JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

EFFECT OF STRUCTURAL WALL PLAN DENSITY ON SEISMIC PERFORMANCE OF RC STRUCTURAL WALL BUILDING

[1]Sarfaraz Chandorewala, [2]Rajesh Chaturvedi
[1]PG student, [2]Assistant Professor,
[1]Department of Civil Engineering,
[1]IES IPS ACADEMY, INDORE, INDIA

Abstract: This study aims to check the adequacy of the minimum structural plan density recommended in the revised Indian standard by evaluating the impact of varying structural wall density on the seismic performance of various regular RC structural wall buildings mainly 9-storey, 12-storey, 15-storey, 20-storey, 25-storey and 30-storey building models located in high seismic zone. The seismic performance of structural wall buildings with varying structural wall density is evaluated in terms of base shear and maximum inter-story roof drift by performing the time history analysis with different ground motion records. The effect of structural wall plan density on the dynamic properties of the buildings is also studied.

KEYWORDS: **RC structural walls • Structural wall plan density • Linear modal time history analysis• ETABS 2018**

I. INTRODUCTION:

Reinforced Concrete (RC) frame buildings with structural walls are the most common construction practice for mid-rise to high-rise buildings in India like many countries of the world. The consequences of poor performance of structural wall buildings during the 1985 Chilean earthquake stirred the need for research and attracted the attention of the structural community. Structural wall plan density plays an importance role in the overall performance of the structural wall-frame system as the structural walls are the major lateral load resisting elements in the structural wall-frame system. However, in practice, structural wall plan density is kept minimum for getting the architectural view of the building which may lead to possible damage to the buildings during earthquakes. Earthquake reconnaissance reports of the 1985 Chile earthquake revealed that nearly 80% of the buildings with the shear wall are performed satisfactorily without any significant structural damage owing to the Chilean practice of providing a higher structural wall plan density of about 2 to 4% of the plan area along with both the directions of the building. Further, it was also discovered that the higher the shear wall to floor area lower the possibility of damage to buildings with the shear wall even under moderate to severe ground motion. The overall seismic performance of shear wall buildings largely depends on the location of the shear wall in the building, shear wall plan density, and aspect ratio of the shear wall. However, common construction practice is to keep the front and/or side of the building open for commercial and architectural purposes affecting the overall performance. Irregular placement of shear wall further creates torsion in building which causes to ill effect on the seismic performance of buildings. In order to ensure satisfactory performance of the shear wall RC buildings, revised Indian standard for earthquake-resistant design of structures require at least 2% RC structural wall plan density for buildings with open storeys, and for regular buildings, it can be at least 2% along each principal direction. The aim of this manuscript is to check the adequacy of the minimum structural plan density recommended in the revised Indian standard by evaluating the impact of varying structural wall plan density from 0.5 to 4.00% (0.5-2.5% for 9-storey,12-storey,15-storey and 20-storey building models while for 25-storey and 30-storey building models structural wall plan density varies from 2% to 4%) on seismic performance of various regular RC shear wall building located in the high seismic zone. The seismic performance of shear wall buildings is evaluated in terms of base shear and maximum inter-story roof drift by performing time history analysis with different ground motion records. The effect of structural wall plan density on the dynamic properties of the buildings is also studied.

What are the methods of performing seismic analysis?

There are generally 4 methods of seismic analysis i.e.
Linear Static Analysis
Non-Linear Static Analysis
Linear Dynamic Analysis
Non-Linear Dynamic Analysis.

Equivalent static method is a type of linear static method in which the design base shear is calculated for entire building and is distributed along the height of the building. IS 1893-2016 is used to calculate design base shear. Pushover analysis is a type of non-linear static method of analysis in which capacity or pushover curve is plot keeping top displacement at abscissa and base shear at ordinate which ultimately gives total seismic force against deflection.

Another method for calculating seismic response of RC framed structure is by using Linear Dynamic Analysis or Response Spectrum Analysis. This method checks maximum seismic response of building by measuring the natural mode of vibration. IS 1893-2016 is used to get various parameters that are used in Response Spectrum Method.

Non-Linear Dynamic Analysis method is also a precise method which gives result with more accuracy. Time History Analysis is a type of non-linear dynamic analysis which provides the structural response of the structure with respect to ground motion records.

The Objective of the study:

1. To analyze and design various building models of G+8, G+11, G+14, G+19, G+24, and G+29 according to Indian code(IS 456:2000, IS 1893:2016 and IS 13920:2016) using Response spectrum analysis.
2. To assess the optimum percentages of structural wall plan density required in both principal direction by comparing the results obtained from linear modal time history analysis using ETABS software.
3. To compare both the codal method of seismic analysis given in IS:1893-2016 i.e., Equivalent static method and Response spectrum method by comparing results of fundamental natural period and base shear.

II. Literature review:

Reddy and Haldar (2022) conducted time history analysis on the typical 12 storey RC frame structural wall building models. The main aim is to check the efficacy of the minimum structural plan density recommended in the revised Indian standard by evaluating the impact of varying structural wall density on the seismic performance of high-rise regular RC shear wall buildings located in the high seismic zone.

Urkude et al. (2022) studied the behavior of reinforced concrete building by conducting dynamic analysis for most suited position and location of shear wall with and without openings. The seismic parameters are considered as displacements, base shear, storey drift. Earthquake responses under zone III earthquake as per IS 1893(Part 1): 2016 have been carried out.

Mandloi and Sharma (2021) investigated the effects of various size of openings in shear walls on the responses and behaviours of multi-storey buildings also Opening Area Effect of Core Type Shear Wall In Hospital Building with Highest Importance Factor. Many G+20 storey prototype buildings with different types of openings in shear wall with and without incorporating the volume of shear wall reduced in the boundary elements are analyzed using software Staad-Pro using Response spectrum method (1893-2016).

Nagarjuna and Bajamma (2021) studied the effectiveness of reinforced concrete shear wall in the buildings subjected to seismic loads. The shear wall is an alternate structural form for resisting the earthquake forces. A G+10 building is modelled and seismic analysis is carried out with and without shear wall by using response spectrum method as per IS: 1893-2002 (Part I).

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III. RESEARCH METHODOLOGY:

In this study eighty-eight models are designed as per IS 456 :2000 and ductile detailing is done according to IS 13920:2016. The earthquake forces are calculated as per IS 1893:2016 for seismic zone IV of RC structural wall frame system multistoried building, and linear modal time history analysis of the building is performed using E-Tabs software.

The typical plan dimension of the building in X direction length: 25 m and Y direction width: 18 m which is divided into 5 bay and 3 bays respectively.

A G+8, G+11, G+14, G+19, G+24 and G+29 storey RC structural wall frame buildings are analyzed for different parameters for linear modal time history analysis using E-tabs software. A Total of 88 models i.e., 16 models each in G+8, G+11, G+14, G+19 and 12 models each in G+24 and G+29 of varying structural wall plan density are firstly designed and then their responses are obtained for 6 sets of ground motions in terms of base shear and roof storey drift by performing linear modal time history analysis.

Modelling parameters:

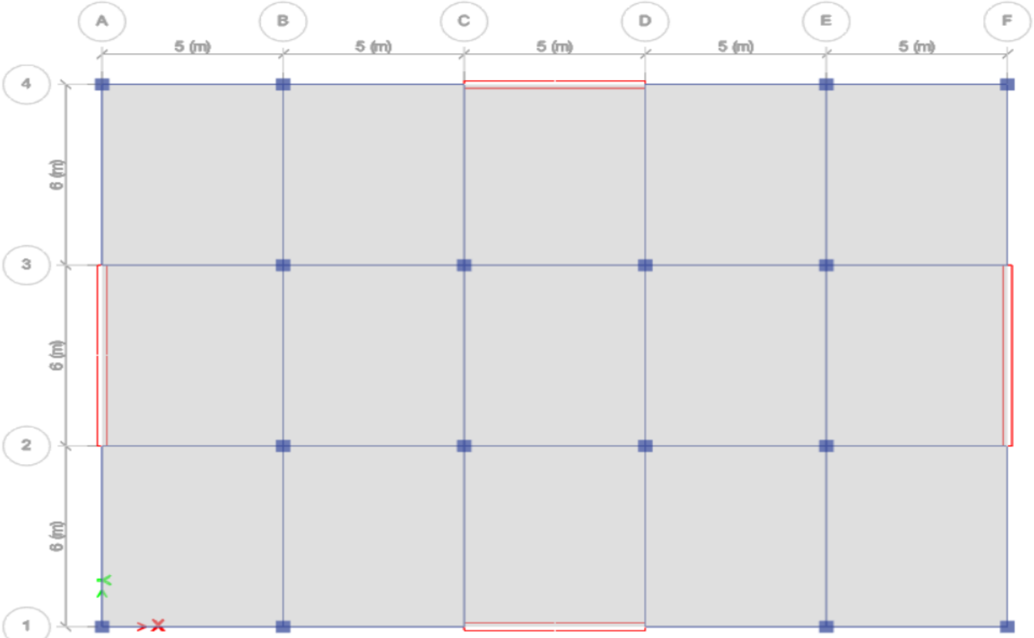

Fig. 3.1 Typical plan of all buildings upto G+19 with 0.56% and 0.67% structural wall plan density in X and Y-Direction respectively.

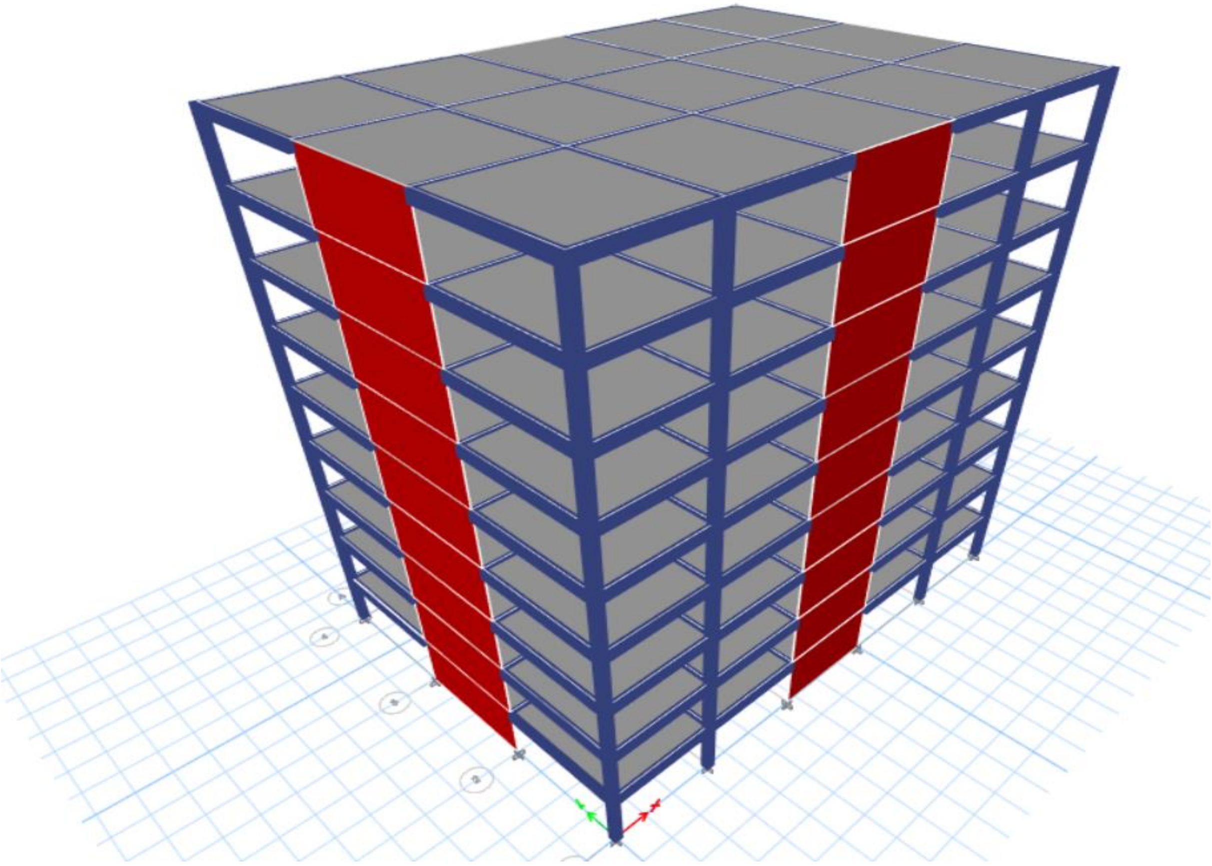

Fig. 3.2 Elevation of the G+8 building with 0.56% and 0.67% structural wall plan density in X and Y-Direction respectively.

Table 3.1 Preliminary data.

Parameters	**Specifications**
Type of structure	Dual System (Structural wall moment frame structure)
Material	M40 and Fe500
Zone	IV
Soil type	II (medium)
Response reduction factor	5
Importance factor	1.5
Damping	5%
Ground floor height	3.3m
Typical floor height	3.3m
External wall	230 mm
Internal wall	115 mm
Unit weight of Infill Wall	20 kN/m^2
Live load	3 kN/m^2
Floor finish	1.5 kN/m^2
Roof Live load	1.5 kN/m^2

Load combinations:

The load combinations that can be considered while designing the structure are as specified which include all load effects mentioned including earthquake loads in both x and y direction. While designing structure, the base shear obtained from response spectrum analysis must be first scaled up to match the base shear obtained from the equivalent static base shear. In order to do so scale factor of $\overline{V_B}$ / V_B where $\overline{V_B}$ is the value of base shear obtained from equivalent static method and V_B is the value of response spectrum base shear in the respective Direction. Scale factor value for X and Y-Direction need to be calculated separately.

Table 3.2 Load combinations

Case	**Load combination**
1	1.5(DL + (LL)
2	1.2(DL + LL + RSX)
3	1.2(DL + LL + RSY)
4	1.2(DL + LL - RSX)
5	1.2(DL + LL - RSY)
6	1.5(DL + RSX)
7	1.5(DL+ RSY)
8	1.5(DL - RSX)
9	1.5(DL - EQY)
10	0.9DL + 1.5RSX
11	0.9DL + 1.5RSY
12	0.9DL - 1.5RSX
13	0.9DL - 1.5RSY

IV. RESULTS AND DISCUSSION:

A G+8, G+11, G+14, G+19, G+24 and G+29 storey buildings were firstly designed as per IS 456:2000 and IS 13920:2016 and then were analyzed for linear modal time history analysis for which 6 sets of ground motion records are used. After the analysis the results are evaluated in the terms of base shear and roof drift.

Equivalent Static Analysis Result:
Time Period Results:

The fundamental natural period Tn and approximate fundamental translational natural period T_a of oscillation and in second in both X and Y-Direction as per IS 1893 (Part 1): 2016 for different models is listed below in the following tables.

$$Ta = \frac{0.09*h}{d^{1/2}}$$ = Approximate fundamental natural period for all other structures.

$$Tasw = \frac{0.075*h^{0.75}}{Aw^{1/2}}$$ = Approximate fundamental natural period for buildings with RC structural walls.

Tn = Fundamental natural period of the building obtained from modal analysis.

Table 4.1 Fundamental natural period for the G+8 building.

SWX	**Taswx (sec)**	**Tax (sec)**	**Tnx (sec)**	**SWY**	**Taswy (sec)**	**Tay (sec)**	**Tny (sec)**
0.56%	1.263	0.534	**1.299**	0.67%	1.123	0.63	1.122
1.11%	0.893	0.534	**1.072**	1.33%	0.793	0.63	0.885
1.67%	0.729	0.534	**0.949**	2.00%	0.648	0.63	0.767
2.22%	0.6314	0.534	**0.870**	2.67%	0.5613	0.63	0.696

- For all the models of 9-storey building, the value of natural period in first fundamental mode along X-Direction is more than the value of natural period in first fundamental mode along Y-Direction.

- The approximate fundamental natural period for buildings with RC Structural walls calculated clearly indicates that for buildings upto 20-storey there is an exceptional case in X-Direction i.e., at **2.22%** Structural wall plan density in X-direction the period value obtained from structural wall empirical formula comes more than that of period value obtained from empirical formula for all other structures i.e., Tax. But for Y-Direction at **2.00%** or higher percentages of structural wall plan density, the value obtained from the structural wall empirical formula always falls below the value obtained using the empirical equation given in IS:1893-2016 for all other structures.

- The approximate fundamental natural period for buildings with RC Structural walls calculated clearly indicates that for buildings higher than 20-storey at **2.00%** or higher percentages of structural wall plan density in both X and Y-Direction, the value obtained from the structural wall empirical formula always falls below the value obtained using the empirical equation given in IS:1893-2016 for all other structures.
- The fundamental natural period obtained from modal analysis is much higher than period values obtained from the empirical equation given in IS:1893-2016 for buildings with RC Structural wall and for all other buildings.

Base Shear Result:

The design lateral strength of the structure due to earthquake forces is denoted as Base shear (kN) and is distributed along the height of the structure.

Table 4.2 Base shear (kN) in X-Direction of the G+8 building.

SWY	**Base Shear KN**			
	0.56% SWX	1.11% SWX	1.67%SWX	2.22% SWX
0.67%	1905.2	2790.68	3536.18	4218.70
1.33%	1986.73	2905.98	3677.43	4381.78
2.00%	2068.25	3021.29	3818.68	4544.86
2.67%	2149.78	3136.60	3959.92	4707.94

- **Comparison between Equivalent Static and Response spectrum base shear:**

➢ For 9-storey building, in 0.56% SWX and 0.67% SWY model equivalent static base shear in X-Direction is **1.23** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.24** times the response spectrum base shear. Furthermore in 2.22% SWX and 2.67% SWY model equivalent static base shear in X-Direction is **1.85** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.49** times the response spectrum base shear.

➢ For 12-storey building, in 0.56% SWX and 0.67% SWY model equivalent static base shear in X-Direction is **1.25** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.3** times the response spectrum base shear. Furthermore in 2.22% SWX and 2.67% SWY model equivalent static base shear in X-Direction is **2.08** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.75** times the response spectrum base shear.

➢ For 15-storey building, in 0.56% SWX and 0.67% SWY model equivalent static base shear in X-Direction is **1.18** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.23** times the response spectrum base shear. Furthermore in 2.22% SWX and 2.67% SWY model equivalent static base shear in X-Direction is **2.04** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.73** times the response spectrum base shear.

➢ For 20-storey building, in 0.56% SWX and 0.67% SWY model equivalent static base shear in X-Direction is **1.33** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.4** times the response spectrum base shear. Furthermore in 2.22% SWX and 2.67% SWY model equivalent static base shear in X-Direction is **2.12** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.62** times the response spectrum base shear.

➢ For 25-storey building, in 2.22% SWX and 2% SWY model equivalent static base shear in X-Direction is **2.33** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.93** times the response spectrum base shear. Furthermore in 3.33% SWX and 4% SWY model equivalent static base shear in X-Direction is **2.23** times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is **1.63** times the response spectrum base shear.

➢ For 30-storey building, in 2.22% SWX and 2% SWY model equivalent static base shear in X-Direction is 2.27 times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is 1.89 times the response spectrum base shear. Furthermore in 3.33% SWX and 4% SWY model equivalent static base shear in X-Direction is 2.20 times the response spectrum base shear in X-Direction while in Y-Direction equivalent static base shear is 1.73 times the response spectrum base shear.

Time History Analysis Result:

There are 16 models of varying structural wall plan density for each building of 9-storey, 12-storey, 15-storey, 20-storey while 25-storey and 30-storey buildings have 12 models each of varying structural wall plan density. Overall, there are 88 models which are analyzed for 6 different sets of ground motions. The results for the same are given below.

Table 4.3 Base shear & Roof drift for 0.56% SWX and 0.67% SWY in X-Direction and Y-Direction of G+8 building

Time History	**Base Shear X (KN)**	**Roof Drift X**	**Base Shear Y (KN)**	**Roof Drift Y**
RSN 825 Cape	35780.6829	0.015084	16575.1278	0.006225
RSN 830 Cape	4689.0532	0.001091	5969.7332	0.000986
RSN 134 Izmir	6528.7574	0.001515	4560.0074	0.000713
RSN 136 Santa	3807.4714	0.002373	5665.800	0.00271
RSN 139 Tabas	9372.126	0.005207	9987.2428	0.004631
RSN 143 Tabas	33994.7254	0.020924	40119.3982	0.013257
Average	**15695.469**	**0.007699**	**13812.8849**	**0.0047536**

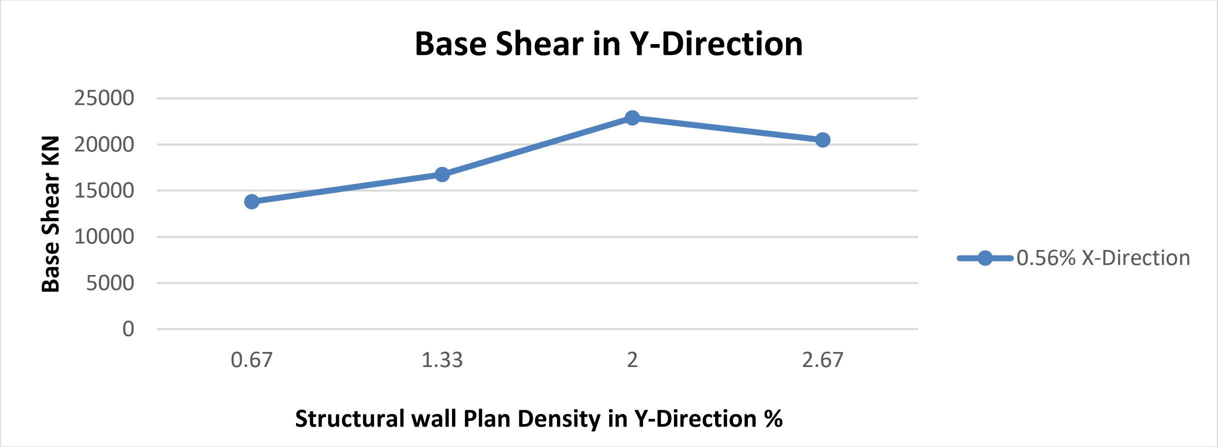

Fig 4.1 Variation of Base Shear in Y-Direction when constant 0.56% SWX and varying SWY of G+8 storey building.

- From the figure 4.1 it can be seen that for constant 1.11% structural wall plan density in X-Direction the value of base shear increases by **18.60%** at 1.33% then increases sharply by **37.88%** at 2% and then decreases by **9.00%** at 2.67%.

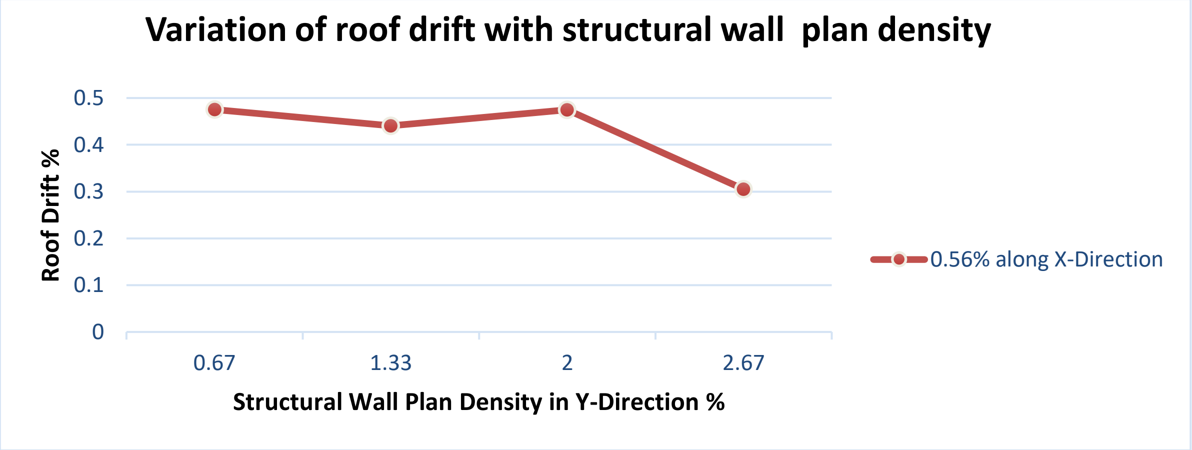

Fig 4.2 Variation of Roof Drift % in Y-Direction when constant 0.56% SWX and varying SWY of G+8 storey building.

- From the Figure 4.2 it can be seen that for constant 1.11% structural wall plan density in X-Direction the value of roof drift % firstly decreased by **0.89** times the value at 0.67% at 1.33% and then increases slightly by **1.12** times the value at 1.33% at 2% and finally decreases by **0.65** times the value at 2% at 2.67%.

V. CONCLUSION:

The conclusions drawn from the study of various multi-storied buildings having same aspect ratio in plan of **1.38** with reinforced concrete structural wall are as follows:

- The value of approximate fundamental period obtained from the RC structural formula gets decreased with an increase in the structural wall plan density and mostly in all cases of having **2%** or more structural wall plan density except few cases, the period value falls from the period value obtained from the empirical formula for all other buildings.

- As per IS:-1893-2016 it is suggested to provide 2% structural wall plan density along each orthogonal direction even in a regular building. So as per my findings the period value at 2% or more structural wall plan density percentages always falls below the period value obtained as per empirical formula for all other buildings.
- For the 9-storey building models, the optimum value of structural wall plan density percentages in X and Y-direction are found to be **1.11%** and **1.33%** respectively.
- For the 12-storey building models, the optimum value of structural wall plan density percentages in X and Y-direction are found to be **1.11%** and **2.00%** respectively.
- For the 15-storey building models, the optimum value of structural wall plan density percentage in X-Direction are **1.67%** among models with constant 0.67% and 1.33% structural wall plan density in Y-Direction and **2.22%** among models with constant 2.00% and 2.67% structural wall plan density in Y-Direction and the optimum value of structural wall plan density percentage in Y-direction is found to be **2.00%**.
- For the 20-storey building models, the optimum value of structural wall plan density percentage in X-Direction are **2.22%** among models with constant 0.67% structural wall plan density in Y-Direction and **0.56%** among models with constant 1.33%, 2.00% and 2.67% structural wall plan density in Y-Direction and the optimum value of structural wall plan density percentage in Y-direction are **2.67%** among models with constant 0.56% structural wall plan density in X-Direction and **0.67%** among models with constant 1.11%, 1.67% and 2.22% structural wall plan density in X-Direction.
- For the 25-storey building models, the optimum value of structural wall plan density percentages in X and Y-direction are found to be **2.22%** and **2.67%** respectively.
- For the 30-storey building models, the optimum value of structural wall plan density percentage in X-Direction are **2.77%** among models with constant 2.00% and 2.67% structural wall plan density in Y-Direction and **2.22%** among models with constant 3.33% and 4.00% structural wall plan density in Y-Direction and the optimum value of structural wall plan density percentage in Y-direction are **4.00%** among models with constant 2.22% and 2.67% structural wall plan density in X-Direction and **2.00%** among models with constant 3.33% structural wall plan density in X-Direction.

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