Indian Journal of Engineering & Materials Sciences
Vol. 29, October 2022, pp. 615-621
DOI: 10.56042/ijems.v29i5.67615

Seismic Response of Y-Shape Multi-Storey Building with Optimum Location of Shear Walls

Rajiv Banerjee[a*], Jyoti Bhushan Srivastava[b], & Nakul Gupta[c]

[a]Department of Civil Engineering, Dr. A.P.J. Abdul Kalam Technical University, Lucknow 226031, India

[b]Department of Civil Engineering, Institute of Engineering & Technology, Lucknow 226021, India

[c]Department of Civil Engineering, GLA University, Mathura 281406, India

Received: 25 January 2022; Accepted: 15 September 2022

Shear walls have extremely high in-plane strength and stiffness and also can counter heavy lateral loads making them quite advantageous in high-rise buildings. It is suggested to incorporate them in structures built in the places where there are chances of large intensity earthquakes or high winds. Positioning of the shear wall plays a very critical task in an asymmetric and irregular building subjected to earthquake forces. In our study, the main aim is to locate the advantageous position of the shear wall in Y-shaped asymmetric and irregular G+14 building in zone IV. The study is done by using a software package, CSI ETABS ver. 18.0.2. We have carried out Response Spectrum Analysis and Time History Analysis for this study. In this study, fourteen test models with unique location of shear wall are considered and parameters such as Time Period, Storey Displacement, Static Eccentricity, Storey Drift, Joint Displacement, Base Shear, and Base Force, are compared with the bare model. Thus, the best location of shear wall is suggested based on models having least static eccentricity, minimum displacement, Minimum drift, Minimum time period, Minimum joint displacement and Maximum base shear.

Keywords: Shear wall, Torsion, Static eccentricity, Irregularity, Seismic behavior

1 Introduction

A reinforced concrete framed structure can be designed in a manner that it can reduce the effect of seismic forces without the presence of shear wall. But the fact of the matter is, column will occupy a significant area of the floor and beam-column junction will be very heavy. This will cause difficulty in placing and vibration of concrete at the joint and there may be chances of reduction in strength of joint.

Modern buildings are seldom if ever perfectly symmetrical and regular but mostly irregular in plan due to functional, architectural beauty and space problem, which is the main cause of the birth of torsionally unbalance system and this occurs because the center of mass (Cm) and center of the rigidity (CR) do not coincide at the same point. Case Studies have been done by Response Spectrum Analysis was used to conduct case studies involving various forms of irregularities[1,2]. Pushover or Nonlinear Time History Analysis was used to determine how to control the vulnerability of asymmetricstructure[3-5]. Damage surveys were conducted after the earthquake in Nepal (2015) and the Imphal earthquake, India (2016) which claimed that many structures were found to be damaged due to their unsymmetrical planning and mainly due to irregularity[6]. Buildings having the irregular shape of a plan like C shape, L shape, T shape, or other irregular form are severely damaged due to tremendous stress concentration occurring at different corners of the building. One of the major examples can be the Bhuj Earthquake[7-9] of 2001. As per FEMA.450-1[10] and UBC-1988[11], In case of plan irregularities extreme torsional irregularity is to be considered when the diaphragm is rigid. FEMA-450-2[11] IS 1983 Part 1[12] includes the English alphabet T, C, H, L, and Y as plan irregularities. According to Euro Code - 8 Part 1 (GEN, 2004), the slenderness (L_{max}/L_{min}) should be less than 4 to meet the rigid diaphragm criteria. L_{max} and L_{min} are the orthogonal dimensions of the building's larger and smaller sides.

An analytical method has been derived to determine the length of shear walls necessary for a regular building seismic resistant against severe earthquakes[13,14]. The challenges faced by the modern multi-purpose mega structure have considerable irregularities due to constraint architectural outlook, site situation, and other useful condition. The research study has been initiated in this direction[15]. To get rid

*Corresponding author (E-mail: rajeev2009banerjee@gmail.com)

of the effect of the torsional moment, the best way is to divide the entire structure into a separately rectangular structural block with provision for safety against ponding by placing a rubber block or spring in between the gaps[16]. But due to site constraint architectural views and other different functional requirements, the construction of irregular structures as a complete block is increasing day by day. However, such structures are highly vulnerable to severe damage due to large stress concentration and they require high stiffness and strength to tackle large displacement and torsional moment about the vertical axis[17].

The inclusion of a shear wall at different location helps to stiffen the building structure system because shear walls contribute significant lateral stiffness, strength, resulting in reduction of the displacement, time period, storey drift and eccentricity. Shear walls placed at an advantageous position in a building can prove to be an efficient seismic resisting system simultaneously reducing the torsional effect and fulfilling other functional requirements.

Y-shaped plan multi storey buildings are famous for their functional and architectural point of view and at the same time are considered well ventilated and are thus preferred for natural light. Common facility such as lift and staircases can be housed at the junction of three wings.[18]

There are several researches on the impact of shear wall on high rise buildings; Most of them are on regular buildings. But very less work has been done on effect of location of shear wall on irregular buildings. Work on optimum location of shear wall on Y-shaped plan building has not been considered by any researcher. Therefore Y-shaped plan irregular building is taken under consideration to find optimum location of shear wall under seismic forces.

A building can be constructed to respond elastically during earthquakes without damage, but it's expensive and may make the project unviable. The building may need to be damaged to disperse seismic energy. Design wind forces don't allow building damage. This is why earthquake resistant design isn't earthquake proof.

Objectives of the present study is to find out the most favorable spot of shear wall for an irregular Y-shaped plan (G+14) storey building by comparing the parameters like Story displacement, story drift, Time Period, Static Eccentricity, Base Shear, Base Force and Joint Displacement of all the 15 models with and without shear wall, which are derived from Response Spectrum Method and Time History Method.

2 Materials and Methods

A commercial building of G+14, Y-shaped asymmetric and plan irregular building having floor area of about 1610 m^2 with typical floor height of 3 m is considered for analysis. Due to the preference for bright light during day time and better ventilation everywhere, the Y-shaped plan configuration are getting popularity day by day for multi-story buildings. Further junction of three wings can be used for various facilities such as place for escalator, lift and staircase. Such buildings are vulnerable to earthquake damage near re-entrant corners due to stress concentration. To get rid of this problem, most codes suggest isolating the wings by separation joints. The provision of a separate joint is not an ideal solution due to ponding between two adjacent blocks. Also, such joints are aesthetically undesirable. It is of interest to see if such a building can be configured to avoid in-plane floor deformation during earthquake ground motion by placing the shear wall at the strategic position of the building. We have chosen 15 test models for the comparative study, out of which 14 models are having shear wall while one of them is bare model. The bare model is the one without shear wall placement. The models will be compared with the bare frame models. Response Spectrum Analysis and Time History Analysis will be done for the comparative analysis. In the following Table 1 representing Geometric Properties and Table 2 representing Test Models, red line indicates the position of shear in the building as per Figs 1 & 2.

3 Results and Discussion

3.1 Response Spectrum Analysis

3.1.1 Modal Analysis

It is essential to design structures such that they mostly oscillate along their sides as per Table 3. Because modes of oscillations such as opening-closing, translation along diagonal and dog-tail-wagging are not beneficial for the seismic performance of buildings, it is preferable to have pure translational modes as the first and second modes of oscillation, and torsional as the third mode of oscillation. Undesirable modes can be controlled by shear walls at advantageous locations.

Table 1 — Geometric Properties

Parameter	Values
Building Type	Commercial
Length of Bay in the X direction	5 m
Length of Bay in the Y direction	5 m
Depth of Slab	150 mm
Shear wall thickness	230 mm
Length of Shear Wall	Length of shear wall is decided by considering a Wall to Floor area ratio of about 1.5%.[12]
Size of Columns at Core	450 mm X 750 mm
Size of other columns	350 mm X 750 mm
Size of Beams at Core	450 mm X 600 mm
Size of other beams	300 mm X 600 mm
Loads types	As pr IS 875 Part-1 & 2
Dead Load	Self-weight
Dead Load – Floor	1 KN/m² (Floor Finish)
Live Load - Floor	3 KN/m²
Material Property	As Per IS 456:2000
Grade of Concrete	M 30
Grade of Rebar	Fe 500
Concrete Density	25 KN/m³
Seismic Parameter	As per IS 1893 (Part-1):2016
Seismic Zone	IV (Table No. 2)
Zone factor (Z)	0.24 (Clause 6.4.2)
Importance Factor (I)	1.2 (Clause 7.2.3,)
Soil type	Type II (Medium Stiff Soil)
Response Reduction Factor (R)	5 (SMRF) (Clause 7.2.6,)
Damping Ratio	5% (Clause 7.2.4)
Earthquake Load	As per IS 1893 (Part-1):2016
Time History Data	Earthquake Data as provided in CSI ETABS ver. 18.0.2 for Array Recording Station, USA with time interval of '0.1' sec.

3.1.2 Static Eccentricity

C_m (Centre of mass) and C_R (Centre of rigidity) are affected by addition and location of shear walls. Since structure is symmetrical about Y-axis, so no effect of torsion due to static eccentricity along Y-direction as per Fig. 3. It is observed that bare Model is showing maximum eccentricity of 4.41 m and after introduction of shear wall at advantageous positions, eccentricity reduces drastically. It is found that Model 6 has got an eccentricity of 0.09 m. This is the lowest value among the models. So arrangement of shear wall as per Model 6 may be considered as best.

Table 2 — Load Combination for Test Models

S. No.	Load Combination
1	DL + LL
2	1.2 DL + 1.2 LL + 1.2 RSX + 0.36 RSY
3	1.2 DL + 1.2 LL + 1.2 RSY + 0.36 RSX
4	1.5 DL + 1.5 RSX + 0.45 RSY
5	1.5 DL + 1.5 RSY + 0.45 RSX
6	0.9 DL + 1.5 RSX + 0.45 RSY
7	0.9 DL + 1.5 RSY + 0.45 RSX
8	1.5 DL + 1.5 LL
9	1.2 DL + 1.2 LL + 1.2 RSX
10	1.2 DL + 1.2 LL +1.2 RSY
11	1.5 DL + 1.5 RSX
12	1.5 DL + 1.5 RSY
13	0.9 DL + 1.5 RSX
14	0.9 DL + 1.5 RSY

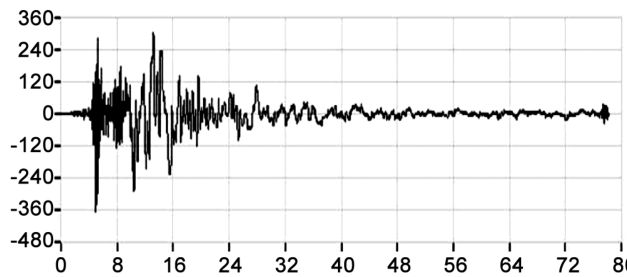


Fig. 1 — Time History Data of Array Recording Station, El Centro, USA (As available in CSI-ETABS ver. 18.0.2).

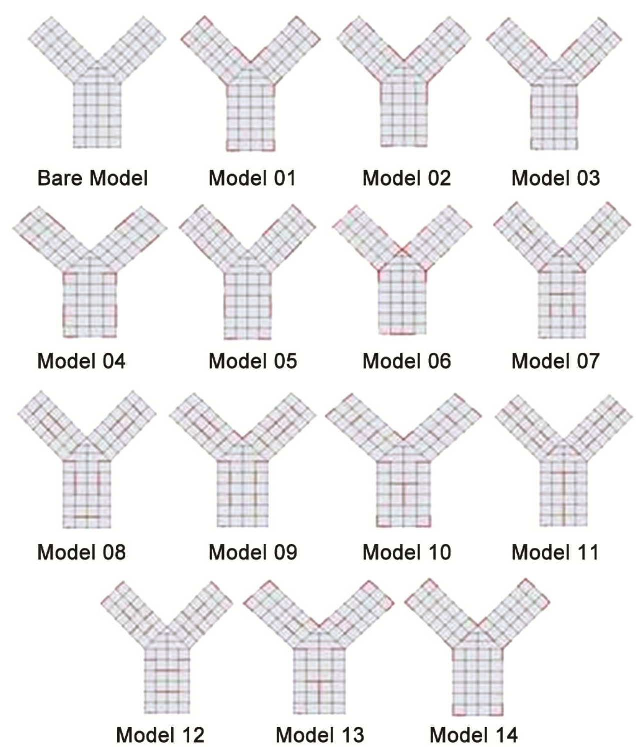


Fig. 2 — Y-Shaped with Shear walls.

Table 3 — Behaviour of Building in first three modes

Model Name	Behaviour in 1st Mode	Behaviour in 2nd Mode	Behaviour in 3rd Mode
Bare Model	Rotation	Translation	Rotation
Model 1	Rotation	Translation	Rotation
Model 2	Rotation	Rotation	Translation
Model 3	Rotation	Rotation	Translation
Model 4	Translation	Rotation	Translation
Model 5	Translation	Rotation	Translation
Model 6	Translation	Translation	Rotation
Model 7	Rotation	Translation	Rotation
Model 8	Rotation	Rotation	Translation
Model 9	Rotation	Translation	Translation
Model 10	Translation	Translation	Rotation
Model 11	Rotation	Translation	Translation
Model 12	Translation	Rotation	Rotation
Model 13	Rotation	Translation	Rotation
Model 14	Translation	Translation	Rotation

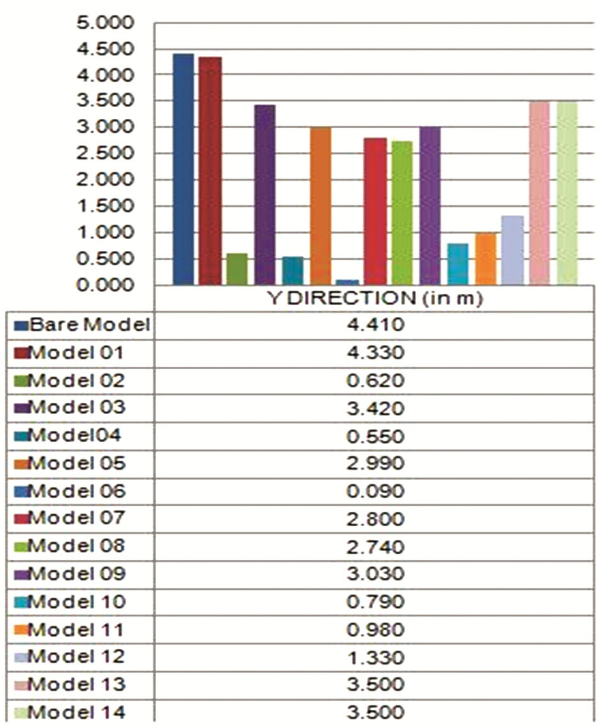


Fig. 3 — Static Eccentricity.

3.1.3 Time Period

The amount of time required to complete one cycle of oscillation is referred to as a building's time period. Mass and flexibility of the structure are the main parameters on which time period depends. More the flexibility, greater would be the time period. It is desirable to have lesser time period for better performance. The Fig. 4 above shows the time period of Model 6, Model 10 and Model 14 are 1.07 sec., 1.15 sec. and 1.17 sec. respectively. Model 6 shows lowest time period among all the models exhibiting T-T-R (Translation – Translation – Rotation) modal behaviour in first three modes of vibration. Thus, Model 6 can be considered as best model in terms of location of shear wall.

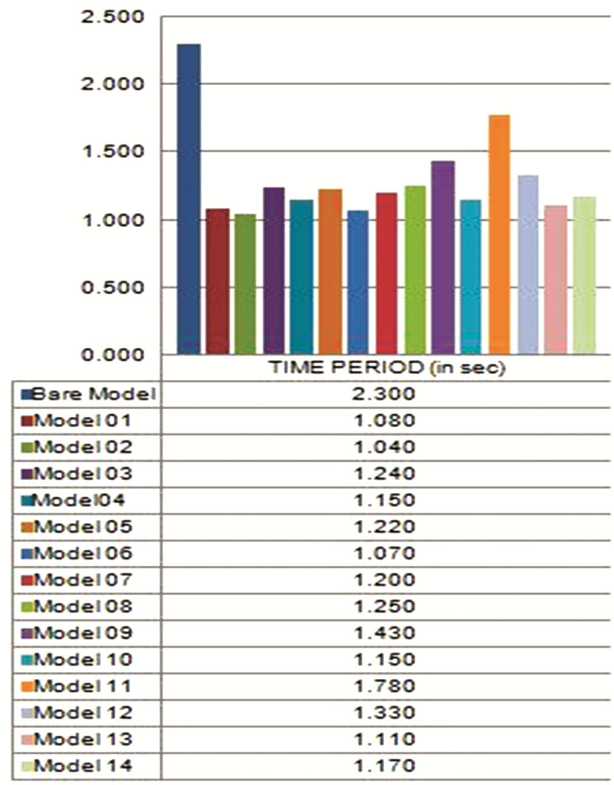
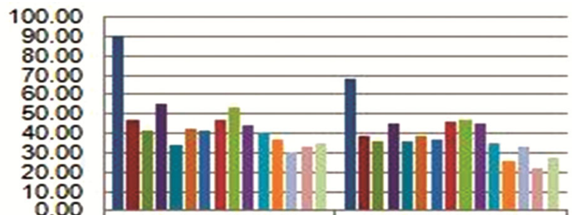


Fig. 4 — Tiewme interval (sec).

3.1.4 Storey Displacement

The maximum allowable displacement as per Eurocode-8[19], is given by H/250.where, H is the total height of the building above ground level. Maximum limit of displacement as calculated using formula H/250 is found to be 180 mm, The storey displacement of different models are shown in Figure 5 with their respective data. After the dynamic analysis from ETABS, evaluated Storey Displacement along X- and Y-direction of the test models.

This is observed from the Fig. 5, storey displacement along X-direction and Y-direction for Bare Models is 90.8 mm and 67.99 mm respectively. Addition of shear wall drastically reduces the storey displacement. It is observed from the table that Model 14 is having least storey displacement among all three T-T-R models (i.e. Model 5, 10, 14). But as Model 14 is having huge amount of static eccentricity, thus



	X DIRECTION (in mm)	Y DIRECTION (in mm)
Bare Model	90.80	67.99
Model 01	46.85	38.74
Model 02	41.27	36.20
Model 03	55.62	44.93
Model04	34.39	35.61
Model 05	42.52	38.55
Model 06	41.00	36.35
Model 07	47.08	45.93
Model 08	52.99	46.90
Model 09	44.51	44.90
Model 10	40.66	34.68
Model 11	36.89	25.60
Model 12	30.48	33.44
Model 13	33.27	22.32
Model 14	35.29	27.33

Fig. 5 — Storey Displacement in X and Y-direction.

considering Model 6 will be better. Model 6 has go 41 mm of displacement in X –direction and 36.3 mm of displacement in Y-direction.

3.1.5 Storey Drift

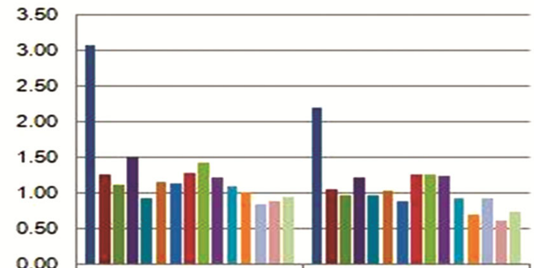
Story drift, shall not exceed 0.004 times of storey height as per IS 1893:2016 (Part-I) (clause 7.11.1)[2] calculated permissible drift as per above mentioned code (0.004x3000 = 12 mm). After the dynamic analysis from ETABS, evaluated Storey Drift in X and Y direction of the test models.

It is observed from the Fig. 6, storey drift for Bare Model along X and Y directions are 3.08 X 10^{-3} and 2.20 X 10^{-3} respectively, these values are within limits. These values are further reduced with addition of shear wall at suitable location. Model 6 exhibit 1.14 X $10^{-3}$and 0.9 X 10^{-3} in X and Y- directions respectively. The values of Model 6 are about 1/3[rd] the value of Bare Model.

3.1.6 Base Shear

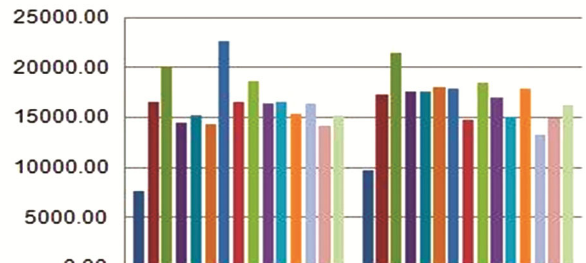
Base shear is the phrase used to describe the maximum lateral force that may be predicted at the base of the building as a result of seismic ground motion[2]. After the dynamic analysis from ETABS, Base shears are shown below for all models

Base Shear for Bare Model in Fig. 7 along X and Y direction are 7600 kN and 9792 kN respectively. It is



	X DIRECTION (x 10^-3)	Y DIRECTION (x 10^-3)
Bare Model	3.08	2.20
Model 01	1.27	1.05
Model 02	1.12	0.97
Model 03	1.51	1.22
Model04	0.94	0.97
Model 05	1.16	1.04
Model 06	1.14	0.90
Model 07	1.28	1.27
Model 08	1.44	1.27
Model 09	1.22	1.24
Model 10	1.10	0.94
Model 11	1.02	0.70
Model 12	0.84	0.94
Model 13	0.90	0.62
Model 14	0.96	0.74

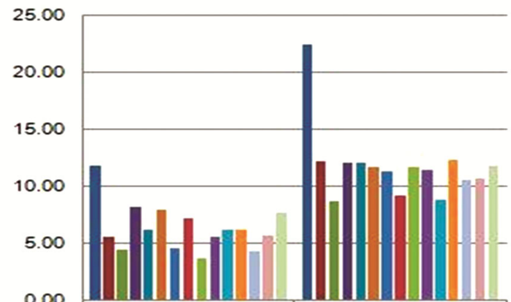
Fig. 6 — Storey Drift in X and Y-direction.



	X DIRECTION (in kN)	Y DIRECTION (in kN)
Bare Model	7600.00	9792.00
Model 01	16555.00	17322.00
Model 02	20163.00	21495.00
Model 03	14480.00	17576.00
Model04	15207.00	17622.00
Model 05	14322.00	17988.00
Model 06	22611.00	17827.00
Model 07	16567.00	14706.00
Model 08	18676.00	18538.00
Model 09	16402.00	16965.00
Model 10	16505.00	15130.00
Model 11	15421.00	17853.00
Model 12	16400.00	13346.00
Model 13	14239.00	14877.00
Model 14	15141.00	16306.00

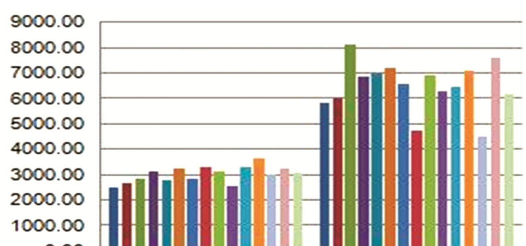
Fig. 7 — Base Shear in X and Y-direction.

observed that Model 6 has values 22661 kN and 17828 kN in X and Y direction respectively. It is highest among the T-T-R exhibiting models. Thus, shear wall location as per Model 6 may be optimum for such type of structure.



	X DIRECTION (in mm)	Y DIRECTION (in mm)
Bare Model	11.80	22.51
Model 01	5.56	12.23
Model 02	4.47	8.68
Model 03	8.20	12.13
Model04	6.17	12.04
Model 05	7.92	11.75
Model 06	4.56	11.28
Model 07	7.20	9.21
Model 08	3.74	11.75
Model 09	5.58	11.46
Model 10	6.20	8.80
Model 11	6.20	12.30
Model 12	4.38	10.59
Model 13	5.77	10.77
Model 14	7.66	11.81

Fig. 8 — Joint Displacement.



	X DIRECTION (in kN)	Y DIRECTION (in kN)
Bare Model	2483.00	5845.00
Model 01	2681.00	5980.00
Model 02	2808.00	8117.00
Model 03	3108.00	6875.00
Model04	2773.00	6955.00
Model 05	3263.00	7185.00
Model 06	2828.00	6558.00
Model 07	3280.00	4752.00
Model 08	3103.00	6931.00
Model 09	2545.00	6262.00
Model 10	3297.00	6449.00
Model 11	3619.00	7114.00
Model 12	2987.00	4481.00
Model 13	3219.00	7617.00
Model 14	3077.00	6170.00

Fig. 9 — Base Force.

3.2 Time History Analysis

3.2.1 Joint Displacement

Joint Displacement represents the maximum storey displacement due to Time History Analysis. It is found from the Fig. 8, the Joint Displacement for Bare Model along X and Y axis is 11.8 mm and 22.56 mm respectively. Least Joint Displacement for Model 6 are 4.56 mm and 11.28 mm along X and Y direction respectively. So, location of shear wall as per Model 6 will be appropriate for this type of building.

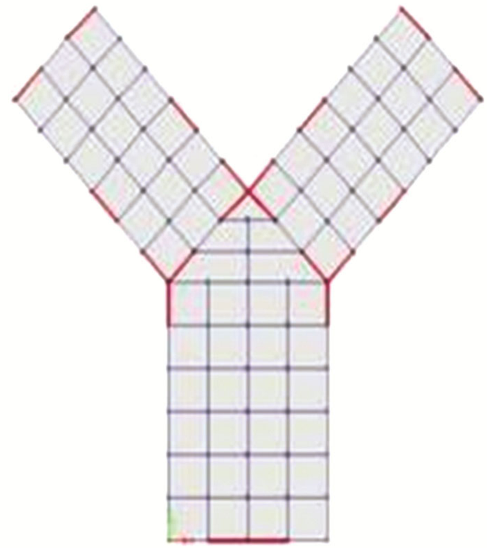


Fig. 10 — MODEL 6 with optimum location of Shear Wall.

3.2.2 Base Force

Base Force in Fig. 9 represents the maximum Base Shear calculated from Time History Analysis. From the recorded data, it was found that Base Force due to Model 6 i.e., 6558 KN in Y direction and 2828 KN in X direction was the highest. The building with more the value of Base Force will be considered good and thus Model 6 may be considered better on the grounds of Base Force.

4 Conclusion

1. It is desirable for better performance against seismic force that the building should have Translational mode be the governing factor for first two modes of vibration and torsion in third modes of vibration.
2. All the building models are symmetrical about Y axis and shear walls are placed in such locations so that centre of mass C_m (Centre of Mass) and C_R (Centre of Rigidity) lie along Y-axis and static eccentricity should be as minimum as possible in order to have minimum torsional effect due to static eccentricity. The structure with optimum location of shear wall shows that C_m (Centre of Mass) and C_R (Centre of Rigidity) will be very close to each other.

3. The addition of shear wall at different location in models results decrease in the time period. Model 6 shown in Fig. 10 shows decrease in Time Period compared to model without shear wall. Model 6 shows minimum Time Period among all Models that satisfy Translation-Translation-Rotation (T-T-R) mode of vibration.
4. Introduction of Shear Wall in different models has decreased the storey displacement compared to the building model without shear wall. Model 6 shows good results with respect to displacement compared to the models having T-T-R behavior in first three modes.
5. Addition of shear walls results increase in seismic weight which causes increased base shear as compared to bare model. Model 6 shows good performance according to Response Spectrum Method among all models having (T-T-R) in first three modes.
6. Base Force increases with addition of Shear Wall at different locations among all models having (T-T-R) modes of vibration. Model 6 gives the best response with respect to Time History Method.
7. Position of Shear Wall has a considerable effect on Storey Drift Model 6 shows good performance according to Response Spectrum Analysis among all the models having (T-T-R) in first three modes
8. Shear Wall also affects Joint Displacement. Model 6 shows good performance according to Time History Analysis.

Acknowledgement

The authors are thankful to the management of Integral University, Lucknow and GLA University, Mathura, INDIA, for their support.

Reference

1 Dutta S, & Roy R, *J Eng Mech,* 138(1) (2012) 1.
2 Gokhan T, & Khalid M A, *Kon J Eng Sci*, 8(9) (2020) 601.
3 Chintanapakdee C, & Chopra A K, *J Struct Eng,* 130(8) (2004) 1177.
4 Jeyasehar CA, Muthmani K S, & Lakhmanan K, *Int J Eng Mater Sci,* 16(4) (2009) 220.
5 Kaplan H, Yilmaz S, Nihat C, & Atimtay E, *Sadhana,* 36(1) (2011) 17.
6 Das P K, Dutta SC, & Datta T K, *Nat Hazards Rev*, *22*(2) (2020) 04020062
7 Jain S K, Murty C V R, Dayal U, Arlekar J N, & Chaubey S K, *The republic day earthquake in the land of MK Gandhi, the father of the Nation, EERI,* field report, USA and Indian Institute of Technology, Kanpur (2001).
8 Riddell R, Llera J C, & Wood S L, *Struct characteristics and damage statistics for the building inventory in Vina del Mar, Urbana, IL:* Thesis, University of Illinois (1987).
9 Gudainiyan J, & Parihar H.S, *Mater Sci Eng,* 1116 (2021) 012155.
10 FEMA: 450 (Part-1), *NEHRP Recommended provision for seismic regulations for new buildings and other structures*, (2003).
11 FEMA: 450 (Part-2), *NEHRP Recommended provision for seismic regulations for new buildings and other structures*, (2003).
12 IS: 1893 (Part-1) *Criteria for earthquake-resistant design of structure,* (2016).
13 Ahmet T, & Nadeem S, *Arab J Sci Eng,* 38(10) (2012) 2639.
14 Alashker Y, Nazar S, & Ismaiel M, Open Civ Eng J, 5(02) (2015), 203.
15 Dutta SC, Das PK, & Sengupta *P, Struct Eng Int,* 27(4) (2017) 526.
16 Siamak T, & Mahdi R, *Front Struct Civ Eng,* 14(5) (2020) 1131.
17 Jain SK, & Mandal UK, Struct Eng, 121(6) (1995) 1004.
18 Chintanapakdee C, & Chopra A K, *Earthq. Eng Struct. Dyn, 32*(3) (2003) 417.
19 Eurocode 8 (Part-1) *Design of structures for earthquake resistance-:General rules, seismic actions and rules for buildings,*(2004).