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Determination of Optimum Position of Shear Wall in an Irregular Building for Zone III & IV

Rajiv Banerjee, J.B. Srivastava

Abstract- ***Stiffness is the property of the structure that is responsible for absorbing the external forces. For the case a multistory building, when the height of the building increases, the lateral stiffness of the building decreases. With low lateral stiffness, the building becomes more vulnerable to lateral forces like wind and earthquake. In order to prevent the structure from damage from the lateral forces, lateral stiffness is induced in the structure by means of shear walls. With the introduction of shear wall, we observe a considerable decrement in lateral displacement and increase in base shear. The resistance of lateral forces in terms of magnitude by shear wall depends on its location in the building. In this paper, a G+15 storey building is considered. The building is irregular in nature (T shaped). A comparative study is done to obtain the optimum position of shear wall in the structure. For optimization, the total length of the shear wall in the structure is kept constant. The whole modeling and analysis is done by ETABS v. 2016. The comparative study is done on the basis of base shear, storey displacement & storey drift. The above values are calculated by the dynamic approach of analysis of building subjected to seismic loading.***

Keywords: Shear Wall, Response Spectrum Analysis, Time History Analysis, Irregular Buildings

I. INTRODUCTION

Shear Wall are one of the vital structural elements of a multi-storey building with major function to introduce lateral stiffness in the building. The increase in lateral stiffness results in high resistance towards lateral forces. Apart from that shear wall also accompanies with the structural elements carrying gravity loads in order to transfer it to the ground. This causes reduction in reinforcement in those elements.

Shear walls can be of various shape and sizes and also can be placed at various position of building. The position of shear wall plays an important role in determining the behavior against lateral forces. The following literatures are related to the location of shear wall in building-

- **Lakshmi K.O., Prof. Jayshree ramanujan, Mrs. Bindu Sunil, Dr. Taju Koltali, Prof. Mercy Joseph, Poweth (2014)** [25] **-** In medium high rise building, provision of shear wall is found to be effective. The efficiency varies as per location of shear wall in the building.
- **S.K. Hirde and N.K. Shelar (2015**) [22] - There is a significant improvement in seismic performance of building on a level ground as well as sloping ground by providing shear wall at certain locations.
- **Suchita Tuppad and R.J. Fernanded (2015)** **[**20]**–** By analyzing the seismic behavior of the building by genetic algorithm, buildings without shear wall was having storey displacement. However, a particular type of configuration was giving better resistance to seismic loading.
- **Poornima D., Sanjay S.J., Yajnobhavi H.M. (2017)** **[**24] **-** For a symmetric building, there is considerable reduction in displacement in X and Y direction because of a certain configuration of shear wall.
- **Abhija Mohan, Arathi S. (2017)** [21]- For a G+10 storey regular building with shear wall having staggered opening, 12.92% reduction in displacement is observed in X – direction and 13.15% reduction in displacement in Y – direction.

There are many research works for the location of shear wall but most of them are for regular building. In this paper, we will discuss the position of shear wall in irregular building. Irregular buildings are defined in Table – 6 of IS 1893 (Part -1):2016 [3].

A. Earthquake - When energy from the earth crust is abruptly released, earthquake happens. The source of this energy is the tectonic plates which resettle itself at various intervals of time. When the energy is released, it travels in the form of waves (primary waves and secondary waves) at the surface of earth.

As per Newton's first law of motion, everybody tries to maintain its inertia. When there is sudden movement in foundation of a building, the distant members (members situated at certain height from foundation) tries to maintain inertia and the relative displacement cause damage in the buildings. Damages can be from cracks in the building to the collapse of the structure.

B. Earthquake Resistant Design of Building - Mass of a building along with its stiffness controls the seismic design of the building. Earthquake induces inertia forces which are proportional to the mass and on the other hand the lateral displacement due to these seismic forces is controlled by stiffness of the structure. Thus, mass and stiffness are two basic properties which define the seismic strength of the building.

Apart from that, designing buildings to behave elastically during earthquake without any damage may render the project economically unviable. Thus, the buildings are designed to be earthquake resistant not earthquake proof. As per the publication[1] by Gujarat State Disaster Management Authority, earthquake resistant design of building exhibit following characteristic in a building in the given conditions-

- Minor (frequent in occurrence) – No damage to the structural and non structural elements.

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* Correspondence Author
Rajiv Banerjee*, pursuing Ph. D from Dr. A.P.J. Abdul Kalam Technical University, Lucknow, India.
Dr. J. B. Srivastava, Professor in Institute of Engineering and Technology, Lucknow, India.

- Moderate Shaking – Minor damage to the structural elements and some damage to the non structural elements.
- Severe (infrequent in occurrence) – Shaking with damage to structural elements, but no damage to life and property. The building is unable to serve again.

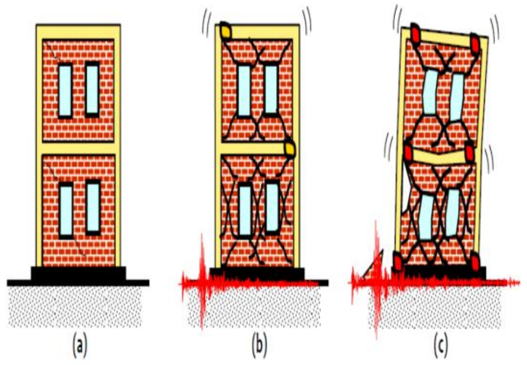


Fig. 1 Behavior of Earthquake Resistant Buildings in minor, moderate and severe shaking [1]

So in order to design an earthquake resistant building, we only consider 8-14 % of the earthquake force. This reduction of the earthquake forces is done by Response Reduction Factor given in Table – 9 of IS 1893 (Part – 1):2016.

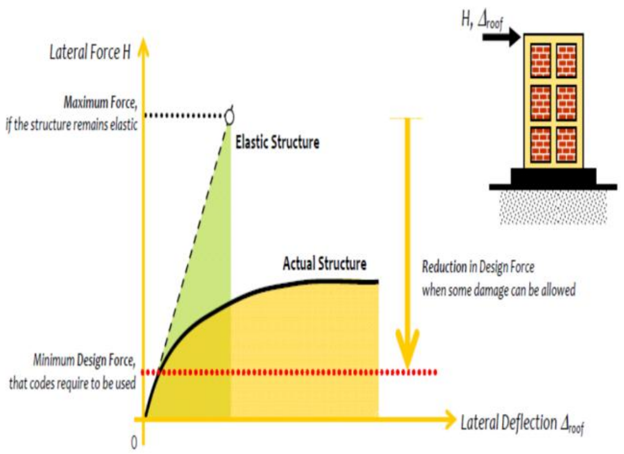


Fig. 2 Concept of Earthquake Resistant Building [1]

C. Analysis of effects of earthquake in a building – The analysis of an earthquake force on a building can be categorized as -

- Static Analysis
- Dynamic Analysis

As per clause 6.4.3 of IS 1893(Part – 1):2016 [3], the following approach for the analysis is prescribed-

a) Equivalent Static Method – As per this method, first the design base shear, V_B (maximum lateral load at the building) shall be distributed to various floors and then further distributed to structural elements at the floors. The method is only applicable for regular buildings with height less than 15 m in seismic zone – III.

b) Linear Response Spectrum Method –

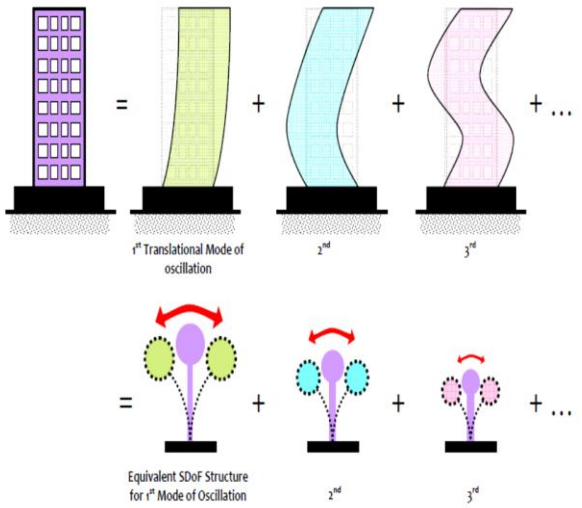


Fig. 3 Mode Shape at various frequencies in Response Spectrum Method [1]

It is plot of maximum response of SDOF (Single Degree of Freedom System) subjected to specific earthquake ground motion and time period. The response at various time periods is called mode shape. The mode shape at maximum time period or minimum frequency is called natural mode shape of the building. The response of all the mode shape is combined by certain methods to obtain maximum response plot. The methods like complete quadratic combination (CQC) are used for obtaining the maximum response.

c) Non-Linear Time History Analysis – It is a non linear dynamic analysis approach. This approach uses the record of ground motion in terms of acceleration with respect to time period. The record is subjected to the base of the building to obtain the maximum response. The response can be plotted in the form of spectral displacement, etc.

II. METHODOLOGY

For doing a comparative study in order to determine the optimum position of shear wall, 10 test models are modeled and analyzed. Out of the ten test models, one of them is a bare frame model (with no shear wall). The other nine models have a unique configuration of shear wall. Please note that the total length of shear wall in any of the nine models is constant i.e. 80 m.

A. Modeling Details- The modeling is done in ETABS v. 16 with concrete grade of M25 and rebar grade of Fe-415 for all the models. The details of the models are as follows –

Table I: Geometrical Details of The Models

Sr. No.	PARTCULARS	DESCRIPTION
01	Column Size	350 X 750 (in mm)
02	Beam Size	300 X 450 (in mm)
03	Slab Thickness	150 mm
04	Shear Wall Thickness	300 mm
05	Typical Storey height	3 m
06	Height between foundation base and plinth level.	2.6 m
07	Centre to Centre distance of columns (X & Y direction)	5 m

Table II: Loading Details of the Models

Sr. No.	PARTCULARS	DESCRIPTION
01	DEAD LOAD a) Floor Finish b) Masonry Load for 4.5" wall	 1.5 kN/m^2 6.9 kN/m^2
02	LIVE LOAD a) Floor Load at floor b) Floor Load at terrace	 3 kN/m^2 1 kN/m^2
03	SEISMIC LOAD a) Seismic Zone b) Response Reduction Factor c) Importance Factor d) Soil Type	 ZONE III & ZONE IV 5 1 Medium Stiff

The test model layouts are given below –

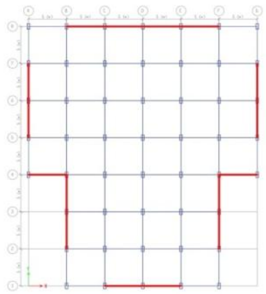


Fig. 3 MODEL 01

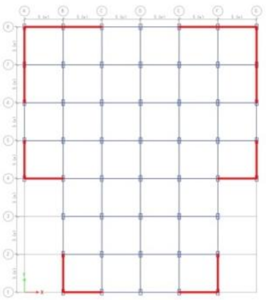


Fig. 4 MODEL 02

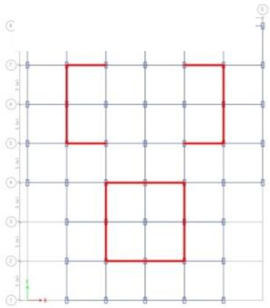


Fig. 5 MODEL 03

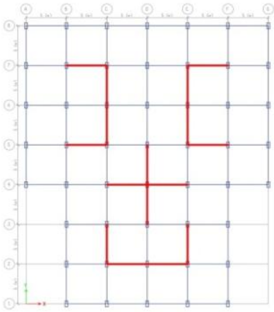


Fig. 6 MODEL 04

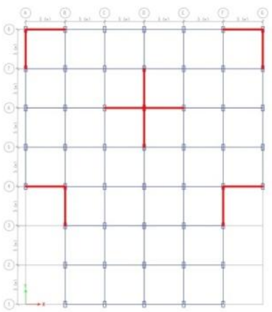


Fig. 8 MODEL 05

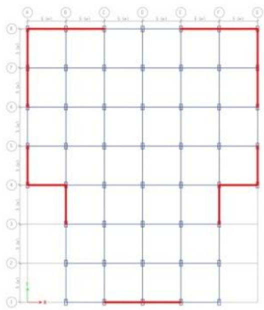


Fig. 9 MODEL 06

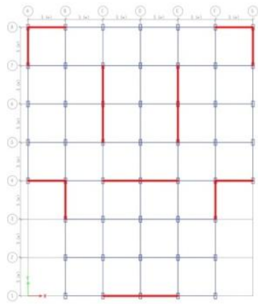


Fig. 10 MODEL 07

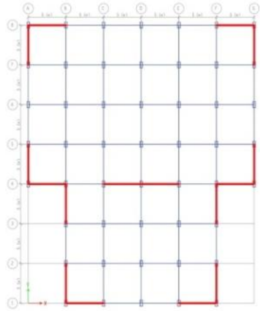


Fig. 11 MODEL 08

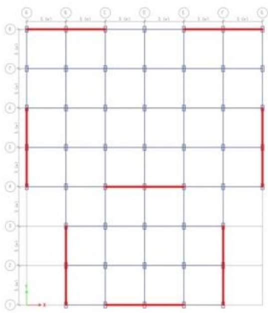


Fig. 12 MODEL 09

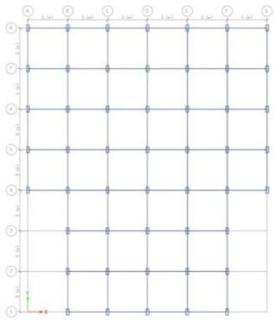


Fig. 13 BARE FRAME MODEL

B. Analysis Details – The model analysis is done as for seismic zone III & IV, thus there is no scope for equivalent static method. The models will undergo dynamic analysis from ETABS v. 16 with following details-

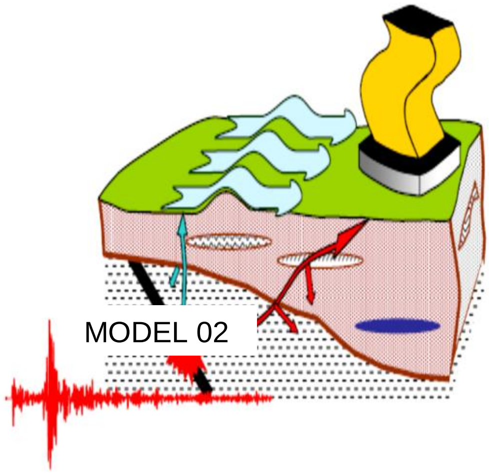


Fig. 14 Acceleration in ground due to earthquake

a) Linear Response Spectrum Analysis –

1. Total no. of modes to be taken at a time for analysis = 30
2. The values for the analysis (Design acceleration coeff MODEL 04 ing) are taken as per Fig. 2 of IS 16.
3. The overall response will be combined as per CQC (Combined Quadratic Response) Approach.
4. Separate analysis will be done for zone III & zone IV for calculation of Base Shear, Storey Displacement & Storey Drift.

b) Non Linear Time History Analysis -

I. The recorded data for the analysis is of El Centro earthquake from Array Recording Station, USA. At time interval of .010 sec.

II. Since the analysis is not considering the seismic zones in India, thus the there is no significance of them. So, all the models will be analyzed only once for Non Linear Time History Analysis for the results like - Spectral Displacement, Joint Displacement at top storey, Base Force in X & Y direction.

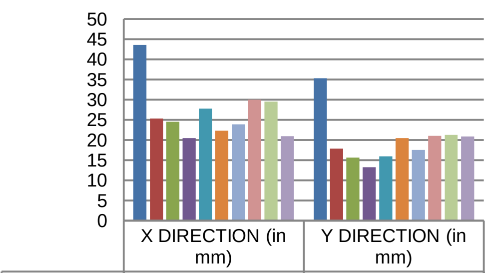
C. Areas of Comparison –

The models will be compared on the following ground in order to determine the optimum position of shear wall in the irregular shaped building –

- Storey Displacement
- Storey Drift
- Base Shear
- Spectral Displacement
- Joint Displacement at the terrace level because of Time History Data
- Base Force at the foundation level because of the Time History Data

III. RESULTS

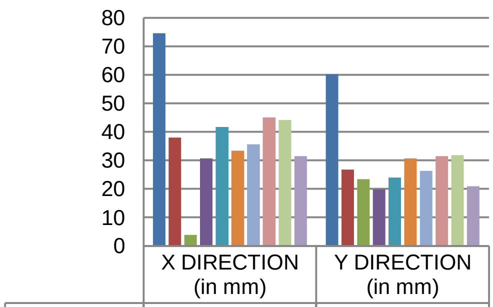
A. Storey Displacement by Linear Response Spectrum Method at ZONE III -



	X DIRECTION (in mm)	Y DIRECTION (in mm)
Bare Model	43.53	35.3
Model 01	25.3	17.83
Model 02	24.52	15.59
Model 03	20.43	13.23
Model04	27.78	15.95
Model 05	22.28	20.49
Model 06	23.84	17.55
Model 07	30.01	21.01
Model 08	29.47	21.24
Model 09	20.97	20.88

Fig. 15

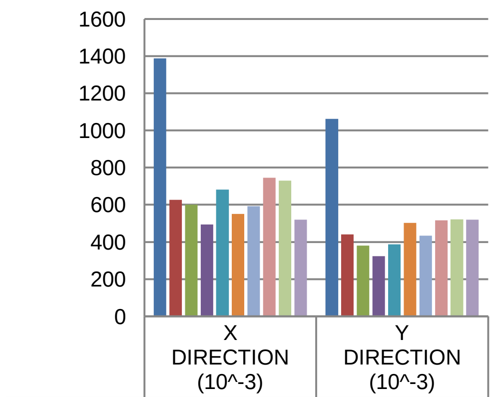
B. Storey Displacement by Linear Response Spectrum Method at ZONE III –



	X DIRECTION (in mm)	Y DIRECTION (in mm)
Bare Model	74.61	60.17
Model 01	37.96	26.75
Model 02	3.86	23.44
Model 03	30.74	19.85
Model04	41.68	23.93
Model 05	33.42	30.74
Model 06	35.68	26.28
Model 07	45.01	31.52
Model 08	44.21	31.86
Model 09	31.46	20.88

Fig. 16

C. Storey Drift by Linear Response Spectrum Method at ZONE III –



	X DIRECTION (10^-3)	Y DIRECTION (10^-3)
Bare Model	1387	1063
Model 01	626	440
Model 02	601	380
Model 03	494	324
Model04	682	388
Model 05	550	503
Model 06	593	433
Model 07	746	517
Model 08	730	522
Model 09	520	520

Fig. 17

D. Storey Drift by Linear Response Spectrum Method at ZONE IV –

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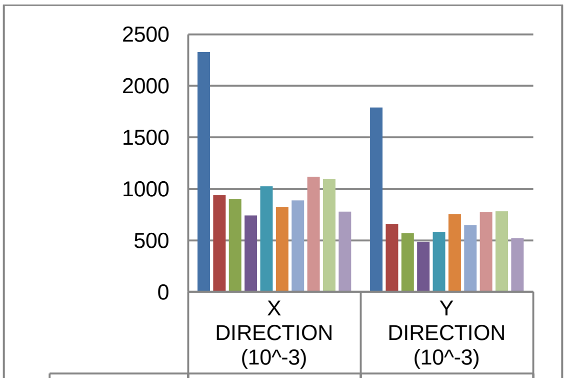
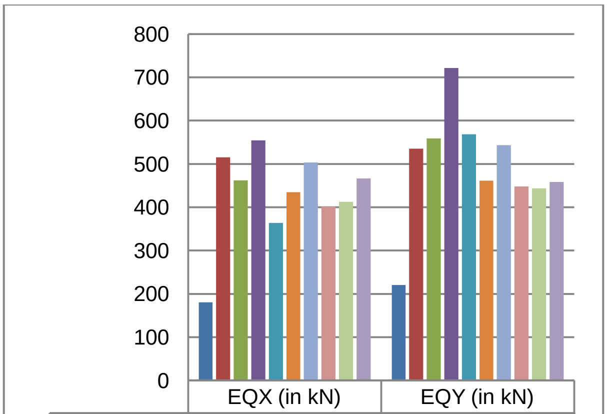


	X DIRECTION (10^-3)	Y DIRECTION (10^-3)
Bare Model	2328	1791
Model 01	939	661
Model 02	903	571
Model 03	742	486
Model04	1023	582
Model 05	825	755
Model 06	889	648
Model 07	1119	776
Model 08	1095	783
Model 09	780	520

Fig. 18

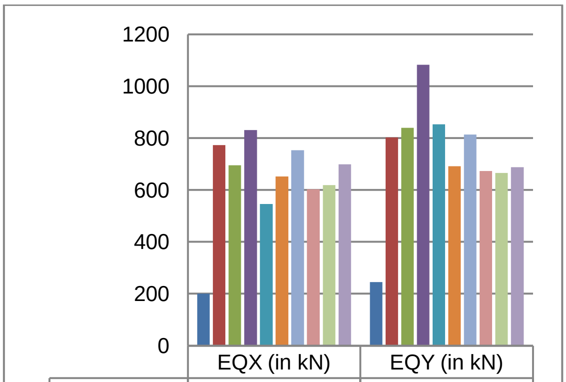
E. Base Shear by Linear Response Spectrum Method at ZONE III -



	EQX (in kN)	EQY (in kN)
Bare Model	180.5	220.7
Model 01	515.39	534.82
Model 02	462.39	558.8
Model 03	554.2	721.45
Model04	363.6	568.8
Model 05	434.94	461
Model 06	503.65	543
Model 07	401.5	448
Model 08	412.2	443.6
Model 09	466.2	458.15

Fig. 19

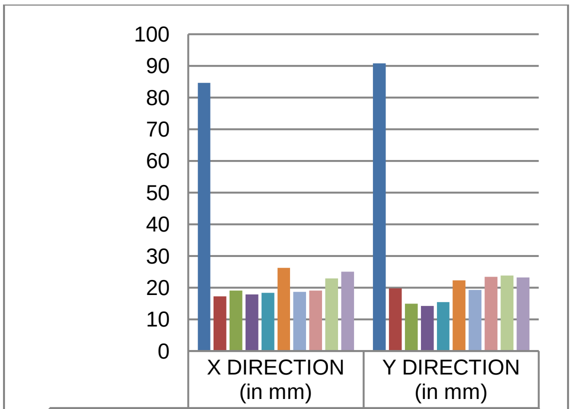
F. Base Shear by Linear Response Spectrum Method at ZONE IV –



	EQX (in kN)	EQY (in kN)
Bare Model	200.5	245.08
Model 01	773	802
Model 02	694.7	839.9
Model 03	831.35	1082.18
Model04	545.44	853.26
Model 05	652.41	691.55
Model 06	753.68	814.03
Model 07	602.9	672.37
Model 08	618.417	665.43
Model 09	699.3	687.23

Fig. 20

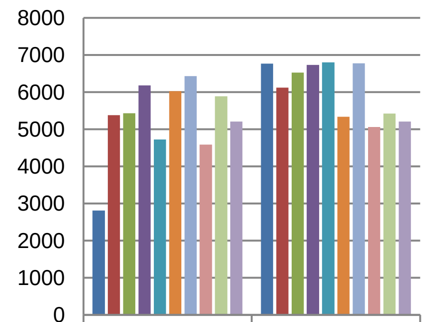
G. Joint Displacement by Time History Record –



	X DIRECTION (in mm)	Y DIRECTION (in mm)
Bare Model	84.6	90.8
Model 01	17.3	19.76
Model 02	19.07	14.89
Model 03	17.9	14.25
Model04	18.37	15.41
Model 05	26.24	22.34
Model 06	18.67	19.29
Model 07	19.11	23.38
Model 08	22.9	23.8
Model 09	25.04	23.21

Fig. 21

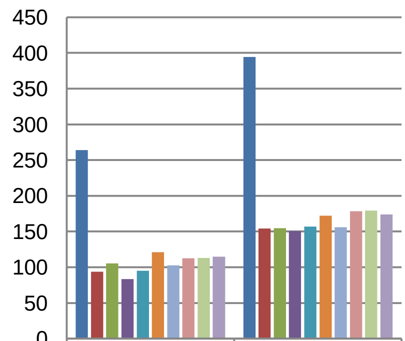
H. Base Force by Time History Record –



	X DIRECTION (in kN)	Y DIRECTION (in kN)
Bare Model	2809	6763.17
Model 01	5375	6116
Model 02	5430.66	6527
Model 03	6177.2	6729
Model04	4720.8	6802.57
Model 05	6025	5333.9
Model 06	6425.4	6774.4
Model 07	4582	5057.6
Model 08	5884	5417
Model 09	5201	5200

Fig. 22

I. Spectral Displacement at 5% damping by Time History Record –



	X DIRECTION (in mm)	Y DIRECTION (in mm)
Bare Model	263.8	394.24
Model 01	93.86	154.09
Model 02	105.59	154.72
Model 03	83.39	150.64
Model04	95.01	156.9
Model 05	121.25	172
Model 06	102.64	155.9
Model 07	112.72	178.41
Model 08	113.19	179.1
Model 09	114.7	174.03

Fig. 23

A. Comparison –

After the comparison of above results from both linear and non linear analysis, the configuration of MODEL 03 is found to be the best in order to resist the lateral forces.

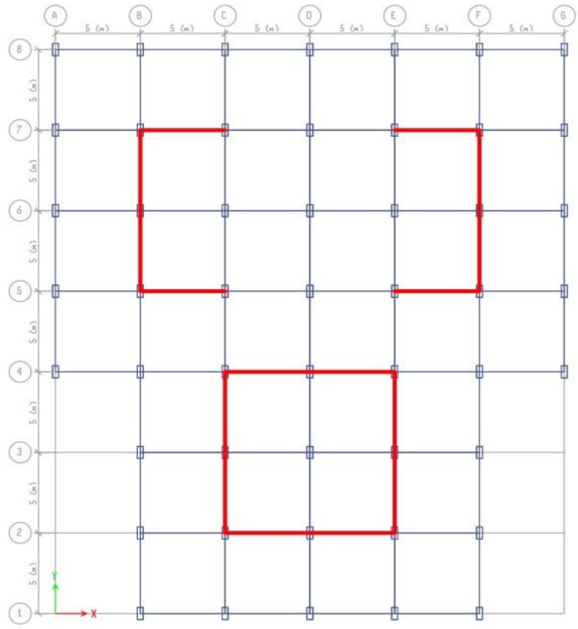


Fig. 24 Shear Wall Configuration for Model – 03

B. Discussion -

The discussion about the extreme response from above comparisons are given below-

1) Storey Displacement–

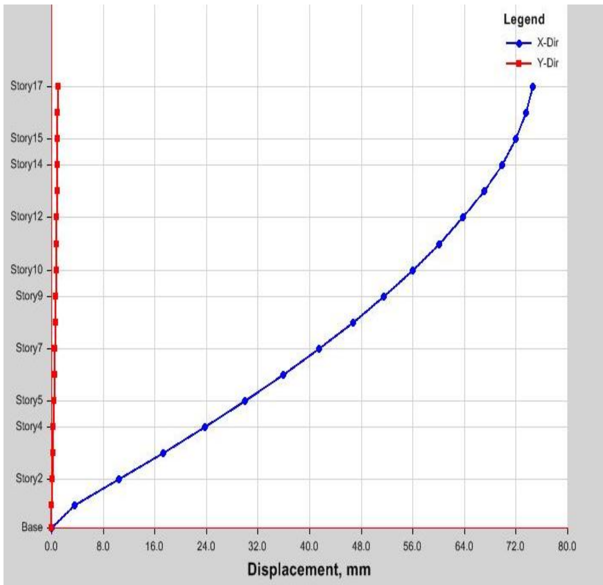


Fig. 25 Storey Displacement in X direction of Bare Model

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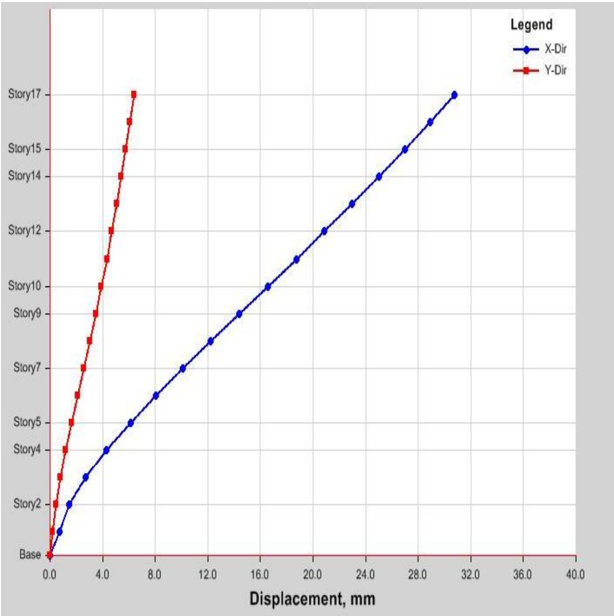

Fig. 26 Storey Displacement in X direction of Model 03

The lateral displacement increases because of lower value of stiffness provided by shear wall. Apart from that, mass of the building is defining factor for inertia forces, thus if it is distributed evenly, we will have favorable results. MODEL 03 is providing maximum resistance against lateral displacement because it has got such a configuration that provides better stiffness to the structure and at the same time the distribution of mass is also better.

2) Base Shear–

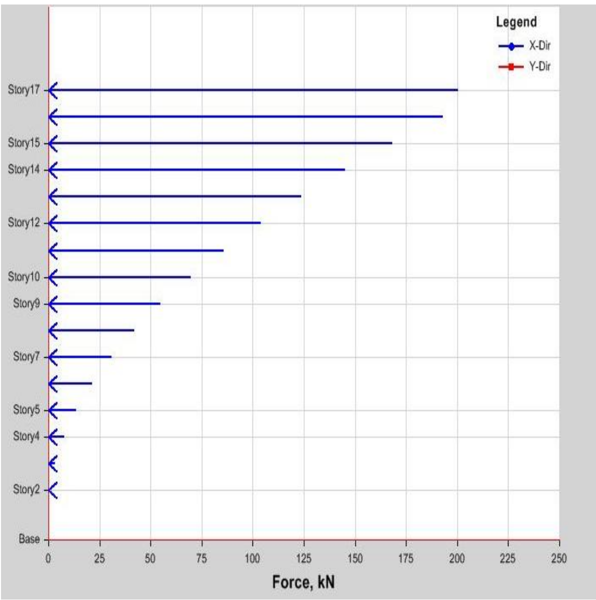

Fig. 27 Earthquake Forces along X direction of Bare Model

Base Shear is defined as the maximum seismic load subjected to the building during an earthquake. Due to position of shear wall, the earthquake forces increase in the building. This indicates that the stiffness of the building is increased by placing shear wall. This is in turn giving more force absorption in the structure. Thus in this manner, the buildings are able to resist moderate earthquake with vary less damage to the structural elements as described in section 1.3.

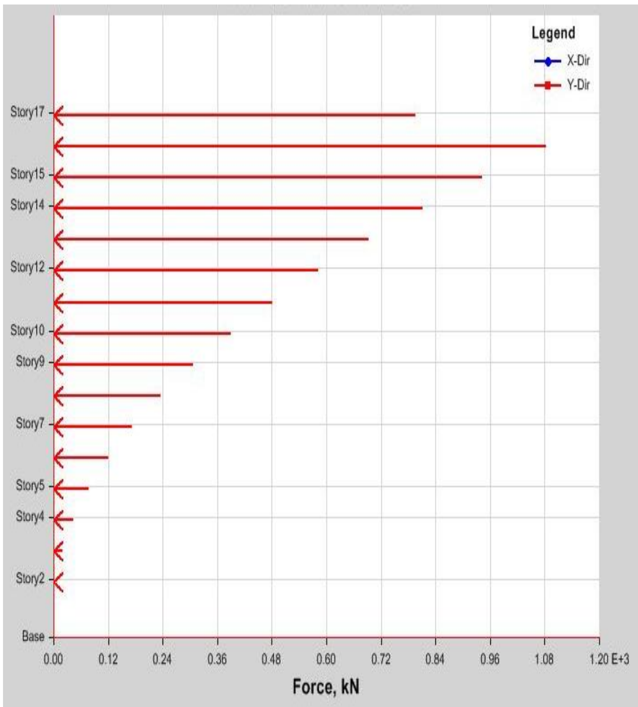

Fig. 28 Earthquake Forces along X direction of Model 03

3) Joint Displacement at terrace level due to Time History Data -

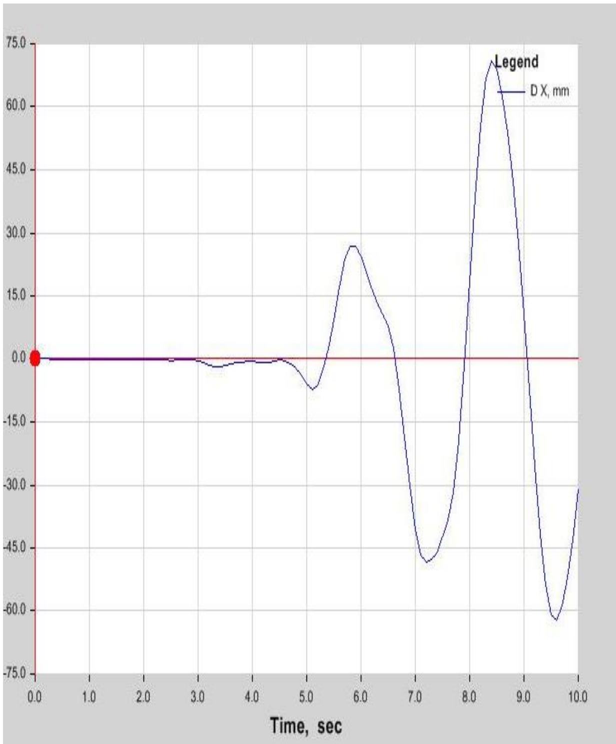

Fig. 29 Joint Displacement at terrace level due to Time History Data along X direction in Bare Frame Model

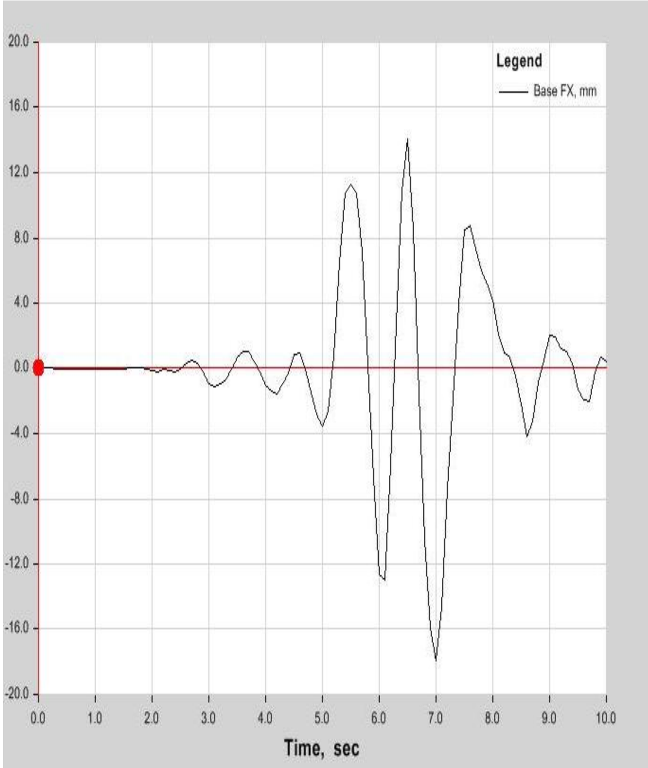

Fig. 30 Joint Displacement at terrace level due to Time History Data along X direction in Model 03

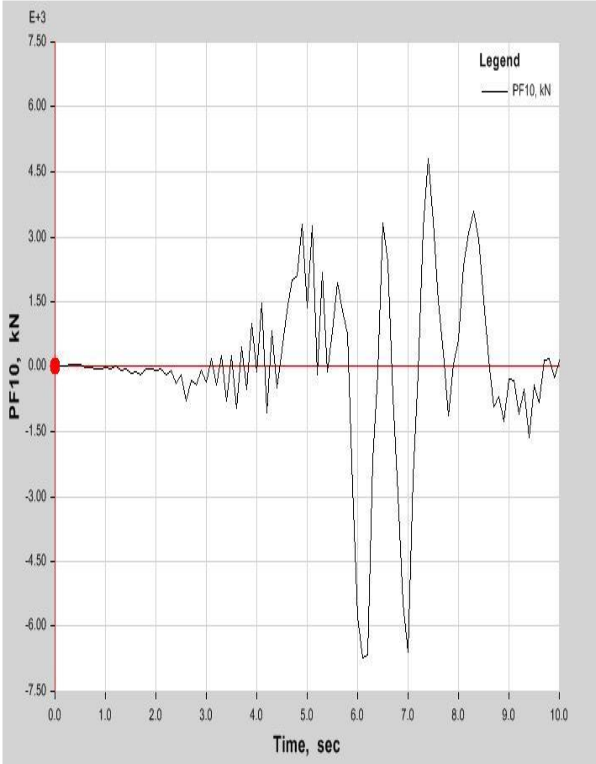

Fig. 32 Base Force due to Time History Data for Model 03 in X direction

4) Base Force due to Time History Data –

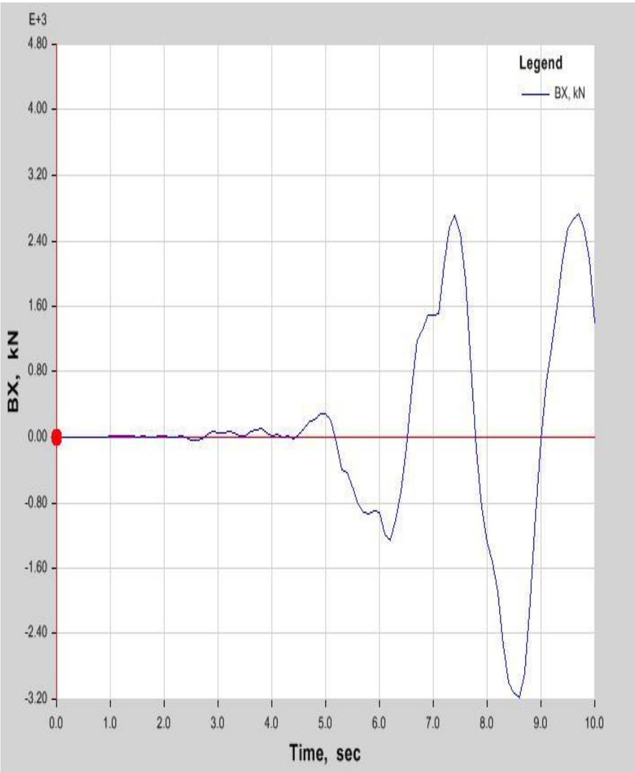

Fig. 31 Base Force due to Time History Data for Bare Frame Model in X direction

5) Spectral Displacement due to Time History Data-

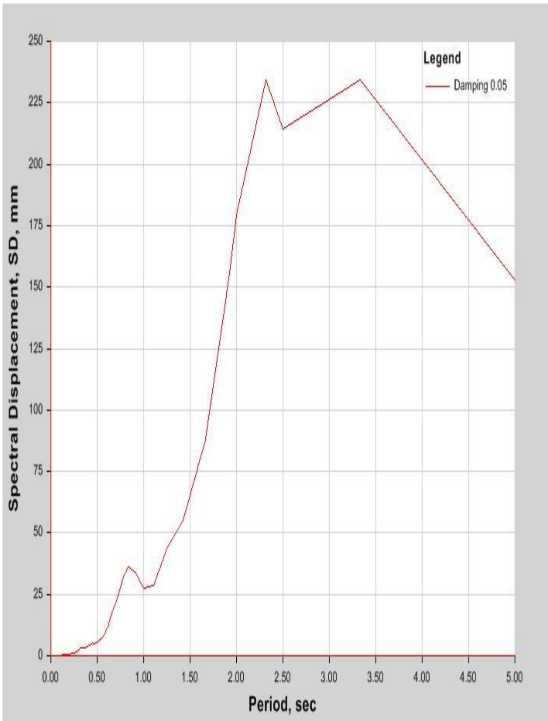

Fig. 33 Spectral Displacement due to Time History Data for Bare Model in X direction

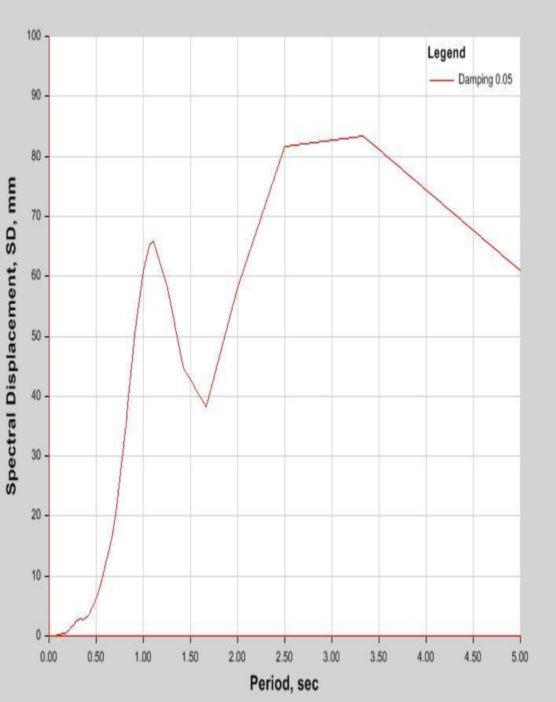

Fig. 34 Spectral Displacement due to Time History Data for Model 03 in X direction

Discussion for Time History Analysis

- Joint Displacement due to Time History Record is very high because this is a result of non linear analysis from the extreme earthquake data.
- Base Force is introduced at the base of building in terms of reaction from the ground acceleration record. These values are also very high but after the introduction of shear wall, there is rapid variation in the values.
- Spectral Displacement is defined as peak response in terms of displacement plot for varying frequencies. The above plots are defined from the records of El Centro Earthquake from Array Recording Station, USA. At 5% damping. The shear wall configuration easily reduces the spectral displacement.

IV. CONCLUSION

From the comparative study, it was concluded that location of shear wall plays a very important role in increasing the resistance against the lateral forces. The location should be such that it should distribute the gravity loads and the lateral loads such that the building retains it centre of gravity in best way possible.

Configuration of MODEL 03 is such that it easily distributes the lateral forces in best possible manner. Thus, this reduces the values of Spectral Displacement, Storey drift, Storey Displacement due to earthquake forces. Apart from that, seismic forces increase in the buildings in terms of base shear. This indicates that building with shear wall is able to capture more seismic loads.

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AUTHORS PROFILE

Rajiv Banerjee is currently pursuing Ph. D from Dr. A.P.J. Abdul Kalam Technical University, Lucknow, India. He did his B.Tech in 1984 from Institute of Technology, Banaras Hindu University (Now IIT-BHU), Varanasi and M.E. from All India Institute of Public Health & Hygiene, Kolkata. He has worked in Municipal Engineering Directorate, Govt. of West Bengal in capacity as an Assistant Engineer and Executive Engineer for 24 years. He also worked as Consulting Engineer in School Service Commission, Govt. of West Bengal. He has served in Gannon Dunker Lay Ltd. & Company as an Engineer. He has an industry experience of 27 years as well as an academic experience of 8 years. He is a member of Institution of Engineers, India.

Dr. J. B. Srivastava is a Professor in Institute of Engineering and Technology, Lucknow, India. He obtained his B.Tech in Civil Engineering from NIT – Warangal in year 1982. He got admitted in M.E. for Transportation Engineering in year 1982 and completed his P.G. Course in 1987. He worked as a research associate in IIT – Roorkee in a Govt. of India Project. He started his teaching job as a Lecturer at Madan Mohan Malviya Engineering College, Gorakhpur. Later he was selected for Ph.D program in QIP scheme (GOI) at IIT – Roorkee in 1990 and completed Ph. D in Civil Engineering in 1995. He joined Institute of Engineering and Technology, Lucknow as a Professor on 5th February, 2004. He also served as Head of Department of Civil Engineering for two terms. He is nominated as a Director in the Board of U.P. Samaj Kalyan Nigam Ltd. He is a Coordinator for Pradhamantri Gram Sadak Yojna, Govt. of India. He has guided two Ph.D Thesis and many M.Tech Dissertations. He has also published more than 30 papers. He is member in various selection boards inclusing Uttar Pradesh Lok Seva Ayog, Allahabad.