Effect of Pounding on RC Buildings

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***Abstract* - Earthquakes have always been a source of great devastation for mankind. It is evident from the past and recent earthquake damages records, that the building structures are subjected to severe damages/collapse during earthquakes. Nowadays with the fast growth of metropolitan cities, land limitation has become a critical issue, thereby resulting in construction of high rise buildings very close to each other. Such buildings are prone to seismic pounding. Pounding is a phenomenon, in which two buildings strike due to their lateral movements induced by lateral forces. So in this study attempt was made to analyze the seismic response due to pounding between the buildings that are constructed without sufficient separation gap. A model of two buildings closes to each other one being G+ 8 storey and other being G+5 storey were considered. The parameters like displacement and impact force were considered for the analysis using SAP 2000 software.**

***Index Terms* - Pounding, Time history analysis, SAP 2000, Seismic gap, Node to node pounding, Floor to column pounding, El Centro earthquake.**

I. INTRODUCTION

As time passed and population of cities increased, the civil structures expands are erected horizontally and vertically to meet human demands, due to presence of these tall and massive structures in the seismically active area the structural failure conditions became more severe. The number of buildings in modern cities constructed rapidly to fulfil the human needs and most of the times the structures are normally constructed in close proximity to each other. This creates a new problem in structural engineering called as mutual pounding of adjacent buildings during occurrences of natural tremors like earthquakes. In practice, adjacent structures tremble out of phase due to different dynamic characteristics. Moreover, in current design process, adjacent buildings with insufficient clear spacing are designed as a standalone structure by ignoring the pounding action during earthquake loading. This negligence causes failure of structures. This is because of huge amount of additional shear forces and bending moments developed in the columns due to repeated impulsive actions during tremor.

Anagnostopoulos [6] has analyzed the response of adjacent buildings in city blocks to several strong earthquake, taking into account the mutual collisions, or pounding, resulting from insufficient or non-existing separation distances. Garcia and Soong [4] have examined the accuracy of the double difference combination rule in predicting the separation necessary to prevent seismic pounding between linear structural systems. Muthukumar and Des Roches [5] have investigated the cogency of various impact models in capturing the seismic pounding response of adjacent structures. The aim of this paper is to study the closely built building system without proper separation distances in order to ensure protection for both life and property.

II. METHODOLOGY

In order to study pounding, a three dimensional reinforced concrete moment resisting frame buildings is taken and analyzed in SAP2000. The two buildings consist of eight stories (G+8) and five stories (G+5). All columns in all models are to be fixed at the base. The height of all floors is 3.2m and also for studying floor to column pounding a floor height of 3.1m is also used. Slab of eight stories and five stories is modeled as rigid diaphragm element of 125mm thickness respectively, for all stories considered. Live load on floor is taken as 3kN/m2. The seismic weight is calculated conforming to IS 1893- 2002(part-I). The unit weights of concrete is taken as 24kN/m3. The grade of concrete for column is M-25 and for beam and slab is M-20. Both buildings are analyzed in SAP2000. To observe pounding, Time History Analysis is carried out taking data of El Centro ground motion database.

Building Description

Building-1 (G+8) has 3 bays in X and Y directions, having all columns dimension of 0.3x0.9 m2. Width of each bay in X and Y direction is 3m, and the beam size is 0.3x0.6 m2 in both the direction. Building-2 (G+5) has 3 bays in X and Y directions, width of each bay in X and Y direction are 3m, having column dimension of 0.3x0.9 m2. Beam size is 0.3x0.6 m2 in both the direction. Pounding is considered in top floor of G+ 5 story i.e. at fifth floor, for observation Positive displacement of eight stories and negative displacement of five stories is considered, as we are going for worst condition due to its different dynamic characteristics. For observing node to node pounding buildings with same floor height that is 3.2 m is used and for floor to column pounding, taller building has a floor height of 3.2 m and shorter building has a floor height of 3.1 m. In this paper, seismic gap needed to prevent pounding is studied by varying the expansion joint provided. The separation gap used are 20 mm, 80 mm and 4 m.

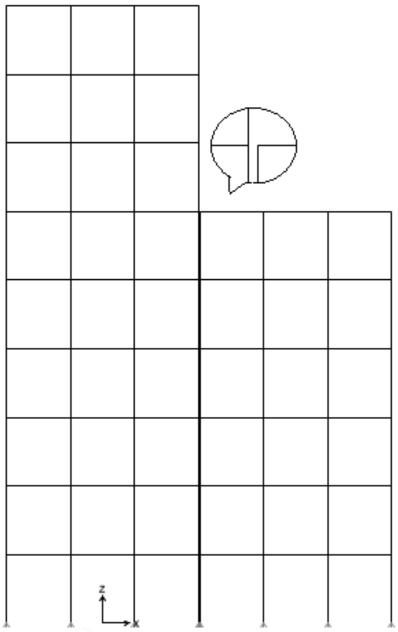

Fig. 1. G+8 and G+5 building with 80 mm seismic gap

The building described above is analyzed for time history analysis using the ground motion database for Imperial Valley 1940 earthquake as shown in Figure 2.

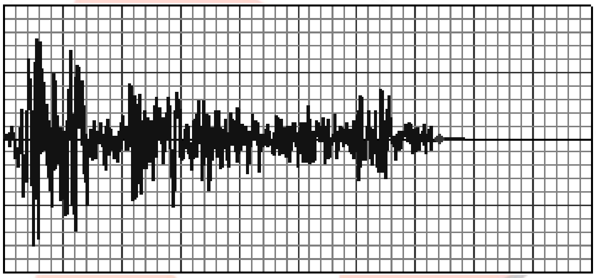

Fig. 2. Accelaration time history of El Centro Imperial valley 1940 Ground motion records.

Gap Element

The portion of 80 mm indicates gap between two adjacent buildings. The minimum seismic gap as per Indian seismic code IS 1893:2002 (Part-I) is 20 mm for moment resistant reinforced concrete frame. After this gap is overcame during dynamic response by the buildings, pounding will occur. Gap has been defined as link elements in SAP 2000. It is a compression-only element required to assess the force of pounding and simulate the effect of pounding. The purpose of the gap element is to transmit the force through link only when the contact occurs and the gap is closed. The effective stiffness of gap element is 1.5 x 10^8 N/mm2. Gap elements are provided in first five node points of the buildings where the shorter building collide with the taller one. For building with different floor height, gap elements are provided between floor node and column.

III. Structural Analysis

The following studies are carried out in order to observe pounding between adjacent buildings

1. Buildings G+8 and G+5 with 20 mm seismic gap without gap elements
2. Buildings G+8 and G+5 with 20 mm seismic gap with gap elements
3. Buildings G+8 and G+5 with 80 mm seismic gap with and without gap elements
4. Buildings G+8 and G+5 with 4m seismic gap.
5. Floor to column pounding.

All these studies are carried out for buildings with same floor height and different floor height and also with unsymmetrical floor plans.

IV. Results and Discussions

Graphical representation for horizontal displacement of buildings nodes during earthquake excitation are drawn to show pounding effectively.

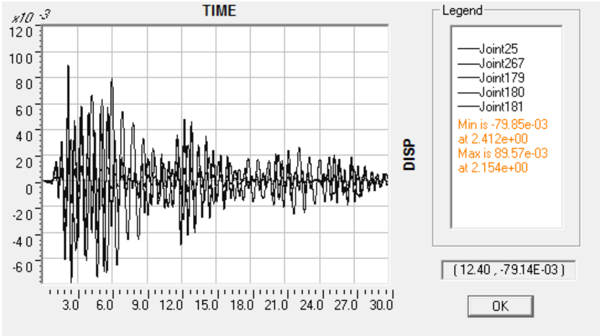

Fig. 3. Displacement graph for study IV

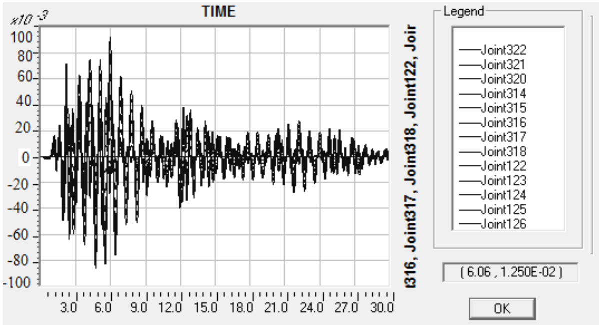

Fig. 4. Displacement graph for study I

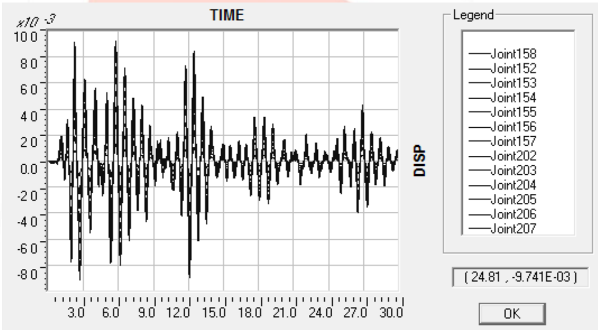

Fig. 5. Displacement graph for study II

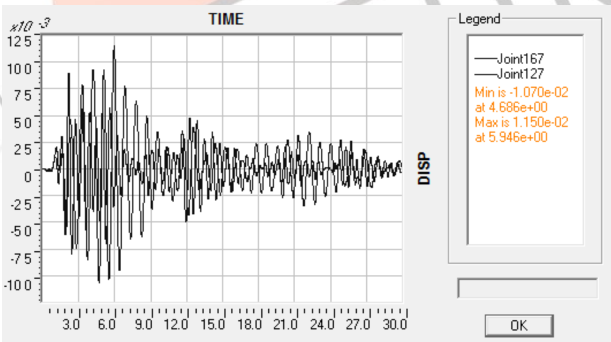

Fig. 6. Displacement graph for study III (with gap elements)

The graphical representation of horizontal displacement of buildings during earthquake excitation is shown in Figures 3 to 6 for each studies. From the plot in fig 3, it is clear that in study IV as the separation distance provided is 4 m hence the maximum horizontal displacement of this case (0.08957 m) is less than that of separation distance and there is no pounding.

In case of study I, the value of maximum horizontal displacement is 0.0935 m which is more than that of separation distance provided i.e. 0.02m between adjacent buildings, hence interference of two responses can be seen from fig 4 (there is no link or gap element) and pounding will occur and building will get damaged in this case. For study II, both buildings are forced to respond together due to presence of gap element to assess realistic picture of pounding. While, for study of floor to node pounding for 20 mm seismic gap with gap elements, maximum horizontal displacement obtained is 0.145 m which increased tremendously. The increased displacement within the adjacent buildings will give rise to more impact on each other and may lead to collapse. These different studies were carried out to identify the gap distance between two buildings so that pounding effect shall be evident.

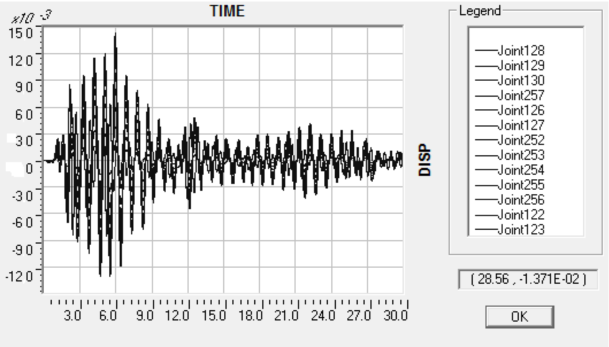

Fig. 7. Displacement graph for study V.

Shear Force

The maximum shear forces for general and pounding case is studied. It is observed that the shear forces in pounding case is increased by 33% for symmetric plan, 37.5% for unsymmetrical plan and 40.9% for floor to column pounding for 20 mm seismic gap.

Table 1 Maximum shear force in buildings with 20 mm gap

Type	General case	Pounding case	% increment
Symmetrical plan	175 kN	232 kN	33%
Unsymmetrical plan	260 kN	357 kN	37.5%
Unsymmetrical plan floor to column pounding	267 kN	376 kN	40.9%

Bending Moment

The maximum bending moment for general and pounding case is studied. It is observed that the bending moment in pounding case is increased by 25.8% for symmetrical plan, 26.8% for unsymmetrical plan and 40.9% for floor to column pounding for buildings with 20 mm gap.

Table 2 Maximum bending moment in buildings with 20 mm gap

Type	General case	Pounding case	% increment
Symmetrical plan	242 kN	304 kN	25.8%
Unsymmetrical plan	289 kN	366 kN	26.8%
Unsymmetrical plan floor to column pounding	385 kN	542 kN	40.9%

V. Conclusions

The linear analysis of adjacent buildings with a seismic gap less than the expected lateral displacement is carried out using SAP 2000. Following conclusions can be made

1. The structural behavior of the building is altogether different with and without consideration of pounding.
2. Introduction of gap element lead to change in response of closely spaced buildings. Neglecting pounding effect will lead to design of unsafe structure and consequently a collapse.
3. Location of pounding is one of the important factor to be considered. It is more severe in the case of node to column pounding.
4. During pounding smaller building experience more displacement and liable to greater damage than larger building
5. The location of maxima for different functions such as BM, SF are different for pounding and buildings without consideration of pounding. As a result the building element shall be subjected to forces of higher magnitude for which it was not designed. This might be one of the major reasons behind the collapse or damage of the structure.
6. In this paper the column size used is comparatively large. Hence the drift observed is less.
7. As pounding force decreases for greater separation, hence it reduces damages to the neighboring buildings.

8. Displacement of buildings can be greatly reduced by providing a shear wall, bracings or dampers.

From this study, it is clear that the designer should include the effect of pounding for closely spaced buildings.

VI. ACKNOWLEDGMENT

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