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ANALYSIS AND DESIGN OF TALL EARTHQUAKE RESISTANT CONCRETE DIAGRID STRUCTURE

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Abstract— In the modern era, constrained by scarce land resources, the architectural planning and structural engineering of tall buildings are predominantly shaped by the lateral forces induced by wind or seismic activities. Diverse construction techniques are deployed to resist these horizontal pressures. This approach is exemplified in the initial blueprint of a 14-story building located in Bangalore, set amidst soil conditions of moderate density. The modeling and analysis of structural elements are conducted using STAAD. Pro software. Recent occurrences underscore the importance of factoring accidental loads into the seismic design process. The foundation for the diagrid structure is meticulously crafted utilizing STAAD Advance Foundation, incorporating pile caps and mat foundations.

Keywords— Ring Beam, Precambered Core, Diagrid, Floor Slab, Outer Diagrid, Inner Diagrid.

INTRODUCTION

Diagrid structures are gaining popularity for their architectural design and stability towards resisting seismic load and horizontal wind load.

Objectives

• Utilize STAAD.Pro software to examine, analyze, and devise the structural elements of a Diagrid framework employing concrete as the primary material.

• Assess the diverse structural loads influencing the structure, encompassing gravitational forces, wind pressures, and seismic forces.

• Adhere to pertinent building codes and standards while enhancing the structural resilience of tall structures in seismic-active areas, accounting for accidental loads.

Components

Diagrids - A diagrid represents a structural framework composed of diagonally intersecting beams crafted from materials such as metal, concrete, or wood. This term is formed by combining "diagonal" and "grid."

Inner Diagrid - Referring to an Internal Block Diagram (IBD), this static structural illustration reveals the internal arrangement of a block, detailing the connections among its internal components and their interfaces.

Outer Diagrid - An outer diagrid constitutes a tubular structure enveloping the exterior of a building, engineered to endure both vertical and lateral forces.

Precambered Core - A pre-cambered core denotes a concrete core fortified with steel, deliberately constructed slightly off-center.

Floor slab - Serving as a linkage between the internal and outer diagrids, a floor slab forms a crucial element within the structural design.

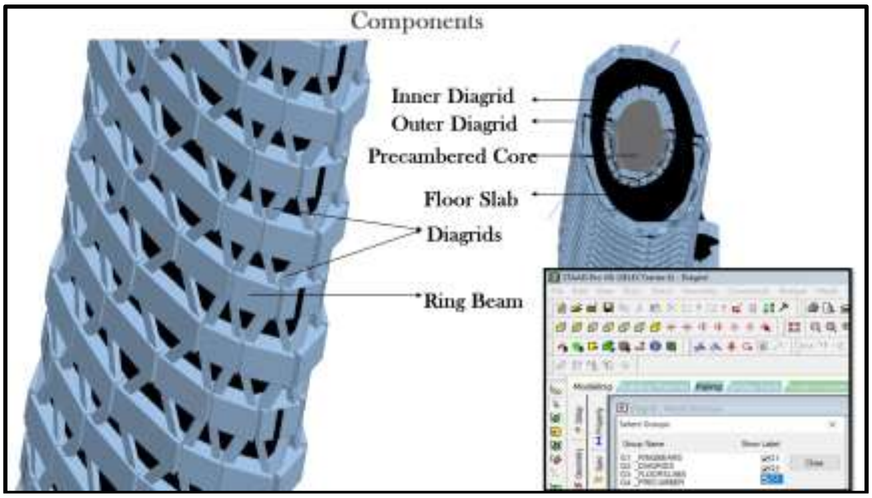

Fig. 1: Components of Diagrid Structure

LITERATURE REVIEW

Optimization of diagrid tall buildings for seismic response using the parameter space multi-objective method. Lotfy[1], Mohamed E. El Madawy[2] employ the Parameter Space Multi-Objective Method to optimize the seismic response of diagrid tall buildings, focusing on determining the optimal diagonal size through Parameter Space Investigation [1].

Dynamic Analysis of Vertical Irregular Tall Structural System HB Akhilesh[1] and BO Naveen[2] conduct a dynamic analysis of three types of vertical geometrically irregular tall reinforced concrete buildings, varying in plan dimensions. These structures feature cantilevered offset lengths ranging from 11% to 15% of the building lateral dimension, with increments of 0.5% [2].

Comparative Study on Dynamic Analysis of Diagrid Bracings and Shear Wall in Different Locations in Terms of Sustainability using ETABS Arbaz Ahmad Lone[1], Er. Gurpreet singh[2] and Jagdish Chand[3] compare the dynamic analysis of diagrid bracings and shear walls in different locations, emphasizing sustainability using ETABS. Their findings, derived from response spectrum analysis, suggest that diagrid structural systems offer superior cost-effectiveness, sustainability [3].

Displacement-based design of tall earthquake-resistant diagrid systems Amador Terán-Gilmore Ph.D. [a], Samuel Roeslin [b], Edgar Tapia-Hernández Ph.D. [a], Edgar Cuadros-Hipólito [c] assess the displacement-based design of earthquake-resistant diagrid systems. They delve into the performance-based design background and underscore the economic and environmental advantages associated with such designs [4].

Analysis of Diagrid Structural System for High Rise Steel Buildings. Procedia Engineering- Elsevier, Khushbu Jani [a], Paresh V. Patel [b] discuss the analysis of the diagrid structural system for high-rise steel buildings. They highlight how the structural design of such buildings is primarily influenced by lateral loads due to wind or earthquakes, with lateral load resistance provided by either interior or exterior structural systems [5].

METHODOLOG Y

Designing a diagrid structure in STAAD Pro under lateral loading conditions, particularly under seismic loading in Zone III. Created a 3D model of the diagrid structure in STAAD Pro, representing its geometry. apply lateral loads representing seismic forces based on Zone III requirements of IS 1893. Consider other lateral loads such as wind loads and gravity loads as per the design criteria. Performed a dynamic analysis to evaluate the response of the structure to seismic forces. Utilize STAAD Pro's dynamic analysis capabilities like response spectrum analysis to determine modal frequencies, mode shapes, and dynamic amplification factors.

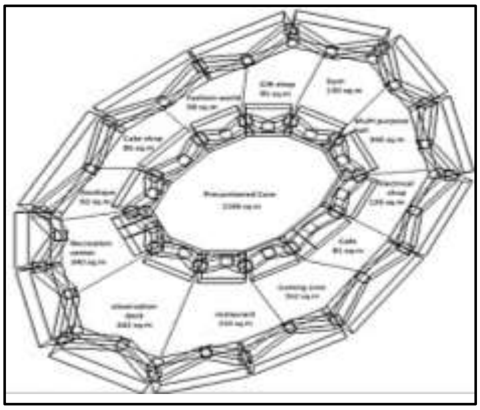

Fig. 2 : Diagrid Building Plan

The structural element properties are as follows:

- Diagrid dimensions measure 0.45 meters by 0.40 meters.
- Ring beam dimensions are 0.50 meters by 0.45 meters.
- Plate thickness is 0.35 meters.
- Column dimensions are 0.40 meters by 0.35 meters.

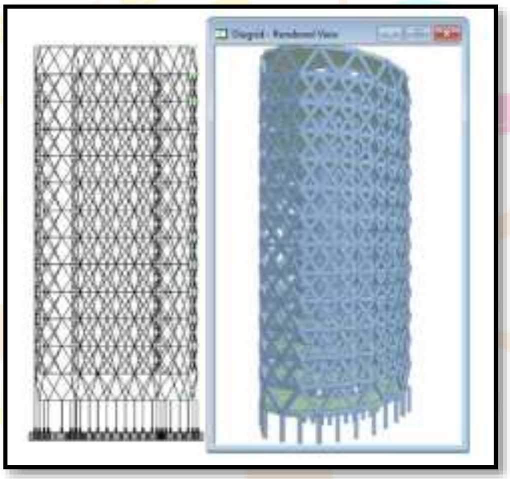

Fig. 3: Diagrid Building 3d Rendering

Loads & Definitions

- IS 875 1987 Part-01 for calculation of Dead Load.
- IS 875 1987 Part-02 for calculation of Live Load.

Seismic Loads –Type (IS 1893-2002/2005) Earthquake Resistant Design Analysis **Include accidental load.**

Zone : III
Soil type : Medium
Self-Weight : -1
Direction : X&Z
Response Reduction Factor (RF): 5
Importance Factor : 1.5
Factor direction : X&Z
Zone value : 0.1

Wind Load IS 875 2015 Part-03 for calculation of Wind Load.

Table -1 Wind Intensity calculation

Building Height	45m
Building Length along the direction of Wind(L)	25m
Building Length Normal to the direction of Wind(B)	20m
Building Natural Frequency	2
Building Damping Ratio	0.01
Enclosure Classification	Enclosed Building

Node Displacement summary

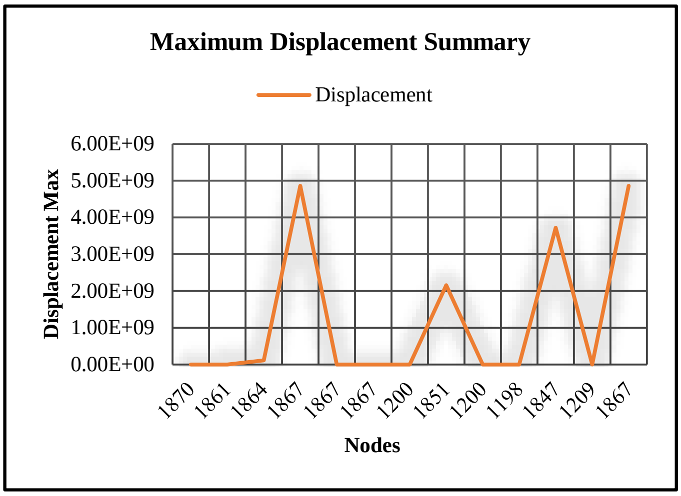

Fig. 4: Node displacement analysis

The maximum resultant displacement is observed to be 4.86E9 mm at a node. Notably, the maximum resultant displacement significantly exceeds individual directional displacements. These findings are critical for assessing structural stability and informing necessary adjustments or reinforcements.

Beam Forces Summary

The beam force summary presents maximum values for axial force, bending moment, shear force, and torsion in a diagrid structure analyzed using STAAD Pro.

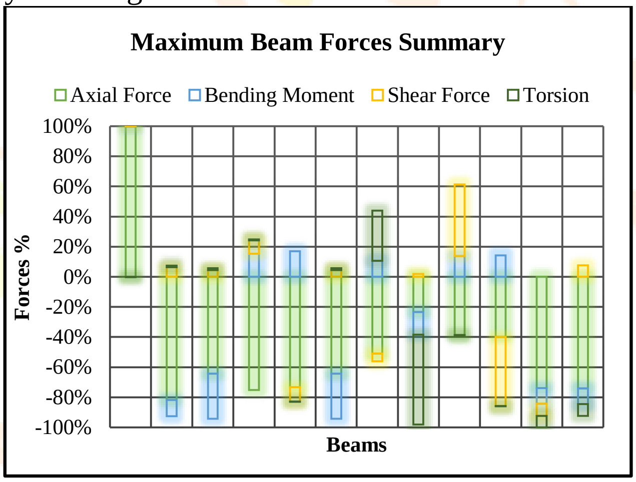

Fig. 5: Beam Forces analysis

Maximum axial force recorded was 2.30E+03, while the maximum bending moment was -314.1. Maximum shear force and torsion were 47.9 and 9.8 respectively. Some beams experienced negative values indicating compressive forces or clockwise torsion.

Plate center Principal Stresses Summary

Maximum principal stresses for plate elements at the top and bottom surfaces of a diagrid structure analyzed using STAAD Pro. The table lists plate numbers along with their corresponding maximum stress values in MPa.

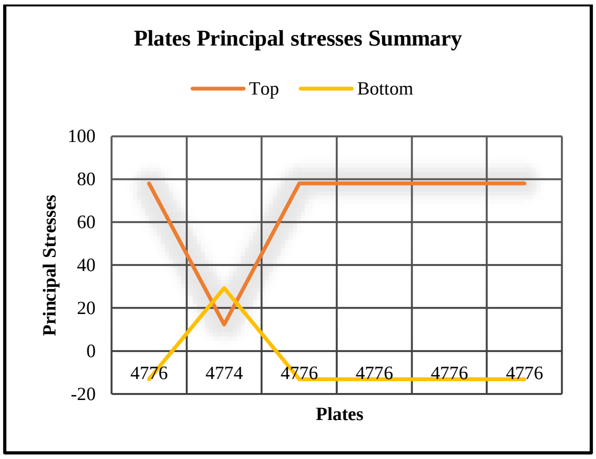

Fig. 6: Plate Center principal stresses analysis

The top surface experiences predominantly positive stresses, reaching a maximum of 77.97 MPa, while the bottom surface shows a mix of positive and negative stresses, with a maximum of -56.5 MPa.

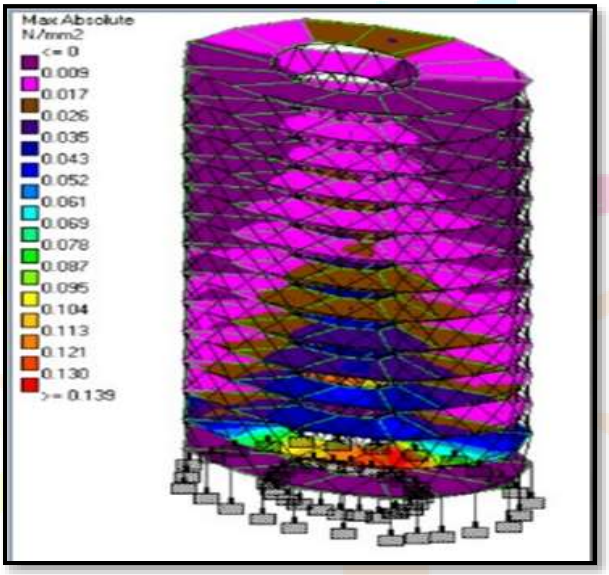

Fig. 7: Plate Maximum absolute principal stresses

RESULTS AND DISCUSSIONS

Design Parameters

- FC (30000kN/m2)
- FYMAIN (500000kN/m2)

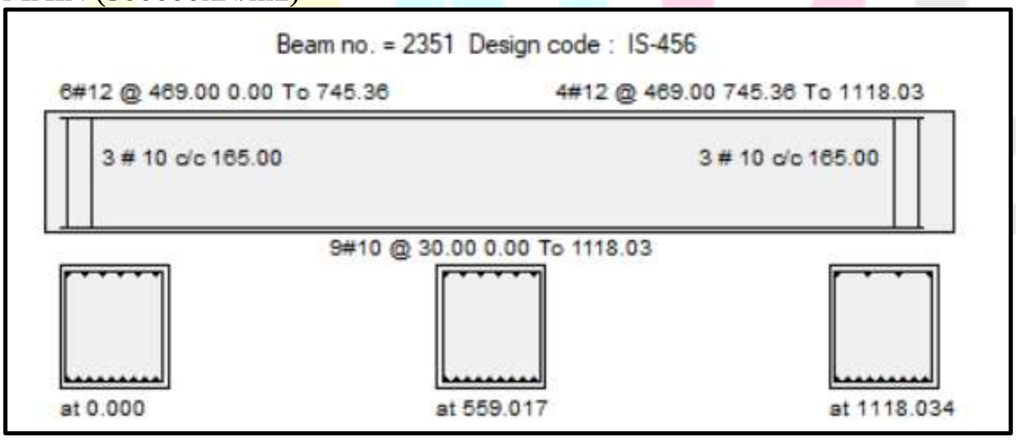

Fig .8 : Ring Beam Reinforcement Detailing

Ring beam reinforcement detailing for designing a diagrid structure involves placing vertical and horizontal reinforcement bars around the perimeter of the structure's top and bottom sections. In this case, for a beam with dimensions 450 mm x 500 mm and cover of 25 mm, the reinforcement consists of 4-12 mm bars placed at 279.5 mm, 559.0 mm, 838.5 mm, and 1118.0 mm intervals from the starting point for the top section, and 5-

10 mm bars placed similarly for the bottom section. Additionally, shear reinforcement consists of 10 mm bars placed at varying intervals along the beam's height to provide adequate support against shear forces.

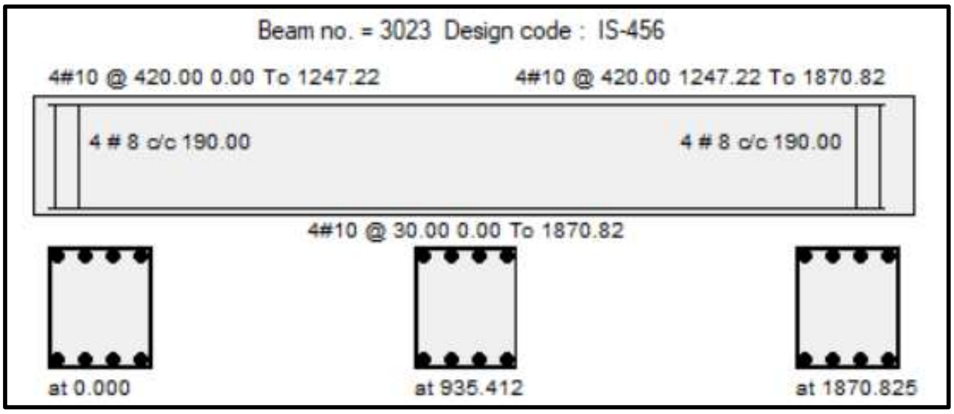

Fig . 9 : Diagrid Beam Reinforcement Detailing

A diagrid beam with a 63-degree angle module reinforcement detailing involves using diagonal members in a crisscross pattern to distribute loads efficiently. Reinforcement consists of layers of 4-10mm bars on both top and bottom faces, with spacing at 190mm centers for shear reinforcement. Materials specified are M30 concrete and Fe500 for main reinforcement and Fe415 for secondary reinforcement. The beam dimensions are 400mm x 450mm with a cover of 25mm.

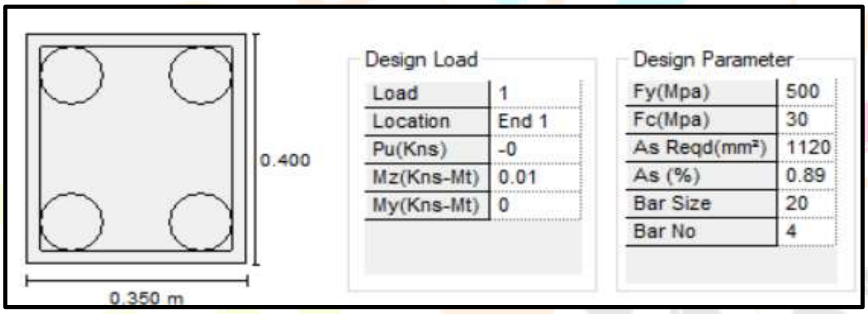

Fig . 10 : Column Reinforcement Detailing

Column reinforcement detailing for a diagrid structure involves providing main reinforcement bars (Fe500) of 20 mm diameter, equally distributed, totaling 1256.64 Sq.mm. Additionally, rectangular ties of 8 mm diameter are provided at 300 mm c/c spacing.

ELEMENT DESIGN SUMMARY

ELEMENT	LONG. REINF (SQ.MM/ME)	MOM-X /LOAD (KN-M/M)	TRANS. REINF (SQ.MM/ME)	MOM-Y /LOAD (KN-M/M)
1893 TOP :	396.	0.08 / 6	396.	1.09 / 5
BOTT:	396.	-2.70 / 5	396.	-0.35 / 2
1894 TOP :	396.	0.17 / 6	396.	0.16 / 6
BOTT:	396.	-3.65 / 5	396.	-0.40 / 5
1895 TOP :	396.	0.05 / 1	396.	0.28 / 6
BOTT:	396.	-3.67 / 5	396.	-0.44 / 1
1896 TOP :	396.	0.22 / 1	396.	1.23 / 5
BOTT:	396.	-1.76 / 5	396.	-0.75 / 2
1897 TOP :	396.	0.20 / 1	396.	0.21 / 6
BOTT:	396.	-1.65 / 5	396.	-0.48 / 5
1898 TOP :	396.	0.39 / 1	396.	0.87 / 5
BOTT:	396.	-3.69 / 5	396.	0.00 / 0
1899 TOP :	396.	0.00 / 0	396.	5.16 / 5
BOTT:	396.	-1.35 / 5	396.	-0.69 / 2
1900 TOP :	396.	0.78 / 5	396.	2.93 / 5
BOTT:	396.	-0.07 / 2	396.	-0.61 / 2

Fig . 11 : Slab Reinforcement Detailing

In the provided slab reinforcement detailing fosr a diagrid structure, the floor slab acts as a connector between the inner and outer diagrid structures. The reinforcement data indicates longitudinal reinforcement (in square millimeters per meter) and moments in both X and Y directions (in kilonewton-meters per meter) for the top and bottom faces of the slab. The top face has longitudinal reinforcement of 396 sq.mm/m with moment values of 0.08 kN-m/m in the X direction and 1.09 kN-m/m in the Y direction. The bottom face also has longitudinal reinforcement of 396 sq.mm/m with moment values of -2.70 kN-m/m in the X direction and -0.35 kN-m/m in the Y direction.

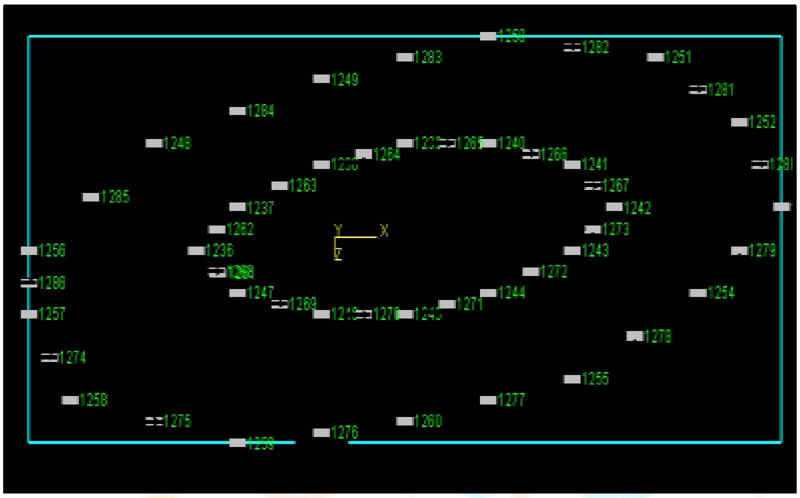

Fig .12 : Foundation Plan

PILE ARRANGEMENT

The column dimensions include a rectangular shape with a length of 0.400 meters along the X-axis and a width of 0.350 meters along the Z-axis. Additionally, the pile cap geometrical data specifies a pile cap length (PCL) of 2.500 meters, a pile cap width (PCW) of 1.000 meter, and an initial pile cap thickness (tI) of 0.300 meters.

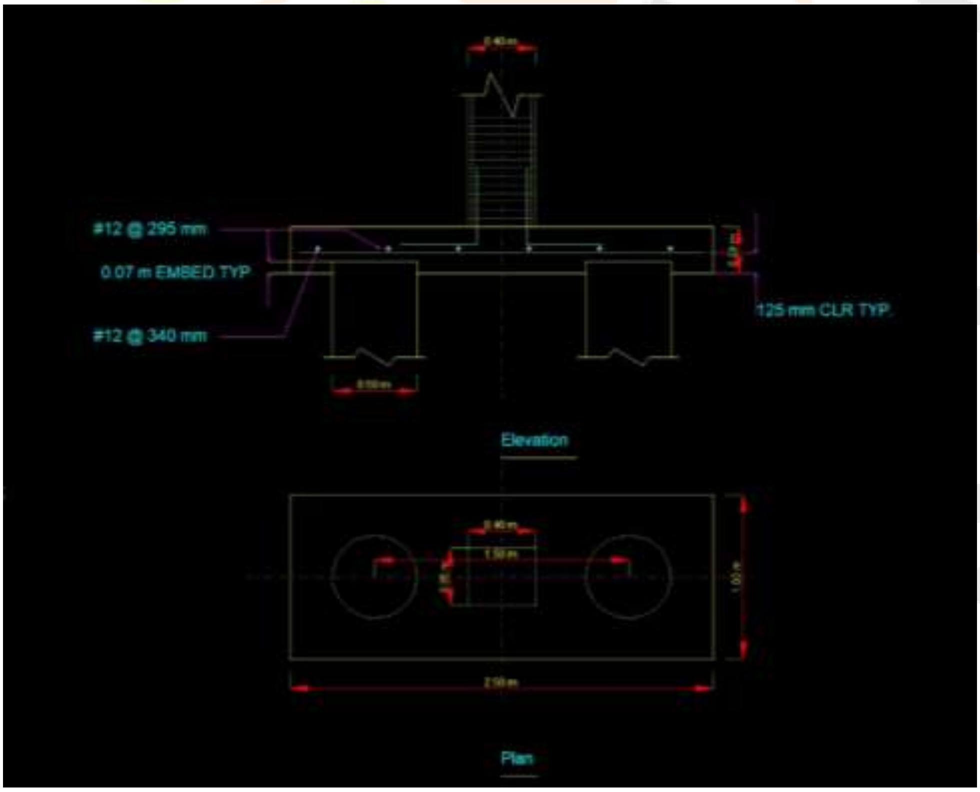

Fig.13: Pile cap Reinforcement Details

Mat Slab Design

Table 2: Mat Foundation Reinforcement Zoning Details

	Area Required "sq.mm"
Longitudinal Top	8776.758
Longitudinal Bottom	8744.328
Transverse Top	8705.443
Transverse Bottom	7879.857

	Mat Footing Reinforcement	
-	Bottom Reinforcement(M_x)	Top Reinforcement(M_z)
Longitudinal	Ø25 @ 85 mm c/c	Ø12 @ 60 mm c/c
Transverse	Ø25 @ 85 mm c/c	Ø12 @ 55 mm c/c

Conclusions

The project "Analysis and Design of Tall Earthquake Resistant Concrete Diagrid Structure" by using IS 1893 -2002 /2005 in STAAD Pro, with consideration of accidental loads, concludes that the diagrid structure demonstrates robust earthquake resistance. Reinforcement detailing for the ring beam of the diagrid structure involves strategic placement of vertical and horizontal bars, with 4-12mm bars at specific intervals for the top section and 5-10mm bars for the bottom section, along with shear reinforcement to bolster its earthquake resistance. The diagrid beam's 63-degree angle module reinforcement employs crisscross diagonal members and layers of 4-10mm bars on both faces, spaced at 190mm centers for shear reinforcement, utilizing M30 concrete and Fe500/Fe415 steel.

STAAD advanced foundation used to design Mat foundation with pile cap design by using STAAD V8i 5 Series , Through analysis, it was determined that the structure meets safety standards outlined in the seismic code. Additionally, incorporation of accidental loads enhances structural integrity, ensuring resilience against unforeseen events like blasts etc. Project highlight the potential for diagrid structures to mitigate seismic risks while offering architectural versatility.

References

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