SEISMIC POUNDING EFFECTS ON ADJACENT TALL BUILDINGS – A REVIEW

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Abstract *- From the past and present investigations of earthquakes, seismologists have shown that, during earthquake, the building structures are vulnerable to severe damages. The adjacent buildings collide and collapse during moderate to strong ground vibrations. Collision of two building which are of different dynamic characteristics is called as seismic pounding and this is a commonly observed phenomenon during a seismic event in metropolitan cities. In order to prevent this failure, the seismic gap between the structures must be sufficient to let structural displacements during strong ground motions. But sometimes availability of required safe separation gap is not possible in metropolitan cities due to high land value and limited availability of land. This paper deals with a systematic study regarding the pounding effects in RC buildings without sufficient seismic gap as well as its mitigation practices.*

Key Words: Seismic pounding, Seismic gap, Gap element, Mid-column pounding, Mitigation.

1 INTRODUCTION

The demand for the space is increasing day by day due to the fast growing construction industry across the globe. In metropolitan cities, due to lack of availability of space, buildings are constructed very close to each other and which leads to a phenomenon called "Seismic Pounding" (Fig.1).If floors of one building hit at the mid height of columns in the other building, pounding effect may be much more serious (Mid-column pounding) .The simplest and most appropriate way for pounding mitigation is to provide safe separation gap. But in metropolitan cities it is tough to fulfill it due to high land value and non-availability of the land. This paper is focusing to evaluate the effects of structural pounding on the global response of building; to determine proper seismic hazard mitigation practice for already existing buildings as well as new buildings. Decreasing lateral displacement by introducing the stiffeners like RC walls, Bracings, dampers etc, is an alternative to the seismic separation gap provision in the structure design.

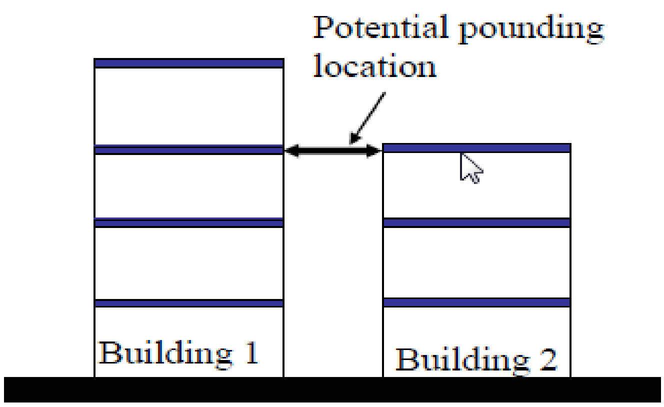

Fig 1 pounding Phenomenon (source: Ref [4])

2 THEORETICAL BACKGROUND

Adjacent buildings with insufficient separation, having different dynamic characteristics may vibrate out of phase during earthquakes causing pounding between them. During the 1985 Mexico, 1994 Northridge, 1995 Kobe, 1999 Kocaeli and 2008 Sichuan earthquakes, seismic pounding damage was found to be significant between adjacent buildings. Some of the major consequences of seismic pounding in buildings are concentrated local damage and increased floor accelerations. It could lead to infill wall damage, plastic deformation, column shear failure, local crushing and sometimes the entire collapse of the structure. Due to additional shear forces on the columns, adjacent structures with different floor levels are more vulnerable when subjected to seismic pounding. The patterns of the damage vary from minor and architectural damages to major structural damages to even total loss of the building function and its stability. In other words, pounding phenomena in adjacent buildings can be catastrophic and more dangerous than the effect of earthquake on a single building.

Bureau of Indian Standards clearly gives in its code IS 4326:1993[1] that a separation section is to be provided between buildings. This is to avoid collision during an earthquake. Minimum width of separation gaps as mentioned in 5.1.1 of IS 4326: 1993[1] shall be as specified in

Table 2.1 .The design seismic coefficient to be used shall be in accordance with IS 1893:1984[3].

Table 2.1: Minimum width of separation gaps as mentioned in 5.1.1 of IS 4326: 1993[1]

Sl No.	Type of construction	Gap width/storey, in mm for design seismic coefficient αh = 0.1
1	Box system or frame with shear wall	15.0
2	Moment resistant reinforced concrete frame	20.0
3	Moment resistant steel frame	30.0

NOTE — Minimum total gap shall be 25mm. For any other value of αh the gap width shall be determined proportionately.

3 LITERATURE REVIEW

A brief review of previous studies on the seismic pounding effect on buildings and its mitigation practices are presented in this section. It focuses on recent contributions related to seismic pounding on structures and past efforts most closely related to the needs of the present work.

K.V.Spiliopoulos and S.A.Anagnostopoulos (1992) analysed the response of adjacent buildings in a row, subjected to strong earthquake motions, taking into account their mutual pounding resulting from insufficient separation distances using lumped mass, MDOF, shear beam type idealization. The seismic separation gaps introduced by codes are highly effective in reducing seismic pounding. They concluded that differences in height, mass and period of adjacent buildings were the factors affecting seismic pounding. The mitigation measures to prevent pounding were not mentioned in this paper.

S.A Anagnostopoulos (1996) presented a detailed review of pounding damage in past earthquakes. The Great Alaska earthquake (1964),The Tokachi-Oki earthquake, Japan (1968),The Managua earthquake (1972),The Guatemala earthquake (1976),The Friuli Italy earthquake (1976),The Romania earthquake (1977),The Greek earthquakes of Thessaloniki (1978),The Mexico earthquake (1985),The Loma Prieta earthquake (1989) ,The Northridge (1994),Kobe (1995) etc. were some of the few examples of past earthquakes at which pounding damages were observed.

Shehata E.Abdel Raheem (2006) studied the effect of impact due to pounding using linear and nonlinear contact force model for different separation distances and was compared with nominal model without pounding consideration. The result of this study shown that pounding was a highly nonlinear phenomenon and that lead to significant structural damage, resulted in amplifying the building displacement and acceleration. They concluded that the simplest and effective way for pounding mitigation was to provide enough separation distance by using the rational approach of double difference combinations (DDS) rule.

Rohit Nikam et.al (2012) investigated the minimum seismic pounding gap between two adjacent structures resting on medium soil by response spectrum analysis. Earthquake recorded excitation were used for dynamic analysis on different models. They concluded that it was necessary to increase the stiffness of the building by providing shear walls or placing them at right angles to the divided line between two adjacent buildings. They acted as bumper elements in the case of pounding. The additional energy dissipation devices such as elastomeric pad, viscous fluid dampers, tuned liquid dampers which increases damping ratio up to 20% were good solutions for this cases. Therefore more research work is needed in the response spectrum analysis to obtain minimum seismic gap between adjacent buildings and also for selection and application of suitable damping material.

Khaja Afroz Jamal et.al (2013) A systematic study regarding pounding of building response as well as seismic hazard mitigation practices like proper separation distances and effect of addition of shear walls were investigated using ETABS nonlinear software. The results were obtained in the form of pounding force and point displacements. It was noticed that, by increasing separation distance and by providing shear wall, pounding effect was reduced greatly and hence damage to neighboring buildings was also minimized.

Mohammed jameel et.al (2013) studied the response behavior of adjacent buildings with dissimilar heights under earthquake induced pounding using ETABS. Non-linear finite element analysis was carried out. Storey shear, pounding force, storey drift, point displacement and acceleration of buildings with and without pounding was studied. They concluded that the conventional modelling of building considering only beams and columns underestimates pounding effects. In order to accurately understand the pounding phenomenon, more realistic modelling such as beams, columns and slabs shall be adopted.

S. Sorace and G. Terenzi (2013) examined a representative case study of potential earthquake-induced pounding between adjacent R/C frame buildings sited in Pordenone, Friuli region – Italy, designed and built in the early 1960s with insufficient separation gaps. The interconnection-based solution devised for pounding mitigation, based on the incorporation of fluid viscous dissipaters across the separation gaps, offered positive indications in the case study examined here. Proper choice of damping devices, optimal sizing and installation procedures represented challenging topics for researchers and designers. The mitigation intervention proposed in this study can be viewed as a global seismic retrofit strategy for adjacent structures having inadequate separation gaps.

Amruta Sadanand Tapashetti et.al (2014) covered the prevention techniques of pounding between adjacent buildings. Construction of new RC walls, cross bracing system and combined RC wall & bracing, fluid viscous damper, combined system of RC wall and dampers and combined system of bracing and dampers with proper placement were proposed as possible prevention techniques for pounding between adjacent buildings. SAP2000 was used for the modelling. They concluded that the stiffness of the buildings can be increased by adopting all this methods. Scope of this study is to replace FVD with different dampers.

Chandra Sekhara Reddy et.al (2014) analyzed buildings with same height and same floor levels, buildings with same height but different floor levels, buildings with different height and same floor levels, buildings with different heights and different floor levels (floor-mid column) and for row of buildings with different height but same floor levels using SAP2000 software package. Buildings placed at different floor levels had greater impact force than that of buildings at same floor levels. When buildings were in a row, exterior building suffered more pounding damage than the interior building. In order to avoid pounding, they suggested constructing adjacent buildings with same floor level and with suitable separation gap. No mitigation techniques were discussed in this paper.

Chetan J. Chitte et.al (2014) evaluated an analytical model and methodology for the formulation of the adjacent building-pounding problem. Parametric study to identify the most important parameters was carried out. They proposed minimum seismic gap between buildings under both far field and near field ground motion. It was noticed that, near source ground motion had much larger displacement than those of far source ground motion. Hence the pounding possibility during near-source ground motion is much larger than during far-source ground motion with same gap.

M. Phani Kumar and J D Chaitanya Kumar (2015) studied the seismic pounding effects between adjacent buildings by linear and nonlinear dynamic analysis by using ETABS computer program. This study investigated the effect of various parameters on the structural pounding by using Response spectrum (linear dynamic) analysis for medium soil at zone V and Time history (Non-linear dynamic) analysis for Bhuj earthquake recorded excitation on different models with varying separation distances. Adjacent buildings of nine storeys and fifteen storeys with full brick infill walls and mixed brick infill and shear walls were considered for the analysis. It was noticed that, compared to the linear dynamic analysis, the storey displacements of the two adjacent buildings increased 90 to 95% with non-linear dynamic analysis. So it is necessary to carry out non-linear dynamic analysis to know the actual response of the structure. It was also observed that the pounding effect can be mitigated by introducing shear walls over brick infill walls and also by increasing separation distance.

Puneeth Kumar M S and S Karuna (2015)considered the pounding effects for adjacent buildings at same floor level, adjacent buildings with different floor level (floor to mid column) and Buildings with Setback of 4m. Lateral load resisting system such as bracings and shear wall were provided as mitigation measures. They concluded that buildings with shear wall were more effective than that with bracings.

Abhina N K and Neeraja Nair (2016) compared the seismic pounding of framed RC as well as soft story RC buildings, and evaluated the prevention techniques of pounding between adjacent buildings using ETABS. They concluded that seismic pounding was more severe in the case of adjacent soft-storey building compared to that of framed buildings. Displacement of soft-storey buildings was larger than framed buildings, and also displacement of buildings with different floor level was much more than that of buildings with same floor level. The mitigation methods such as use of shear wall, bracings and combination of shear wall & bracings were proved to be effective in all cases

Quraishi Izharulhaque and Sangeeta Shinde (2016) studied pounding mitigation techniques using dampers in detail using ETAB. The dampers such as viscous damper, viscoelastic damper, friction damper and tuned mass dampers can be used as an energy dissipation device. The response of viscous and viscoelastic dampers during pounding were studied here. Buildings were subjected to three earthquake ground motion characteristics namely El Centro, Uttarkashi and Chamoli earthquake. Dampers proved to be very effective in reducing the impact force as well as number of impacts. The study of damper regarding their location was out of scope of this paper.

Ravindranatha et.al (2016) covered the effect of structural pounding on conventional beam column system adjacent to flat slab system .In order to observe pounding effect, Time history analysis was carried out by taking 1940 Elcentro earthquake data .Possible mitigation techniques for pounding between adjacent structures were proposed as X cross bracings, Eccen forward and backward cross bracing, V cross bracing systems with proper placement. It was found that, for reducing the lateral displacement, X- cross bracing system was more effective. V-cross bracing contributed partially towards the reduction of lateral displacement. Eccen forward and backward bracing system gave more or less same stiffness to the structures. In comparison with beam – column system, the stiffness of the flat slab system was lesser and hence design engineer have to give more importance while the design of such structures.

4 SUMMARY AND CONCLUSION

From the above literatures, it is cleared that the seismic pounding between buildings had been studied exclusively for more than decades. The following conclusions are drawn from the past studies:

- Adjacent buildings without proper separation gap are affected by seismic pounding

- Pounding effect can be decreased with increasing separation gap
- For seismic pounding analysis, it is necessary to carryout non linear dynamic analysis
- Adjacent buildings of same structural systems and same floor levels encountered same oscillations and same mode of vibrations. As a result no pounding occurs.
- Pounding can be effectively controlled using bracings, shear walls and dampers
- Colliding buildings having different masses, periods and heights can be a serious problem and threat to safety.

Limitations

- Commonly adopted mitigation practices were use of shear walls and bracings. But seismic pounding effects of buildings at different floor levels (ie.mid column pounding) and mitigation practices using various dampers had not drawn much attention.
- Proper choice of damping devices, as well as their optimal sizing and installation procedure represents challenging topic for researchers.
- Effectiveness of different dampers in seismic pounding control is also need to be studied.

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