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## Study on Separation Distance between Adjacent Buildings for Prevention of Seismic Pounding

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**ABSTRACT:** Structures are built close to each other in various cities and urban areas where cost of land is high and availability of land is difficult. Due to this closeness, the structures may collide with each other when subjected to any vibration or earthquake. This collision of buildings or its different parts during the vibration is called pounding which result in architectural and structural damages or collapse of the entire structure. The Among the possible structural damages, seismic induced pounding has been commonly observed in several earthquakes. As a result, a parametric study on buildings pounding response as well as proper seismic hazard mitigation practice for adjacent buildings is carried out. Therefore, the needs to improve seismic performance of the built environment through the development of performance-oriented procedures have been developed. To estimate the seismic demands, nonlinearities in the structure are to be considered when the structure enters into inelastic range during devastating earthquakes. Despite the increase in the accuracy and efficiency of the computational tools related to dynamic inelastic analysis, engineers tend to adopt simplified non-linear static procedures instead of rigorous non-linear dynamic analysis when evaluating seismic demands. This is due to the problems related to its complexities and suitability for practical design applications. The push over analysis is a static, nonlinear procedure that can be used to estimate the dynamic needs imposed on a structure by earthquake ground motions. Papers aims at studying seismic gap between adjacent buildings by dynamic and pushover analysis in software. A parametric study is conducted to investigate the minimum seismic pounding gap between two adjacent structures by response Spectrum analysis for medium soil and Elcentro Earthquake recorded excitation are used for input in the dynamic analysis on different models.. The effect of impact is studied using linear and nonlinear contact force on models for different separation distances and compared with nominal model without pounding consideration. Pounding produces acceleration and shear at various story levels that are greater than those obtained from the no pounding case, while the peak drift depends on the input excitation characteristics. Also, increasing gap width is likely to be effective when the separation is sufficiently wide practically to eliminate contact. The results of pushover analysis viz. pushover curves and capacity spectrum for three different lateral load patterns are observed to study the effect of different lateral load pattern on the structural displacement to find out minimum seismic gap between buildings.

**KEYWORDS:** Structural pounding, Building collision, Adjacent buildings, Seismic separation distance, Pounding analysis

### I. INTRODUCTION

The Seismic Pounding can be defined as the collision of adjacent buildings during the earthquakes. The principle reason for the pounding effect is the insufficient gap in between the adjacent buildings. It is one of the main causes of

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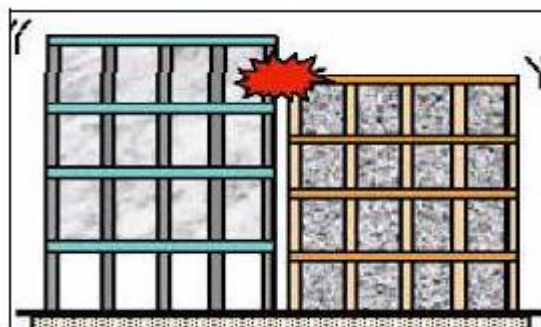
Vol. 7, Issue 12, December 2018

severe building damages in earthquake. The non-structural damage involves pounding or movement across separation joints between adjacent structures. Seismic pounding between two adjacent buildings occur during an earthquake when adjacent buildings of different dynamic characteristics vibrate out of phase at-rest separation is insufficient. A separation joint is the distance between two different building structures – often two wings of the same facility that allows the structures to move independently of one another. Also, Poundings may occur because of structural irregularities. For example eccentricity between mass rigidity centers cause torsion in the structure. Pounding is very complex phenomenon. It could lead to infill wall damage, plastic deformation, column shear failure, local crushing and possible collapse of the structure. Adjacent structures with different floor levels are more vulnerable when subjected to seismic pounding due to additional shear forces on the columns causing more damage and instability to the building. 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.

## 1.1 Causes of Pounding

The various causes of pounding are as follows:-

1. Adjacent buildings with the same heights and the same door levels
2. Adjacent buildings with same floor levels but different heights
3. Adjacent structures with different total height and floor levels
4. Structures are 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. Pounding occurs at the unsupported part (e.g., mid-height) of column or wall.
8. Construction according to the earlier code that was vague on separation distance.
9. Possible settlement and rocking of the structures located on soft soils.
10. Buildings having irregular lateral load resisting systems in plan rotate during an earthquake



**Fig-1: Pounding of Adjacent Buildings**

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## 1.2 Background

Researchers have long examined earthquake-induced pounding between adjacent buildings because of the damage pounding has caused in past earthquakes. We reexamined safe separation distance because recent work on FEMA P-154 [1] suggested US practice is overly conservative. Pounding tends to occur in dense urban areas because of the small separation distances there. Several authors have performed surveys of pounding damage after earthquakes. Rosenblueth and Meli [2] report on a damage survey after the 1985 Mexico City earthquake, performed by teams of engineering students, each team led by one or two experienced structural engineers. The teams performed mostly external (visual) inspection of 330 buildings that experienced severe damage or collapse, associated pounding with 40% of instances, and asserted that “in 15 percent of all cases [pounding] led to collapse.” The authors do not offer the teams’ basis for judgment, evidence, or any validation of the teams’ judgment is offered

## 1.3 Motivation

Survey of pounding damage after the 1989 Loma Prieta earthquake found that about 500 buildings were affected by about 200 instances of pounding, mostly involving older multistory masonry buildings, many with virtually no separation, and predominantly involving minor architectural or structural damage, although the authors warned of the potential for more serious damage in future, closer or larger earthquakes. Cole et al. [4] performed a similar survey of a portion of downtown Christchurch after the 2011 earthquake, most of which had no separation distance. Three notable findings: some buildings suffered partial collapse in part because of pounding; unreinforced masonry buildings were disproportionately likely to experience pounding damage, compared with concrete, timber, and steel; and the authors are not sure that pounding contributed to the complete collapse of any buildings.

## 1.4 Objective

- (i) Seismic analysis of G+4 and G+8 buildings with different plans for medium soil at Zone V.
- (ii) To validate software results by analytical calculations.
- (iii) To evaluate and compare separation distance for different cases to avoid seismic pounding.

## II. LITERATURE REVIEW

C.L. Ng et al [1] studied the application of control devices in coupled building system has been recently recognized as an effective alternative for seismic protection. In consideration of passive control approach, most of previous studies focused on application of fluid dampers, and the buildings in the coupled systems were in similar structural configuration. By recognizing the potential merits, such as simple in design, relatively effective in cost and performance reliability, of passive friction damper, this paper reports an experimental investigation to demonstrate the control effectiveness of passive friction damper as a coupling device implemented in a scaled 12-story building structure with 3-story podium structure tested on a shake table at The Hong Kong Polytechnic University. The passive friction damper was designed in such a way that the friction force could be changed independently of frequency and amplitude. Dynamic characteristics of the test models for uncoupled and rigidly connected cases were first identified, which were followed by seismic simulation tests. The effects of coupling configurations including the uncoupled, rigid coupled and passive controlled cases were evaluated. Passive control force level and ground motion on control performance were also examined. Installation of friction damper showed positive results in reduction of absolute acceleration and interstory drift responses of both buildings. Rigidly connecting 12-story and podium structures, in contrast, revealed its inherent tendency in amplifying the response of 12-story building in particular.

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Vol. 7, Issue 12, December 2018

**D. Lopez Garcia et al [2]** provides relevant insight into the application of the CQC rule in calculating the separation distance necessary to prevent seismic pounding between adjacent structures. In particular, the authors should be commended for their useful analysis of the level of accuracy of the CQC rule and for making the important but often overlooked distinction between the more realistic one-sided demand and the more conservative, usually assumed double-sided demand. It is perhaps opportune to comment that the application of the CQC rule in assessing critical separation distances was first proposed by Jeng et al under the name "spectral difference method". The designation "double difference combination rule" is sometimes also used to indicate the same approach (Valles and Reinhorn, Lopez Garcia). The objective of this discussion is to point out a small error in the paper by Hong et al. For clarity, the description of the problem under consideration is repeated here using the same notation adopted by Hong et al. Consider the adjacent, linear SDOF systems "1" and "2" shown in Fig. 1, and let  $y_i(t)$  be the displacement response of system "i" ( $i = 1,2$ ) to a seismic excitation  $u_g$ . The displacement response of the systems relative to one another (from now on simply referred to as relative displacement) is given by,  $d(t) = y_1(t) - y_2(t)$ . Assuming that  $d(t)$  is a Gaussian, stationary random process, the corresponding mean peak value over a given duration (necessary to calculate the critical separation distance).

**ErsinAydin et al [3]** study prevention of pounding effect is targeted by placement of viscous damping elements within the adjacent buildings. In addition, reduction of relative displacement of the buildings and the effects of various vibration characteristics of each building is investigated based on relative displacement response spectrum concept. Equations of motion of a structure, which are uncoupled when each structure is considered alone, become coupled when damping elements are placed in between the adjacent structures. Each one of two single degree of freedom structural models are analyzed independent of each other in order to calculate their vibration frequencies and their relative displacement behavior defined under selected earthquake ground motion data. Afterwards, an optimal damper is placed in between the adjacent buildings at storey level. The effect of optimal damper design on pounding prevention of the buildings is examined by means of relative displacement response spectrum.

**G. L. Cole et al [4]** investigated recent legislation, the past three years has seen a radical increase in the evaluation of potentially Earthquake Prone Buildings (EPBs) in New Zealand. Using the Initial Evaluation Procedure (IEP), EPBs' vulnerability to seismic pounding must be assessed. Engineers currently have little knowledge of this highly specialized field. This paper aims to assist engineers undertaking either preliminary or in depth assessment of buildings with pounding potential. An international state of the art review is presented with particular emphasis on the loadings caused by pounding. Floor-to-floor collisions are identified as a fundamentally different process to floor-to-column collisions. Current methods of building pounding assessment are reviewed, specifically assessing each method's applicability and weaknesses. Existing mitigation options are also evaluated in terms of practical application to existing structures. Finally, critical building weaknesses that are vulnerable to pounding are presented. It is intended that this paper will provide a useful contextual background on pounding for all engineers using the IEP or higher order analyses.

**H. P. Hong et al [5]** studied separation distance between adjacent buildings is provided to reduce the risk of pounding of adjacent buildings under seismic excitations. It should be recognized that the evaluation of the critical separation distance is a one-sided barrier crossing problem while the problem of structural design under seismic excitations is a two-sided crossing problem. A procedure for assessing the required separation distance with or without considering possible uncertainty in structural properties was presented based on the reliability methods and random vibration theory. The procedure was used to carry out parametric analyses. It is shown that uses of the complete quadratic combination (CQC) rule with the modal responses employed for designing structures may over- or underestimate the critical separation distance, depending on the damping ratios and the closeness of the natural vibration periods of adjacent buildings. This is due to not only one sided versus two-sided crossing problem but also the approximation in the CQC rule. Further, the effect of the uncertainty in structural properties on the estimated separation is investigated. The results indicate that this uncertainty tends to increase the required critical separation distance.

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**Jeng Hsiang Lin et al [6]** Presented herein is a spectral approach to evaluate the seismic pounding probability of two adjacent buildings simulated by multi degree- of-freedom systems and separated by a minimum code-specified separation during a period of time. The analytical approach is based on random vibration theory and total probability theory. Numerical simulations of 36 cases are presented in this study. Results of this investigation reveal that the period ratio of the adjacent buildings plays a major role that affects the pounding risk of adjacent buildings. Also noted is that the effect of period ratio on pounding risk has not yet been taken into account in the seismic pounding related provisions of the Uniform Building Code.

**MizamDoganet al [7]** studied the pounding of adjacent RC Buildings for seismic loads concluded that constructing adjacent buildings with equal floor heights and separation distances reduces the effect of pounding considerably. Existing adjacent buildings which are not properly separated from each other can be protected from effects of pounding by placing elastic materials between them. Also limiting lateral displacement of existing adjacent buildings with cast-in-place RC walls is an effective method for preventing structural pounding. These precautions cannot always isolate adjacent buildings completely from pounding but it can help in damping of pounding energy.

**Valleset al [8]** introduced the Pseudo Energy Radius concept to study, (i) the minimum gap size to avoid pounding, (ii) the amplifications due to pounding, and (iii) the evaluation of different pounding mitigation techniques, including the use of supplemental damping devices and shock absorbers. A simple formulation, based on the Pseudo Energy Radius and statistical linearization, was developed to calculate the minimum gap to avoid pounding. Pounding effects in the response of structures were studied, and a simple methodology based on the Pseudo Energy Radius was developed to estimate these effects. Possible pounding mitigation techniques using energy dissipation devices, such as damper links, shock absorbers, or supplemental damping in the structure are described. The use of the Pseudo Energy Radius is suggested to estimate mitigation effectiveness. The formulations presented are then summarized to provide structural engineers with simple design/evaluation procedures to solve pounding problems. Building code considerations for pounding are reviewed. Critical gap to avoid pounding is usually specified in terms of the sum of the maximum displacements, or as a percentage of the height, or as a fixed quantity, or as aSRSS combination of the response. Making use of the improved correlation coefficient based on the above mentioned Pseudo Energy Radius, the Double Difference Combination rule may be used to calculate the critical gap to avoid pounding. The formulation can be extended to determine more rational critical gap formulations in seismic codes.

**Robert Jankowski [9]** conducted non-linear analysis for earthquake-induced pounding of equal height buildings with substantially different dynamic properties. The structures have been modeled as inelastic multi-degree-of-freedom lumped mass systems and the non-linear viscoelastic model has been incorporated to model impact force during collisions. The study has been focused on three-dimensional pounding between two adjacent three-storey buildings. The results of the parametric investigation carried out for different values of structural parameters have also been presented. The results of the response analysis show that structural pounding during earthquakes has a significant influence on the behaviour of the lighter and more flexible building, especially in its longitudinal direction. On the other hand, the results of the response analysis indicate that the behavior of the heavier and stiffer building in the longitudinal, transverse and vertical direction is nearly unaffected by collisions between structures. The results of the study clearly indicate that special attention should be paid to appropriate design of a weaker building, for which earthquake-induced structural pounding can be catastrophic. In order to prevent destructive collisions, the natural vibration period of the structure 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 between both structures should be provided. If none of the solutions is possible, the application of a certain pounding mitigation technique should be considered at the design stage.

**S. Khatiwadaet al [10]** analyzed two impact models, viz. the elastoplastic impact model by van Mier et al and the nonlinear viscoelastic impact element proposed by Jankowski and proposes a new impact model. The proposed viscous elastoplastic impact element combines all three properties of viscosity, elasticity and plasticity in an impact element for

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the first time. The plastic effect may be due to the material yielding at the contact location of the participating structures. A sample numerical investigation is presented for the seismic pounding between two adjacent buildings due to the 1940 North South El-Centro ground motions. The results show that the time history of the roof displacement of the participating structures is significantly different and the maximum displacement is reduced when the new model is employed when compared to the results obtained from numerical simulations using a nonlinear viscoelastic impact element.

**Shehata E. Abdel Raheem [11]** developed and implemented a tool for the inelastic analysis of seismic pounding effect between buildings. They carried out a parametric study on buildings pounding response as well as proper seismic hazard mitigation practice for adjacent buildings. Three categories of recorded earthquake excitation were used for input. He studied the effect of impact using linear and nonlinear contact force model for different separation distances and compared with nominal model without pounding consideration. These are the some review on the literatures of the work done in past by the researchers worldwide on the effect of pounding on structures and preventive measures provided by them.

### III. METHODOLOGY

- 1) Formulation of 3D model for pushover analysis with software package.
- 2) To analyse the Structure by response spectrum analysis.
- 3) To use software for linear and non-linear static and dynamic analysis and design program for three dimensional structures.
- 4) From analysis of results, the modification of the same for the purpose of no pounding is carried out for different cases.

### IV. CONCLUSION

This paper gives effective information about the topic seismic pounding and also has given a survey of some papers related to the topic along with the important data considered and obtained for and from the study. This paper will be helpful enough to find useful journals to study about the topic and to conduct continued researches on the topic. The Among the possible structural damages, seismic induced pounding has been commonly observed in several earthquakes. As a result, a parametric study on buildings pounding response as well as proper seismic hazard mitigation practice for adjacent buildings is carried out. Therefore, the needs to improve seismic performance of the built environment through the development of performance-oriented procedures have been developed. To estimate the seismic demands, nonlinearities in the structure are to be considered when the structure enters into inelastic range during devastating earthquakes. Despite the increase in the accuracy and efficiency of the computational tools related to dynamic inelastic analysis, engineers tend to adopt simplified non-linear static procedures instead of rigorous non-linear dynamic analysis when evaluating seismic demands. This is due to the problems related to its complexities and suitability for practical design applications. The push over analysis is a static, nonlinear procedure that can be used to estimate the dynamic needs imposed on a structure by earthquake ground motions. Papers aims at studying seismic gap between adjacent buildings by dynamic and pushover analysis in software. A parametric study is conducted to investigate the minimum seismic pounding gap between two adjacent structures by response Spectrum analysis for medium soil and Elcentro Earthquake recorded excitation are used for input in the dynamic analysis on different models.. The effect of impact is studied using linear and nonlinear contact force on models for different separation distances and compared with nominal model without pounding consideration. Pounding produces acceleration and shear at various story levels that are greater than those obtained from the no pounding case, while the peak drift depends on the input excitation characteristics. Also, increasing gap width is likely to be effective when the separation

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