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Behaviour Assessment of High Rise Steel Building with Cantilever Floors Under Lateral Load

Madeeha Banu[1], R Shanthi Vengadeshwari[2]

P G Student, Department of Civil Engineering, Dayananda Sagar College Of Engineering, Bengaluru, India[1]

Associate Professor, Department of Civil Engineering, Dayananda Sagar College Of Engineering, Bengaluru, India[2]

Abstract: This paper compares of lateral load acting on steel structure and their impact on cantilever floors. Height increases vulnerability to buckling under wind loads and seismic loads, affecting high-rise structures' stability. Tall structures are more flexible and can withstand earthquake stresses better. Assessing building height's impact on seismic load resistance is crucial, as it varies with horizontal seismic stresses. Steel frames are popular due to their ease of construction, maintenance, and retrofitting. However, their structural stability increases with height. Steel bracings can increase strength in steel frames. This paper examines the impact of brace types on steel framed structures under Indian Standards.

Keywords: steel structure, lateral load, stability,retrofitting.

1. INTRODUCTION

This As land availability decreases and land costs rise, the choice of high-rise architecture becomes increasingly important. These structures, ranging from 75 feet to 491 feet, must be designed to withstand all lateral loads. Previous earthquakes have shown that if not constructed with appropriate strength, they can collapse completely. Therefore, precise factors for earthquake-resistant structures must be studied. Structural engineers traditionally use linear static analysis to determine design forces, moments, and displacements. However, wind design subjects the structure to pressure on its exposed surface area, while earthquake design subjects the building to random ground motion at its foundation. Research is currently being conducted to understand the response of high-rise steel buildings to earthquake and wind effects. Cantilever structures are increasingly used in modern buildings for various practical purposes, such as urban planning, aesthetics, and creating unique view features. The analysis of previous earthquakes that happened in multi-story buildings reveals that if they are not carefully built and constructed with appropriate strength, the structure collapses completely. So, in order to be safe from further deformations, precise factors for designing earthquake-resistant structures must be studied. Traditionally, structural engineers utilise linear static analysis to determine design forces, moments, and displacements of a structure caused by loads operating on it. Wind design subjects the structure to pressure on its exposed surface area, whereas earthquake design subjects the building to random motion of the ground at its foundation. Wind forces and seismic impacts are designed differently. My current job is to research. a high-rise steel building's response to earthquake and wind effects when its height and the span of its transfer floors are different. A research of current architecture products and construction technologies utilised in engineering and design systems revealed that in the conceptual and architectural stages, architects' creative labour is increasingly tied to the need to apply novel design solutions. The greater the cantilever span, the more complex the calculations necessary for calculating loads, determining the design, and material qualities. All of this, of course, raises the price of such structures and facilities. Despite this, cantilevers are actively employed in modern buildings for a variety of practical purposes. Building cantilever buildings aids in the solution of a variety of issues, including urban planning if there is a problem with a shortage of space on the site due to rough terrain, aesthetics, and creation. extra area with distinctive view features, symbolic ie., generating a mass picture that acts as a landmark and an architectural emblem of a city. As the height increases, so does the vulnerability to buckling under wind loads. In terms of seismic loads, height growth has an equivocal influence on the stability of high-rise structures, because height increase when lateral dimension is constant leads to an increase in building mass and the height of its centre of gravity. This causes an increase in shear force under earthquake stresses. Tall structures, on the other hand, are more flexible and can withstand the fast motion of the bottom better. As a result, it is critical to assess the impact of building height on seismic load resistance. The purpose is to define the impact of building height on the stressed condition as it varies with horizontal seismic stresses.

2. LITERATURE SURVEY

[1]Tirca. L et.al.(2004) This study examined the impact of building height and ground motion type on the seismic performance of zipper concentrically braced steel frames on four, eight, and twelve-story structures exposed to three ground motion types. [2] Bimala Pillai et.al.(2015) This project compares RCC and Steel Structure for constructing a 35-meter-high building using STAAD Pro. Wind force increases bending moment in steel, while seismic stress minimizes it. Steel structures cost more, while concrete is more durable and safe. [3] A. K. Elawady et.al.(2014) The study investigates the seismic behavior of high-rise structures with transfer floors using elastic response spectrum and inelastic nonlinear time history analysis. It found that structures with higher transfer floors flex and respond predominantly as single-degree-of-freedom structures, while structures with lower level transfer floors require additional modal contributions. The study also found that roof drift is greater in structures with lower level transfer floors due to the larger mass above the transfer floor. [4] Honghao Li (2014) This study evaluates the resilience of a seismically constructed steel moment frame building using 3-D nonlinear models. Computational simulations assess the building's reaction to column removal, focusing on composite action between slab and steel beams and slab membrane action. The top stories may be more sensitive to column loss. The slab plays a crucial role in progressive building collapse, but composite action can be lost due to slab deterioration. Membrane activity can strengthen the building's resistance but can accelerate collapse. [5] K. K. Sangle et.al. (2012) The study examines seismic analysis of high-rise steel buildings with and without bracing systems. Results show that bracing elements significantly impact structural behavior during earthquakes. Base shear increases by 38%, roof displacements reduce by 43% to 60%, and modular time decreases by up to 65%. Diagonal bracing is an effective and cost-efficient solution. [6] Meisam Gordan et.al.(2014) This paper reviews scientific progress on wind excitations and tall structures, focusing on their vulnerability. It reveals that vortex shedding reactions are stronger across wind, leading to larger lateral displacements. Aerodynamic adjustments and cross-sectional design changes are needed to reduce wind loads and reduce lateral displacements caused by wind excitations. [7] S. Badami (2014) Wind loads increase lateral deflection and overturning moment at the base of tall structures, necessitating structural material to minimize deflection and withstand overturning moments. Stiffness and stability requirements become more significant as the structure's height increases. The time duration and maximum base shear increase with 15 storeys, primarily determined by the structure's seismic weight. [8] V. Patre (2013) The study examined wind load conditions on building structures, revealing that outer side columns and beams dominate, leading to twisting and displacement in diaphragms. High wind pressure increased diaphragm movement and structural tensions in high-rise structures. [9] D. M. Patil and K. K. Sangle (2015) Nonlinear static pushover studies were performed on different bracing systems in high rise steel structures of 15, 20, 25, 30, and 35 storeys to evaluate structural performance[10] K. T. Tse and Jie Song (2010) The results show that the presence of a link reduces wind-induced reactions by nearly 50%, with ideal connection design parameters being ka 14 100 and h > 0.6. [11] Mitsumasa Midorikawa and Taichiro Okazaki (2012) Steel was used to build most industrial and commercial facilities in the tsunami-affected area, causing widespread damage. Some structures suffered minor structural damage due to washed-away interior and external finishes. [12] Eduardo Miranda, and Carlos J. Reyes (2002) This approach allows for more direct damage management during the design phase. An approximation approach is described for estimating maximum lateral drift requirement in multistory structures. [13] Eduardo Miranda, and Shahram Taghavi (2005) The approximation technique considers the building's first three modes of vibration. The study examines the impact of lateral stiffness decrease along height and offers approximate correction factors for various structures[14] Kartikkumar Prajapati, Roshni John (2015) This method is suitable for spans greater than one meter and meets IS-800:2007 standards for bending, shear, buckling, and web crippling. It offers the best combination of safety and economics during construction[15] Mehdi Setareh (2011) A remote vibration monitoring system was installed to gather vibration recordings, revealing that the presence of human inhabitants reduced the natural frequencies of the structure and increased damping ratios for higher modes. This study provides a realistic estimation of the dynamic features of these structures.

3. METHODOLOGY

- Planning of the structure.
- A 3-D model of a high rise steel building of various height, cantilever span and also with and without bracing systems in STAAD.Pro will be developed.
- Applying vertical loads and lateral loads suitably as per IS standard
    - IS: 875-1987 (Part 1) Dead loads.
    - IS: 875-1987 (Part 2) Live loads.
    - IS: 875-1987(Part 3) Wind loads.
- Structure will be analysed.
- Effects of wind and earthquake loads on high rise steel building will be determined.

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STRUCTURAL MODELLING

General details

MODEL 1	
Building dimension	30m x 30m
Dimension at Cantilever	18m x 6m
Building height	71.7m
Typical storey height	4.2m
Span of each bay	6m x 6m

Seismic Zone	III
Soil type	Medium soil
Response reduction	5
Structure type	Steel framing building
Damping ratio	2%
Importance ratio	1

Table 7.2: Material properties

Grade of steel	Fe 250
Youngs modulus of steel	$2.1*10^6$ KN/m^2
Poisson's ratio of steel	0.3
Grade of concrete	M 30
Density of concrete	25KN/m^3
Young's modulus of concrete	$27386*10^3$ KN/m^2
Poisson's ratio of concrete	0.2

LOAD CALCULATION

Dead load calculation

Static loads are those whose size or intensity do not fluctuate with time or place. It comprises the cost of both structural and non-structural aspects during the life of the building. The dead load is present in all load bearing structures such as columns, beams, walls, floor finishes, and partition walls. For these loads, IS 875(Part 1) was used.

Slab thickness =250mm
Slab weight =25*0.3=7.5KN/m^2

Live load calculations

Live loads are the non-static loads, changing their magnitude or intensity with time. These include loads from people, machineries, vehicles which are movable. These are applied as uniformly distributed loads on the structural and non-structural elements. IS 875(Part 2) is considered for these and their distribution through the floors.4.2.2.1 Live Load Reduction for the model

Live load on all floors = 5KN/m^2

Table 8.1 : Live load reduction as per 875 (Part 2)

No. of floors	Reduction in %	Imposed load in KN/m^2
1	0	5
2	10	4.5
3	20	4
4	30	3.5
5 to 10	40	3
Over 10	50	2.5

Wind load calculation

1. Wind load is calculated using the non-uniform variations in wind speed over time.
2. These loads are not taken into account for tiny buildings since they have no influence on the structures. However, in the case of high-rise buildings, long-span bridges, and chimneys, wind loads must be considered since they have the most significant and leading influence on these structures.
3. Wind loads for constructions longer than 10m are calculated using Indian norms.
4. These loads are non-uniform and increase with altitude, and topographical condition also has a significant impact on their magnitude.
5. Some of the parameters to consider when calculating wind loads are: o Basic wind speed based on structure location

- Basic wind speed relying upon the structure location
- Risk or Probability factor relying upon the usage and the building occupancy's purpose
- Building altitude
- Building's Terrain condition
- Topographical factors
- External and internal pressure co-efficient
- Design Wind Speed

Wind data:

1. Wind zone : Zone III
2. Basic wind speed :33m/s
3. Terrain category : 2 (class C)

Risk coefficient factor, k1= 0.1
Terrain &Height factor,k2 is calculated in table 6.2 for Category 3 Class C
Topography factor, k3 = 1
Design wind speed, Vz =Vb*k1*k2*k3
Wind pressure, Pz = 0.6*Vz^2

Table 8.3: Wind pressure with varying height

Sl no.	Height	k2	Design wind speed, Vz in m/s	Wind pressure in Kg/m
1	10	1	33	43.41
2	15	1.05	34.65	47.3
3	20	1.07	35.31	50
4	30	1.12	36.96	54.43
5	50	1.17	38.61	59

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6	100	1.24	40.92	66.09

Seismic load calculation: The earthquake effect is experienced when the natural frequencies of the structure and ground motion acceleration syncs. Hence, it’s mandatory in tall building’s design to consider about the earthquake effect. In this work, since the structure is assumed to be constructed in Bengaluru, whose earthquake zone is Zone 3 and zone factor of 0.10. Maximum horizontal acceleration experienced in this zone is 10% of the gravitational acceleration. The seismic loads for this structure is given in both x and z directions.
Dead load = 6.25KN/m^2
Live load as in table below

Table 8.4: Live load to be considered

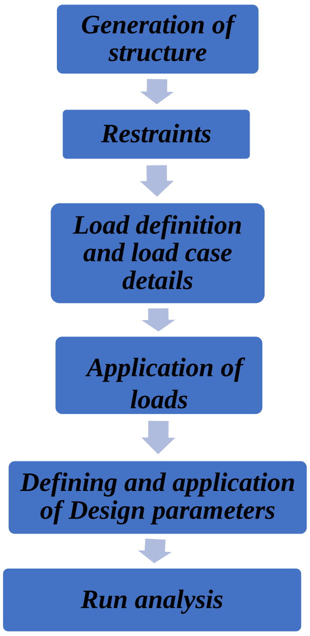
Floors	Actual live load	Percentage of LL to be considered	Pressure to be applied in KN/m^2
1	5	50	2.5
2	4.5	50	2.25
3	4	50	2.0
4	3.5	50	1.75
5 to 10	3	25	0.75
Over 10	2.5	25	0.625

Load combinations

1. DL+LL
2. 0.75(DL+LL+WL in +X)
3. 0.75(DL+LL+WL in -X)
4. 0.75(DL+LL+WL in +Z)
5. 0.75(DL+LL+WL in -Z)
6. 0.75(DL+LL+EL in +X)
7. 0.75(DL+LL+EL in -X)
8. 0.75(DL+LL+EL in +Z)
9. 0.75(DL+LL+EL in –Z)
10. 0.68 DL + 0.75 WL in +X
11. 0.68 DL + 0.75 WL in -X
12. 0.68 DL + 0.75 WL in +Z
13. 0.68 DL + 0.75 WL in -Z
14. 0.68 DL + 0.75 EL in +X
15. 0.68 DL + 0.75 EL in -X
16. 0.68 DL + 0.75 EL in +Z
17. 0.68 DL + 0.75 EL in -Z

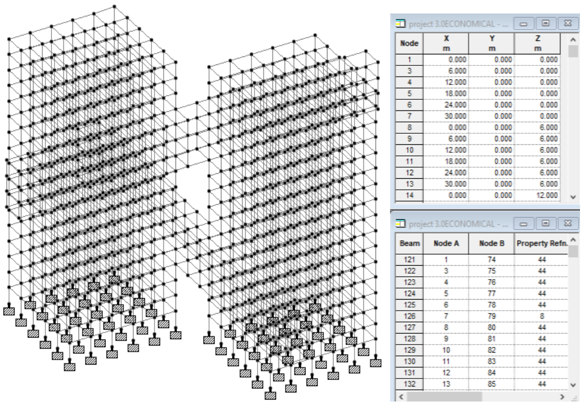
ANALYSIS OF THE STRUCTURE WITH STAAD.PRO

WORKINGWITHSTAAD.pro



GENERATION OF THE STRUCTURE:

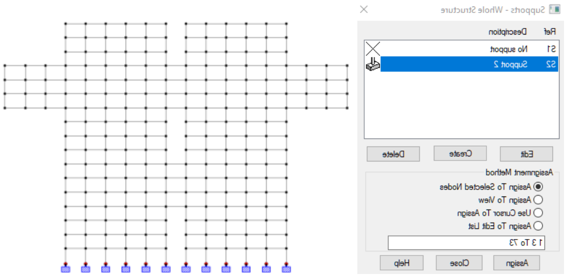
The structure may be generated from the input file or mentioning the co-ordinates in the GUI. The figure below shows the GUI generation method.



Node	X m	Y m	Z m
1	0.000	0.000	0.000
3	6.000	0.000	0.000
4	12.000	0.000	0.000
5	18.000	0.000	0.000
6	24.000	0.000	0.000
7	30.000	0.000	0.000
8	0.000	0.000	6.000
9	6.000	0.000	6.000
10	12.000	0.000	6.000
11	18.000	0.000	6.000
12	24.000	0.000	6.000
13	30.000	0.000	6.000
14	0.000	0.000	12.000

Beam	Node A	Node B	Property Refn.
121	1	74	44
122	3	75	44
123	4	76	44
124	5	77	44
125	6	78	44
126	7	79	8
127	8	80	44
128	9	81	44
129	10	82	44
130	11	83	44
131	12	84	44
132	13	85	44

Generation of model



Assigning support

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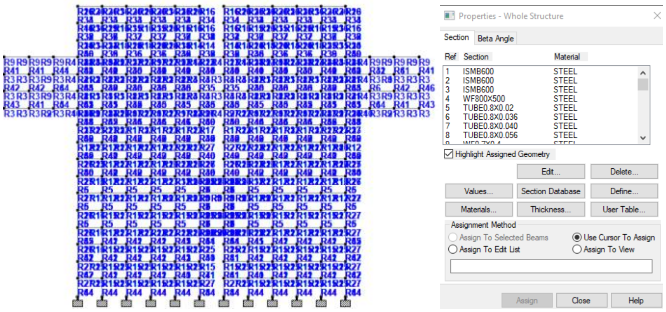
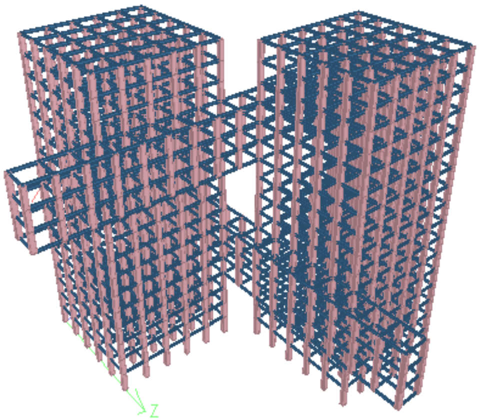


Ref	Section	Material
1	ISMB600	STEEL
2	ISMB600	STEEL
3	ISMB600	STEEL
4	WF800X500	STEEL
5	TUBE0.8X0.02	STEEL
6	TUBE0.8X0.036	STEEL
7	TUBE0.8X0.040	STEEL
8	TUBE0.8X0.056	STEEL

☑ Highlight Assigned Geometry

Assignment Method
○ Assign To Selected Beams
● Use Cursor To Assign
○ Assign To Edit List
○ Assign To View

Assigning member property



3D View of the structure

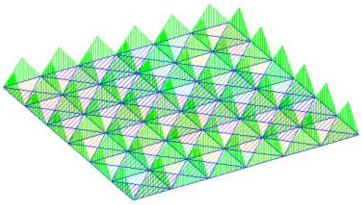
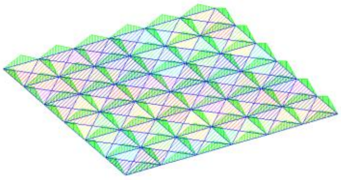
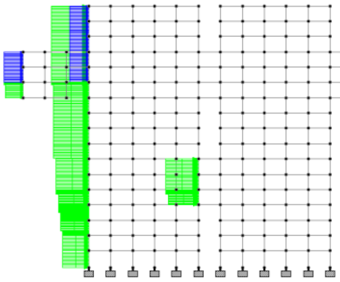


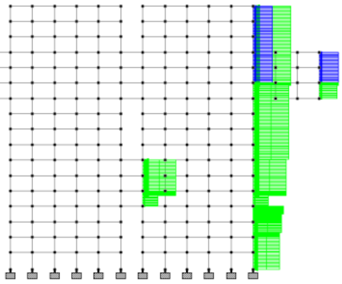
Figure 9.3 :Application dead load



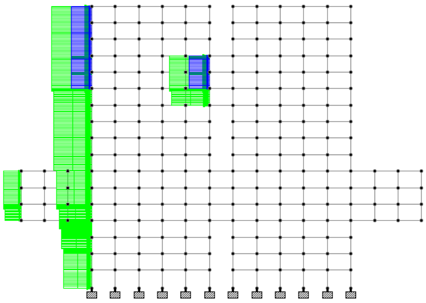
Application live load



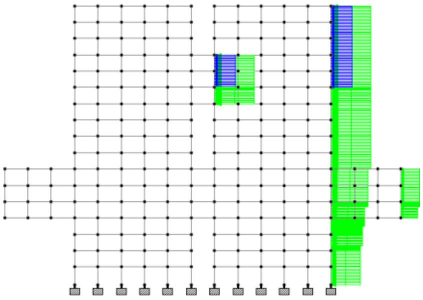
Wind load in X direction



Wind load in –X direction



Wind load in Z direction

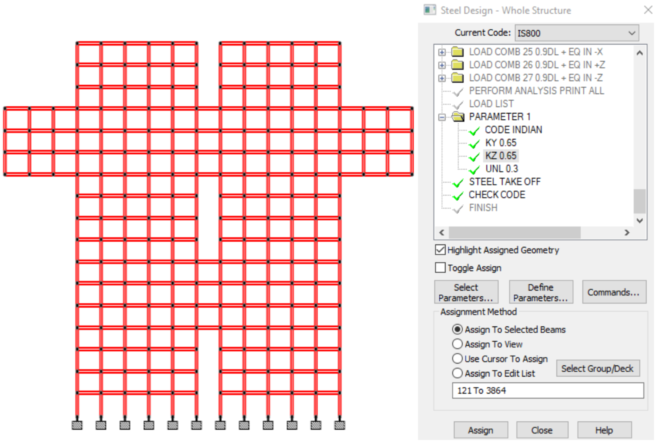


Wind load in -Z direction

Definition of Parameters

Defining appropriate parameters to the structure to avoid the beams failure and to run analysis.

To this structure, Check Code, UNL is 6, Kz and Ky value of 0.8 for some beams and 0.65 for some beams is defined, since the whole beam length wouldn't be the buckling length, are the parameters defined.



Steel Design - Whole Structure

Current Code: IS800

```
LOAD COMB 25 0.9DL + EQ IN -X
LOAD COMB 26 0.9DL + EQ IN +Z
LOAD COMB 27 0.9DL + EQ IN -Z
PERFORM ANALYSIS PRINT ALL
LOAD LIST
PARAMETER 1
    CODE INDIAN
    KY 0.65
    KZ 0.65
    UNL 0.3
STEEL TAKE OFF
CHECK CODE
FINISH
```

☑ Highlight Assigned Geometry

☐ Toggle Assign

Assignment Method

● Assign To Selected Beams

○ Assign To View

○ Use Cursor To Assign

○ Assign To Edit List

121 To 3864

Assigning design parameter

ANALYSIS OF THE STRUCTURE

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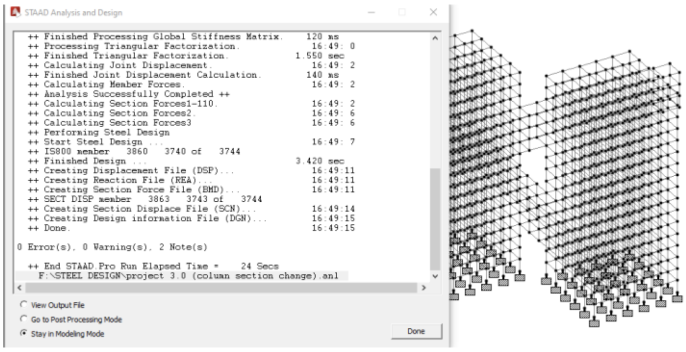


```
  ++ Finished Processing Global Stiffness Matrix.      120 ms
  ++ Processing Triangular Factorization.               16:49: 0
  ++ Finished Triangular Factorization.               1.550 sec
  ++ Calculating Joint Displacement.                    16:49: 2
  ++ Finished Joint Displacement Calculation.          140 ms
  ++ Calculating Member Forces.                         16:49: 2
  ++ Analysis Successfully Completed ++
  ++ Calculating Section Forces1-110.                   16:49: 2
  ++ Calculating Section Forces2.                       16:49: 6
  ++ Calculating Section Forces3                        16:49: 6
  ++ Performing Steel Design
  ++ Start Steel Design ...                             16:49: 7
  ++ IS800 member   3860   3740 of   3744
  ++ Finished Design ...                              3.420 sec
  ++ Creating Displacement File (DSP)...                16:49:11
  ++ Creating Reaction File (REA)...                    16:49:11
  ++ Creating Section Force File (BMD)...               16:49:11
  ++ SECT DISP member   3863   3743 of   3744
  ++ Creating Section Displace File (SCN)...            16:49:14
  ++ Creating Design information File (DGN)...          16:49:15
  ++ Done.                                              16:49:15

0 Error(s), 0 Warning(s), 2 Note(s)

  ++ End STAAD.Pro Run Elapsed Time =    24 Secs
     F:\STEEL DESIGN\project 3.0 (column section change).anl
```

Analysis of the structure
Analysis > zero errors > no warnings.

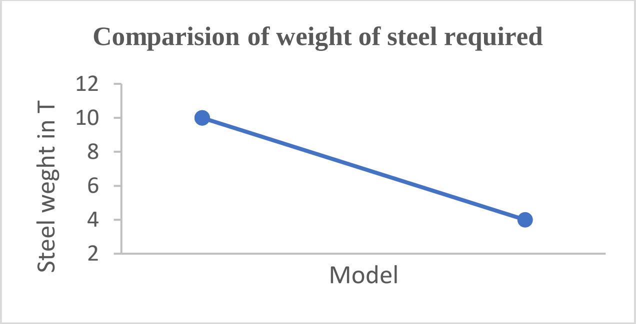
COMPARISION OF STRUCTURE BY CHANGING COLUMN & BEAM SECTION TO MAKE IT MORE ECONOMICAL:

Comparison of steel weight of the models

Weight of steel in Model 1 before changing the column and beam section was 59.76% more than Model 2 and weight of the structure was 10079.29 T.

Weight of steel in Model 2 after changing the column and beam section was 59.76% lesser than Model 2 and weight of the structure is 4055.077 T.

MODEL 1	MODEL 2
Steel weight in T	Steel weight in T
10079.30T	4055.077T



3.RESULT

The steel design is completed in StaadPro software in accordance with IS800: 2000[3]. This construction is designed with the availability of various steel parts in the Indian market in mind.behaviourand assesment of high rise steel structure with cantilever floors subjected to lateral load. The structure includes the Primary beams are designated as ISMB 600, while the columns are designated as tube 1x1x0.02 and at cantilever portion the beams are built-up section wide flange 800x500 and tube section are 1.2x1.2x0.02 then carried out by analysing the structure after results few members were changed to make structure economical.

4.CONCLUSION

The design of an industrial steel structure was carried out employing StaadPro is a piece of software. The superstructure is made of structural steel, while the foundation is made of concrete The building is made up of two 6m bay frames. There are several There are a total of six levels, each measuring 4.2m in height.Rests the apparatus. A stair is also provided in a 4m bay, i.e.,Aside from the main bay for entrance to the floors. A gable structure The building's upper roof is supported. The foundation is 3m deep.under the earth. For this, many IS codes are used.design. Finally, this design was safe and feasible.A market study was also conducted to determine market pricing. of varied materials and operations on numerous building site

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