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Effect of Seismic Pounding between Adjacent RC Framed Buildings with and without Coupled Shear Walls

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Abstract - *During earthquakes, the collision of adjacent buildings due to lack of safe separation gap creates major consideration during the structural design i.e. Pounding effect. Sometimes pounding effect on buildings is more severe than earthquakes. So, in this thesis study attempt was made to analyze the seismic pounding effect between the two adjacent RC framed buildings with and without coupled shear walls for various conditions such as adjacent buildings with same floor levels, different floor levels, different floor thickness and the setback distance of 3.5m is studied. The adjacent buildings are connected by 60mm link element to study the pounding force, transmitted by one building to another building due to pounding effect. The modelling and Time history analysis for all cases is carried out by using ETABS software. The parameters that are studied Pounding force, displacement, and required safe separation gap by SRSS and ABS methods. The study showed that safe separation gap required for RC frames structure is more than RC framed structure with couple shear walls. And also pounding effect can be reduced by using coupled shear walls.*

Key Words: *Seismic pounding effect, Safe separation gap, Coupled shear walls, Time history analysis, ETABS.*

1. INTRODUCTION

In metropolitan cities due to an increase in population the construction of buildings is increasing day by day. This leads to a decrease in the availability of land for construction and also increases in land cost. Results in construction of adjacent buildings is very close to each other. During earthquakes, due to insufficient separation gap between the adjacent buildings the buildings cannot vibrate freely which leads to buildings strikes to each other. “The collision of adjacent buildings due to their lateral movements induced by lateral forces (earthquakes) is known as seismic pounding”. The seismic pounding effect on adjacent buildings will cause serious damage to life, structure, and economy.

The main cause for occurring of seismic Pounding is the lack of seismic separation gap between the adjacent buildings and also rise of displacements of structure because of an insufficient structural system. The present codes specify the minimum safe separation gap but it still fails to consider all other parameters that affect seismic pounding. The effective way to reduce the pounding effect is to provide enough separation gap but sometimes is difficult to provide the required separation gap due to the complete use of land. In such cases, we reduce the pounding by providing the lateral resisting systems in the structure.

1.1. Safe Separation Gap:

To minimize the pounding effect, a minimum safe separation gap is to be provided between adjacent buildings, which is equal to the peak displacement of the two potentially colliding building systems. So, to minimise this pounding effect on adjacent structure the design codes specified minimum safe separation gap. In many design codes and regulation worldwide, the minimum safe separation seismic gap (Lopez Garcia 2004) is given as:

$S = \sqrt{(Q_1^2+Q_2^2)}$ is an SRSS (Square Root of the Sum of the Squares) Method
$S = Q_1 + Q_2$ is an Absolute Sum Method (ABS)

Where,
Q1= Peak displacement of building-A
Q2= Peak displacement of building-B
S = Separation distances

According to the Bureau of Indian Standards provides in code IS 4326 in table1 that a safe separation gap is to be given to avoid pounding between the adjacent buildings during an earthquake. The safe separation gap for adjacent structures as per IS 4326 has been shown in below Table 1.

S.no:	Type of construction	Gap width/ storey in mm for design seismic coefficient of αh=0.1
1	Box system or frame with shear wall	15.0
2	Moment resistant reinforced concrete frame	20.0
3	Moment resistant steel frame	30.0

Table -1: Minimum gap width for adjacent structures as per IS 4326-1993 clause 5.1.1.

1.2. Coupled Shear Walls:

In multi-storey buildings, the lateral loads are restrained by shear walls due to their strength and stiffness. These walls contain many openings such as windows, doors, elevators, etc. Which divides the entire shear wall into slender walls. To improve the shear capacity these walls are interconnected by short beams along with their height. These beams are named as coupling beams. Coupled shear wall systems will offer more efficient as well as effective structural systems than single shear wall systems further these systems possess more exceptional stiffness, durability, and energy diffusion. Also, the structure can dissipate most of the energy by yielding the coupling beams with no structural damages to the main walls. The coupled shear walls should meet the accompanying the following two provisions:

- The system should produce hinges only in the coupling beam before shear damage.
- The coupling beam should be designed to produce sufficient energy diffusion properties.

1.3. Objectives of the Present Project:

The purposes of this investigation are as follows:

1. To know the pounding effect on the adjacent building
2. Analysing the buildings to pounding due to earthquake by Time history analysis by using ETABS software.
3. Determination of the pounding effect between the equal height, unequal height, different floor thickness, and setback distance of the adjoining structures due to seismic forces.
4. Determination of pounding effect between the two adjacent RC framed buildings with and without coupled shear walls
5. Determination of the maximum lateral displacement, and maximum pounding force for various conditions.
6. Computation of minimum seismic gap required between buildings by both SRSS and ABS methods for various conditions.
7. To compare the results such as maximum displacement, pounding force, and seismic separation distance for different building cases.

2: LITERATURE REVIEW

Khaja Afroz Jamal and H.S. Vidyadhara [2013]: Analysed seismic pounding of multi-storeyed buildings this study is carried out by analysing reinforced concrete frames using response spectrum analysis and nonlinear time history analysis in ETABS software. Two multi-story structures are studied in aspects of displacement and pounding force. The effect of variation of gap and addition of shear wall is also studied. For linear analysis, the structure in earthquake zone V is considered. For Time History function, ground excitation data of the El Centro earthquake is chosen.

Rabindranath and S.M.H Suresh [2014]: Investigated pounding between adjacent buildings. To study the seismic pounding effect between the structures, a three-dimensional RC moment resisting frame structures with open ground floor is taken and analysed by using SAP2000 structural analysis and design software. The two buildings (G+8) and (G+5) are considered. The height of all floors is 3.2m. The buildings are separated by a gap of 80mm. Time History Analysis is done by using SAP2000 and is designed as per Indian standards. And considered the adjacent structures are subjected to static and dynamic loads and load combinations.

Building-1 (G+8) has 3 bays in X and Y directions. The width of each bay in the X direction is 3.5m, and that of in Y direction is 4.5m. Building-2 (G+5) has 3 bays in X and Y directions, the width of each bay in the X direction is 3m, in Y direction it is 4.5m. Pounding is considered on top floor of the G+ 5 story building, for examine the results Positive displacement of eight stories and negative displacement of five stories is considered, as we are going for the worst condition due to its different dynamic characteristics.

Puneeth Kumar and MS, S Karuna [2015]: Studied effect of seismic pounding between adjacent buildings and mitigation measures. In this study, to observe the pounding between adjacent buildings, they considered two buildings closest to each other, one being G+ 10 story and other being G+ 7 story were considered. These structures are separated by an expansion joint and are subjected to gravity and dynamic load. The storey displacement and pounding force of the adjacent structures are considered for the analysis using SAP 2000 software.

The pounding effect is considered for the following different case's

- Adjacent buildings at same floor level
- Adjacent buildings with different ground level condition
- Adjacent buildings with different floor heights
- Buildings with a setback of 4m

Mitigation measures are implemented utilizing lateral load countering systems such as bracings and shear wall.

Seema V, and Mrs. B. R Shilpa [2018]: Studied the pounding effect on Adjacent RCC Buildings. Two adjacent buildings of (G+7) and (G+4) are considered for the study. The gap elements considered are 50, 80, 110, and 140 mm for each case. The Response Spectrum Analysis is carried out for each of the cases.

Case 1: Adjacent Buildings at the same floor level with different story heights.

Case 2: Adjacent Buildings at the same floor level and story heights.

Case 3: Adjacent Buildings with a setback of 3m with equal floor level with and different story height.

Dhananjay S, Vasudev M V, and Al Shoty M [2019]: Examined Response of Adjacent Building for Seismic Pounding Effect on Bare Frame and Masonry Infill Frame by using ETABS. Two adjacent structures (tower A and tower B) are considered. The gap between the adjacent buildings is 100mm.The tower A 30m in the x-direction and 24m y-direction and tower B 22.5m in x the direction and 24m in the y-direction. Floor height 3m. The following cases are studied for this project

- Tower A and Tower B with an equal number of stories with equal story height (Bare frame)
- Tower A and Tower B with unequal number of stories with equal story height (Bare frame)
- Tower A and Tower B with unequal number of stories with equal story height with mid column pounding (Bare frame)
- Tower A and Tower B with unequal number of stories with equal story height with 2/3 column length pounding (Bare frame)
- Tower A and Tower B with an equal number of stories with equal story height (Bare frame with masonry infill)
- Tower A and Tower B with unequal number of stories with equal story height (Bare frame with masonry infill)
- Tower A and Tower B with unequal number of stories with equal story height with mid column pounding (Bare frame with masonry infill)
- Tower A and Tower B with an unequal number of stories with equal story height with 2/3 column length pounding (Bare frame with masonry infill).

3. BUILDING MODELLING

To observe the pounding effect between the two adjacent buildings Building A and Building B are considered for this study. The buildings were modelled by using Auto CAD and ETABS software. The gap element 60 mm for all cases. The following cases are studied in this project

I. Both Building A and Building B are RC framed structures

Case 1: Adjacent buildings with an equal number of stories (i.e. Building A and Building B are both G+19 buildings)
Case 2: Adjacent buildings with unequal number of stories (i.e. Building A is G+19 and Building B is G+14)
Case 3: Adjacent buildings with an equal number of stories but with different floor thicknesses (i.e. Slab A is 150 mm and Slab B is 180 mm)
Case 4: Adjacent buildings with setback distance of 3.5m

II. Building A is RC framed structure with coupled shear walls and Building B is RC framed structure

Case 5: Adjacent buildings with an equal number of stories (i.e. Building A and Building B are both G+19 buildings)
Case 6: Adjacent buildings with unequal number of stories (i.e. Building A is G+19 and Building B is G+14)
Case 7: Adjacent buildings with an equal number of stories but with different floor thicknesses (i.e. Slab A is 150 mm and Slab B is 180 mm)
Case 8: Adjacent buildings with setback distance of 3.5m

III. Both Building A and Building B are RC framed structure with coupled shear walls

Case 9: Adjacent buildings with an equal number of stories (i.e. Building A and Building B are both G+19 buildings)
Case 10: Adjacent buildings with unequal number of stories (i.e. Building A is G+19 and Building B is G+14)
Case 11: Adjacent buildings with an equal number of stories but with different floor thicknesses (i.e. Slab A is 150 mm and Slab B is 180 mm)
Case 12: Adjacent buildings with setback distance of 3.5m

3.1. Loads and Load Combinations

The loads acting on the structure is calculated based on the IS 875-1987. The IS 875-1987 is Code of Practice for Design Loads (other than earthquake loads for buildings and structures) deals with the magnitude of such loads that being used for designs in India. And the earthquake loads are calculated as per IS 1893-2002. Load combinations taken as per IS 456-2000 Table No.18.which are presented in "Table 2"

3.2. Adjacent Buildings Descriptions

Table -2: The Various Parameters Considered for this Study

Description	Specification
Number of stories (except for Case 2,6, & 10)	G+19
Number of stories (for Case 2,6, &10)	G+14
Story height	3.0m
Grade of concrete (for beams and slabs)	M30
Grade of concrete (for columns)	M40
Grade of steel	Fe500
Unit weight of concrete	25 kN/m^3
Unit weight of brick masonry	20 kN/m^3

Floor Finish+ unknown force	2 kN/m²
Live load	4 kN/m²
Beam size	0.3m x 0.45m
Column size	0.6m x 0.6m
Gap element	60mm
Zone	V
Response reduction factor (for RC framed)	3
Response reduction factor (for coupled shear wall)	5
Importance factor	1
Soil type	I

4. STRUCTURAL ANALYSIS

To determine seismic pounding effect between the adjacent RC framed buildings (i.e.: Building A and Building B) with and without coupled shear walls is studied using the Response spectrum Analysis procedure as with respect to the Code of practice IS 1893. the maximum displacement, pounding force, and required seismic separation gap between the structures Time history analysis by using Bhuj Earthquake of January 26, 2001 data has been carried out by using ETABS software.

5. RESULTS AND DISCUSSION

In this chapter results obtained from the time history analysis for all cases are presented in tabular and graphical form. And also, the variation of displacements, pounding force, and required seismic gap by various methods are mentioned in it.

5.1. Storey Displacement (mm)

Case 1: In this case the maximum displacement of Building A and Building B is at Storey 20 is 54.19 mm and 55.93 mm respectively.

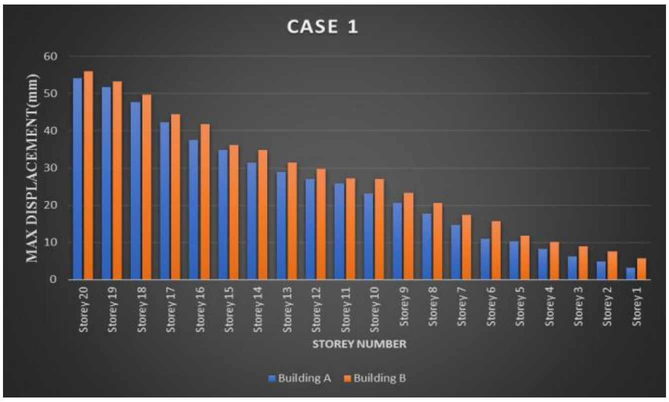

Fig -1: Displacements of Adjacent Buildings (Case 1)

Case 2: In this case the maximum displacement of Building A and Building B is at Storey 15 is 60.66 mm and 61.89 mm respectively.

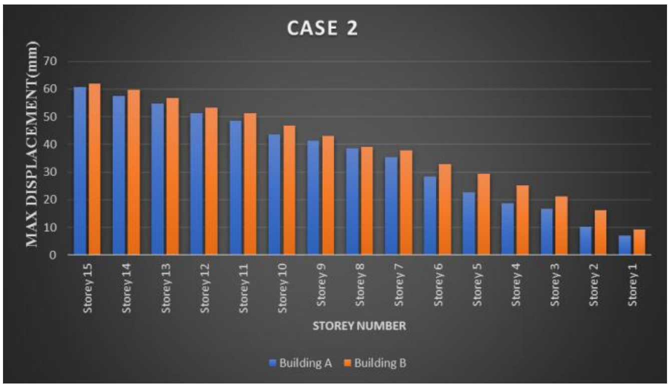

Fig -2: Displacements of Adjacent Buildings (Case 2)

Case 3: In this case the maximum displacement of Building A and Building B is at Storey 20 is 54.92 mm and 58.03 mm respectively.

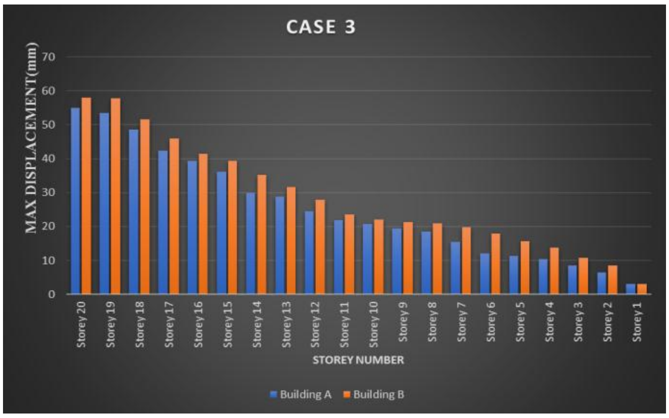

Fig -3: Displacements of Adjacent Buildings (Case 3)

Case 4: In this case the maximum displacement of Building A and Building B is at Storey 20 is 48.37 mm and 49.01 mm respectively.

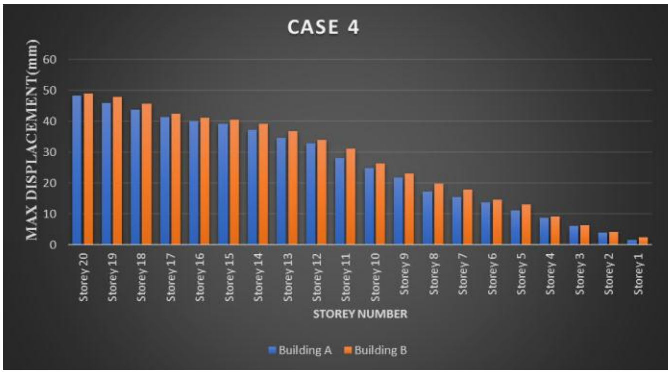

Fig -4: Displacements of Adjacent Buildings (Case 4)

Case 5: In this case the maximum displacement of Building A and Building B is at Storey 20 is 38.55 mm and 42.31 mm respectively.

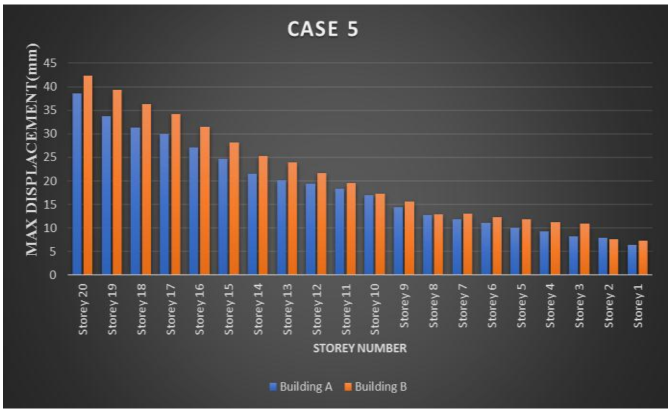

Fig -5: Displacements of Adjacent Buildings (Case 5)

Case 6: In this case the maximum displacement of Building A and Building B is at Storey 20 is 35.49 mm and 41.63 mm respectively.

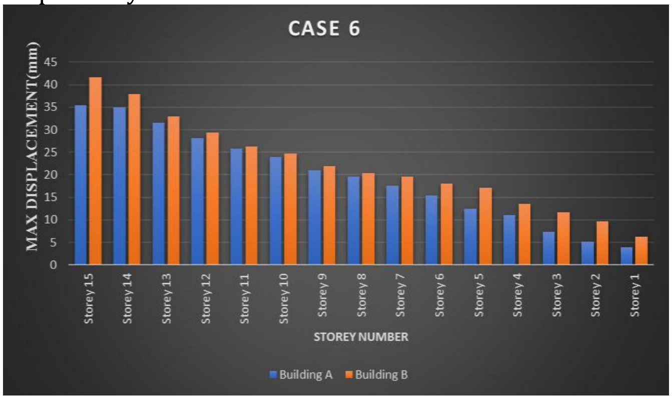

Fig -6: Displacements of Adjacent Buildings (Case 6)

Case 7: In this case the maximum displacement of Building A and Building B is at Storey 20 is 38.85 mm and 42.89 mm respectively.

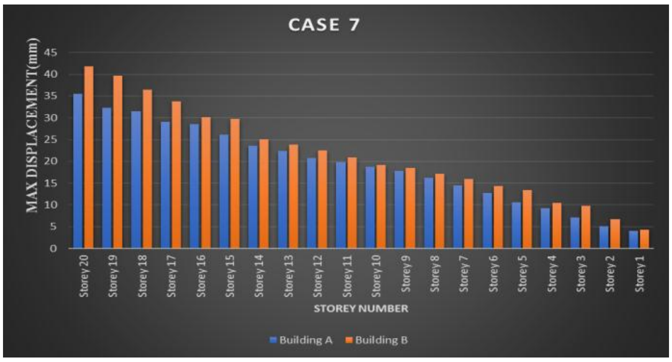

Fig -7: Displacements of Adjacent Buildings (Case 7)

Case 8: In this case the maximum displacement of Building A and Building B is at Storey 20 is 23.16 mm and 28.33 mm respectively.

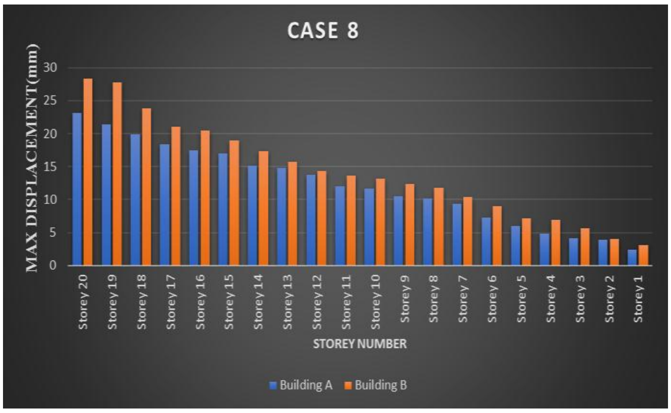

Fig -8: Displacements of Adjacent Buildings (Case 8)

Case 9: In this case the maximum displacement of Building A and Building B at Storey 20 is 16.68 mm and 17.23 mm respectively.

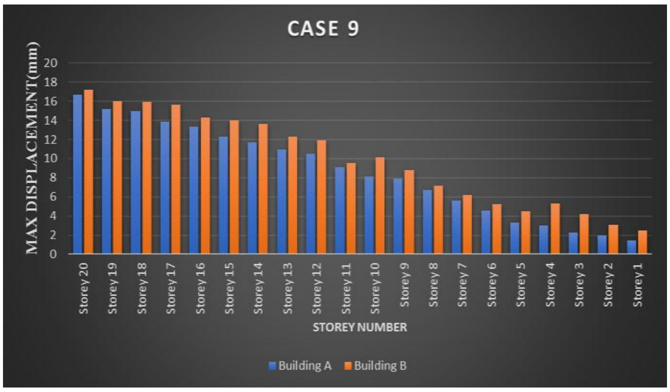

Fig -9: Displacements of Adjacent Buildings (Case 9)

Case 10: In this case the maximum displacement of Building A and Building B at Storey 20 is 15.69 mm and 16.12 mm respectively.

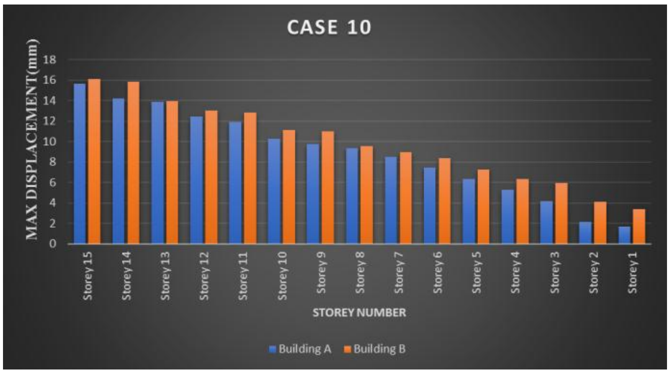

Fig -10: Displacements of Adjacent Buildings (Case 10)

Case 11: In this case the maximum displacement of Building A and Building B at Storey 20 is 16.87 mm and 17.31 mm respectively.

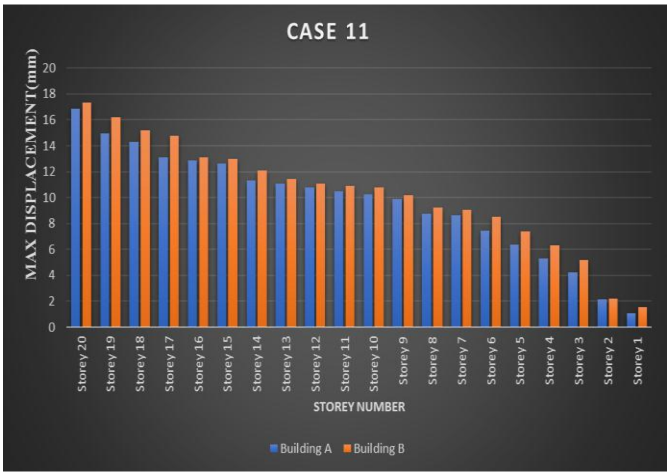

Fig -11: Displacements of Adjacent Buildings (Case 11)

Case 12: In this case the maximum displacement of Building A and Building B at Storey 20 is 13.48 mm and 14.56 mm respectively.

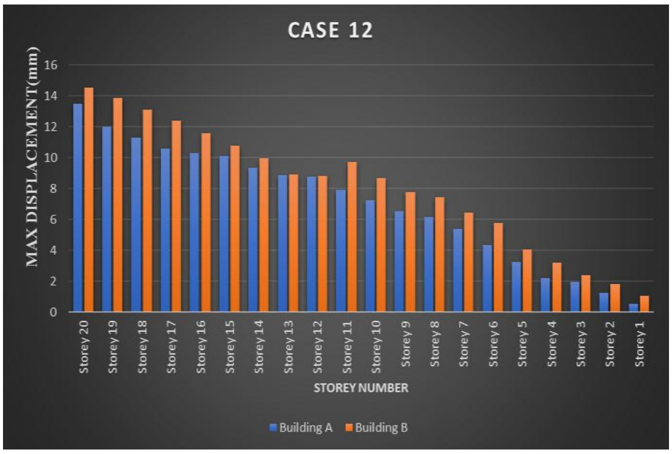

Fig -12: Displacements of Adjacent Buildings (Case 12)

5.2. Comparison of Maximum Storey Displacements (mm)

The below "Table-3" represents the comparison between the structures of adjacent buildings with different structural systems which includes RC framed structures, RC framed structure with coupled shear wall, and combination of both and also for different cases i.e. buildings with same floor level, different floor levels, different slab thickness, and with setback distance of 3.5m.

Table -3: Maximum Storey Displacement (mm)

Case Number	Building A	Building B
Case 1	54.19	55.93
Case 2	60.66	61.89
Case 3	54.92	58.03
Case 4	48.37	49.01
Case 5	38.55	42.31
Case 6	35.49	41.63
Case 7	38.85	42.89
Case 8	23.16	28.33
Case 9	16.68	17.23
Case 10	15.69	16.12
Case 11	16.87	17.31
Case 12	13.48	14.56

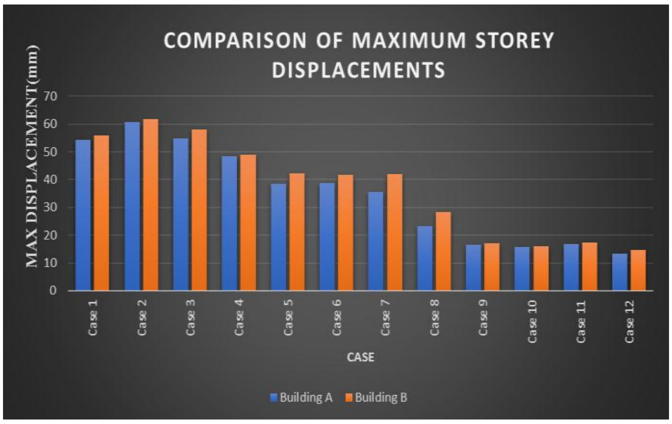

Fig -13: Graphical Representation of Maximum Storey Displacement for Each Case

If both Building A and Building B are RC framed structure the maximum displacement occurred in buildings in the different floor levels. Whereas if both building A and building B are RC framed structure with coupled shear wall and also if Building A is RC framed structure with coupled shear wall and Building B is RC framed structure the maximum displacement has occurred in buildings with different slab thickness.

In all the cases the maximum displacement is less in buildings with a setback distance of 3.5m. And by observing the above "Fig-13" the displacement of structure is reduced by providing coupled shear wall. If both Building A & B are RC framed structure with coupled shear wall has better stiffness compared other two structural system cases.

5.3. Required Seismic Separation Gap for Each Case by SRSS and ABS Methods:

Table -4: Required Seismic Separation Gap for Each Case

Case	Pounding force (kN)
Case 1	527.4
Case 2	1102.43
Case 3	389.75
Case 4	336.68
Case 5	324.11
Case 6	819.10
Case 7	379.40
Case 8	237.67
Case 9	251.53
Case 10	694.84
Case 11	183.12
Case 12	165.61

From "Table 4" it is observed that the maximum seismic separation gap required for Case 1 and the minimum gap is for Case 12. And the required maximum seismic separation gap is reduced due to providing of coupled shear walls. It is better to use the Absolute Sum Method (ABS) for calculation of seismic separation gap for safe construction and for better performance during their design period of the structure.

If both Building A and Building B are RC framed structure the maximum separation gap is required for buildings with different floor levels. Whereas if both building A and building B are RC framed structure with coupled shear wall and also if Building A is RC framed structure with coupled shear wall and Building B is RC framed structure the maximum seismic separation gap required for buildings with different slab thickness.

5.4. Pounding Force Occurred in Different Cases

From the "Fig-14" it is observed that maximum pounding force occurs in buildings with different floor levels in all cases. The maximum pounding force is 1102.43 kN if both buildings with RC framed structures. The pounding force is reduced by providing coupled shear walls.

Table -5: Pounding Force Occurred in Different Cases

Case	Building A	Building B	SRSS (mm)	ABS (mm)
Case 1	54.19	55.93	77.87	110.12
Case 2	60.66	61.89	86.66	122.55
Case 3	54.92	58.03	79.89	112.95
Case 4	48.37	49.01	68.85	97.38
Case 5	38.55	42.31	57.23	80.86
Case 6	35.49	41.63	54.70	77.12
Case 7	38.85	42.89	57.86	81.74
Case 8	23.16	28.33	36.59	51.49
Case 9	16.68	17.23	23.98	33.91
Case 10	15.69	16.12	22.49	31.81
Case 11	16.87	17.31	24.17	34.18
Case 12	13.48	14.56	19.84	28.04

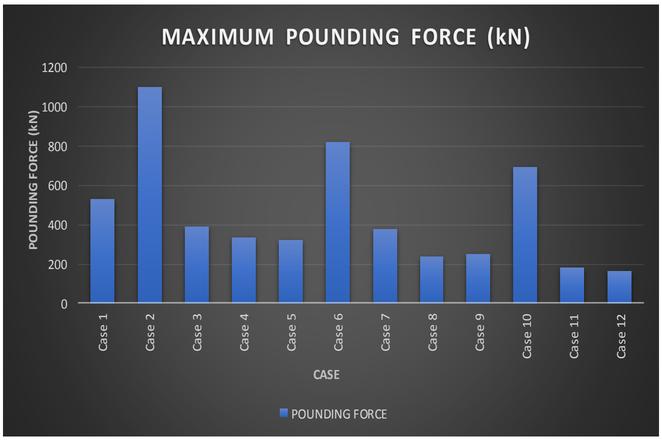

Fig -14: Graphical Representation of Maximum Pounding Force

6. CONCLUSIONS

The following major conclusions obtained from the study are enlisted:

1. Adjacent buildings having a different structural systems, masses, and heights can be a serious problem and threat to safety due to pounding effect.
2. Adjacent buildings with the same structural systems and same floor levels will show similar behavior.
3. The decrease in pounding force is observed that in (case 9-12) due to an increase in the lateral stiffness and reduction in the displacement result due to the coupled shear wall.

4. From the case (5-12) it is observed that the safe separation gap is decreased by incorporation of a coupled shear wall. From this, we conclude that to achieve the minimum safe separation gap sufficient lateral resisting structural systems should be provided.

5. The coupled shear wall is found to be more effective when they are incorporated for the building.

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