction. The width of each bay in the X direction is 4m, and that of Y direction is 5m. Building-B, Flat slab system having six (G+6) storey has 4 bays in X and Y directions, the width of each bay in the X direction is 3m, in Y direction is 5m, having external column size of $0.3\times 0.75\text{ m}^2$, whereas all internal column size of $0.3\times 0.9\text{ m}^2$ and no beams in both directions (Flat slab structural system).Figure 1 Shows Plan view of Conventional beam column system adjacent to Flat slab system separated by a expansion joint of 100 mm.

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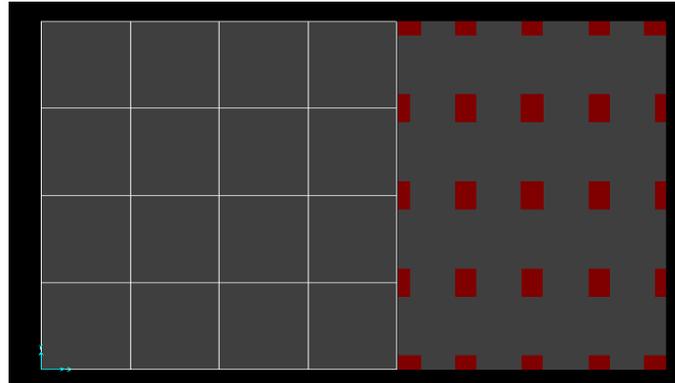


Figure -1: Plan view of beam column system adjacent to Flat slab system

IV. REQUIRED SEISMIC SEPARATION DISTANCE TO AVOID POUNDING

Minimum safe separation gap to be provided between adjacent buildings to avoid pounding effect, which is equal to the peak displacement of the two potentially colliding building systems. For instance, according to the 2000 edition of the international building code and in many seismic design codes and guidelines worldwide, the minimum safe separation gap (Lopez Garcia 2004) is as follows:

$S = \sqrt{(Q1^2 + Q2^2)}$ is an SRSS (Square Root of the Sum of the Squares) Method

$S=Q1+Q2$ is an Absolute Sum Method (ABS)

Where,

Q1= Peak displacement of building-A

Q2= Peak displacement of building-B

S = Separation distances

A. Required Seismic Separation Distance to Avoid Pounding

According to Bureau of Indian Standards clearly gives in its code IS 4326 that a safe separation distance is to be provided to prevent pounding between the building during an earthquake. The same is mentioned in following Table 1.

TABLE I: The design seismic coefficient to be used in accordance with IS 1893:1984

Sl.No.	Type of Constructions	Gap Width/Storey , in mm for Design Seismic Coefficient $ah=0.12$
1	Box system or frames with shear walls	15.0
2	Moment resistant reinforced concrete frame	20.0
3	Moment resistant steel frame	30.0

Note: Minimum total gap shall be 25 mm. For any other values of ah , the gap width shall be determined accordingly.

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4.1. Beam column system adjacent to Flat slab system without any stiffeners.

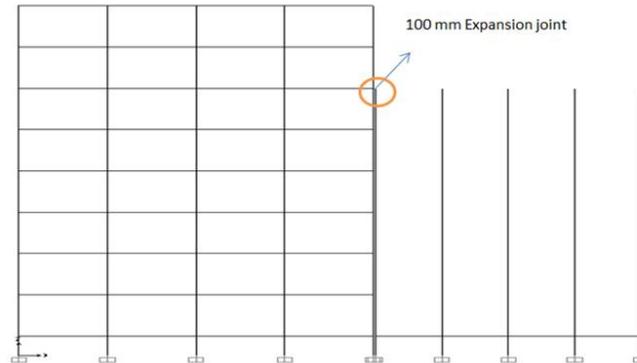


Figure-2: Elevation view of beam column system adjacent to flat slab system without any stiffeners

After analysing these two buildings in SAP2000 under time history record of Elcentro earthquake data which is to be known as above average earthquake, the behaviour of the buildings i.e. displacement with respect to time was observed. Pounding analysis carried out on the roof of the sixth floor, to observe the positive displacement of G+ 8 storey and negative displacement of the G+6 storey, as we are going to consider worst condition due to its different dynamic characteristics.

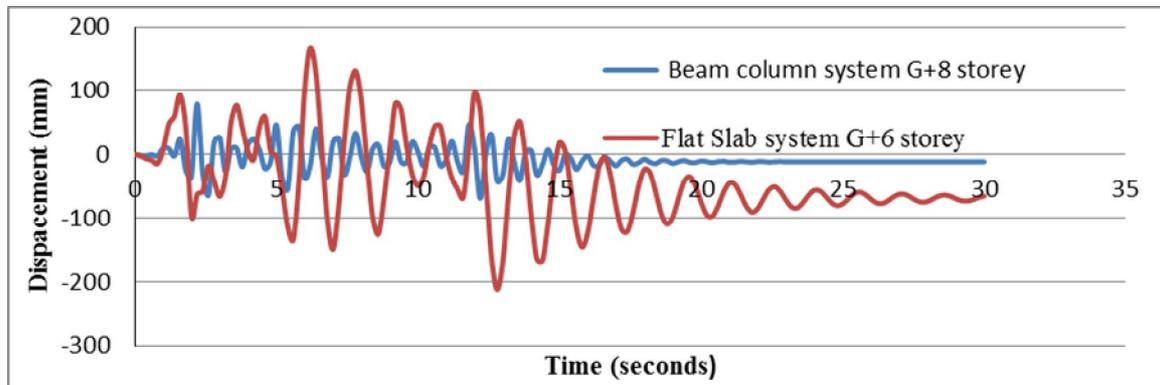


Figure- 3: Time vs. displacement graph of beam column system adjacent to flat slab system at sixth-floor level without any stiffeners

Figure-3 shows time vs. displacement graph at the sixth-floor level, in this maximum positive displacement of G+8 storey building is 80.30 mm at 2.2 seconds and maximum negative displacement of G+6 storey building is 212.53 mm at 12.8 seconds. From the figure, it is noticed that maximum out of phase movement of both building is $(80.30+212.53)-100= 192.83$ mm which is greater than the given expansion joint, hence which is unable to accommodate this out of phase movement, and adjacent buildings will strike or collide each other.

4.2. Providing X Cross Bracings to Increase Stiffness:

Since the gap between the buildings not able to increase to accommodate the relative displacement of the both the building, but we can reduce this relative displacement by providing additional stiffeners i.e. by introducing new X cross bracings. In this study ISWB- 175 wide flanges are used for the steel bracing to reduce the lateral displacement (Amruta Sadanada Tapashetti et.al, (2014) [5]). Figure 4 shows X cross Bracings are provided at the exterior panels of the both buildings in X direction to reduce the lateral displacements. The connection of steel cross braces with concrete frame structure requires a very special consideration and the strong connection should be there to transfer the load safely.

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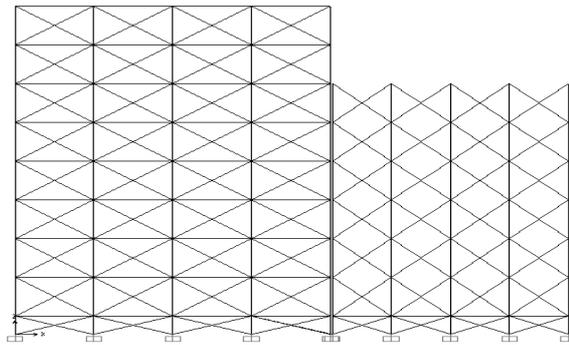


Figure-4 Shows the X- Cross bracings of eight-storey and six-storey buildings

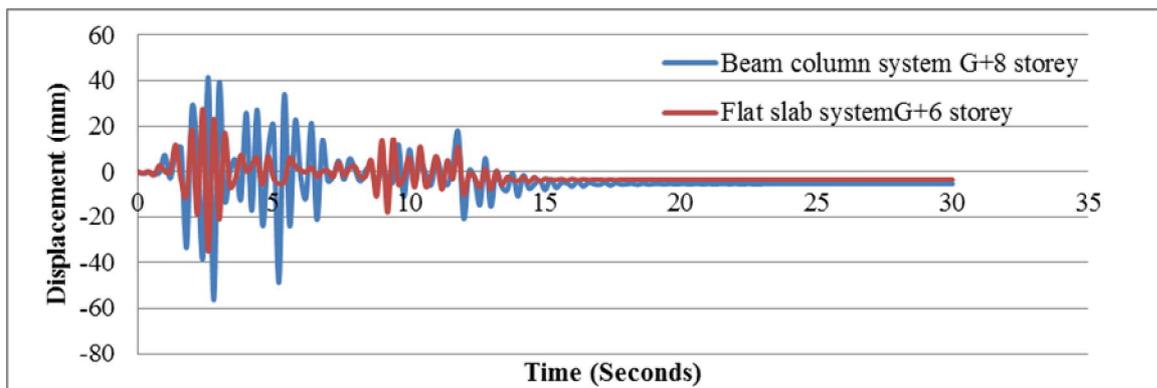


Figure 5: Time vs. displacement graph of beam column system adjacent to flat slab system with additional X cross bracings at sixth -floor level

Figure- 5 shows time vs. displacement graph at the sixth-floor level, in this Maximum Positive displacement of the eight-storey building is 41.26 mm at 2.6 second and maximum negative displacement of six-storey is 35.12 at 2.6 second Maximum out of phase movement is $41.26+35.12=76.38$ mm, it is less than given expansion joint hence, no chance of pounding at any interval of time.

4.3. Increasing the stiffness of building by using combined RC wall and steel bracings:

Figure 6 shows, New RC walls of 150 mm thickness (Tauseef M honnyal et. al,(2014)[6]) are provided at end panels and cross bracings are provided in mid two panels in X direction to increase the stiffness of the both the buildings, Time History Analysis is done by taking Elcentro Earthquake data, for which Time vs. Displacement graph is plotted to observe the displacements of both the buildings at sixth-floor level.

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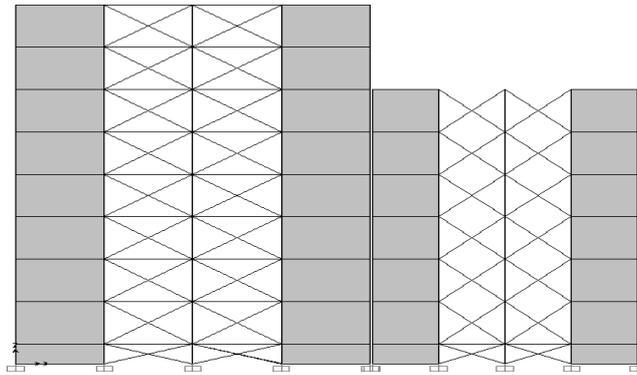


Figure 6: Shows RC wall at the end panels and X cross bracing in the mid two panels in the X direction

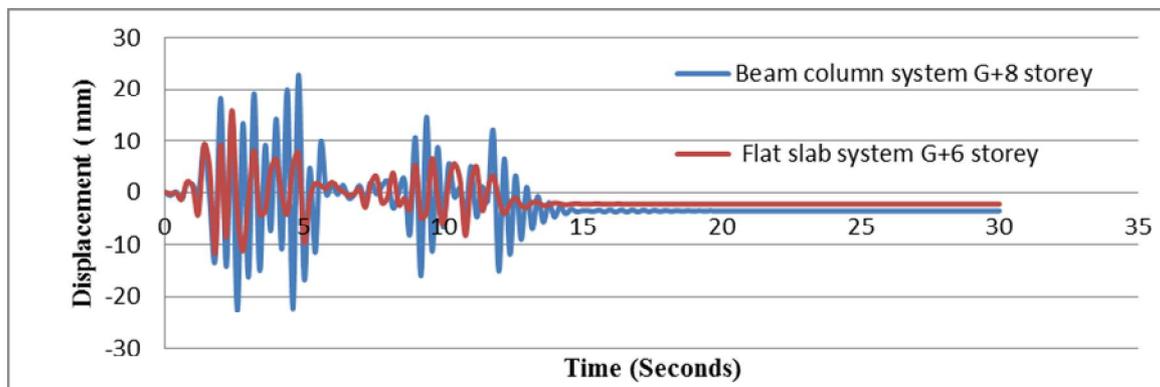


Figure 7: Time vs. displacement graph for both the buildings with combined RC wall and Steel bracing

Figure-7 shows time vs. displacement graph at the sixth-floor level, in this Maximum Positive displacement of the G+8 storey at 6th floor is 22.78 mm at 4.8 second and maximum negative displacement of G+ 6 storey is 11.68 mm at 1.8 seconds. It shows that Maximum out of phase movement is $22.78+11.68= 34.46$ mm which is lesser than the expansion joint i.e. 100mm, hence no chance of pounding at any interval.

V. CONCLUSION

- From the analysis it was found that stiffness of the flat slab system is less in comparison with beam – column system and hence design engineer have to give more importance while design such type of structures.
- The stiffness of the buildings can be increased by providing new RC wall, Cross bracings so that lateral displacement can be reduced and hence seismic pounding can be prevented.
- At the time of design, Design Engineer has to ensure that there will be no pounding between adjacent buildings.
- It is better to leave set back/safe separation gap according to FEMA 273-1997 when the buildings are in early stage of design.
- If buildings are old and are not in a stage to provide safe separation gap, then prevention measure should be taken by using retrofitting's like introducing new RC wall, Cross bracings, Dampers etc.

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- All the prevention methods that are used in this study proved effective to prevent pounding between adjacent buildings.

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