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Linear Dynamic Analysis and Design of Composite Steel Structure

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***Abstract*: To create a composite steel structure, a steel structural frame is created, and then a concrete slab, cast in place on a profiled deck, is attached to the beam using mechanical shear connectors. In today's construction industry, composite steel constructions are a common material. Many studies, applications, and builds have proven that composite steel structures are an efficient and cost-effective building material. In this project it is presented the current state of the art related to design and analysis in steel-concrete composite structures. Furthermore, it explains some provisions of recently adopted by Indians and that are being using for our structures construction and their applications in composite construction. The focus is on steel beam-column joints and their connections and the effects of their interaction. Various components (Girders, Joists and Columns) of a structure and their properties are considered. A G+5 storey office building with 3.60m height of each floor is considered, which is situated in earthquake zone III (Vijayawada) & wind speed 50 m/s. The overall plan dimension of the building is 20 X 30 m. Linear dynamic Analysis will be performed. For modelling and design of structure, STAAD-Pro software is used and the analysis results are used to design the connections for various joints using shear connections or moment connections.**

***KeyWords:* Composite Steel Structure, Linear Dynamic Analysis, Girder, STAAD-Pro.**

1. INTRODUCTION

1.1.Objective:

The use of Steel in construction industry is rapidly growing in India from the last decade when compared to many developing countries. There is a great potential for increasing the volume of Steel in construction, especially in the current development needs in India. Exploring Steel as an alternative construction material and using it where it is economical is a heavy profit for the country infrastructure needs. Also, it is evident that now-a-days, the composite sections using Steel encased with Concrete are economic, cost and time effective solution in major civil structures such as bridges and high rise commercial buildings when compared to conventional reinforced concrete structures.

In due consideration of the above fact, this project has been envisaged which consists of analysis and design of a commercial office building using Steel-Concrete composites.

1.2.Composite Structures

Composite Steel-Concrete Structures are used widely in modern bridge and building construction. A composite member is formed when a steel component, such as I beam, is attached to a concrete component, such as a floor slab or bridge deck. In such a composite T-beam the comparatively high strength of the concrete in compression complements the high strength of the steel in tension. The fact that each material is used to the fullest advantage makes composite Steel-Concrete construction very efficient and economical. However, the real attraction of such construction is based on having an efficient connection of the Steel to the Concrete, and it is this connection that allows a transfer of forces and gives composite members their unique behaviour.

1.3Need of Steel in Construction

In building construction, role of steel is same as that of bones in a living being. Steel is very advantageous because it:

Offers considerable flexibility in design and is easy for fabrication.
Facilities faster construction scheduling of projects.
Enables easy construction scheduling even in congested sites.
Permits large span construction repair/modification.
Is an ideal material in earthquake prone locations due to high strength, stiffness, ductility.
Is environment friendly and fully recyclable on replacement
Abroad, the use of structural steel has been growing, and has now become one of the important input materials of construction. In India, until nineties, availability of structural steel was in less and weather resistant and or strength grades were not readily available. Thus, steel did not make much in-road in building construction and highways, and its share in bridge construction also started decreasing. This coupled with many other reasons led to stagnation of steel demand, while large-scale production capacity has been created in the country during initial liberalization period of our country. Hence, proper development of steel application sectors has become an important issue and the steel framed composite construction is considered to be a cost effective solution for multi-storied buildings due to optimum use of materials.

1.4. Structural Steel Pros and Cons

Some of the advantages of structural steel as a building material are as follows:
1. Structural steel has a high strength-to-weight ratio.
2. The properties of structural steel are uniform and homogeneous, and highly predictable.
3. It has high ductility, thus providing adequate warning of any impending collapse.sssss

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4. It can easily be recycled. In fact, a very high percentage of the structural steel used in many modern structures is made from recycled steel.
5. Steel structures are easier and quicker to fabricate and erect, compared to concrete structures.
6. The erection of steel structures is not as affected by weather compared to other building materials, enabling steel erection to take place even in the coldest of climates.
7. It is relatively easier to retrofit existing steel structures because of the relative ease of connecting the new framing members to existing structural steel members.

2. COMPOSITE MULTI-STOREYED BUILDING:

The basic structural steel elements and members that are used to resist gravity loads and lateral loads in steel-framed buildings as shown in Figures 1 & 2.

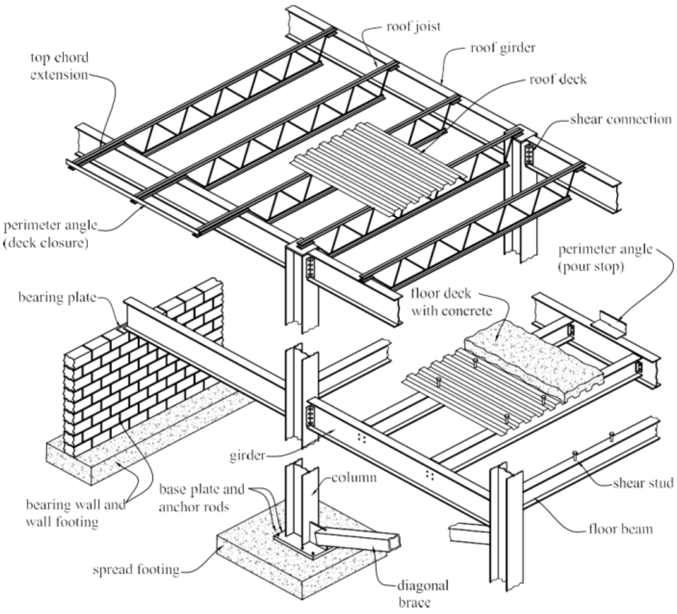

Figure-1 Typical steel building – basic structural elements (3D)

2.1Beams and Girders

The infill beams or joists support the floor or roof deck directly and spans between the girders. The roof or floor deck usually spans in one direction between the roof or floor infill beams. The girders support the infill beams and span between the columns. While the beams along the column lines are usually connected to the web of the columns, girders are typically connected to the column flanges since the girders support heavier reactions than the typical in-fill beams. Thus, the girder reaction eccentricity at the columns is resisted by the bending of the column about its stronger axis.

2.2 Columns

These are vertical members that support axial compression loads only. They are sometimes referred to as struts when they are used in the horizontal position (as in bracings for soil excavations) or as diagonal struts to resist axial compression loads from discontinued columns. In real-world structures, structural members are rarely subjected to pure compression loads alone since the members cannot be fabricated perfectly straight and we cannot assure that the line of application of the axial loads will line up perfectly with the centroid axis of the column.

2.3 Beam–Columns

Beam-columns are members that support axial tension or axial compression loads in addition to bending moment. In practice, typical building columns usually act as beam-columns due to the eccentricity of the beam and girder reactions relative to the column centroid axis.

2.4 Gravity and Lateral Load Paths and Structural Redundancy

The typical path of a gravity load from its point of application on the structure to the foundation is as follows: The gravity load applied to the roof or floor deck or slab is transmitted- ted horizontally to the in-fill beams, which in turn distribute the load horizontally to the girders. The girders and the beams along the column lines transfer the load as vertical reactions to the columns, which in turn transmit the load safely to the foundation and to the ground or bedrock. So, in essence, the flow of gravity load is as follows: Load applied to the Slab or Roof Deck to Beams to Girders to Columns to Foundations. The gravity load path is illustrated in Figure 2.

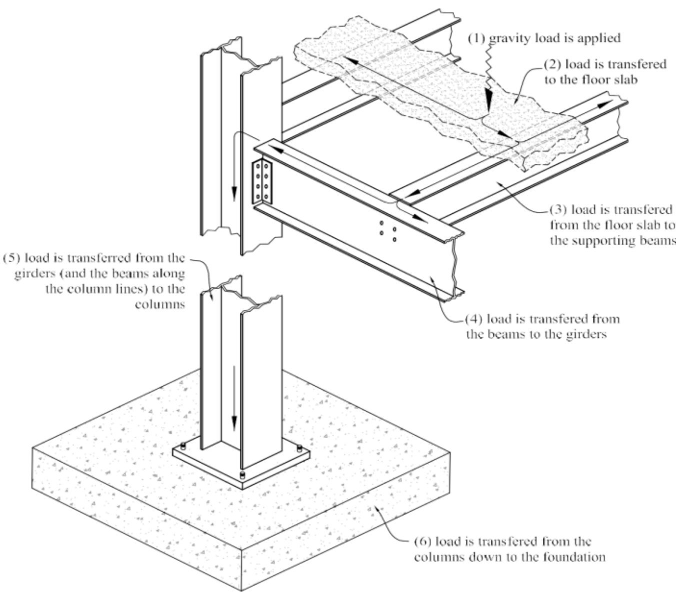

Figure 2. Gravity load path

For the lateral wind load path, the wind load is applied directly to the surface area of the vertical wall on the windward side of the structure, and this wall bends vertically and transfers the horizontal reactions to the horizontal roof or floor diaphragms. The horizontal diaphragms transfers the lateral wind load to the vertical lateral force resisting system (LFRS) - (e.g., moment-resisting frame, braced frame, or shear wall) that have their longitudinal axis parallel to the lateral load, and these vertical lateral force resisting systems then transmit the lateral loads to the foundation and the soil or bedrock. So, in essence, the flow of lateral wind load is as follows: Wind pressure on the windward vertical wall surface area to Roof or Floor Diaphragm to Vertical Lateral Force Resisting System to Foundations. The lateral load path for wind loads is illustrated in Figure 3.

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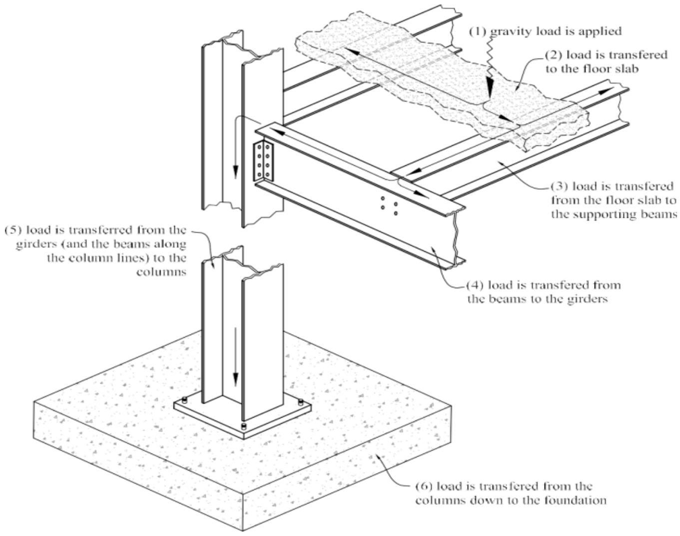

Figure 3.Lateral load path

3. STRUCTURAL MODELING

3.1 Layout

The Five - storey structure is considered with plan dimensions of 30.0 m x 20.0 m for the analysis purpose. The building is considered to serve as a office commercial building. The height of typical floor height was considered as 3.60m and the building height is comprised as 25.20 m including head room. The Fig 4 represents the plan in Ground and typical floor plan of the building.

3.2 Preliminary Data

Dead load was taken as per IS 875 (Part I)-1987
Live load was taken as per IS : 875 (Part II)-1987
Wind load was taken as per IS : 875 (Part III) -2015 Location: Vijayawada
Seismic load were taken as per IS: 1893(Part I): 2002 (The Response spectrum method is adopted for linear dynamic analysis.

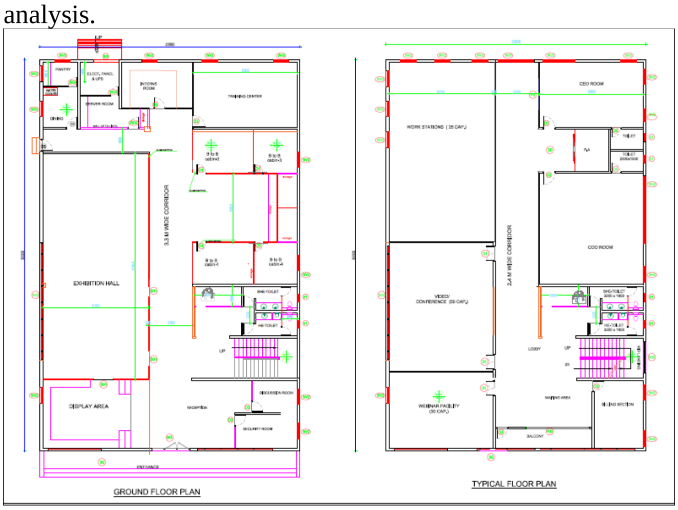

Figure 3. Ground Floor and Typical Floor Plan

4.MODELLING AND ANALYSIS IN STAAD PRO

4.1.Analysis Procedure

Step-1: Before modelling the structure in STAAD PRO as per the plan given by the architecture proper placing of columns, beam frame and slab panels should be decided and column orientation should be considered by which proper load distribution that is from Joists to Girders and Girders to columns and then foundation to soil will take place.
Step-2: After placing of columns girders and joists (one way).
Step-3: After that give the section properties and grade of steel and grade of concrete, and assign the section properties for the frame.
Step-4: Now define the load cases.
Step-5: Now assign supports of the structure it is very important for calculation of reaction. For the design of foundation and calculation of base plates.
Step-6: Define the load combinations; the following load combinations are defines for this project.
Step-7: Check the section capacity that is under stressed or over stressed.
Step-8: Analyze the results from the Analysis Results Tables for selected load case or for Envelope.

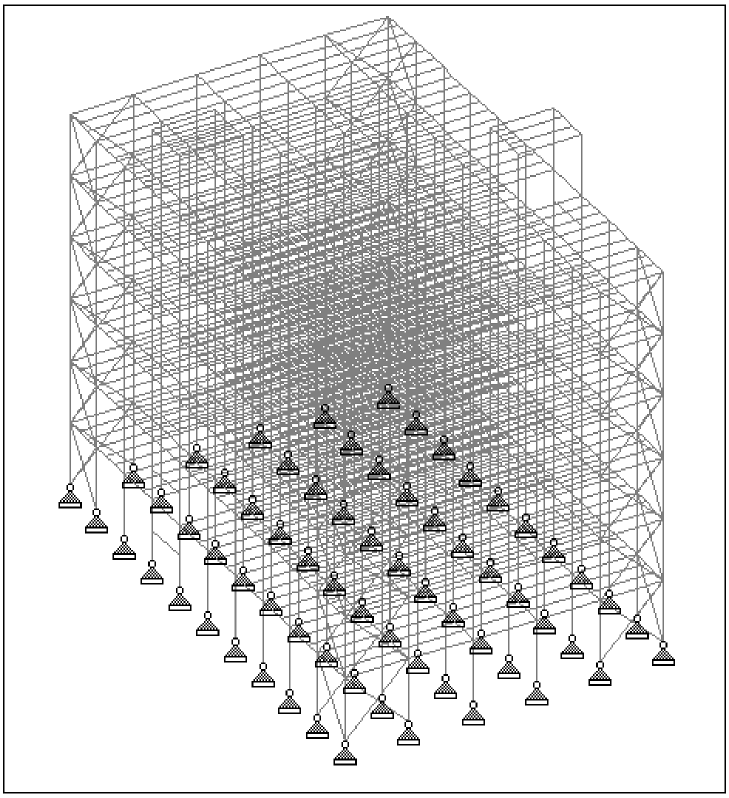

Figure 4. 3D MODEL

5. PREMILINARY DATA

5.1 DEAD LOAD

Dead load was taken as per IS 875 (Part I)-1987
At any floor level

Weight of Deck Profile	= 0.11 Kn/m^2
Load from Concrete	= 0.2945 Kn/m^2
Floor finishes	= 0.025 x 20 =0.5 KN/ m^2

Total = 3.57 KN/m^2

5.2 LIVE LOAD

Live load was taken as per IS : 875 (Part II)-1987

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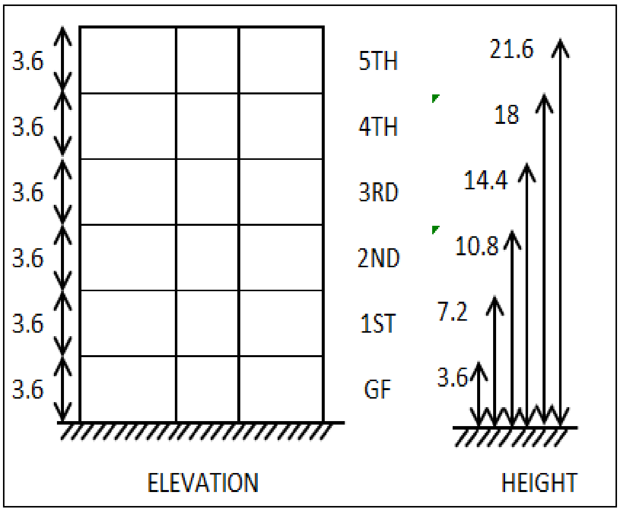
ISSN: 2278-0181
Vol. 12 Issue 12, December-2023

Live load was found to be 3.00 KN/m^2 for Office Buildings at all typical floor levels.
Live load was found to be 1.50 KN/m^2 for Office Buildings at terrace floor level.

5.3 LATERAL LOAD CALCULATION

5.3.1 WIND LOAD

Wind load was taken as per IS : 875 (Part III) -2015
Location = Vijayawada
Basic wind speed = 50 m/s
K1 = Risk factor Design life for 50 yrs
K1 = 1.0
K2 = Terrain, Height & Structure size factor
Terrain type - Category 2 (More Exposed Area)
Structure - Class B
Height – 7.20m, 10.8m, 14.40m, 18.00m, 21.60m & 25.20m (Head Room)



K2 – 1.00, 1.05, 1.054, 1.078
K3 – Topography Factor
Assuming that upwind slope < 3 degrees
Topography is not significant
K3 = 1.0
K4 – Cyclonic Importance Factor
Industrial Structure or not Lattice Structure
Clyclonic Importance is not significant.
K4 = 1.0
Design Wind Speed $V_z = V_b K_1 K_2 K_3 K_4$
Design Wind Pressure $P_d = 0.6 V_z^2$
The design wind Pressure for different levels were shown in below

Table 5.1 :Design Wind Pressure

Floor	Height, m	K_1	K_2	K_3	K_4	V_b, m/s	V_z, m/s V_b*K1*K2*K3	P_d, kN/m^2 0.6*V_z^2
1ST FLOOR	7.2	1	1	1	1	50	50	**1.5**
2ND FLOOR	10.8	1	1.02	1	1	50	51	**1.56**
3RD FLOOR	14.4	1	1.05	1	1	50	52.7	**1.67**
4TH FLOOR	18	1	1.07	1	1	50	53.5	**1.72**
5TH FLOOR	21.6	1	1.08	1	1	50	53.9	**1.74**
HEAD ROOM	25.2	1	1.1	1	1	50	54.8	**1.8**

5.3.2 SEISMIC LOAD

Seismic load were taken as per IS:1893(Part I) : 2002
The Response spectrum method is adopted for linear dynamic analysis.

- The city of Vijaywada falls under Zone III

Zone Factor = 0.16
Importance Factor = 1.0 Response Reduction Factor = 4
Soil Consition = 1
Approximate Fundamental Period = 0.09 H /D$^{1/2}$
T_x = 0.09 x 21.6 / 20$^{1/2}$
= 0.43s
T_y = 0.09 x 21.6 / 30$^{1/2}$
= 0.355s

- Base Shear
  $V_b = A_h W$

W = Seismic Weight = 21969.5 kN (From STAAD reactions)
Ah = $\frac{Z}{2}\frac{I}{R}\frac{Sa}{g} = \frac{0.16}{2} x \frac{1.0}{4} x\ 1.85$ = 0.037
V_b = 0.037 x 21969.5 = 812.8715 kN
Calculation of Lateral Forces
Qi = VB Wihi2/∑Wihi2

Qi = Lateral Force at floor i
Wi = Load on the floor i
hi = Height measured from the base of the building to the floor i

Table 5.2 : Lateral force distribution

Floor level	h_i (m)	W_i (kN)	$W_i h_i^2$	$Q_i = V_B\ W_i h_i^2/\sum W_i h_i$	V_j, kN = $\sum Q_i$
G floor	3.6	3727.2	4.83E+04	5.84	812.87
1st floor	7.2	3727.2	1.93E+05	23.38	807.03
2nd floor	10.8	3727.2	4.35E+05	52.6	783.65
3rd floor	14.4	3727.2	7.73E+05	93.51	731.05
4th floor	18	3727.2	1.21E+06	146.1	637.55
5th floor	21.6	3727.2	1.74E+06	210.39	491.44
Terrace floor	25.2	2272.3	1.44E+06	174.58	281.06
Head Room	28.8	1061	8.80E+05	106.47	106.47
			6.72E+06		

6.1 ANALYSIS PROCEDURE

Modelling in STAD PRO will start with placing of columns, beam frame and slab panels should be decided and column orientation should be considered by which proper load distribution that is from Joists to Girders and Girders to columns and then foundation to soil will take place. After that give the section properties and grade of steel and grade of concrete, and assign the section properties for the frame. Now define the load cases of Gravity and lateral. Assign supports of the structure for calculation of reaction. For the design of foundation and calculation of base plates. Define the load combinations, the following load combinations are defines for this project. Analyse the model for errors and check the section capacity that is under stressed or over stressed. Analysis Results Tables for selected load case or for Envelope.

International Journal of Engineering Research & Technology (IJERT)
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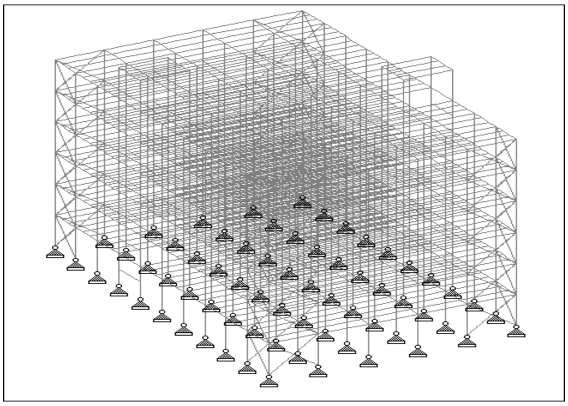
FIGURE 6-1.3D MODEL

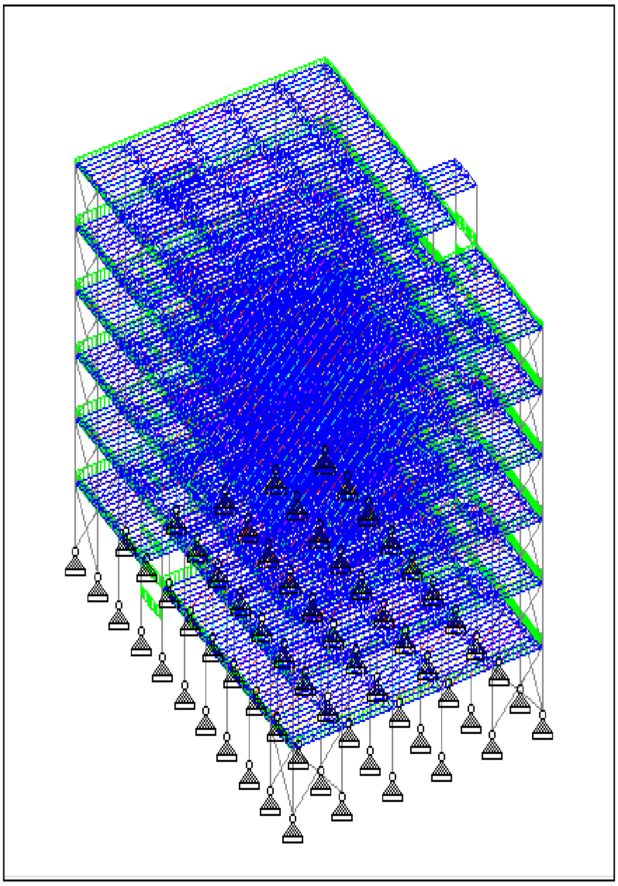
FIGURE 6-3 DEAD LOAD APPLICATION

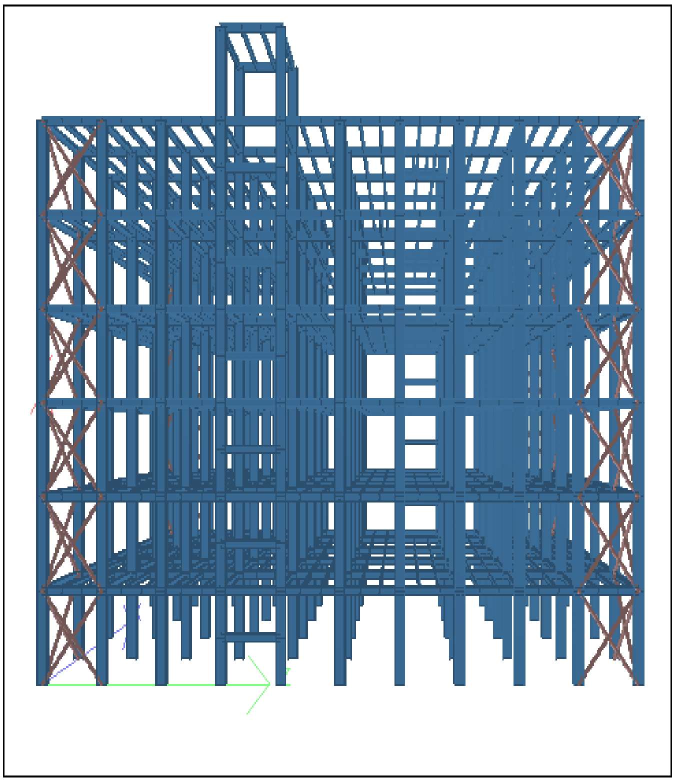
FIGURE 6.2 RENDERED VIEW

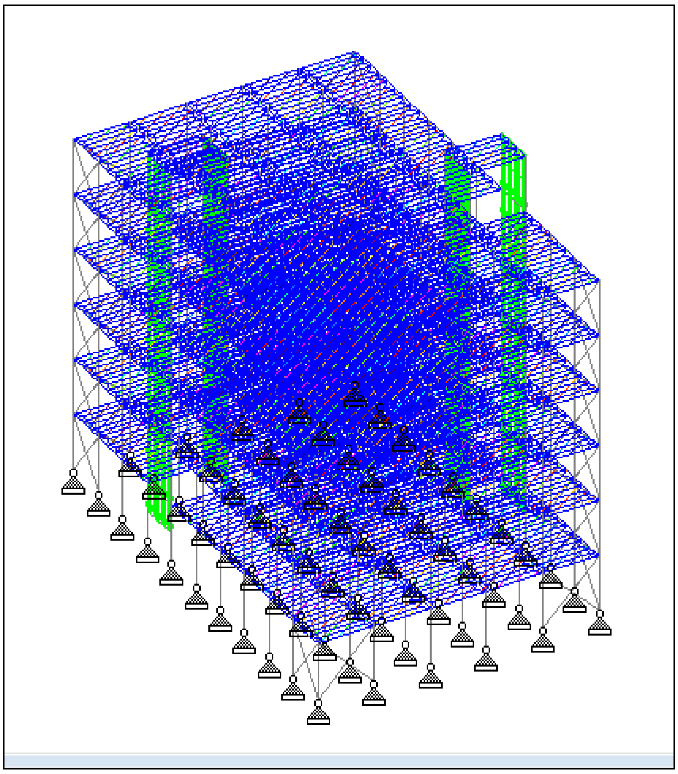
FIGURE 6-4 LIVE LOAD APPLICATION

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 12, December-2023

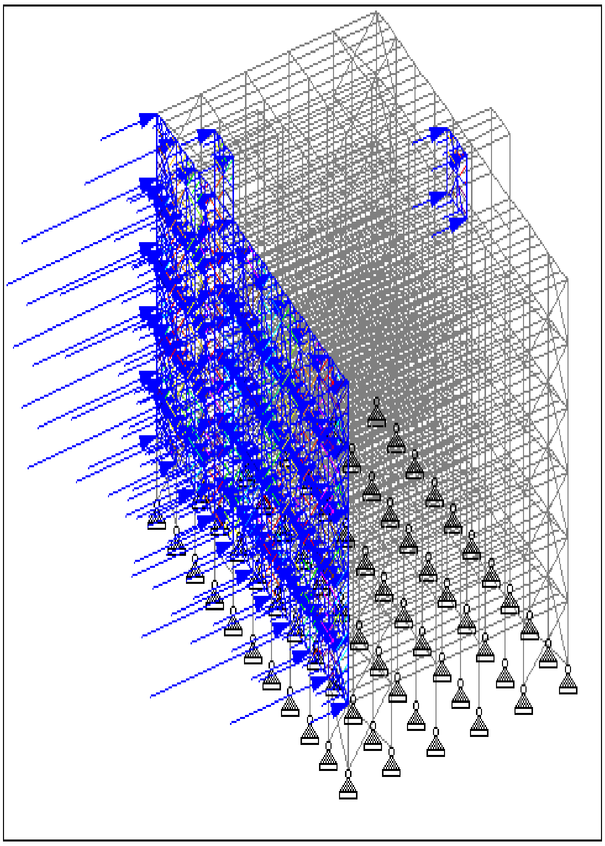

FIGURE 6-5 WIND LOAD ON +X-DIRECTION

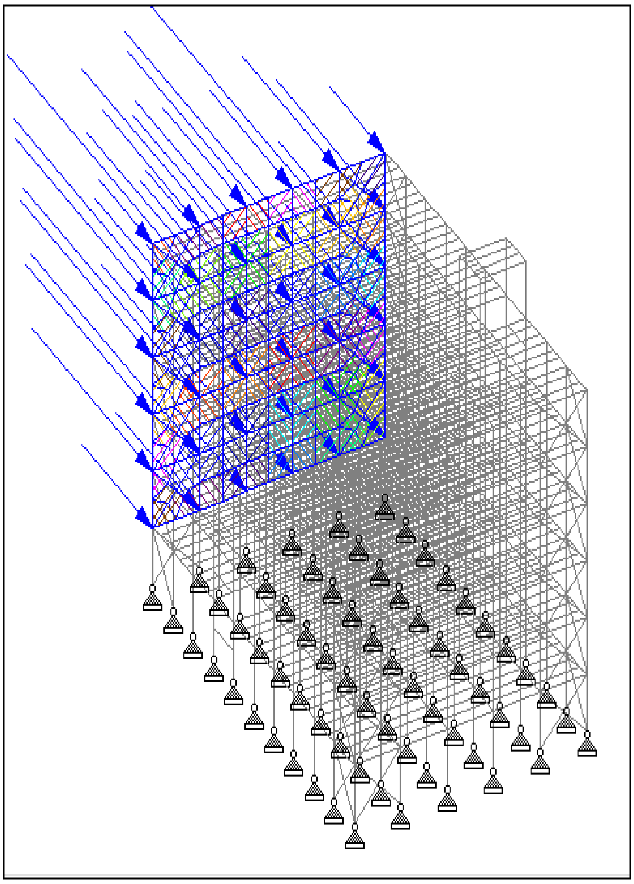

FIGURE 6-7 WIND LOAD ON +Z-DIRECTION

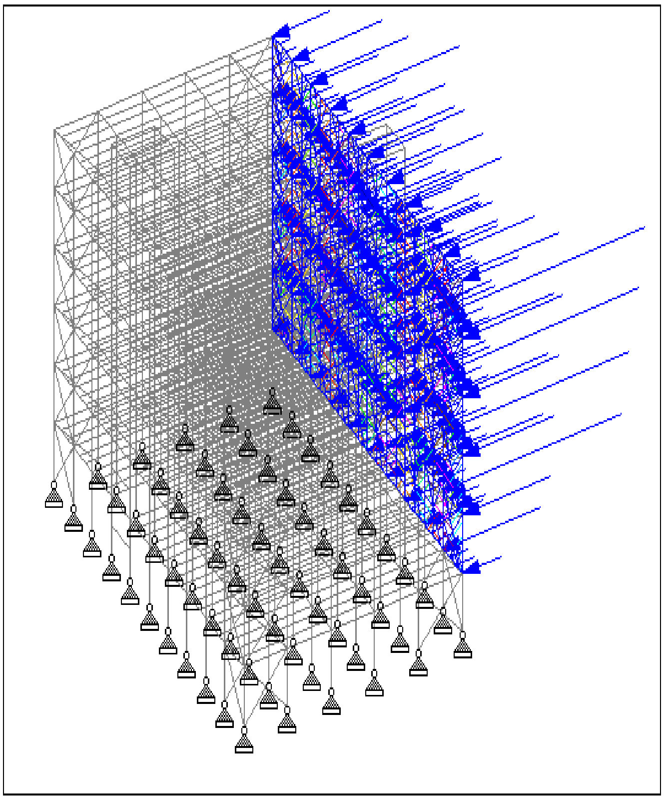

FIGURE 6-6 WIND LOAD ON -X-DIRECTION

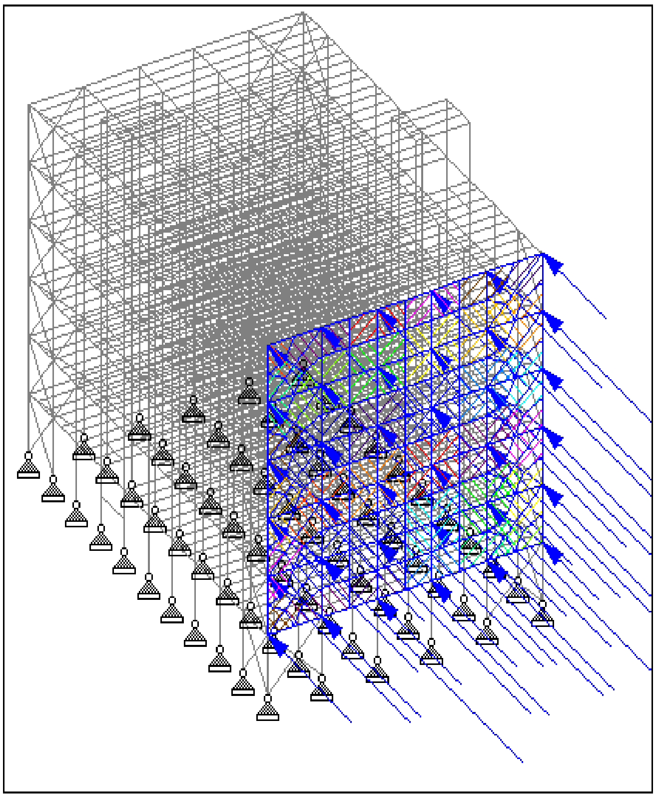

FIGURE 6-8 WIND LOAD ON -Z-DIRECTION

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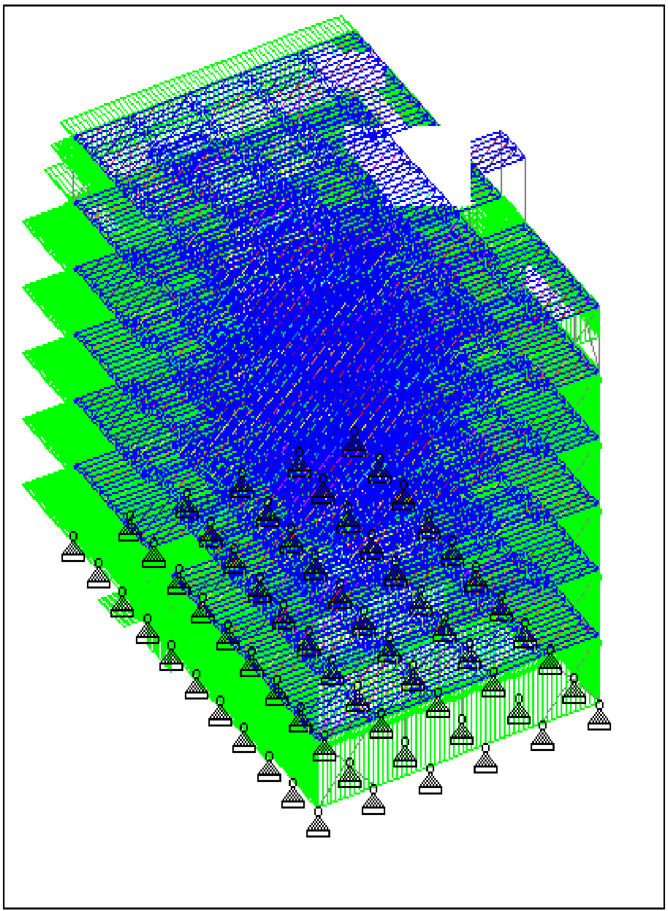

FIGURE 6-9 SEISMIC WEIGHT MODAL MASS APPLICATION

7.1 RESULTS FROM RESPONSE SPECTRUM ANALYSIS

The results found from the linear dynamic analysis are tabulated in Table- 7-1 to 7-4 and the graphical representation of modes are shown in Fig 7-1 to 7.3 The graphs show the variations in seismic responses Base shear and Storey Shear.

TABLE 7-1 VERTICAL STRUCTURAL IRREGULARITIES : SOFT STORY CHECK

STORY	FL. LEVEL ,M	STATUS	
		X	Z
1	3.6	OK	OK
2	7.2	OK	OK
3	10.8	OK	OK
4	14.4	OK	OK
5	18	OK	OK
6	21.6	OK	OK
7	25.2	OK	OK

TABLE 7-2 Mode Time period and frequencies

MODE	FREQUENCY (CYCLES/SEC)	PERIOD(SEC)	ACCURACY
1	0.908	1.10167	0.00E+00
2	1.199	0.83422	0.00E+00
3	1.562	0.64029	1.48E-16
4	2.886	0.34653	0.00E+00
5	3.332	0.30014	2.59E-16
6	3.874	0.25813	0.00E+00

TABLE 7-3 STORY SHEAR

STORY	LEVEL,m	PEAK STORY	SHEAR,kN
		X	Z
7	25.2	36.5	0
6	21.6	262.81	0
5	18	444.12	0
4	14.4	548.29	0
3	10.8	640.33	0
2	7.2	741.81	0
1	3.6	827.3	0
BASE	0	828.39	0

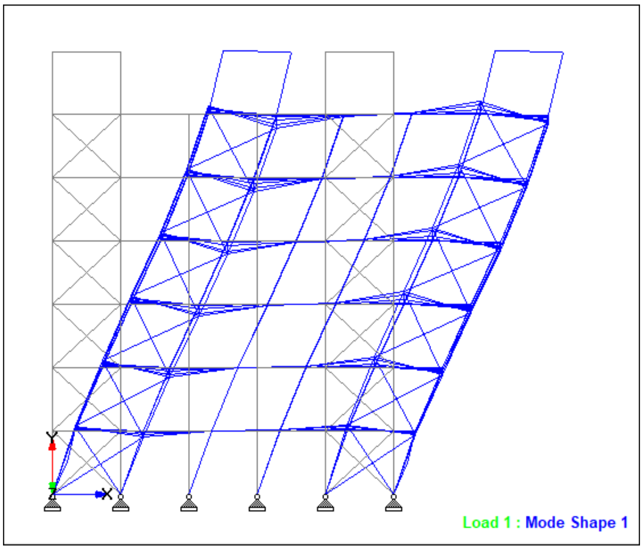

FIGURE 7-1. MODE-1 TRANSLATION–X

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 12, December-2023

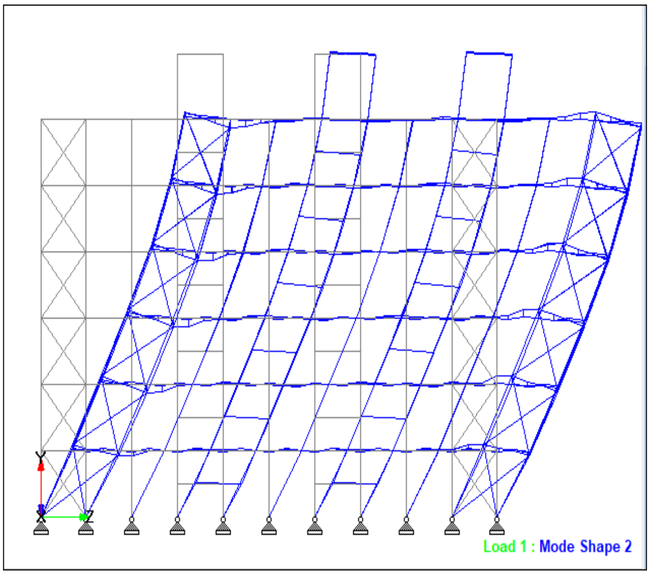

FIGURE 7-2. MODE-2 TRANSLATION– Z DIRECTION

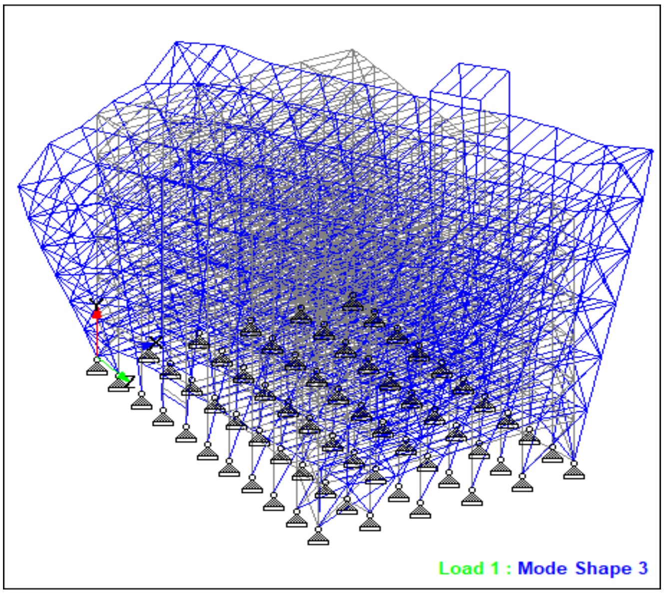

FIGURE-7-3. MODE-3 TORSIONAL

7.2 CONNECTIONS

The connections are designed from OSDAG open software from Indian Steel Construction form the results taken from STAAD and grouped into shear and Moment connections as shown in Fig 7-4 & 7-5. The shear connections are fin plate connections between beams ISMB 225 & ISMB 300 and the moment connections are designed between column and beam ISMB 500 & ISMB 300.

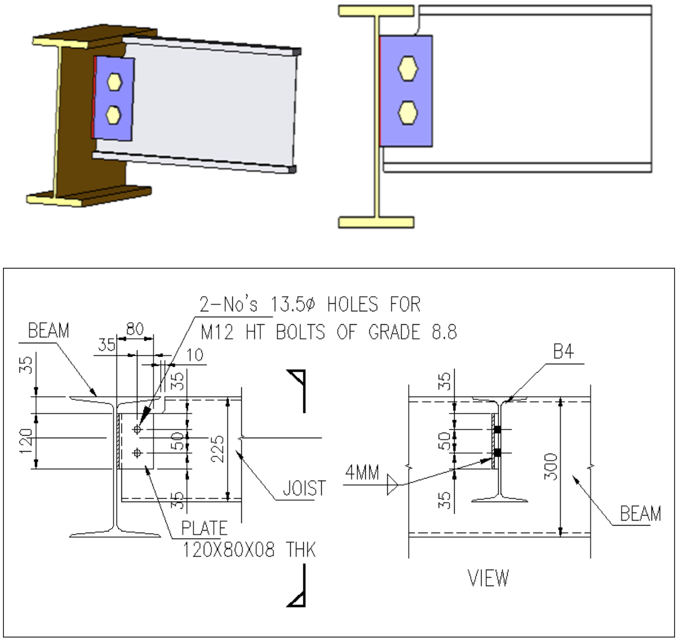

FIGURE-7-4. Beam to Beam Shear Connection

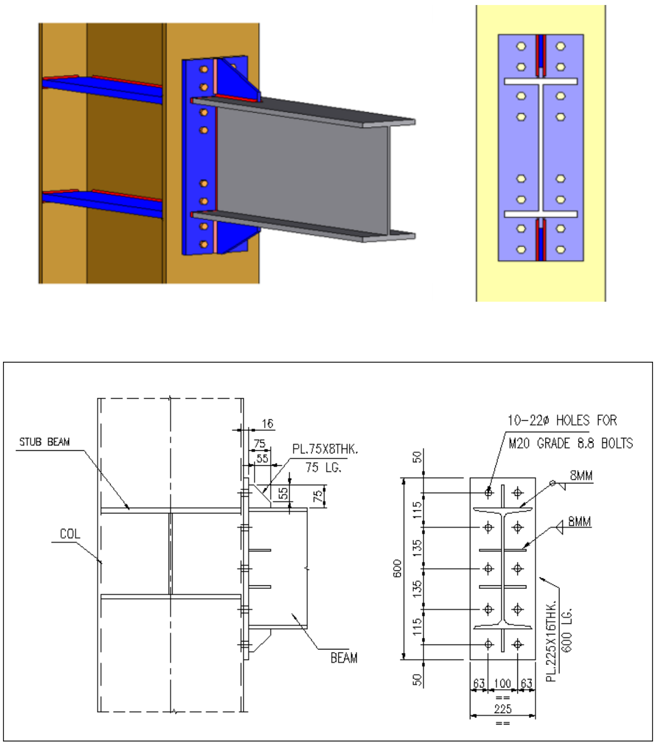

FIGURE-7-5. Column to Beam Moment Connection

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