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Analysis & Design of (G+6) Industrial Shed Building using STAAD.PRO

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Abstract: The main aim of structural engineer is to design the structure for a safe, serviceable, durable and economical. The entire process of structural planning and design is required imaginations and sound knowledge. Analysis and design of G+6 storey PEB Industrial Shed building structure as per IS Code method. This is a complete steel building building designed as per IS 800:2007 with 6 RCC decks provided of size 150 X150 mm. Analysis and Design of entire structure have been completed by manual design and verifies using STAAD.PRO Software. In this project, the design of beam, column, slab, is calculated by "Limit State Method" using IS: 456-2000 code book. Different load active on the member are consider according to IS: 875-1987 (part 1, part 2, part-3) & IS: 1893-2005 for seismic load. Hence this Industrial building is properly planned and designed in accordance with Indian Standard Code of India.

Keywords: (G+6) Industrial Shed, STAAD.PRO, STAAD. Foundation, Selfweight (Dead Load), Live load, Seismic Analysis & Wind Analysis.
Specifications: IS CODE 800: 2007 (Design of Indian Steel), IS CODE 1893: 2002/05 **(**Earthquake Loading Analysis, IS CODE 875: 1967 (part 1, part 2, part 3).

1. Introduction

Pre-Engineered Buildings (PEB) are the buildings which are engineered at a factory and assembled at site. Usually, PEBs are steel structures. Built-up sections are fabricated at the factory to exact size, transported to site and assembled at site with bolted connections. This type of Structural Concept is generally used to build Industrial Buildings, Metro Stations, Ware houses etc. The "Adoptability of PEB in the place of Conventional Steel Building design concept resulted in many advantages, including economy & easier fabrication". The PEB Steel Structure of a Pre-Engineered Steel Building generally accounts for over 80% of the weight of the Pre-Engineered Steel Building. This 80% is an average and may change plus or minus 10% depending on the presence of mezzanines, crane runway beams, type of Panels used and the amount of building accessories that are included in a building. The unit of measure for PEB Steel Structures is metric ton (MT). As a general average, one square meter (1 m^2) of PEB Steel Structure weighs 25 kg. Its primary purpose is to form a skeleton for the building or the structure essentially the part of the structure that holds everything up and together. India is a developing country; huge construction projects are yet to come as undeveloped cities are needed to develop since so many years. In current century, many projects all over the world are going on, time delay takes place which in turn affects the growth of the construction of huge projects. To avoid time delay and thereby the growth, economic construction methodology should be adopted. To economize the structure, structural optimization techniques should be used. The software used in the project are:

1. Bentley STAAD.PRO V8iSS6
2. STAAD.FOUNDATION

2. Aim & Objective of Study

- Identification of structural arrangement of plan.
- Identification of criticality and weakness due to Seismic, wind performance on the building.
- Study of seismic, wind and design of steel structure codal provisions.
- Modelling of the building for structural analysis using STAADPRO.

- Providing Channel Section and designing effectively according to all analysis.
- To check & design of the seismic, Wind Reaction of (G+6) building using STAADPRO.
- To make building earthquake and Wind Resistant to establish a Pre-Engineered Structure.

3. REVIEW OF LITERATURE

Ravi Shankar Raman, Shaik Anjimoon Anandhi R J, Ayaz Sheikh, Ashish Parmar, Niti Sharma, Myasar Mundher Adnan (2024) In India's seismically active region, the necessity forearthquake-resistant structures is highlighted by seismic waves that alter the motion of the earth. Response spectrum analysis combines modal responses via techniques including CQC, and ABS,taking into account a variety of response modes. This study compares earthquake loads usingvarious soil types in Zone III and evaluates building performance during seismic events. The primary goal of the entire project is to analyse the seismic response of multistory buildings. StaadPro Software does load calculations in order to analyse the entire structure. The outcomes turned out to be incredibly exact and precise. A G+7 and G+10 storey building was examined for every potential load combination (seismic, live, and dead loads) during my analysis and design process. The highly interactive and user-friendly user interface of Staad. Pro allows. The parametric study presented in this work looks into how site factors affect ground motion during earthquakes. We calculated the response reduction of the common moment-resisting body case and the unique moment-resisting frame values Tall Construction's seismic reaction using the Staad Pro.

Sudhir Paswan, Manas Rathore (2022): Structural Steel is a common building material used throughout the construction industry. Its main purpose is to build the skeletal structure of a building, the part of the structure that holds everything up and connected. Metal is one of the most environmentally friendly materials that can be used 100%. The structure of the building has changed, largely due to the demand caused by the earthquake. By using the available ISMB steel parts the required design requirements cannot be met, especially in heavily loaded buildings, as the moment of inertia and cross-sections play a major role. Reinforced concrete sections also carry a heavy load but when the assembly is facing a maximum height of about 50-60 meters it is not advisable to use concreting processes, thus using a built structure it is easy to make a permanent structure. However, like all new things, technology breeds its own set of new problems. So, with the use of STAADPro, seismic analysis is done fairly easily. The multi-story Industrial Building has been selected and carefully analyzed and designed. Selected floor + floor + floor + floor selected. Analysis and design will be done according to standard specifications as far as possible extensions. Structural analysis will be performed using the software package STAAD PRO.V8i.

Sayyed A. Ahad et al. (2017) have analysed and designed a multistoried building located in Latur, Maharashtra with B+G+10 storeys having a car parking facility provided at basement floor. The building has a shear wall around the lift pit. The modelling and analysis of the structure is done by using STAADPRO and the designing was done. Design of slab, stair case and an isolated footing was done manually. The design methods involve load calculations manually and analyzing the whole structure by STAADPRO. It has been concluded that analysis is done by using the software STAADPRO V8i SS6, which proved to be premium of great potential in analysis and design of various sections. The structural elements like RCC frame, shear wall and retaining walls are also provided. As per the soil investigation report, an isolated footing is provided. The design of RCC frame members like beam and column was done using STAADPRO. The analysis and design were done according to standard specifications to the possible extend. The various difficulties encountered in the design process and the various constraints faced by the structural engineer in designing up to the architectural drawing were also understood.

Mohammed Imranuddin, Abdul Kareem, Kha Yasir(2019) have done an analysis of 16 storied high rise building with and without shear wall by computer aided software Staadpro. The model is analyzed for axial load, lateral loads and wind loads. Response spectrum analyses are also done. The displacement of the 2 models having different load cases are observed. He concluded that lateral loads are reducing when shear walls are added at the corner location having minimum lateral forces. He also observed that static analysis is not sufficient for high rise buildings. It is necessary to provide dynamic analysis. Response spectrum analysis can be seen that the displacement values in both x and y directions are least in model with shear wall in core and corners when compared to other models.

The following conclusions was observed:

1) The PEB steel structures warehouses, shed needs low maintenance as compared to conventional structure and Placement of steel building is much faster than RCC buildings.
2) The story stiffness is more in PEB steel buildings than in Conventional framed structure.
3) The PEB structures can withstand the seismic and wind loads more efficiently.
4) The performance of PEB structures is better compared to the RCC structures.
5) The cost of construction of PEB structure is less.
6) Due to the High Stiffness, Modulus of Elasticity, Poisson's Ratio. Density and Load Bearing Capacity of PEB it is more suitable in earthquake and Wind prone areas for Industrial and Commercial purposes.

4. PROJECT DESCRIPTION

A. Building Specifications:

Purpose of Building	Private/Commercial/ Industrial Building
Shape of the Building	Regular (Rectangular)
No. of Stories	(G+6) Storey
Height of Stories	3 m (Similar Stories)
Type of Section	Steel Section of HYSD, I100016A50012, 180012B50012
Depth of Foundation	1.5 m
Building height	21 m
Plinth surface Area	200.34 m^2
Total built-up Area	1402.38 m^2
Slab thickness	150mm

Zone	4
Location	Mumbai Outskirt
Zone factor	0.24
Response Reduction Factor	5
Type of soil	Medium Stiff

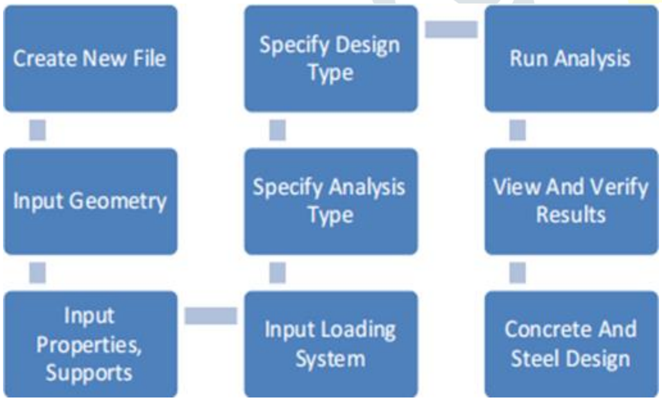

Fig 1: flow chart diagram

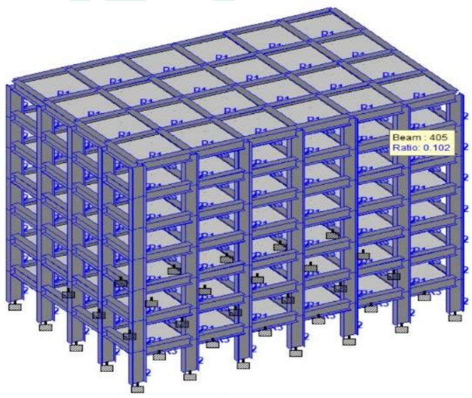

Fig 2: 3D View of the Building

5. METHODOLOGY

5.1: Modelling of the Structure

In this Project have we analyzed and designed the G+6 PEB Industrial Building with I channel Section and Assigning and Analyzing the loads of Seismic load, Wind load in X and Y direction using STAAD.PRO Bentley V8iSS6 and then designing the sections as per the output of the structure for accuracy, safety and optimizing the structure economic stability. The following are the specification of the project. A multistory G+6 Industrial building located in Bombay (zone IV) with 3 meter of floor-to-floor height and dimensions of 24x16x21 meters is planned, Designed and analyzed using STAAD.PRO software. The building has an Special Moment Resisting Force. The building has Nodal pates of 150x150 mm designed as as per IS

456:2000. The special earthquake and wind resistance of the structure and for extra strength of structure the section are designed as per codal provisions. On the other hand, we have tried to make our structure as economical as possible by trying sections of Columns and Beams of I Channel sections, Mininal Bolting joints are used for foundation design and isolated footing is used to hold the structure.

5.2: Loads & Definitions:
Building Loads Categorized by Orientation:
Types of loads on a hypothetical building are as follows:

- ✓ Vertical Loads
- ✓ Dead Load (gravity)
- ✓ Live Load (gravity)
- ✓ Wind Analysis (uplift on roof)
- ✓ Seismic and wind Analysis (overturning)
- ✓ Seismic Analysis (vertical ground motion)
- ✓ Load Combinations

1. 1.5 (DL+LL)	6. 1.5 (DL+EQX)
2. (DL+LL+EQX)	7. 1.5 (DL+EQY)
3. 1.2 (DL+LL+EQY)	8. 1.5 (DL-EQX)
4. 1.2 (DL+LL-EQX)	9. 1.5 (DL-EQY)
5. 1.2 (DL+LL-EQY	10. 0.9DL+1.5EQX

5.3: Analysis & Interpret the Result:
✓ Analysis of Steel Structure & RCC working Deck
✓ Torsional Force, Bending moment and Axial force assessment of Serviceability
✓ Design of this structure in accordance to IS:800- 2007(Indian Steel Design) and footing as per IS: 456-2000 (Design of Isolated Footing)

5.4: Design Method:

- ❖ LIMIT STATE METHOD (Flexure, collapse, Serviceability, Torsion)
- ❖ IS CODES: IS 800: 2007 (INDIAN STEEL DESIGN)
- ❖ IS 1893: 2002/05 (Design of Seismic Resistant Building)
- ❖ IS 875: 1987 (part 3) (Design of Wind Resistant Building)
- ❖ IS 456: 2000 (Design of Isolated Footing)
- ❖ Plan Dimensions: 24 X16 X 21 m

5.5: Input Data:

- ❖ Length of the Building: 24 m
- ❖ Height of the Building: 21 m
- ❖ Width of the Building: 16 m
- ❖ Number of Bays along length: 6 Bays
- ❖ Number of Bays along height: 7 Bays
- ❖ Number of Bays along width: 4 Bays

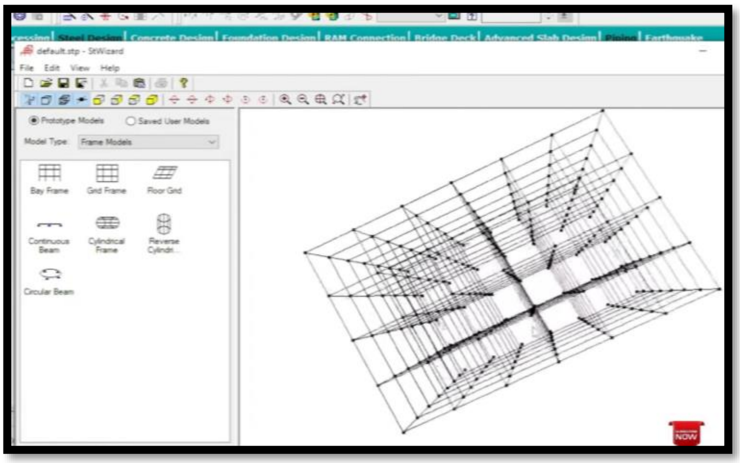

Fig 3: Top View of the Structure

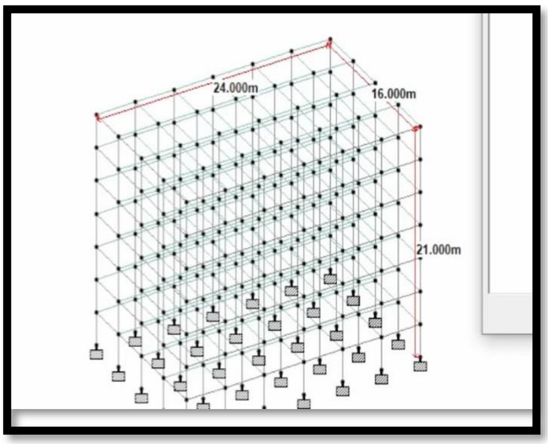

Fig 4: Skeletal View of the Structure

6. ASSIGNING OF THE LOADS

6.1 Seismic load:(IS: 1893-2002/2005)

Zone: IV
Zone factor: 0.24
Damping ratio: 0.05
Period in X direction: 0.58 seconds
Period in Z direction: 1.05 seconds
Response reduction factor: 5
Soil type: 2(medium)

- ✓ Unit weight of concrete = 25 KN/m^3
- ✓ Unit weight of mortar = 18 KN/m^3
- ✓ Init weight of brick masonry = 20 KN/m^3
- ✓ Density of Steel: 78.5 KN/m^3

6.2 Dead load: (IS: 800-2007)

1. Due to self-weight of slab (RCC Working Deck):
   Thickness of slab= 150mm
   Slab load per m =thickness X unit weight =0.150 X 25 = 3.75 KN/m^2
   Floor finished load per m = 1.5 KN/m^2

2. Due to Vertical Section:
   Thickness of section = 230 mm
   Section load = Thickness X unit weight X (height of typical storey – depth of section)
   = 0.230 X 78.5 X (3-0.824)
   = 39.27 KN/m^2

3. Due to Horizontal Section:
   Thickness of Section = 127 mm
   Section Load = Thickness X unit weight X (height of typical storey – depth of section)
   = 0.127 X 78.5 X (3-0.824)
   = 21.69 KN/ m^2

4. Due to parapet wall:
   Thickness of parapet wall= 125mm
   Parapet wall load= 0.125 X 78.5 X 1= 9.81 KN/m^2

6.3: Live Load: (IS 800:2007)

Plate= 0.15 X 0.15X25X16=9 m
Horizontal= 0.824 X 4= 12.3 m
Vertical= 0.824 X 3= 9.2 m
9+9.2.12.3= 30.5 m
0.2m (Deducing Clear cover of 100m from top and bottom)
Live Load= 30.5- 6.2 = 24.3 KN/m
The above example shows a sample calculation of Live Load of our structure.

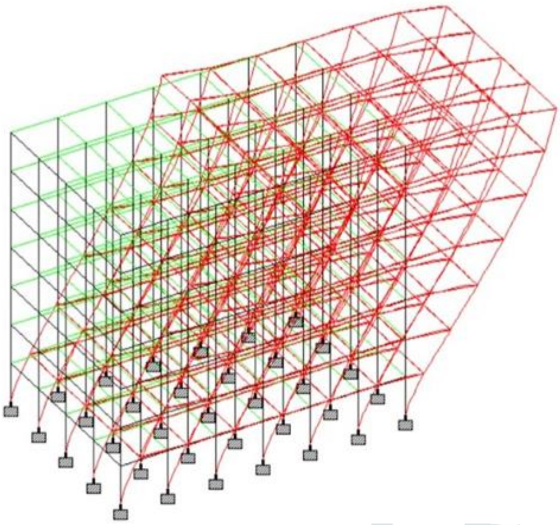

Fig 5: Due to Live Load

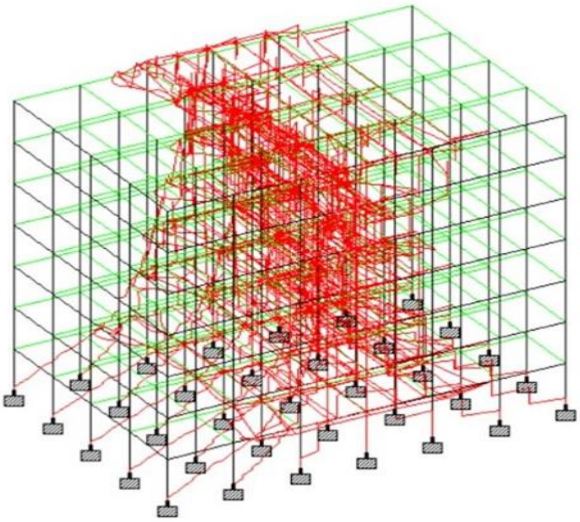

Fig 6: Due to Dead Load

6.4: Wind Load (IS 875: Part 3)
For some pressure zones, the peak pressure depends on an arrow range of wind .
Therefore, the wind directionality effect must also be factored into determining risk consistent wind loads on Buildings.
The basic wind speed (Vb) for any site shall be obtained the following effects to get design wind velocity at any height (Vz) for the chosen structure.
a) Risk level
b) Terrain roughness, height and size of the structure and
c) Local topography
It can be mathematically expressed as follows:
Vs.=Vb* K1* K2* K3
Where,
Vz= design wind speed at any height Z in m/s
K1= probability factor (risk coefficient)
K2=terrain height and structure size factor and
K3=topography factor

6.5: Load Combinations:

For Superstructure	For Substructure
1.5(D. L+L.L)	D.L+L.L
1.2(D. L+L.L±EQ (X, Z))	D.L+0.5L. L±EQ (X, Z)
1.5(D. L±EQ (X, Z))	D.L±EQ (X, Z)
0.9D. L±1.5EQ (X, Z)	

Tab 2: Load Combinations

7. ANALYSIS & INTERPRET THE RESULT:

7.1: Interpreting the Wind Loads

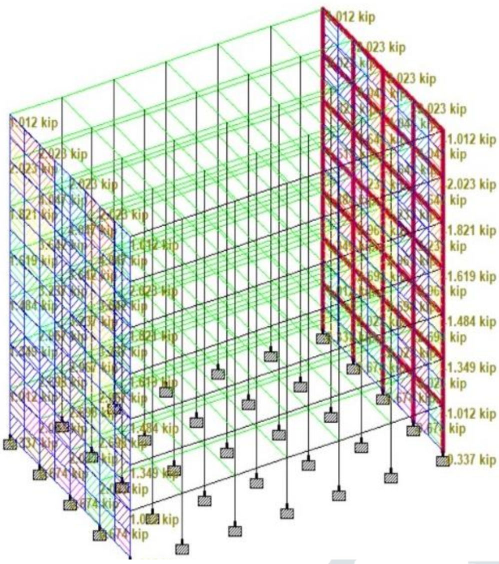

Fig 7: Due to Wind Load in X direction

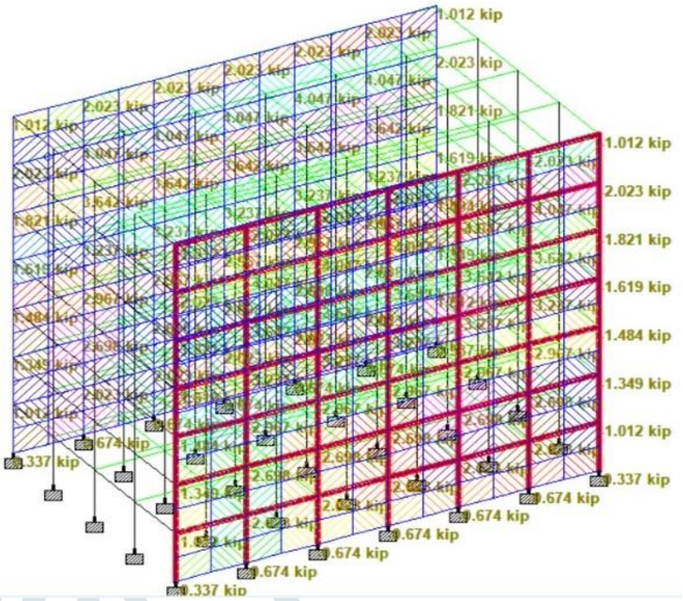

Fig 8: Due to Wind Load in Z direction

7.2: Interpreting the Seismic Loads

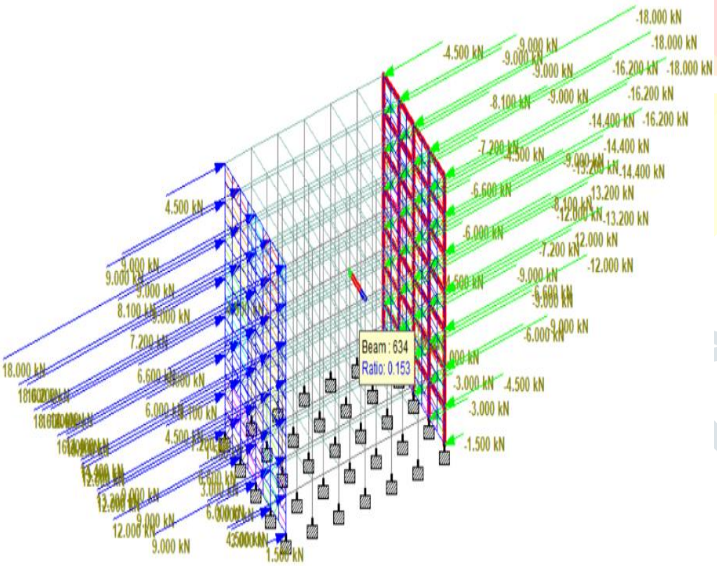

Fig 9: Due to Seismic Load in X direction

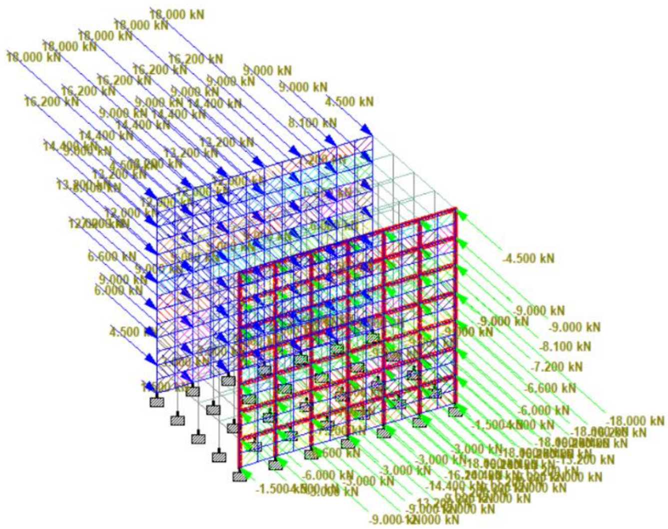

Fig 10: Due to Seismic Load in Z direction

7.3: INTERPRETING SHEAR BENDING & DEFLECTION:

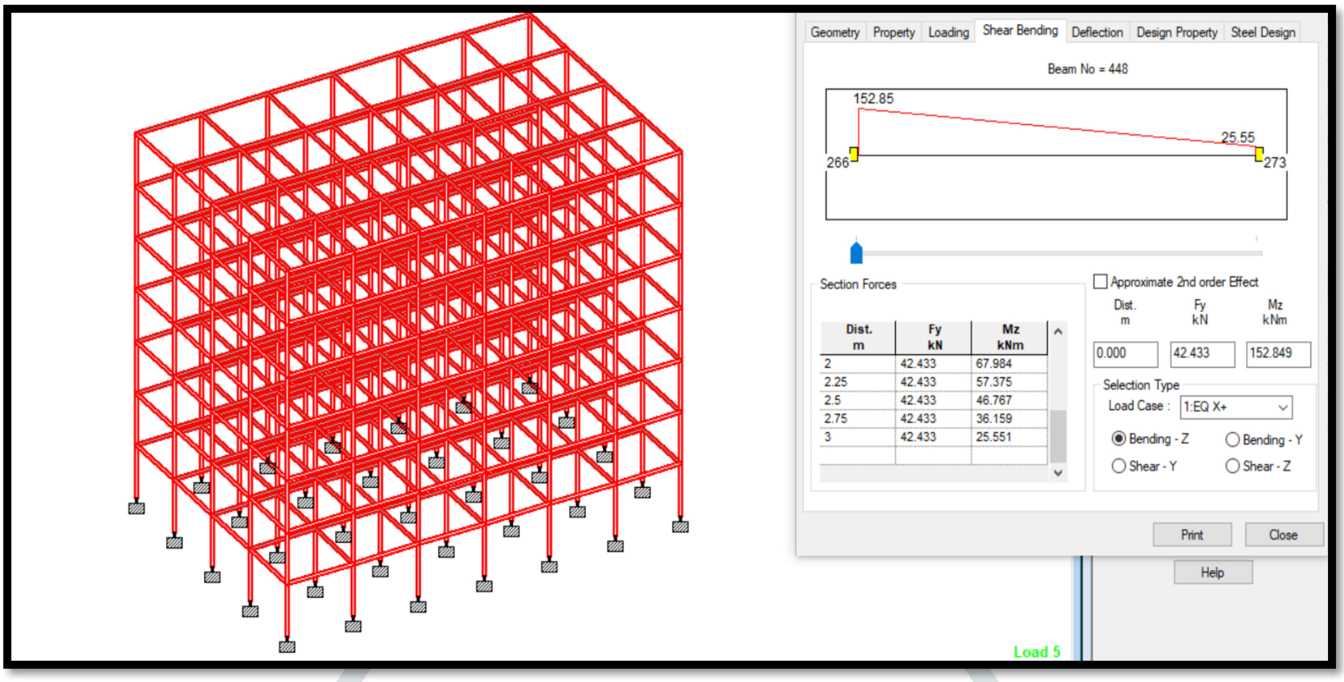

Fig 11: Due to Shear Bending

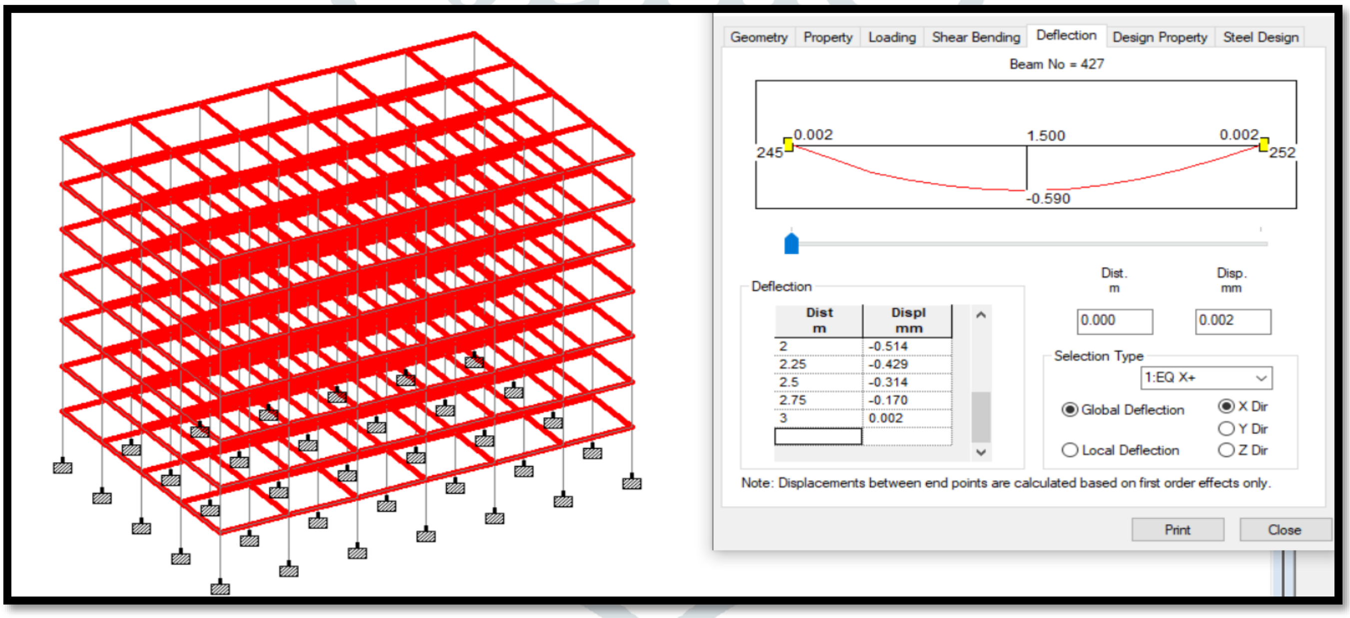

Fig 12: Due to Deflection

7.4: STRESS DUE TO RCC DECK:

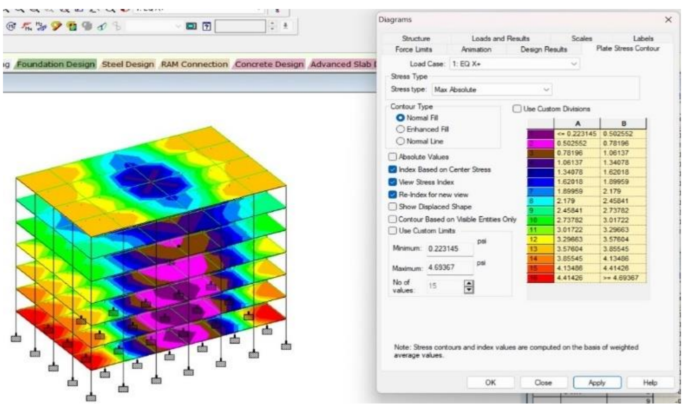

Fig 13: Due to Seismic Load

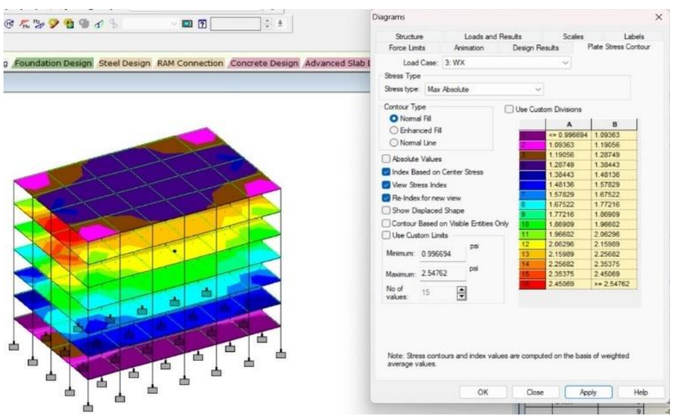

Fig 14: Due to Wind Load

8. DESIGN OF THE STRUCTURE:

8.1: Detailing of the I Channel:

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|-------------------------------------------------------------------------------------|
|  Member Number:        1                                                            |
|  Member Section:  ST    I80012B55012      (INDIAN SECTIONS)                         |
|-------------------------------------------------------------------------------------|
|  Tension:      (Unit:  KN     METE)                                                 |
|  Parameters:        FYLD:       250.000E+03        FU:       420.000E+03            |
|                      NSF:            1.000     ALPHA:              0.800            |
|  Yielding    :  Design Force:        19.005E+00      LC:      8                     |
|                 Capacity:             9.068E+03     As per:  Sec. 6.2              |
|  Rupture     :  Design Force:        19.005E+00      LC:      8                     |
|                 Capacity:            10.725E+03     As per:  Sec. 6.3              |
|-------------------------------------------------------------------------------------|
|  Compression:     (Unit:  KN     METE)                                              |
|  Buckling Class:    Major: a     Minor: b     As per:Cl. 7.1.2.2                    |
|  Major Axis:    Design Force:         4.911E+00     LC:    10  Loc:      0.000      |
|                 Capacity:             8.258E+03     As per:  Sec. 7.1.2            |
|  Minor Axis:    Design Force:         4.911E+00     LC:    10  Loc:      0.000      |
|                 Capacity:             7.540E+03     As per:  Sec. 7.1.2            |
|-------------------------------------------------------------------------------------|
|  Shear:    (Unit:  KN   )                                                           |
|  Major Axis:    Design Force:      -226.416E-03     LC:     8  Loc:      0.000      |
|                 Capacity:             1.732E+03     As per:  Sec. 8.4              |
|  Minor Axis:    Design Force:       185.175E+00     LC:    10  Loc:      0.000      |
|                 Capacity:             1.297E+03     As per:  Sec. 8.4              |
|-------------------------------------------------------------------------------------|
|  Checks                     Ratio   Load Case No.       Location from Start( METE)  |
|                                                                                     |
|  Tension                     0.002        8                      0.000E+00          |
|  Compression                 0.001       10                      0.000E+00          |
|  Shear Major                 0.000        8                      0.000E+00          |
|  Shear Minor                 0.143       10                      0.000E+00          |
|-------------------------------------------------------------------------------------|
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Fig 15: Detailing of the Beam

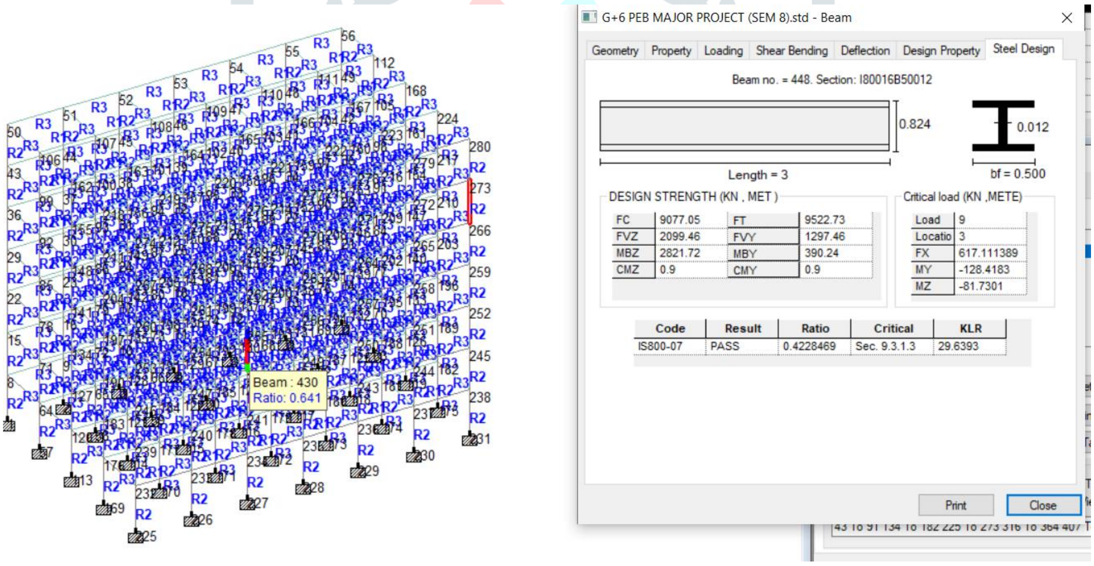


Fig 16: Section Design of the Beam

8.2: Detailing of the Nodal Plates:

In STAAD.Pro, when analyzing RCC (Reinforced Concrete) plates such as slabs or flat structural elements, several parameters are computed to understand the behavior and performance of the structure. Here's a detailed explanation of corner stresses, center stresses, principal stresses, and displacements in RCC plates:

1. Corner Stresses:

Corner stresses refer to the stresses computed at the corners of the plate elements (slabs) in STAAD.Pro.These stresses are the result of the applied loads and boundary conditions on the structure. Corner stresses are crucial for assessing the stress distribution across the plate and identifying critical regions that may experience high stress concentrations.

2. Center Stresses:

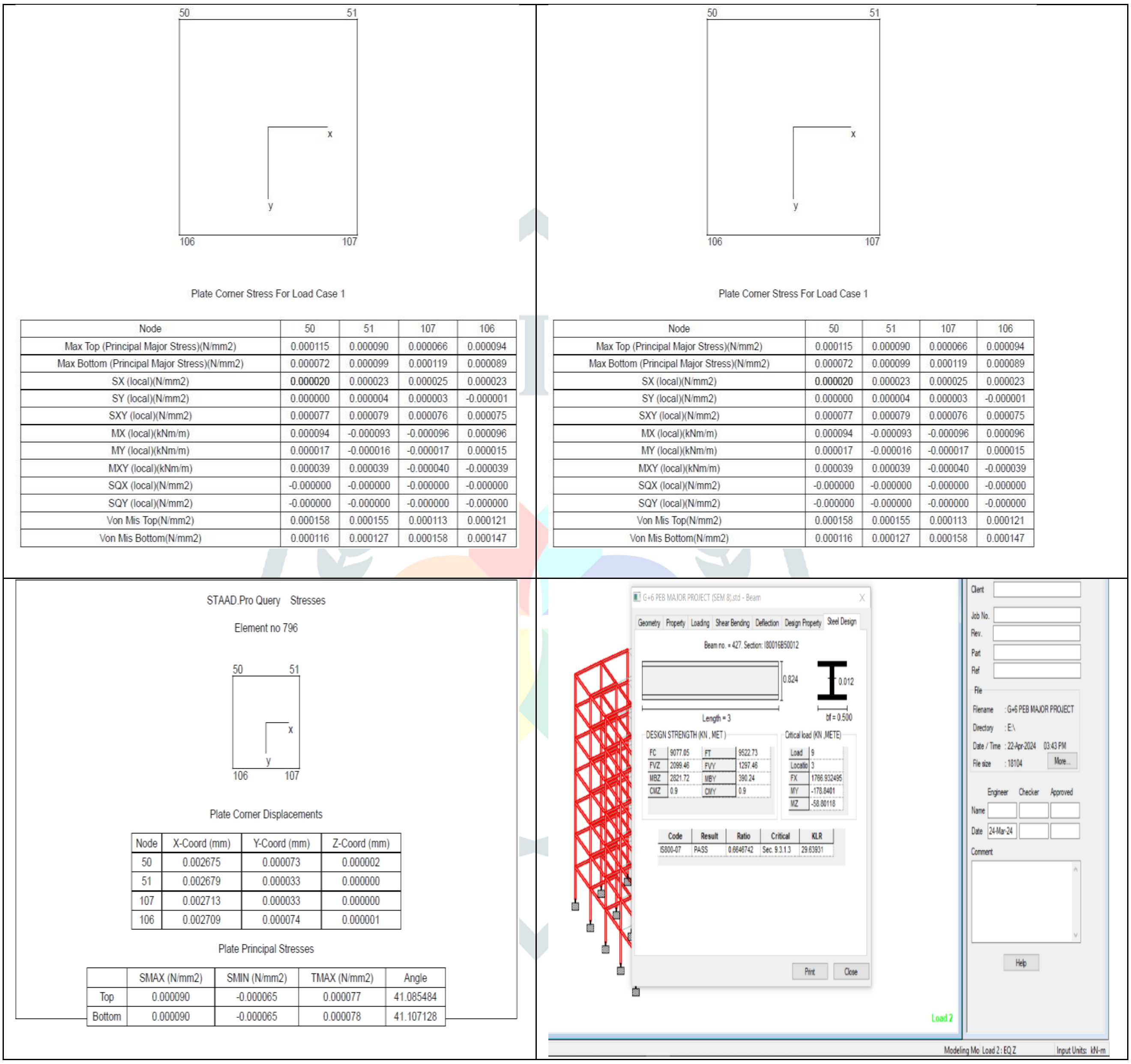
Center stresses are the stresses computed at the center of the plate elements. These stresses represent the average stress within the plate element and provide insight into the overall behavior Center stresses are essential for understanding the global response of the structure and evaluating its overall Performance.

3. Principal Stresses:

Principal stresses are the maximum and minimum normal stresses that occur at a specific point in a structure. In RCC plates analyzed in STAAD.Pro, principal stresses indicate the maximum tensile and compressive stresses. Understanding principal stresses helps in assessing the critical regions of the plate where failure may occur.

4. Displacements:

Displacements represent the movement or deformation of the structure under applied loads. InRCC plates, displacements computed in STAAD.Pro indicate how much the plate deflects or moves due to seismic load. Displacement analysis helps in evaluating the structural integrity, serviceability, and overall behavior of the plate.



Node	50	51	107	106
Max Top (Principal Major Stress)(N/mm2)	0.000115	0.000090	0.000066	0.000094
Max Bottom (Principal Major Stress)(N/mm2)	0.000072	0.000099	0.000119	0.000089
SX (local)(N/mm2)	0.000020	0.000023	0.000025	0.000023
SY (local)(N/mm2)	0.000000	0.000004	0.000003	-0.000001
SXY (local)(N/mm2)	0.000077	0.000079	0.000076	0.000075
MX (local)(kNm/m)	0.000094	-0.000093	-0.000096	0.000096
MY (local)(kNm/m)	0.000017	-0.000016	-0.000017	0.000015
MXY (local)(kNm/m)	0.000039	0.000039	-0.000040	-0.000039
SQX (local)(N/mm2)	-0.000000	-0.000000	-0.000000	-0.000000
SQY (local)(N/mm2)	-0.000000	-0.000000	-0.000000	-0.000000
Von Mis Top(N/mm2)	0.000158	0.000155	0.000113	0.000121
Von Mis Bottom(N/mm2)	0.000116	0.000127	0.000158	0.000147

Node	50	51	107	106
Max Top (Principal Major Stress)(N/mm2)	0.000115	0.000090	0.000066	0.000094
Max Bottom (Principal Major Stress)(N/mm2)	0.000072	0.000099	0.000119	0.000089
SX (local)(N/mm2)	0.000020	0.000023	0.000025	0.000023
SY (local)(N/mm2)	0.000000	0.000004	0.000003	-0.000001
SXY (local)(N/mm2)	0.000077	0.000079	0.000076	0.000075
MX (local)(kNm/m)	0.000094	-0.000093	-0.000096	0.000096
MY (local)(kNm/m)	0.000017	-0.000016	-0.000017	0.000015
MXY (local)(kNm/m)	0.000039	0.000039	-0.000040	-0.000039
SQX (local)(N/mm2)	-0.000000	-0.000000	-0.000000	-0.000000
SQY (local)(N/mm2)	-0.000000	-0.000000	-0.000000	-0.000000
Von Mis Top(N/mm2)	0.000158	0.000155	0.000113	0.000121
Von Mis Bottom(N/mm2)	0.000116	0.000127	0.000158	0.000147

Node	X-Coord (mm)	Y-Coord (mm)	Z-Coord (mm)
50	0.002675	0.000073	0.000002
51	0.002679	0.000033	0.000000
107	0.002713	0.000033	0.000000
106	0.002709	0.000074	0.000001

	SMAX (N/mm2)	SMIN (N/mm2)	TMAX (N/mm2)	Angle
Top	0.000090	-0.000065	0.000077	41.085484
Bottom	0.000090	-0.000065	0.000078	41.107128

Fig 17: Nodal Plates Design & Design of I section

8.3: Design of Foundation:

Foundations are structure elements that transfer loads from building or individual column to earth these loads are to be properly transmitted foundations must be designed to prevent excessive settlement is rotation to minimize differential settlements and to provide adequate safety isolated footings for multi storey buildings.

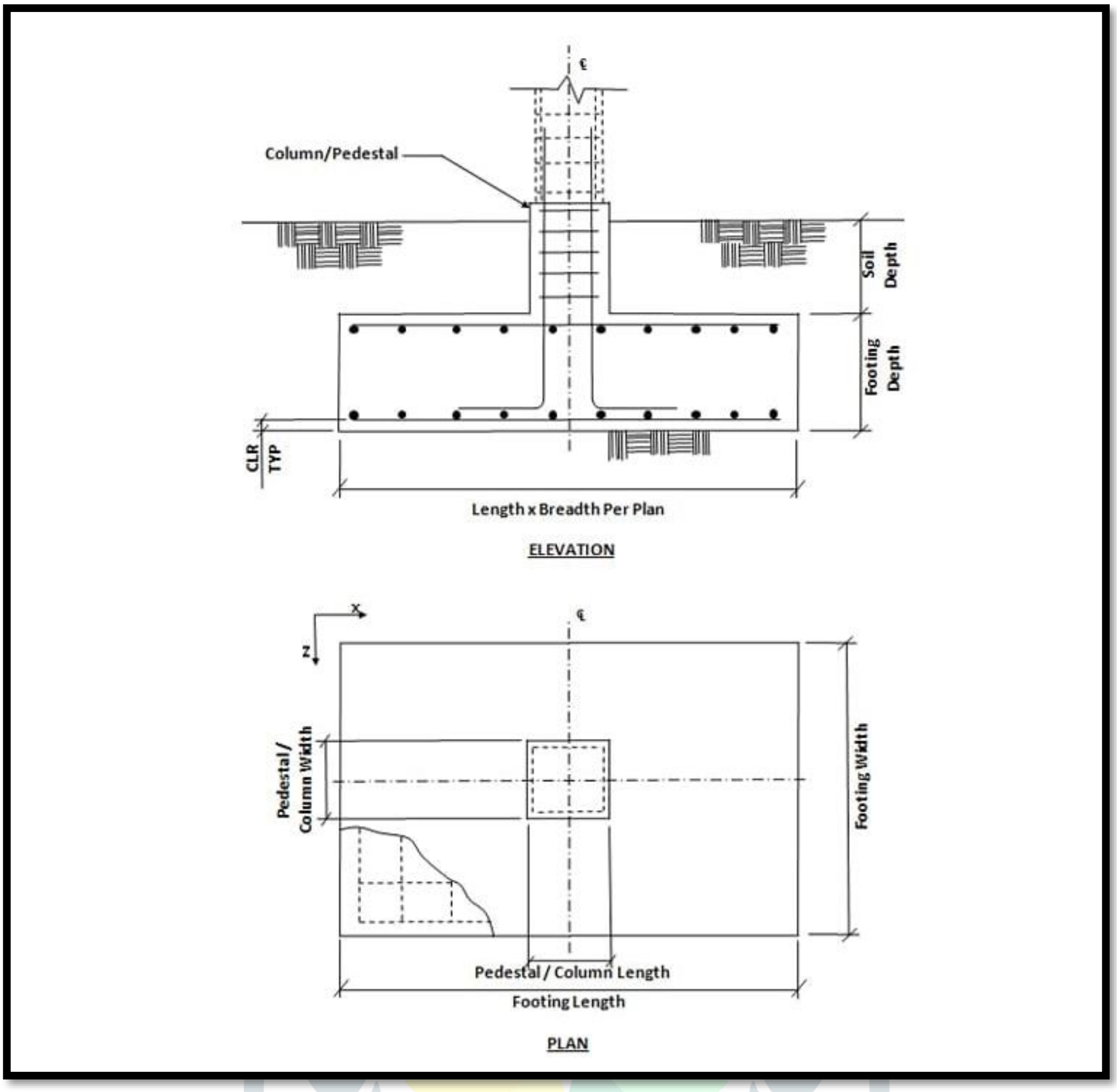


Fig 18: Isolated Footing Design

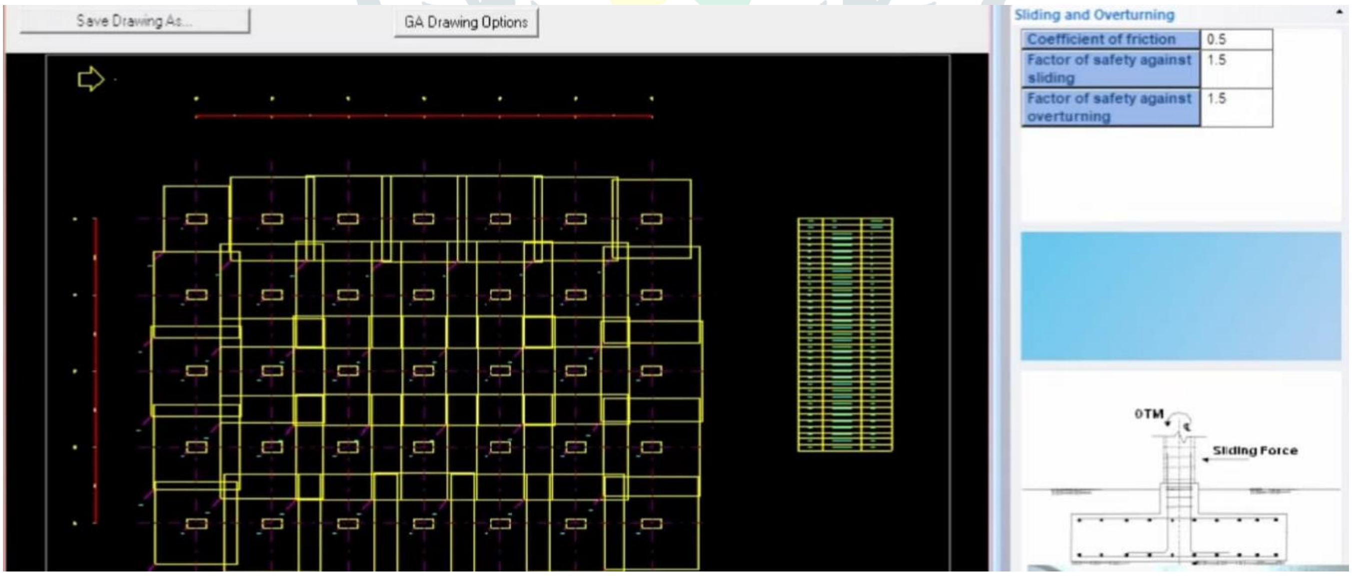


Fig 19: Footing Plan

8.4: Design of Column:

A column may be defined as an element used primary to support axial compressive loads and with a height of a least three times its lateral dimension. The strength of column depends upon the strength of materials, shape, size of cross section, length and degree of proportional and dedicational restraints at its ends.

Design Type	Calculate Dimension
Footing Thickness (Ft)	305 mm
Footing Width - Z (Fw)	1000 mm
Footing Length - X (Fl)	1000 mm
Column Shape	Rectangular
Column Length - X (Pl)	1.024 m
Column Width - Z (Pw)	0.500 m

Tab 3: Footing and Column Parameters

Unit weight of Concrete	25 KN/m^3
Strength of Concrete	25 N/mm^2
Yield Strength of Steel	415 N/mm^2
Minimum Bar Size	10 mm
Maximum Bar Size	32 mm
Minimum Bar Spacing	50 mm

Tab 4: Design Parameters

8.5: Soil Properties & Sliding & Overturning:

Soil Properties
Soil Type : Drained
Unit Weight : 22.000 kN/m3
Soil Bearing Capacity : 100.000 kN/m2
Soil Surcharge : 0.000 kN/m2
Depth of Soil above Footing : 0.000 mm
Cohesion : 0.000 kN/m2
Min Percentage of Slab : 0.000

Fig 20: Footing Layout

Sliding and Overturning
Coefficient of Friction : 0.500 Factor of Safety Against Sliding : 1.500 Factor of Safety Against Overturning : 1.500

Minimum Area of Steel (Astmin) = 2442.000 mm^2
Calculated Area of Steel (Ast) = 6091.614 mm^2
Provided Area of Steel (Ast,Provided) = 6091.614mm^2

Astmin<= Ast,Provided
Steel area is accepted
Governing Moment = 83.707 kN.m
Selected bar Size (db) = Ø10
Minimum spacing allowed (Smin) = = 50.000 mm
Selected spacing (S) = 63.506 mm
$S_{min} <= S <= S_{max}$ and selected bar size < selected maximum bar size...
The reinforcement is accepted.
Based on spacing reinforcement increment; provided reinforcement is

Ø10 @ 60 mm o.c.

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CONCLUSION:

The project on analysis and design of the PEB G+6 Industrial building with analysis of seismic and wind loads with design of steel channel section is efficiently accomplished using STAADPRO & have demonstrated successful outcomes.

1. Incorporating steel sections along the perimeter has proven effective in enhancing structural integrity and meeting safety standards.
2. The building design with seismic resistant and wind resistant factors have passed seismic tests, Wind load analysis, Storey drift checks and stiffness checks indicating its ability to withstand seismic loads and wind loads efficiently.
3. This study highlights the importance of integrating usage of PEB Industrial Shed with complete sreel designed sections in structural design for seismic resilience while optimizing costs.
4. Overall, the findings contribute valuable insights to the field of structural engineering, emphasizing the significance of PEB in seismic-resistant building design.
5. The time period and frequency increases with addition of Steel sections.
6. Storey stiffness is more in shear wall structures.
7. Importantly, the inclusion of steel Columns and Beams has not only enhanced structural robustness but has also led to an economically efficient design.
8. This comprehensive approach enhances the resilience of the building, contributing to safer and more reliable infrastructure in seismic and windy prone regions.