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Study of Impact between Two Equal & Unequal Buildings during Earthquake

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Abstract: *Increasing population and growing social and commercial activities but limited land resources available in a modern city lead to more and more buildings being built closely to each other. These buildings, in most cases, are separated without any structural connections. The ground motion during earthquakes causes damage to the structure by generating inertial forces caused by the vibration of the buildings masses. From previous studies it was observed that majority researchers did the work on the separation gap between two adjacent structures. Thus, after reviewing the existing literature it was observed that most of literature compares existing & low-rise structure. The project objective is to decrease the effect of earthquake responses on structures. The main objective and scope are to evaluate the effects of structural pounding on the global response of building structures and to determine the minimum seismic gap between equal and unequal but adjacent buildings. In this project using response spectrum analysis we have checked whether two models have displacement within the permissible limit for adjacent buildings as well as to determine & compare the seismic gap provided as per IS 1893-2002 and other codal provisions.*
Keywords - *Low-rise structure, adjacent building, Response spectrum analysis*.

I. Introduction

1.1 General

Increasing population and growing social and commercial activities but limited land resources available in a modern city lead to more and more buildings being built closely to each other. These buildings, in most cases, are separated without any structural connections. Hence, wind-resistant or earthquake resistant capacity of each building mainly depends on itself. The ground motion during earthquakes causes' damage to the structure by generating inertial forces caused by the vibration of the buildings masses. Tall structures are extremely vulnerable to the structural damage because the masses at the levels are relatively large, supported by slender columns. The displacement of the upper stories is very large as compared to the lower ones. This includes large shear forces on the base columns. If the separation distances between adjacent buildings are not sufficient, mutual pounding may also occur during an earthquake. During strong earthquakes, adjacent structures that do not have appropriate distance and hit each other, that is called impact. The difference between dynamic properties (mass, hardness and height) of adjacent structures results different-phase oscillations which is the main cause to impact and the more different in shape of vibration causes stronger impact and vice versa. Impact phenomenon has been reported in the strong earthquakes**.**

1.1.1 Various Types of Impacts:

Various types of impact seen in the recent earthquakes can be categorized into 5 main groups.

1.1.2 Impact of the Structure On the Column Of an Adjacent Building:

This type of impact occurs in some adjacent buildings in which the floors levels are not in the same heights. Therefore, when shaking with different phases occurs, the floor of one building hits the column of another and causes serious damages which can lead to the fracture of the columns of the story. This type is the most dangerous impact that can result in sudden destruction of the structure.

1.1.3 Impact of a Heavier Building On a Lighter One:

Since adjacent buildings may differ in the structural system of floors and/or in their applications, they have different masses, this can cause different phase oscillations, since the lighter building tolerates more intensive response.

1.1.4 Impact of a Shorter Building On a Taller One:

When two structures with different heights are adjacent, because of different dynamic properties, the shorter structure hits the adjacent one, which results in floor shearing in higher levels of impact part. It is important to know that the higher in the impact part level, the greater impact is tolerated more intensive response.

1.1.5 Impact of Two Adjacent Buildings With Non-Coaxial Mass Centres:

In building with non-coaxial mass centres, the structure may pound on the edge of the adjacent structure and cause strong tensional torques, which can lead to seriously damage to the column on the edges and corners of the pounded building.

1.1.6 Pendulum-Like Impact of Buildings:

This type of impact is usually seen in buildings, which are built completely the same (e.g., small towns). In this type of impact, some similar buildings that oscillate similarly, in strong earthquakes, hit the last building in the series and cause serious displacement in the pounded building. Existence of the same shape of the vibration in some building and the high momentum lead to last building has intensive responses. Numerous cases of this type of impact occurred in Mexico City earthquake in 1985.

1.2 Separation Gap:

A separation gap is the distance between two different building structures often two wings of the same facility that allows the structures to move independently of one another. 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.

1.3 Objectives of the study:

From literature survey, it was observed that majority researchers did the work on the separation gap between two adjacent structures. Thus, after reviewing the existing literature it was observed that most of literature compares existing & low-rise structure. In this thesis separation gap is determined & compared as per Indian codal provision & other relevant codes. The objective of the thesis is to ensure that the overall building behavior meets stated performance objectives at serviceability and code design levels. The resulting design provides a level of safety and overall building occupant comfort equivalent to that provided by building code requirements (Indian and in some instances American) as well as good practices for tall buildings.

II. Structural Modelling and analysis:

1.2 Problem description:

In order to evaluate the Seismic separation gap between buildings with rigid floor diaphragms using dynamic and P-Delta analysis procedures five case studies are adopted.

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. Dynamic analysis.

- Linear Dynamic Analysis.
- Non-Linear Dynamic Analysis.

2. – P-Δ (Delta) Analysis.

The basic configuration of the towers is as follows

No. Of Case	Configuration	Base dimension		Height (From Base)	Aspect Ratio (Ht./Base Dim.)
		LX	Ly		
Model- Case-1	S + 30 floors	32.4 m.	29.0 m.	91.20m	3.144
Model- Case- 2	S + 25 floors	32.4 m.	29.0 m.	76.7m	2.64
Model- Case-3	S + 20 floors	32.4 m.	29.0 m.	65.10m	2.244
Model- Case-4	S + 10 floors	32.4 m.	29.0 m.	36.10m	1.244

The floor heights for various floors are as follows:

- Stilt floor : 4.2 m

- Typical floor : 2.9 m

The dimension of columns & beams for various floors are as follows:

- Typical Columns : 600 X 600
- Typical Beams : 230 X 600

The shear wall thicknesses for various floors are as follows:

- Typical floor : 230 mm
- Podium : 300 mm
- Stilt : 350 mm

Seismic Design Parameters- ***(As per IS 1893-(part 1)2002)***

Sr. no.	Parameter	Description	Reference
1.	Analysis	Dynamic Analysis (Response Spectrum Method)	
2.	Seismic Zone	Mumbai - III	**Fig-1: I.S1893 (Part 1) : 2002)**
3.	Zone factor: Z	0.16	**Table-2 : I.S1893 (Part 1) : 2002)**
4.	Importance factor : I	1	**Table-6: I.S 1893 (Part 1) : 2002**
5.	Soil Type	I	
6.	Response Reduction Factor : R	4	**Table-7 : I.S1893 (Part 1) : 2002)**
7.	Seismic resisting structural system	Ductile shear walls with Special Moment Resisting Frame	

Wind Design Parameters-*(As per IS875-part 3)*

Sr. no.	Parameter	Description	Reference
1.	Basic Wind Speed	44m/sec (Mumbai)	**Appendix A, I.S 875 (Part 3): 1987)**
2.	Probability factor : k1	1.0	**Table-1, I.S 875 Part3):1987**
3.	Terrain Factor : k2	0.24 to 0.67 (Category -3) / Class C)	**Table-33, I.S 875 (Part 3) 1987)**
4.	Topography Factor : k3	1.0	**Clause 5.3.3, I.S 875 (Part 3): 1987**

1.3 **Analysis done using finite element software:**

The response spectrum analysis procedures have been carried out for determining the various structural parameters of the model. Here we are mainly concerned with the behavior of the structure under the effect of ground motion and dynamic excitations such as earthquakes and the displacement of the structure.

Seismic Weights Of the Buildings

The Seismic Weight of the whole building is the sum of the seismic weights of all the floors. The seismic weight of each floor is its full dead load plus appropriate amount of imposed load. While computing the seismic weight of each floor, the weight of columns and walls in any storey shall be equally distributed to the floors above and below the storey.

Seismic weight of Case-1 : W = (DL +0.25 LL)

W = 277074.36 kN

Seismic weight of Case-2 : W = (DL +0.25 LL)

W = 236122.08kN

Seismic weight of Case-3 : W = (DL +0.25 LL)
W = 191915.2 kN
Seismic weight of Case-4 : W = (DL +0.25 LL)
W = 109920 kN
Base shear & Fundamental Natural Period
The response spectrum ordinates used are for type (Hard soil) for 5% damping and for seismic zone-III. The design seismic base shear (V_b) has been calculated using procedure given in IS 1893(part 1)-2002 as follows,

$$V_b = (A_h \text{ x } W)$$

Where, A_h is the design horizontal seismic coefficient and is given by,

$$Ah = \frac{Z \text{ x } I \text{ x } Sa}{2 \text{ x } R \text{ x } g} \qquad \text{(Clause 6.4.2)}$$

Where, Z = Zone factor given in Table 2 of IS 1893-2002
I = Importance factor given in Table 6 of IS 1893-2002
R = Response reduction factor given in Table 7 of IS 1893-2002
Sa/g =Average response acceleration coefficient.
Fundamental Natural Period for *Case*-1 model
As per clause 7.6.1 of IS 1893 (part 1) 2002 the fundamental time period of vibration (Ta) is,
Along x-direction:

$$Tx = \frac{0.09 \text{ x } H}{\sqrt{dx}}$$

$$Tx = \frac{0.09 \text{ x } 91.2}{\sqrt{32.4}}$$

$$Tx = 1.44 \text{ sec}$$

Along y-direction:

$$Ty = \frac{0.09 \text{ x } H}{\sqrt{dy}}$$

$$Ty = \frac{0.09 \text{ x } 91.2}{\sqrt{29}}$$

$$Ty = 1.52 \text{ sec}$$

From the response spectrum graph (fig 3.2), Average response acceleration coefficient (Sa/g) is found to be 1.4183.
Along x-direction:

$$Ahx = \frac{Z \text{ x } I \text{ x } Sa}{2 \text{ x } R \text{ x } g}$$

$$Ahx = \frac{0.16 \text{ x } 1 \text{ x } Sa}{2 \text{ x } 4 \text{ x } g}$$

$$Ahx = 0.0139$$

Along y-direction:

$$Ahy = \frac{Z \text{ x } I \text{ x } Sa}{2 \text{ x } R \text{ x } g}$$

$$Ahy = \frac{0.16 \text{ x } 1 \text{ x } Sa}{2 \text{ x } 4 \text{ x } g}$$

$$Ahy = 0.0132$$

Design Base Shear (Vb)
Along x-direction:

$$Vbx = Ahx \text{ X } W$$

$$Vbx = 0.0139 \text{ x } 277074.36$$

$$Vbx = 3848.25 \text{ kN}$$

Along y -direction:

$$Vby = Ahy \text{ X } W$$

$$Vby = 3645.72 \text{ kN}$$

III. Result & Discussion:

Mass Participation Ratios

Table 3.1 : Modal Mass Participation Ratio

Mode	Period	UX	UY	RZ	SumUX	SumUY	SumRZ
1	4.102127	67.2025	0.462	2.193	67.2025	0.462	2.193
2	3.853656	1.6528	3.6317	63.5429	68.8553	4.0937	65.7359
3	3.255156	0.9656	64.4105	3.0769	69.8209	68.5042	68.8128
4	1.18427	14.8532	0.0376	0.9981	84.6741	68.5417	69.8109
5	1.083609	0.8091	0.8291	13.7401	85.4832	69.3708	83.5511
6	0.899231	0.2253	15.4244	0.6332	85.7085	84.7952	84.1842
7	0.598399	5.4291	0.004	1.1736	91.1377	84.7992	85.3578
8	0.546116	1.1129	0.2802	6.0512	92.2506	85.0794	91.409
9	0.43387	0.094	6.385	0.2328	92.3446	91.4644	91.6418
10	0.379017	2.4285	0.004	0.7152	94.773	91.4684	92.357
11	0.33997	0.7193	0.145	2.7161	95.4924	91.6134	95.0731
12	0.267001	0.1043	3.1346	0.0802	**95.5967**	**94.748**	**95.1533**

Conclusion :Modal Mass Participation Ratio above 90% satisfy IS1893 clause

Load Participation Ratio

Table3.2 : Load Participation Ratio

Type	Load	Accel	StatPercent	DynPercent
Load	DEAD		0.2529	0
Load	LIVE		0.5251	0
Load	EQX		99.9999	99.8496
Load	EQY		99.9999	99.8635
Load	WLX		99.9979	92.3582
Load	WLY		99.9982	92.2717
Accel		UX	99.9877	95.5967
Accel		UY	99.9881	94.748
Accel		UZ	0	0
Accel		RX	106.3169	99.96
Accel		RY	93.645	99.9678
Accel		RZ	88.284	95.1533

Conclusion : Load Participation Ratio of Static & dynamic percentage above 90%

Figure 3.1: Mass Participation Ratio vs Mode

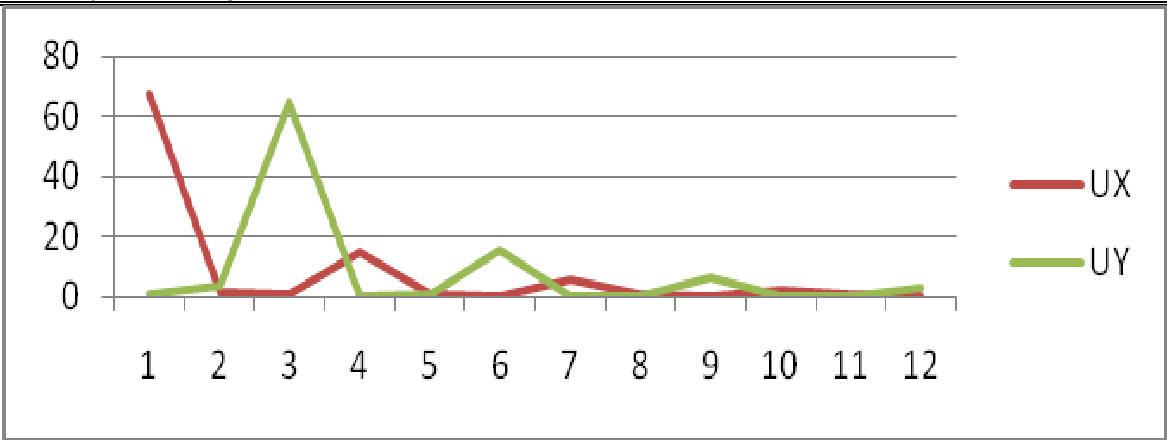


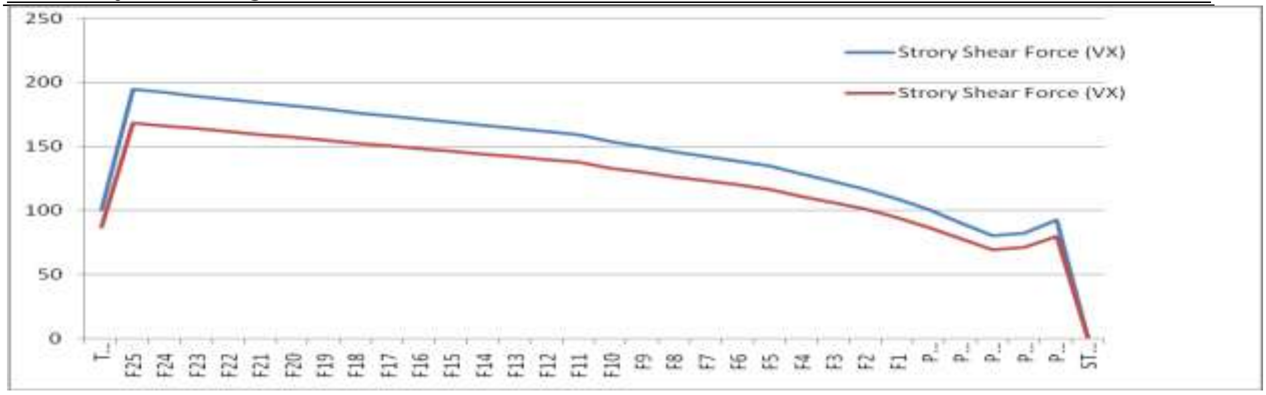
Figure 3.2 Seismic Story shear –Storey shear vs storey

Conclusion : *Story shear(EQ) along x direction* -410.54 kN
Story shear(EQ) along y direction –388.98 kN

Figure 3.3 Seismic Base shear –Storey shear vs storey

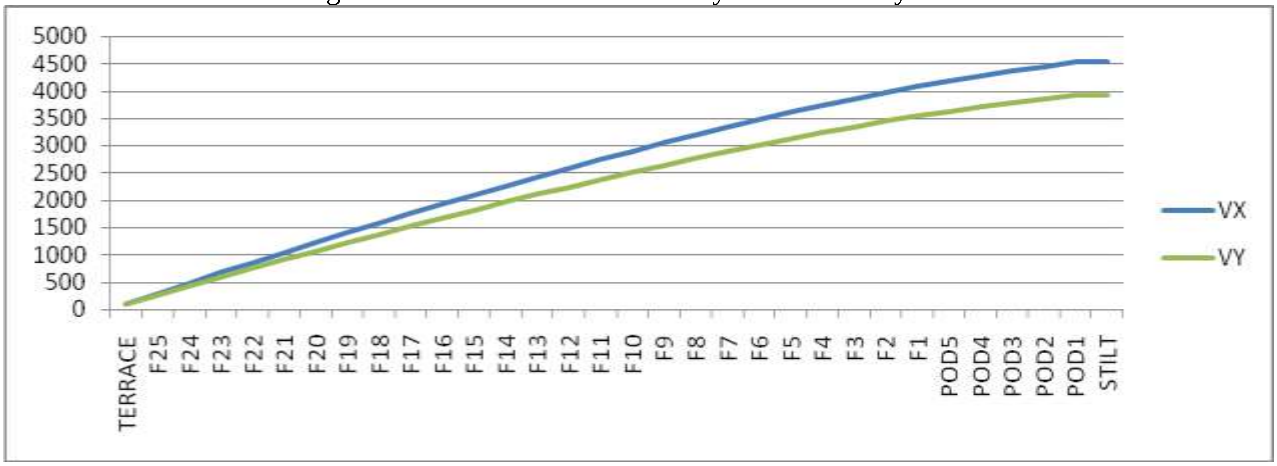
Conclusion : *Base shear(EQ) along x direction* –3847.95 kN
Base shear(EQ) along y direction –3645.37 kN

Figure 3.4 Wind Story shear –Storey shear vs storey



Conclusion : *Story shear(WL) along x direction* -194.4 kN
Story shear(WL) along y direction –168.39 kN

Figure 3.5 Wind Base shear –Storey shear vs storey



Conclusion : *Base shear(WL) along x direction* –4535.40 kN
Base shear(WL) along y direction –3928.69 kN

Table 3.3 Response Spectrum Amplitude x & y- Direction

Spec	Mode	Period	U1
SPEC1	1	4.10213	6.43959
SPEC1	2	3.85366	-0.9285
SPEC1	3	3.25516	0.60083
SPEC1	4	1.18427	0.85431
SPEC1	5	1.08361	0.18349
SPEC1	6	0.89923	0.0807
SPEC1	7	0.5984	-0.2607
SPEC1	8	0.54612	-0.1111
SPEC1	9	0.43387	-0.0254
SPEC1	10	0.37902	-0.1045
SPEC1	11	0.33997	-0.0458
SPEC1	12	0.267	0.01075

Spec	Mode	Period	U2
SPEC2	1	4.10213	0.39853
SPEC2	2	3.85366	-1.0274
SPEC2	3	3.25516	-3.6629
SPEC2	4	1.18427	0.03208
SPEC2	5	1.08361	0.13864
SPEC2	6	0.89923	-0.4984
SPEC2	7	0.5984	-0.0053
SPEC2	8	0.54612	-0.0416
SPEC2	9	0.43387	0.15639
SPEC2	10	0.37902	-0.0032
SPEC2	11	0.33997	-0.0153
SPEC2	12	0.267	-0.044

Conclusion : Amplitude(Spec) along x direction –6.439
Amplitude(Spec) along y direction –0.398

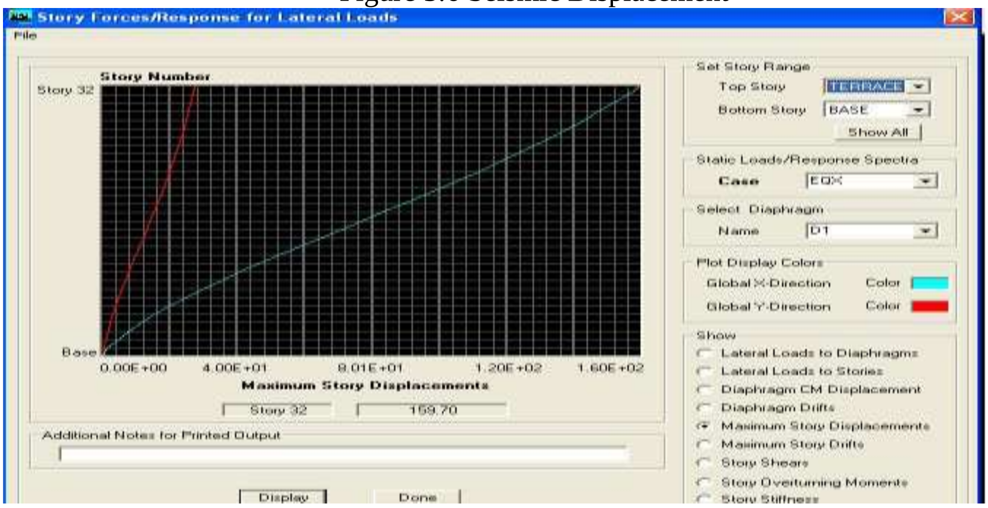
Response Spectrum Acceleration

Table 3.4: Response Spectrum Acceleration x & y- Direction

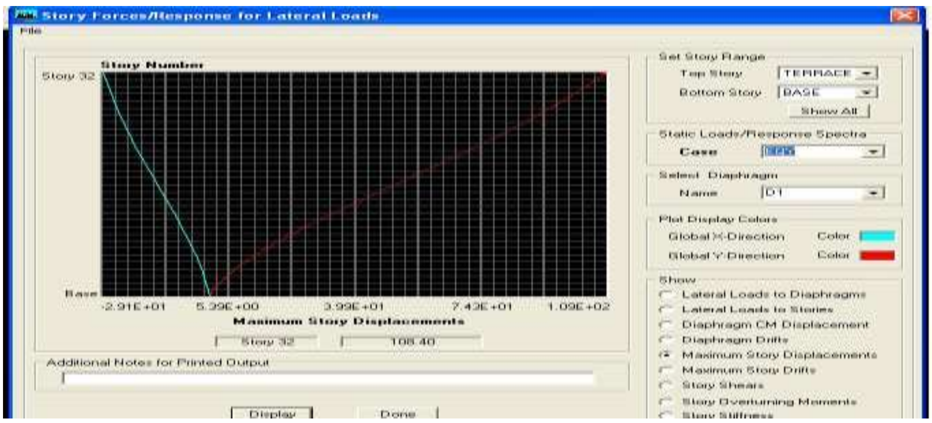
Mode	Period	DampRatio	Spec	U1	Spec	U2
1	4.10213	0.05	SPEC1	0.10964	SPEC2	0.08184
2	3.85366	0.05	SPEC1	0.11422	SPEC2	0.08526
3	3.25516	0.05	SPEC1	0.13553	SPEC2	0.10117
4	1.18427	0.05	SPEC1	0.37122	SPEC2	0.27709
5	1.08361	0.05	SPEC1	0.408	SPEC2	0.30455
6	0.89923	0.05	SPEC1	0.4938	SPEC2	0.3686
7	0.5984	0.05	SPEC1	0.73386	SPEC2	0.54778
8	0.54612	0.05	SPEC1	0.8294	SPEC2	0.6191
9	0.43387	0.05	SPEC1	1.03451	SPEC2	0.7722
10	0.37902	0.05	SPEC1	1.0964	SPEC2	0.8184
11	0.33997	0.05	SPEC1	1.0964	SPEC2	0.8184
12	0.267	0.05	SPEC1	1.0964	SPEC2	0.8184

Conclusion : *Acceleration (Spec) along x & y direction*
–Time period more acceleration less vice versa

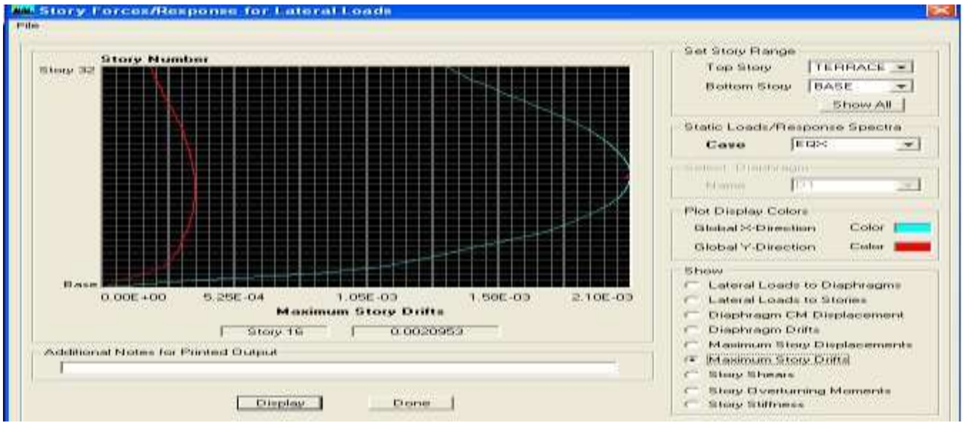
Figure 3.6 Seismic Displacement



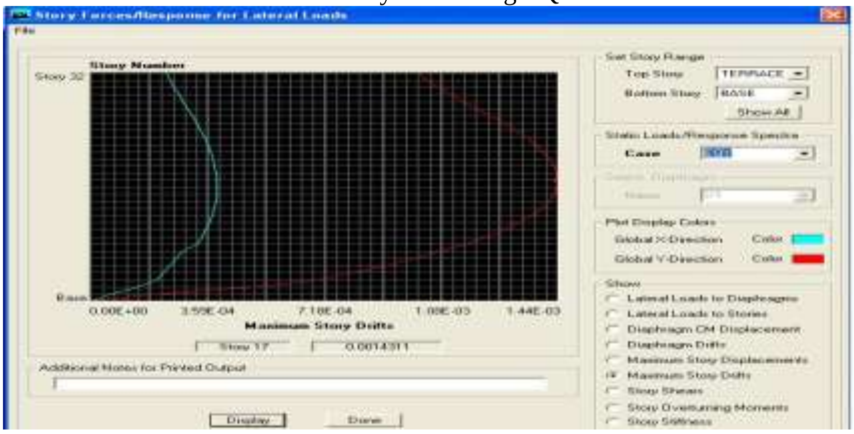
Maximum Story Displacements along EX-Direction.



Maximum Story Displacements along EQ Y- Direction.



Maximum Story Drift along EQ X- Direction.



Maximum Story Drift along EQ Y- Direction.

Table 3.5 Comparison of Shears:

Case 1			Case 2		
	Seismic Storey Shear (kN)	Seismic Base Shear (kN)		Seismic Storey Shear (kN)	Seismic Base Shear (kN)
EQX	410.54	3847.95	EQX	484.21	3902.84
EQX	410.54	3847.95	EQX	410.54	3847.95
EQY	388.98	3645.37	EQY	472.52	3808.33
EQY	388.98	3645.37	EQY	388.98	3645.37

Case 3			Case 4		
	Seismic Storey Shear (kN)	Seismic Base Shear (kN)		Seismic Storey Shear (kN)	Seismic Base Shear (kN)
EQX	543.14	3870.07	EQX	884.96	3799.64
EQX	543.14	3870.07	EQX	543.14	3870.07
EQY	509.91	3596.44	EQY	836.52	3591.68
EQY	509.91	3596.44	EQY	509.91	3596.44

Case 5					
	Seismic Storey Shear (kN)	Seismic Base Shear (kN)		Seismic Storey Shear (kN)	Seismic Base Shear (kN)
EQX	410.54	3847.95	EQY	388.98	3645.37
EQX	543.14	3870.07	EQY	509.91	3596.44

Case 1			Case 2		
	Wind Storey Shear (kN)	Wind Base Shear (kN)		Wind Storey Shear (kN)	Wind Base Shear (kN)
WLX	194.40	4535.40	WLX	149.80	2976.80
WLX	194.40	4535.40	WLX	194.40	4535.40
WLY	168.39	3928.69	WLY	172.7	3431.08
WLY	168.39	3928.69	WLY	168.39	3928.69

Case 3			Case 4		
	Wind Storey Shear (kN)	Wind Base Shear (kN)		Wind Storey Shear (kN)	Wind Base Shear (kN)
WLX	150.36	3135.81	WLX	118.15	1385.39
WLX	150.36	3135.81	WLX	150.36	3135.81
WLY	146.83	3097.29	WLY	117.16	1380.61
WLY	146.83	3097.29	WLY	146.83	3097.29

Case 5					
	Wind Storey Shear (kN)	Wind Base Shear (kN)		Wind Storey Shear (kN)	Wind Base Shear (kN)
WLX	194.40	4535.40	WLY	146.83	3097.29
WLX	150.36	3135.81	WLY	168.39	3928.69

Table 3.6 Deflection:

Model –M1 Equal Height

S+30			*S+30*		
	Max. Deflection(mm)	*Permissible Limit*		*Max. Deflection(mm)*	*Permissible Limit*
EQX	*156.7939*	*364.8*	*EQX*	*156.7939*	*364.8*
EQY	*105.7987*	*364.8*	*EQY*	*105.7987*	*364.8*

WLX	*155.2225*	*182.4*	*WLX*	*155.2225*	*182.4*
WLY	*68.691*	*182.4*	*WLY*	*68.691*	*182.4*

Model -M2 Unequal Height

S+25			*S+30*			
	Max. Deflection(mm)	*Permissible Limit*		*Max. Deflection(mm)*	*Max. Def.@25th FL(mm)*	*Permissible Limit*
EQX	*120.1265*	*306.8*	*EQX*	*156.7939*	*135.651*	*364.8*
EQY	*82.9824*	*306.8*	*EQY*	*105.7987*	*90.605*	*364.8*
WLX	*77.6978*	*153.4*	*WLX*	*155.2225*		*182.4*
WLY	*44.559*	*153.4*	*WLY*	*68.691*		*182.4*

Model –M3 Equal Height

	S+20		*S+20*		
	Max. Deflection(mm)	*Permissible Limit*		*Max. Deflection(mm)*	*Permissible Limit*
EQX	*91.955*	*260.4*	*EQX*	*91.955*	*260.4*
EQY	*60.401*	*260.4*	*EQY*	*60.401*	*260.4*
WLX	*60.583*	*130.2*	*WLX*	*155.2225*	*130.2*
WLY	*29.0524*	*130.2*	*WLY*	*68.691*	*130.2*

Model –M4 Unequal Height

	S+20			*S+10*		
	Max. Deflection(mm)	*Max. Def.@10h FL(mm)*	*Permissible Limit*		*Max. Deflection(mm)*	*Permissible Limit*
EQX	*91.955*	*60.5878*	*260.4*	*EQX*	*36.7048*	*144.4*
EQY	*60.401*	*42.5704*	*260.4*	*EQY*	*22.7745*	*144.4*
WLX	*60.583*		*130.2*	*WLX*	*11.1502*	*72.2*
WLY	*29.0524*		*130.2*	*WLY*	*4.9809*	*72.2*

Model –M5 Unequal Height

	S+30	*S+20*

	Max. Deflection(mm)	Max. Def.@20h FL(mm)	Permissible Limit		Max. Deflection(mm)	Permissible Limit
EQX	156.7939	104.283	364.8	EQX	91.955	260.4
EQY	105.7987	68.8604	364.8	EQY	60.401	260.4
WLX	155.2225		182.4	WLX	60.583	130.2
WLY	68.691		182.4	WLY	29.0524	130.2

Table 3.7 Separation Gap:

Model –M1 Equal Height				
	IS1893-2002	IS4326-1993	FEMA-273(1997)	IBC-2001
EQX	627.17	553.2	221.74	235.185
EQY	423.19	553.2	149.62	
Model -M2 Unequal Height				
	IS1893-2002	IS4326-1993	FEMA-273(1997)	IBC-2001
EQX	1023.11	506.7	181.194	203.47
EQY	694.34	506.7	122.86	
Model –M3 Equal Height				
	IS1893-2002	IS4326-1993	FEMA-273(1997)	IBC-2001
EQX	367.82	365.2	130.04	137.93
EQY	241.60	365.2	85.41	
Model –M4 Unequal Height				
	IS1893-2002	IS4326-1993	FEMA-273(1997)	IBC-2001
EQX	389.13	303.6	70.83	90.87
EQY	261.29	303.6	48.26	
Model –M5 Unequal Height				
	IS1893-2002	IS4326-1993	FEMA-273(1997)	IBC-2001
EQX	784.955	471.9	139.09	156.42

EQY	*517.045*	*471.9*	*91.597*	

Conclusion:
As per IS1893 -Unequal height required more separation gap Equal height required less separation gap

IV. Conclusion:

Based on the results presented herein and subject to the limitations of the underlying assumptions, it may be concluded that using well designed shear walls as "collision " walls is an attractive and viable alternative to the seismic separation requirement between adjacent buildings that modern codes require.

The advantages of this solution are:

1. It can minimize and practically eliminate the seismic separation gap and all its disadvantages.
2. It can protect both buildings, even if one is already built up to the property line and does not have "collision" walls from shearing of their columns by the impacting horizontal slabs of the other building. This is by far the greatest danger posed by earthquake induced pounding.
3. Being part of the earthquake resisting system, it appears that the shear walls could survive the pounding by suffering only local and repairable damage.
4. Away from the points of impact, the effects of pounding do not appear to pose any significant threat to the other structural members.
5. The impacts at the walls generate high, short duration, acceleration spikes that may cause nonstructural damage, if no provisions are made for the building contents. Such provisions however, will not be different from those required to protect building contents from earthquakes even without pounding.
6. The strengths given to the structure that were analysed were minimum values to comply with design code requirements. Most structures in practices have reserve strength in excess of these values, which in practices can used for resisting P-delta actions.
7. In this study, it is concluded that constructing adjacent buildings with equal floor heights and separation distances reduces the effects of pounding considerably.
8. Existing adjacent buildings which are not properly separated from each other can be protected from effects of pounding by placing elastic materials between them.
9. As the PGA value increases, the minimum separation between the structures also increases.
10. The separation distance between the two structures decreases, the amount of impact is increases, which is not applicable in all cases. It is only applicable when the impact time is same. It may also decreases when separation distance decreases, which leads to less impact time.
11. At resonance condition the response of the structure is more and may lead to collapse of the whole structure.
12. The duration of strong motion increases with an increase of magnitude of ground motion.

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