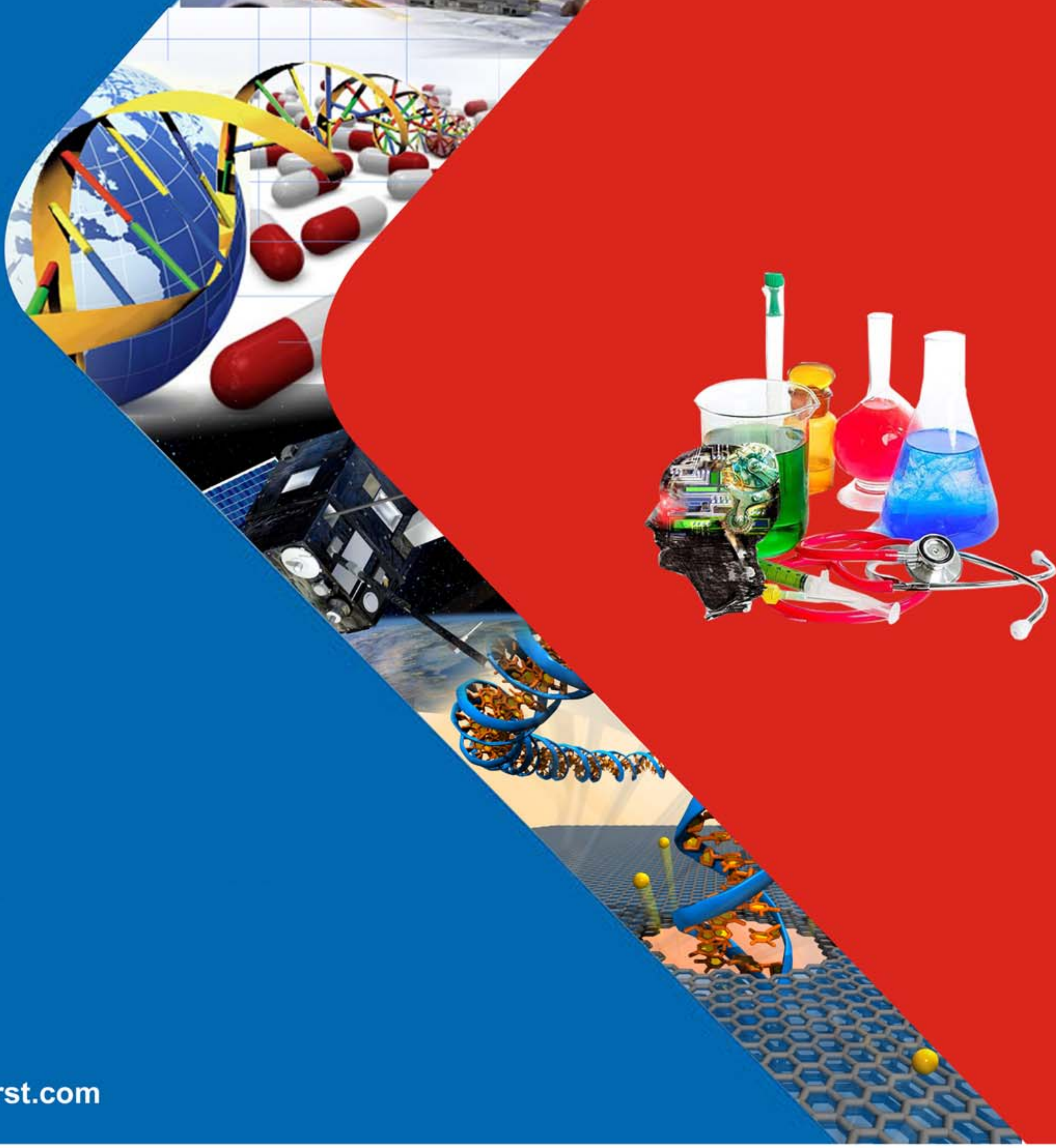
IJERST

International Journal of Engineering Research and Science & Technology

ISSN : 2319-5991
Vol. 4, No. 4
November 2015



www.ijerst.com

Email: editorijerst@gmail.com or editor@ijerst.com

International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Vol. 4, No. 4, November 2015

Research Paper

SEISMIC POUNDING OF THE ADJACENT BUILDINGS WITH DIFFERENT HEIGHTS

M Phani Kumar[1]* and J D Chaitanya Kumar[2]

Corresponding Author: **J D Chaitanya Kumar ✉ jd2sai@gmail.com*

This project aims at studying seismic pounding effect between adjacent buildings by linear and nonlinear dynamic analysis using ETABS (Non Linear) computer program. A detailed parametric study is carried out to investigate the effect of various parameters on the structural pounding by Response Spectrum (Linear Dynamic) Analysis for medium soil at zone V and Time History (Non-Linear Dynamic) Analysis for Bhuj earthquake recorded excitation on different models with varying separation distances. Pounding produces acceleration and shear at various storey 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. Finally the results are observed to study the effect of structural displacements and pounding forces between two adjacent buildings.

Keywords: Seismic pounding, Separation distance, Seismic gap, Adjacent buildings, Storey displacements, Pounding force

INTRODUCTION

The term "structural pounding" is used to describe collisions between adjacent buildings during earthquakes. This is common when there is insufficient separation distance between the adjacent buildings. The pounding phenomenon has been the main cause for the initiation of collapse in many recorded earthquakes. The severe damage caused by pounding can be noticed easily when strong earthquakes strike metropolitan cities and densely populated urban areas.

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

[1] M.Tech Scholar, Department of Civil Engineering, MVR College of Engineering and Technology, Vijayawada Rural, 521180.
[2] Assistant Professor, Department of Civil Engineering, KL University, Green Fields, Vaddeeswaram, Guntur Dst-522502.

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.

CHARACTERISTICS OF POUNDING

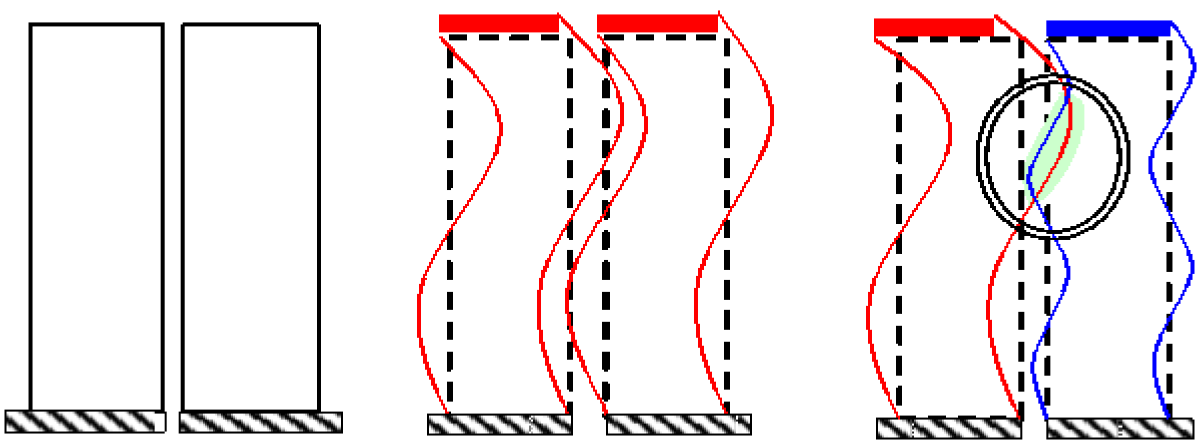
Structural pounding happens because of swaying of adjacent buildings with different mode shapes and periods under seismic loads which are not separated from each other properly. During earthquakes, structure's mass and rigidity affect seismic behavior. It is nearly impossible to construct a building which has similar seismic behavior to another building.

Poundings may occur because of structural irregularities. For example eccentricity between mass rigidity centers cause torsion in the structure. If pounding is regular an impact surface can be formed between two adjacent buildings. The structural behavior of the pounding effect in various places are shown in Figures 1 to 3.

The powerful 2001 Bhuj earthquake (Jain *et al*., 2001) has been most damaging earthquake in the last five decades in India. Reinforced concrete buildings suffered the heaviest damage during the earthquake because of poor design and construction practices. Pounding of adjacent structures was evident at Ajodhya apartments in Ahmadabad with significant damages. The Sikkim earthquake (Kaushik *et al.*, 2006) on February 14, 2006 of 5.3 magnitude caused damage to a nine storey masonry infill RC frame hostel building at Sikkim Manipal Institute of Medical Sciences (SMIMS) Tadong, Gangtok which caused severe damages in walls and columns. Pounding damages were observed two long wings in the building and corridors connecting the wings.

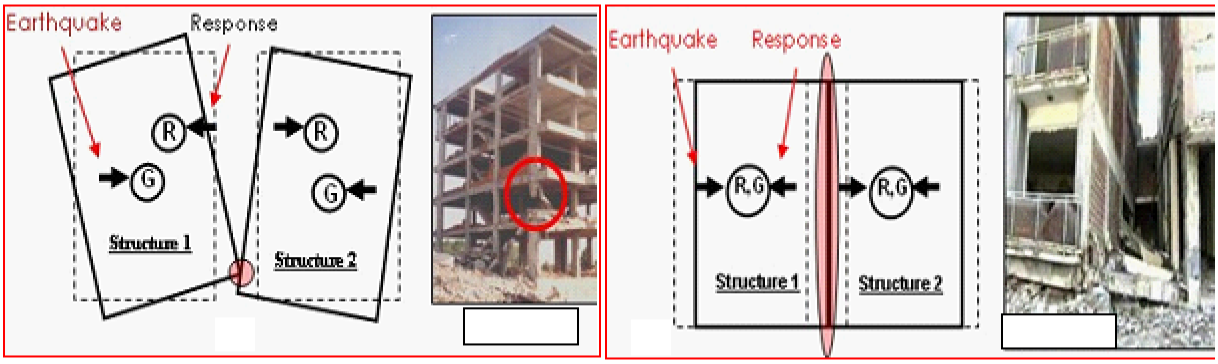
The only road link between Kutch and Saurashtra areas is the road bridge at Surajbadi, which was damaged. Pre-stressed concrete girder bridge spans sustained substantial damage like pounding of the deck slab, horizontal movement of girder, and damage at the bottom of girders (Mistry *et al*., 2001). In Diglipur (Rai *et*

Figure 1: Seismic Behaviour of Adjacent Buildings



a) Before earthquake b) Similar Seismic behaviour c) Different seismic behaviour

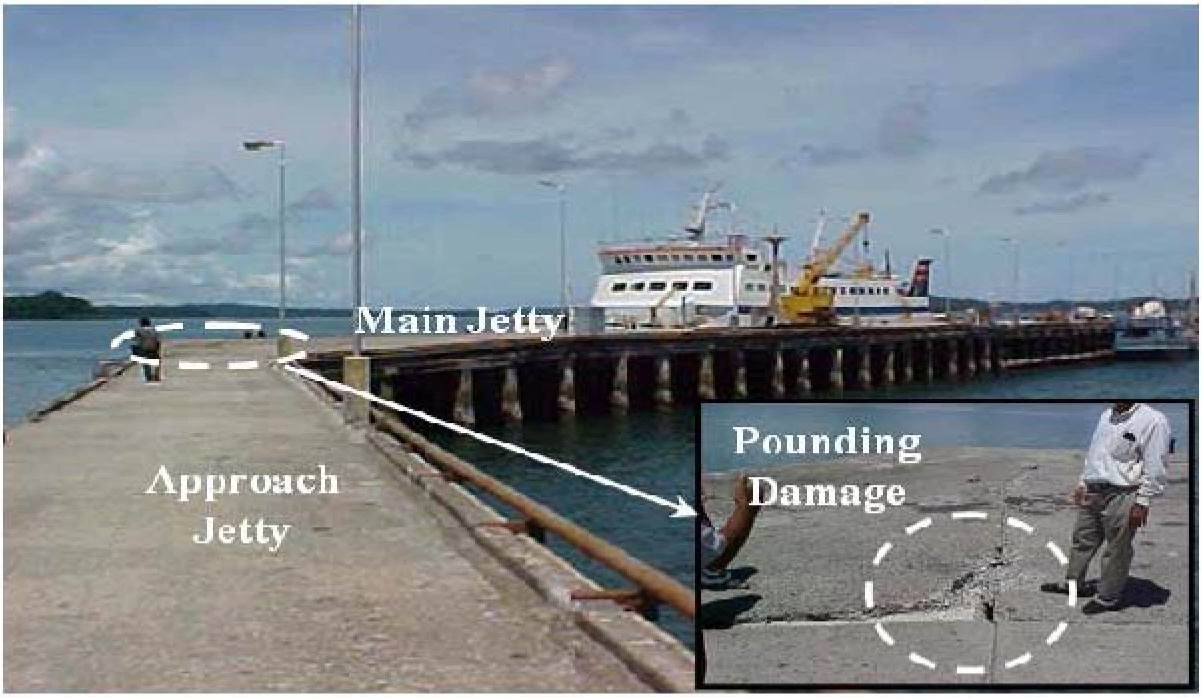
Figure 2: Pounding of Regular and Irregular Adjacent Buildings



al., 2003) harbor pounding damage was observed at the intersection of the approach segment and the main berthing structure. During Sumatra earthquake (Rai *et al.*, 2005) of December 26, 2004, pounding damage at junctions was noticed at the same top ends of piles of the approach jetty, which were covered up.

Seismic pounding occurs when the separation distance between adjacent buildings is not 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 pounding, which

Figure 3: Pounding Damage at the Intersection of Approach to main jetty at Diglipur Harbor During Diglipur Earthquake



is obviously equal to the relative displacement demand of the two potentially colliding structural systems. For instance, according to 2006 edition of the International Building Code and in many seismic design codes and regulations worldwide, minimum separation distance (Lopez Garacia, 2004) are given by ABSolute Sum (ABS) or Square Root of Sum of Squares (SRSS) as follows:

$$S = U_A + U_B \qquad \text{ABS (1)}$$

$$S = \sqrt{(U_A^2 + U_B^2)} \qquad \text{SRSS (2)}$$

where S = Separation distance and U_A, U_B = Peak displacement response of adjacent structures A and B, respectively.

Previous studies have shown that they give poor estimates of S, especially when the natural periods of the adjacent structures are close to each other. In these cases, the ABS and SRSS rules give excessively conservative separation distances, which are very difficult to effectively implement because of maximization of land usage.

Bureau of Indian Standards clearly gives in its code IS 4326: 1993 that a Separation Gap is to be provided between buildings. Separation of adjoining structures or parts of the same structure is required for structures having different total heights or storey heights and different dynamic characteristics. This is to avoid collision during an earthquake.

LITERATURE REVIEW

Jeng *et al* (1998) Taipei City, with its high seismicity, soft soil condition, and many tall buildings without proper seismic separation, is vulnerable to seismic pounding destruction similar to that occurred in Mexico City during the 1985 earthquake. Amar M Rahman *et al* (2000) Collisions between adjacent structures due to insufficient separation gaps have been witnessed in almost every major earthquake since the 1960's.

Jeng-Hsiang Lin and Cheng-Chiang Weng (2001) The need to investigate the level of seismic pounding risk of buildings is apparent in future building code calibrations. In order to provide further insight into the pounding risk of adjacent buildings, this study develops a numerical simulation approach to estimate the seismic pounding risk of adjacent buildings separated by a minimum code-specifed separation distance during a certain period of time.

Hong *et al.* (2003), A separation distance between adjacent buildings is provided to reduce the risk of pounding of adjacent buildings under seismic excitations.

Robert Jankowski (2004) During sever earthquakes, pounding between neighboring, inadequately separated with different dynamic characters has been observed repeatedly. It can lead to considerable damage or can be even the reason of structure's total collapse. Shehata E Abdel Raheem (2006) 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.

Agarwal *et al*. (2007) the earthquake induced upper story pounding response of two buildings in close proximity is investigated. The formulation models each building as two degree of freedom oscillators and allows for impact at mid-level and top-level elevations. Warnotte Viviance (2007) adjacent buildings subjected to seismic excitations collide against each other when the separation distance is not large enough to accommodate the displacement response of the structures relative to one another.

Anagnostopoulos and Karamaneas (2008) the use of collision shear walls, acting transversely to the side subjected to pounding as a measure to minimize damage of reinforced concrete buildings in contact, is investigated using 5-storey building models. Abdel-Mooty *et al* (2009) studied the factors affecting seismic pounding of adjacent buildings and critically examined. The formulation and modeling of pounding phenomenon is introduced. Parametric study on seismic pounding phenomenon is conducted to examine the effects of various factors on seismic pounding.

Structural pounding is a complex phenomenon which involves local damage to structures during earthquake. It is necessary to study the seismic pounding effect between adjacent buildings. The principal objectives of the study are as follows:

- Comparison of displacement profiles for 9-storey and 15-storey adjacent buildings by linear and non-linear dynamic analysis.
- Comparison of effect of shear walls over brick infill walls on displacement profiles to study the minimum seismic gap to be provided.
- Comparison of effect of separation distances on pounding forces between 9-storey and 15-storey adjacent buildings.
- Comparison of effect of shear walls over brick infill walls on pounding forces between 9-storey and 15-storey adjacent buildings.

SEISMIC ANALYSIS PROCEDURES

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

1. Linear Procedures.
   - Linear Static Analysis (Seismic Co-efficient Analysis).
   - Linear Dynamic Analysis (Response Spectrum Analysis).
2. Nonlinear Procedures.
   - Non-Linear Dynamic Analysis (Time History Analysis).

ANALYTICAL MODELING AND ANALYSIS

Building Geometry

The analysis considers two nine storey and fifteen storey adjacent buildings with full brick infill walls and mixed brick infill and shear walls. The details of the structures are shown below.

RESULTS AND DISCUSSION

Figure 4: Plan Elevation of Nine and Fifteen Storey Adjacent Buildings with Brick Infill Walls

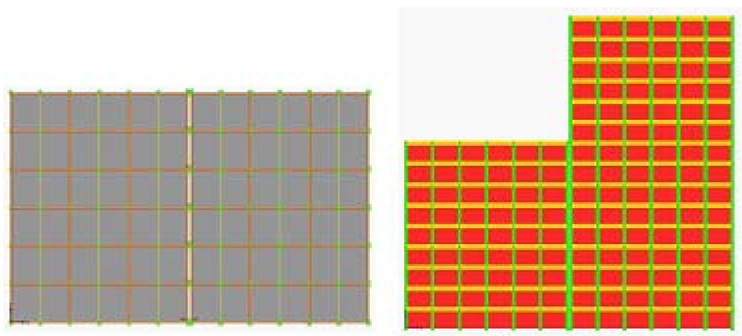
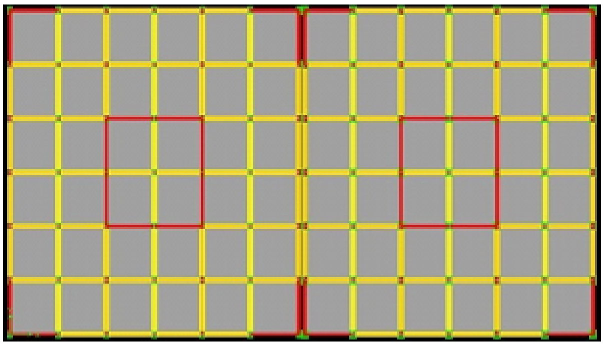


Figure 5: Plan Layout of Nine and Fifteen Storey Adjacent Buildings with Mixed Brick Infill Walls and Shear Walls



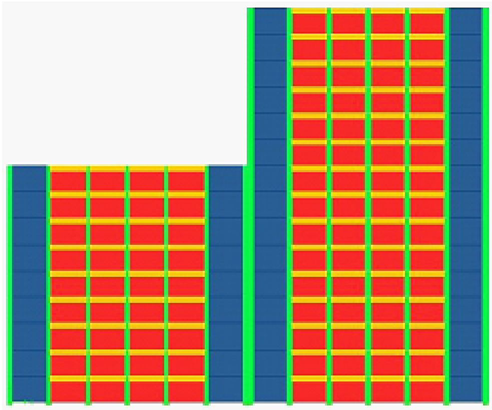


Table 2: Material and Member Properties

M25- Grade of concrete and Fe415- Grade of steel are considered

Member property	
Thickness of slab	150 mm
Column size for eight storey building	400 mm x 700 mm
Column size for fourteen storey building	550 mm x 800 mm
Beam size	400 mm x 600 mm
Thickness of brick wall	230 mm
Thickness of R.C.C wall	230 mm

Table: 3 Loads for the Building

LOADS	
Gravity loads	**Earthquake loads**
Floor finishes as uniform area load on slabs = 1.50 kN/m^2 Live load on typical floors = 3kN/m^2 Live load on roof = 2kN/m^2	Zone factor, Z = 0.36 (zone-V) Importance factor, I = 1.0 Response reduction factor, R = 5.0 (SMRF) Type of soil = Type II (Medium soil)

Table 4: Time Period

TIME PERIOD	
X-direction - 0.443 Sec	X-direction - 0.739 Sec
Y-direction - 0.496 Sec	Y-direction - 0.826 Sec

Table 5: Base Shear

BASE SHEAR	
FOR 9-STOREY BUILDING	FOR 15-STOREY BUILDING
Sesimic coefficient	
X-Direction, Ah = 0.09Y-Direction, Ah = 0.09	X-Direction, Ah = 0.066Y-Direction, Ah = 0.059
Seismic weight W = 89831.00 kN	Seismic weight W = 155230.00 kN
Seismic weight as per IS-1893:2002	
In X-Direction, Vb = 8085.00 kNIn Y-Direction, Vb = 8085.00 kN	In X-Direction, Vb = 11015.00 kNIn Y-Direction, Vb = 9856.00 kN

The results are plotted below. The response of the displacement is plotted in Figures 6 to 9).

In this chapter the results of the nine storey and fifteen storey buildings for rigid floor diaphragm

Fig:6 Maximum Storey Displacements For 9-storey and 15-storey Buildings With Brick Infill Walls In X and Y Direction

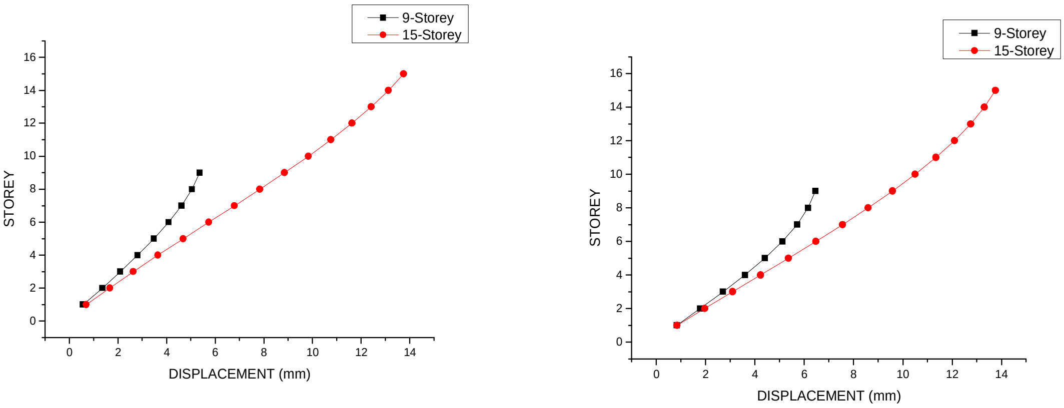


Figure 7: Maximum storey displacements for 9-storey and 15-storey buildings with mixed brick infill walls and shear walls in x and Y -directions

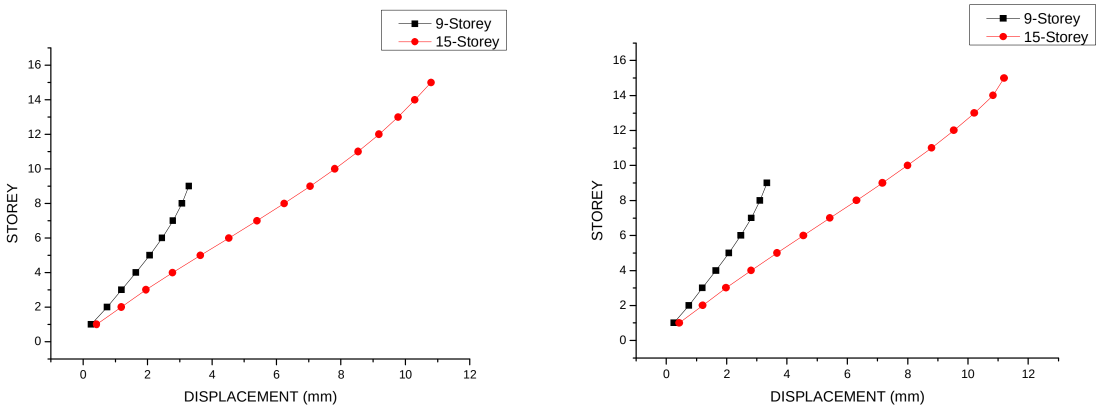


Figure 8: Maximum Storey Displacements For 9-storey And 15-storey Buildings With Brick Infill Walls In X And Y Directions

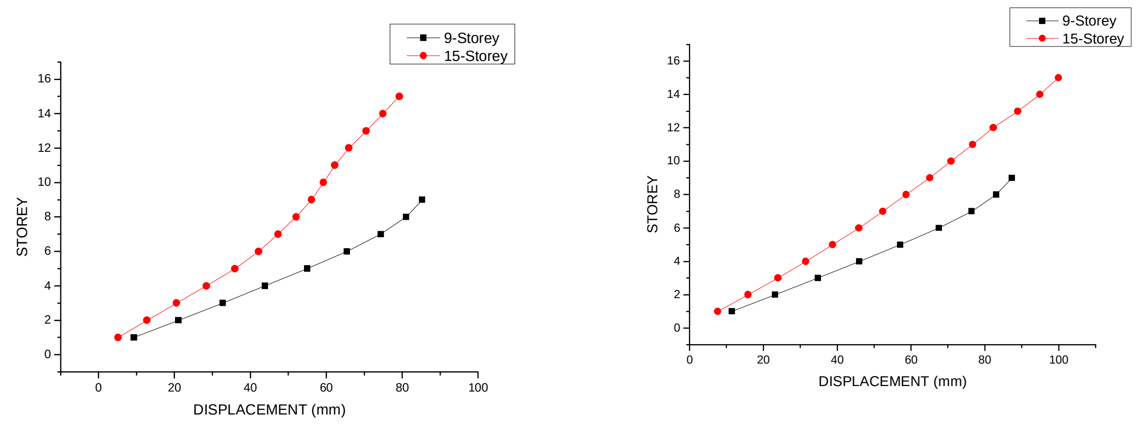
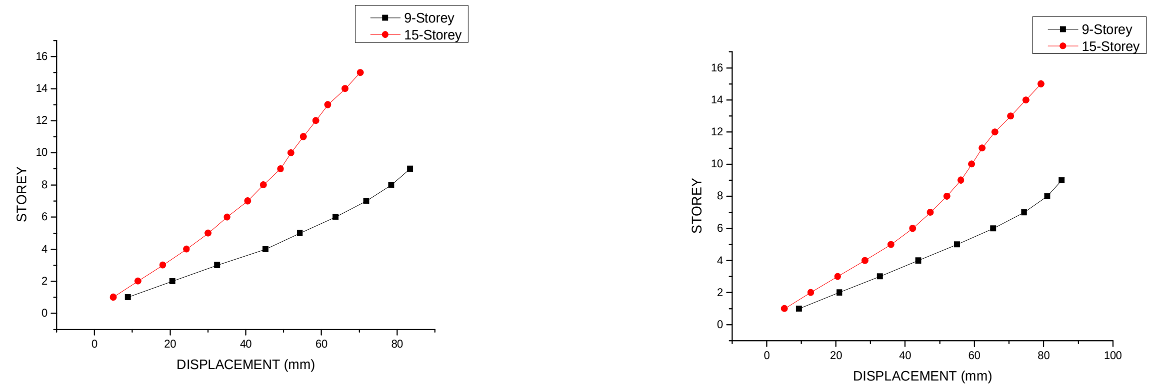


Figure 9: Maximum Storey Displacements For 9-storey And 15-storey Buildings With Mixed Brick Infill Walls and Shear Walls In X And Y Directions



are presented and discussed in detail for Linear Dynamic (response spectrum) and Non-linear Dynamic (time history) analysis. The analysis and design for the two adjacent buildings is performed using ETABS (Non-linear) computer program. The material properties are mentioned in Table 2, the gravity and seismic load condition are listed in Table 3, the calculated time period values are listed in Table 4 and the Base shear values are shown in Table 5.

Response Spectrum Analysis Results

Response spectrum analysis has been carried out as per the response spectra mentioned in IS 1893(Part 1):2002. The displacement values for each floor of the two adjacent buildings have been tabulated as below.

Response spectrum results for pounding case are observed. From the above results it have been seen that the maximum storey displacements for 9-storey and 9th storey of 15-storey building with brick infill walls are 6.454 and 9.58 mm and with mixed brick infill wall and shear walls are 3.335 and 7.165 mm. As per codal provisions the minimum seismic gap to be provided is sum of the peak displacements, i.e., 16.034 mm and 10.5 mm. Since we considered 20 mm physical

Figure 10: Distribution Of Pounding Forces Along The Building Height With 20, 30 And 40 Mm Gap Between 9-storey &15-storey Buildings With Brick Infill Walls

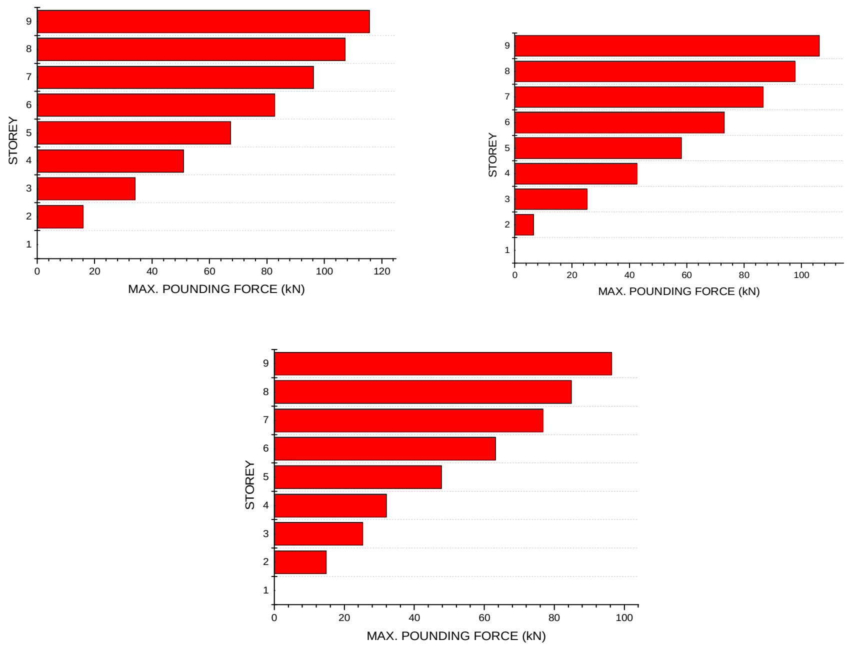


Figure 11: Distribution Of Pounding Forces Along The Building Height With 20, 30 and 40 Mm Gap Between 9-storey &15-storey Buildings With Mixed Brick Infill Walls And Shear Walls

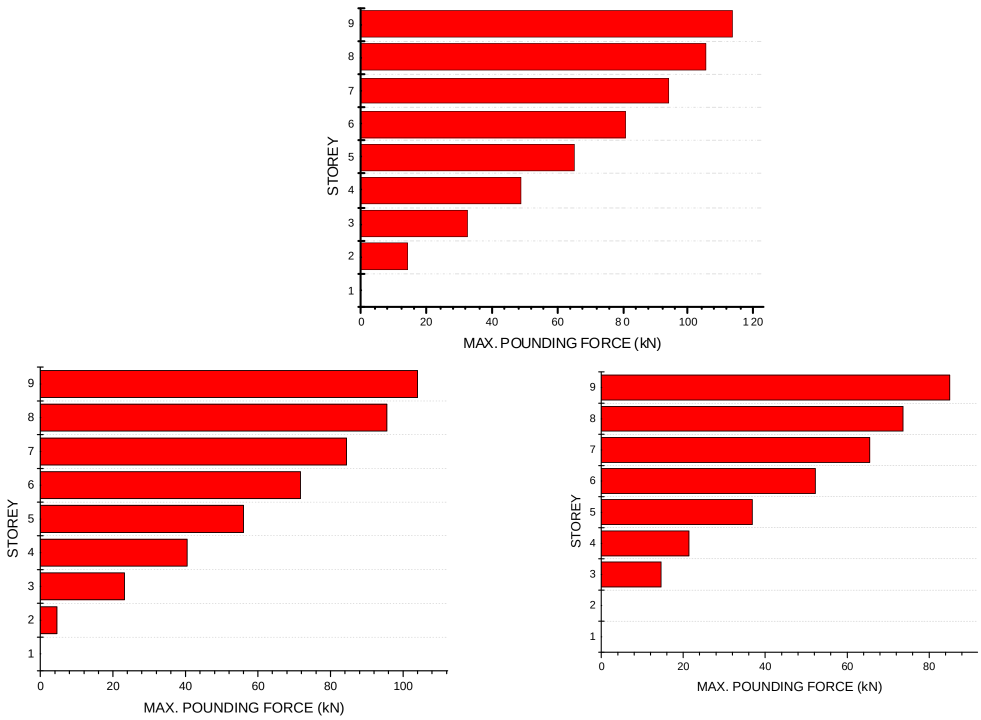


Figure 12: Effect Of Shear Wall On Pounding Forces For 9-storey &15-storey Adjacent Buildings

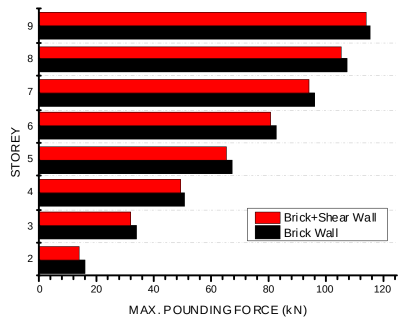
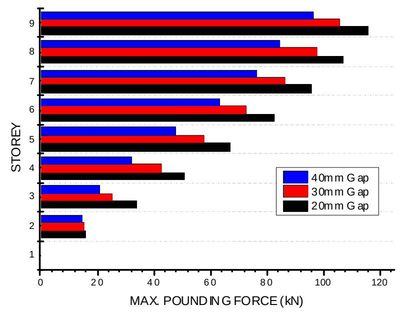


Figure 13: Effect Of Separation Distance On Pounding Forces For 9-storey & 15-storey Adjacent Buildings



gap between two adjacent buildings there will be no pounding between buildings. The response of the maximum pounding is plotted in Figures 10-13.

TIME HISTORY ANALYSIS

Time history analysis has been carried out using the Bhuj Earthquake record excitation. The displacement values and pounding force for each floor of the two adjacent buildings have been tabulated as below.

Time History results for pounding case are observed. From the above results it have been seen that the maximum storey displacements for 9-storey and 9th storey of 15-storey building with brick infill walls are 87.387 and 65.111 mm and with mixed brick infill wall and shear walls are 85.287 and 56.119 mm. As per codal provisions the minimum seismic gap to be provided is sum of the peak displacements, i.e., 152.49 mm and 141.40 mm. Since we considered 20 mm, 30 mm and 40 mm physical gap between two adjacent buildings there will be pounding effect between buildings.

The figures show that the pounding forces are much affected by the characteristics of the earthquake records, dynamic and stiffness characteristics of the building. We can observe that the pounding forces between two adjacent buildings reducing by introducing shear walls and also we can observe that the pounding forces are reducing with increasing separation distance between two adjacent buildings.

CONCLUSION

In this thesis the factors affecting seismic pounding of adjacent buildings were identified and critically examined. Parametric study on seismic pounding phenomenon is conducted to examine the effects of various factors on seismic pounding. Pounding forces can be calculated using commercial software packages like ETABS where nonlinear gap elements between the adjacent building floors are used to calculate pounding forces.

Based on the observations from the analysis results, the following conclusions can be drawn.

Compared to the linear dynamic analysis the storey displacements of the two adjacent buildings increased 90 to 95% with non-linear dynamic analysis. There is no pounding between two adjacent buildings when it is analyzed by linear dynamic analysis because the displacement are very small, but there is a pounding effect when it is analyzed by non-linear dynamic analysis because the displacements increased largely.

It is concluded that it is necessary to carry out non-linear dynamic analysis to know the actual response of the structure.

- The displacements of the buildings decreasing gradually by introducing shear walls over brick infill walls at suitable locations. From this we can say that the minimum seismic gap can be reduced by introducing shear walls when the separation distance available is less.
- The pounding forces are decreasing by 10 to 15% between two adjacent buildings as the separation distance is increasing with a variation of 10 mm gradually. So, we can say that the pounding effect can be decreased with increasing separation distance.
- The pounding forces are also decreasing gradually between two adjacent buildings by introducing shear walls at suitable locations compared to fully brick infill walls. So, we can say that pounding effect can be mitigated by introducing shear walls over brick infill walls.

REFERENCES

1. Amar M Rahman, Athol J Carr and Peter J Mass (2000), "Seismic pounding of a case of adjacent multi-storey buildings of different total heights considering soil flexibility effects", Bulletin of the New Zealand National Society for Earthquake Engineering, Vol. 34.
2. Anil K Chopra and Rakesh K Goel (2000), "Evaluation of NSP to estimate seismic deformation: SDF system", *Journal of Structural Engineering, American Society of Civil Engineers,* Vol. 126, No. 4, pp. 482-490.
3. Agarwal V K, Niedzwecki J M and Van de Lindt.J W (2007), "Earthquake induced pounding in friction varying base isolated buildings", *Engineering Structures*, Vol. 29, Elsevier Science Ltd.
4. Anagnostopoulas S A and Karamaneas C E (2008), "Collision shear walls to mitigate seismic pounding of adjacent buildings", 14th World Conference on Earthquake Engineering, Beijing, china.
5. Abdel-Motty M, Al-Atopy H and Ghouniem M (2009), "Modeling and analysis of factors affecting seismic pounding of adjacent multi-storey buildings", Earthquake Resistant Engineering Structures VII, WIT Transactions on the Built Environment, Vol. 104.
6. ATC-40 (1996), *Seismic evaluation and retrofitting of concrete buildings,* Vol. 1, Applied Technology Council, Seismic Safety Commission, State of California.
7. Bertoro.V.V (1986), "Observations of Structural Pounding", Proceedings of the International Conference: The Mexico Earthquake-1985, American Society of Civil Engineers.
8. Barbara Borzi, Michael Hasson, Andrew Morrison, Dave Sanderson, Pushover Analysis of RC Structures, Earthquake Engineering International Ltd.
9. Chau K T and Wei X X (2001), "Pounding of Structures modeled as Non Linear Impacts of two Oscillators", Earthquake Engineering and Structural Dynamics.

10. Des Roches R and Muthukumar S (2002), "Effect of Pounding and Restrainers on Seismic Response of Multiple Frame Bridges", Earthquake Engineering and Structural Dynamics.

11. Earthquake Engineering Research Institute, Managua, Nicaragua Earthquake of December 23, 1972. Report EP-12, Oakland, CA, 1973.

12. Hao H and Zhang S (1999), "Spetial Ground Motion Effect on Relative Displacement of Adjacent Building Structures", *Earthquake Engineering and Structural Dynamics*, Vol. 28.

13. Hong H P, Wang S S and Hong P (2003), "Critical building separation distance in reducing pounding risk under earthquake excitation", *Structural Safety*, Elseivier Science Ltd.

14. Jeng V and Tzeng W L (1998), "Assessment of seismic pounding hazard for Taipei city", *Engineering Structures,* Vol. 22, Elsevier Science Ltd.

15. Jeng-Hsiang Lin and Cheng-Chiange Weng (2001), "Probability analysis of seismic pounding of adjacent buildings", *Earthquake Engineering and Structural Dynamics*, Taiwan.

16. Lin J H and Weng C C (2001), "Probability Analysis of Seismic Pounding of Adjacent Buildings", *Earthquake Engineering and Structural Dynamics*.

17. Robert Jankowski (2004), "Non-linear viscoelastic model of structural pounding", 13th World Conference on Earthquake Engineering, Canada.

18. Shehata E Abdel Raheem (2006), "Seismic pounding between adjacent building structures", *Electronic Journal of Structural Engineering.*

19. Warnotte Viviance (2007), "Mitigation of pounding between adjacent buildings in earthquake situations", LESSLOSS Final Workshop, Risk mitigation for Earthquakes and Ladslides integrated project.

International Journal of Engineering Research and Science & Technology
Hyderabad, INDIA. Ph: +91-09441351700, 09059645577
E-mail: editorijlerst@gmail.com or editor@ijerst.com
Website: www.ijerst.com

ISSN 2319-5991
9 772319 599001 04