TORSIONAL IMPROVEMENTS IN A MULTISTORIED BUILDING WITH PLAN IRREGULARITIES

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Abstract

Irregular buildings consist of large number of modern urban structures. Though some buildings look symmetrical in plan might have irregular distribution of mass, strength and stiffness along the plan and height of the buildings. In common sense, a building with a regular geometry is supposed to be regular building. While the building is designed to be used for different functions along the building area and along the building plan the presence of opening, staircase positioning and positioning of the shear/core wall for different purpose like lift and HVAC (Heating, Ventilation and Air Conditioning) leads to the irregularity in the plan. Ultimately, torsion irregularity occurs, which if remains not taken care properly may create substantial damage of the building structures. The purpose of this study is to determine the conditions for excessive torsional irregularity and solve them with the proper positioning of the shear wall to counter the torsional behavior of the building. A linear response analysis was conducted and the studied structures were both six- storey buildings. First building has opening left for different purpose like lift and HVAC systems. While the second building has shear wall for lift at the edge of the building. Though both buildings seem fine with their geometrical orientation after the analysis torsional irregularity was evident. The proper placement of the shear wall has been used to stiffen the building to counter for the torsional modal and make to regular in terms of the mass and stiffness distribution

Keywords:

1. Introduction

Nepal lies in seismically vulnerable zone**.** It is located in the boundary of the two tectonic plates-the Indian plate (Indo-Australian plate) and Tibetan plate (Eurasian Plate) which is known as **"**Subduction Zone**"**. Records of earthquakes are available in Nepal since 1255 A.D. Those records reveal that Nepal was hit by 18 major earthquakes since then, resulting in huge loss of life and property. Out of these earthquakes, the 1833, 1934 and 2015 earthquakes were the most destructive ones. So, the structures here need to be design in view of withstanding major earthquake. However, country lacks enough infrastructures to train and produce a skilled manpower. There is no sufficient support for doing research studies. But for the time after the major 2015 earthquake Nepal has been focusing on providing structural and earthquake engineering knowledge. Many research studies have to be performed in order to improve the practice of the designing of the structures. So, this thesis is focused on how a building can be structurally safe and perform well in event of the earthquake. It focuses in the dynamic properties of structures and aims at providing solutions for a complex irregular designed building and how the solution can be taken as per the geometrical attributes of the structures.

2. LITERATURE REVIEW

M.D. Bensalah, M. Bensaibi, A. Modaressi, (2012) have focused on two building one with symmetrical and other unsymmetrical building in terms of rigidity. This paper highlighted that in terms of capacity the lateral yielding strength is higher in asymmetrical structure. The reduction factors gets reduced when the period of the earthquake increases. The ductility increases with increasing input motion and decreases with increasing period with significant variantion in case of asymmetrical structure.

O. Mohamed, (2015), has concluded that the torsional irregularity based on the diaphragms or floor systems leads to amplified structural responses including bending moments and drifts. The amplified effects caused by torsional irregularity can be accounted for by amplifying the accidental torsion moments applied to the structures. The proper selection of shear wall position provides resisting moment to counter accidental torsion.

H. Gokdemir , H. Ozbasaran, M. Dogan, E. Unluoglu, U. Albayrak, (2013), focused that the eccentricity between center of mass and center of rigidity cause torsion in structures and magnitude the torsional moment. It he building suffers extreme torsion, structural elements may reach to their torsional moment capacity or the whole structure may be forced to deflect beyond its lateral deflection limit.

It the strength of the structural system is increased in the weak direction or decreasing strength in stronger direction can reduce the torsional effects.

T. Marcilla, A. Liel, (2018), concluded the studies aiming to quantify the relationship between torsional irregularity and collapse risk of older non ductile RC buildings by modeling 15 variations of a real building in three-dimensions and asses the collapse performance using incremental dynamic analysis.

The study shows that some torsional irregularity can be present before the torsion

substantially affects the collapse risk. The finding is used to quantify an upper limit on torsional irregularity, which, in combination with a building's strength, identifies buildings that are exceptionally high risk on the basis of torsion.

G. Ozmen, K. Girgin, Y. Durgun, (2014), highlighted the result of the investigation on six types of typical structures by considering different shear wall positions and story number is concluded. The results obtained are: 1) Torsional irregularity coefficients increase as the story numbers decrease, i.e., maximum irregularity coefficients occur for single-story structures. 2)Floor rotations increase in proportion to the story numbers. 3)Torsional irregularity coefficients reach maximum values when the shear walls are placed as close as possible to the centers of mass without coinciding them. 3)When the center of rigidity approaches to the center of mass, torsional irregularity coefficients increase due to decreasing torsional rigidity of structure. 4)Floor rotations attain their maximum values for the structures where the walls are in farthest positions from the centers of mass.

S. Anagha, N. Joshuva, (2018), used steel strips in order to perform the analysis to overcome the torsional irregularity. They concluded the steel strips provided can increase the stiffness of the buildings. Steel strips placed opposite to the stiffness irregularity balances the irregularity as it reduces eccentricity between center of stiffness and center of mass whereas the strips provided along the full length in one direction can eliminate torsion.

S. Hussain, (2018), focused analysis based on the regular and irregular building with plan irregularities and concluded that the irregularities effects building in terms of displacement and base shear, increase in shear in columns hence special moment resisting frame is more suitable in severe seismic zones than ordinary moment resisting frame.

S. Oman, K.S. Suresh, R. Aruna (2018), analyzed on buildings with partial infill and mass irregularities and concluded that the storey displacement is maximum in case of bare frame and minimum in case of infilled frames and also concluded that irregular buildings under goes more displacement in top storey while in lower the displacement is similar as that of regular buildings.

Ramesh Konakalla (2014) analysed four different 20 story building for effect of vertical irregularity under Dynamic Loads Using Linear Static Analysis. Response of all cases is compared and concluded that in regular structure there is no torsional effect in the frame because of symmetry. The response for vertically irregular buildings is different for the columns which are located in the plane perpendicular to the action of force. This is due to the torsional rotation in the structure.

Methodology

Selecting two building models:

Building details/parameters	**Building A**	**Building B**
Source	Siddhartha designers pvt. Ltd	Nirmal rana creative studio
Location	Baneshwor 10, kathmandu	Baluwatar, kathmandu
Type of Structure	Rcc framed	RCC framed
Size of building	1966 sft	1666.8 sft
Orientation of building plan:	Irregular due to presence of voids and opening, staircase at two different direction	Irregular due to presence of staircase and lift wall at the face of the building
Thickness of slab:	125 mm	125 mm
Size of beam:	300mm x 500 mm and 300mm x 450mm	300mm x 600 mm and 300mm x 500mm
Size of column:	500mmx500mm	• 500mmx500mm
Seismic zone	Zone v	Zone V
Importance factor	1	1
Soil type	Medium	Medium
Response reduction factor	5	5

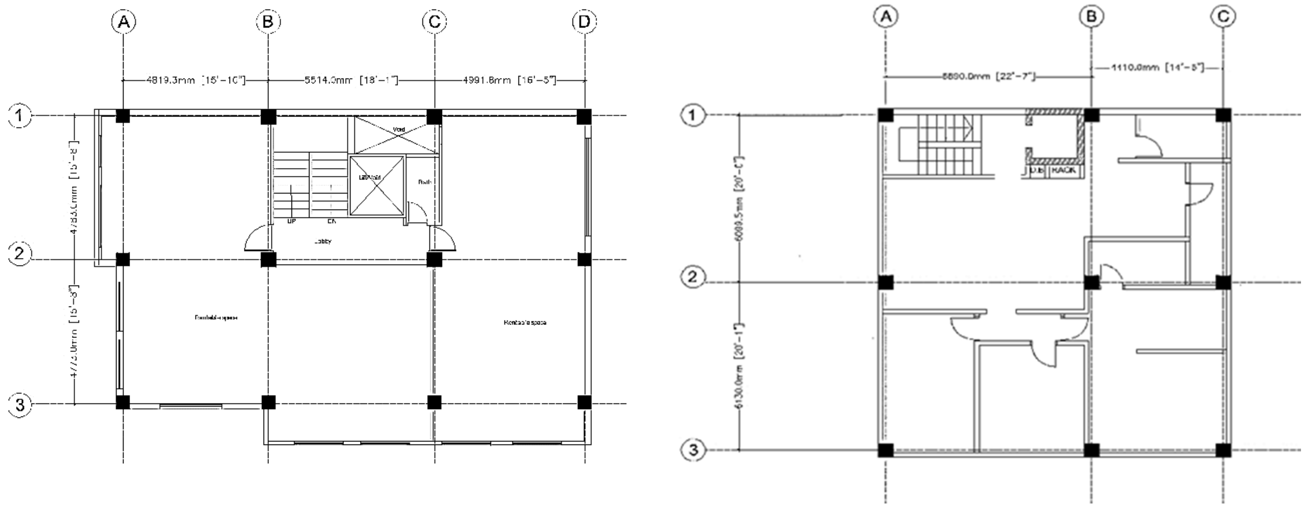

Figure 1: Typical plan of Building A, Building B

Dividing Building A into independent units with regular configuration:

The plan I obtained is irregular and has un-inform distribution of the mass along the centroid axis. I divided the plan into three different independent systems. The purpose of dividing the building into independent system is to obtain a regular shape of the building. The building is separated enough so that the buildings do not pound each other. The building has uniform distribution of mass so during the earthquake doesn't not affect the buildings eliminating the effect of torsion.

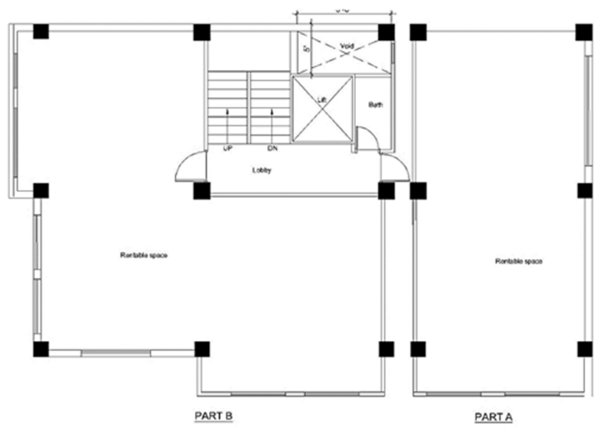

Figure 2: Building A separated into two independent units

Model Generation using ETABs software

It involves the modeling of building into the ETABs. The modeling of the regular sized building is done in a first step. Second step involves the modeling of the single irregular building. The generation of building is nearly same in both the steps.

3. RESULT AND DISCUSSION

Building Model-Bare frames:

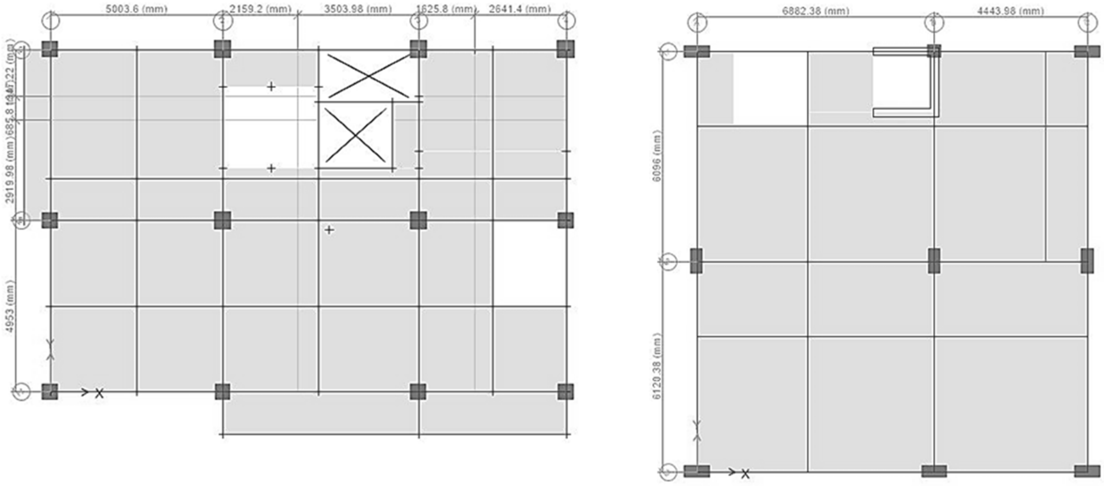

Figure IV: Building A, B with no shear walls

TABLE 1: Torsional Irregularity Check Building A with no shear walls(IS 1893:2016 Clause 7.1)

Load case	**Direction**	**□max**	**□min**	**□max/□min**	**Check**	
RSx scaled	X	44.39	36.751	1.20785829	<1.5	ok
RSy scaled	Y	53.051	34.408	1.54182167	>1.5	not ok

TABLE 2: Modal Participating Mass Ratios of framed structure

Case	**Mode**	**Period**	**UX**	**UY**	**RZ**
Modal	1	1.219	0.1811	0.2577	0.2409
Modal	2	1.096	0.4385	0.219	0.0091
Modal	3	0.942	0.0455	0.1927	0.415

As evident in above table, the ratio of the maximum to minimum top displacement is greater to 1.5 so the building is torsionally irregular in Y direction. The total mass participation of the building in all the modes have the coupled translation and torsional behavior i.e. diagonal behavior is obtained. The building thus should be corrected to obtain separate two orthogonal translation and torsional rotation separately in each mode.

TABLE 3: Torsional Irregularity Check Building B with no shear walls (IS 1893:2016 Clause 7.1)

Load case	**Direction**	**□max**	**□min**	**□max/□min**	**Check**	
RSx scaled	X	40.257	20.277	1.98535286	>1.5	not ok
RSy scaled	Y	25.002	22.096	1.13151702	<1.5	ok

TABLE 4: Modal Participating Mass Ratios of Building B with no shear walls

Case	**Mode**	**Period**	**UX**	**UY**	**RZ**
Modal	1	1.238	0.3745	0.0176	0.3483
Modal	2	0.912	0.0143	0.66	0.0019
Modal	3	0.683	0.3079	0.0019	0.3782

Like in first building, the Building B was modeled and analyzed using only the typical frame structure with only columns and beam. As evident in above table, the ratio of the maximum to minimum top displacement is greater to 1.5 so the building is torsionally irregular in X direction. The total mass participation of the building in all the modes have the coupled translation and torsional behavior i.e. diagonal behavior is obtained. The building thus should be corrected to obtain separate two orthogonal translation and torsional rotation separately in each modes.

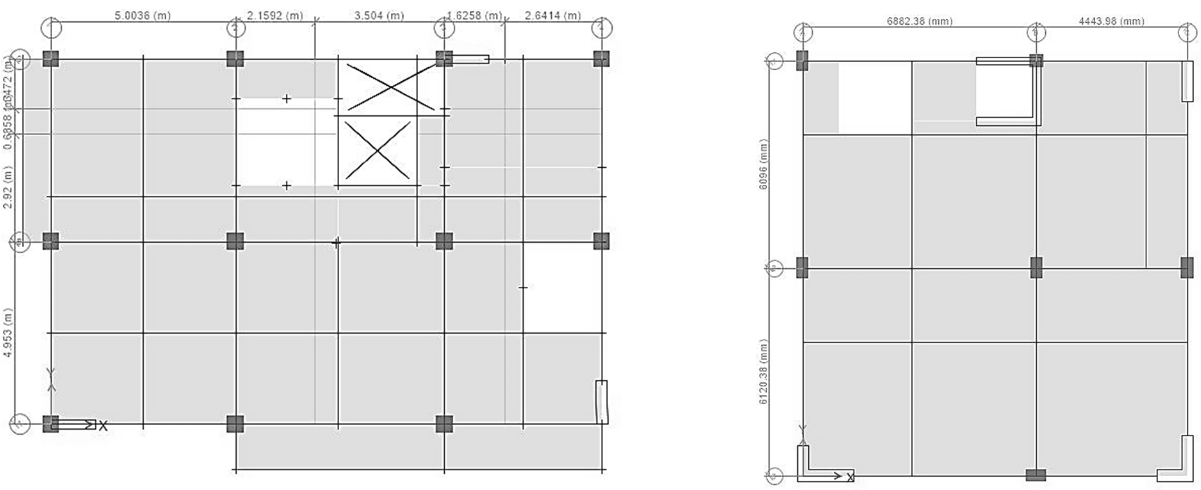

Figure V: Building A,B with shear walls

TABLE 5: Torsional Irregularity Check Building A shear walls (IS 1893:2016 Clause 7.1)

Load case	Direction	□max	□min	□max/□min	Check	
RSx scaled	X	38.09	26.08	1.46050613	<1.5	ok
RSy scaled	Y	32.5	30.5	1.06557377	<1.5	ok

TABLE 6: Modal Participating Mass Ratios of Building A with shear walls

Case	Mode	Period	UX	UY	RZ
Modal	1	0.997	0.0061	0.6549	0.0041
Modal	2	0.941	0.5487	0.0077	0.0215
Modal	3	0.809	0.0721	0.0002	0.565

The above table shows after the proper orientation of shear walls the ratio of the maximum and minimum displacement along Y direction has been reduced to less than 1.5. Also, can be seen in above table, the total mass participation of the building in first mode, second mode and third mode were uncoupled separately showing two orthogonal translation directions and torsional rotation for each mode. The building has thus been corrected

TABLE 7: Torsional Irregularity Check Building B with shear walls (IS 1893:2016 Clause 7.1)

Load case	Direction	□max	□min	□max/□min	Check	
RSx scaled	X	25.806	19.408	1.32965787	<1.5	ok
RSy scaled	Y	20.535	18.877	1.08783175	<1.5	ok

TABLE 8: Modal Participating Mass Ratios of Building B with shear walls

Case	Mode	Period	UX	UY	RZ
Modal	1	0.794	0.0361	0.6245	0.0204
Modal	2	0.761	0.632	0.0418	0.0077
Modal	3	0.6	0.0163	0.0108	0.6598

The above table shows after the proper orientation of shear walls the ratio of the maximum and minimum displacement along X direction has been reduced to less than 1.5. Also, can be seen in above table, the total mass participation of the building in first mode, second mode and third mode were uncoupled separately showing two orthogonal translation directions and torsional rotation for each mode. The building has thus been corrected.

Building model A separated in two parts as PART A and PART B providing a enough seismic gap as seen in fig below.

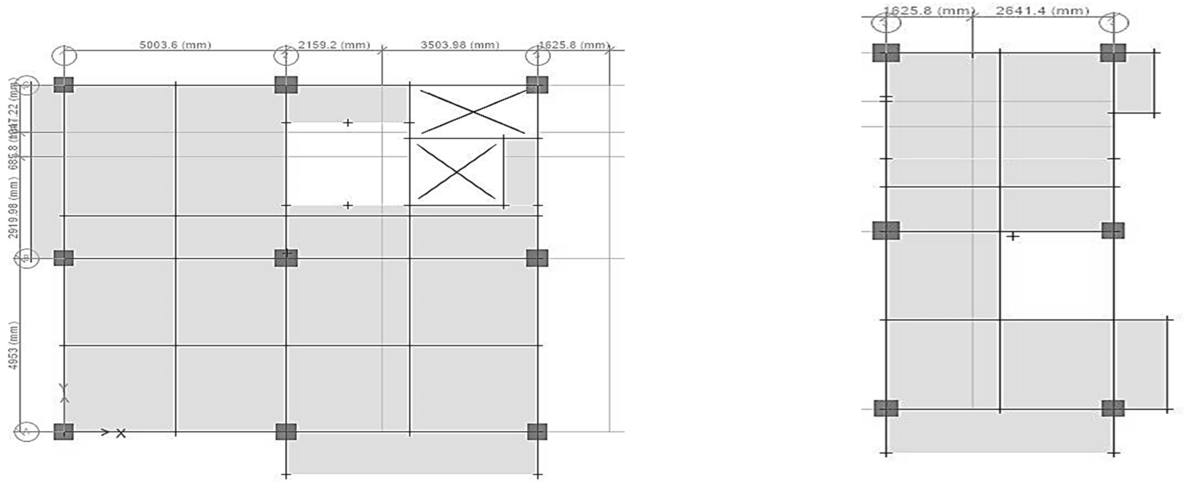

Figure 6: Building A Separated into two parts B (left) and part A.

TABLE 9 : Modal Participating Mass Ratios of part A

Case	Mode	Period	UX	UY	RZ
Modal	1	1.32	0.66	0.02	0.08
Modal	2	1.22	0.01	0.66	0.01
Modal	3	0.98	0.05	0.00	0.63

The total mass participation of the building in first mode, second mode and third mode are uncoupled separately showing two orthogonal translation directions and torsional rotation for each mode.

TABLE 10: Modal Participating Mass Ratios of part B

Case	Mode	Period	UX	UY	RZ
		sec			
Modal	1	1.05	0.58	0.01	0.05
Modal	2	0.94	0.01	0.64	0.00
Modal	3	0.87	0.05	0.00	0.59

Likewise, another part of the building was modeled and analyzed the total mass participation of the building in first mode, second mode and third mode are uncoupled separately showing two orthogonal translation directions and torsional rotation for each mode.

1.1. Summary and Conclusion:

The above results have been compared for each type of building and following results have been summarized.

Summary of the result of the building A:

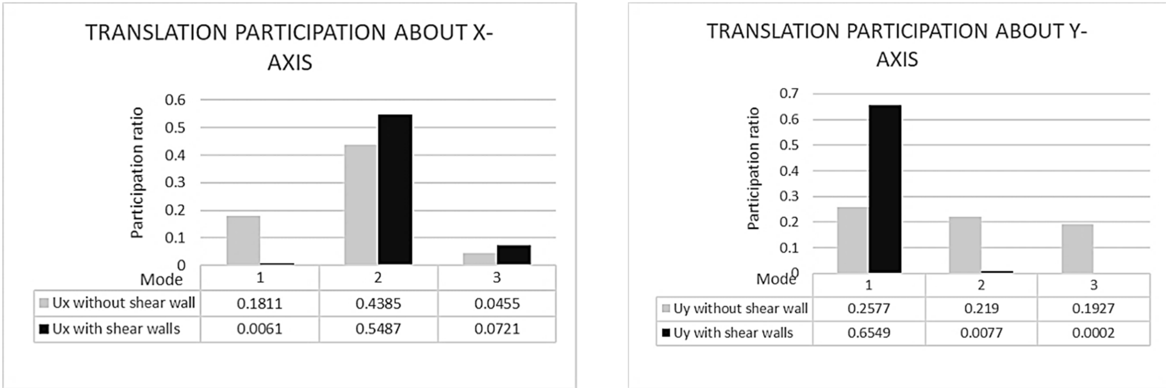

Figure 10: Mass participation of the Building A along X, Y and Z axis

As, can be seen in above graph, the translation mode of the building with shear wall had uncoupled motion in X-direction in the second mode with 54.87% while the building with no shear wall had motion been coupled with other directional motion in all three modes.

The translation mode of the building with shear wall had uncoupled motion in Y-direction in the first mode with 65.49% while the building with no shear wall had motion been coupled with other directional motion in all three modes.

Most importantly, the torsion mode of the building with shear wall has torsion only in the third mode with 56.5% and with negligible torsion in first two modes.

Summary of the result of the building B:

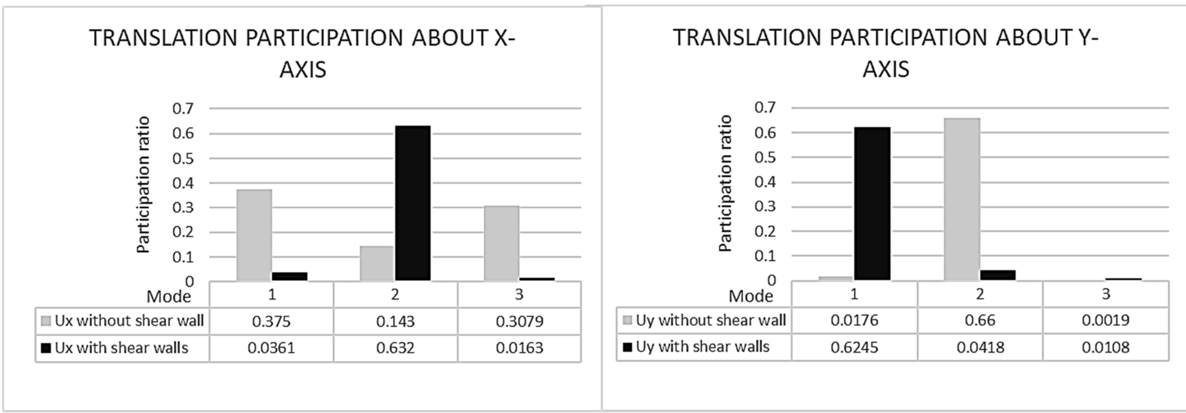

Figure 8: Mass participation of the Building A along X, Y and Z axis

As, can be seen in above graph, the translation mode of the building with shear wall haduncoupled motion in X-direction in the second mode with more than 63.2% while the building with no shear wall had motion been coupled with other directional motion in all three modes.

The translation mode of the building with shear wall has and with no shear wall both had distinct motion in Y-direction with 66% and 62.45% respectively so the motion of building in Y satisfies the seismic performance of the than buildings with two shear and no shear wall.

Most importantly, the torsion mode of the building with shear wall has torsion only in the third mode with 65.98% and with negligible torsion in first two modes.

Summary of the separated part of the building A:

The separated part A has all three motions separated distinctly in three modes. The translation along X is 66% in first mode, translation in Y-direction is 66% in second mode and torsional motion about Z with 63% in third mode.

Similarly, **t**he separated part B has all three motions separated distinctly in three modes. The translation along X is 58% in first mode, translation in Y-direction is 64% in second mode and torsional motion about Z with 59% in third mode.

Conclusion:

By adding the shear wall at the right position, it helps to stiffen the building in the weaker direction, the torsion is uncoupled and could be obtained separately with no translation behavior attached to the motion. Similarly, if the building could be detached and separated to obtain a regular configuration the torsion could be uncoupled.

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