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Control of Seismic Pounding between Adjacent Reinforced Concrete Buildings isolated with Triple Friction Pendulum System

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Abstract - *The paper represents the effect of two adjacent building in terms of story displacement and required gap under seismic effect. The methods used for analysis are Equivalent Static Analysis (ESA) and Response Spectrum Analysis (RSA). Comparison of ESA & RSA methods has been carried out to calculate the gap required. The study compares the story displacement and required gap of fixed base building and building isolated with Triple Friction Pendulum System. The study has been carried out for different story heights. The paper also includes the use of bracing system and shear wall. The paper also represents required seismic gap between two adjacent buildings to eliminate the collision during earthquake. The methods adopted for finding required gap is Absolute Sum Method (ABS) and Square Root of Sum of Square (SRSS). For the analysis commercial, software ETABS has been used.*

Keywords- *Seismic Pounding, Story Displacement, Separation Distance, Fixed Base, Triple Friction Pendulum System.*

I. INTRODUCTION

From previous earthquake study and damage assessment, it is found that the adjacent buildings in cities and towns create more damage to the building when they displaces under the action of earthquake. The buildings vibrates horizontally under the earthquake and when the separation between adjacent building is not sufficient than there are more chances of collision of buildings but the collision of the adjacent building can be neglected by introduction of sufficient gap between two adjacent buildings also called seismic gap. The other way to reduce the collision is to provide bracing system and shear walls to reduce the displacement under strong and moderate ground motion. The different base isolation systems can be adopted to reduce the collusion effect.

II. LITERATURE SURVEY

Lakshmi and George (2015) investigated the effect of pounding on RC buildings. They modeled the G+8 and G+5 story buildings close to each other. They concluded that during pounding smaller building experience more displacement and liable to greater damage than larger building. The displacement of buildings can be reduced by providing a shear wall, bracing or dampers. Raghunandan and Devi (2015) worked on seismic pounding between adjacent RC buildings with and without base isolation system. The main aim was to reduce the pounding effect and to provide safe separation distance for buildings. They have considered G+9 and G+14 story buildings which are situated in seismic zone V having medium soil and intended for residential use. Both buildings are analyzed in ETABS nonlinear software. They concluded that the maximum relative displacement is decreased by using shear wall, bracings, lead rubber bearing and gap element. Decrease in the relative displacement with required seismic gap can be minimized. Matsagar and jangid (2006) investigated on base isolated building connected to adjacent building using viscous dampers. They investigated seismic response of multi-storied building on various isolation systems connected using the viscous dampers to an adjacent dissimilar base isolated or fixed base building. They concluded that connecting of two adjacent base isolated building with the viscous dampers is eliminate isolator damages due to large displacement or pounding with adjacent structures during the earthquake. Panchal and Purohit (2013) investigated dynamic response control of a building model using bracing systems. They concluded that increment in natural time period and damping ratio is observed for controlled systems as compared to uncontrolled system and they also concluded that inverted V-type concentric bracing was found to have maximum increase in the damping as compared to other types of the bracing system. Jamal and Vidyadhara (2013) carried out systematic study regarding pounding of buildings by analysis of reinforced concrete frames using linear static analysis, response spectrum analysis and nonlinear time history analysis on ETABS. They concluded that displacement of buildings can be greatly reduced by providing a shear wall, as it influences on pounding and reduce the effect on buildings.

III. VALIDATION

Validation of my research work has been carried out with paper of Ghouse et al. (2016). Tables 1 indicates the storey displacement of the G+10 storey building. Figures 1, 2 and 3 show the storey displacement of the top storey, 10th storey and base level, respectively.

Table 1. Storey displacement

No. of storey	Storey displacement (mm) Ghouse et al. (2016)
11	45.1
10	44.4
9	43.3
8	41.6
7	39.4
6	36.7
5	33.5
4	29.8
3	26.2
2	22.1
1	17.5
0	12.3

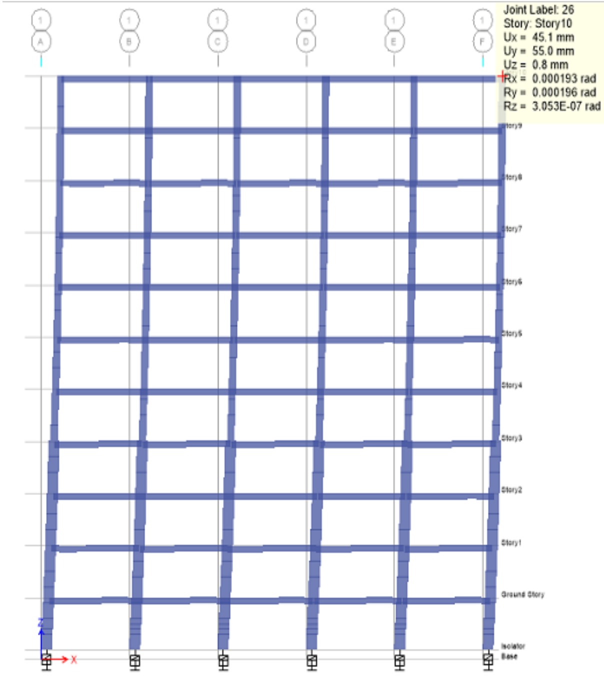

Figure 1. Result of 11th storey

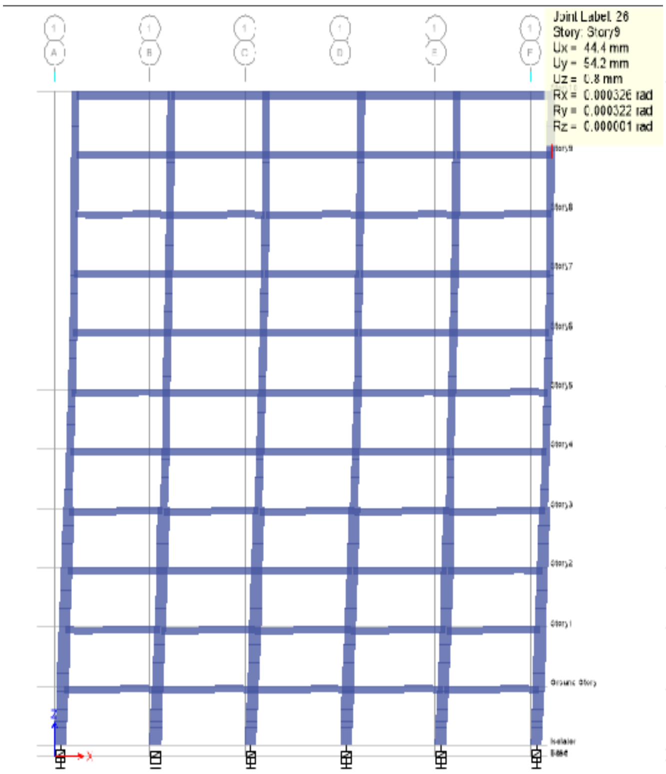

Figure 2. Result of 10th storey

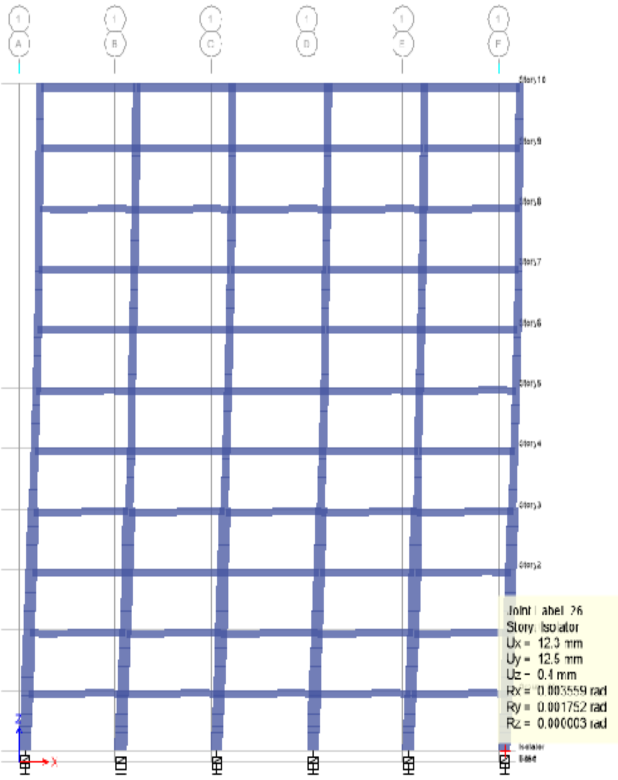

Figure 3. Result of base level

IV. GAP ELEMENT

Gap element is an element which connects two adjacent nodes to model the contact and is defined as a link element in ETABS software. This link element is activated only when the structures come closer and deactivated when they go far away and a collision force will be generated when they come closer. So, it is a compression-only element required to assess the pounding force and to simulate the effect of pounding.

V. INPUT DATA

The multi-storeyed RC frame buildings are modeled in ETABS nonlinear software. The two buildings consist of G+14 and G+9 separated by an initial gap of 50mm. Tables 2, 3 and 4 indicate Geometrical details, Building plan and Seismic parameters of the both buildings.

A. Geometrical details

Table 2. Geometrical details

Grade of concrete	M-20 for beam, slab, brace & shear wall. and M-25 for column
Unit weight of concrete	25 kN/m^3
Column dimension	0.6 × 1 m
Beam dimension	0.35 × 0.6 m
Bracing dimension	0.2 × 0.2 m
Thickness of slab	130 mm
Shear wall thickness	200 mm

B. Building plan

Table 3. Building plan

Building plan	Building 1	Building 2
No. of story	G+14	G+9
No. of bays in X-direction	5	4
No. of bays in Y-direction	5	5
Width of bay in X-direction	4.5m	5m
Width of bay in Y-direction	4.5m	4.5m

C. Seismic parameters

Table 4. Seismic parameters

Seismic zone	V
Zone factor	0.36
Importance factor	1
Type of soil	Medium soil
Response reduction factor	5

D. Load combination

Load combination were taken as per IS 1893-2002, Clause 6.3.1.2.

E. Geometry generated in ETABS

Figures 4 & 5 show the elevation of the buildings without isolator and with isolator, respectively. Figure 6 displays the plan layout of the buildings as well as locations of shear walls and X bracings. Figure 7 shows 3D view of the buildings.

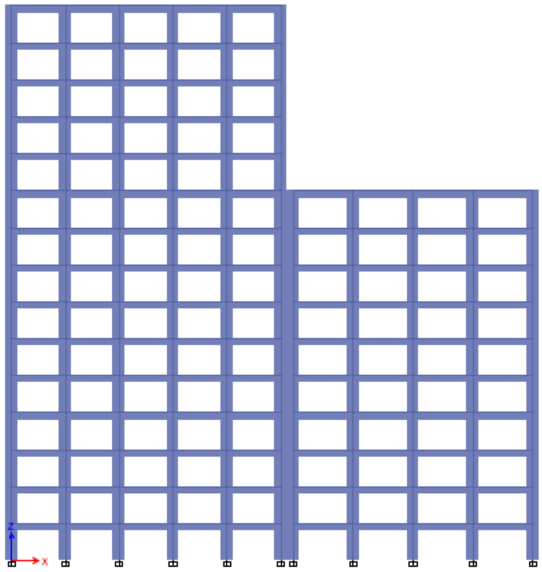

Figure 4. Elevation view without isolator

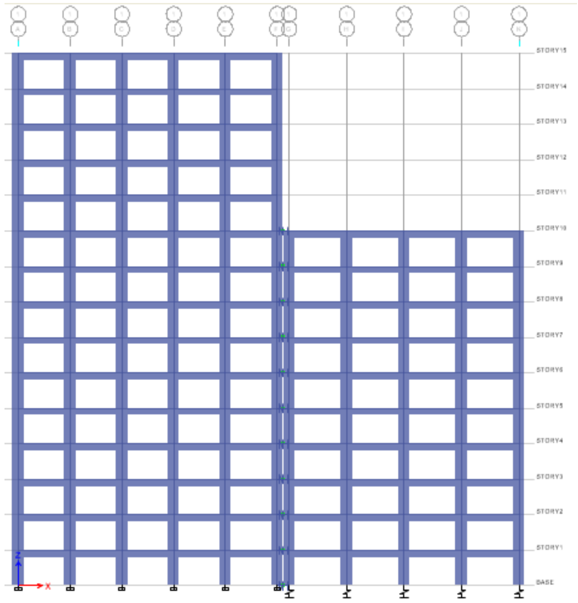

Figure 5.Elevation view with isolator

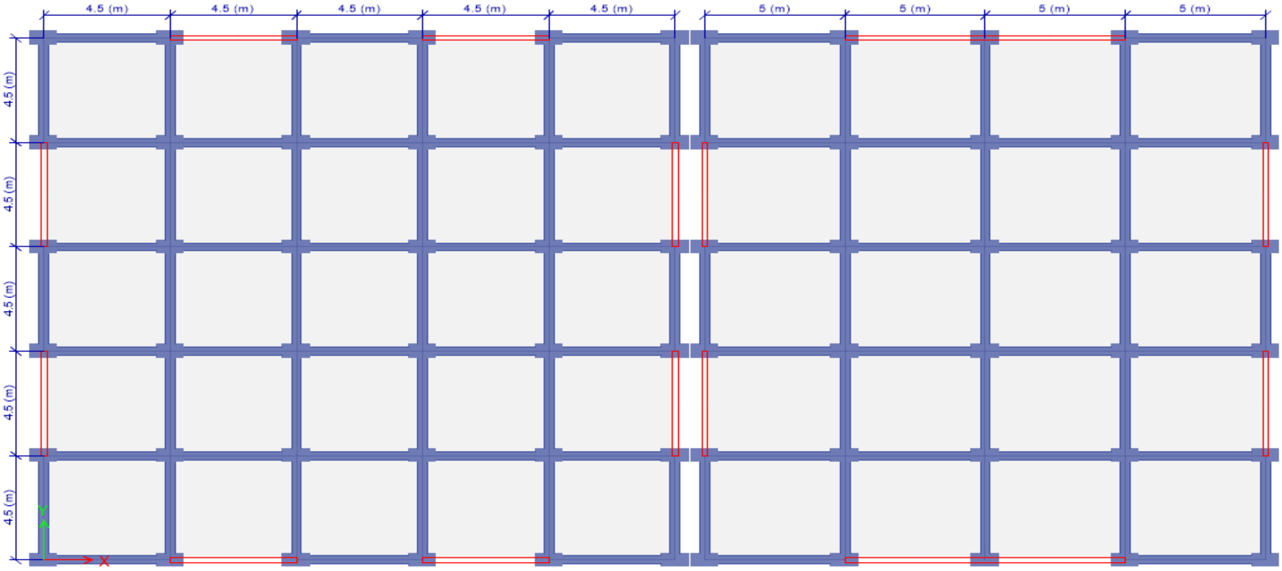

Figure 6. Plan view location of shear walls and bracings

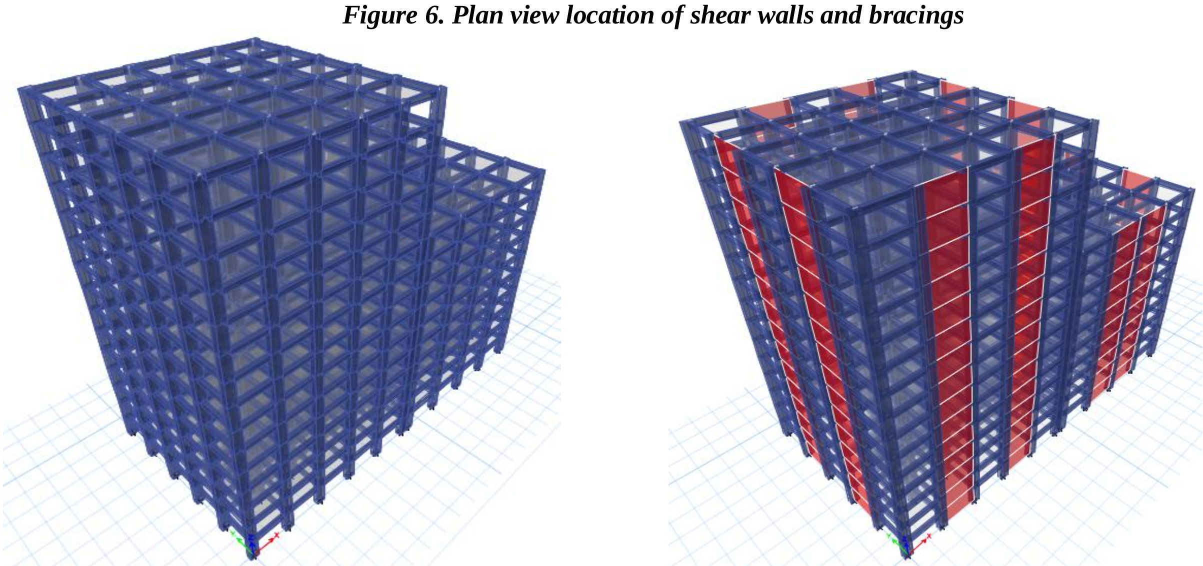

Figure 7.3D view

VI. ANALYSIS RESULTS AND DISCUSSION

Equivalent static analysis (ESA) and Response spectrum analysis (RSA) have been carried out to find the seismic gap required between two adjacent buildings to reduce the damage due to collusion. Comparison has been made between two methods for different heights of the building. For present study, four cases have been considered as mention below.

A. G+9 and G+14 fixed.
B. G+9 and G+14 both with isolators.
C. G+9 with fixed and G+14 isolated.
D. G+9 with isolator and G+14 fixed.

Tables 5 & 6 indicate required seismic gap for various analyzed models by Square Root of Sum of Square (SRSS) and Absolute Sum Methods (ABS). For analysis purpose, in G+14 storey building, the displacement of 10th floor is considered and in G+9 storey building, top storey displacement is considered.

Table 5. Calculation of required seismic gap for various analyzed models by SRSS and ABS methods

Calculation of required gap by SRSS and ABS methods										
		G+14 & G+9 fixed base					G+14 & G+9 isolated base			
		Story displacement (mm)		Required gap (mm)			Story displacement (mm)		Required gap (mm)	
		G+14 @ 10th level	G+9 @ 10th level	SRSS	ABS		G+14 @ 10th level	G+9 @ 10th level	SRSS	ABS
		BARE FRAME					BARE FRAME			
2.8m Story height	ESA	30.2	22.07	37.5	52.3		80.7	77.9	112.2	158.6
	RSA	20.07	16.3	25.8	36.1		78.8	77.8	110.7	156.6
3m Story height	ESA	33.1	24.9	41.4	58		84.5	81.5	117.4	166
	RSA	22.1	17.8	28.3	39.9		82	80.9	115.2	162.9
3.2m Story height	ESA	35.4	27.5	44.8	62.9		88.5	85.2	122.8	173.7
	RSA	23.5	19.7	30.7	43.2		85.4	84.2	119.9	169.6
		WITH BRACING					WITH BRACING			
2.8m Story height	ESA	26.03	16.8	30.9	42.8		78.1	75.3	108.5	153.4
	RSA	16.4	12.6	20.7	29		77.2	76	108.3	153.2
3m Story height	ESA	27.8	18.4	33.4	46.2		81	78	112.4	159
	RSA	17.9	13.4	22.2	30.9		79.8	78.5	112	158.3
3.2m Story height	ESA	29.8	20.3	36.1	50.1		84.2	80.8	116.7	165
	RSA	19.2	14.5	24.1	33.7		82.5	81.1	115.7	163.6
		WITH SHEARWALL					WITH SHEARWALL			
2.8m Story height	ESA	21.6	9.7	23.7	31.7		82.7	79.7	114.8	162.4
	RSA	12.4	7	14.2	19.4		82.1	80.9	115.2	163
3m Story height	ESA	23.7	11.1	26.2	34.8		86	82.7	119.3	168.7
	RSA	13.7	8	15.9	21.7		85.1	83.7	119.4	168.8
3.2m Story height	ESA	25.5	12.8	28.5	38.3		89.4	85.9	124	175.3
	RSA	14.8	9.2	17.4	24		88.2	86.2	123.3	174.4

Table 6. Calculation of required seismic gap for various analyzed models by SRSS and ABS methods

Calculation of required gap by SRSS and ABS methods									
		G+14 isolated & G+9 fixed base				G+14 fixed & G+9 isolated base			
		Story displacement (mm)		Required gap (mm)		Story displacement (mm)		Required gap (mm)	
		G+14 @ 10th level	G+9 @ 10th level	SRSS	ABS	G+14 @ 10th level	G+9 @ 10th level	SRSS	ABS
		BARE FRAME				BARE FRAME			
2.8m Story height	ESA	33.6	26	42.5	59.6	31.7	25.5	40.7	57.2
	RSA	25	20.7	32.4	45.7	22.7	20	30.2	42.7
3m Story height	ESA	36.1	28.6	46	64.7	34.3	27.8	44.1	62.1
	RSA	26.6	22.5	34.8	49.1	24.6	21.6	32.7	46.2
3.2m Story height	ESA	38.6	31.2	49.6	69.8	37	30.3	47.8	67.3
	RSA	28.4	24.5	37.5	52.9	26.4	21.3	33.9	47.7
		WITH BRACING				WITH BRACING			
2.8m Story height	ESA	29.3	19.7	35.3	49	27.1	20.8	34.1	47.9
	RSA	21.8	15.6	26.8	37.4	19.5	17	25.9	36.5
3m Story height	ESA	31.1	21.6	37.8	52.7	29.2	22.5	36.9	51.7
	RSA	23	17	28.6	40	20.9	18	27.6	38.9
3.2m Story height	ESA	33.1	33.5	47.1	66.6	31.4	24.3	39.7	40.5
	RSA	24.2	18.4	30.4	42.6	22.4	19.1	29.4	41.5
		WITH SHEARWALL				WITH SHEARWALL			
2.8m Story height	ESA	25.8	11.7	28.3	37.5	23.5	17	29	40.5
	RSA	18.1	8.6	20	26.7	16.1	14.2	21.5	30.3
3m Story height	ESA	27.5	13.5	30.6	41	25.7	18.5	31.7	44.2
	RSA	19.2	9.8	21.5	28.7	17.7	14.9	23.1	32.6
3.2m Story height	ESA	29.2	15.3	32.9	44.5	28	20.1	34.5	48.1
	RSA	20.2	11.1	23	31.3	19.2	15.8	24.9	35

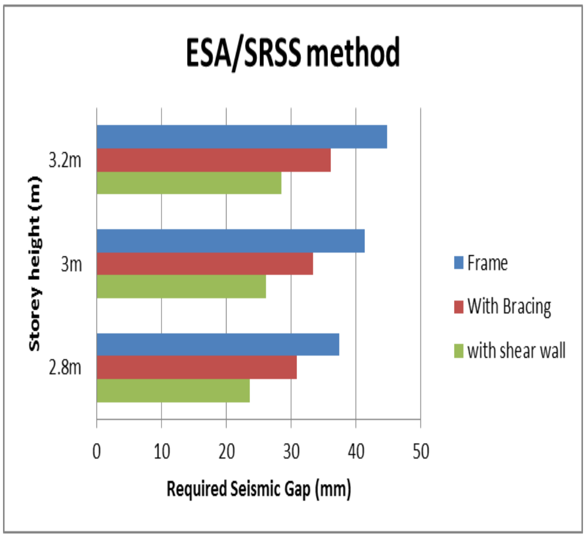

Figure 8. (a)

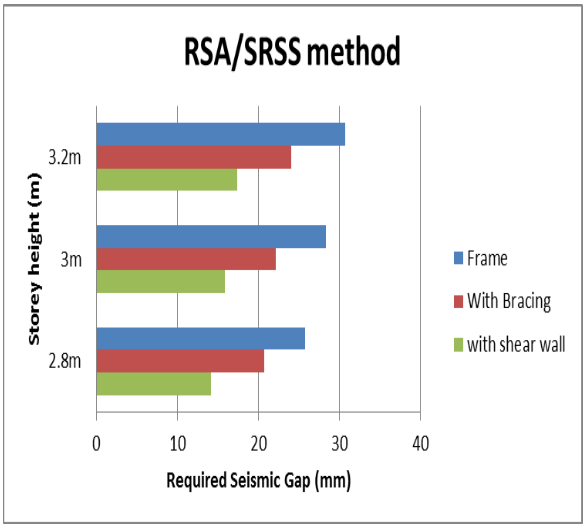

Figure 8. (b)

Figure 8 (a) & (b): Comparison of required seismic gap between G+14 and G+9 both fixed base adjacent buildings by SRSS

Figure 8 (a) represents G+14 and G+9 story both with fixed base buildings. By using ESA, it is observed that seismic gap required for frame structure is higher as compared to structure with bracing and shear wall. Building with shear wall shows least requirement of seismic gap as compared to other.

Figure 8 (b) represents G+14 and G+9 story both with fixed base buildings. By using RSA, it is observed that seismic gap required for frame structure is higher as compared to structure with bracing and shear wall. Building with shear wall shows least requirement of seismic gap as compared to other.

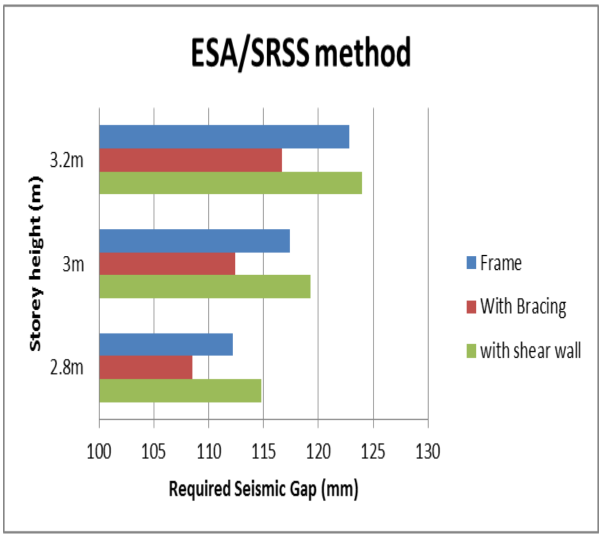

Figure 9. (a)

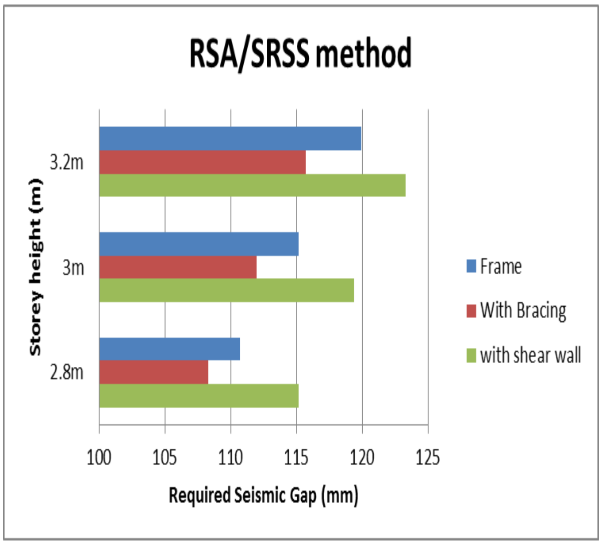

Figure 9. (b)

Figure 9 (a) & (b): Comparison of required seismic gap between G+14 and G+9 both base isolated adjacent buildings by SRSS method

Figure 9 (a) represents G+14 and G+9 story both with isolated base buildings. By using ESA, it is observed that seismic gap required for shear wall structure is higher as compared to structure with bracing and frame. Building with bracing shows least requirement of seismic gap as compared to other.

Figure 9 (b) represents G+14 and G+9 story both with isolated base buildings. By using RSA, it is observed that seismic gap required for shear wall structure is higher as compared to structure with bracing and frame. Building with bracing shows least requirement of seismic gap as compared to other.

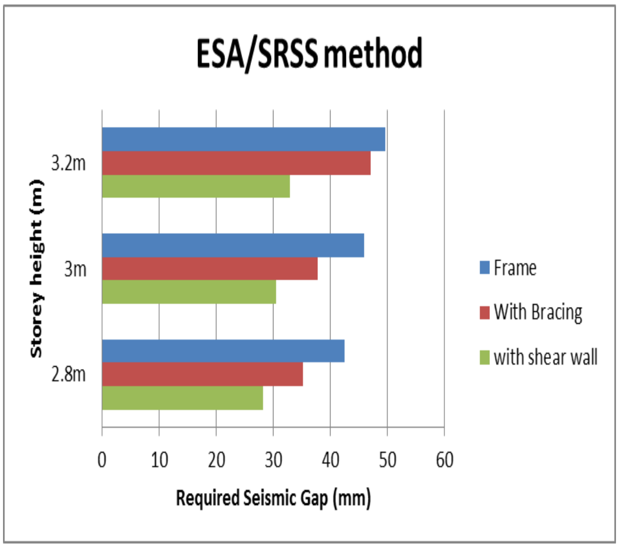

Figure 10. (a)

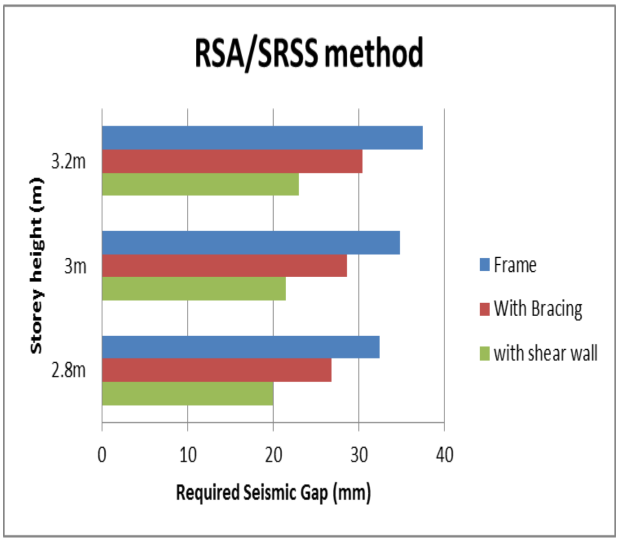

Figure 10. (b)

Figure 10 (a) & (b): Comparison of required seismic gap between G+14 isolated and G+9 fixed base adjacent buildings by SRSS method

Figure 10 (a) represents G+9 fixed base building and G+14 isolated base building. By using ESA, it is observed that seismic gap required for frame structure is higher as compared to structure with bracing and shear wall. Building with shear wall shows least requirement of seismic gap as compared to other.

Figure 10 (b) represents G+9 fixed base building and G+14 isolated base building. By using RSA, it is observed that seismic gap required for frame structure is higher as compared to structure with bracing and shear wall. Building with shear wall shows least requirement of seismic gap as compared to other.

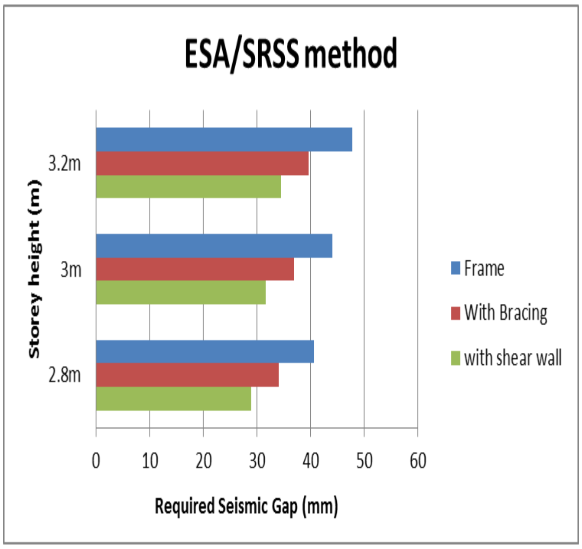

Figure 11. (a)

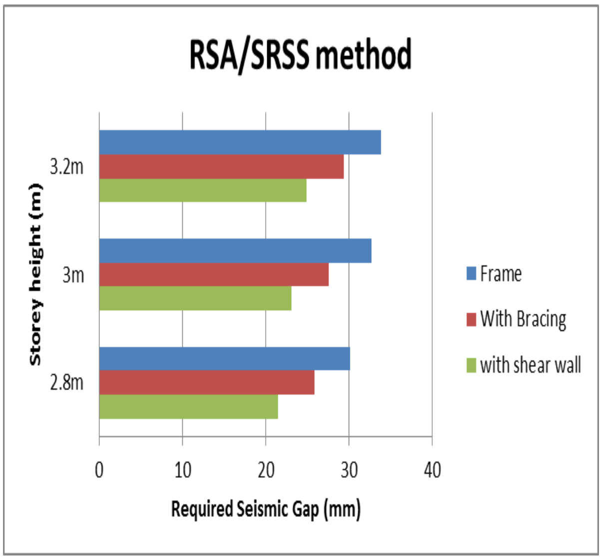

Figure 11. (b)

Figure 11 (a) & (b): Comparison of required seismic gap between G+14 fixed and G+9 base isolated adjacent buildings by SRSS method

Figure 11 (a) represents G+9 isolated base building and G+14 fixed base building. By using ESA, it is observed that seismic gap required for frame structure is higher as compared to structure with bracing and shear wall. Building with shear wall shows least requirement of seismic gap as compared to other.

Figure 11 (b) represents G+9 isolated base building and G+14 fixed base building By using RSA, it is observed that seismic gap required for frame structure is higher as compared to structure with bracing and shear wall. Building with shear wall shows least requirement of seismic gap as compared to other.

VII. CONCLUSION

(A) The seismic gap increases with the use of Triple Friction Pendulum Isolator (TFPS).

(B) The maximum relative displacement of top story for G+9 and G+14 decreases up to 14-26% by using bracings and 34-46% by shear walls. As relative displacement of top story decreases, the required seismic gap can be minimized.

(C) The gap required between fixed base taller adjacent to isolated base shorter buildings & fixed base shorter adjacent to isolated base taller buildings increases by 4-14% and 14-24% with ESA and RSA, respectively when compared with fixed base adjacent buildings.

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