Pounding Response of Buildings under Earthquake Motions

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Abstract

Pounding of structures is a common phenomenon between adjacent structures, which are subjected to strong earthquake motions. The pounding can be seen both in urban and rural area. But urban area damage will be more compared to rural area, because of heavy structures strike by ground motion. The investigations which are made by past and present earthquake seismologist say that the building structures which are closely packed are vulnerable to serve damages. The main aim of this research is to analyze the pounding response of commercial buildings having equal heights and unequal heights produced by ground motion for different EQ zones, by using Staad Pro and ETABS software, by using Elcentro data of Time Vs Acceleration. The analysis is done based on Seismic Coefficient Method.

Keywords— *Pounding, adjacent structures, ground motion, structures strike, Elcentro data, Seismi Coefficient Method.*

I. INTRODUCTION

In India most of land area is considered likely to shaking of intensity VII and above. Some of massive earthquake exceeding magnitude of 8.0 occurred in the year of 1897 Assam (M8.7), 1905 Kangra (M8.7) 1934 Bihar Nepal (M8.4) and 1950 Assam-Tibet (M8.7). And some of the earthquake which cause heavy damage to the buildings are 2001 Gujarat (7.7), 1993 Maharashtra (6.4), 1991 Uttarkashi (6.1). Pounding means repeated heavy striking or hitting of someone or something. This pounding is frequently occurring between adjacent structures with insufficient distances, during earthquake where the distance between structures is not adequate to accommodate the relative movements. Previous seismic could not give fixed guidelines to prevent pounding due to economic considerations, especially in the metro politician cities; there are already built extremely close to each another, this could suffer pounding damage in forth coming earthquakes. A large separation gap between buildings may not probable from technical and economical point of view [1]. This paper is almost solved problem, considering previous papers analysis is done.

II. DATA AND METHODOLOGY

This report examines the pounding response of two sets of buildings which heights are equal and also un-equal. The design of building is done according to Indian Standard codes. The building behaviour will be different compared with the heights, the buildings with less heights will effect more than the buildings with more heights underground motions. The earthquake zone factors are considered with the corresponding zones consideration. The simplest and most appropriate way for pounding mitigation is to provide safe separation gap[2], but it is sometimes difficult to fulfil due to the high cost of land.
Seismic pounding between adjacent buildings occurs when the structures are built in following patterns [3]:

- Adjacent buildings with same heights and same floor level.
- Adjacent buildings with same floor level and different heights.
- Adjacent buildings with different total height and different floor level.
- Buildings situated in a row.
- Adjacent building with different dynamic characteristics.
- Adjacent buildings with unequal distribution of mass or stiffness.

The minimum safe separation gap to be provided between adjacent buildings to avoid pounding effect, which is equal to the peak displacement of the two potentially colliding building system. According to international building code and in many seismic design codes and guideline worldwide the minimum safe separation gap provided is as follows [2],[4-9].

- $S=\sqrt{Q_1^{\,2}+Q_2^{\,2}}$
  Is a SRSS (Square Root of Sum of Square Method).
- $S=Q_1+Q_2$
  Is an ASM (Absolute Sum Method).

Where Q_1 = Peak Displacement of building-A.
Q_2 = Peak Displacement of building-B.
S = Separation distance between buildings.

According to Indian Standards clearly gives in IS 4326:1993 that a safe separation distance is to be provided to prevent pounding between the building during an earthquake is shown in Table-1 [4], [5].

Table.1: Maximum Gap Between Adjacent Buildings According To Is 4326:1993

Sl. No.	Types of constructions	(Gap width/story) in mm for design seismic coefficient αh=0.12
1.	Box system or frames with shear walls	1.5
2.	Moment resistant reinforced concrete frame	20.0
3.	Moment resistance steel frame	30.0

Note: Minimum total gap shall be 25mm. For any other values of αh, the gap width should be determined accordingly.

Considerations: INPUT

1. Consideration of buildings: Fig.1 Red=Columns in Plan

Two Commercial buildings having equal and unequal heights are selected.

Set-1: Fig.2

Commercial Building A = G+8Stories.

Commercial Building B = G+8Stories.

Set-2: Fig.3

Commercial Building A = G+8Stories.

Commercial Building B = G+5 Stories.

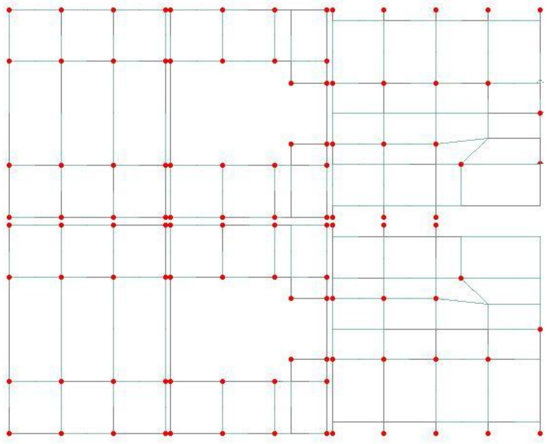

Fig.1: Plan of Buildings

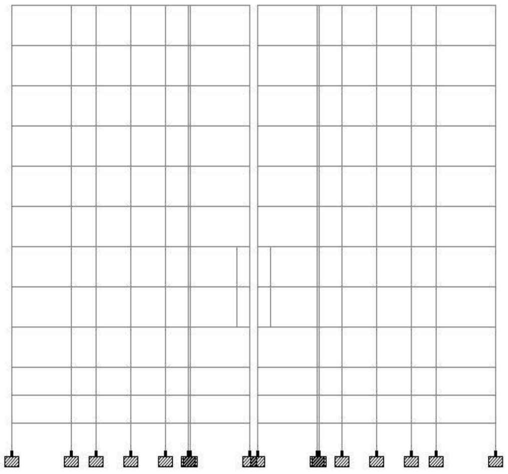

Fig.2: Set-1

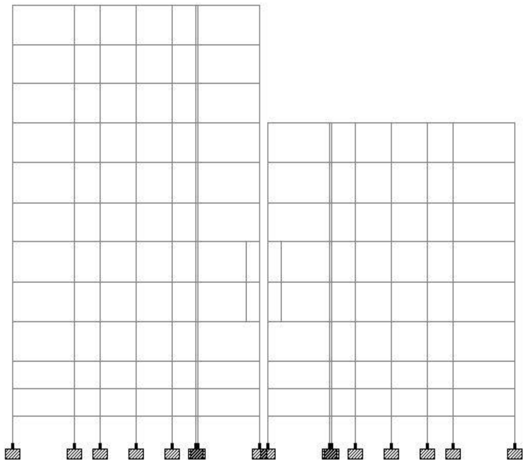

Fig.3: Set-2

2.Consideration of materials:

i. Beam to Beam distance center to center = 6.096m.

ii. Height of each floor from ground = 3.66m.

iii. Height of basement below ground = 2.54m.

iv. Size of beam and column = 0.6096*0.6096m.

v. Thickness of slab = 200mm.

vi. Assumed distance between buildings =250mm.

vii. Density of engineering bricks IS: 1077-1987 = 21 Kg/m^3.

viii. Thickness of outer walls = 0.2286m.

ix. Thickness of inner walls = 0.1143m.

x. Depth of wall = 3.66m.

3. Consideration of loads:

i. Dead load: Calculated by considering self-weight of all materials, and wall weight.

ii. Live load: Consider the floor weight as per IS 875:1987 part-2 for Commercial Building.

iii. Wind Load: According to IS 875:1987 part-3

A. Zone-V Guwahati:

a. Wind zone V_b = 50m/s
b. Risk coeff factor k_1 = 1.07.
c. Terrain height k_2 = Varying with height.
d. Topography factor k_3 = 1.00.

e. % of openings n = ≥5.
f. design wind speed V_z = $V_b * k_1 * k_2 * k_3$
= 50 * 1.07 * k_2 * 1
= (53.5 * k_2)m/s .
g. Area of middle wall A_1 =6.096 * 3.66 = 22.311m^2.
h. Area of corner wall A_2 = 3.048 * 3.66 =11.1557m^2.
i. Area of front wall A_3 = 12.192 * 3.66 =44.627m^2.
j. Local external pressure coff C_{pe} = 1.1.
k. Local internal pressure coff C_{pi} = 0.5.
l. Force F = Table-2.

B. Zone-IV New Delhi:

a. Wind zone V_b = 47m/s
b. Risk coeff factor k_1 = 1.07.
c. Terrain height k_2 = Varying with height.
d. Topography factor k_3 = 1.00.

e. % of openings n = ≥5.
f. design wind speed V_z = $V_b * k_1 * k_2 * k_3$
= 50 * 1.07 * k_2 * 1
= (53.5 * k_2)m/s .
g. Area of middle wall A_1 =6.096 * 3.66 = 22.311m^2.
h. Area of corner wall A_2 = 3.048 * 3.66 =11.1557m^2.
i. Area of front wall A_3 = 12.192 * 3.66 =44.627m^2.
j. Local external pressure coff C_{pe} = 1.1.
k. Local internal pressure coff C_{pi} = 0.5.
l. Force F = Table-3.

C. Zone-III Ahmedabad:

a. Wind zone V_b = 39m/s
b. Risk coeff factor k_1 = 1.07.
c. Terrain height k_2 = Varying with height.
d. Topography factor k_3 = 1.00.

e. % of openings n = ≥5.
f. design wind speed V_z = $V_b * k_1 * k_2 * k_3$
= 50 * 1.07 * k_2 * 1
= (53.5 * k_2)m/s .
g. Area of middle wall A_1 =6.096 * 3.66 = 22.311m^2.
h. Area of corner wall A_2 = 3.048 * 3.66 =11.1557m^2.
i. Area of front wall A_3 = 12.192 * 3.66 =44.627m^2.
j. Local external pressure coff C_{pe} = 1.1.
k. Local internal pressure coff C_{pi} = 0.5.
l. Force F = Table-4.

D. Zone-II Bangalore:

a. Wind zone V_b = 33m/s
b. Risk coeff factor k_1 = 1.07.
c. Terrain height k_2 = Varying with height.
d. Topography factor k_3 = 1.00.

e. % of openings n = ≥5.
f. design wind speed V_z = $V_b * k_1 * k_2 * k_3$
= 50 * 1.07 * k_2 * 1
= (53.5 * k_2)m/s .
g. Area of middle wall A_1 =6.096 * 3.66 = 22.311m^2.
h. Area of corner wall A_2 = 3.048 * 3.66 =11.1557m^2.
i. Area of front wall A_3 = 12.192 * 3.66 =44.627m^2.
j. Local external pressure coeff C_{pe} = 1.1.
k. Local internal pressure coeff C_{pi} = 0.5.
l. Force F = Table-5.

iv. Seismic coefficients: IS 4326:1993 given in Table6.

v. Load Combinations: IS 456:1987- 2000 given in Table-7.

vi. Time History Analysis: In time history analysis, the time history of structural response of a given input is obtained as a result Elcentro data of Time Vs Acceleration data is used.

III. RESULTS AND DISCUSSION: OUTPUT

A. Displacements:

Maximum displacement of two sets of buildings from Staad pro. for each zone is given in Table-8, and also maximum Story Drift of each floor from ETABS is given in Table-9.

The values from ETABS of Story Drift give absolute and total horizontal displacement at each floor, including the displacement caused by rotational deformation, so the values are non-zero.

B. Time History Analysis Results:

The graphs show the time-acceleration of 2 sets of buildings. The mentioned graphs are small part of the preliminary numerical simulation at first floor which is done to determine the procedure for verification of numerical results from both Staad pro. And ETABS.

Table-2: Calculation of Wind Load for Zone-V

Height m	Risk coefficient K_2	Design wind pressure $P_z = 0.6V_z^2$	Force $F=(C_{pe}-C_{pi})*A_1*P_z$ kN/m	Force $F=(C_{pe}-C_{pi})*A_2*P_z$ kN/m	Force $F=(C_{pe}-C_{pi})*A_3*P_z$ kN/m
7.32-10.98	0.8297	1.182	15.826	9.036	23.744
10.98-14.64	0.8663	1.288	17.253	9.849	25.879
14.64-18.3	0.8962	1.379	18.466	10.541	27.699
18.3-21.96	0.9197	1.452	19.446	11.1	29.168
21.96-25.6	0.938	1.511	20.228	11.54	30.34
25.6-29.27	0.9563	1.570	21.025	12.002	31.536
29.27-32.93	0.9687	1.611	21.573	12.315	32.359

Table-3: Calculation of Wind Load for Zone-IV

Height m	Risk coefficient K_2	Design wind pressure $P_z = 0.6V_z^2$	Force $F=(C_{pe}-C_{pi})*A_1*P_z$ kN/m	Force $F=(C_{pe}-C_{pi})*A_2*P_z$ kN/m	Force $F=(C_{pe}-C_{pi})*A_3*P_z$ kN/m
7.32-10.98	0.8297	1.044	13.984	7.983	20.976
10.98-14.64	0.8663	1.138	15.245	8.703	22.876
14.64-18.3	0.8962	1.218	16.317	9.315	24.475
18.3-21.96	0.9197	1.283	17.182	9.809	25.773
21.96-25.6	0.938	1.335	17.873	10.203	26.809
25.6-29.27	0.9563	1.387	18.577	10.605	27.865
29.27-32.93	0.9687	1.423	19.062	10.882	28.593

Table-4: Calculation of Wind Load for Zone-III

Height m	Risk coefficient K_2	Design wind pressure $P_z = 0.6V_z^2$	Force $F=(C_{pe}-C_{pi})*A_1*P_z$ kN/m	Force $F=(C_{pe}-C_{pi})*A_2*P_z$ kN/m	Force $F=(C_{pe}-C_{pi})*A_3*P_z$ kN/m
7.32-10.98	0.8297	0.707	9.463	5.402	14.195
10.98-14.64	0.8663	0.77	10.316	5.889	15.475
14.64-18.3	0.8962	0.825	11.042	6.303	16.563
18.3-21.96	0.9197	0.868	11.62	6.638	17.441
21.96-25.6	0.938	0.903	12.095	6.904	18.142
25.6-29.27	0.9563	0.939	12.571	7.176	18..857
29.27-32.93	0.9687	0.963	12.899	7.364	19.349

Table-5: Calculation of Wind Load for Zone-II

Height m	Risk coefficient K_2	Design wind pressure $P_z = 0.6V_z^2$	Force $F=(C_{pe}-C_{pi})*A_1*P_z$ kN/m	Force $F=(C_{pe}-C_{pi})*A_2*P_z$ kN/m	Force $F=(C_{pe}-C_{pi})*A_3*P_z$ kN/m
7.32-10.98	0.8297	0.515	6.84	3.935	10.341
10.98-14.64	0.8663	0.561	7.516	4.290	11.273
14.64-18.3	0.8962	0.601	8.04	4.592	12.065
18.3-21.96	0.9197	0.633	8.471	4.835	12.706
21.96-25.6	0.938	0.658	8.811	5.029	13.216
25.6-29.27	0.9563	0.684	9.158	5.228	13.37
29.27-32.93	0.9687	0.702	9.397	5.364	14.095

Table-6: Seismic Coefficients

	Zone-V	Zone-IV	Zone-III	Zone-II
Risk Coefficient	0.36	0.24	0.16	0.1
Importance factor	1.5	1.5	1.5	1.5
Response Reduction factor	4	4	4	4
Rock and soil site factor	2	2	2	2
Damping Ratio	0.05	0.05	0.05	0.05

Table-7: Load Combinations

Load Combination	Limit State of Collapse		
	DL	***IL***	***WL***
DL+IL	1.5		1
DL+WL	1.5 or 0.9	-	1.5
DL+IL+WL	1.2		

Table-8: Calculation of Safe Separation Distance by Using SRSS Method.

Zones	Set-1			Set-2		
	Max. disp A Q_1 (mm)	*Max. disp B Q_2 (mm)*	*SRSS (mm)*	*Max. disp A Q_1 (mm)*	*Max. disp B Q_2 (mm)*	*SRSS (mm)*
Zone-II	103.408	-202.004	226.933	108.715	-191.379	220.101
Zone-III	130.530	-202.004	240.507	148.443	-191.379	242.200
Zone-IV	169.958	-202.004	263.991	208.317	-191.379	282.881
Zone-V	237.746	-242.210	339.394	244.332	-191.379	310.361

Table-9: Story Drift.

	Set-1				Set-2			
	Zone-V	**Zone-IV**	**Zone-III**	**Zone-II**	**Zone-V**	**Zone-IV**	**Zone-III**	**Zone-II**
Story8	0.000165	1.10E-04	0.000073	7.70E-05	0.000204	0.000136	9.10E-05	0.000057
Story7	0.000165	1.10E-04	0.000073	7.80E-05	0.000204	0.000136	9.10E-05	0.000057
Story6	0.000164	0.00011	0.000073	7.80E-05	0.000204	0.000136	9.10E-05	0.000057
Story5	0.000164	0.00011	0.000073	7.80E-05	0.000204	0.000136	9.00E-05	0.000057
Story4	0.000165	1.10E-04	0.000073	7.80E-05	0.000204	0.000136	9.10E-05	0.000057
Story3	0.000169	1.12E-04	0.000075	8.00E-05	0.000209	0.000139	9.30E-05	0.000058
Story2	0.000165	1.10E-04	0.000073	7.90E-05	0.000202	0.000135	9.00E-05	0.000056
Story1	0.000172	1.15E-04	0.000077	8.40E-05	0.00021	0.00014	9.30E-05	0.000058
Ground	0.00021	1.40E-04	0.000094	1.05E-04	0.000261	0.000174	1.20E-04	0.000072
Basement-2	0.000212	1.41E-04	0.000094	1.07E-04	0.000263	0.000175	1.20E-04	0.000073
Basement-1	0.000603	0.000402	0.000268	1.96E-04	0.000747	0.000498	4.13E-04	0.000208
Foundation	0.001833	0.001331	0.000815	1.33E-03	0.002261	0.001507	1.33E-03	0.000628

1) ***Staad pro:***

Set-I: Buildings having equal heights, Time Vs Acceleration graph for X & Z direction shown in Fig.4-7:

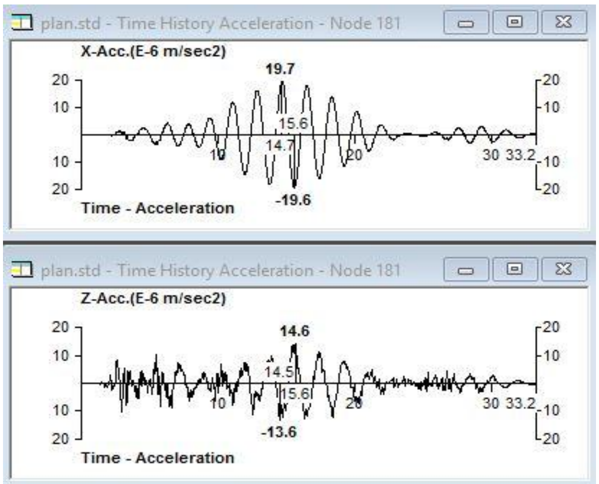

Fig.4: Zone-V

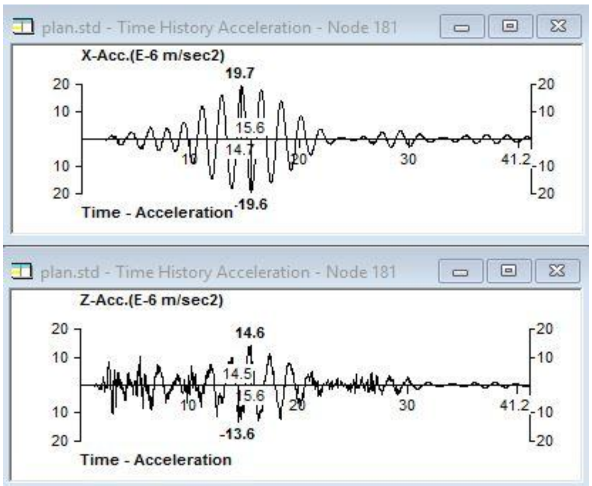

Fig.5: Zone-IV

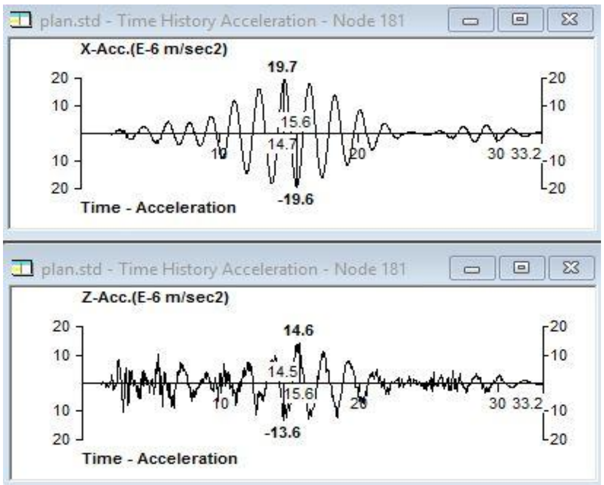

Fig.6: Zone-III

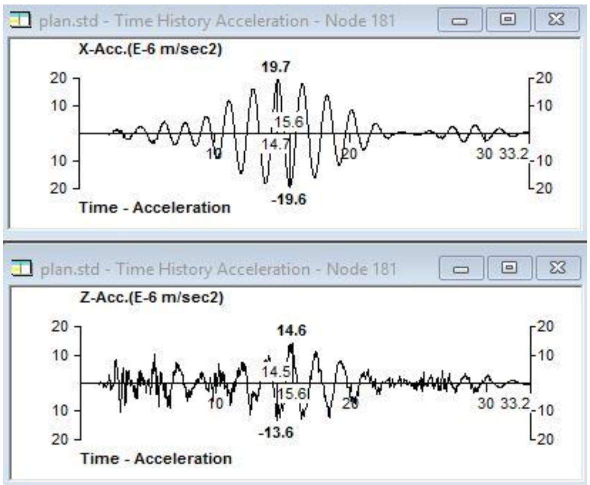

Fig.7: Zone-II

Set-2: Buildings having unequal heights, Time Vs Acceleration graph for X & Z direction shown in Fig.8-11:

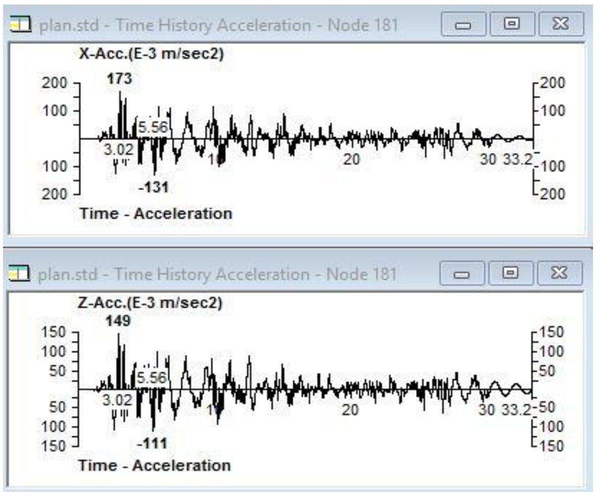

Fig.8: Zone-V

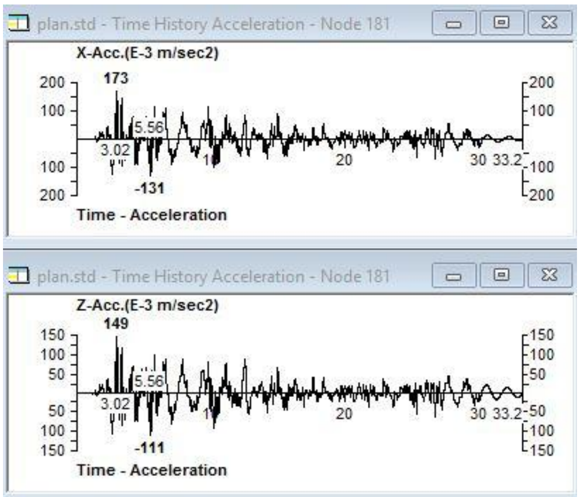

Fig.9: Zone-IV

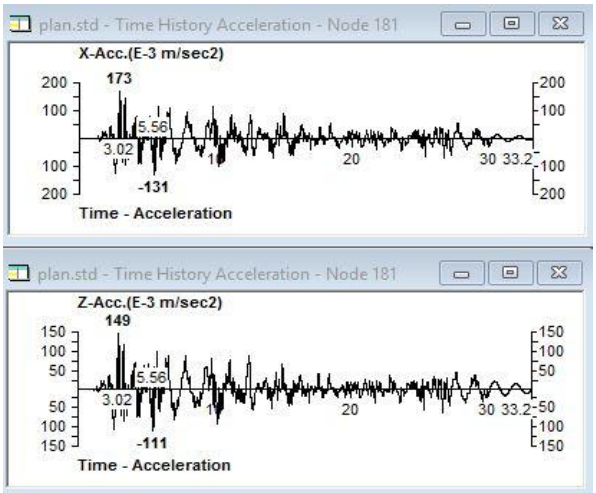

Fig.10: Zone-III

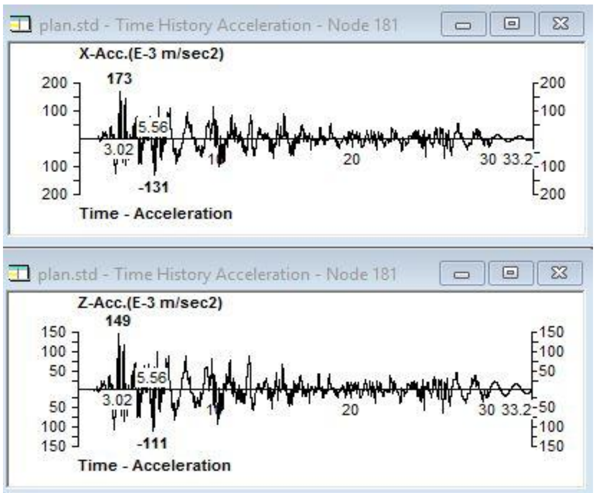

Fig.11: Zone-II

2) ETABS:

Set-1 Time History Analysis, Time Vs Acceleration graph shown in Fig.12- 19:

Zone-V:

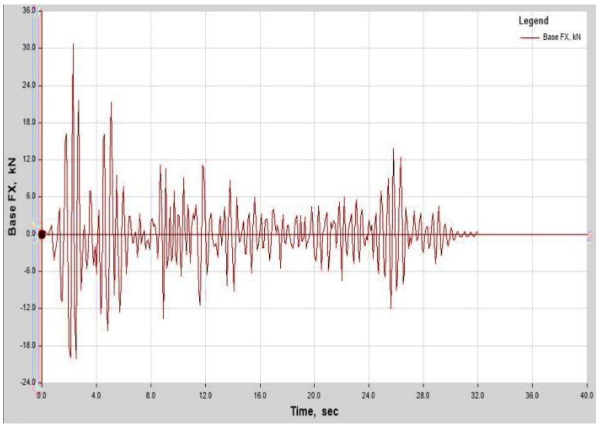

Fig.12: X-Axis

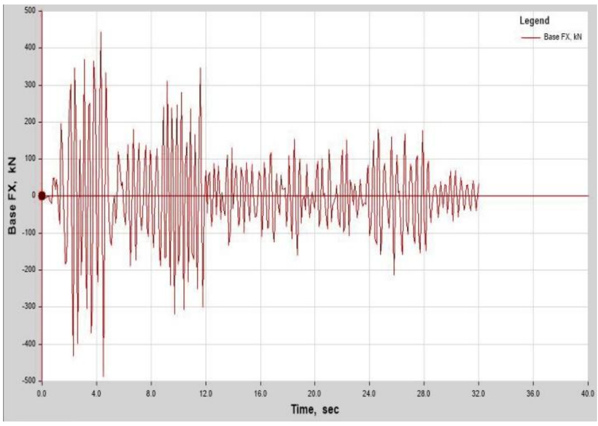

Fig.13: Y-Axis

Zone-IV:

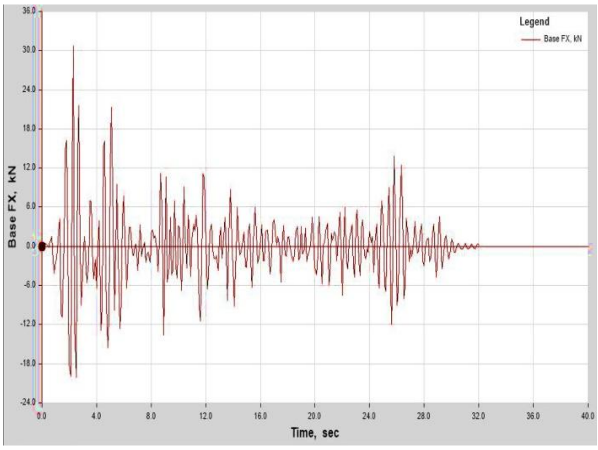

Fig.14: X-Axis

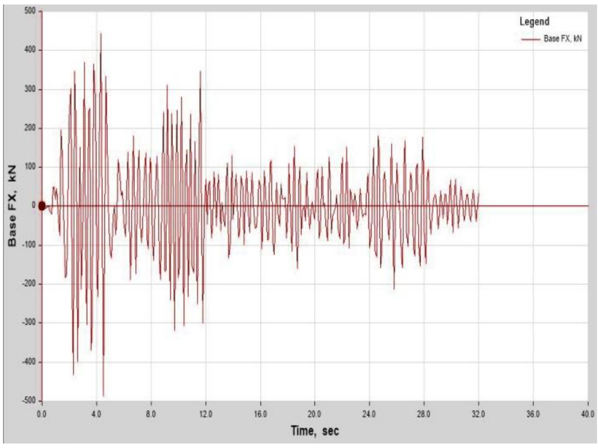

Fig.15: Y-Axis

Zone-III:

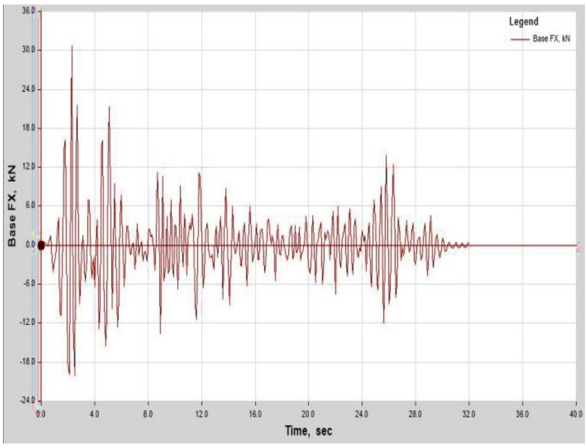

Fig.16: X-Axis

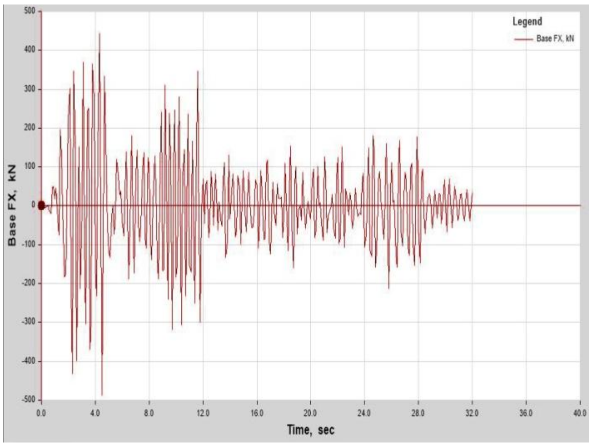

Fig.17: Y-Axis

Zone-II:

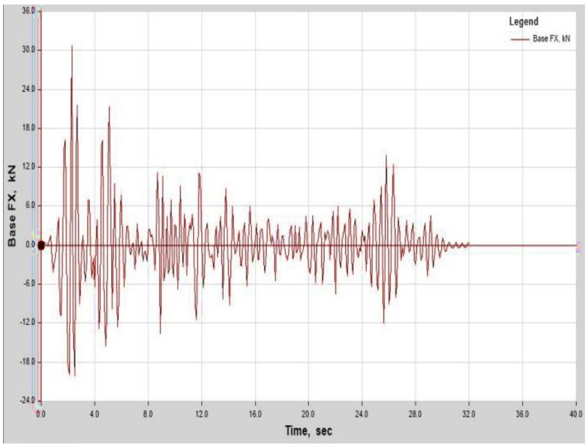

Fig.18: X-Axis

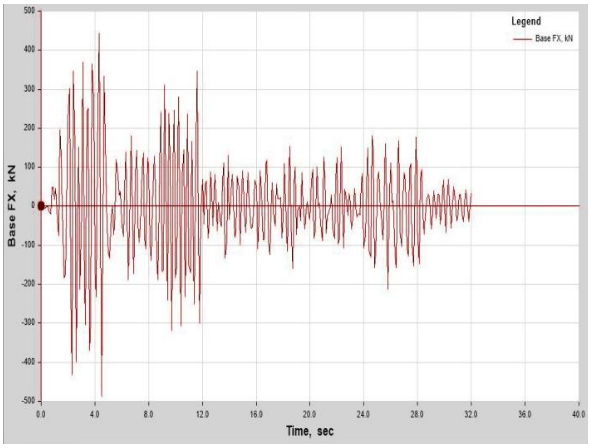

Fig.19: Y-Axis

Set-2 Time History Analysis Time Vs Acceleration graph shown in Fig.20-27:

Zone-V:

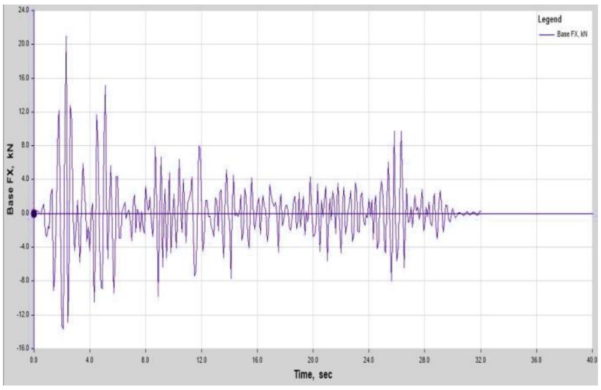

Fig.20: X-Axis

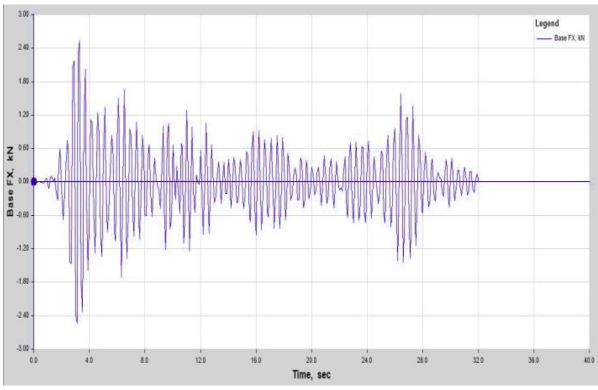

Fig.21: Y-Axis

Zone-IV:

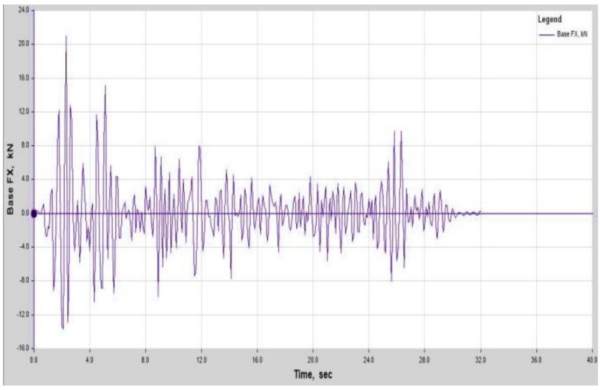

Fig.22: X-Axis

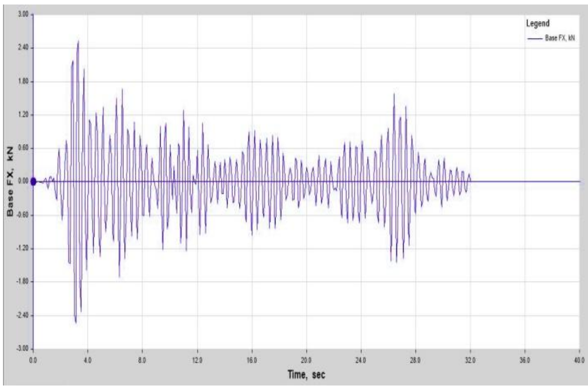

Fig.23: Y-Axis

Zone-III:

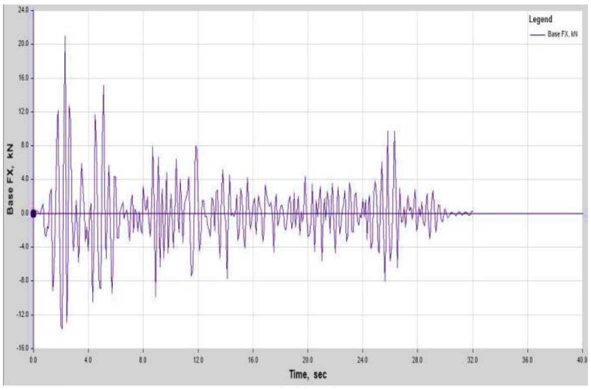

Fig.24: X-Axis

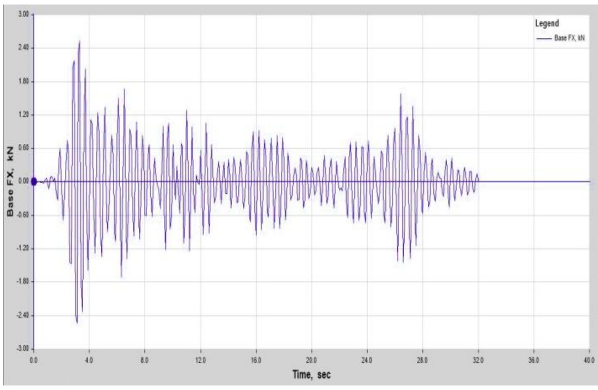

Fig.25: Y-Axis

Zone-II:

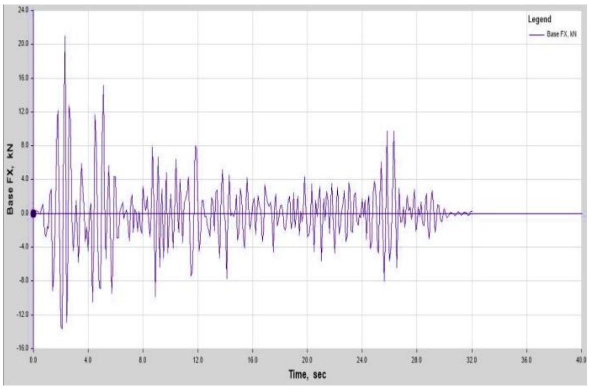

Fig.26: X-Axis

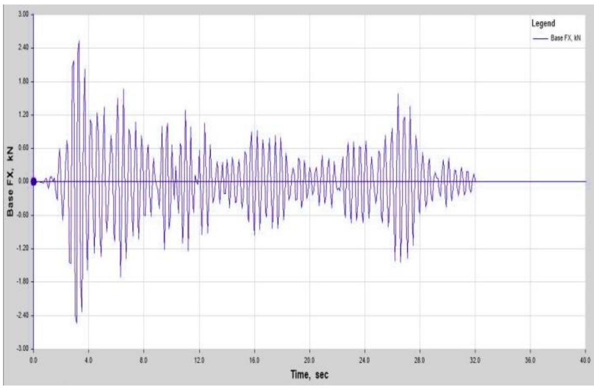

Fig.27: Y-Axis

The maximum and minimum acceleration from graphs of ETABS are mentioned in Table -10.

Table-10: Maximum and Minimum Acceleration from above Graphs of ETABS

		Set-1				Set-2			
		Zone-V	Zone-IV	Zone-III	Zone-II	Zone-V	Zone-IV	Zone-III	Zone-II
X-Axis	Maximum	(2.3,30.717)	(2.3,30.717)	(2.3,30.717)	(2.3,30.717)	(2.3,20.974)	(2.3,20.974)	(2.3,20.974)	(2.3,20.974)
	Minimum	(2.5,-20.004)	(2.5,-20.004)	(2.5,-20.004)	(2.5,-20.004)	(2.1,-13.607)	(2.1,-13.607)	(2.1,-13.607)	(2.1,-13.607)
Y-Axis	Maximum	(4.3,442.95)	(4.3,442.95)	(4.3,442.95)	(4.3,442.95)	(3.3,252.6)	(3.3,252.6)	(3.3,252.6)	(3.3,252.6)
	Minimum	(4.5,-486.94)	(4.5,-486.94)	(4.5,-486.94)	(4.5,-486.94)	(3.1,-252.7)	(3.1,-252.7)	(3.1,-252.7)	(3.1,-252.7)

IV. CONCLUSION

1. Assumed separation gap for buildings is 250mm. Calculated Safe Separation Gap for Zone-II & Zone III is less than 250mm and for Zone IV and Zone V is more than 320mm for both sets of buildings. Provision of 350 mm Safe Separation gap is necessary to avoid pounding of buildings in Zones-IV & V.
2. It is found that if the earthquake intensity increases the structural damage also increases.
3. For adjacent buildings the structural damage is more for unequal heights compared to equal heights, due to difference in their masses and periods.
4. The separation distance between two buildings decreases, the amount of impact increases.
5. By introducing contact elements which are acceptable to the buildings of Zones-IV, V pounding can be resist for some time. There are different types of contact elements available in markets which are shown in Fig.28-30 below. Before selecting the type of contact element different tests has to done in laboratories and also many experiments has to do. These contact elements are placed between buildings from beam to beam, column to column, and column to beam.

a). Hopkinson Pressure Bar: The bar is constructed in 3 parts Hopkinson pressure bar, Striker and Specimen shown in Fig.28. The impact of the model is done between concrete-concrete, steel-concrete and steel-steel [10].

b). The Ruaumoko program is used for the analysis, accounting for the material (inelastic behavior) and geometrical (second-order effects through large displacements, contact/impact modelling) nonlinearities [11] shown in Fig.29.

c). Spring-dampers made of an internal cylindrical casing filled with a compressible silicone fluid pressurized by a static pre-load applied upon manufacturing; of a piston moving in this fluid; and of an external casing shown in Fig.30. The operating mechanism of piston is based on the silicone fluid flowing through the thin annular space found between the piston head and the internal casing [12]. The inherent re-centering capacity of the device is ensured by the initial pressurization of the fluid.

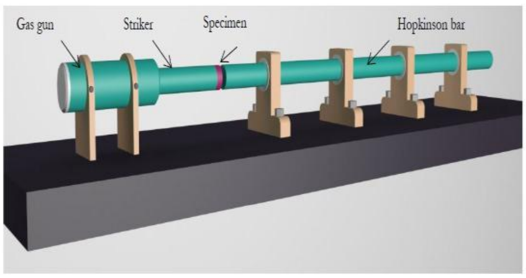

Fig.28: Hopkinson Pressure Bar Set-Up[10].

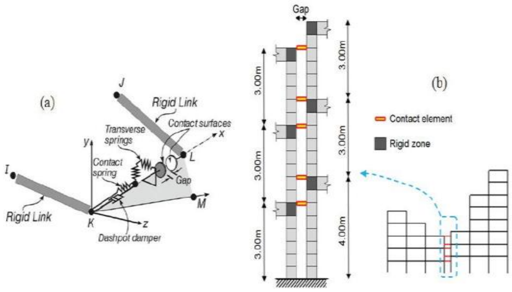

Fig.29: Ruaumoko Contact Element [11].

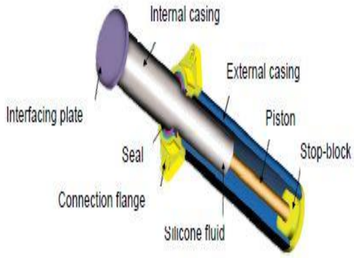

Fig.30: Piston Type Contact Element [12].

REFERENCES

[1] Shehata E. Abdel Raheem., Seismic Pounding Between Adjacent Structures, Electronic Journal of Structural Engineering, 6(2006).

[2] AmilaMohdAlwi, Dr. Dina D'Ayala., Pounding Effect Between Adjacent Buildings during Seismic Shaking, USL Department of Civil, Environmental And Geometrical Engineering Gower St. London, WC1E 6BT.

[3] ChennaRajaram, Ramancharla P. Kumar., Calculation of Seperation Distance between Adjacent Buildings: A Review on Codal Provisions, Earthquake Engineering Research Centre International Institute of Information Technology INDIA, JSEE Vol.17, No.1, 2015.

[4] Kawade A.B, Mr. Adhijeet., Seismic Pounding Effects In Buildings.

[5] KhazaAfroz Jamal, HS. Vidyadara., Seismic Pounding of Multistoried Buildings, International Journal of Research in Engineering & Technology eISSN:2319-1163 | PISSN:2321:7308.

[6] IRFAN Ahmed &MohdUmair ., Pounding Response between Equal Heights Multistory Buildings with different Dynamic Properties, International Journal Series in Multidisciplinary Research (IJSMR), Volume 1, Issued 1,2015.

[7] Bipin Shrestha., Effects of separation distance & non-linearity on pounding response of adjacent structures, EWES Nepal, International Journal of Civil & Structural Engineering Volume 3, No.3, 2013, ISSN 0976-4399.

[8] Pradeep Karanth, Ravindranatha, Pounding Effect in Building, Dept. of Structural Engineering, Manipal Institute of Technology Karnataka, International Journal of Innovative Research in Science and Engineering & Technology Vol.5, Special Issue 9, May 2016. ISSN(Print):2347-6710.

[9] Chaitanya Kumar .J.D, Phani Kumar .M, Seismic Pounding Of Adjacent Buildings with Different Heights, International Journal of Engineering Research & Science & Technology, Vol.4, No.4 November-2015, ISSN 2319-5991.

[10] Farhazadeh N., Pounding response of structures under earthquake motions, The Annual Postgraduate Research Student Conference-2015, Sheffield UK. 15thApril 2015, 20-24.

[11] Efraimiadou .S&Hatzigeorgiou .G.D., Structural Pounding between Adjacent Buildings, the effects of different structures configuration and multiple Earthquakes. 15WCEE LISBOA 2012.

[12] Sorace .S, Terenzi .G, Damped Interconnection-Based Mitigation of seismic Pounding between Adjacent R/C Building, IACIST International Journal of Engineering & Technology- Vol. 5, No. 3, June 2013.