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Effect of Shear Wall Area to Floor Area Ratio on the Seismic Behavior of Reinforced Concrete Buildings

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Abstract:

An analytical study is performed to evaluate the effect of shear wall area to floor area ratio on the seismic behavior of midrise RC structures. For this purpose, 24 midrise building models that have five and eight stories and shear wall ratios ranging between 0.51 and 2.17% in both directions are generated. Then, the behavior of these building models under earthquake loading is examined by carrying out nonlinear time history analyses. In the analyses, seven different ground motion records are applied to the building models, and the average of the obtained data is used in the evaluation of the seismic performance. Main parameters considered in this study that affect the overall seismic performance of the buildings are the roof and interstory drifts and the base shear responses. The analytical results indicate that at least 1.0% shear wall ratio should be provided in the design of midrise buildings to control the drift. In addition, when the shear wall ratio increases beyond 1.5%, it is observed that the improvement of the seismic performance is not as significant.

Keywords: ***Reinforced concrete; Earthquake-resistant structures; Shear walls; Nonlinear analysis.***

INTRODUCTION

1.1 General

In the last few decades, shear walls have been used extensively in countries especially where high seismic risk is observed. The major factors for inclusion of shear walls are ability to minimize lateral drifts, inter storey displacement and excellent performance in past earthquake record. Shear walls are designed not only to resist gravity loads but also can take care overturning moments as well as shear forces. They have very large in plane stiffness that limit the amount of lateral displacement of the building under lateral loadings. Shear walls are intended to behave elastically during moderate or low seismic loading to prevent non-structural damage in the building. However, it is expected that the walls will be exposed to inelastic deformation during less or frequent earthquakes. Thus, shear walls must be designed to withstand forces that cause inelastic deformations while maintaining their ability to carry load and dissipate energy. Structural and non-structural damage is expected during severe earthquakes however; collapse prevention and life safety is the main concern in the design.

1.2 Definition of Soft Storey

The essential distinction between a soft story and a weak story is that while a soft storey is classified based on stiffness or simply the relative resistance to lateral deformation or story drift, the weak story qualifies on the basics of strength in terms of force resistance (statics) or energy capacity (dynamics).

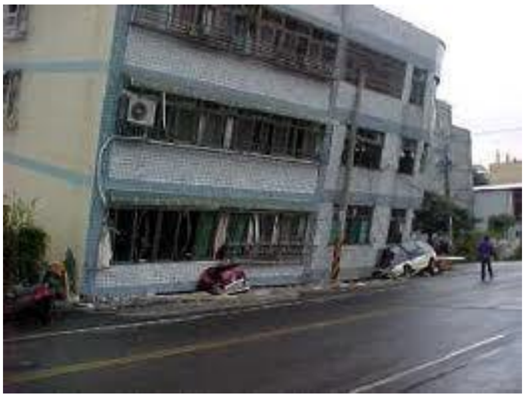


Fig 1.1 Soft story failure Pattern

1.3 Storey Drift

Floor deflections are caused when the buildings are subjected to seismic loads. These deflections are multiplied by the ductility factor, resulting the total deflection which accounts for the inelastic effect. The drift in a story is computed as difference of deflection of the floor at the top and bottom of the story under consideration. The total drift in any story is the sum of shear deformation of that story, axial deformation of floor system, overall flexure of the building and foundation rotation. It is normally specified at the elastic design level, although it will be greater for the maximum earthquake.

LITERATURE REVIEW

2.1 Literature Reviews

Riddell et al. [1] **(1987)** a study was performed by to define the general features of the buildings located in Vina del Mar that experienced the 1985 Chile earthquake and to identify the related earthquake damage. Data of 178 low and midrise buildings representing a stock of 322, of which 319 have shear walls, were used in the evaluation. Most of these buildings were designed with considerably high shear wall ratios (varying between 3.0 and 8.0%, with an average of 6.0%), independent of the number of stories.

METHODOLOGY

3.1 Introduction

Earthquake and its occurrence and measurements, its vibration effect and structural response have been continuously studied for many years in earthquake history and thoroughly documented in literature. Since then the structural engineers have tried hard to examine the procedure, with an aim to counter the complex dynamic effect of seismically induced forces in structures, for designing of earthquake resistant structures in a refined and easy manner

3.2 General Terms

- Natural Period (T): Natural period of a structure is its time period of undamped free vibration.
- Fundamental Natural Period (T1): It is the first (longest) modal time period of vibration.
- Diaphragm: It is a horizontal or nearly horizontal system, which transmits lateral forces to the vertical resisting elements, for example, reinforced concrete floors and horizontal bracing systems.
- Seismic Mass: It is the seismic weight divided by acceleration due to gravity.
- Seismic Weight (W): It is the total dead load plus appropriate amounts of specified imposed load.
- Centre of Mass: The point through which the resultant of the masses of a system acts. This point corresponds to the centre of gravity of masses of system.
- Storey Shear: It is the sum of design lateral forces at all levels above the storey under consideration.

3.3 Methods of Seismic Analysis

Once the structural model has been selected, it is possible to perform analysis to determine the seismically induced forces in the structures. There are different methods of analysis which provide different degrees of accuracy. The analysis process can be categorized on the basis of three factors: the type of the externally applied loads, the behavior of structure/or structural materials and the type of structural model selected

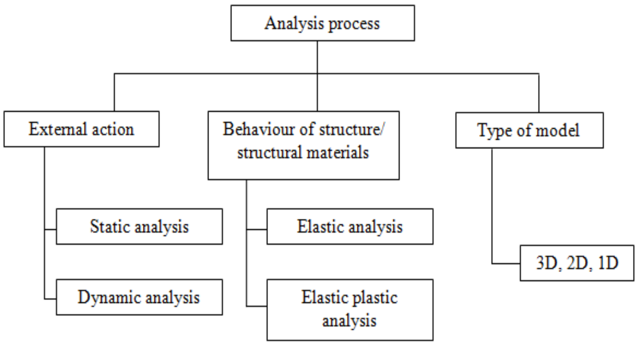


Fig 3.1 Method of Analysis Process (Syrmakezis, 1996)

CASE STUDY

4.1 Introduction

Most building codes prescribe the method of analysis based on whether the building is regular or irregular. Almost all the codes suggest the use of static analysis for symmetric and selected class of regular buildings.

4.2 Description of the Building Model's

Table 1 Description of Building Models

Model Id	Number of Storey	SWA / FA %	
		X - Direction	Y - Direction
1	5	0.70	0.70
2	5	0.91	0.91
3	5	1.11	1.11
4	5	1.31	1.31
5	8	0.70	0.70
6	8	0.91	0.91
7	8	1.11	1.11
8	8	1.31	1.31
9	12	0.70	0.70
10	12	0.91	0.91
11	12	1.11	1.11
12	12	1.31	1.31

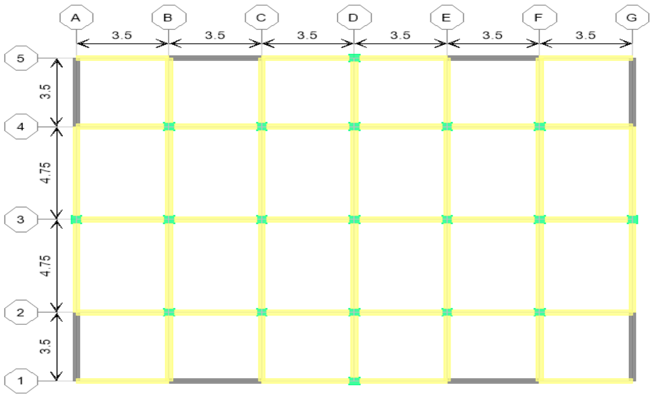


Fig 4.1 Plan layout of five storey building models

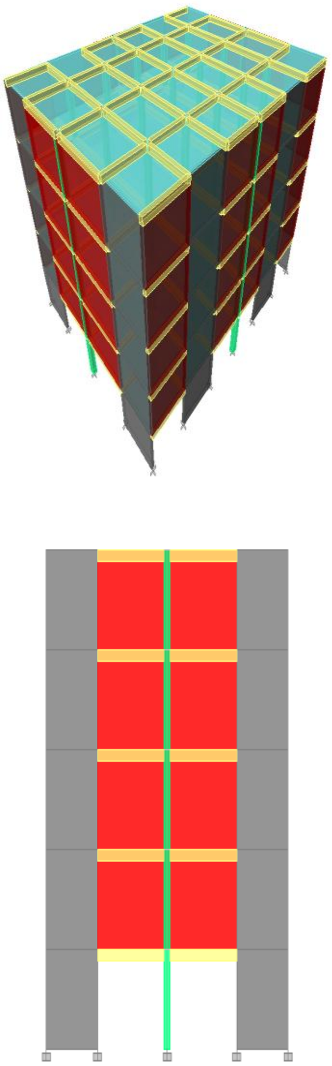


Fig 4.2 Isometric view and front elevation of five storey building model

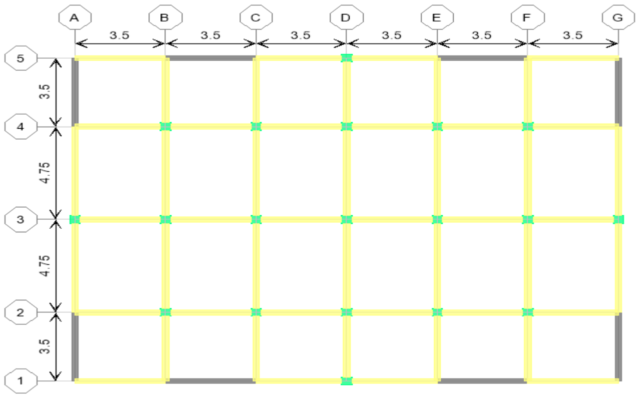


Fig 4.3 Plan layout of eight storey building models

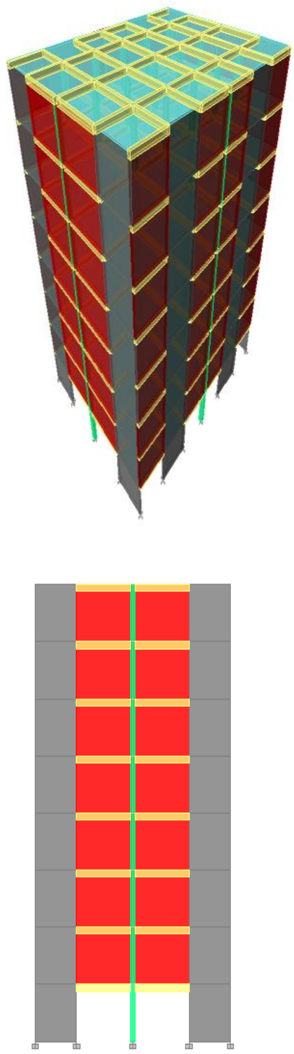


Fig 4.4 Isometric view and front elevation of eight storey building model

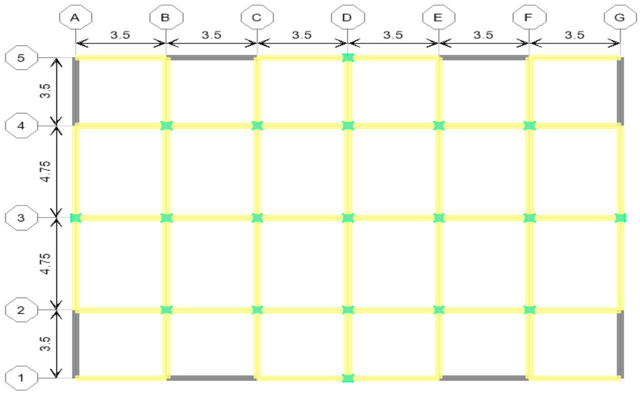


Fig 4.5 Plan layout of twelve storey building models

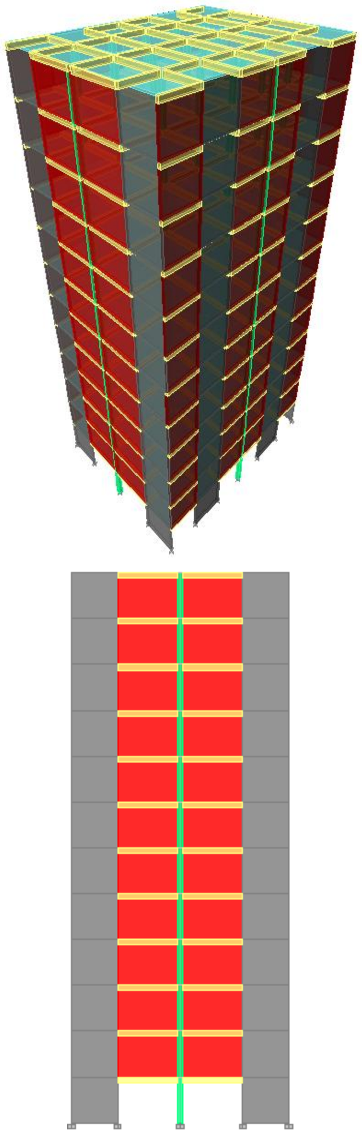


Fig 4.6 Isometric view and front elevation of twelve storey building model

4.2.1 Design Data:

Material Properties:

Young’s modulus of (M20) concrete, E = 22.360x10^6 kN/m²

Density of Reinforced Concrete = 25kN/m³

Modulus of elasticity of brick masonry = 3500x10³kN/m²

Density of brick masonry = 19.2kN/m³

Assumed Dead load intensities

Floor finishes = 1.5kN/m²

Live load = 4 kN/ m²

Member properties

Thickness of Slab = 0.125m

Column size = (0.4mx0.4m)

Beam size = (0.25m x 0.400m)

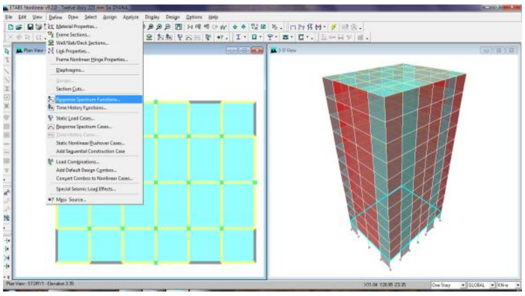
Thickness of wall = 0.250m

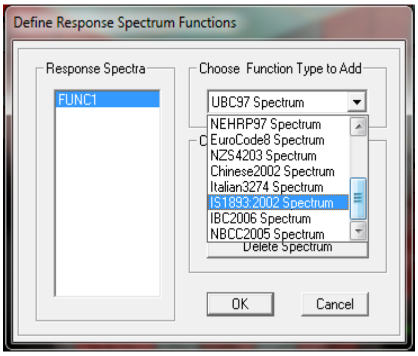
Thickness of shear wall = 0.175, 0.225, 0.275 and 0.325m

Earthquake Live Load on Slab as per clause 7.3.1 and 7.3.2 of IS 1893 (Part-I) - 2002 is calculated as:

Roof (clause 7.3.2) = 0

Floor (clause 7.3.1) = 0.5x4 = 2 kN/m2

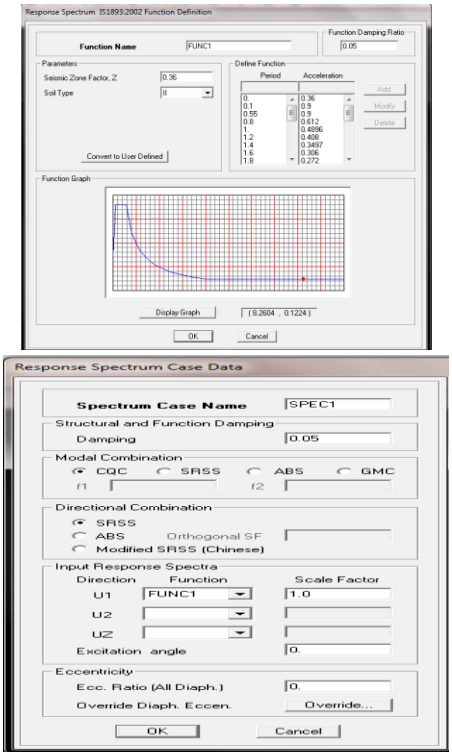




Define Response Spectrum Functions

Response Spectra: FUNC1

Choose Function Type to Add: UBC97 Spectrum



Response Spectrum IS1893:2002 Function Definition

Function Name: FUNC1

Function Damping Ratio: 0.05

Parameters

Seismic Zone Factor, Z: 0.36

Soil Type: II

Define Function

Period	Acceleration
0.	0.36
0.1	0.9
0.55	0.9
0.8	0.612
1.	0.4896
1.2	0.408
1.4	0.3497
1.6	0.306
1.8	0.272

Function Graph: (8.2604 , 0.1224)

Response Spectrum Case Data

Spectrum Case Name: SPEC1

Structural and Function Damping

Damping: 0.05

Modal Combination: ● CQC ○ SRSS ○ ABS ○ GMC

f1 f2

Directional Combination: ● SRSS ○ ABS ○ Modified SRSS (Chinese)

Orthogonal SF

Input Response Spectra

Direction	Function	Scale Factor
U1	FUNC1	1.0
U2		
UZ		

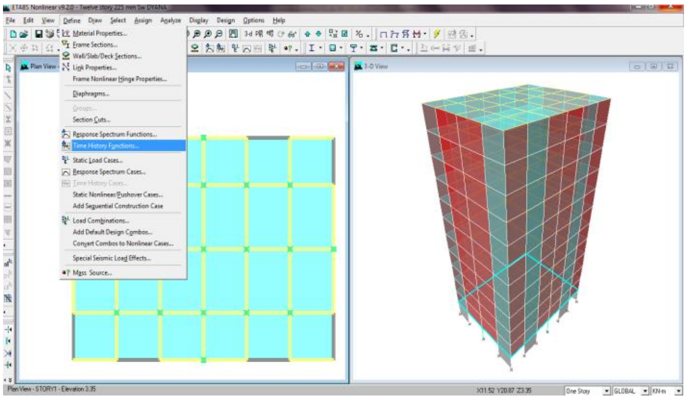
Excitation angle: 0.

Eccentricity

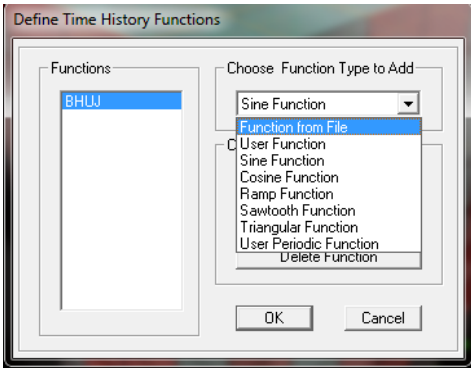
Ecc. Ratio (All Diaph.): 0.

Override Diaph. Eccen.

Fig 4.7 View of Response spectrum analysis in E-TABS



(a)



Define Time History Functions

Functions: BHUJ

Choose Function Type to Add: Sine Function

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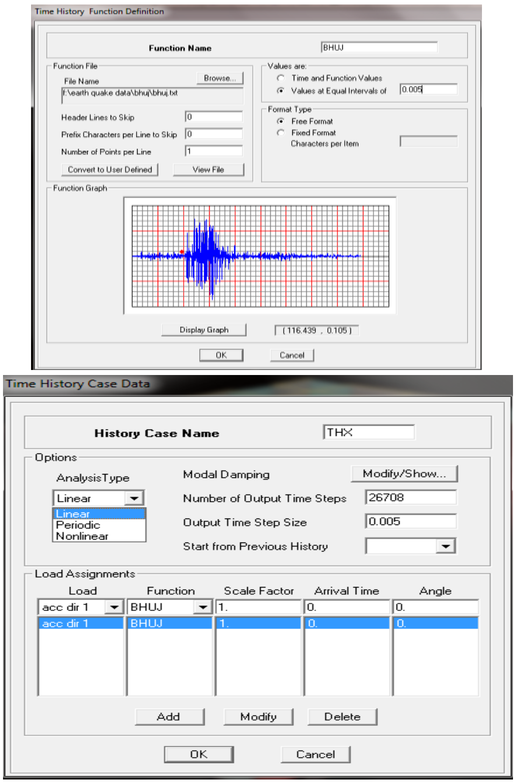

Function Name BHUJ

Function File

File Name f:\earth quake data\bhuj\bhuj.txt

Header Lines to Skip 0

Prefix Characters per Line to Skip 0

Number of Points per Line 1

Values are:

○ Time and Function Values

● Values at Equal Intervals of 0.005

Format Type

● Free Format

○ Fixed Format

Characters per Item

(116.439 , 0.105)

History Case Name THX

Options

AnalysisType Linear

Linear
Periodic
Nonlinear

Modal Damping

Number of Output Time Steps 26708

Output Time Step Size 0.005

Start from Previous History

Load Assignments

Load	Function	Scale Factor	Arrival Time	Angle
acc dir 1	BHUJ	1.	0.	0.
acc dir 1	BHUJ	1.	0.	0.

Fig 4.8 View of Time history analysis in E-TABS

4.4 Selection of Ground Motion Records

In this study, to observe the seismic behavior of different building models under earthquake loading, three ground motion records are selected. The records are obtained from the database of Earthquake Engineering Research Centre, IIIT Hyderabad. The properties of the selected ground motions records is tabulated below

Table 2 Properties of selected ground motion records

Earthquake	Magnitude mb	Acceleration m/s/s
Bhuj Earthquake (2001)	7.0	0.005
Chamba Earthquake (1995)	4.9	0.02
Uttarkasi Earthquake (1991)	6.8	0.02

RESULTS AND DISCUSSION

5.1 Introduction

The results of Fundamental natural period of vibration, relationship between shear wall area and Base shear, relationship between shear wall area and roof displacement, storey displacement and storey drift for the different building models for each of the above analysis are presented and compared. An effort has been made to study the effect of shear wall area to floor area ratio by considering ground floor as soft storey in the analysis.

A) Response Spectrum Analysis

5.2.1 Fundamental Natural Period

Natural Period of Vibration for five eight and twelve storey building models along longitudinal and transverse directions are shown below

5.2.2 Shear Wall Area to Floor Area Ratio (SWA / FA) % vs. Base Shear

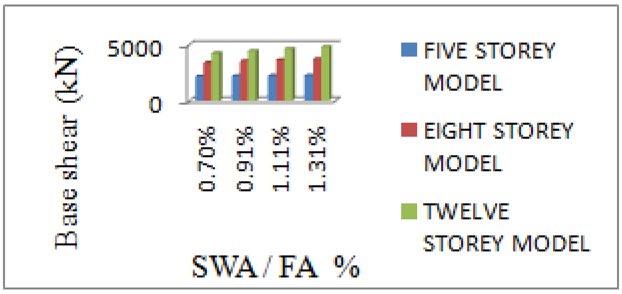

Fig 5.1 SWA / FA (%) vs. Base shear of five, eight and twelve storey – Seismic force in X- direction

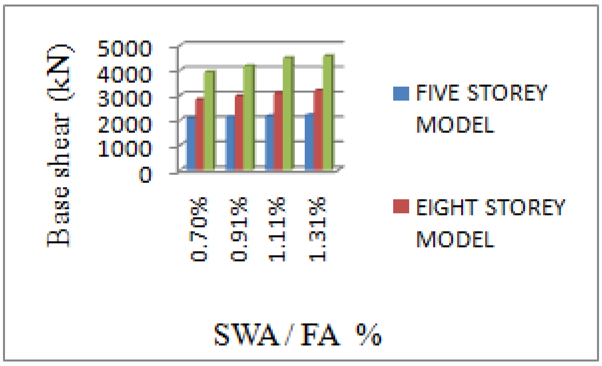

Fig 5.2 SWA / FA (%) vs. Base shear of five, eight and twelve storey – Seismic force in Y- direction

5.2.3 Shear Wall Area to Floor Area Ratio (SWA / FA) % vs. Roof Displacement

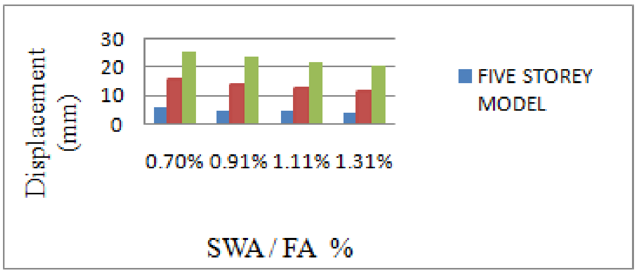

Fig 5.3 SWA / FA % vs. Roof displacement of five, eight and twelve storey models –Seismic force in X-direction

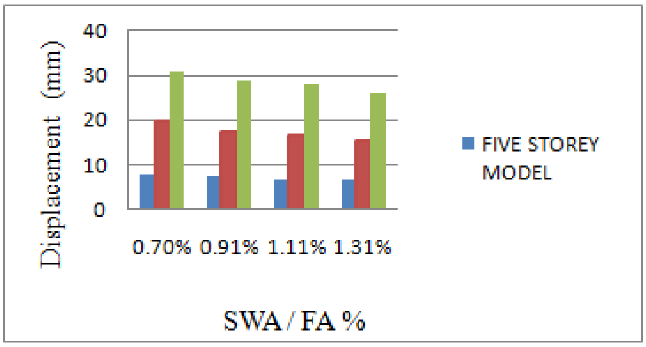

Fig 5.4 SWA / FA % vs. Roof displacement of five, eight and twelve storey models –Seismic Force in Y-direction

5.2.4 Storey Displacement

The below graphs represents the relationship between SW area vs. Base shear for different types of building Models (0.70%, 0.91%, 1.11% and 1.31%), performed by using Response Spectrum Analysis.

Five storey model

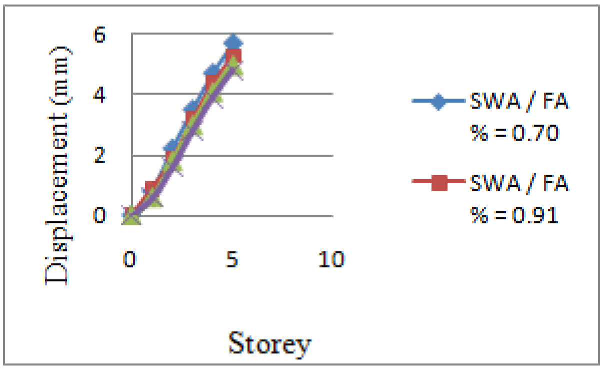

Fig 5.5 Storey displacement of five storey model –Seismic force in X- direction

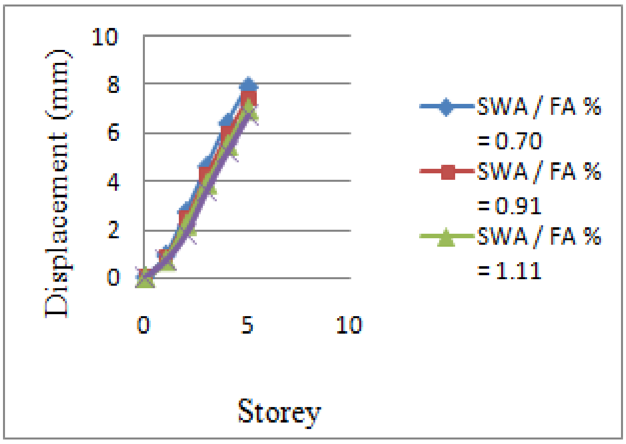

Fig 5.6 Storey displacement of five storey model –Seismic force in Y- direction

Eight storey model

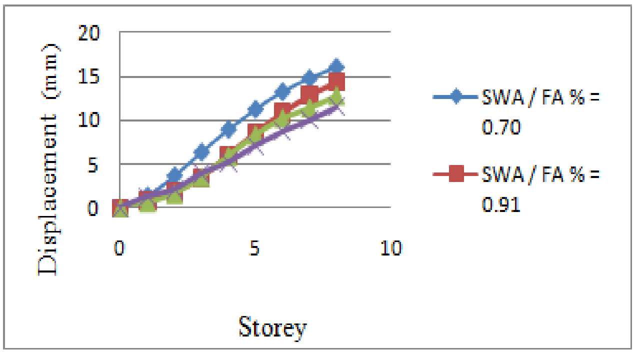

Fig 5.7 Storey displacement of eight storey model –Seismic force in X- direction

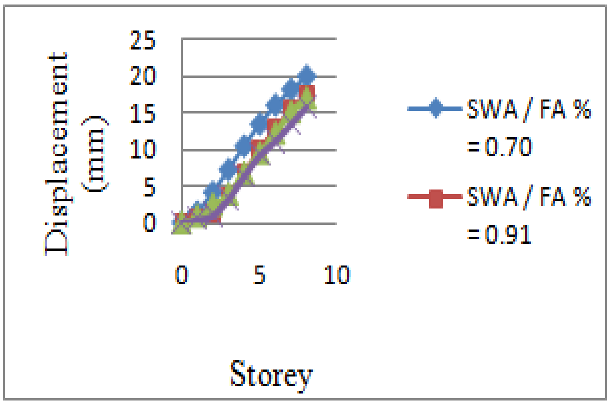

Fig 5.8 Storey displacement of eight storey model –Seismic force in Y- direction

Twelve storey model

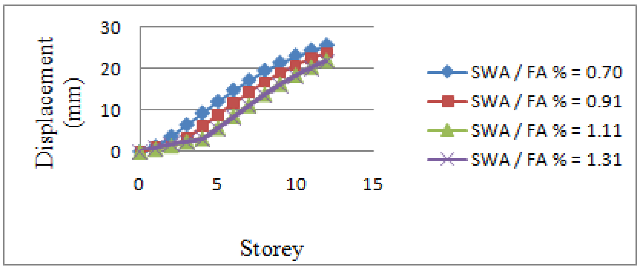

Fig 5.9 Storey displacement of twelve storey model – Seismic force in X- direction

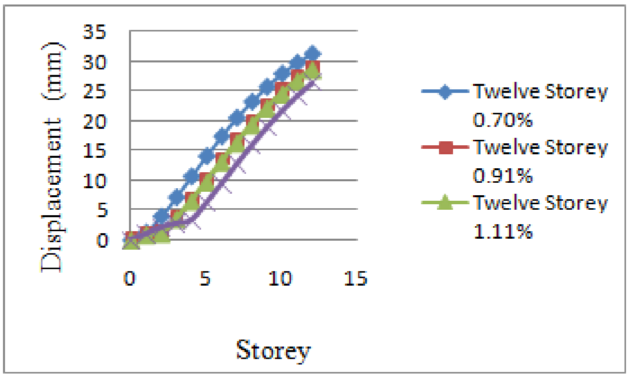

Fig 5.10 Storey displacement of twelve storey model – Seismic force in Y- direction

5.3 Discussion of Results

A) Response Spectrum Analysis

5.3.1 Fundamental Natural Period

It can be observed that the Fundamental natural period of five storey building for model 1 is more than the codal provision when comparing it with analytical results. Were as in model 2 by increasing the shear wall area ratio, natural period is almost similar to codal provision. Thus by increasing the shear wall area ratio there is a considerable reduction in time period.

It can be clearly understood from the table no 5.1 and 5.2 that by increasing shear wall area ratio in both x and y direction reduction in the time period takes place.

5.7 Summary

In this chapter, the results obtained from Response Spectrum Analysis and Time History Analysis performed by using E-tabs includes relationship between shear wall area and Base shear, relationship between shear wall area and Roof drift, Storey Drift and Storey Displacements has been discussed for different building model with increasing Shear wall area ratio by considering the ground floor as soft storey.

CONCLUSION

6.1 Conclusions

On the basis of the results of the analytical investigation of 5, 8 and 12 storey RC building models with increasing shear wall to floor area ratio (SWA / FA) % by considering the ground floor as soft storey, the following conclusions are drawn:

- In case of response spectrum analysis it is observed that base shear values are increasing with increase in SWA / FA % for all the models.
- In case of Time History Analysis also it is observed that base shear values kept increasing with increase in SWA / FA %, however Uttarkasi Earthquake data on the models produced maximum base shear as compared to Bhuj and Chamba Earthquake data.
- For SWA / FA % = 1.11 a significant decrease in roof displacement is observed as compared to lower SWA / FA %. The decrease in roof displacements becomes less pronounced with increase in SWA / FA % beyond 1.11. This indicates that SWA / FA % of 1.11 is effective in reducing the roof displacements.
- In case of Time History Analysis for the three ground motion data the maximum roof displacement is observed in case of Bhuj and Uttarkasi than that of Chamba Earthquake Data.
- Storey Displacement in both the case of Response Spectrum and Time History analysis indicates that, the decrease in displacement with increasing shear wall area to floor area ratios is in between 1.11% and 1.31%.
- It is observed from both Response Spectrum and Time History Analysis that the storey drift

decreased with increase in SWA / FA % from 0.70 to 0.91. However decrease in roof drifts is observed to be more significant for SWA / FA % 1.11.

6.2 Scope for Further Study

Further it would be desirable to study more cases before reaching definite conclusion about the behavior of RC frames buildings. Studies can be conducted on high rise buildings (Multistoried) by providing more thickness of shear walls, providing shear wall at various other locations and also by providing dual system, which consists of shear wall (or braced frame) and moment resisting frame.

The study can also be done on Sloping grounds, various damping mechanisms and its applications on structures, and also by conducting the structures having base isolation system.

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