Effect of Openings in Shear wall on Seismic Behaviour of Regular and Irregular Buildings Using ETABS

K.Srinivasa Rao[1] Y.Dhana Lakshmi[2] Dr.N.C.Anil[3] V.V.Amar Narasing Rao[4]
[2,4]Assistant Professor [3]Associate Professor
[1,2,3,4]Department of Civil Engineering
[1,2,3,4]Sanketika Vidya Parishad College of Engineering, India

Abstract— Shear wall system is one of the lateral resisting system and most commonly used in high rise buildings. They contribute in absorbing shear forces, moments and reduce torsional response during seismic excitation. Generally, architectural design contains openings in shear wall due to functional requirements such as door, windows and other openings. This study outlines the seismic behaviour or performance of multi-storied regular and horizontally irregular buildings with shear wall and the effect of openings in shear wall. For this study, a G+15 story structure with shear wall have been considered. The modelling and analysis has been carried out using ETABS 2018 software and for analysis Response Spectrum Analysis has been done. After analyzing the models, the effect of opening sizes are compared for the results of parameters like story displacement, story drift and base shear in both regular and irregular buildings.

Keywords: Horizontal Irregularity, Shear Wall, Openings, Seismic Performance, Response Spectrum Analysis, ETABS, Story Drift, Story Displacement, Base Shear

I. Introduction

Shear wall is a vertical member that can resist lateral forces directed along its orientation. Shear walls are structural system consisting of braced panels, also known as Shear Panels. Concrete Shear walls are widespread in many earthquake-prone countries like Canada, Turkey, Romania, Colombia, and Russia. Shear walls helps to minimize the beam and column dimension. It also reduces the cost. The provision of shear walls enhances stiffness and strength. Generally , shear wall is provided in the range of thickness from 200 to 400mm.The steel required for the shear wall is of minimum percentage is 0.25% and maximum 4%.Shear walls which decreases the damage to the structure by decreasing the sway in lateral. Shear wall represents a structurally efficient solution to stiffen a structural system because the main function of a shear wall is to increase the rigidity against lateral load. When a building has a story without shear wall, or with poorly placed shear walls, it is known as a soft story building. Shear walls of varying cross sections i.e. rectangular shapes to more irregular cores such as channel, T, L, barbell shape, box etc. can be used.

II. Literature review

Wesam Al Agha, Nambiappan Umamaheswari et al.[1], performed seismic analysis of buildings by using Equivalent Static and Response Spectrum method, it is essential to determine the characteristics of seismic evaluation like base shear, fundamental natural period, displacement, and bending moment values. The results carried out by (ETABS) finite element program in which irregular configuration building with two structural system. The results is conducted that the values increased in Response Spectrum Method over than Equivalent Static Method with the both direction (X, Y) of all models excepting there are differences of maximum top story displacement in X - direction by comparing between Response Spectrum Method and Equivalent Static Method, especially in model (3, 7). Otherwise, it was Duel structural system in some models.

Prit B Sathwara, Abbas Jamani et al.[2], carried out dynamic analysis on two types of vertical geometric irregular frame are taken in this project such as Set back frame and Step Frame. Also vertical geometric irregular frames are analyzed with having one story basement. Total 32 model are considered in this project such as 8 types (One Regular type RC Frame, four type of Set Back Irregular frame and three type of Step Irregular frame) of frame are having modeled as one irregular frame, second Shear Wall at core, third is shear wall at Periphery and fourth is irregular frame with Basement. Linear Static Dynamic Analysis such as Response Spectrum Analysis has been carried out for seismic zone V specified in IS 1893 (Part I): 2016 to understand the performance characteristics of the irregular frame in comparison with regular RC frame. All building frames are modeled & analyzed in software ETABS 2018. Regular frame with shear wall shows maximum value of base shear. Also regular frame with basement shows the maximum time period among all models. Step frame with basement shows maximum value of story drift while step frame without shear wall gives maximum value of top story displacement. The entire frame with basement gives higher value of story stiffness.

The effective of shear wall in terms of structural in symmetrical structures was studied by Dinesh Kumar, Mr. Nandeswar Lata, Dr. Bharat Nagar [3]. In this study, seven frame models are considered having different arrangement of shear wall. These frame models are subjected to perform Equivalent Linear Static Analysis and Response Spectrum Analysis with the help of platform ETABS 16.2.1. Both the analysis are carried out under the guidelines of IS: 1893 (Part 1)-2002 in the form various load combinations. Various parameters such as maximum lateral displacement, story drift and story shear are evaluated from the both analyses and best arrangement of shear wall is suggested, which is at corners.

III. Methodology

A. *Building Modelling*

For this study, a 1G+15-storey building with a 3-meters height for each story is modeled. These buildings were designed in compliance to the Indian Code of Practice for Seismic Resistant Design of Buildings .The buildings are assumed to be fixed at the base and the floors acts as rigid diaphragms. The sections of structural elements are square and their dimensions are changed for different building. Story heights of buildings are assumed to be constant. The buildings are modelled using software ETABS 2018. Three different models were studied with regular and horizontal irregularities in building with shear walls at corners. Models are studied for various opening sizes comparing base shear, lateral displacement, and story drift for all models.

The approximate fundamental translational natural period T_a (sec) is calculated in both X & Y directions as per clauses 7.6.2(a), and 7.6.2(b) of IS 1893(Part1) : 2016, and are shown below:

For Bare RC frames without shear walls,

$T_a = 0.075h^{0.75}$,as per clause 7.6.2(a) of IS 1893(Part1) : 2016

For buildings with RC structural walls (Shear walls),

$T_a = \frac{0.075h^{0.75}}{\sqrt{A_w}} \geq \frac{0.09h}{\sqrt{d}}$,as per clause 7.6.2(b) of IS 1893(Part1) : 2016

Where A_w is total effective area (m^2) of walls in the first story of the building given by:

$$A_w = \sum_{i=1}^{N_w}\left[A_{wi}\left\{0.2 + \left(\frac{L_{wi}}{h}\right)^2\right\}\right]$$

where

h = height of building (m)

A_{wi} = effective cross-sectional area of wall *i* in first story of building (m^2)

L_{wi} = length of structural wall *i* in first story in the considered direction of lateral forces (m)

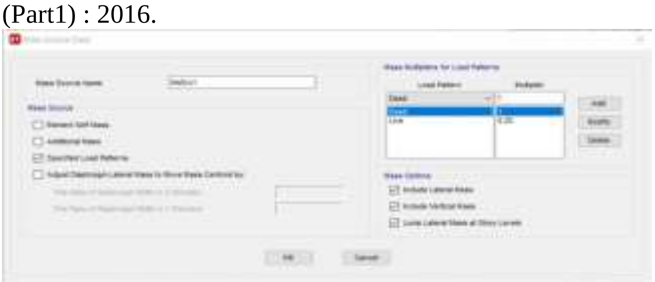
d = base dimension of the building at the plinth level along the considered direction of earthquake shaking (m), and

N_w = number of walls in the considered direction of earthquake shaking.

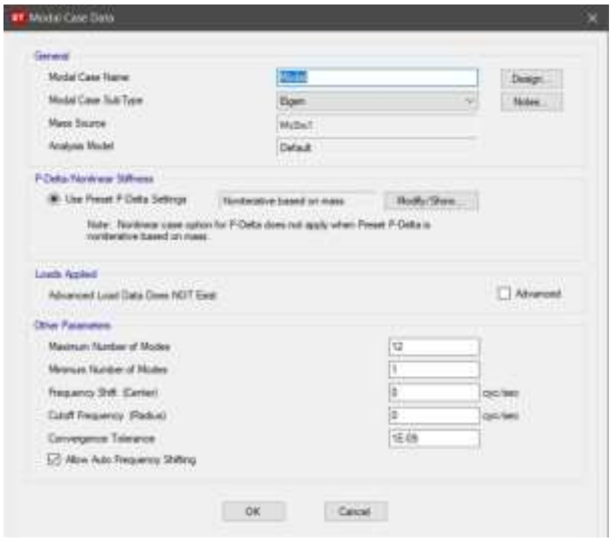
The value of L_{wi}/h to be used in this equation shall not exceed 0.9.

The value of T_a that is calculated using the formulas is found to be > 0.4 sec. So, the dynamic analysis shall be performed for the modelled buildings, as per clause 6.4.3 of IS 1893 (Part1) : 2016. And Response Spectrum Analysis (Linear Dynamic Analysis) is adopted as per clause 7.7.1 of IS 1893 (Part1) : 2016.

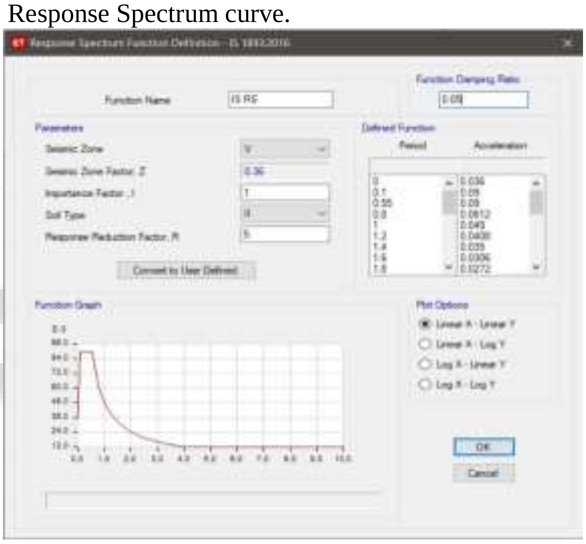
Defined the mass source in ETABS 2018 as shown below. The live load is considered 25% in mass source for calculation of Seismic weight as per Table 10 of IS 1893 (Part1) : 2016.



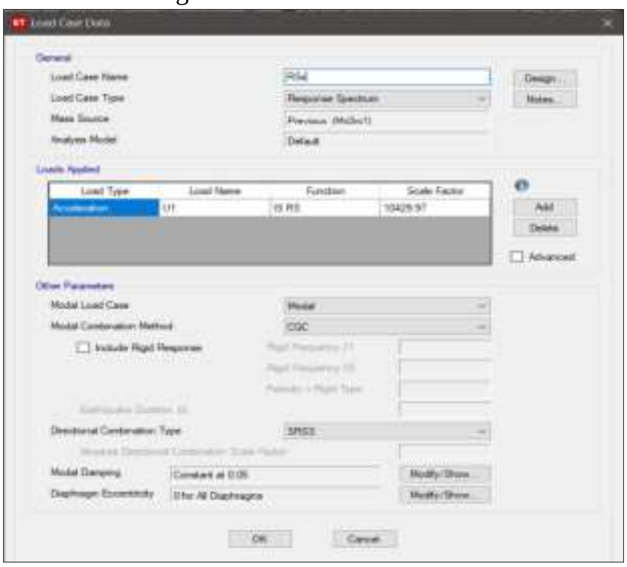
The Modal case with Eigen Modal Type is defined as shown below for Horizontal acceleration U1, and U2. Eigen mode are most suitable for determining response from horizontal ground acceleration. And Ritz mode are most suitable for determining response from vertical ground acceleration. Both Eigen and Ritz modes may be calculated simultaneously, in the same model, and in the same analysis run, so that their behavior can be compared.



The Response Spectrum Function for horizontal acceleration is defined in ETABS 2018 as per code, and shown in the figure below. The damping ratio is considered as 5%. Damping ratio identifies the damping used to generate the Response Spectrum curve.

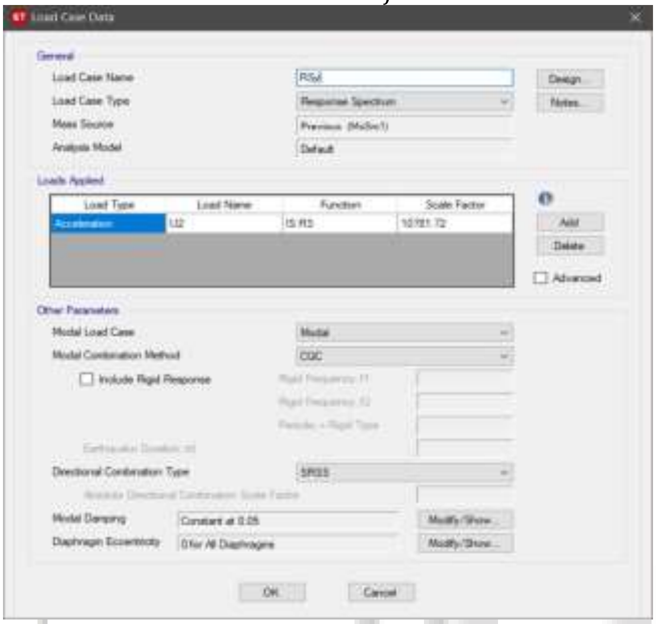


Defined the Response Spectrum load cases in X and Y direction as shown below. The scale factor used is Ig/2R as per CSI Knowledge Base of ETABS for Indian Code.



Ran the analysis with the scale factor Ig/2R and found the base shear for EQ (Earthquake) load case and RS (Response Spectrum) load case are not equal in both X and Y directions. Then the scale factor is rescaled by the formula shown below to match the base shear values of EQ and RS load cases.

$$Rescaled\ Scale\ Factor = \left(\frac{Ig}{2R}\right) x \left(\frac{Base\ Shear\ of\ EQ\ load\ case}{Base\ Shear\ of\ RS\ load\ case}\right)$$



IV. RESULTS AND DISCUSSIONS

A. Introduction

The results of seismic parameters for regular and horizontal irregular building models (L-Shape & U-Shape) with shear wall and various sizes of openings by Response Spectrum Analysis using ETABS software are presented in this chapter. The seismic parameters that are considerd in the present study are as follows:

1) Base Shear
2) Story Displacement
3) Story Drift

B. Model Description

For analysis, a G+15 story building is modeled in ETABS. The building does not represent any real existing building.The building have been analyzed by Response Spectrum Analysis, which is a linear dynamic analysis. Dynamic Analysis is adopted since it gives better results than static analysis. The specifications of the frame are given in Table 4.1.

The buildings are modelled with shear walls at corners, and the effect of openings in shear wall are presented in the study. Various sizes of openings and changing shape of openings have been performed and investigation the optimum results of model has been studied. The various shapes of building and sizes of openings in shear wall as shown in Table 4.2. The nomenclature used for the model ID is REG represents the regular building, LS represents the L-shaped building, and US represents the U-Shaped building.

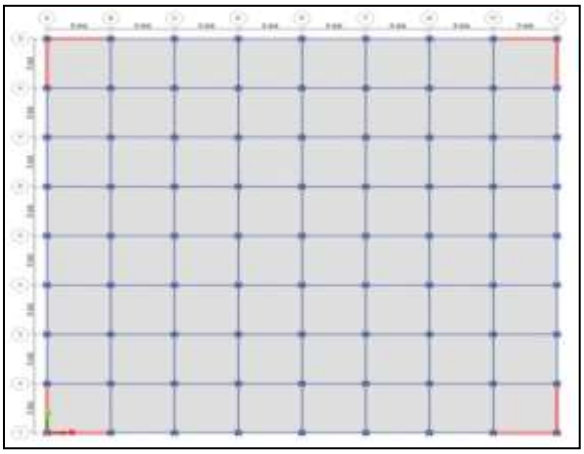
Geometric Parameters	
Typical Storey Height	3m
Bottom Storey Height	5m
Number of Floors	G+15
Total dimension of plan in X-direction	8 bays @ 5m = 40m
Total dimension of plan in Y-direction	8 bays @ 5m = 40m
Dimension of Members	
Column Size	600mm x 600mm
Beam Size	300mm x 530mm
Slab Thickness	150mm
Thickness of Shear Wall	150mm
Material Properties	
Grade of Concrete	M30
Grade of Steel	Fe 500
Loads	
Live Load	3 KN/m2
Floor Finish Load	1 KN/m2
Wall Load	13 KN/m
Seismic Load	As per IS1893:2016
Seismic Parameters	
Seismic Zone Factor	0.36 (Zone-V)
Response Reduction Factor	5
Importance Factor	1
Type of Soil	Medium (II)
Damping Ratio	5%

Table 1: Building Description

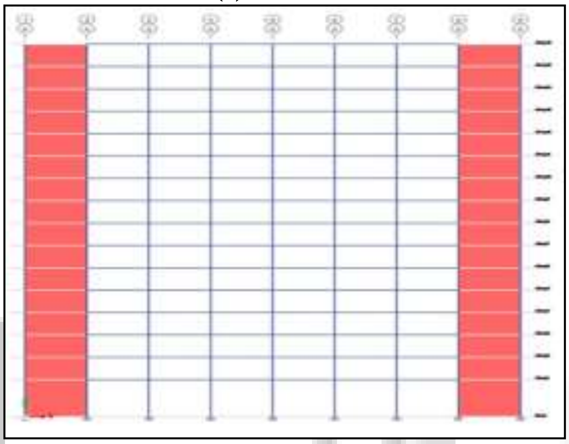
Model ID	Shape of Building	Opening size in Shear Wall (mxm)	Percentage of Opening (%)
REG1	Regular	-	0
REG2		0.8x0.6	3.2
REG3		1.2x1.4	11.2
REG4		2.0x1.4	18.67
REG5		2.4x1.6	25.6
LS1	L - Shape	-	0
LS2		0.8x0.6	3.2
LS3		1.2x1.4	11.2
LS4		2.0x1.4	18.67
LS5		2.4x1.6	25.6
US1	U - Shape	-	0
US2		0.8x0.6	3.2
US3		1.2x1.4	11.2
US4		2.0x1.4	18.67
US5		2.4x1.6	25.6

Table 2: Model Description and various sizes of openings

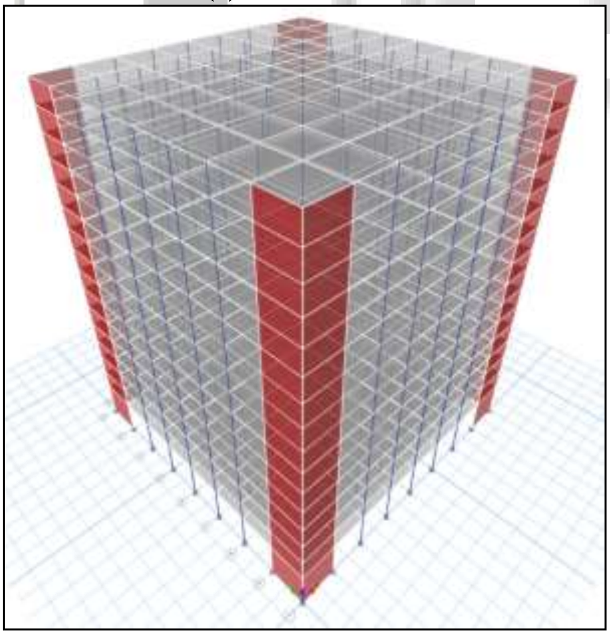
The plan, elevation, 3D view, and 3D view with openings of the building is shown in Fig. 4.1 for Regular building, in Fig. 4.2 for L-Shape building, and in Fig 4.3 for U-Shape building. In the entire study, X and Y are taken as the horizontal axes and Y as the vertical axis.



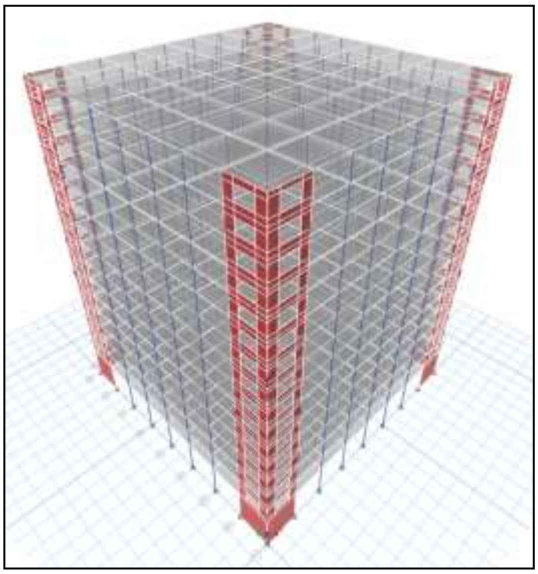
(a) Plan view



(b) Elevation view

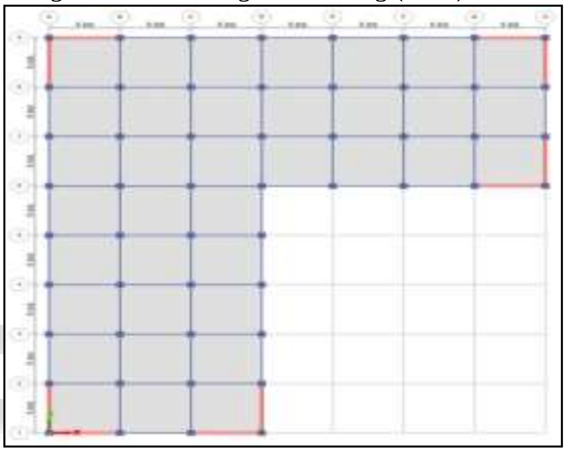


(c) 3D view

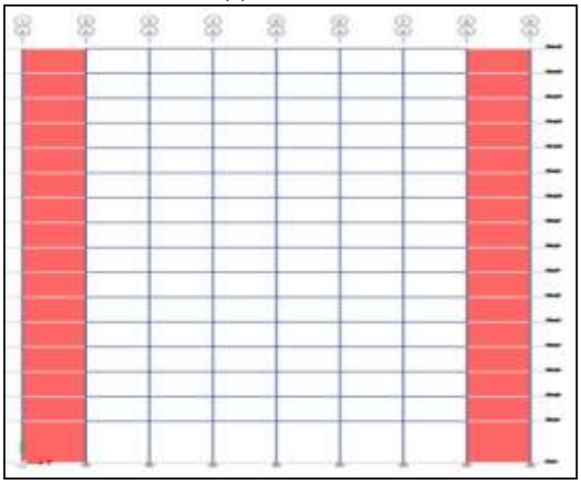


(d) 3D view with openings

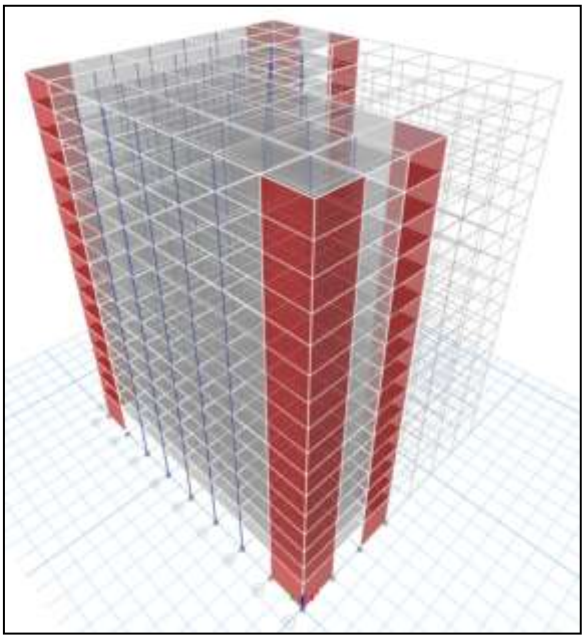
Fig. 1: Views of Regular building (REG) model



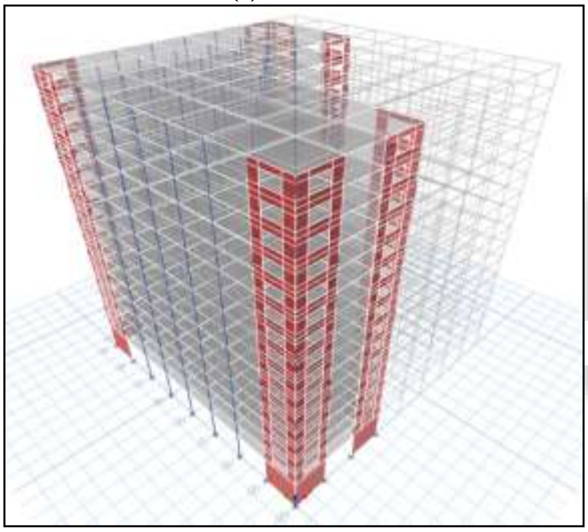
(a) Plan view



(b) Elevation

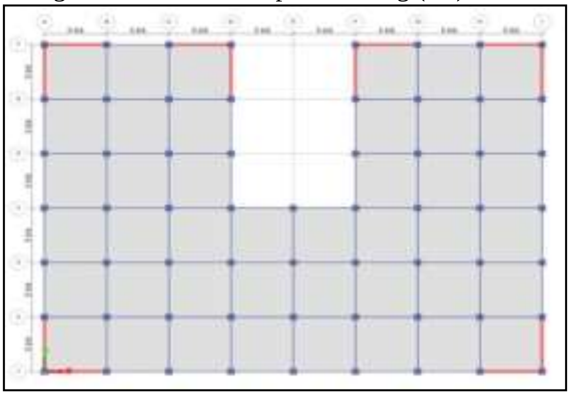


(c) 3D view

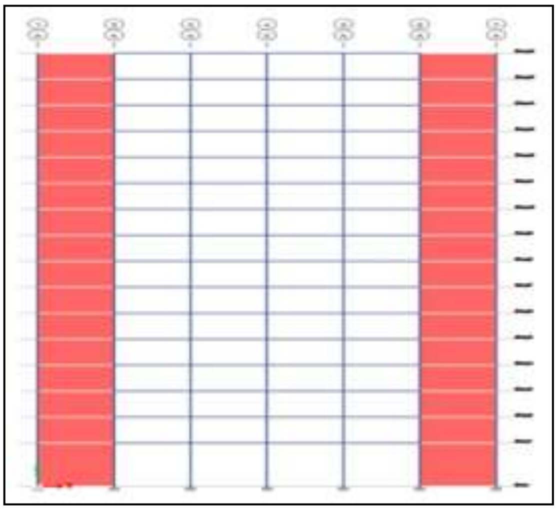


(d) 3D view with openings

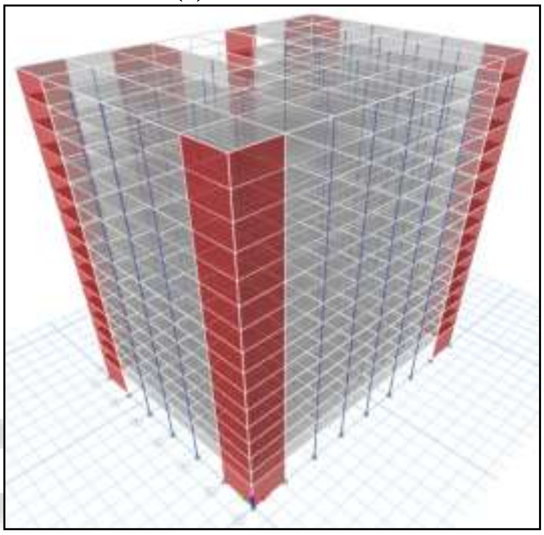
Fig. 2: Views of L-Shaped building (LS) model



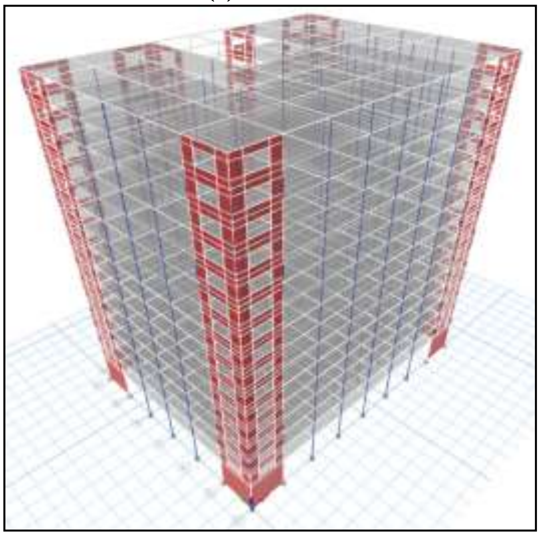
(a) Plan view



(b) Elevation view



(c) 3D view



(d) 3D view with openings

Fig. 3: Views of U-Shaped building (US) model

C. Base Shear

In this section, the base shear obtained in X & Y directions by analyzing the 15 models shown in Table 4.2 using Response Spectrum Analysis. The effect of opening sizes on base shear for various building shapes are presented in tabular form in Tables 4.3.1, 4.3.2, 4.3.3 and also represented in graphical form in Fig. 4.4.1, 4.4.2, 4.4.3 for Regular, L-shaped, and U-shaped buildings respectively.

Model ID	Base Shear (KN)	
	In X - Direction	In Y - Direction
REG1	7654.4915	7654.4915
REG2	7630.3942	7630.3942
REG3	7523.3483	7523.3483
REG4	7412.963	7412.963
REG5	7138.2227	7138.2227

Table 3: Base Shear for Regular building models in both X & Y directions

Model ID	Base Shear (KN)	
	In X - Direction	In Y - Direction
LS1	5330.8812	5512.2482
LS2	5295.3621	5468.5593
LS3	5219.507	5382.056
LS4	5076.8465	5216.2203
LS5	4925.4129	5042.424

Table 4: Base Shear for L-Shaped building models in both X & Y directions

Model ID	Base Shear (KN)	
	In X - Direction	In Y - Direction
US1	6285.6838	6386.7292
US2	6258.1168	6359.1228
US3	6140.9062	6243.8995
US4	5956.8862	6061.7291
US5	5763.0537	5870.2253

Table 5: Base Shear for U-Shaped building models in both X & Y directions

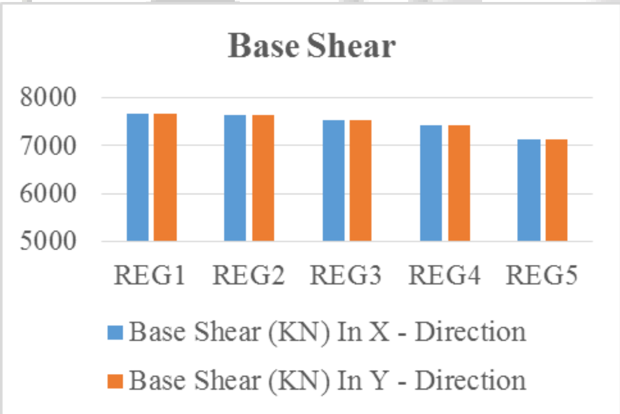


Fig 4: Base Shear for Regular building models in both X & Y directions

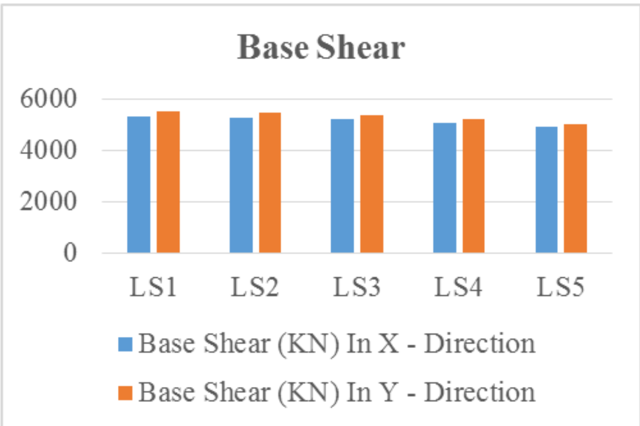


Fig 5: Base Shear for L-Shaped building models in both X & Y directions

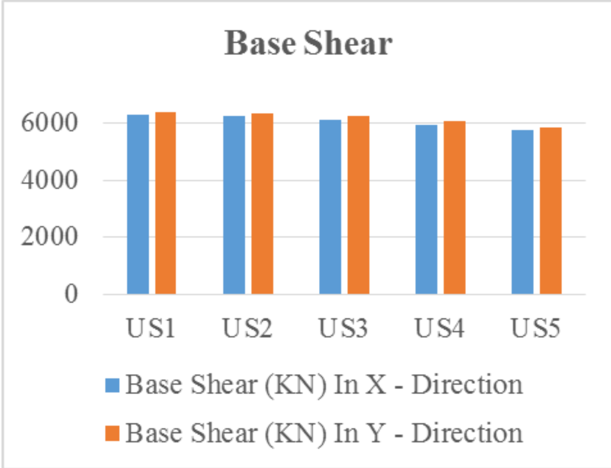


Fig 6: Base Shear for U-Shaped building models in both X & Y directions

V. STORY DISPLACEMENT

The displacements at each story in both directions for all the 15 models considered in the study are presented in tabular and graphical forms. The dispacements are shown in table 4.4.1 and Fig. 4.5.1 for regular buildings, in tables 4.4.2(a), 4.4.2(b) and Fig. 4.5.2(a), 4.5.2(b) for L-shaped building in X, Y directions respectively, in tables 4.4.3(a), 4.4.3(b) and Fig. 4.5.3(a), 4.5.3(b) for L-shaped building in X, Y directions respectively. In all the models it is observed that the displacement is increasing with increase in opening size.

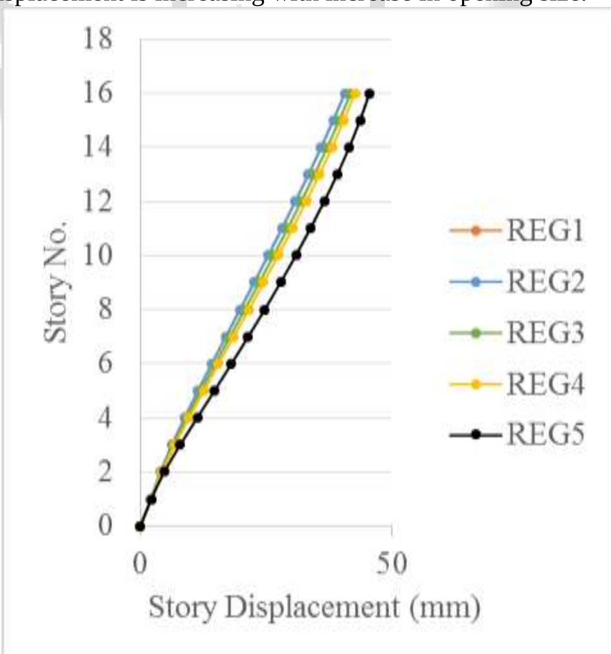


Fig. 7: Story Displacement for Regular building models in both X & Y directions

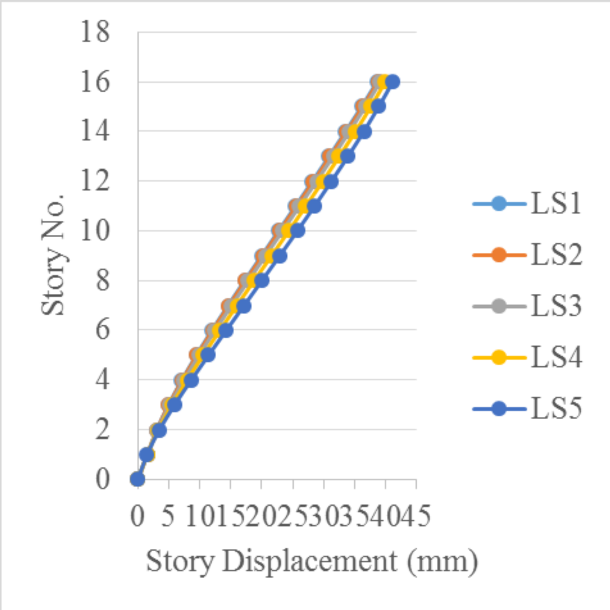


Fig. 8: Story Displacement for L-Shaped building models in X direction

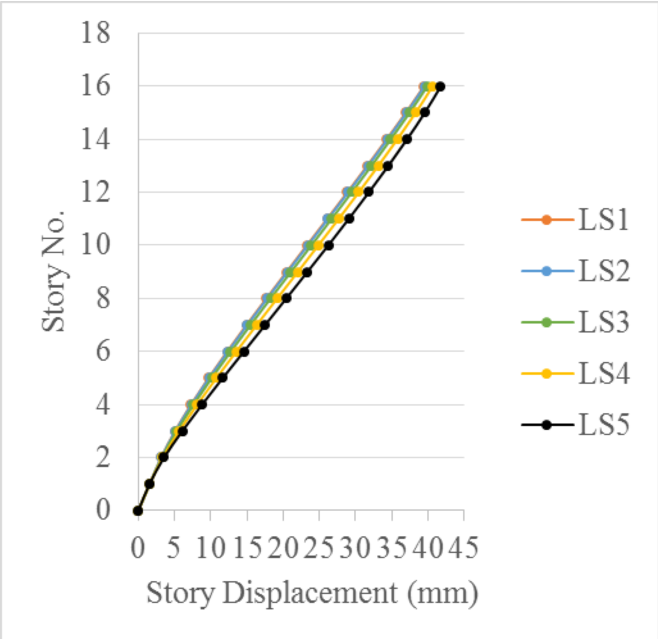


Fig. 9: Story Displacement for L-Shaped building models in Y direction

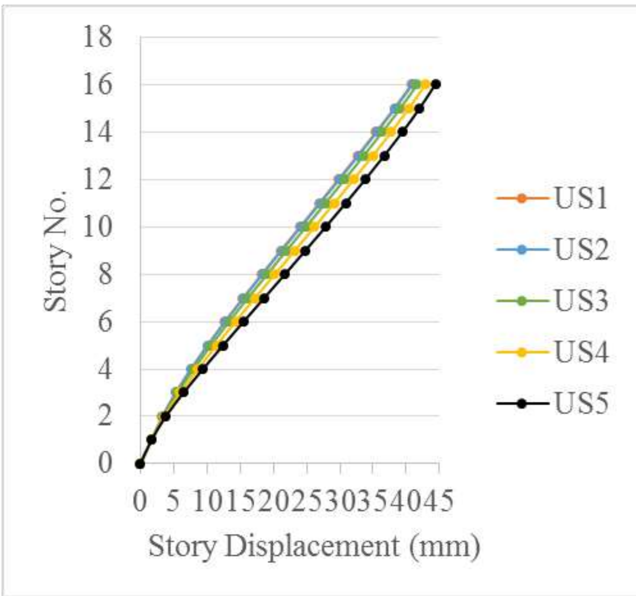


Fig. 10: Story Displacement for U-Shaped building models in both X direction

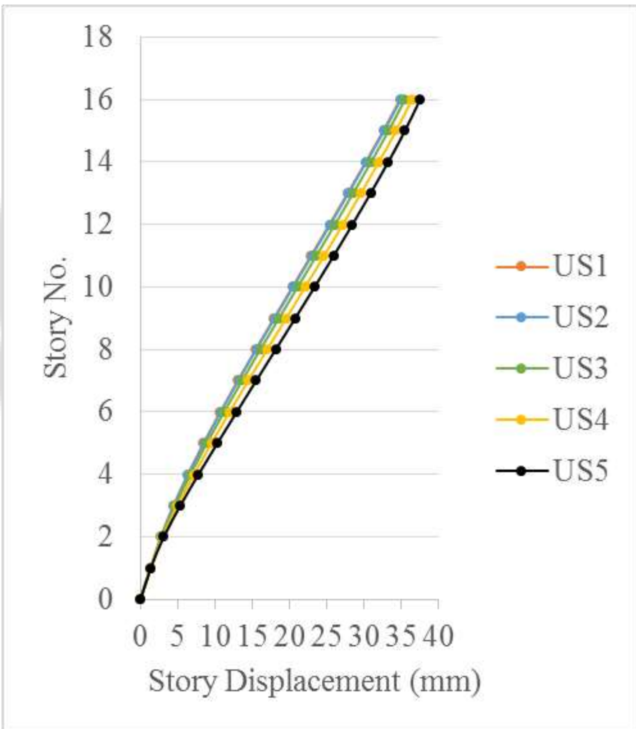


Fig. 11: Story Displacement for U-Shaped building models in both Y direction

A. *Story Drift*

In this section, the story drift values in X & Y directions are presented by analyzing all the 15 models considered for study. It is observed from the results that the max storey drift is at 10^{th} Story for regular buildings, at 11^{th} story for L-Shaped and U-Shaped buildings. The story drifts are shown in table 4.5.1 and Fig. 4.6.1 for regular buildings, in tables 4.5.2(a), 4.5.2(b) and Fig. 4.6.2(a), 4.6.2(b) for L-shaped building in X, Y directions respectively, in tables 4.5.3(a), 4.5.3(b) and Fig. 4.6.3(a), 4.6.3(b) for L-shaped building in X, Y directions respectively.

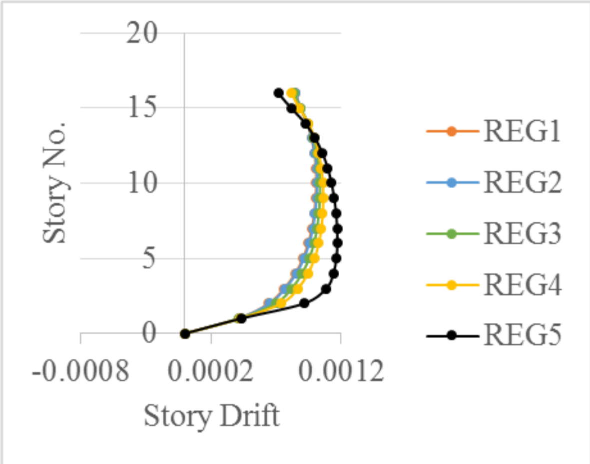


Fig. 12: Story Drift for Regular building models in both X & Y directions

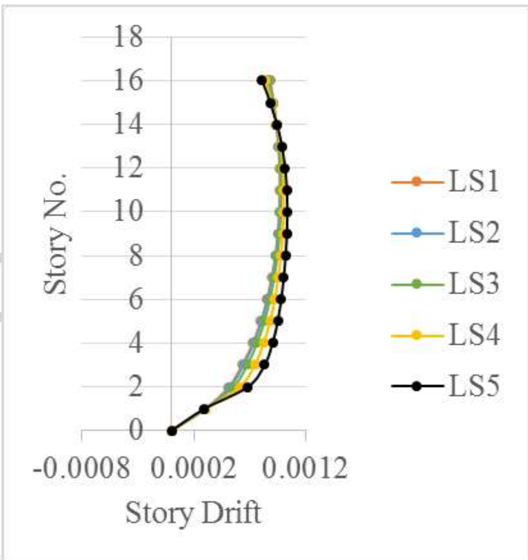


Fig. 13: Story Drift for L-Shaped building models in both X direction

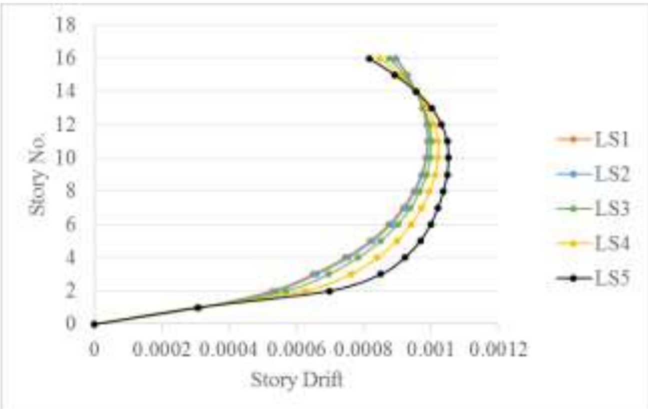


Fig. 14: Story Drift for L-Shaped building models in both Y direction

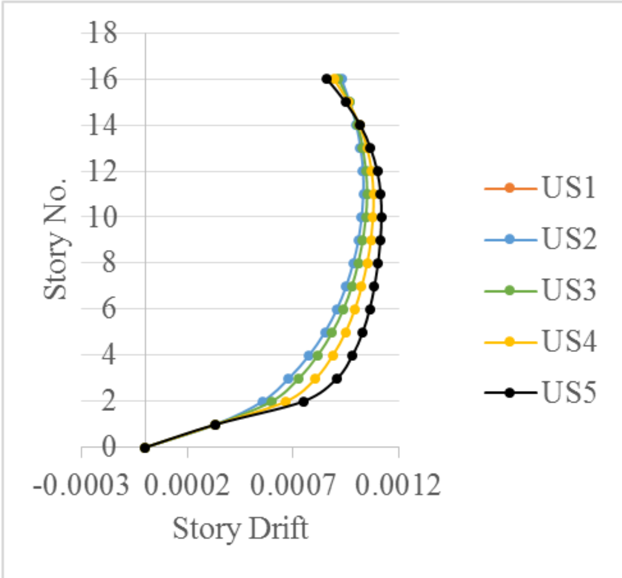


Fig. 15: Story Drift for U-Shaped building models in both X direction

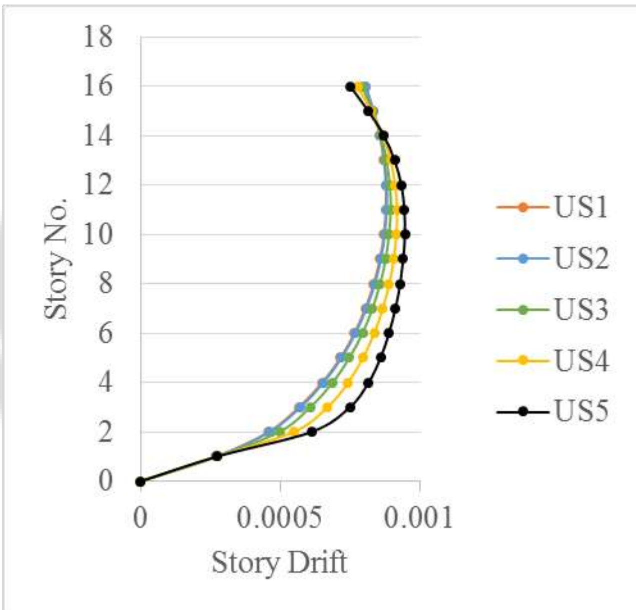


Fig. 16: Story Drift for U-Shaped building models in both Y direction

VI. CONCLUSIONS

Based on the analysis results for the effect of opening sizes in on regular and irregular buildings i.e., on 15 models considered for this study, the following conclusions can be drawn:

A. For Regular building models

- It is found that with the increase in opening size, the base shear is decreasing. there is 0.315%, 1.713%, 3.155%, and 6.745% reduction in base shear for 3.2%, 11.2%, 18.67%, and 25.6% of openings in shear wall respectively.
- For the 3.2%, 11.2%, 18.67%, and 25.6% of openings in shear wall, observed a increase in maximum storey displacement of 0.47%, 2.907%, 4.957%, and 12.11% respectively in both X & Y directions at story 16.

- With the 3.2%, 11.2%, 18.67%, and 25.6% increase of openings in shear wall, there is 0.496%, 2.775%, 5.253%, and 15.956% increase in story drift respectively at story 10 in both X & Y directions.

B. *For L-Shaped building models*

- A reduction of 0.66%, 2.09%, 4.76%, and 7.6% in base shear is found for 3.2%, 11.2%, 18.67%, and 25.6% of openings respectively in X-direction.
- A reduction of 0.79%, 2.36%, 5.37%, and 8.52% in base shear is found for 3.2%, 11.2%, 18.67%, and 25.6% of openings respectively in Y-direction.
- It is observed that the maxm displacement for 3.2%, 11.2%, 18.67%, and 25.6% of openings is increased by 0.46%, 1.33%, 3.51%, and 6.54% respectively in X-direction.
- It is observed that the maxm displacement for 3.2%, 11.2%, 18.67%, and 25.6% of openings is increased by 0.203%, 1.115%, 3%, and 5.87% respectively in Y-direction.
- It is found that with the 3.2%, 11.2%, 18.67%, and 25.6% increase of openings, there is 0.517%, 1.34%, 3.61%, and 6.82% increase in story drift in X-direction.
- It is found that with the 3.2%, 11.2%, 18.67%, and 25.6% increase of openings, there is 0.303%, 1.21%, 3.13%, and 6.27% increase in story drift in Y-direction.

C. *For U-Shaped building models*

- A reduction of 0.44%, 2.3%, 5.23%, and 8.32% in base shear is found for 3.2%, 11.2%, 18.67%, and 25.6% of openings respectively in X-direction.
- A reduction of 0.43%, 2.23%, 5.1%, and 8.1% in base shear is found for 3.2%, 11.2%, 18.67%, and 25.6% of openings respectively in Y-direction.
- It is observed that the maxm displacement for 3.2%, 11.2%, 18.67%, and 25.6% of openings is increased by 0.34%, 2.1%, 5.1%, and 8.76% respectively in X-direction.
- It is observed that the maxm displacement for 3.2%, 11.2%, 18.67%, and 25.6% of openings is increased by 0.3%, 1.9%, 4.57%, and 7.75% respectively in Y-direction.
- It is found that with the 3.2%, 11.2%, 18.67%, and 25.6% increase of openings, there is 0.39%, 2.14%, 5.06%, and 8.76% increase in story drift in X-direction.
- It is found that with the 3.2%, 11.2%, 18.67%, and 25.6% increase of openings, there is 0.34%, 1.94%, 4.56%, and 7.75% increase in story drift in Y-direction.

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