EFFECT OF CONFIGURATION ON LATERAL DISPLACEMENT AND COST OF THE STRUCTURE FOR HIGH RISE STEEL SPACE FRAMES SUBJECTED TO WIND LOADS

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Abstract

The choice of a cost effective lateral-force-resisting system for high-rise structures is challenging. There is no streamlined methodology to quantitatively compare the cost-effectiveness of each system beyond the more qualitative perception based evaluation of advantages or disadvantages. Developers currently base their decisions on architectural layout and structural integrity. Cost considerations are often primarily based on experience.
This decision making process has three primary shortfalls.
1) It may not incorporate factors which greatly affect the economy of a particular framing system.
2) It may not allow engineers to carryout designs at the least cost.
3) Comparison of framing systems may not address the specific building types.

This investigation proposes a prototype cost-effective model for selecting either a skeleton framing system or skeleton frame with bracing system for steel structural frames. A model for selecting cost-effective skeleton framing system or skeleton frame with bracing system will be a valuable tool for all decision makers. Engineers, in particular, will be able to select optimal steel framing faster, thus reducing design time and iterations. Furthermore, selection of economic framing system will also result in direct cost savings for steel structural frames.

The study involves the design and cost estimation of steel frames representing skeleton framing system and skeleton frame with bracingsystem. The cost effectiveness of the framing systems are compared based on lateral displacement requirements and cost.The preferred framing system should meet lateral displacement requirements and is lower in cost. The results of this pilot study showed that the Skelton framing system with bracing is the cost-effective choice for 30storeys steel space frames at wind speeds of 55m/sec, 50m/sec and 47m/sec.

Keywords: *Bracings, SFS (Skeleton framing system), SFWB (Skeleton frame with bracing system) etc…*

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1. GENERAL ON TALL BUILDINGS

High-rise structures have certain features. The structures are high & lead to higher vertical loads and higher lateral loads in comparison with lower buildings. Buildings between 75 feet and 491 feet (23 m to 150 m) high are the materials used for the structural system of high-rise buildings are reinforced concrete and steel

Vertical loads on the high rise structures have Dead loads arise from the weigh to the individual construction elements and the finishing loads and Live loads are dependent on use depending on the number of stories, live loads can be reduced for load transfer and the dimensioning of vertical load-bearing elements.

Horizontal LoadsCalculation of lateral loads should be carefully scrutinized. It generally arises from unexpected deflections, wind and earthquake loads

Unexpected Deflections arises from imprecision in the manufacture of construction elements and larger components, another cause is the uneven settling of the foundation at an in-homogeneous site.

Wind loadsHigh-rise buildings are susceptible to oscillation. It should not be viewed as statically equivalent loads, but must be investigated under the aspect of sway behavior. Wind tunnel experiments are used to see the influence of the building shape on the wind load. The ability of wind loads to bring a building to sway must also be kept in mind. This oscillation leads both to a perceptible lateral acceleration for occupants, and to a maximum lateral deflection

1.1 Objectives of the Present Investigation:

The aim of this thesis is therefore to make a comparative study of structural costs of high rise buildings designed with and without bracings. The study is to be restricted to a study of steel space frames only.

Whether a building requires provision of bracings or not depends not only on the height of the building but also on the intensity of lateral loads. So it is proposed to carry out this comparison for different wind speeds of the country. i.e. 55m/sec, 50m/sec and 47m/sec

Although principles for analysis of multi storied frames with bracings are quite well known, computer software packages are not readily available for carrying out such an analysis. Hence it is first necessary to develop efficient methods of analysis of framed buildings with bracings.

Hence the aims of the thesis are chosen as the following:
1. To select a "bench mark” structural configuration which could serve as the basis for comparative studies.
2. To develop a suitable method for analyzing multi storied frames with bracings interaction and establish its validity.
3. To carry out analysis and design of the chosen building for heights of 30, 60, and 90 m to be constructed in various wind speeds 55m/sec, 50m/sec and 47m/sec.
4. To make an analysis of the Displacement- values of the chosen high- rise buildings.
5. To obtain the total quantity of steel consumed for each of the examples studied and evaluate the efficiency or otherwise provision of bracings.
6. To provide guide lines for structural designers on the economies that could be obtained by using bracings.

1.2 Scope of the Project:

For the purpose of developing the Effectiveconfiguration framing system
1. The important factors are limited to lateral displacement and cost effectiveness subjected to wind loads
2. Designs are carried out using IS 800-1984
3. Cost comparison is done with respect to percentage variation in quantity of steel.

Here the study is primarily focused on a 30 storey structure representing skeleton framing system and skeleton frame with bracing systems. 10 and 20 storeys are also modeled and designed for cost comparison (with respect to quantity of steel) .This 30 storey structure is modeled in a plan area of 15 m x 40m and height is 90m above G.L. with 3m each floor level. For the analysis and design STAAD.Pro-2006 software is used.

Codes used for design are:

For Dead load IS: 875 (Part-I)
For Live load IS: 875 (Part-II)
For wind load IS: 875 (Part-III)
For Design IS: 800-1984

The dimensions of the building frame components are calculated by preliminary approximate approach and the dimensions are revised accordingly using STAAD.Pro-2006 software.

In case of steel space frames with bracings, thebracings are provided along the periphery of the structure.

2. LITERATURE REVIEW

Chaudhary[1]et al Explained about India buildings which can be classified as tall buildings exist only in Mumbai and Delhi. Hence the literature available in Indian Journals on this topic is scarce. Some of the publications from Indian Journals are reviewed below. They presented in their paper, describing the basis for the selection of structural system and the corresponding analysis and design adopted for high-rise building (20 storeys). The principles involved in the selection of a structural system arc highlighted. The suitability of different structural system was discussed corresponding to the site chosen by them. Finally they selected shear wall core with space frame structural system to resist certain wind forces. They concluded that selection of a suitable system finally depends on necessary stiffness, strength and serviceability.

P. Jayachandran[2] Explained about the design of tall buildings essentially involves a conceptual design, approximate analysis, preliminary design and optimization, to safely carry gravity and lateral loads. The design criteria are strength, serviceability, stability and human comfort. The strength is satisfied by limit stresses, while serviceability is satisfied by drift limits in the range of H/500 to H/1000. Stability is satisfied by sufficient factor of safety against buckling and P-Delta effects. The factor of safety is around 1.67 to 1.92. The human comfort aspects are satisfied by accelerations in the range of 10 to 25 milli-g, where g=acceleration due to gravity, about 981cms/sec^2. The aim of the structural engineer is to arrive at suitable structural schemes, to satisfy these criteria, and assess their structural weights in weight/unit area in square feet or square meters. This initiates structural drawings and specifications to enable construction engineers to proceed with fabrication and erection operations. The weight of steel in lbs/sqft or in kg/sqm is often a parameter the architects and construction managers are looking for from the structural engineer. This includes the weights of floor system, girders, braces and columns. The premium for wind, is optimized to yield drifts in the range of H/500, where H is the height of the tall building. Herein, some aspects of the design of gravity system, and the lateral system, are explored. Preliminary design and optimization steps are illustrated with examples of actual tall buildings designed by CBM Engineers, Houston, Texas, with whom the author has been associated with during the past 3 decades. Dr.JosephP.Colaco, its President, has been responsible for the tallest buildings in Los Angeles, Houston, St. Louis, Dallas, New Orleans, and Washington, D.C, and with the author in its design staff as a Senior Structural Engineer. Research in the development of approximate methods of analysis, and preliminary design and optimization, has been conducted at WPI, with several of the author’s graduate students.

3 PROJECTMETHODOLOGY

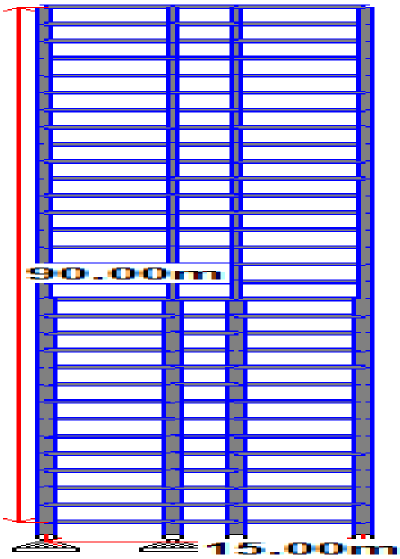
3.1 Introduction

This chapter presents the methodology adopted to evaluate the effective configuration among the skeleton framing system and skeleton frame with bracing systems for high rise building. The methodology includes analysis and design of the systems against different lateral loads followed by cost estimation. This chapter gives detailed description of the model considered for the framing system. For analysis and design, STAAD PRO- 2006 software is used. Cost estimation is done based on the quantities obtained from computer analysis. The steps involved in the methodology are:

- Basic model specifications.
- Modeling of skeleton framing system and skeleton frame with bracing system.
- Analysis and design.
- Cost estimation and comparison.

Basic model specification are first outlined as they describe the study variables and constants for the two framing system. For the purpose of simplicity, building type, floor system, floor area, bay size and column height remain constant through the study. However,numbers of stories and members sizes are varied. The next step examines modeling of the framing system and material specification. Analysis and design was done by working stress method using critical load combinations follows. This part mainly focuses on a 30 storey structure.

Cost estimation deals with the criteria for calculating quantity of steel for framing systems. The final step in the methodology outlines the comparison criteria which are the lateral displacement and steel cost. Lateral displacement of the framing systems are checked against code requirements. The preferred structural system must meet lateral displacement requirements as well as be lower in cost the governing parameter is lateral displacement.



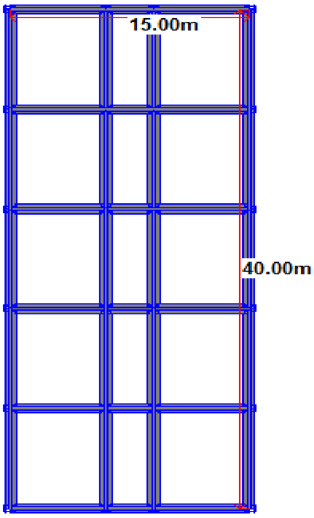


Fig: 3.1 Plan and elevation of 30 storey SFS

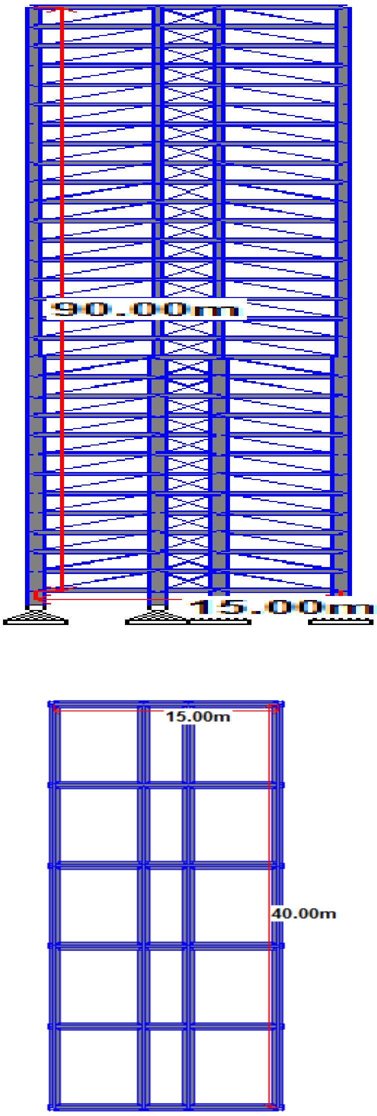


Fig: 3.2 Plan and elevation of 30 storey SFWB system

3.2 Loads Considered for the Design

3.2.1 Dead Load

All the material weights as per IS: 875(Part-I)

3.2.2 Live Load

Design live load intensity was taken as 2 KN/m^2as per IS:875-II

3.2.3 Wind Load: (IS 875- part- III)

V_b= basic wind speed i.e 55m/sec , 50m/sec and 47m/sec
V_z= design wind speed
V_z= $K_{1,}K_2K_3V_b$
K_1=Risk coefficient
K_2=Size, height and terrain factor
K_3=topography factor
Wind pressure = $0.6(V_z)^2$
At V_b= 55m/sec for 30- storey
V_z=1*0.93*1*55=51.15m/sec ,P_z= $0.6(V_z)^2$= 1.57KN/m^2 at 10m
V_z=1*0.97*1*55=53.35m/sec ,P_z= $0.6(V_z)^2$= 1.71KN/m^2 at 15m
V_z=1*1*1*55=55m/sec ,P_z= $0.6(V_z)^2$= 1.81KN/m^2 at 20m
V_z=1*1.04*1*55=57.2m/sec ,P_z= $0.6(V_z)^2$= 1.96KN/m^2 at 30m
V_z=1*1.10*1*55=60.5m/sec ,P_z=$0.6(V_z)^2$= 2.19KN/m^2 at 50m
V_z=1*1.17*1*55=64.35m/sec ,P_z= $0.6(V_z)^2$= 2.48KN/m^2 at 100m
V_z=1*1.21*1*55=66.55m/sec ,P_z= $0.6(V_z)^2$= 2.66KN/m^2 at 150m

3.3 Load Combinations Considered

1—DL + LL
2—(DL +WLX)
3—(DL +WL (-X))
4—(DL +WLZ)
5—(DL +WL (-Z))
6—0.75(DL + LL + WLX)
7—0.75(DL + LL + WL (-X))
8—0.75(DL + LL + WLZ)
9—0.75(DL + LL + WL (-Z))

3.4 Analysis and Design

The structure with different framing systems has been modeled on STAAD PRO-2006 software with the above said load conditions and combinations. The analysis is done for both Skelton framing system and Skelton framing system with Bracing.

3.4.1 Skelton Framing System:

This comprises of columns and beams alone with support condition pinned. These columns and beams are created using beams elements of the software. Here instead of slab panels created, loads directly applied by software.

3.4.2 Skeleton Frame with Bracing Systems

This comprises of columns and beams as the framing systems, withbracings atperiphery of the frame.

4. RESULTS & DISCUSSIONS

4.1 General Consideration

Comparison of lateral force resisting systems is done for each building category based on lateral loads, lateral displacement, material quantity and cost of structure. The building type is a multi storey structure with a 15m x 40m plan area. Lateral force considered was windalone for basic wind speed 55m/sec, 50m/sec and 47m/sec. Lateral displacement is checked against the requirements of IS:800-1984 i.e. Under transient wind load the lateral deflection of the structure should not exceed H/325, where H is the total height of the structure. Cost of the framing system includes cost of columns, beamsand bracings (wherever bracings areused). The cost of foundation is not included. Findings are discussed below for 10, 20, 30 storey structures at basic wind speeds 55m/sec, 50m/sec and 47m/sec.

4.2 Comparison of Displacements for 30 Storey Structure

In order to ascertain the simplest yet reliable method for analyzing the combined action of frame plus bracings, the combined system has been analyzed for a load combination of DL+WL

The result from all these analysis are compared to find out their validity

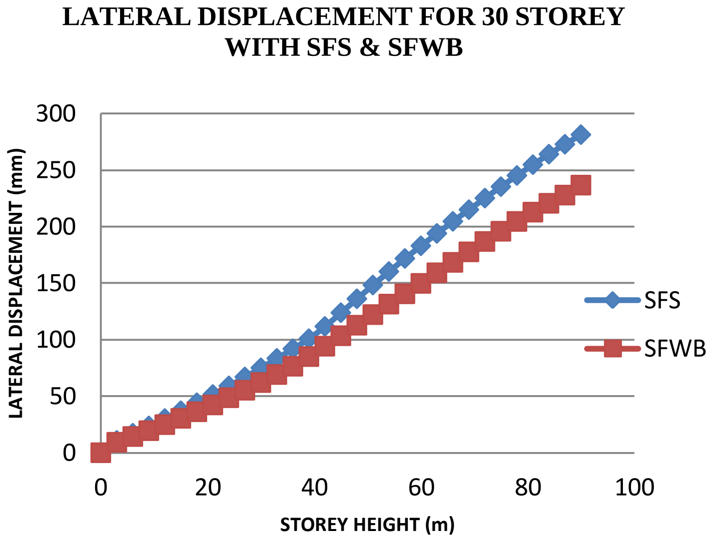


Fig: 4.1 Comparison of lateral displacement (WLX) for SFS and SFWB for basic wind speed 55 m/sec

From the figure 4.1, it is observed thatwhile comparing SFS with SFWB system, upto 18m (6 storeys) the lateral displacement due to wind load in X- direction are not considerable, beyond that there is a considerable amount of lateral displacement for wind speed of 55m/sec.

Percentage of steel variation w.r.t S.F.S (30 STOREY)

WIND SPEED (m/sec)	SFS	SFWB	PERCENTAGE VARIATION
55	2043	2033	0.48
50	1996	1982	0.7
47	1966	1951	0.8

Lateral Displacement:
30-storey at basic wind speed 55m/sec

The result for the lateral displacement for 55m/sec are presented in fig 4.7 The relation is shown between the lateral displacement for the two framing systems and the displacement limit which is 276mm calculated from H/325 whereH is height of the structure. The lateral displacement for SF system is 281.39mm. While that of the skeleton framing with bracing system is 236.73mm. SFS exceeds permissible limit, so SFWB system is the effective configuration in terms of lateral displacement and cost effective.

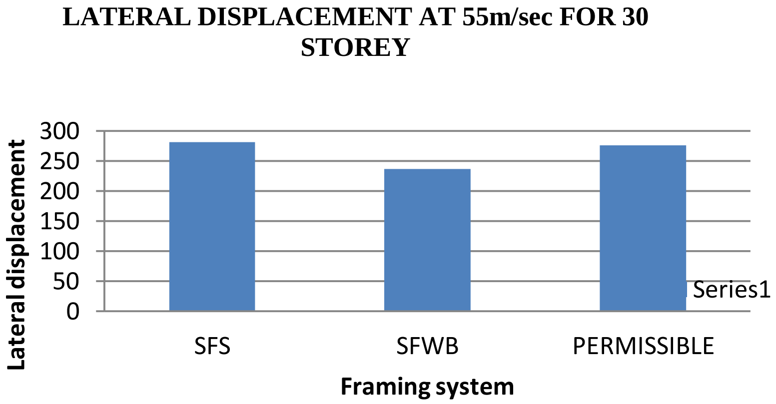


Fig: 4.2 Comparison of lateral displacement for SFS and SFWB with basic wind speed 55 m/sec

Material quantity: The SFWB system has about 0.48 % reduction inpercentage of steel,is calculated as the difference in quantities divided by quantity used in the SFS multiplied by 100.

Weight of steel forvarious framing systems at different wind speeds are shown in table below:

Table: 4.1 Tonnage of steel required for SFS and SFWB (in Tonnes)

No of storeys	Tonnage of steel obtained for 55 m/sec		Tonnage of steel obtained for 50 m/sec		Tonnage of steel obtained for 47 m/sec	
	SFS	SFWB	SFS	SFWB	SFS	SFWB
30	2043	2033	1996	1982	1966	1951

4.3 Variation in Displacement for Basic Wind Speeds 55m/sec, 50m/sec and 47m/sec

Variation = Actual Displacement / Allowable Displacement

For SFS & SFWB, for basic wind speed 55m/sec

Table 4.2: Variation in displacement for all storeys

Storey	SFS Displacement (mm)	SFWB Displacement (mm)	Allowable Displacement (mm)	SFS Variation in Displacement	SFWB Variation in Displacement
30	281.39	236.73	276	1.019	0.85
20	123.345	105	184	0.67	0.57
10	69.36	56.06	92	0.75	0.61

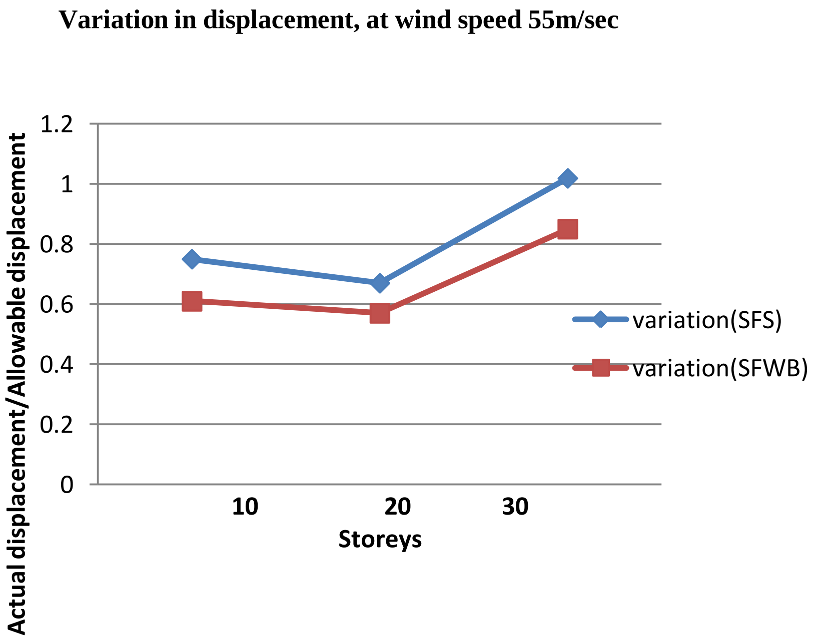


Fig 4.3: Comparison of displacement variation for the two systems, at wind speed 55m/sec

For SFS & SFWB, for basic wind speed 50m/sec

Table 4.2: Variation in displacement for all storeys

Storey	SFS Displacement (mm)	SFWB Displacement (mm)	Allowable Displacement (mm)	SFS Variation in Displacement	SFWB Variation in Displacement
30	252.11	211.08	276	0.91	0.76
20	110.384	93.076	184	0.59	0.51
10	67.90	54.01	92	0.73	0.58

Variation in displacement, at wind speed 50m/sec

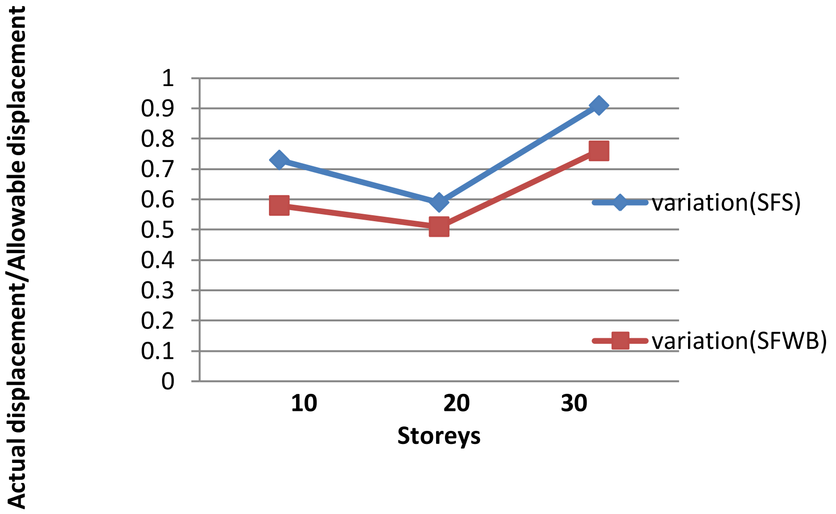


Fig4.4: Comparison of displacement variation for the two systems, wind speed 50m/sec

For SFS & SFWB, for basic wind speed 47m/sec

Table 4.3: Variation in displacement for all storeys

Storey	SFS Displacement (mm)	SFWB Displacement (mm)	Allowable Displacement (mm)	SFS Variation in Displacement	SFWB Variation in Displacement
30	233.362	196.158	276	0.84	0.71
20	102.328	86.362	184	0.56	0.47
10	66.81	51.63	92	0.73	0.56

Variation in displacement, at wind speed 47m/sec

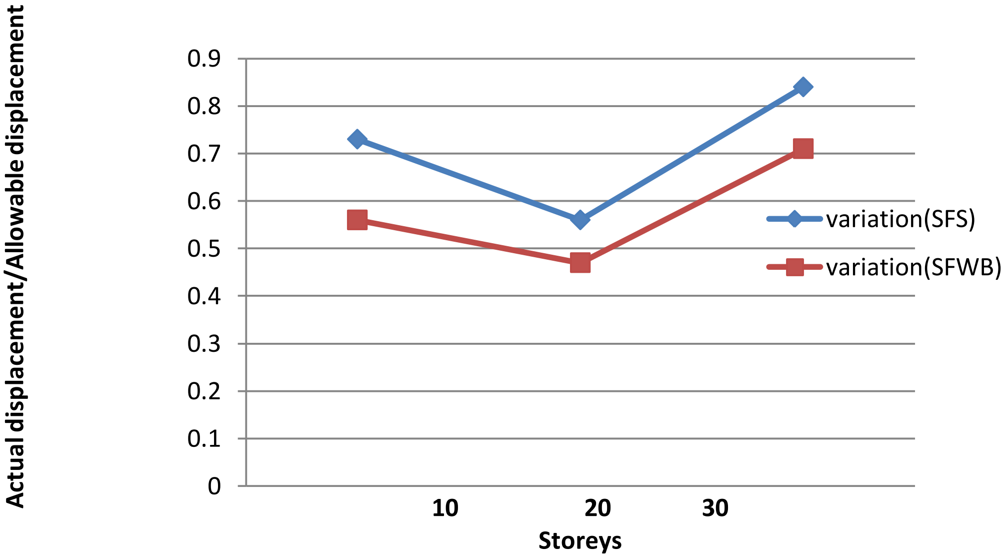


Fig4.6: Comparison of displacement variation for the two systems, wind speed 47m/sec

4.4 Comparison on Weight of Steel per Unit Area for the Two Systems

For basic wind speed 55m/sec:

SFS:

Table- 4.5: weight/unit area, SFS

Storey	Total weight of steel(tons)	Total area (sqm)	Wt/sq m (inKg/m^2)
30	2043	18000	113.5
20	1258	12000	104.8
10	303	6000	50.5

SFWB:

Table- 4.6: weight/unit area, SFWB

Storey	Total weight of steel(tons)	Total area (sqm)	Wt/sq m (inKg/m^2)
30	2033	18000	113
20	1199	12000	100
10	292	6000	48.7

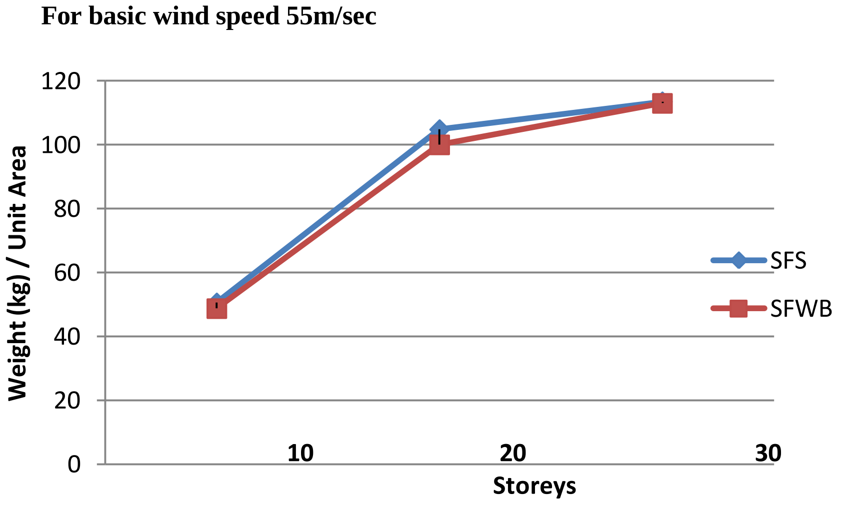


Fig4.7: Comparison of weight of steel for two systems, basic wind speed 55m/sec

For basic wind speed 50m/sec:

SFS:

Table- 4.6: weight/unit area, SFS

Storey	Total weight of steel(tons)	Total area (sqm)	Wt/sq m (inKg/m^2)
30	1996	18000	111
20	1243	12000	103.6
10	289	6000	48.16

SFWB:

Table- 4.7: weight/unit area, SFWB

Storey	Total weight of steel(tons)	Total area (sqm)	Wt/sq m (inKg/m^2)
30	1982	18000	110
20	1175	12000	98
10	281	6000	46.8

For basic wind speed 50m/sec

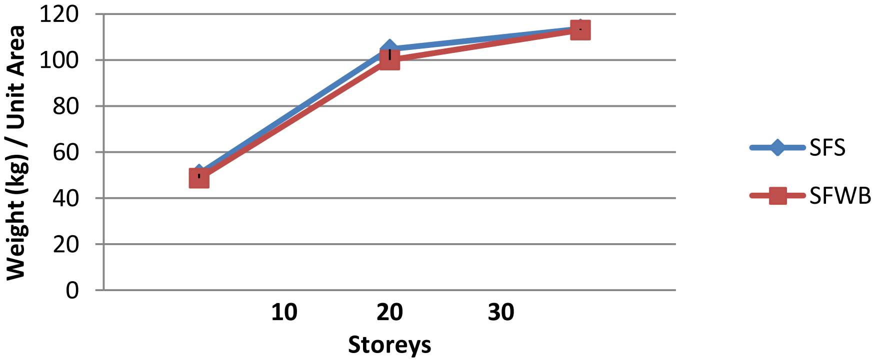


Fig4.8 Comparison of weight of steel for two systems, basic wind speed 50m/sec

For basic wind speed 47m/sec:

SFS:

Table- 4.8: weight/unit area, SFS

Storey	Total weight of steel(tons)	Total area (sqm)	Wt/sq m (inKg/m^2)
30	1966	18000	109
20	1235	12000	102.9
10	280	6000	46.7

SFWB:

Table- 4.9: weight/unit area, SFWB

storey	Total weight of steel(tons)	Total area (sqm)	Wt/sq m (inKg/m^2)
30	1951	18000	108
20	1164	12000	97
10	277	6000	46.2

For basic wind speed 47m/sec

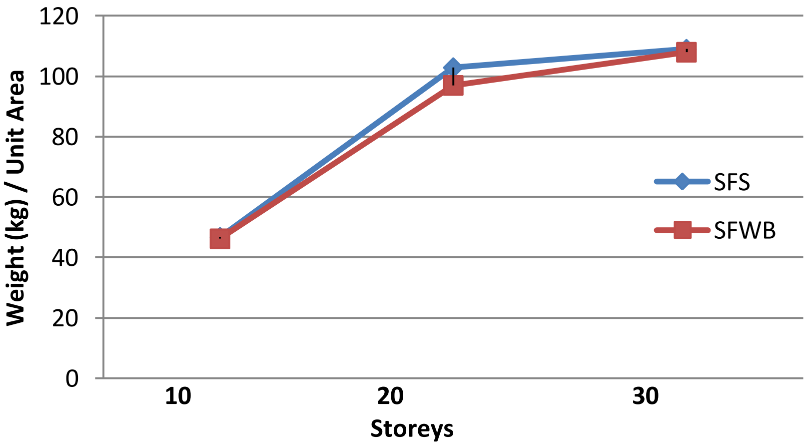


Fig: 4.9 Comparison of weight of steel of two systems, basic wind speed 50m/sec

4.5 Comparison of Cost per Unit Area for the Two systems

Cost of steel per Metric Ton is taken as RS 48,000/- as per SSR-2011 September revision

For basic wind speed55 m/sec:

SFS:

Table- 4.10: Cost/unit area, SFS,

Storey	Total cost of steel(rupees)	Total Area(sqm)	Cost/sqm
30	9,80,64,000	18000	5448
20	6,03,84,000	12000	5032
10	1,45,44,000	6000	2424

SFWB:

Table- 4.11: Cost/unit area, SFWB,

Storey	Total cost of steel(rupees)	Total Area(sqm)	Cost/sqm
30	9,75,54,000	18000	5419
20	5,75,52,000	12000	4796
10	1,40,16,000	6000	2336

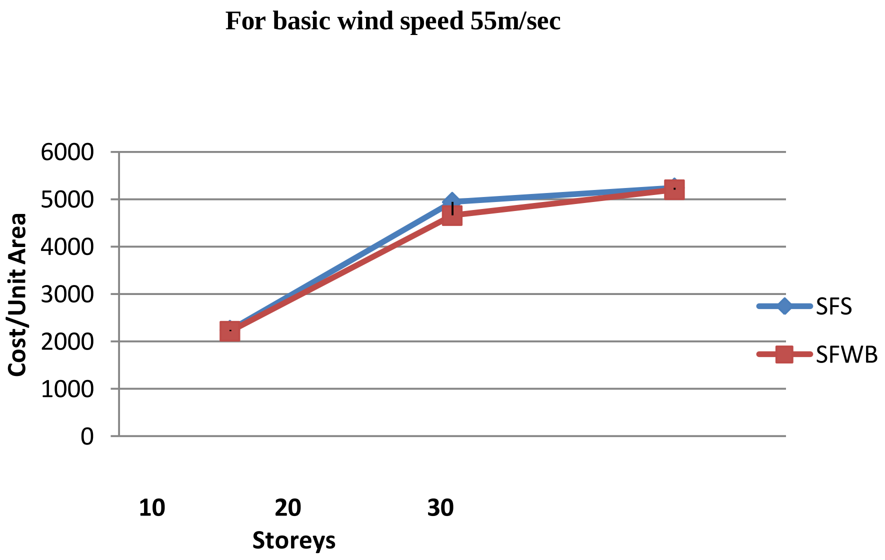


Fig: 4.10 comparison of cost/unit area for the two systems, 55m/sec

For basic wind speed50m/sec:

SFS:

Table- 4.12: Cost/unit area, SFS,

Storey	Total cost of steel(rupees)	Total Area(sqm)	Cost/sqm
30	9,58,08,000	18000	5322
20	5,96,64,000	12000	4972
10	1,38,72,000	6000	2312

SFWB:

Table- 4.13: Cost/unit area, SFWB,

Storey	Total cost of steel(rupees)	Total Area(sqm)	Cost/sqm
30	9,51,36,000	18000	5,285
20	5,64,00,000	12000	4700
10	1,34,88,000	6000	2248

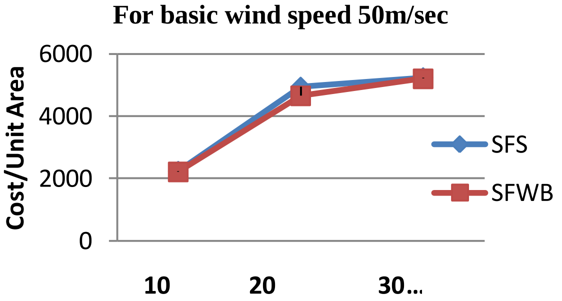


Fig: 4.11 comparison of cost/unit area for the two systems, 50m/sec

For basic wind speed47 m/sec:

SFS:

Table- 4.14: Cost/unit area, SFS,

storey	Total cost of steel(rupees)	Total Area(sqm)	Cost/sqm
30	9,43,68,000	18000	5242
20	5,92,80,000	12000	4940
10	1,34,40,000	6000	2240

SFWB:

Table- 4.15: Cost/unit area, SFWB,

Storey	Total cost of steel(rupees)	Total Area(sqm)	Cost/sqm
30	9,36,48,000	18000	5202
20	5,58,72,000	12000	4656
10	1,32,96,000	6000	2216

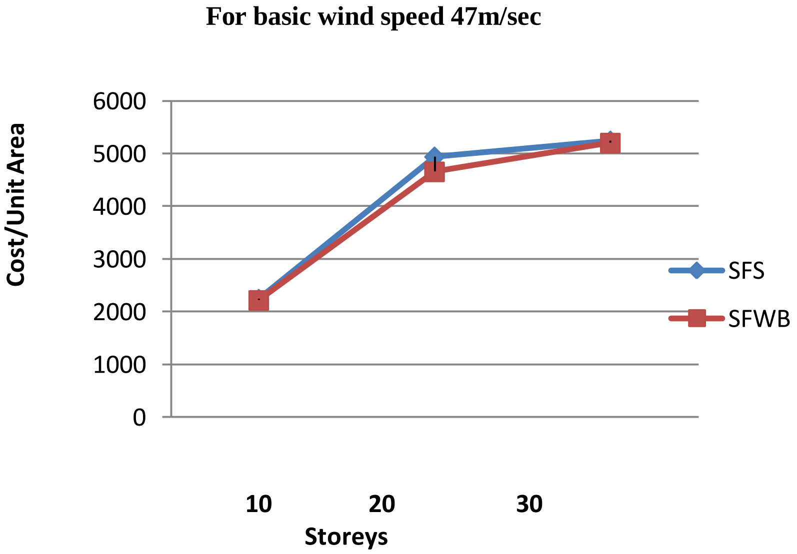


Fig: 4.12 comparison of cost/unit area for the two systems, 47m/sec

5. SUMMARY ANDCONCLUSIONS

The major conclusions and recommendations are outlined below:

1. The concept of using steel bracing is one of the advantageous concepts which can be used to strengthen structure.
2. Steel bracings reduce flexure and shear demands on beams and columns and transfer the lateral load through axial load mechanism.
3. The lateral displacement of 10 storey structure reduced by 14%, 16%, 16% in SFWB system at considered wind speeds, i.e 55m/sec, 50m/sec, and 47m/sec respectively. In all considered cases the lateral displacement in SFS and SFWB systems are within the permissible limit.
4. The lateral displacement of 20 storey structure reduced by 19%, 21%, 23% in SFWB system at considered wind speeds, i.e 55m/sec, 50m/sec, and 47m/sec respectively. In all considered cases the lateral displacement in SFS and SFWB systems are within the permissible limit.
5. The lateral displacement of 30 storey structure reduced by 16% in SFWB system at all considered wind speeds,i.e 55m/sec, 50m/sec, and 47m/sec respectively. In all considered wind speeds of 30 storey structure the lateral displacement in SFS and SFWB systems are with in the permissible limit,but in the case of basic wind speed 55m/sec, observed that SFS exceeds the permissible limit (i.e H/325) ,where as SFWB system is within the permissible limit. So we strongly recommended SFWB system at 55m/sec in the view of requirement of lateral displacement.
6.While comparing the cost of the structure, in all the considered cases we concluded that there is a less margin of percentage of variation of cost. Whereas, the margin in percentage of variation of cost was low, but it should also meet lateral displacement criteria.
7. While comparing lateral displacements of 10, 20 and 30 storey of SFS at wind speeds of 50m/sec and 47m/sec with 10, 20 and 30 stories SFWB system, observed that there is a considerable reduction in the lateral displacement at wind speed of 55m/sec.
8. From the study, concluded that for 30 storey structurethe SFWB system will be the effective in configuration (i.e.; both lateral displacement and cost) subjected to wind loads.

SUGGESTIONS FOR FUTURE WORK

1. Because of time constraints the study in this particular theory was restricted to the comparison of weight of super structure in different systems. A more meaningful comparison will be to compute the total cost of the structure.i.e. Both super structure and sub structure.
2. It will be interesting to carry out similar studies for severe seismic zones also.
3. A more meaningful study will be to analyze and design connections and their quantity.

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