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Seismic Pounding and Vulnerability to the High Rise Building Structures

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Abstract: Collision of buildings is known as pounding. Investigations of past and recent earthquake damage have illustrated that the building structures are vulnerable to severe damage and/or collapse during moderate to strong ground motion. Among the possible structural damages, seismic pounding has been commonly observed in several earthquakes. Seismic pounding between adjacent buildings can cause severe damage to the structures under earthquakes, when owing to their different dynamic characteristics. During earthquake, the buildings vibrate out of phase and at rest separation is deficient to accommodate their relative motions. Such buildings are usually separated by expansion joint which is insufficient to provide the lateral movements of the buildings during earthquakes. It can be prevented by providing safe separation distances, sometimes getting of required safe separations is not possible in metropolitan areas due to high land value and limited availability of land space. If building separations is found to be deficient to prevent pounding, then there should be some secure and cost effective methods to prevent structural pounding between adjacent buildings. There are many buildings which are constructed very nearly to one another in Metropolitan cities, because everyone wants to construct up to their property line due to high cost of land. This study covers the prevention techniques of pounding between adjacent buildings due to earthquakes. Constructing 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.

Key words: Seismic Pounding, Non –linear Time history modelling, Shaking Table, Experiment, Base Isolation.

I. INTRODUCTION

Seismic pounding occurs when two adjacent buildings collide. Earthquake can cause this effect when adjacent buildings have no gap of separation. Pounding is one of the major causes of severe building damages in earthquake. The non structural damage involves movement across the separation joint between adjacent buildings. This effect is more pronounced in taller buildings. When building height do not match, the roof of shorter building may pound at the mid height of the columns in taller buildings. This can be very dangerous and can lead to storey collapse.

II. DAMAGES DUE TO POUNDING

- Separation of joint due to pounding effect
- Storey collapse due to Pounding Seismic Pounding and Vulnerability to the buildings.

1.1 Critical Weaknesses that are Vulnerable to Pounding:

By taking review of all information collected on pounding damages, following are some critical weaknesses found that greatly affect the safety of building structures.

1.2.1 Floor-to-column pounding:

In particular, the columns that suffer collision are subject to very high shear forces. Typically these columns fail in shear, although column ductility requirements may also be exceeded. Pounding categorizations

1.2.2 Adjacent buildings with greatly differing mass:

The momentum transfer from the heavier building can greatly increase the velocity in the lighter structure during impact. Thus the lighter building is susceptible to collapse.

1.2.3 External buildings of a row when all buildings have similar properties:

This scenario is analogous to Newton's cradle. If there is a street of similar buildings with little or no building separation, then the end buildings suffer increased damage due to the momentum transfer from the interior buildings. Subsequently the interior buildings may actually suffer less damage than if pounding were not to occur.

1.2.4 Building subject to torsional actions arising from pounding.

Certain building configurations can excite torsional modes in one or both structures which can lead to greatly increased loading demands. This is particularly dangerous if floor-to-column pounding occurs.

1.2.5 Buildings made of brittle materials.

Unreinforced masonry is particularly vulnerable to any lateral loading. Collision causes a very high temporary force which may cause explosive failure of brittle structural elements.

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1.2.6 Buildings with significantly differing total heights:

A collision between a tall and a short building changes the taller building's displacement mode. The floor that suffers collision in the taller building is restrained, while the rest of the building is 'whip-lashed' over top. This creates a major increase in shear and ductility demands in the taller building in the storey immediately above the top floor of the shorter building.

Buildings that are prone to pounding but do not meet any of the above criteria are significantly more likely to survive during an earthquake. However, pounding creates large acceleration demands on any floors directly involved in collision, which may cause significant damage to contents and endanger human lives. Thus care must be taken with all buildings that may suffer pounding.

III. ANALYSIS OF POUNDING

This study considers the simple case of collision between two buildings with floors at the same height. the common method of modelling approximates the collision of two floors as collision between two lumped masses. floors are modelled as lumped masses under two conditions; if only one node is used to represent the floor, or if all nodes in a floor are horizontally slaved together. by using conservation of momentum and conservation of energy, the post collision velocity (v') of each floor can be calculated in terms of each buildings mass (m) and initial velocity (v). However the lumped mass assumption prevents any calculation of collision force or collision duration.

An alternate solution may be found by modelling the mass as evenly distributed over the length of the floor. The solution to this model requires the use of the one dimensional wave equation Seismic Pounding And Vulnerability to the buildings. The resulting relationships differ when compared to the lumped mass models. Furthermore, both collision duration and collision force can be easily calculated. The solution introduces new parameters including the axial stiffness (k) of the each floor, and the 'collision period' (T) of each building.

3.1. Experimental Analysis:

Use of Shaking Table To Study Different Methods Of Reducing Effects Of Buildings Pounding During Earthquake. The paper by Arash Rezavani and A.S. Moghadam presents shaking table experiments on two adjacent small scale (almost 1/10 scale) moment resisting frames, one 3 and the other 6-story subjected to harmonic excitation and seismic loading. To examine different techniques for reducing the effects of pounding, a series of experiments have been conducted. The measures include increasing distance of the buildings, application of impact absorbing material, and connecting the two building together.

3.1.1 The experimental model properties and setup:

The specimens consist of two small scale (almost 1/10 scale) single bay moment resisting steel frames. The frames are designed based on static analysis approach of building code. The story height of the frames is 0.3 meter. The total height of the 6-story building is 1.8 meter, and the total height of the 3-story building is 0.9 meter.

Beam and column sections consist of 3mm*50mm and 4mm*50mm plates. The connections are built from 5mm*50mm*50mm angles with the length of 70cm. Fillet weld with 3mm dimension has been used to provide rigid connections. Column base is connected by angle to a 60mm*40mm*10mm plate. the two test frames and the column base connection shows the concentrated masses on beams. Two concentrated masses (700 to 750 grams each) are placed on roof level beams and four concentrated masses are placed on floor beams. The impacts between two frames are accomplished at the third level through a contact element.

3.1.2 The conducted tests:

The main tests conducted in the experimental study were:
1. Vibration of structures without pounding;
2. Vibration of structures with pounding in two cases with 0.5cm and 1.0cm distance between structures;
3. Vibration of structures with pounding, when polystyrene material is installed at the third floor of the 6-story structure;
4. Vibration of the buildings, when they are connected at their third floors;
5. Vibration of the buildings, when they are connected at their first and third floors.

The general conclusions made by Arash Rezavani and A.S. Moghadam are:

1. If by increasing the distance of the two buildings still pounding occurs, this increase of distance increases the responses.
2.By using impact absorbing material, the acceleration response of structures has reduced which can be very important, especially for non-structural elements.
3. Connecting the structures at a floor level reduced the responses. Connecting the two buildings at more than a level did not improve very much the responses of the structures
2. Global damage resulting from the energy and momentum transfer caused by collision.

IV. PREVENTIVE MEASURES FOR REDUCING EFFECT OF POUNDING

4.1 Buildings should required Separation Distance to Avoid Pounding. Seismic pounding occurs when the separation distance between adjacent buildings is not large enough to accommodate the relative motion during earthquake events. Seismic codes and regulations worldwide specify minimum separation distances to be provided between adjacent buildings, to preclude

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pounding, which is obviously equal to the relative displacement demand of the two potentially colliding structural systems. For instance, according to the 2000 edition of the International building code and in many seismic design codes and regulations worldwide, minimum separation distances (Lopez-Garcia 2004) are given by ABSolute sum (ABS) or Square Root of Sum of Squares (SRSS) as follow:

$S=U_a+U_b$ ……………. ABS (1)

$S = \sqrt(U_a^2 + U_b^2)$ ………..SRSS (2)

where S = separation distance and Ua , U b = peak displacement response of adjacent structures A and B, respectively.

4.2 Use of Viscous Dampers:

In order to understand and prevent poundings many researches were done for decades. So far suggestions for preventing and mitigating the pounding effect can be categorized in three groups: measures at the possible pounding locations, minimum separation distance between the structures, and link of the structures.

[1] Anagnostopoulos and Spiliopoulos (1992) investigated the pounding behaviour of series of buildings and analyzed the collision walls for mitigating the pounding. This measure is also suggested in the European codes (Anagnostopoulos, 1996). Jankowski, Wilde and Fujino (2000) analyzed hard rubber bumpers between bridge girders, and their results showed that placing of rubber bumpers decreased the forces at the bridge piers.

[2]Kasai (1996) studied seismic separation gap, and he suggested the spectral difference method. Penzien (1997) suggested a complete-quadratic combination method for determining the necessary separation distance between the structures. This measure, seismic separation gap, has been required also in many codes (American UBC 1993, NEHRP 1991, Canadian NBCC 1990, Chinese GBJ11-89).

[3]Westermo (1989) investigated analytically the seismic behaviour of adjacent buildings connected by rigid links with hinges. Luco and De Barros (1998) determined the optimal value of uniformly installed viscous dampers between the adjacent structures. Zhang and Xu (1999) presented a procedure for estimating the modal damping ratios in order to reduce the response of buildings by connecting them with visco-elastic dampers. Yang and Xu (2003) performed experimental investigations to determine the effect of the number and location of viscous dampers between the adjacent structures. Seismic separation gap is not applicable in some cases, for example, if the structures are already built very close to each other. In such a case we can either install equipment at the possible pounding locations or we can connect the structures. **Uemuet Goerguelue** in his research paper addresses the possible measures for reducing the pounding effect. In order to apply the measures, structures are connected with link elements that can have a gap, viscous damper, friction device and elastic spring. The influence of considered measures on the structures under the 1994 Northridge earthquake and the 1999 Turkey earthquake is examined.

4.2.1. Location of Viscous Damper:

In order to investigate the effect of the location of the viscous dampers the maximum horizontal displacements of structures are considered. Uemuet Goergueluein his paper displayed the response of the structures for different viscous damper locations. The damping constant is 104Ns/m. When the structures are linked at all floor levels, compared to other link conditions the response of the flexible structure decreases. The relative displacement along the height of structure also becomes small. His study also reveals that in case of horizontal ground motions the fundamental mode of the structures determines the response. Therefore, uniformly distributed viscous dampers will control the response effectively. If we install the viscous dampers at lower levels their effectiveness will decrease. In order to compensate this disadvantage a higher damping value has to be used. The result shows that viscous dampers at all floors with the value of 104Ns/m, at third floor with the value of
104.3Ns/m, at second floor with the value of 104.5Ns/m, and at the first floor with high value of 105Ns/m, all dampers cause almost the same response.

V. POUNDING IN FIXED FOUNDATION VS BASE ISOLATED BUILDINGS

Residential and commercial buildings in metropolitan areas are often built very close to one another, making them at risk to collide on each other under strong ground motion. further, architectural projections may raise this situation by decreasing the local spacing between the adjacent buildings. it is becoming more common in engineering practice to retrofit mid-rise structures with seismic response modification devices.

One approach that has been commonly observed over the last few years is the use of base isolators. Base Isolators are the units located between the foundation and the superstructure to reduce the force effect of strong ground motions. This reduces the base shear force transferred to the structure, by reducing the displacement of the floors with respect to the base, and hence reducing the internal forces produced in the structure. These devices are designed to permit sliding of the structure during strong earthquakes. However, this sliding motion can be significant (depending on their design) and although the structure itself may not be deformed significantly, the total deformation may be greater than without this device.

Thus, while the risk of damage due to structural deformations is decreased, the risk of damage due to collision between adjacent buildings may be increased with the use of base isolation devices. This collision effect is investigated by V.K. Agarwala1, J.M. Niedzweckia2, J.W. van de Lindtb. He modelled two example one is two

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fixed foundation buildings and other is two Base isolated buildings for following conditions:

5.1 Fixed Foundation Buildings:

5.1.1When separation distance is less than maximum lateral displacement:

When the two adjacent buildings are on fixed foundations, the number of upper story impacts increases when spacing between the buildings is very less. Because of insufficient separation gap between adjacent buildings, this may lead severe damages due to pounding like storey collapse or separation of joints.

5.1.2 When separation distance is greater than Maximum lateral displacement:

The separation distance that are larger than the maximum lateral displacement of fixed foundation buildings, there is little or no interaction between the buildings, there are few impacts, and the maximum lateral displacement is just that of a single isolated building. When the initial gap is roughly the same size as the maximum displacement, interaction increases, the number of impacts rises rapidly, and the maximum lateral displacement tends to be reduced.

5.2 Base Isolated buildings:

When both the adjacent buildings are base isolated, the impact force is very high. However, the impact force is quite low when the friction coefficient is allowed to vary with velocity. For most of the earthquakes, pounding occurs only at very small initial gaps, because both buildings tend to slide in the same direction, keeping the gap between them approximately constant. This is a natural coupling which occurs since the model assumes that the foundations move exactly with the ground displacement. Thus, in this case the probability of impact depends on the earthquake motion, presumably the location of the seismic source, as well as the stiffness of the buildings. The specifics of the earthquake ground motion play a dominant role in the maximum gap at which pounding was found to be present. Base isolation is able to reduce the number of impacts for some earthquakes, while increasing the number for others. Thus, it can be concluded from the several examples in this study that a basic set of rules needs to be established to determine for such conditions. It would also be advantageous to investigating coupling the foundations through rigid (or other) connections to alter the effect of the relative motion essentially creating a single base isolated structure.

VI. CONCLUSION

In recent years, there has been an increasing demand to minimize structural and non-structural damage under extreme earthquake excitations. Although pounding incidences between fixed-supported buildings during strong earthquakes motivated the civil Engineers to innovative earthquake resistant design approach to reduce damages due earthquake motion. The purpose of this report has been to lighten the seismic pounding effects between buildings and measures to reduce this effect. The most direct way to reduce or avoid pounding is to provide an adequate separation distance between the buildings. If by increasing the distance of the two buildings still pounding occurs, this increase of distance increases the responses of adjacent structure. When adjacent buildings are linked with gap reduces pounding or reduces the response of the adjacent structures. The viscous damper and elastic spring can reduce the structural response. The elastic spring itself can limit the pounding force. By connecting the structures at a floor level reduced the response of adjacent structure. Connecting the two buildings at more than a level did not improve very much the responses of the structures.

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