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A Study on Behavior of Structural Systems for Tall Buildings Subjected To Lateral Loads

Shruti Badami
PG Student
Department of Civil Engineering,
Dr. Ambedkar Institute of Technology
Bengaluru, India.

M. R. Suresh
Associate professor
Department of Civil Engineering,
Dr. Ambedkar Institute of Technology
Bengaluru, India.

***Abstract*— This paper describes an investigation has been carried out to examine the most common structural systems that are used for reinforced concrete tall buildings under the action of gravity and wind loads. These systems include "Rigid Frame", "Shear Wall/Central Core", "Wall-Frame Interaction", and "Outrigger". The basic modeling technique and assumptions are made by "ETABS" Program, in 3-D modeling. Design considerations are made according to Indian Standards. This comparative analysis has been aimed to select the optimal structural system for a certain building height. The structural efficiency is measured by the time period, storey displacement, drift, lateral displacement, base shear values and core moments. The recommendations for each structural are based upon limiting the wind drift of the structure, and increasing the lateral stiffness. The achievement of structural system for tall buildings is not an easy task. Whereas building height increases the importance of lateral loads action rises in an accelerating rate. There are two types of lateral loads, wind and seismic loads. Wind load presents the most critical lateral loading for modern tall buildings, which have lightweight skeletons that cause uncomfortable horizontal movements for occupants. Also, wind is not constant either with height or with time and is not uniform over the sides of a building. So, windy weather creates a variety of problems in tall buildings, causing concern for buildings owner and engineers alike. Where, excessive vibration due to this load is a major obstacle in design and construction of a modern tall building. It should be limited to prevent both structural and non-structural damage**.

Keywords*— *Tall buildings; structural systems; core moment; and drift control

I INTRODUCTION

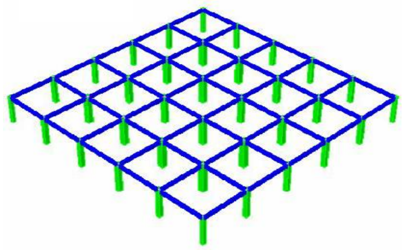
The achievement of structural system for tall buildings is not an easy task. Where, as building height increases the importance of lateral loads action rises in an accelerating rate. There are two types of lateral loads, wind and seismic loads. Wind load presents the most critical lateral loading for modern tall buildings, which have lightweight skeletons that cause uncomfortable horizontal movements for occupants. Also, wind is not constant either with height or with time and is not uniform over the sides of a building. So, windy weather creates a variety of problems in tall buildings, causing concern for buildings owner and engineers alike. Where, excessive vibration due to this load is a major obstacle in design and construction of a modern tall building. It should be limited to prevent both structural and nonstructural damage.

The five major structural systems used for the Tall Buildings are:

1. Rigid frame system
2. Rigid frame with shear wall
3. Shear wall with opening
4. Outrigger system

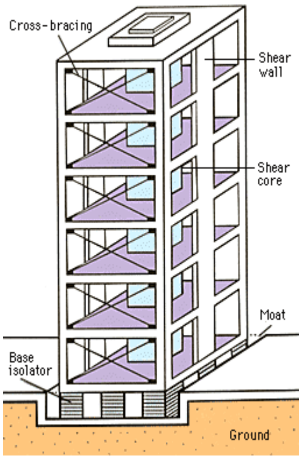
Rigid frame system

Consist of column and girders joined by moment resistant connections. The lateral stiffness of a rigid-frame bent depends on the bending stiffness of the columns, girders and connections in the plane of the bent



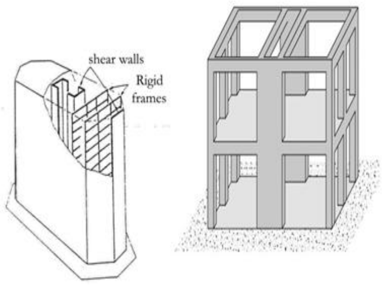
Shear Wall Structure

It is a vertical continuous stiffening element, that deform in bending mode.It is Used in reinforced concrete buildings and suited to residential buildings and hotels.



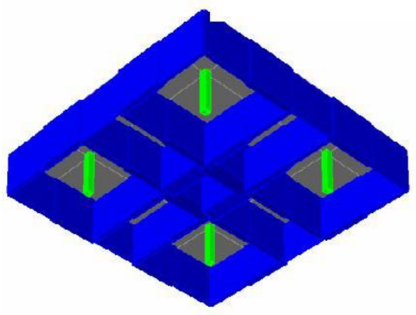
Wall-Frame Structures

1. When shear walls are combined with rigid frame the walls, which tend to deflect in a flexural configuration, and the frames, which tend to deflect in shear mode are constrained to adopt a common deflected shape by the horizontal rigidity of the girders and slabs.
2. Consequences, the walls and frames interact horizontally, especially at the top to produce a stiffer and stronger structure.
3. The interacting wall-frame combination is appropriate for building in the 40 to 60 stories range, well beyond that of rigid frames or shear walls alone.



Outrigger-Braced Structures

Outriggers are connected directly to the core and to exterior columns. Used in reinforced concrete and steel buildings. Outriggers restrain the rotation of the core and convert part of the moment in the core into a vertical couple at the columns (columns restrained outriggers).



II MAIN OBJECTIVES

1. Recommending a structural system for a certain building height, with the intention of limiting the wind drift to acceptable limits without paying a high premium in the quantity of structural material.
2. Presenting a comparative analysis between the most common structural systems of tall buildings built around the world within the past decades according to structural period and base shear values, drift and displacements.
3. Conceiving and applying the structural systems to extremely tall buildings is a practical demonstration of the engineer's confidence in the predictive ability of the analysis by commercial software.

III METHODOLOGY

The methodology of this study is on comparison of behavior of structural systems on tall building is having various types of structural systems for various building heights, storey and load intensities. Shear walls and outriggers are also considered in this project and outriggers optimum location such that maximum utilization of this can be achieved is also given due importance.

This study is intended to be helpful to clear the ambiguity in choosing the required type of system for a building as per the requirements of our building height, its location and its loading intensities.

1. Model Data

Structure	OMRF
No of stories	G+15, G+30, G+45, G+60
Story height	3.5 m
Grade of concrete	M50
Grade of steel	Fe415
Thickness of slab	0.125m
Beam size	0.45x0.6m
Column size (1.8x1.8,1.4x1.4,1.0x1.0,0.8x0.8)	
Seismic zone	III
Soil type	II
Importance factor	1
Response reduction factor	3
LL	4 kN/m^2
SDL	2 kN/m^2
TRL	1.5 kN/m^2

2. The model is a regular-shaped symmetrical plan with dimensions 49x49m. In all structural modeling, slab spans are assumed to be 7m, arranged in five bays in each direction, as shown in Fig. 1. The plan has a 7x7 m central core opening. The storey height is assumed to be 3.5 m. The analysis used is a three-dimensional analysis of detailed finite element models. The columns and beams were represented by frame-type element, while shear walls and core components were represented by shell-type element.

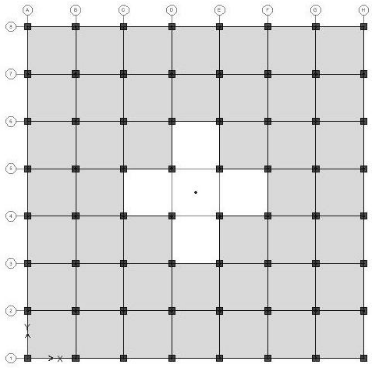


Fig.1 General Layout for all structural model plans

Method of Analysis Equivalent Static Force Method

In the present study, the analysis of the structure is made for seismic loads using Equivalent Static Force Method because of symmetry of the structure, both in geometry and in mass.

Analysis of Structural Systems

ETABS software is used for the analysis of all structural systems by Equivalent Static Lateral Force Method for Zone III. Based on the method of analysis considered, lateral load calculations are made by the software itself and then applied to the structure to analyze. Hence the results are tabulated for the study of behavior of structural systems

Load Calculations

All the structural systems are subjected to three types of primary load cases as per the provisions of IS Code of Practice for Structural Safety of Buildings Loading Standard IS 875-1987 (Part I).

They are:

1. Dead Load (From IS: 875-1987(Part I))
2. Live Load (From IS: 875-1987(Part II))
3. Seismic Load (From IS: 1893-2002(Part I)

Type of Structure

Type of structure considered for the analysis is a ORDINARY reinforced concrete moment resisting frame. Hence response reduction factor, R=3.0 from Table 7 of IS 1893(Part I) 2002

Importance of Structure

As this structure can be used as general building, its importance of structure is represented by the

Importance factor, I=1.0 from Table 6 of IS 1893(Part I) 2002.

Soil Type

The average response acceleration coefficient (Sa/g) depends on the type of soil where the structure is located and the fundamental natural time period (Ta) of buildings. Hence knowing the soil type becomes important for the calculation of lateral load

Seismic Zones

In the present study, the behavior of all the structural systems is studied for all the seismic zones of India as per IS 1893(Part I) 2002. The Zone Factors and Seismic Intensities are as mentioned below as per Table 2 of IS 1893(Part I) 2002

Method of Analysis

In the present study, the analysis of the structure is made for lateral loads using Equivalent Static Force Method because of symmetry of the structure, both in geometry and in mass.

Assumptions

1. *Material:* Concrete is assumed to behave linearly elastic. The modulus of elasticity E_c will be taken as $4700f'_c$. Where, the specified compressive strength of concrete f'_c is assumed equal to 40 Mpa, as used in practical applications of tall buildings.

2. *Participating components*: Only the primary structural components are assumed to participate in the overall behavior. The effects of secondary structural components and nonstructural components are assumed to be negligible; these include staircases, partitions, cladding, and openings.

3. *Floor slabs*: are assumed to be rigid in plane, with thickness equal to 30 cm in all models. This assumption causes the vertical elements at any floor level undergo the same components of translational displacement and rotation in the horizontal plane.

4. *Cracking:* The effect of cracking in reinforced concrete members due to flexural tensile stresses is represented by reducing moment of inertia,

5. *Constraints*: Supporting bases of all structural models are fixed supports.

6. *Loading:*

i. *Gravity Loads*: Dead load is taken as 2kN/m², the building weight and its content is considered in the dead load and calculated based on material densities by the program. While, live load is taken as 4kN/m² .

ii. *Wind loads*: will be developed according to Indian standard.

7. *Wind loading*:

Vb=50

Terrain category =3

Structure class=B

Risk co-efficient k1=1
Topography k3=1

Sample Calculations

Natural Time Period for Rigid System:

For 15 storey building

$Ta=0.075 = 0.075(51)^{0.75}= 1.43s$

For 30 storey building Ta= 2.43s
For 45 storey building Ta= 3.31s
For 60 storey building Ta= 4.11s

Natural Time Period for Rigid Frame With Shear Wall, Shear Wall With Opening And Outrigger System

For 15 storey building

$Ta=0.09x51 = 0.075(51)/49^{1/2}= 0.65s$

For 30 storey building Ta= 1.333s
For 45 storey building Ta= 2.00s
For 60 storey building Ta=2.68s

Storey V/S Drift

According to Clause 7.11.1 of IS 1893-Part I: 2002 and Clause IS 456:2000, the maximum allowable drift is 0.04h and allowable displacement is 0.04H (H/250) where h is the storey height and H is the total height of the building, for a partial safety factor of 1.0.

Hence, the allowable displacements of a particular height of the building and maximum allowable storey drifts are given in

No. OF STORIES	RF	RF WITH SW	SW	OUTRIGGER
15	0.000966	0.000174	0.000192	-
30	0.00199	0.000598	0.000796	0.000498
45	0.002436	0.000853	0.001285	0.00069
60	0.002709	0.001229	0.001994	0.001007

Table 1 for a storey height of 30m

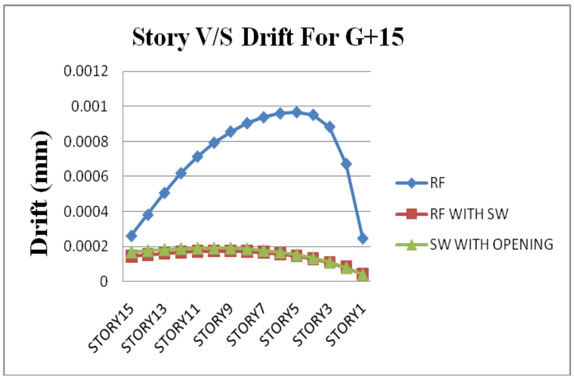


Fig.3 Story V/S Drift for G+15

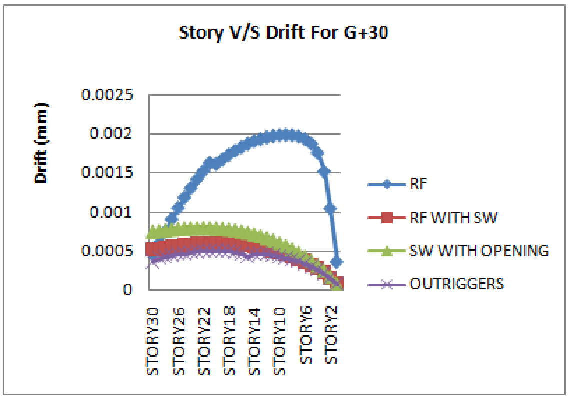


Fig.4 Story V/S Drift for G+30

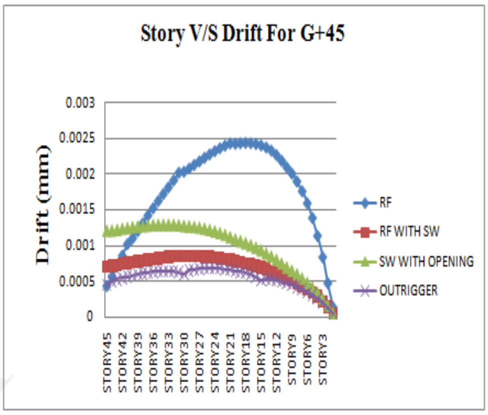


Fig.5Story V/S Drift for G+45

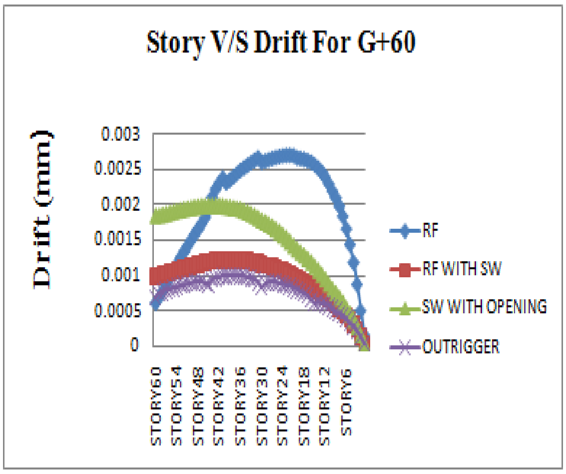


Fig.6 Story V/S Drift for G+60

The above investigation comes to the conclusion that rigidity/stiffness of composite high-rise building is inversely proportional to its height i.e. the lateral stiffness decreases with increase in height of structure. Story drift value for all structural systems are within the limits specified in IS 1893 2002, But my comparative study it can be observed that, story drift is maximum in the case of Rigid frame, and minimum in case of outrigger system, and story drift in case of shear wall systems where there are no beams, drift is more that rigid frames with shear wall system.

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TOP MOMENTS		
Stories	RF With SW	Outrigger
15th	146986.9	-
30th	496955.8	438561.1
45th	469433	398915.8
60th	549684.2	464363.9

Table 2 Top Core Moments for rigid Frame with Shear Wall and Outrigger System

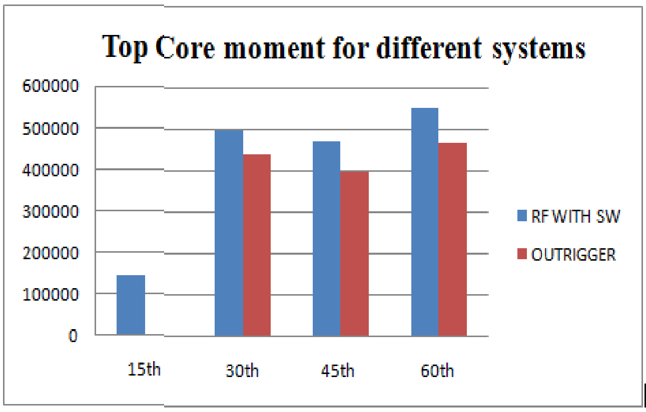

Fig 7 Top Core Moments for Rigid Frame with Shear Wall and Outrigger System

BOTTOM MOMENTS		
Stories	RF With SW	Outrigger
15th	154190.1	-
30th	511205.9	452783
45th	475548.4	405016.9
60th	556031.6	470692.3

Table 3 Core Moments at Base Level for rigid Frame with Shear Wall and Outrigger System

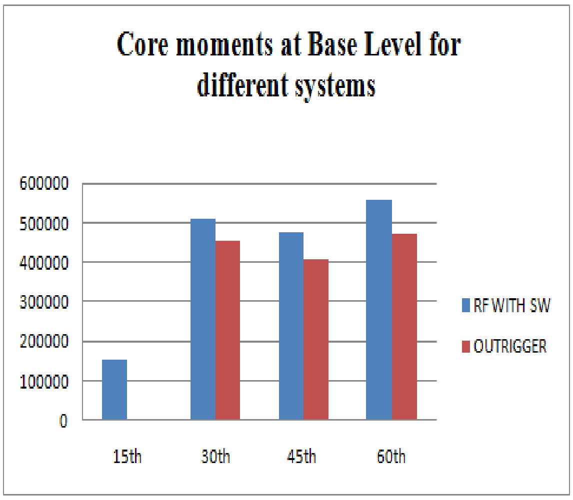

Fig 8 Core Moments at Base level For Rigid

Frame With Shear Wall And Outrigger Systems

From above graphs we can conclude there is substantial reduction in bending moment in core, when outrigger system is added to the structure. There is substantial reduction in forces in core bending moment in particular when outrigger system is added to the structure

IV CONCLUSION AND FURTHER SCOPE OF PROJECT

Based On The Limited Study Carried Out, The Following Conclusions Are Made**:**

1. Under the effect of wind loads, as the height of the structure increases, the lateral deflection and the overturning moment at the base increase. Tall buildings almost always require additional structural material, in order to limit the lateral deflection and resist the overturning moment, over and above that required for gravity loads only.

2. The key idea in limiting the wind drift in a tall building is by changing the structural form of the building into something more rigid and stable to confine the deformation and increase stability

3. The stiffness (rigidity) and stability requirements become more important as the height of the structure increases, and they are often the dominant factors in the design

4. As the building height increases time period has increased i.e., 45% to 50% increase can be observed from the graphs for every addition of 15 stories.

5. Maximum base shear at the base of the building increase with the increase in number of stories. Hence it can be conclude that base shear depends mainly on seismic weight of the building.

6. The reduction in the displacement of rigid frame with shear wall framed structure is 50 % with respect to R.C.C. frame

Structure, 25% in case of shear walls and 60 % when outrigger is used.5.2 Structural systems conclusions.

The main conclusions of this comparative study, concerning the efficiency of the presented five structural systems and the ability of each system in limiting the wind drift for a certain building height, can be summarized in the following:

Rigid frame system

The relatively high lateral flexibility calls for uneconomically large members.

It is not possible to accommodate the required depth of beams within the normal ceiling space in tall rigid frame.

Not stiff as other three systems and considered more ductile and more susceptible to wind failures.

Rigid frame with shear wall

The benefits of this system depend on the horizontal interaction, which is governed by the relative stiffness of walls and frames and the height of the structure.

As the structure height and the stiffness of the frames increase, the interaction between walls and frames increases.

The major factor in determining the influence of the frames on the lateral stiffness of this system is the height.

As the structure height increases, the sharing of walls from the base shear decreases with respect to frames and more interaction induced between both of them.

Shear wall/central core system

- More economic than rigid frame.
- A great increase in flexural stiffness with respect to rigid frame and Outrigger system
- The most economic system.
- Creates a wider effective system for reducing the overturning moment in the core structures.

The outrigger structural systems not only proficient in controlling the top displacements but also play substantial role in reducing the inter storey drifts

The beneficial action is a function of two factors:

1. The stiffness of the outrigger (Varies inversely with the outrigger distance from the base)
2. Its location in the building.

An effective system in case of finding out at what level the outriggers should be placed in order to have a maximum impact on the wind drift.

Very effective in increasing the structure's flexural stiffness, but it does not increase its resistance to shear, which has to be carried mainly by the core

Suggested Systems for Different Heights

Table 3 demonstrates the recommended structural systems for different heights. This table is organized according to the structural efficiency in limiting the wind drift as well as the cost and stiffness of the structure. These suggestions provide a direction to structural engineers for optimum system selection.

Height	Suggested System
10 stories (35 m)	Rigid Frame , Shear Wall
20 stories (70 m)	Shear Wall, Outrigger
30stories (105 m)	Rigid Frame with Shear Wall, Outrigger
40stories (140 m)	Rigid Frame with Shear Wall, Outrigger
50stories (175 m)	Outrigger
60stories (210 m)	Outrigger

Table 3 structural systems for different heights

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