"STUDY OF SEISMIC POUNDING EFFECTS BETWEEN ADJACENT STRUCTURES"

Mr.Ravi Ramesh Patel ,Dr.Ajay Swarup

[1] *M Tech scholar,Civil Department, SSSUTMS-Sehor, Madhya Pradesh, India*
[2] *Professor, Civil Department, SSSUTMS-Sehor, Madhya Pradesh, India*

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.,*

---

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

C.L. Ng *et al* [7] 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.

D. Lopez Garcia *et al* [8] 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).

Ersin Aydin *et al* [9] 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* [10] 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.

Hasan *et al* [11] presented a simple computer based pushover analysis technique for performance based design of building frameworks subject to earthquake loading. The concept is based on conventional displacement method of elastic analysis. To measure the degree of plastification the term plasticity factor was used. The standard elastic and geometric stiffness matrices for frame elements are progressively modified to account for non-linear elastic-plastic behavior under constant gravity loads and incrementally increasing lateral loads.

H. P. Hong *et al* [12] 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.

Ishan Joyti Sharma [13] presented a thesis on seismic pounding effects in buildings aims at studying seismic gap between adjacent buildings by dynamic and pushover analysis in SAP 2000. A parametric study is conducted to investigate the seismic gap between two adjacent structures and the effect of impact is studied using linear and non-linear contact force on models for different separation distances and compared with nominal model without pounding consideration. 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.

Jeng Hsiang Lin *et al* [14] 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.

Korkmaz and Sari [15] studied the performance of structures for various load patterns and variety of natural periods by performing pushover and nonlinear dynamic time history analysis and concluded that for taller structures pushover analysis is underestimating seismic demands.

Maison *et al* [16] presented a formulation and solution of the multiple degree of freedom equations of motion. The studied building undergoes pounding at a single floor level with a rigid adjacent building. A single linear spring represents the local flexibility of the buildings at their locations of contact. They found that even at the relatively large separation (90% of the sum of maximum displacements obtained without pounding) the increases in drifts and shears are significant. In situations where pounding may potentially occur, neglecting its possible effects leads to unconservative building design/evaluation. The story drifts, shears, and overturning moments in the stories above the pounding elevation will be underestimated (pounding occurred at 8th level in a 15 story structure).

Mizam Dogan *et al* [17] 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.

R. E. Valles *et al* [18] 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 a SRSS 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 calculated the critical gap to avoid pounding. The formulation can be extended to determine more rational critical gap formulations in seismic codes.

Robert Jankowski [19] 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. Khatiwada *et al* [20] 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 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 [21] 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.

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

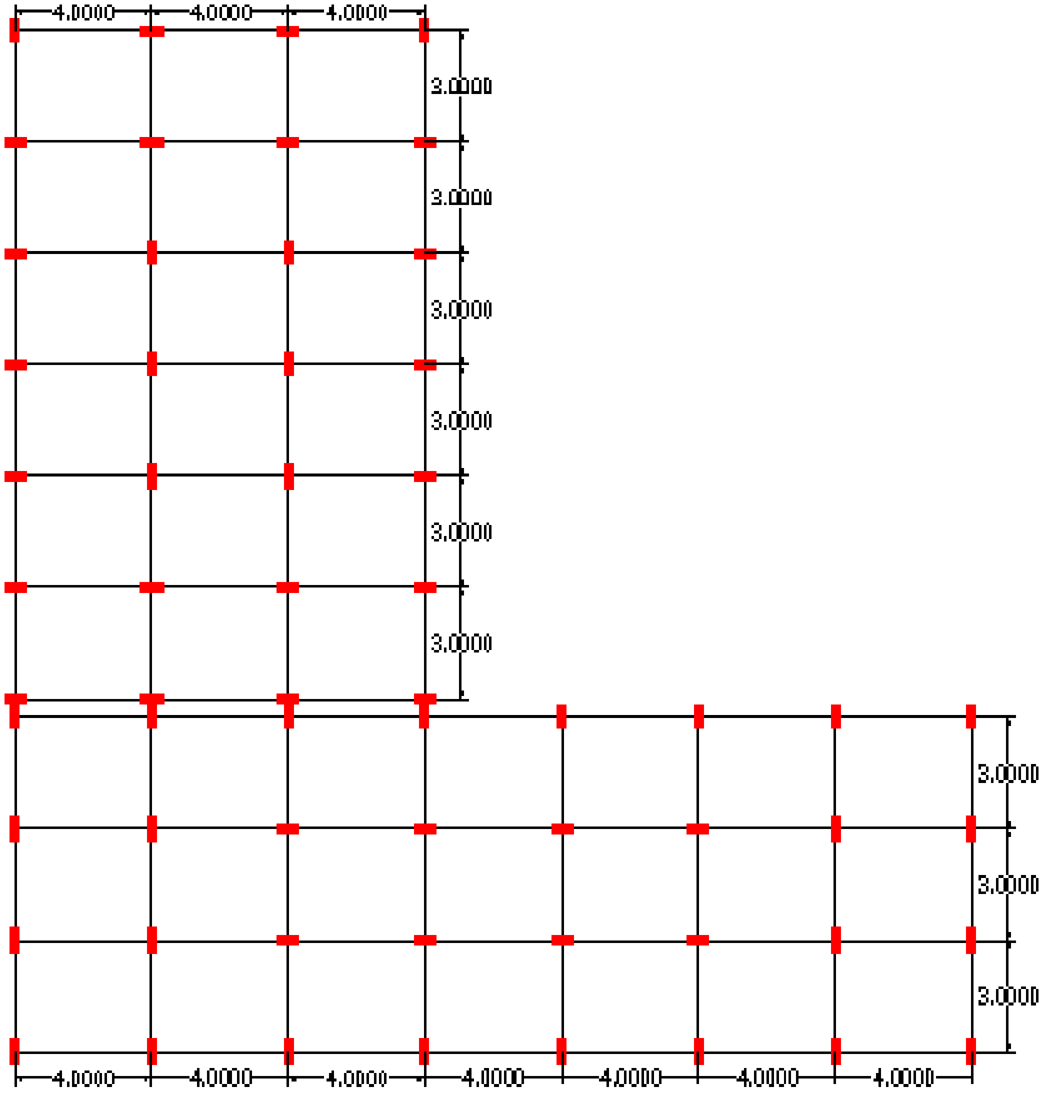
The models which have been adopted for study are ten storey and fifteen storey buildings having minimum separation gap between them.

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

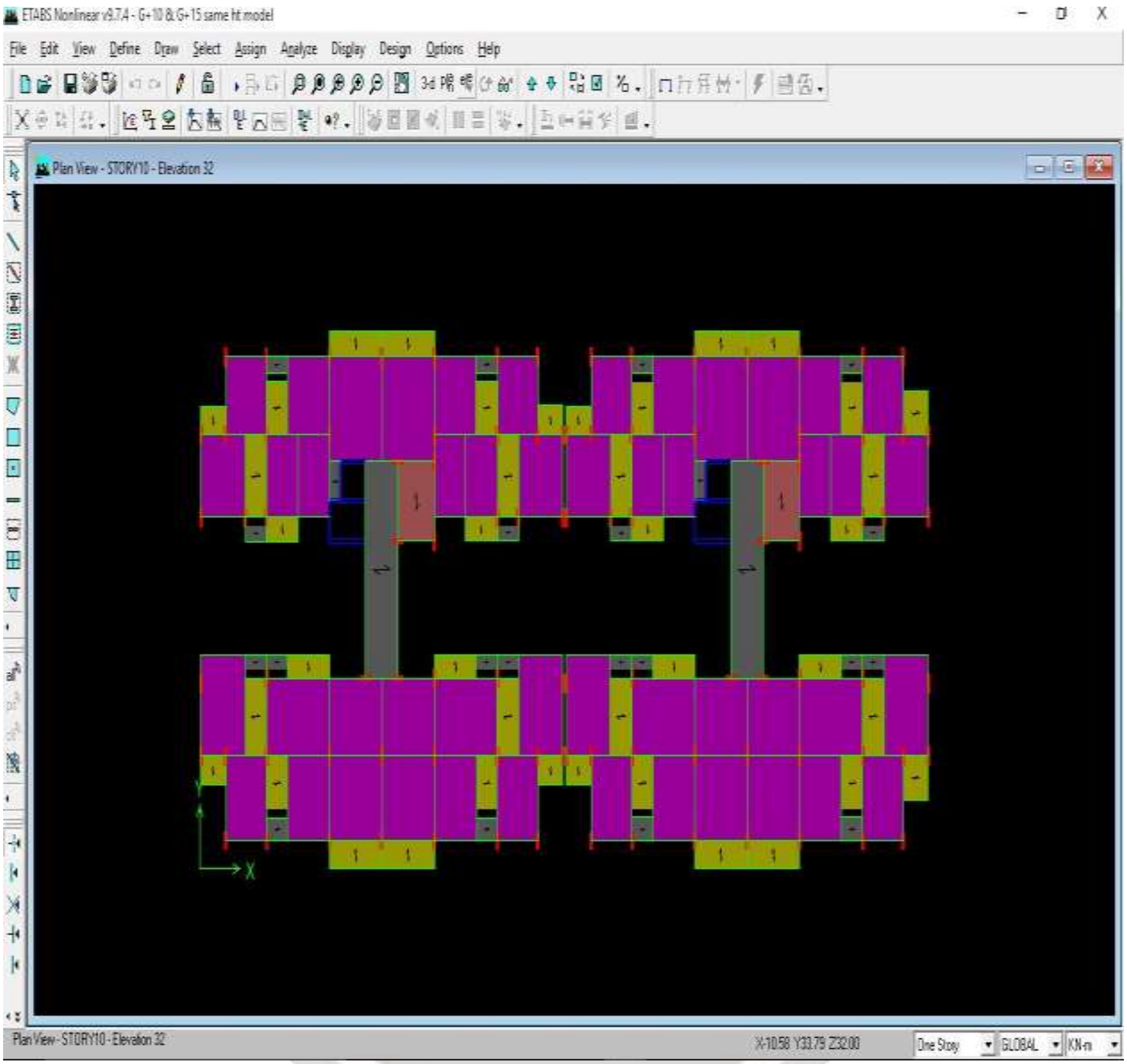
1. Ten and Fifteen storey adjacent buildings.

2. Ten storey adjacent buildings.

The plan of the buildings is as shown



Typical Plan of Buildings



Center line plan

4 RESULT AND DISCUSSIONS

General

ETABS is used to compute the response of ten and fifteen storey buildings for rigid floor diaphragm Linear Dynamic (response spectrum) analysis.

Results from Response Spectrum analysis are observed for the natural frequencies and modal mass participation ratios and Displacements of the joints to determine the seismic pounding gap between adjacent structures of two models.

. Response spectrum analysis

Response spectrum analysis has been carried out as per the response spectra mentioned in IS 1893(Part I) 2002. The results of analysis for the two models have been shown in tabular form as below.

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

Analysis of Ten & Fifteen storey adjacent buildings (Model 1)

Analyzing the Model 1 in ETABS Results are as follows.

a) Mass Participation Ratio

Table 4.1 Mass Participation Ratio for Model 1

Mode	**Period**	**UX**	**UY**	**RZ**	**SumUX**	**SumUY**	**SumRZ**
1	1.678984	52.459	10.3446	9.9942	52.459	10.3446	9.9942
2	1.579194	19.9193	29.081	22.2235	72.3783	39.4256	32.2177
3	1.190333	0.0409	30.5994	39.8005	72.4192	70.025	72.0182
4	0.622114	8.3674	0.2451	1.4869	80.7866	70.2701	73.5052
5	0.579255	2.6751	3.1093	2.5736	83.4617	73.3794	76.0788
6	0.475915	0.2404	8.4932	5.9106	83.702	81.8725	81.9894
7	0.33383	4.6759	0.6373	1.4961	88.3779	82.5098	83.4855
8	0.307607	1.0306	3.8657	5.0173	89.4085	86.3755	88.5028
9	0.235731	0.0638	3.5459	1.532	89.4723	89.9214	90.0348
10	0.207638	2.2308	0.0293	0.1409	91.7031	89.9507	90.1757
11	0.17786	0.6133	0.55	0.6629	92.3164	90.5007	90.8387
12	0.173042	0.0767	0.0033	0.0119	92.3931	90.504	90.8506
TOTAL		92.3932	90.5041	90.8504			

From the above table no. of modes to be used in the analysis should be such that the sum of total model mass consider is at greater than 90% as per IS 1893(Part I)-2002 clause no.7.8.4.2.

LOAD CASE	**ALONG X (mm)**	**AVERAGE (mm)**
WX	8.5	8.2
EQX	71.4	69.5
SPECX	15.4	14.7
LOAD CASE	**ALONGY (mm)**	**AVERAGE (mm)**
WY	12.9	11.4
EQY	56.5	47.5
SPECY	16.6	13.7

I have taken maximum value of earthquake forces along x direction=71.4mm

Therefore,

Permissible displacement as per IS875,

H/250 = 198mm Hence safe.

Hence, the Storey maximum and average lateral displacement for Ten & Fifteen storey adjacent buildings comes out to be 71.4mm. So it is clear that in this cases results are less than as per clause IS 875.

5. CONCLUSION

The study of the creation and analysis of the models by linear dynamic analysis (i.e. response spectrum analysis) for hard soil condition has been carried out on those models to observe displacement at the joints of structure. The models have been studied are a) Ten and Fifteen storey adjacent buildings, b) Ten storey adjacent buildings. Based on the observations from the analysis results, the following conclusion can be drawn.

1. Model mass participation ratio for adjacent Ten & fifteen storey and Ten storey adjacent buildings comes out to be 90.8506% and 97.61% respectively, which are greater than 90% as per clause 7.8.4.2 IS 1893 (Part I) : 2002.
2. In the pounding case constructing the separated buildings is the best way of preventing structural pounding. Storey maximum and average lateral displacement for Ten & Fifteen storey adjacent buildings comes out to be 71.4 mm as well as storey maximum and average lateral displacement for ten storey adjacent buildings comes out to be 58.7 mm so it is clear that in both cases results are less than as per clause IS 875.
3. From the calculations of damping ratios for adjacent Ten and Fifteen storey buildings is 7.83% and for adjacent Ten storey buildings is 5.03%. As we have already incorporated 5% inherent damping in the response spectrum analysis, so the excess damping results in the pounding between adjacent buildings.
4. The minimum Seismic gap between two adjacent structures is provided to be 56.5 mm.
5. Hence from the above conclusion it is clearly seems that there is need to increase the stiffness of the buildings by providing shear walls or placing them at right angles to the divided line between two adjacent buildings, so that they can be used as bumper elements in the case of pounding, otherwise additional energy dissipation devices such as elastomeric pad, viscous fluid dampers, tuned liquid dampers which increases damping ratio up to 20% are good solutions for this cases.

.

6 REFERENCES

[1] A.V. Bhaskararao, *'Seismic Response of Adjacent Buildings Connected with Dampers'* ,13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6, 2004,Paper No. 3143.

[2] A.V. Bhaskararao, *'Seismic analysis of structures connected with friction dampers',* Department of Civil Engineering, IIT Bombay, Powai, Mumbai, India

[3] Alireza M.Goltabar, *'Study of Impact between Adjacent Structures during of Earthquake and their Effective Parameters'*, American J. of Engineering and Applied Sciences 1 (3): 210-218, 2008

[4] Anagnostopoulos S A., *'Pounding of Buildings in Series during Earthquakes',* Earthquake Engineering and Structural Dynamics, Vol.16, pp. 443-456, 1988.

[5] Anagnostopoulos, S. A. and Spiliopoulos, K.V. (1992), *'An investigation of earthquake induced pounding between adjacent buildings',* Earthquake Engineering and Structural Dynamics, Vol. 21, pp. 289-302.

[6] Arash Rezavani, A.S. Moghadam, '*Using Shaking Table to Study Different Methods of Reduceing Effects of Buildings Pounding During Earthquake',* Paper No. 698, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6- 2004.

[7] Bruce D. Westermo., *'The Dynamics of Interstructural Connection to Prevent Pounding',* Earthquake Engineering and Structural Dynamics, Vol.18, pp. 687-699, 1989.

[8] Christina J Athanassiadou, George G Penelis and Andreas J Kappos., *'Seismic Response of Adjacent Buildings with Similar or Different Dynamic Characteristics',*Earthquake Spectra, Vol.10, No.2, pp. 293-317, 1994.

[9] C.L. Ng, Y.L. Xu, *'Experimental Study on Seismic Response Mitigation of Complex Structure using Passive Friction Damper'.*
[10] D. Lopez Gracia, *'Discussion on: Critical Building Separation Distance in Reducing Pounding Rrisk Under Earthquake Excitation',* Structural Safety, 27 (2005) 393–396.

[11] Diego Lopez Garcia., *'Separation between Adjacent Nonlinear Structures for Prevention of Seismic Pounding',* Proceedings on 13th World Conference on Earthquake Engineering, 2004.

[12]Ersin Aydin, Baki Ozturk and Latif Yesil, *'Application of Viscous Dampers for Prevention of Pounding effect in Adjacent Buildings',* 14th Conference, ECEE, 2010.

[13] G.L. Cole, R.P. Dhakal, A.J. Carr, D.K. Bull, *'Building pounding state of the art: Identifying structures vulnerable to pounding damage',* NZSEE Conference, 2010.

[14] H. P. Hong, S. S. Wang, P. Hong, *'Critical Building Separation Distance in Reducing Pounding Risk Under Earthquake Excitation',* Structural Safety, 25 (2003), 287-303.

[15] Jeng Hsiang Lin, Cheng Chiang Weng, *'Spectral analysis on pounding probability of adjacent buildings',* Engineering Structures 23 (2001), 768–778.

[16] Jeng-Hsiang Lin., *'Separation Distance to Avoid Seismic Pounding of Adjacent Buildings",* Earthquake Engineering and Structural Dynamics, Vol 26, pp. 395-403, 1997.

[17] S. Khatiwada, N. Chouw, J.W. Butterworth, *'Development of pounding model for adjacent structures in earthquakes',* Proceedings of the Ninth Pacific Conference on Earthquake Engineering Building an Earthquake-Resilient Society , Auckland, New Zealand, 14-16 April, 2011.