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STUDY OF SEISMIC SEPARATION GAP TO MITIGATE POUNDING BETWEEN TWO ADJACENT BUILDINGS

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Abstract— *The aim of this study is to correlate the seismic performance of a real RC frame structure at different levels with the inadequate separation gap against pounding with an adjacent same height structure. Seismic pounding damage is the most common phenomena among the possible building damage during seismic excitation. Therefore it is imperative to consider pounding effects for structures. To understand the seismic behavior of structures, non-linear finite elements analysis is carried out for pounding of adjacent structure having same heights. The results were obtained in the form of storey shear, pounding force, storey displacement, storey drift and acceleration. The acceleration significantly increases during collision of buildings. Pounding produces more shear at the different storey location than the no pounding case. Increasing gap between two structures will decreases the storey shear of respective structures. The damage assessment can be carried out by the obtained pounding force. The result shows for the different time history data of India. The modeling and analysis done in CSI ETABS v16.2 software package.*

Keywords: *seismic pounding, separation gap, storey displacement, pounding force, acceleration, Etabs software.*

I. INTRODUCTION

Pounding of building is a dynamic phenomenon and which depends on many factors that is mass of building, height of building, time period and stiffness. The pounding is critical at floor levels at the peak acceleration. For the assessment of pounding case, pounding force is required to understand the impact. The typical measure for the structural pounding is to provide sufficient separation gap between two adjacent structures. Pounding can be causes damage to structures so the code provisions give suggestion for pounding mitigation but many times it will not effective or applicable, such are:

- Modern code practices give the existence of large deformations during major earthquakes due to inelastic response of structures but the earlier codes not give adequate separation to avoid pounding.
- The seismic separation required for the buildings is not easy to apply in metropolitan cities because of high cost of land.
- The earlier codes have not included response factor for structure to finding out safe separation gap which results inadequate separation.
- There are many structures which are already designed and constructed according to old earthquake resistant codes in which separation distance between structures have not been provided.

During ground motion, building often collide with each other due to different dynamic properties and insufficient gap distance. This collision can be called as pounding. Under the earthquake excitation the building responses more at the PGA (peak ground acceleration). The pounding may damage the structure and may partial or complete collapse of structure. The Mexico City earthquake in 1985 revealed that pounding was present in over 40% of the 330 collapsed or critically damaged building surveyed [1]. This earthquake illustrated seismic hazard of pounding, with the largest number of buildings damaged by this effect during a single earthquake. A survey of San Francisco Bay area during the 1989 Loma Prieta earthquake also results the extensive pounding incidents. [2].

II. LITERATURE REVIEW

Pounding is very dangerous when major earthquakes occur so many investigation have been carried out on pounding damage during previous earthquake events. Stavros A Anagnostopoulos (1987) studied the pounding of several adjacent building in series during strong earthquakes [3]. Each structure is modeled as a single degree of freedom (SDOF) system and pounding is simulated by impact elements. Kasai, V. Jeng, P.C. Patel and J.A. Munshi (1992) have surveyed and analyzed the damages in structures during 1989 Loma Prieta earthquake [4]. They have proposed the dampers for pounding mitigation. The building having inadequate seismic separation will have more internal damage or collapse of structures. An experimental study on seismic pounding done by A. Filiatrault and P. Wagner and S. Cherry [5]. They have concluded the amplitude and acceleration at pounding location are very sensitive to the mass at contact nodes. Fabian R. Rojas and James C. Anderson studied Pounding of an 18-Storey Building during recorded earthquakes a case study in Los Angeles (2012, ASCE)[6].

III. CODE PROVISIONS ON POUNDING

The pounding phenomenon is not taken by the many country codes, but India, Canada, Australia, Mexico, European and USA codes have clause for safe separation distance to avoid the pounding. The calculation of separation distance varies from country to country. FEMA and UBC-1997 are given the SRSS (Square Root Sum Square) rule to find separation distance. The final separation distance depends upon the maximum displacement of each building.

According to FEMA: 273-1997 (Federal Emergency Management Agency) the separation distance between adjacent structures shall be less than 4% of the building height and above to avoid pounding. It states that the separation distance should be adequate to prevent pounding during response to the design earthquake, except as indicated in *section 2.11.10.2*. Pounding may be presumed not to occur whenever the buildings are separated at any level *i* by a distance greater than or equal to s_i as given by the equation:

$$s_i = \sqrt{\Delta^2_{i1} + \Delta^2_{i2}} \qquad (1)$$

where:
Δ^2_{i1} = Estimated lateral deflection of building 1 relative to the ground at level *i*
Δ^2_{i2} = Estimated lateral deflection of building 2 relative to the ground at level *i*
The value of s_i calculated by equation (1) need not exceed 0.04 times the height of the buildings above grade at the zone of potential impacts.

Indian seismic code (IS: 1893-2002) also gives the separation distance formulation in *clause 7.11.3*. It states that the separation gap between two adjacent units shall be separated by a distance equal to the amount R (Response reduction factor) times the sum of the calculated storey displacement i.e. R $(\Delta_1 + \Delta_2)$. When floor levels of two similar adjacent units are at same levels, factor *R* in this replaced by *R/2*.

In IBC-2009 and ASCE-7-10 separation distance between two adjacent buildings is obtained from equation

$$\delta_M = C_d\, \delta_{Max} / I \qquad (2)$$

Where, δ_{Max} is the maximum displacement occurs anywhere in a floor from the application of the design base shear to the structure. C_d is the deflection amplification factor and 'I' is the importance factor for the seismic loading.

The recent Indian seismic code (IS: 1893-2016) gives the separation distance formulae as per *clause 7.11.3*. It says that two adjacent buildings, or two adjacent units of the same building with separation joint between them, shall be separated by a distance equal to R times sum of storey displacements Δ_1 and Δ_2 calculated as per drift limitation of the two buildings or two units of the same building, to avoid pounding as the two buildings or two units of same building oscillate towards each other. When floor levels of adjacent units are at same level than distance calculated as $(R_1 \Delta_1 + R_2\Delta_2)/2$ (as per Amendment No.1 Sept 2017), where R_1 and Δ_1 correspond to building 1, and R_2 and Δ_2 to building 2.

Sr.No.	Country Code	Provision
1	FEMA: 273-1997	Separation distance between adjacent structures shall be less than 4% of the building height and calculated (*section 2.11.10.2)* as $s_i = \sqrt{\Delta^2_{i1} + \Delta^2_{i2}}$
2	UBC 1997	$\delta_M = \sqrt{\delta^2_{M1} + \delta^2_{M2}}$ (*Clause 1633.2.11*)
3	Indian (IS: 1893-2002)	$R(\Delta_1 + \Delta_2)$ for different height level $R/2(\Delta_1 + \Delta_2)$ for same height building (*Clause 7.12.3*)
4	IBC 2009	$\delta_M = C_d\, \delta_{Max} / I$
5	ASCE-7-10	$\delta_M = C_d\, \delta_{Max} / I$ (*Clause 12.12.3*)
6	Indian (IS: 1893-2016)	$R(\Delta_1 + \Delta_2)$ for different height level building $(R_1 \Delta_1 + R_2 \Delta_2)/2$ for same height level building (*Clause 7.11.3*)

Table 1: Code provisions for different countries.

Where,
S_i = Separation distance
Δ_{i1}, Δ_{i2} = Deflection of building 1 and 2 relative to the ground at level *i*
δ_M = Separation distance between two structures.
δ_{M1}, δ_{M2} = Peak displacement correspond to building 1 and 2
R = Response reduction factor
Δ_1, Δ_2 = Maximum storey displacement correspond to building 1 and 2
C_d = Deflection amplification factor
δ_{Max} = Maximum elastic displacement that occurs anywhere in a floor from the application of design base shear to the structure.
I = Importance factor for seismic loading

IV. MODEL STUDY

Pounding study can be done by contact modelling or force based contact model. Force based model can simulate by linear spring model in Etabs software. This model is derived as "GAP" property in Etabs software. For the study of pounding, two identical height buildings are taken. The buildings having different plan geometry to satisfy pounding behavior. When two building are of same heights than pounding can occurs if the dynamic property or mass of the buildings are different. The pounding between two same height buildings simulate by different masses in the form of slab thickness and plan variation. The slab thickness 150mm and 120mm are taken into study for the both the model. Equivalent static and response spectrum analysis done to find the seismic response of the buildings. The buildings having different masses responses differently in earthquake. The pounding study done by "GAP" element. The property of gap element required to simulate. The initial gap required to start contact i.e. the initial gap distance after which buildings collide. Stiffness of gap elements depends on stiffness of stiffer buildings. The best manner to simulate it for pounding modelling is to taken 100 times greater stiffness than stiffer buildings. The force after response of building in seismic modes are depend on the oscillation and acceleration of building. The building acceleration decreases when mass of building increase. The energy requires more to response it in different modes.

Two G+14 buildings are taken for the study of pounding behavior. The general building data are given as follows,

Height of Floor = 3 m
Height of Parapet = 1.2 m
Grade of Steel = Fe415
Grade of Concrete for Column = M30
Grade of Concrete for Beams and Slab = M25
External Wall = 230 mm
Internal Wall = 115 mm
Unit Weight of Brick Masonry = 18Kn/m^3
Unit Weight of AAC Masonry = 9 Kn/m^3
Floor Finish = 1.875Kn/m^3
Live Load = 2.5 Kn/m^3
Size of Columns = 300X900 mm , 300X750 mm
Size of Beams = 300X450 mm
Frame type = Special moment Resistant Frame
Importance Factor = 1.2 (as IS 1893-2016)
Response Reduction Factor = 5 (as IS 1893-2016)
Soil Type: Medium
Gap Element
Grade of Shear wall = M30
Thickness of Shear wall = 180 mm

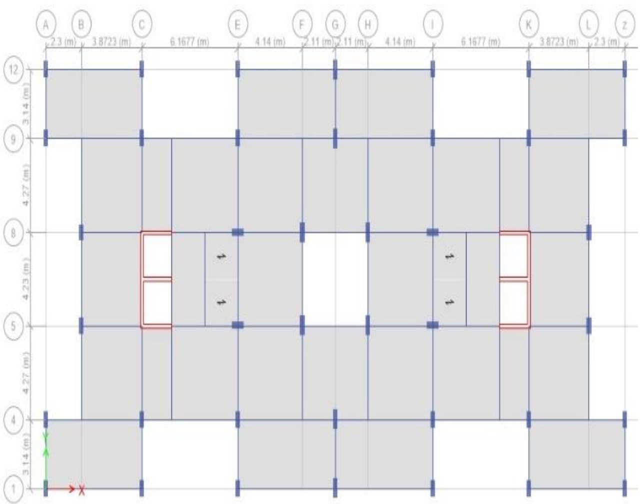

Figure 1: Model 1(G+14)

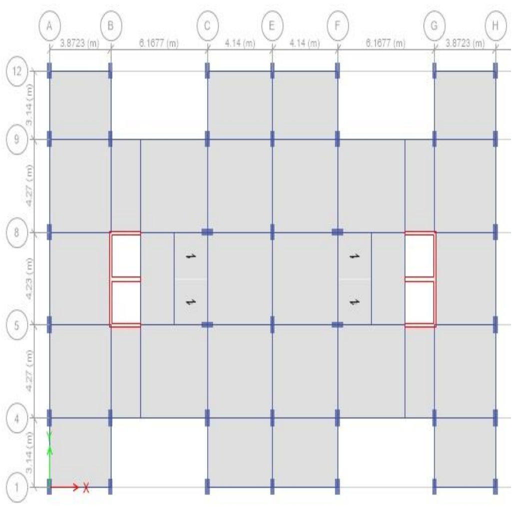

Figure 2: Model 2 (G+14)

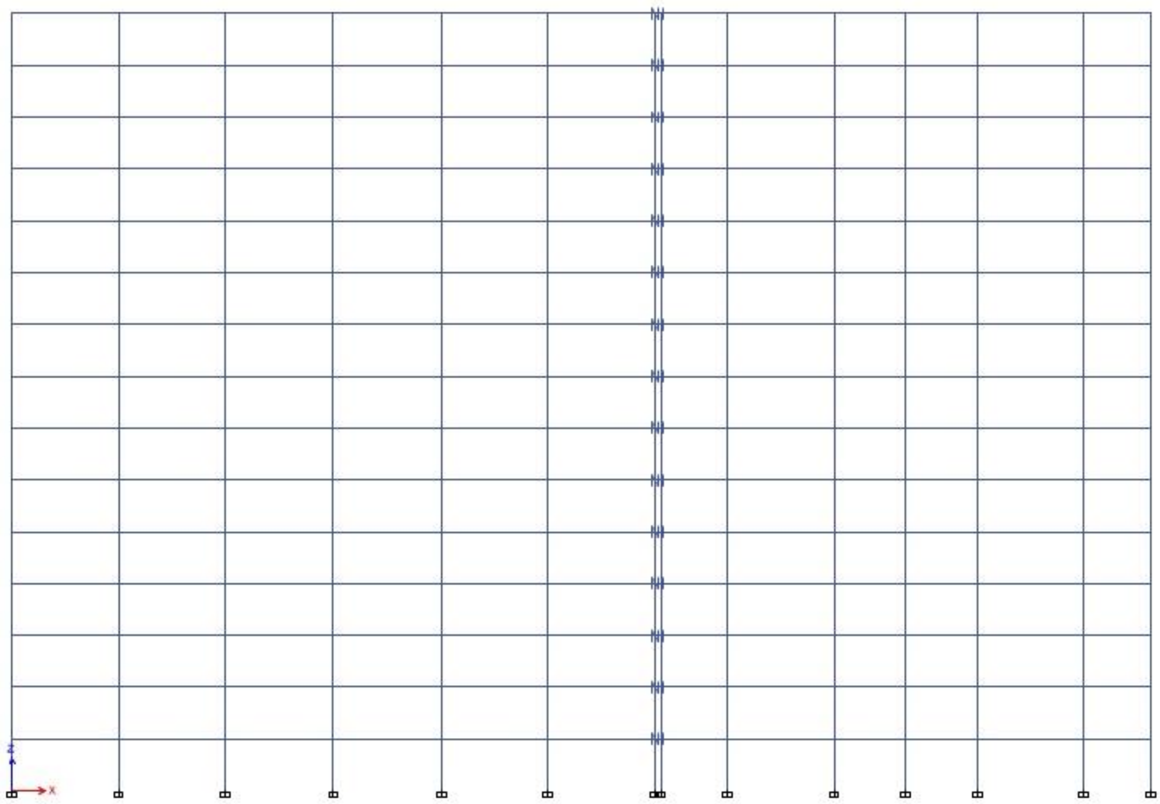

Figure 3: Elevation of Two Adjacent Buildings

V. GAP ELEMENT MODEL

Gap is a link element property which connect two adjacent nodes. The gap property works on a contact mechanism, it activated when they come closer and deactivated when they go far away. A force is generated when they come closer and at the contact. The stiffness of the gap property are in range of 10^2 to 10^4 times more than stiffness of connected elements.

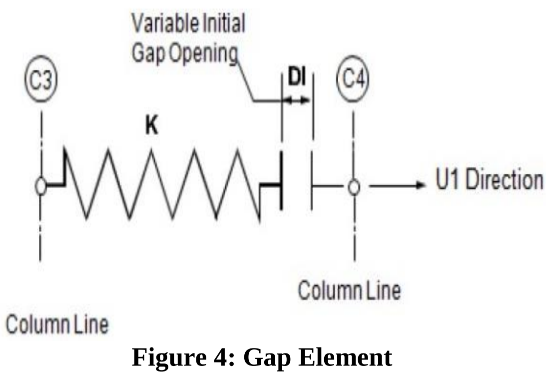

Figure 4: Gap Element

The linear analysis are based upon linear stiffness and damping properties. For the nonlinear analysis force deformation relationships are used at all degree of freedom for which nonlinear properties were specified. Generally Gap property only simulate compression force so it can be modeled for pounding study. When the earthquake strikes on two adjacent buildings than the gap element behave as to record collision. The collision results in forces that is in U1 direction. The count of collision also can obtain from the force results. The stiffness of gap element as greater as to accommodate forces in it. So,

VI. SOLUTION TECHNIQUE

Pounding solution can be done by considering FNA (fast nonlinear analysis) in the Etabs software. For FNA method for this case all nonlinearities restricted toward gap element only. The specific time history data applied from PEER database. The response of model in nonlinear time history analysis exerts some amount of force at the collision moment. The nonlinear equations are solved iteratively in each time steps. Gap element will active at the time step when building oscillates towards each other and in the verge of contact. The results in the form of axial forces at contact level.

VII. RESULTS AND DISCUSSION

The models are analyzed separately and results are obtained for the separation gap study. Further results are compared with different masses and respective top storey displacements.

Slab Thickness (mm)	Masonry Load	EQ-X	Response Spectrum
150	AAC	134.06	96.74
150	Brick	162.06	116.4
120	AAC	144.84	103.69
120	Brick	177.56	125.69

Table 2: Displacement results for Model-1

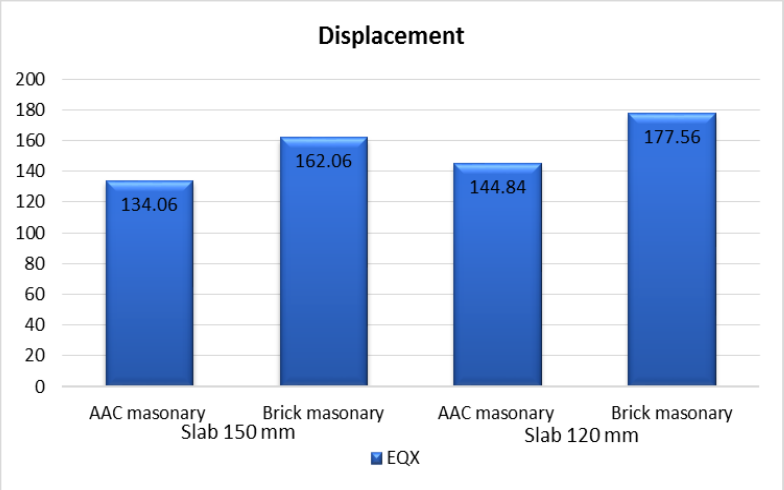

Figure 5: Maximum Displacement for Model-1

Slab Thickness (mm)	Masonry Load	EQ-X	Response Spectrum
150	AAC	94.42	67.76
150	Brick	120.75	86.44
120	AAC	101.51	72.21
120	Brick	131.68	93.62

Table 3: Displacement results for Model-2

Here, two models are taken for the study of pounding between two adjacent buildings. Model-1 having larger plan dimension than Model-2, so the displacement results are higher for Model-1. The displacement result required to calculate separation gap between two buildings.

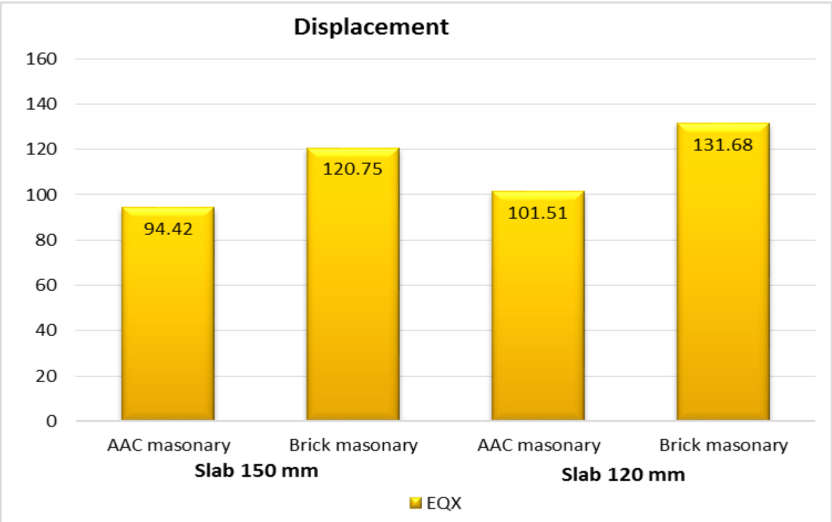

Figure 6: Maximum Displacement for Model-2

The results shows data of models with respect to their configuration. Here we can see that when the mass of the buildings are greater, than the building required more energy to deform. The displacements corresponds to slab thickness 150mm are lower than 120mm thickness. When the masonry loading on buildings increases as per their unit weights than also buildings requires more energy to oscillate. The displacements data are taken at the roof levels where it occurs maximum. Here it is concluded that the building having more masses corresponds to less displacements which can minimize the separation gap.

1. Seismic Separation Gap between Buildings as per Code provisions

The separation gap between Model 1 and Model 2 calculated after the analysis results. The separation gap for many possible combination for two models are calculated. The two models when they are adjacent to each other than the configuration regarding their masses and loading are taken for the study. The separation gap by FEMA and UBC are same as per their gap distance formulas. However the ASCE gives greater distance for all configuration systems.

	120mm Slab		Separation gap by different Codes			
Configuration	Model-1	Model-2	FEMA	UBC	IS 1893-2016	ASCE
1	AAC	AAC	176.87	176.87	615.88	778.23
2	Brick	Brick	221.06	221.06	773.10	972.66
3	AAC	Brick	195.75	195.75	691.30	861.30
4	Brick	AAC	204.53	204.53	697.68	899.92

Table 4: Adjacent building with different masses and their respective separation gap for 120mm slab.

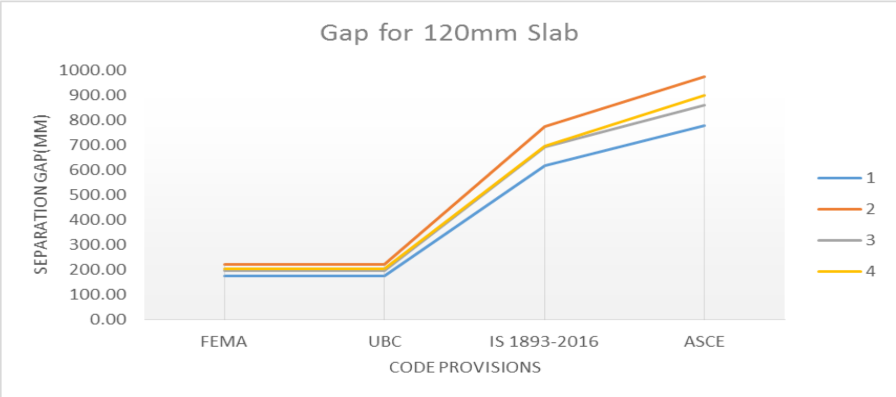

Figure 7: Separation gap for 120 mm slab

	150mm Slab		Separation gap by different Codes			
Configuration	Model-1	Model-2	FEMA	UBC	IS 1893-2016	ASCE
1	AAC	AAC	163.97	163.97	571.20	721.48
2	Brick	Brick	202.10	202.10	707.03	889.24
3	AAC	Brick	180.42	180.42	637.03	793.86
4	Brick	AAC	187.56	187.56	641.20	825.26

Table 5: Adjacent building with different masses and their respective separation gap for 150mm slab.

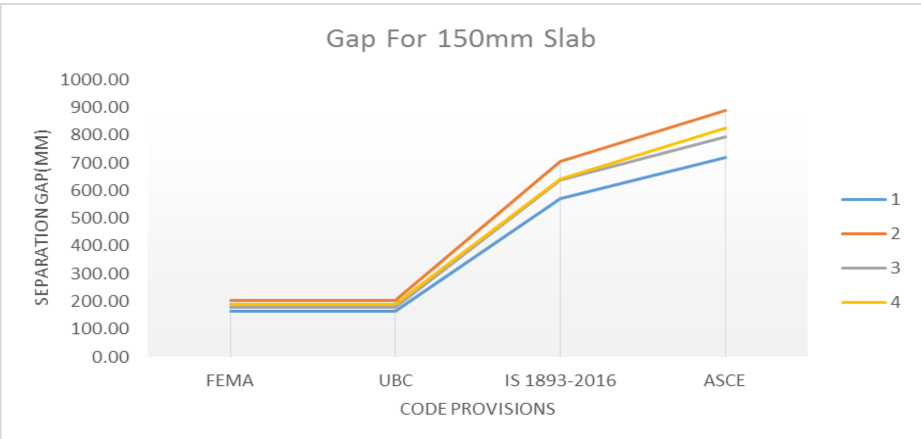

Figure 8: Separation gap for 150 mm slab

2. Safe Separation gap obtaining by nonlinear analysis

The two buildings had modeled with the gap element property between them to simulate pounding behavior. The initial gap is taken 60mm and further it increases till the gap elements did not shows any axial forces in it. It is a trial and error method by which we can conclude the actual safe separation gap distance between two structures. When the time period of two buildings are different than the case is critical and hence required pounding study. When both the buildings are subjected to ground motion, collision may take place and during collision energy transfer from one building to another building is natural. Due to energy transfer, both structures behave different as one of them losses the energy and another one gaining the energy. The impact study can be simulated by applying time history analysis to the link elements. Four time history data taken for the nonlinear time history analysis.

Earthquake Name	Location	Year	M_w	PGA (m/s/s)
Bhuj Earthquake	Ahmedabad	2001	7.7	0.78

When these ground motion data applied to the structures, collision may takes place because of different time period. The buildings subjected to different masses with same height collide at a point and energy transfer from one to another. The impact force after collision concluded as axial force in the gap element which is in compression. Axial force obtained after the ground motion is very high and critical to carry by structure hence results in damages or failure of complete structure. Bhuj earthquake ground motion gives better simulation of pounding because of high magnitude and PGA. The ground motion reveals impact forces in the gap type link element. The impact forces for different separation gaps are present here.

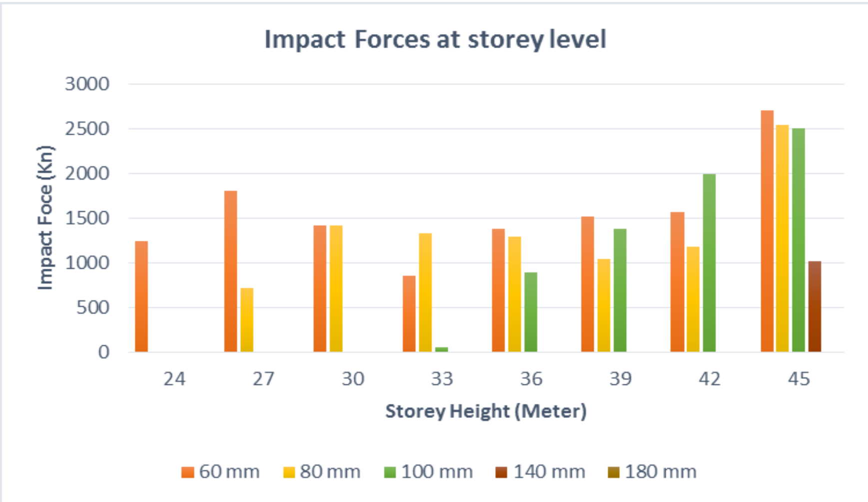

Figure 9: Impact forces at different storey heights for various gap distances.

These graph represents the max impact forces at story level for Bhuj Earthquake data. The forces for 60mm gap is very much high than the other gap distances. As the gap reaches to 180mm no impact force generated between the structures. So we can conclude 180mm gap is adequate to prevent pounding. The gap distance obtained by this technique is less than the calculated separation gap by IS 1893 and ASCE code.

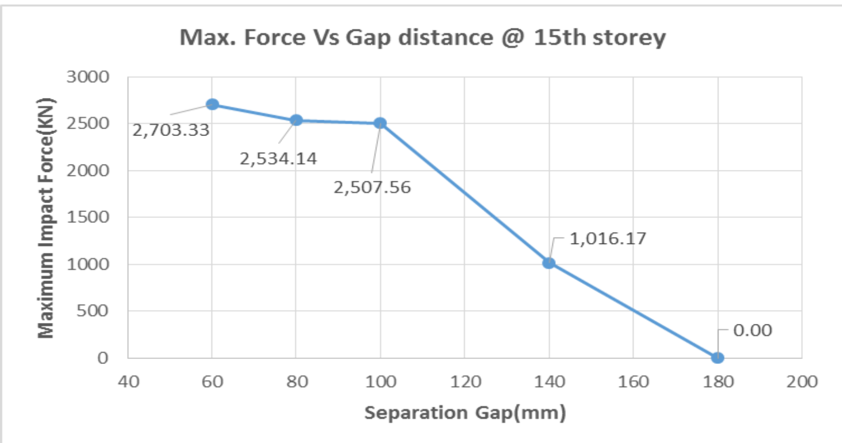

Figure 10: Maximum force at 15th storey for different gap distances.

The results represent that when we increase the separation gap by 20mm than the impact force reduces by 6.25% and when the gap distance further increase by 40mm after reaching to 100mm gap distance than the impact forces reduces 60%. As the gap distance increases than number of impact decreases.

VIII. CONCLUSION

The seismic separation gap is very important to consider when two buildings are adjacent to each other. The gap distance calculated as per code provisions are depends on displacement of the structures. When the structures oscillate under ground motion than the displacement and acceleration are play main role part in building response. The gap element firstly put 60mm in which the separation distance is too low to prevent collision. The concluded results are as follows:

1) When the gap distance firstly increases by 40mm than the reduction in impact force is 7%, i.e. when the gap increases 60mm to 100mm than the reduction in force is 195.77Kn.
2) When further increase the gap distance by 40mm i.e. 100mm to 140mm than 60% reduction in impact force.
3) The gap distance also depends on the impact count of two adjacent structures which can be decreased by increasing gap distance.
4) For this model study 180mm separation is adequate to mitigate pounding which is very much less than the distance calculated by code provisions.
5) The buildings with different masses have different response behavior, so the building should separate by adequate distance to prevent pounding.
6) Building having heavy mass will displace less than lighter mass for the same stiffness.

The study also represents the separation gap for any two adjacent building gives more value when calculated by code provisions. The calculated gap are depending upon displacement parameters. The proposed separation distance find out by analysis and simulation process.

REFERENCES

[1] V. JENG and W.L. TZENG "Building seismic separation at Taipei city" Eleventh world conference on earthquake engineering 1996.
[2] "Survey and analysis of building pounding during 1989 loma prieta earthquake" Kazuhiko Kasai, Anil R. Jagiasi and Bruce F. Maison.
[3] "Evaluation of building separation in series consideration" Stavros A Anagnostopoulos (1987).
[4] "Impact element simulation against pounding for Loma prieta earthquake" Kasai, V. Jeng, P.C. Patel and J.A. Munshi (1992)
[5] "Internal damage or collapse of structures: An experimental study on seismic pounding" A. Filiatrault and P. Wagner and S. Cherry
[6] "Pounding of an 18-storey building during recorded earthquakes" Fabian R. Rojas and James C. Anderson (2012,ASCE)
[7] "Study on impact between adjacent buildings: Comparison of codal provisions" Chenna Rajaram, Ramancharla Pradeep Kumar.
[8] "Pounding force response spectrum under earthquake excitation" Robert Jankowski.
[9] "Development of pounding model for adjacent structures in earthquakes" S. Khatiwada, N. Chouw, J.W. Butterworth
[10] "Nonlinear Modelling of earthquake induced pounding on buildings" Robert Jankowski.
[11] "Earthquake induced pounding in adjacent building" K.V. Spiliopoulos and S.A. Anagnostopoulos.
[12] IS 1893 (PART1):2002 "Indian Standard Code of Practice for Earthquake Resistant Design of structures, Part 1 General provisions and Buildings, (Fifth revision)".
[13] IS 1893 (PART1):2016 "Indian Standard Code of Practice for Earthquake Resistant Design of structures, Part 1 General provisions and Buildings, (Sixth revision)".
[14] FEMA 273-1997(Federal Emergency Management Agency)
[15] ASCE-7-10 (American Society of Civil Engineering), IBC 2009 (Internation Building Code)