"STUDY OF SEISMIC POUNDING EFFECTS BETWEEN ADJACENT STRUCTURES"

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ABSTRACT

Major seismic events during the past decade such as those that have occurred in Northridge, Imperial Valley (May 18, 1940), California (1994), Kobe, Japan (1995), Turkey (1999), Taiwan (1999) and Bhuj, Central Western India (2001) have continued to demonstrate the destructive power of earthquakes, with destruction of engineered buildings, bridges, industrial and port facilities as well as giving rise to great economic losses. 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, linearity of the structure is to be considered during devastating earthquakes. Despite the increase in the accuracy and efficiency of the computational tools related to dynamic analysis, engineers tend to adopt simplified solution oriented procedures instead of doing rigorous analysis when evaluating seismic demands. This is due to the problems related to its complexities and suitability for practical design applications. This project entitled "**Study of Seismic Pounding Effects Between Adjacent Buildings**" aims at studying seismic gap between adjacent buildings by linear dynamic analysis in ETABS .A parametric study is conducted to investigate the minimum seismic pounding gap between two adjacent structures by response Spectrum analysis for hard soil and Earthquake recorded excitation are used for input in the dynamic analysis on different models. 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.

Keyword: - *seismic ponding.,*

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1. INTRODUCTION

Pounding is one of the main causes of severe building damages in earthquake. The non-structural damage involves pounding or movement across separation joints between adjacent structures. Investigations of past and recent earthquake damage have illustrated that the building structures are vulnerable to severe damage and collapse during moderate to strong ground motion. An earthquake with a magnitude of six is capable of causing severe damages of engineered buildings, bridges, industrial and port facilities as well as giving rise to great economic losses. Several destructive earthquakes have hit Egypt in both historical and recent times from distant and near earthquakes. The annual energy release in Egypt and its vicinity is equivalent to an earthquake with magnitude varying from 5.5 to 7.3. Pounding between closely spaced building structures can be a serious hazard in seismically active areas. Investigations of past and recent earthquakes damage have illustrated several instances of pounding damage (Astaneh-Asl et al.1994, Northridge Reconnaissance Team 1996, Kasai& Maison 1991) in both building and bridge structures. Pounding damage was observed during the 1985 Mexico earthquake, the 1988 Sequenay earthquake in Canada, the 1992 Cairo earthquake, the 1994 Northridge earthquake, the 1995 Kobe earthquake and 1999 Kocaeli earthquake. Significant pounding was observed at sites over 90 km from the epicenter thus indicating the possible catastrophic damage that may occur during future earthquakes having closer epicenters. 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 or energy dissipation system to accommodate the relative motions of adjacent buildings. Past seismic codes did not give definite guidelines to preclude pounding, because of this and due to economic considerations including maximum land usage requirements, especially in the high density populated areas of cities, there are many buildings worldwide which are already built in contact or extremely close to another that could suffer pounding damage in future earthquakes. A large separation is controversial from both technical (difficulty in using expansion joint) and economical (loss of land usage) views. The highly congested building system in many metropolitan cities constitutes a major concern for seismic pounding damage. For these reasons, it has been widely accepted that pounding is an undesirable phenomenon that should be prevented or mitigated zones in connection with the corresponding design ground acceleration values will lead in many cases to earthquake actions which are remarkably higher than defined by the design codes used up to now. The most simplest and effective way for pounding mitigation and reducing damage due to pounding is to provide enough separation but it is sometimes difficult to be implemented due to detailing problem and high cost of land. An alternative to the seismic separation gap provision in the structure design is to minimize the effect of pounding through decreasing lateral motion (Kasai et al. 1996, Abdullah et al. 2001, Jankowski et al 2000, Ruangrassamee & Kawashima 2003,Kawashima & Shoji 2000), which can be achieved by joining adjacent structures at critical locations so that their motion could be in-phase with one another or by increasing the pounding buildings damping capacity by means of passive structural control of energy dissipation system or by seismic retrofitting. The focus of this study is the development of an analytical model and methodology for the formulation of the adjacent building pounding problem based on the classical impact theory, an investigation through parametric study to identify the most important parameter damping ratio is carried out. The main objective and scope are to evaluate the effects of structural pounding on the global response of building structures; to determine the minimum seismic gap between buildings and provide engineers with practical analytical tools for predicting pounding response and damage. A realistic pounding model is used for studying the response of structural system under the condition of structural pounding during earthquakes for hard soil condition at seismic zone IV. Two adjacent multi-story buildings are considered as a representative structure for potential pounding problem. Dynamic analysis is carried out on the structures to observe displacement of the buildings due to earthquake excitation. The behavior of the structures under static loads is linear and can be predicted. When we come to the dynamic behaviors, we are mainly concerned with the displacements, velocity and accelerations of the structure under the action of dynamic loads or earthquake loads.

For the purpose of this study, ETABS have been chosen, a linear static and dynamic analysis and design program for three dimensional structures. The application has many features for solving a wide range of problems from simple 2-D trusses to complex 3-D structures. Creation and modification of the model, execution of the analysis, and checking and optimization of the design are all done through this single interface. Graphical displays of the results, including real-time animations of time-history displacements, are easily produced.

2. LITRATURE SURVEY

A series of integrated analytical and experimental studies has been conducted to investigate the seismic gap between adjacent buildings located in regions of high seismic risk. When a building experiences earthquake vibrations its foundation will move back and forth with the ground. These vibrations can be quite intense, creating stresses and deformation throughout the structure making the upper edges of the building swing from a few mm to many inches dependent on their height, size and mass. This is uniformly applicable for buildings of all heights, whether single storied or multi-storied in high risk earthquake zones. In Mexico earthquake it was observed that buildings of different sizes and heights vibrated with different frequencies. Where these were made next to each other they created stresses in both the structures and thus weakened each other and in many cases caused the failure of both the structures. Pounding produces acceleration and shear at various story levels that are greater than those obtained from the no pounding case. Pounding between closely spaced building structures can be a serious hazard in seismically active areas. Also, increasing gap width is likely to be effective when the separation is sufficiently wide practically to eliminate contact.

After a brief evaluation of methods currently standard in engineering practice to estimate seismic gap between buildings, nonlinearities in the structure are to be considered when the structure enters into inelastic range during devastating earthquakes. To consider this nonlinearity effects inelastic response spectra analysis is a powerful tool for the study of structural seismic performance. A set of carefully selected ground motion records can give an accurate evaluation of the anticipated seismic performance of structures. Despite the fact that the accuracy and efficiency of the computational tools have increased substantially, there are still some reservations about the dynamic inelastic analysis, which are mainly related to its complexity and suitability for practical design applications.

A.V. Bhaskararao *et al* [1] studied the structural response of two adjacent buildings connected with various types of dampers under different earthquake excitations is studied. A formulation of the equations of motion for multi-degree of freedom model of buildings connected with dampers is presented. The effectiveness of various types of dampers, viz., viscous, viscoelastic and friction dampers in terms of the reduction of structural responses (i.e., displacement, acceleration and shear forces) of connected adjacent buildings is investigated. A parametric study is also conducted to investigate the optimum parameters of the dampers for adjacent buildings of different heights. In addition, the optimal placement of the dampers, rather than providing the dampers at all the floor levels, is also studied. Results show that connecting the adjacent buildings of different fundamental frequencies by passive dampers can effectively reduce the earthquake induced responses of either building. There exist optimum damper properties for minimum earthquake response of the buildings. In addition, it is not necessary to connect the two adjacent buildings by dampers at all floors but lesser dampers at appropriate locations can also significantly reduce the earthquake response of the combined building system.

A.V. Bhaskararao *et al* [2] had done Analytical seismic responses of two adjacent structures, modeled as single-degree-of-freedom (SDOF) structures, connected with a friction damper are derived in closed-form expressions during non-slip and slip modes and are presented in the form of recurrence formulae. However, the derivation of analytical equations for seismic responses is quite cumbersome for damper connected multi-degree-of-freedom (MDOF) structures as it involves some dampers vibrating in sliding phase and the rest in non-sliding phase at any instant of time. To overcome this difficulty, two numerical models of friction dampers are proposed for MDOF structures and are validated with the results obtained from the analytical model considering an example of SDOF structures. It is found that the proposed two numerical models are predicting the dynamic behavior of the two connected SDOF structures accurately. Further, the effectiveness of dampers in terms of the reduction of structural responses, namely, displacement, acceleration and shear forces of connected adjacent structures is investigated. A parametric study is also conducted to investigate the optimum slip force of the damper. In addition, the optimal placement of dampers, rather than providing dampers at all floor levels is also studied to minimize the cost of dampers. Results show that using friction dampers to connect adjacent structures of different fundamental frequencies can effectively reduce earthquake-induced responses of either structure if the slip force of the dampers is appropriately selected. Further, it is also not necessary to connect two adjacent structures at all floors but lesser dampers at appropriate locations can significantly reduce the earthquake response of the combined system.

Alireza M. Goltabar *et al* [3] has done research on buildings with 2-15 stories and different heights were put together using GAP joint element and nonlinear time-history analyses were done for Tabas, Elcentro and Sakaria accelerographs. The responses of both impact and non-impact cases were compared. With results analyzing, we found out that the impact increased the responses in taller buildings but decreased them in shorter ones. The largest increase was occurred when the height difference was 3 stories. Then the effective parameters in impact phenomenon, hardness and the distance between the structures were studied. The results shown that existence of the distance and hardening the structures (esp. in taller ones) may result to decrease the effect of impact in the structure responses.

Anagnostopoulos *et al* [4] studied the earthquake induced pounding between adjacent buildings. They idealized the building as lumped-mass, shear beam type, multi-degree-of-freedom (MDOF) systems with bilinear force deformation characteristics and with bases supported on translational and rocking spring dashpots. Collisions between adjacent masses can occur at any level and are simulated by means of viscoelastic impact elements. They used five real earthquake motions to study the effects of the following factors: building configuration and relative size, seismic separation distance and impact element properties. It was found that pounding can cause high overstresses, mainly when the colliding buildings have significantly different heights, periods or masses. They suggest a possibility for introducing a set of conditions into the codes, combined with some special measures, as an alternative to the seismic separation requirement.

Arash Rezavani *et al* [5] had done a general study on the effect of pounding. Then two series of shaking table experiments on small scale moment resisting frames subjected to harmonic excitation and seismic loading are described. For new buildings, there are provisions in the seismic design building codes regarding the distance between adjacent buildings to accommodate the potential of pounding. However, for existing building the solution is not as easy. Therefore, final part of the paper explains a series of experiments regarding some measures to reduce the damaging effects of pounding. The measures include increasing distance of the buildings, application of impact absorbing material, and connecting the two building together. The results of experiments indicate the effectiveness, also problems associated with each method.

Chenna Rajaram [6] presented a research work In numerical modeling, different combination of structures are considered for doing the analysis using Applied Element Method (AEM). The separation distances between the structures is provided according to various codes from different countries and are subjected to ten different ground motions. Some codal provisions failed to satisfy the requirements. The shortcomings in codal provisions are identified and provided with proper suggestions to them. To study the behavior of structures due to structural pounding, linear and nonlinear analyses are done for different structures subjected to ground motion. The analysis considers equal and unequal height of structures. The behavior of adjacent structures is similar as linear till failure of first spring or first collision. The displacement responses for flexible structures are less compared to stiff structures when structures vibrate at dominant period and also the responses for flexible structures are more when structures vibrate at non-dominant period. Also we estimate the amount of damage for structures in terms of sti_ness degradation. For unequal height of structures, the interaction is between slab and column. During this interaction, shear causes more damage to the column which leads to collapse of structure. To study the torsional effects due to pounding, buildings with different setbacks and unequal storey levels are analyzed using SAP 2000. The effect of collision is more when structures are kept at extreme levels of setback. When the structures are kept at different elevation levels (setback=0), the pounding response changes significantly as the height of structure decreases. At mid height of structure, the collision force is more compared to other height levels because of shear amplification.

3 STRUCTURAL MODELING AND ANALYSIS

In order to evaluate the Seismic gap between buildings with rigid floor diaphragms using dynamic procedure two sample building was adopted.

The finite element analysis software's ETABS Nonlinear is utilized to create 3D model and run all analyses. The software is able to predict the geometric nonlinear behavior of space frames under static or dynamic loadings, taking into account both geometric nonlinearity and material inelasticity. The software accepts static loads (either forces or displacements) as well as dynamic (accelerations) actions nonlinear dynamic analyses.

3.2 Methods of Seismic Analysis of a Structure

Various methods of differing complexity have been developed for the seismic analysis of structures. The two main techniques currently used for this analysis are:

1. Dynamic analysis.

Linear Dynamic Analysis.

Non-Linear Dynamic Analysis.

2. Push over analysis.

3.2.1 Dynamic Analysis

All real physical structures, when subjected to loads or displacements, behave dynamically. The additional inertia force from Newton's second law are equal to the mass times the acceleration. If the loads or displacements are applied very slowly then the inertia forces can be neglected and a static load analysis can be justified. Hence, dynamic analysis is a simple extension of static analysis.

3.2.1.1 Response Spectrum Analysis

The response spectrum technique is really a simplified special case of modal analysis. The modes of vibration are determined in period and shape in the usual way and the maximum response magnitudes corresponding to each mode are found by reference to a response spectrum. The response spectrum method has the great virtues of speed and cheapness. The basic mode superposition method, which is restricted to linearly elastic analysis, produces the complete time history response of joint displacements and member forces due to a specific ground motion loading. There are two major disadvantages of using this approach. First, the method produces a large amount of output information that can require an enormous amount of computational effort to conduct all possible design checks as a function of time. Second, the analysis must be repeated for several different earthquake motions in order to assure that all the significant modes are excited, since a response spectrum for one earthquake, in a specified direction, is not a smooth function.

There are significant computational advantages in using the response spectra method of seismic analysis for prediction of displacements and member forces in structural systems. The method involves the calculation of only the maximum values of the displacements and member forces in each mode using smooth design spectra that are the average of several earthquake motions. In this analysis, the CQC method to combine these maximum modal response values to obtain the most probable peak value of displacement or force is used. In addition, it will be shown that the SRSS and CQC3 methods of combining results from orthogonal earthquake motions will allow one dynamic analysis to produce design forces for all members of the structure.

3.2.1.2 Nonlinear Dynamic Analysis

Nonlinear Dynamic analysis can be done by direct integration of the equations of motion by step by step procedures. Direct integration provides the most powerful and informative analysis for any given earthquake motion. A time dependent forcing function (earthquake accelerogram) is applied and the corresponding response–history of the structure during the earthquake is computed. That is, the moment and force diagrams at each of a series of prescribed intervals throughout the applied motion can be found. Computer programs have been written for both linear elastic and non-linear inelastic material behavior using step-by-step integration procedures.

3.2.2 Push over Analysis

The non-linear static procedure or simply push over analysis is a simple option for estimating the strength capacity in the post-elastic range. This procedure involves applying a predefined lateral load pattern which is distributed along the building height. The lateral forces are then monotonically increased in constant proportion with a displacement control node of the building until a certain level of deformation is reached.

The applied base shear and the associated lateral displacement at each load increment are plotted. Based on the capacity curve, a target displacement which is an estimate of the displacement that the design earthquake will produce on the building is determined. The extent of damage experienced by the building at this target displacement is considered representative of the damage experienced by the building when subjected to design level ground shaking.

3.3 Details of the Models

The models which have been adopted for study are ten storey and fifteen storey buildings having minimum separation gap between them.

Two models have been considered for the purpose of the study.

1. Ten and Fifteen storey adjacent buildings.

2. Ten storey adjacent buildings.

7. CONCLUSION

After studing the concept of seimic ponding to analysis of structure**.**The response spectrum analysis procedures have been carried out for determining the various structural parameters of the model. Here we are mainly concerned with the behavior of the structure under the effect of ground motion and dynamic excitations such as earthquakes and the displacement of the structure.

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