A Comparative Study On The Seismic Performance Of Multi-storey Buildings With Different Structural Systems

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Abstract. The increasing need of shelter in urban cities due to overpopulated spaces and land inadequacy has forced people to limit their needs and spaces. High-rise buildings are the best solution for providing people space for living and to work on, as the buildings are getting higher and slender, they are exposed to different loading condition, which leads the building to experience higher lateral deformations. With the help of different structural systems, the lateral stiffness of the buildings can be improved, there are many structural systems introduced for the high-rise structures which can provide the buildings adequate strength and stability against lateral loading. This paper examines behaviour of Special Moment Resisting Frame System with shear wall, Outrigger Core Belt Truss Structural System and Braced Frame System on a 30 storey building under worst seismic conditions in India i.e. Zone V. To understand effectiveness of the structural systems subjected to lateral loads, three different structural system are modelled using 3D finite element software ETABS 2018, all the models are subjected to the same loading conditions with same geometrical dimension and typical storey height. Comparison is examined on the basis of different parameters like Modal Mass Participation, Base shear, storey shear, Time period, Lateral displacement, storey drift, storey stiffness, and performance points. It was observed by the dynamic analysis method i.e., response spectrum analysis, and non-liner static analysis, the parameters which were compared between three structural system observed that building with outrigger core belt truss system performs better than Special Moment Resisting Frame + Shear Wall and Braced Frame Structural System.

Keywords: Dynamic analysis, non-Liner static analysis, Special Moment Resisting Frame, Outrigger’s, flat slab, shear wall.

1. Introduction

A building is said to be high-rise when its height is greater than 50m as per Indian Standards. The evolution of high-rise buildings has started around 19th century in United States when the invention of elevators has been introduced in the building as a source of transport or connection with the higher floors. The materials used in construction by this time have become lighter when compared with old constructions. Vertical cities or high-rise buildings throughout the world have become popular with new construction methods and research in this field with the intention of achieving the requirements like safety, architecture, and overall economy of construction. Another reason to prefer the high-rise buildings is to control the urban sprawl with their comparatively small impression. The architectural requirements of the buildings are one of the reasons that engineers are challenged to design the structure to meet all architectural, financial, and structural parameters.

The engineering of tall buildings requires the use of different systems for different building elevations. Each system, therefore, has an economical height range, beyond which a different system is needed. The necessity of these systems and their ranges are somewhat imprecise because the demands imposed on the structure significantly influence these systems. However, knowledge of different structural systems, their approximate ranges of application, and the premium that would result in extending their range is indispensable for a successful solution of high-rise building project.
To conquer the failure of structural member different structural systems were developed; many structural systems were introduced from ordinary moment resisting frame. The structural system is defined as the structural arrangement of elements to form a frame which are used for the buildings in structural engineering to transfers loads from super structure to the sub structures, IS 16700-2017 classifies structural systems in clause 3.12.1 to 3.12.9, it specifies different structural systems. Details about the structural system used in the work is explained below.

1.1. Special Moment Resisting Frame with Shear Wall(SW)
Shear Wall or Structural Wall system is a system in which gravitational and lateral loads are resisted by the combine action of concrete wall i.e., shear wall or structural wall and interconnecting elements i.e., beams and columns, these systems are very commonly used in India for high rise construction due to its easy in construction and design calculation, there are different types of shear walls depending on the material steel, timber and concrete.

1.2. Braced Frame Structural System(BFS)
The members in a braced frame are generally made of steel which can work effectively both in tension and compression. Generally, in this type of structural system bracing resist the lateral forces, where beams and columns withstand the gravity loads. Bracing is of different types like Cross bracings, K-bracing, V-bracing diagonal bracings and etc.

1.3. Outrigger Belt truss Structural System(OBS)
Generally, outriggers are defined as a structural system composite of core wall perimeter columns and beams to withstand the lateral forces acting on the buildings. Perimeter columns usually carry the gravity loads and the beams are connected to core wall to generate the lever arm and provide effective use of core wall, some beams, wall, or truss which are directly connecting to core and external columns with equal length are often known as outrigger. This connection of elements can result in reduction of lateral displacement and also in overturning moment generated in the core. Outrigger system is being used for the buildings for past 30-35 years because of their effectiveness against the seismic loads.

2. Literature Review
The literature available on the performance of the buildings with different structural systems is majorly focused on investigating the complications of the high-rise buildings with various analytical approaches. Some of the research also provides an outline with the reviews on existing high rises building with different structural systems.

2.1. Prof. N. G. Gore, Miss Purva Mhatre (2018) Volume 64 Number 1: He studied the concept of Outrigger system and briefly explains its structural composition and advantages and different types of outriggers conventional, offset and virtual. It also compares the virtual system with the conventional outrigger system. And brief explanation on structural systems as interior structural system and exterior structural system and a study on existing buildings.

2.2. Lekshmi Soman and Sreedevi Lekshmi (2017) ISSN: 2278-0181; Vol. 6 Issue 06, June - 2017
The objective of the paper was to investigate the comparative lateral load resistance of the structure with a braced frame core and RC shear core along with outrigger system. To study the characteristics of a high rise building with the inclusion of outriggers. For the study outriggers were located at three different locations.

2.3. Raghunath.D.Deshpande, Sadanand M.Patil et al (2015), e-ISSN:2395-0056; Volume:02 Issue:03. In this research two different structural systems i.e Diagrid steel structure and
conventional structure are compared. They are analysed and designed for 60 storeys with a floor plan of 24 m x 24 m in size. These structures were designed on ETABS software as per IS 800:2007.

2.4. Sumit Pahwa, Devkinandan Prajapati et al (2017) ISSN: 2248-9622; Vol. 7, Issue 7: In this study a 30 Storey building is designed under different soil conditions and was observed that the building having no shear wall drift increases in initial 4th or 5th Storey there after it remain constant about 0.6667 of total height and then it decreases. A twist was observed where column sections are changed moderately reduction in thickness of structural wall has better drift control.

2.5. S.P.Sharma, and J.P.Bhandari (2015), ISSN 2319-7064; It gives a brief overview on research workdone on multi-Storey, RC frame structure with lateral load resisting systems such as shear wall and diagrid system. In this paper seismic analysis was performed on multi- Storey buildings with different locations of shear wall and on different heights. The paper gives a brief overview of different research journals.

3. Objectives of the Study
1. To study the response of high-rise buildings with different structural systems, SW, OBS and BFS when subjected to Seismic loads.
2. To evaluate the parameters like Base shear, Storey stiffness, Storey drift, Storey displacements, storey drifts.
3. To determine the performance points of these structural systems by pushover analysis.

4. Building Description

Three analytical models of concrete frame structure of 30 storeys with same in-plan dimensions were used in the study.

| Table 1. Building Data |
|------------------------|
| **Building Data**      | **Specifications**          |
| Plan dimension         | 49 m x 49 m                |
| Height of typical story| 3.33 m                     |
| Slab thickness         | 200 mm                     |
| Column size            | 1200 x 1200 mm             |
| Main beam size         | 300 x 600 mm               |
| Wall thickness         | 230 mm thick at periphery  |
| Grade of concrete      | M30                        |
| Grade of steel         | Fe 500                     |
| Density of concrete    | 30 kN m⁻³                  |
| Damping ratio          | 5%                         |
| Density of brick masonry| 20 kN m⁻³                |

Figure 1: Plan of the Structures
5. Methodology

5.1. Response Spectrum Analysis

Response spectrum method is also called as Modal analysis, it is one of the most frequently used method for performing dynamic analysis of high-rise buildings. This method uses the response range to give a set of possible forces and deformations on a structure it could undergo. This method transfigures a dynamic analysis into partly dynamic and partly static analyses for finding the maximum displacement. It gives clear understanding of modal vibrations and the design forces for the elements of structures. It also approximates the safety design of structures under seismic loads. In Response spectrum method the dynamic analysis is carried out to find maximum response of the structure with parameters like acceleration, velocity and displacement, of an extraction of SDOF system subjected to lateral. Using modal analysis mode shapes, frequencies, and mode participation factors of a building are known in this method. Input response spectrum function for all the models used is as per figure 5.

![Figure 2: 3D view of BFS](image1)

![Figure 3: 3D view of OBS](image2)

![Figure 4: 3D view of SW](image3)

![Figure 5: Input function for all the models as per 1893:2016](image4)
5.2. **Push Over Analysis**
The need of pushover analysis is to estimate and anticipate the performance of the structural systems by static nonlinear analysis method, where the structure is subjected to gravitational, and displacements controlled lateral Patterns which continuously increases through the elastic and inelastic behavior until an ultimate condition is achieved.

5.2.1. **Types of pushover analysis**
Pushover analysis is classified into two, one termed as the Displacement Coefficient Method (DCM) documented in FEMA-356 and other the Capacity Spectrum Method (CSM) documented in ATC-40. Both methods depend on lateral load deformation variation obtained by non-linear static analysis under the gravitational loading and idealized lateral loading due to the seismic action.

6. **Results and Discussion**

6.1. **Pushover Curves – Performance points**

**Figure 6.** Graphical representation for OBS building. The Performance point found at 67372 kN Shear at 196mm Displacement (D)

**Figure 7.** Graphical representation for SW building. The Performance point found at 64342 kN Shear at 187.675mm Displacement (D)

**Figure 8.** Graphical representation for BFS building. The Performance point found at 47502 kN Shear at 112.883mm Displacement (D)
6.2. Static Analysis - Story Shear

Figure 9. Graphical representation of Story shear for EQ

6.3. Static Analysis – Story Displacements

Figure 10. Graphical Representation of Story Displacements for EQ
6.4. Response Spectrum Analysis – Story Shear

![Image of Story Shear Graph]

**Figure 11.** Graphical representation of Story shear for SPEC

6.5. Response Spectrum Analysis – Story Displacements

![Image of Story Displacements Graph]

**Figure 12.** Graphical Representation of story Displacements (RS)
6.6. Response Spectrum Analysis – Story Drift

![Graphical representation of Story drift (RS)](image1)

**Figure 13.** Graphical representation of Story drift (RS)

6.7. Response Spectrum Analysis – Story Stiffness

![Graphical representation of Story stiffness (RS)](image2)

**Figure 14.** Graphical representation of Story stiffness (RS)
6.8. Results for Base Shear

![Figure 15: Base shear for SW V/S OBS V/S BFS](image)

6.9. Results for Model Time Periods

| Mode   | SW  | OBS | BFS |
|--------|-----|-----|-----|
| 1 (Sway) | 3.297 | 2.333 | 3.735 |
| 2 (Sway) | 3.297 | 2.333 | 3.375 |
| 3 (Torsion) | 2.011 | 1.982 | 3.094 |

7. Conclusions

Based on the observations and the results obtained during the course of this study, the following conclusions can be arrived.

- The modal mass participating ratio for all the structure have reached 85% in 3rd mode and 90% in both x and y directions at 8th mode.
- Base shear of the buildings was compared, it was found that BFS is having 44% less base shear than OBS and SW is having 25% less base shear than OBS.
- It was observed that, OBS is having lesser time-period than both SW and BFS. OBS 3.012sec, BFS 3.235sec and SW 2.342sec.
- It was found that, OBS provides more lateral stiffness by 63% and 81% than SW and BFS at top storey.
- Lateral displacements of all the buildings are under permissible limits but when comparing the results, OBS is having 31% lesser values than SW and 46% less than BFS.
• Storey Drift of all the buildings are in permissible limits as per IS 1893:2016, when compared at the top story it was found that SW experiences 61% and BFS experiences 66% more drift than OBS.
• From the performance curve of the structures shown in Figure 6, 7 & 8. It can be concluded that the building with OBS has better control for roof displacement compared with SW and BFS.

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