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Effect Of Shear Wall Area On Seismic Behavior Of Multistoried Building With Soft Storey At Ground Floor

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ABSTRACT

The advances in three-dimensional structural analysis and computing resources have allowed the efficient and safe design of taller structures. These structures are the consequence of increasing urban densification and economic viability. The trend towards progressively taller structures has demanded a shift from the traditional strength based design approach of buildings to a focus on constraining the overall motion of the structure. Now a day's reinforced concrete (RC) wall-frame buildings are widely recommended for urban construction in areas with high seismic hazard. Presence of shear walls imparts a large stiffness to the lateral force resisting system of the RC building. Proper detailing of shear walls can also lead to ductile behavior of such structures during strong earthquake shaking. One of the major parameters influencing the seismic behavior of shear wall frame buildings is the shear wall area ratio. Thus shear wall area ratio is set as a key parameter which is needed to be study. Thus an analytical study is performed to evaluate the effect of Shear Wall Area to floor area ratio (SWA/FA %) on the seismic behavior of multistoried RC structures with soft storey at ground floor. For this purpose, 12 building models that have Five, Eight and Twelve stories with SWA/FA % ranging between 0.70% and 1.31% in both directions are generated. Then, the behavior of these building models under earthquake loading is examined by carrying out Response Spectrum Analysis and Linear Time History Analysis using structural analysis software E-TABS. Response Spectrum Analysis is done according to seismic code IS 1893:2002. Linear Time History Analysis is carried out by considering the three ground motion records namely Bhuj, Chamba and Uttarkasi. The main parameters considered in this study are the relation SWA / FA % has with base shear and roof displacement, storey displacement and storey drift. The analytical results indicated that building models with SWA / FA % equal to 1% behaved satisfactorily under earthquake loads. In addition when the SWA / FA % increased beyond 1% it is observed that the improvement of the seismic performance is not as significant.

Key words: Reinforce concrete, Shear wall area ratio, Response Spectrum and Time History Analysis.

1.1 Introduction

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). It is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storey's above.

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.

1.4 Shear wall and Effect of Shear wall

The wall in a building which resists lateral loads originating from wind or earthquakes are known as shear walls. Reinforced concrete walls are strength and portent elements frequently used in constructions in seismic areas because they have a high lateral stiffness and Resistance to external horizontal loads, these shear walls may be added solely to resist horizontal forces or concrete walls enclosing stairways elevated shafts and utility cores may serve as shear walls. shear walls not only have a very large in plane stiffness and therefore resist lateral load and control deflection very efficiently but they also helps in reductions of structural & non-structural damage. The building incorporated with shear wall sufficiently ductile will be much away from seismic vulnerability and building failure in the earthquake sensitive zones thus resulting in increased life safety & low property loss.

2. METHODOLOGY

2.1 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.
- Zone Factor (Z):It is a factor to obtain the design spectrum depending on the perceived maximum seismic risk characterized by Maximum Considered Earthquake (MCE) in the zone in which the structure is located. The basic zone factors included in this standard are reasonable estimate of effective peak ground acceleration.
- Response Spectrum Analysis: It is the representation of the maximum response of

idealized single degree freedom system shaving certain period and damping, during earthquake ground motion. The maximum response is plotted against the undamped natural period and for various damping values, and can be expressed in terms of maximum absolute acceleration, maximum relative velocity, or maximum relative displacement.

- Time History Analysis: It is an analysis of the dynamic response of the structure at each increment of time, when its base is subjected to a specific ground motion time history.

2.2 Determination of Eigen values and Eigen vectors, Clause 7.8.4.1:

- Let the shear stiffness of the i^{th}storey is k_i and the mass is m_i subjected to an external the system in small, so it may be ignored and the system is analyzed as undamped system. Using D'Alemberts's principle, the dynamic equilibrium equation of mass at each floor is,

$$m\ddot{x}_{n-1} + k_n(x_{n-1} - x_{n-2}) - k_n(x_n - x_{n-1}) = f_{n-1}(t)$$

- Dynamic force $f_i(t)$ and the corresponding displacement $x_i(t)$. Assuming damping in
- The equilibrium equations can be expressed in matrix form as,

$$M\ddot{X} + KX = F$$

- In that case, displacement x can be defined at time t as,

$$x(t) = x \sin(\omega t+\varphi)$$

- Substitution, equation for free undamped vibration of the MDOF system becomes

$$K X = \omega^2 M X$$

- From the relation that, natural time period, $T = 2\Pi/\omega$

X is known as an eigen-vector/modal vector or mode shape (Clause 7.8.4.1), represented as,

$$\{\Phi\} = \{ \Phi_1 , \Phi_2 , \Phi_3 , \Phi_4 \dots \Phi_n\}$$

$$M^* = \{ \Phi_i\}^T [M]\{ \Phi_i \} = 1.0$$

$$\{\Phi_i\} = [X] / (X^T M X)^{1/2}$$

2.3 Determination of the Modal Participation Factors

Using the eigen-vectors determined for the structure, modal participation factors and effective masses for all the four modes can be calculated as:

$$P_k = (\textstyle\sum_{i=1}^{n} W_i \Phi_{ik})/(\sum_{i=1}^{n} W_i(\Phi_{ik})^2)$$

The modal mass (M_k) of mode k is given by,

$$P_k = (\textstyle\sum_{i=1}^{n} W_i \Phi_{ik}) / (g * (\sum_{i=1}^{n} W_i(\Phi_{ik})^2)$$

2.4 Maximum Absolute Response (ABS)

The ABS for any system response quantity is obtained by assuming that the maximum response in each mode occurs at the same instant of time. Thus the maximum values of the response quantity are the sum of the maximum absolute value of the response associated with each mode. Therefore using ABS, maximum storey shear for all modes shall be obtained as,

$$\lambda = \sum_{c}^{r} \lambda_c$$

2.5 Square Root of the Sum of Squares (SRSS)

A well-separated vibration frequencies is the Square Root of the Sum of Squares (more reasonable method of combining modal maxima for two-dimensional structural system exhibiting SRSS). The peak response quantity (λ) due to all modes considered shall be obtained as,

$$\lambda = \sqrt{\sum_{k=1}^{r} (\lambda_k)^2}$$

2.6 Complete Quadratic Combination (CQC)

For three dimensional structural systems exhibiting closely spaced modes, the peak

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response quantities shall be combined as per Complete Quadratic Combination (CQC) method,

$$\lambda = \sqrt{\sum_{i=1}^{r}\sum_{j=1}^{r} \lambda_i \rho_{ij} \lambda_j}$$

$$\rho_{nm} = \frac{8\zeta^2(1+\beta_{ij})\beta^{1.5}}{(1-\beta_{ij}{}^2)^2 + 4\zeta\beta^2(1-\beta_{ij})^2}$$

2.7 Time History Analysis

It is an analysis of dynamic response of the structure at each increment of time, when its base is subjected to a specific ground motion time history. A linear time history analysis overcomes all the disadvantages of modal response spectrum analysis, provided non-linear behavior is not involved. The Time History Analysis technique represents the most sophisticated method of Dynamic Analysis of the building. In this method mathematical model of the building is subjected to accelerations from earthquake records that represent the expected earthquake at the base of the structure.

2.8 Time Stepping Method

For an inelastic system the equation of motion to be solved numerically is

$$m\,\ddot{u} + c\,\mathring{u} + f_s\,(u\,,\,\mathring{u}\,) = p(t) \text{ or } -m\,\ddot{u}_g(t)$$

Subject to initial conditions

$$u_o = u(0)\;\mathring{u}_o = \mathring{u}(0)$$

3. Description of the Building Model's

Table 3.1 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

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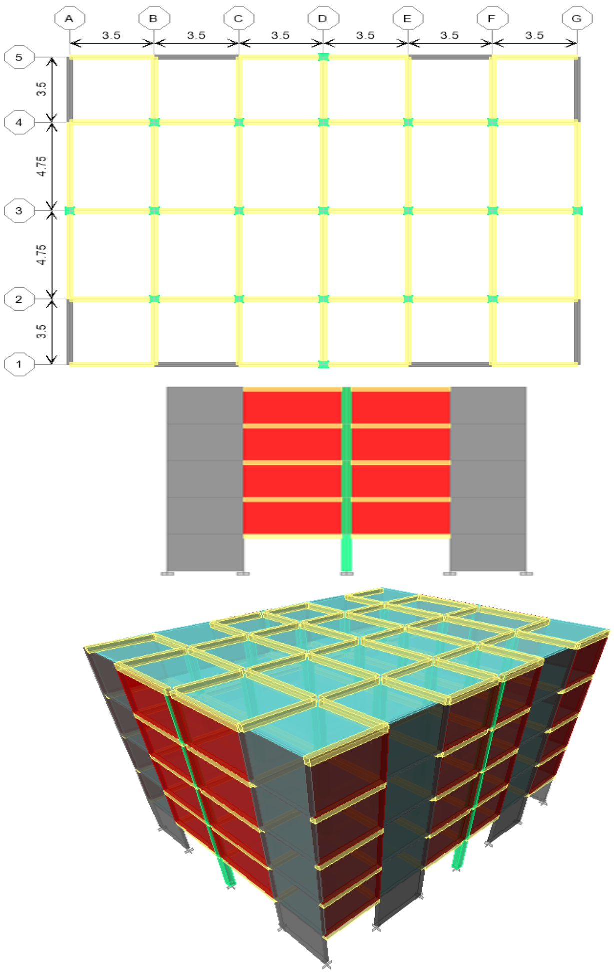

Fig 1. Isometric view and front elevation of eight storey building model

3.2 Design Data:

Material Properties:

Young's modulus of (M20) concrete, E = 22.360×10^6 kN/m²
Density of Reinforced Concrete = 25kN/m³
Modulus of elasticity of brick masonry = 3500×10^3 kN/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/m

4. RESULTS AND DISCUSSION

4.1 Fundamental Natural Period

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

Table 4.1 Codal and Analytical Fundamental natural periods for different building models along longitudinal – direction

Fundamental Natural Period T (sec)			
Model No.	Number of story	Codal	Analytical
1	5	0.329	0.393
2	5	0.329	0.378
3	5	0.329	0.367
4	5	0.329	0.358
5	8	0.526	0.69
6	8	0.526	0.671
7	8	0.526	0.657
8	8	0.526	0.647
9	12	0.789	1.12
10	12	0.789	1.09
	12	0.789	1.07

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11			
12	12	0.789	1.03

Table 4.2 Codal and Analytical Fundamental natural periods for different building models along transverse direction

Fundamental Natural Period T (sec)			
Model No.	Number of story	Codal	Analytical
1	5	0.371	0.393
2	5	0.371	0.378
3	5	0.371	0.367
4	5	0.371	0.358
5	8	0.593	0.69
6	8	0.593	0.671
7	8	0.593	0.657
8	8	0.593	0.647
9	12	0.89	1.12
10	12	0.89	1.09
11	12	0.89	1.07
12	12	0.89	1.03

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

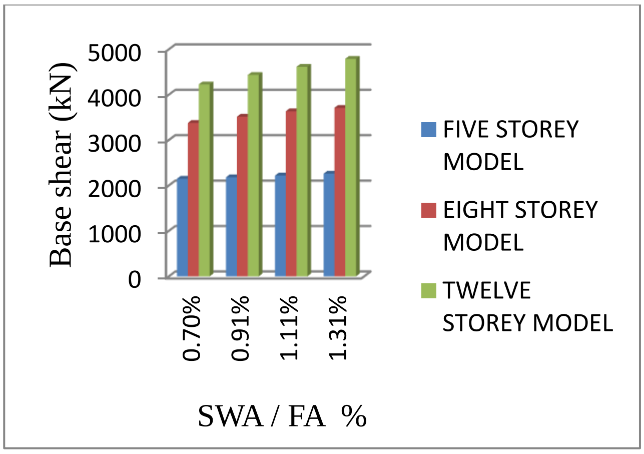

Fig 2. SWA / FA (%) vs. Base shear of five, eight and twelve storey – Seismic force in X- direction

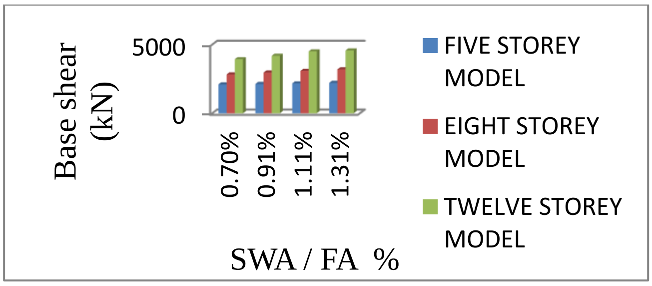

Fig 3. SWA / FA (%) vs. Base shear of five, eight and twelve storey – Seismic force in Y- direction

4.3 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

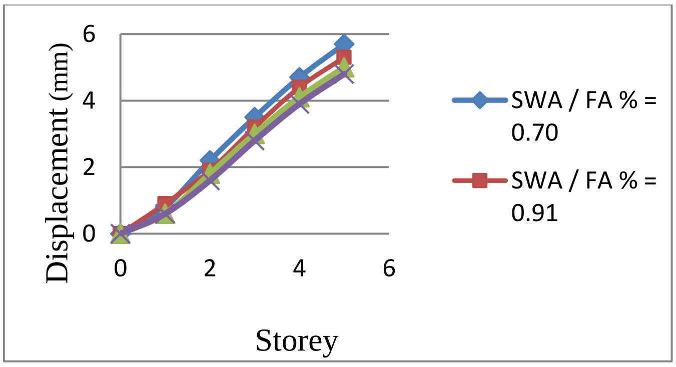

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Fig 4 Storey displacement of five storey model – Seismic force in X- direction

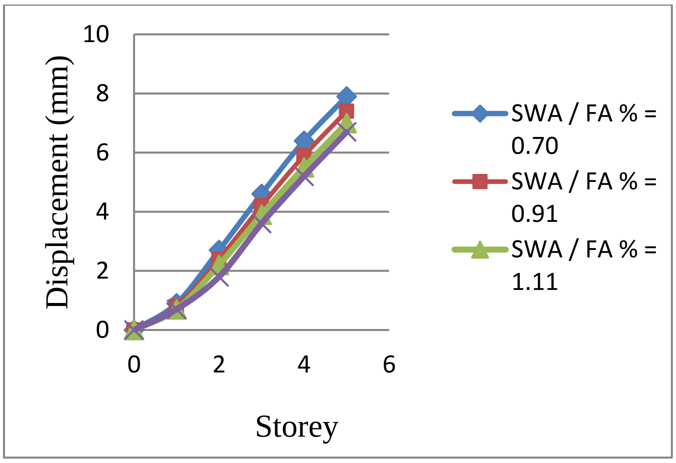

Fig 5. Storey displacement of five storey model – Seismic force in Y- direction

4.4 TIME HISTORY ANALYSIS

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

Bhuj Earthquake Data

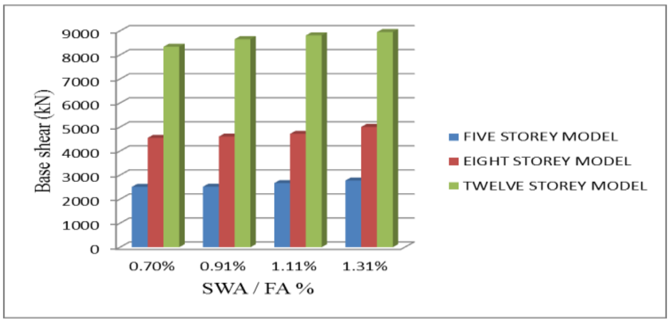

Fig 6. SWA / FA (%) vs. Base shear of five, eight and twelve storey – Seismic force in X- direction

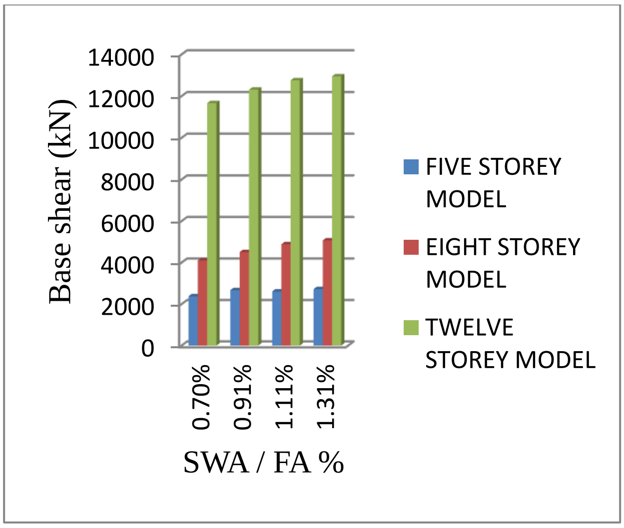

Fig 7. SWA / FA (%) vs. Base shear of five, eight and twelve storey – Seismic force in Y- direction

4.5 Storey Displacement

Five storey model - Bhuj earthquake data

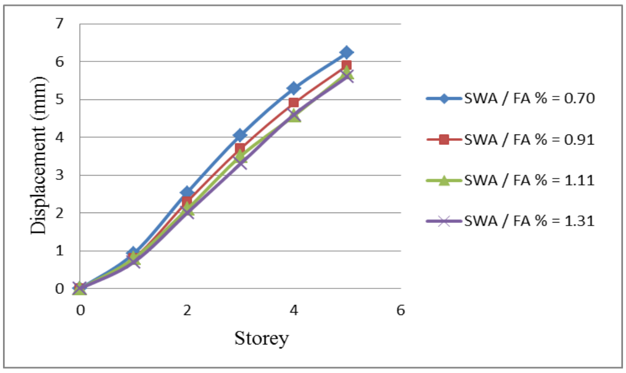

Fig 8. Storey Displacement of five storey models – Seismic force in X- direction

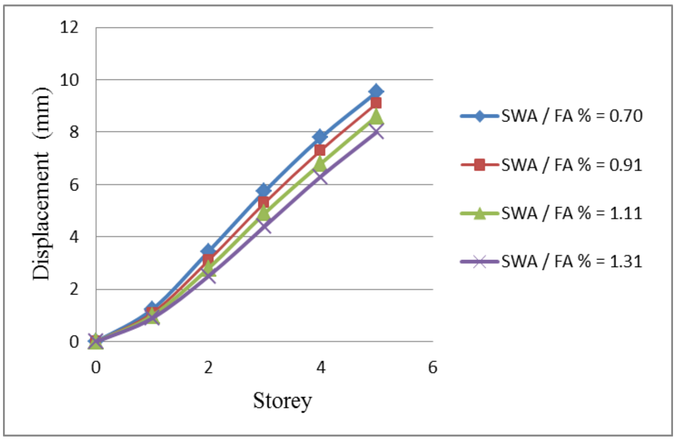

Fig 9. Storey Displacement of five storey models – Seismic force in Y- direction

5. 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
- That SWA / FA % of 1.11 is effective in reducing the roof displacements 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.
- 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.

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