3D Modelling and Analysis of RC Structure using STAAD. Pro

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Abstract— The principle objective of this research is the comparative study on design, modelling and analysis of residential building (G+4) and 9.75x13.25m in plan by using civil designing software's. Auto CAD is used for 2D drafting of building plan, Revit Architecture is for 3D modelling and STAAD. Pro is used for 3D analysis, calculation of loads and their effects on building. STAAD. Pro is one of the leading software's for the design and analysis of structures. This project is done to analyse the multi-storey building for finding the maximum shear forces, bending moments, axial force & reinforcement details for the structural components of building (such as Beams, columns & foundation) to develop the economic design.
Keywords: Auto CAD, deflection, Foundation, Reinforcement, Revit Architecture, Structure, STAAD.Pro

I. INTRODUCTION

Structural Analysis helps in determination of behaviour of real structures such as buildings, bridges, water tanks, retaining walls and dams, under the loading like self-weight, imposed loads & external environment like wind and earthquake effects during the service life of structure. The analysis results are used to check the stability and load carrying capacity of structure. Computer software's are also being used for the calculation of forces, bending moment, stress, strain &deformation or deflection for a complex structural system. In this project Auto CAD is used for 2D drafting, Revit architecture is used for 3D modelling and STAAD.pro is used for design and analysis of (G+4) residential building.

Salient features of building:

Building plan:

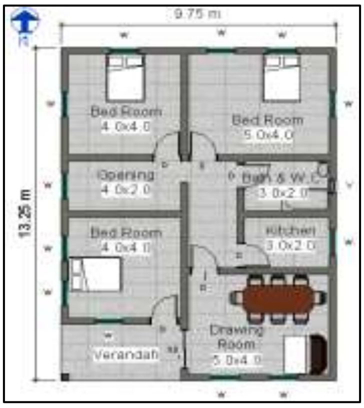

Fig. 1: 2D ground floor plan of building

Building type: Residential building
Plan area of building: 9.75x13.25m (including walls)
No. of stories: G+4
No. of floors: 4(+1 roof)
Thickness of ground floor: 0.400m
Thickness of roof slab: 0.15m
Type of construction: RCC framed structure
Type of walls: Brick wall
Thickness of walls: 0.250m
Floor to floor height: 3.5m
Height of mumty walls: 2.1m
Vertical opening: 1 (for staircase)

II. RESEARCH METHODOLOGY

A. Drafting of plan using Auto CAD:

Auto CADD (Computer Aided Designing & Drafting) is released in Dec 1982, developed and marketed by Autodesk. It is an application software used by architectures, engineers, project managers, other professionals etc. Auto CAD version 2013 is used for drafting the plan in this project with file format .DWG.

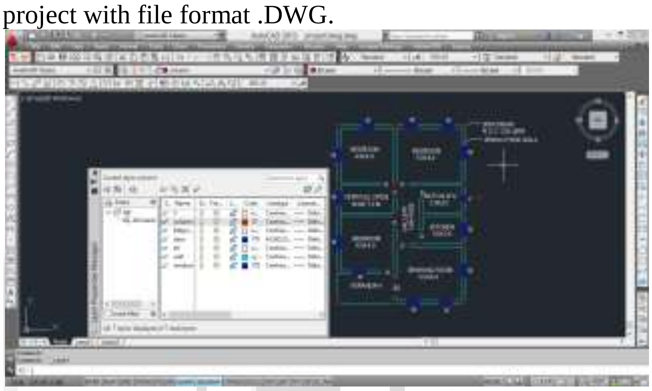

Fig. 2: Preparation of plan in Auto CAD

Most commonly used command to prepare this plan in Auto CAD are Lim max, Line, Rectangle, Trim, Extend, Erase, Copy, Move, M text, Dimensions, Layer properties manager etc.

B. 3D modelling of building using Revit Architecture:

Revit Architecture is acquired by Autodesk in 2002. It is a building information modelling (BIM) software for architects, structural engineers, mechanical electrical & plumbing (MEP) engineers, designers etc. Revit Architecture version 2013 is used for 3D modelling of this project with file format .RVT. To work in Revit we have to create levels which acts as floors like: plinth level, first floor etc. Total height of building is 16.1m with floor to floor height 3.5m, height of mumty walls 2.1m, height of parapet wall is 1m.

Fig. 3: Creation of levels in Revit Architecture

For ease of work we can directly import cad drawing with. DWG format into the Revit or we can use architectural walls of 0.250m thickness for create this plan.

Thickness of ground floor is 0.400m with a layer of DPC, P.C.C., bricks, earth soil, at the base and tiles at the top. Thickness of RCC roof slab is 0.15m thick.

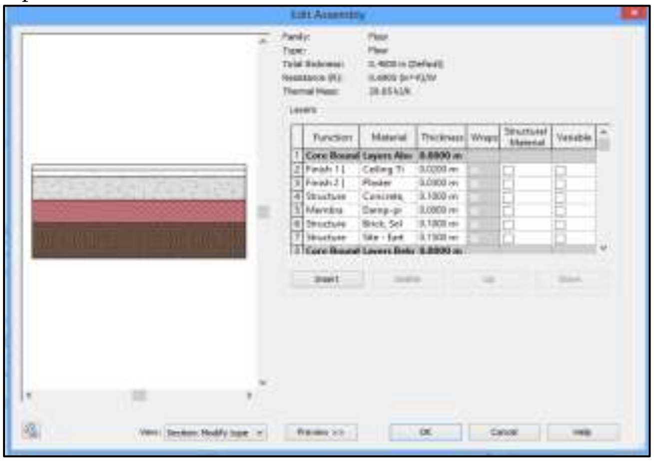

Fig. 4: Layers of ground floor 0.4m thick

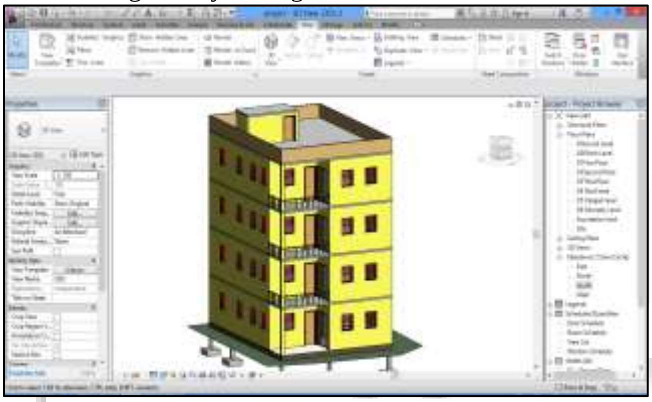

Fig. 5: 3D view of the building

Fig. 6: South elevation of building

C. Formation of RCC framed structure using STAAD.Pro:

It is a Structural Analysis and Design Program used to analyse input data, verify results and using these results steel or concrete designing is done. STAAD.Pro v8i is used in this project.

X-coordinate of structure= 0 to 9m

Y-coordinate of structure= -2 to 16.1m

(-2 to 0 m for substructure & 0 to 16.1 m for super structure)

Z-coordinate of structure= 0 to 12m

Total no. of nodes=118

Total no. of beams (both horizontal & vertical) =241

Snap node/ beam or add node is used to create nodes then beams are placed between two nodes. Beams cursor and nodes cursor are used to select beams and nodes respectively. Also select beams parallel to X, Z, direction is used to select horizontal beams and beams parallel to Y direction is used to select vertical beams (i.e. columns).

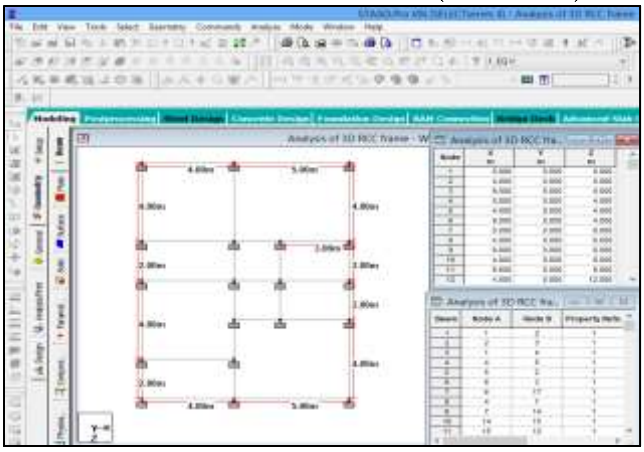

Fig. 7: Top view of RCC framed structure in STAAD.Pro

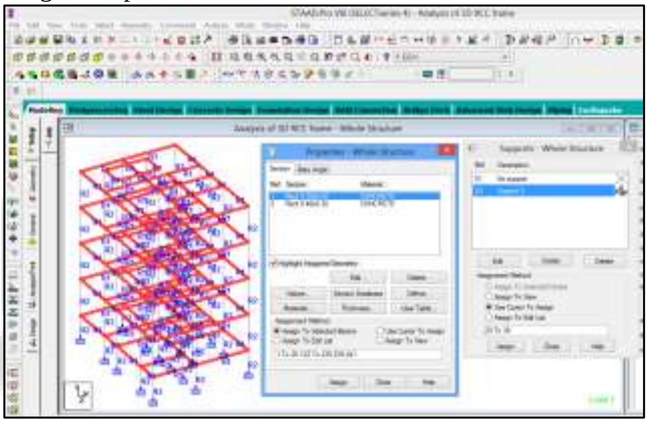

Fig. 8: Apply properties and supports for RCC framed structure in STAAD.Pro

A translational repeat of 4 no. of steps with spacing of 3.5m is done in Y direction and link step is used to make vertical beams. Fixed supports are applied at the bottom of all the nodes by support page. By using property page, apply properties to all the beams. Size 0.30x0.35m for horizontal beams and 0.3x0.4m for vertical columns.

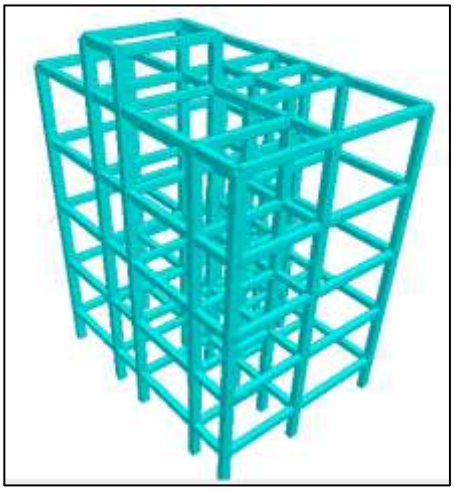

Fig. 9: Rendered view of RCC frame in STAAD.Pro

III. LOAD CALCULATION

A. *Dead Load:*

It is due to self-weight of all the members, slab loads and wall loads etc.

Slab load = thickness of slab x unit wt. of RCC (25 KN/m^3)

For 0.4m thick floor; 0.4 x 25 = -10 KN/m^2

For 0.15m thick roof; 0.15 x 25 = -3.75 KN/m^2

(Slab load is applied as floor load in STAAD.Pro and negative sign indicate downward direction of load)

Wall load = thickness x height x unit weight of brick mortar

For main wall; 0.25 x 3.5 x 20 = -17.5 KN/m

For parapet wall; 0.12 x 1 x 20 = -2.4 KN/m

(Wall load is applied as uniform force in STAAD.Pro and negative sign indicate downward direction of load)

B. *Live Load:*

It is assumed as floor load of,

-3 KN/m^2; (from plinth level 0m to third floor 10.5m)

-1.5 KN/m^2; (at roof 14m)

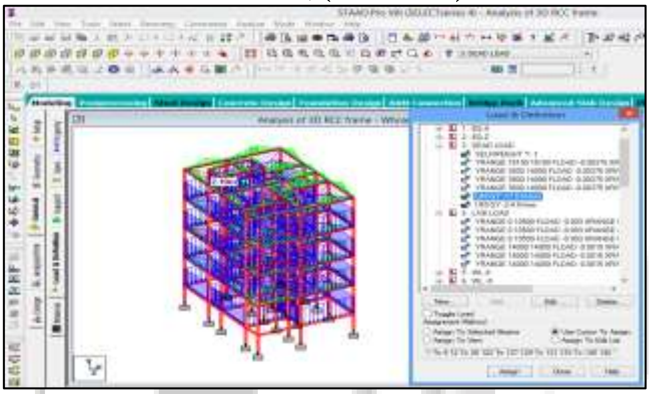

Fig. 10: Application of dead and live load in RCC frame

C. *Wind load:*

From the IS code 875(Part-3) of wind load:

Design wind pressure: $P_Z = 0.6 \times V_z^2$ in KN/m^2

Design wind speed: $V_Z = V_B \times K_1 \times K_2 \times K_3 \times K_4$ in m/s

Basic wind speed: $V_B = 39$ m/s

(For Dehradun, Uttarakhand, India from IS Code)

K_1 (Risk coefficient) = 1.0(for all general buildings)

K_2 (Terrain & height factor) = 1.054 (for height 16.1m)

K_3 (Topography factor) = 1.0 (for slope >3˚)

K_4 (Cyclonic factor) = 1.0 (for other structures)

$V_Z = 39 \times 1 \times 1.054 \times 1 \times 1 = 41.125$ m/s

$P_Z = 0.6 \times 41.125^2 = 1.015$ KN/m^2

Exposure factor = 1 (for all the nodes)

Wind load is applied with both factors (1 & -1) in both X & Z directions from 0 m (ground level) to 16.1m (top) height.

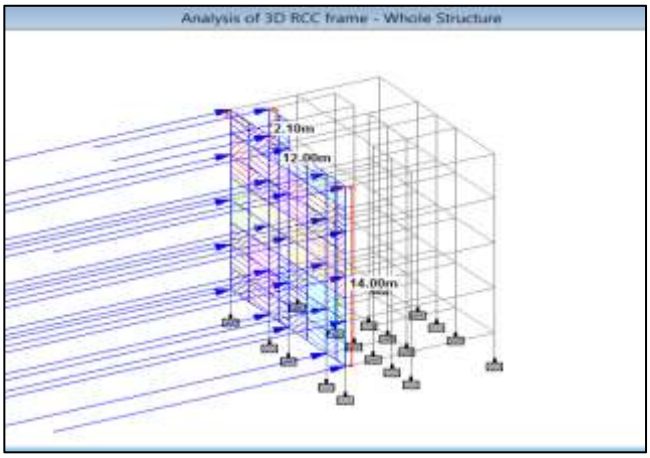

Fig. 11: Wind load in X direction

D. *Seismic Load:*

From the IS code 1893-2002/2005 of seismic load:

Location of structure- Dehradun, Uttarakhand, India

Seismic Zone- IV (Z=0.24)

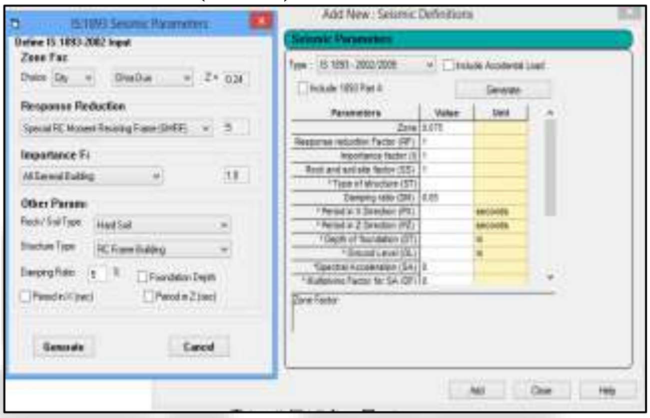

Fig. 12: Seismic parameters in STAAD.Pro

In seismic definition dead load and 25% of live load is combined with seismic parameters. By using STAAD editor floor load or member load is replaced as floor weight or member weight. Load case is applied on both X & Z directions.

1) *Load Combinations:*

There are total 29 no. of auto generated load cases. Mainly:

1.5[DL + LL]

1.2[DL + LL ± WL]

1.2[DL + LL± EQ]

1.5[DL ± WL]

1.5[DL ± EQ]

0.9DL ± 1.5EQ

(Both WL and EQ are applied in X & Z directions. Also WL is applied in negative X & Z directions.)

IV. CONCRETE DESIGN DATA

A. *Design parameter for beams and columns:*

Following are the design parameters used:

Code used= IS 456

Clear cover= 25mm (for beams)

= 40mm (for columns)

Grade of concrete = M25

Compressive strength of concrete; fc = 25 N/mm^2

Grade of steel = fe415

Yield strength of main reinforcement; F_Y = 415 N/mm^2
Yield strength of shear reinforcement; F_Y = 415 N/mm^2
Maximum size of main reinforcement = 25mm
Maximum size of secondary reinforcement = 12mm
Minimum size of main reinforcement = 10mm
Minimum size of secondary reinforcement = 8mm
Maximum % of longitudinal reinforcement allowed = 4%

B. *Design parameter for Foundation:*

Following design parameters are used for designing of isolated footings:
Type of footing = Isolated footing (uniform thickness)
No. of footings = 9 (Node no. 20,21,22,26,27,28,31,32,34)
Design code = Indian
Grade of concrete & steel = M25 & Fe415 respectively
Maximum bar size = 25mm
Minimum bar size = 12mm
Soil type = Drained condition
Bottom clear cover = 50mm
Depth of soil above footing = 1.5 m
Unit wt. of concrete = 25 KN/m^3
Unit wt. of soil = 22 KN/m^3
Soil bearing capacity = 100 KN/m^2 (assumed)
Coefficient of friction = 0.5
F.O.S. against sliding & overturning = 1.5

V. RESULTS AND DISCUSSIONS

Following are the results obtained by analysing the structure for the applied load cases:

A. *Total applied load on structure:*

Load case	Total Applied Load (in KN)		
	F_X	F_Y	F_Z
1. EQ (X)	382.99		
2. EQ (Z)			382.99
3.DL		-9085.25	
4. LL		-1350.00	
5. WL (X)	174.783		
6. WL (-X)	-174.783		
7. WL (Z)			136.416
8. WL (-Z)			-136.416

Table 1: Total load applied on structure

B. *Reactions & moments due to loads:*

Node	L/C	Maximum Reactions & Moments
36	1.5(DL-EQ X)	Max F_X = 51.027 KN
21	1.5(DL+LL)	Max F_Y = 1266.806 KN
26	1.5(DL-EQ Z)	Max F_Z = 41.651 KN
26	1.5(DL-EQ Z)	Max M_X = 48.138 KN-m
28	1.5(DL+EQ Z)	Max M_Y = 2.631 KN-m
24	1.5(DL+EQ X)	Max M_Z = 70.312 KN-m

Table 2: Maximum reactions & moments

C. *Lateral load on structure:*

Lateral loads are live loads due to horizontal forces like: wind load and seismic load.

Height of floor in (m)	Lateral load in (KN)
0.0	4.977
3.5	28.48
7.0	76.26
10.5	147.11
14.0	115.95
16.1	10.22

Table 3: Lateral load at different levels

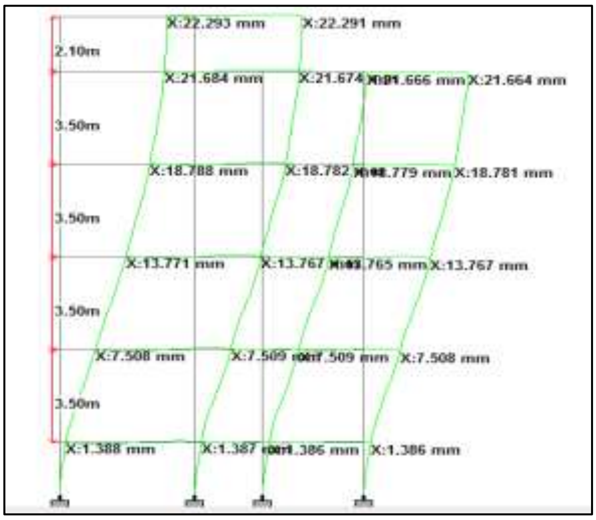

Fig. 13: Displacement of frame in X- direction

D. *Maximum bending moment:*

Maximum B.M.; M_Z = 136.651 KN-m (Beam no- 123)
Due to load combination of; 1.5[DL – EQ(x direction)]

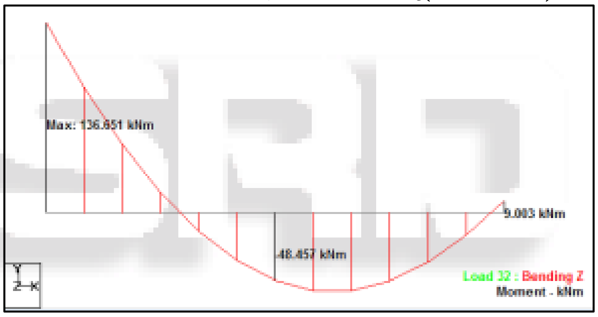

Fig. 14: Maximum B.M. diagram for beam 123

E. *Maximum shear force:*

Maximum S.F.; F_Y = 119.903 KN (Beam no.- 126)
Due to load combination of; 1.5[DL – EQ(x direction)]

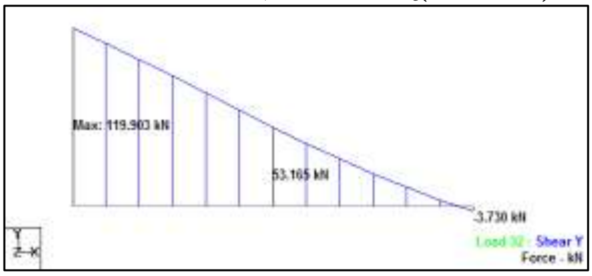

Fig. 15: Maximum S.F. diagram for beam 126

F. *Maximum axial force:*

Maximum axial force; F_X = 1266.806 (Beam no. 28)
Due to load combination of; 1.5[DL + LL]

G. *Concrete design of beam:*

Concrete design results for the beam of maximum bending moment (i.e. beam no. 123);

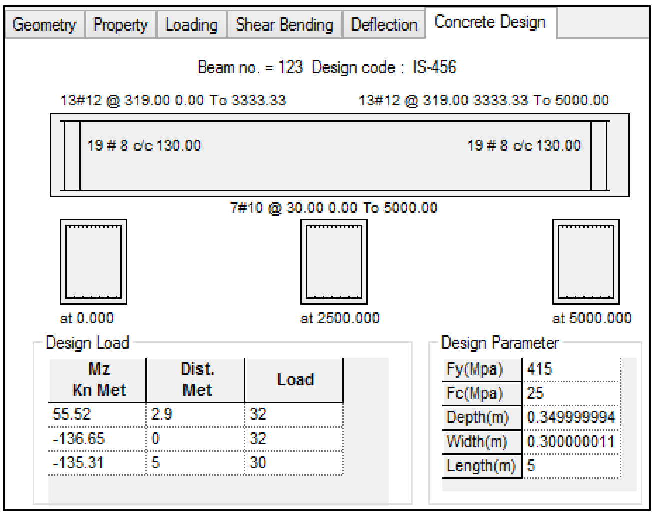

Fig. 16: Concrete design of beam no. 123

Design Results of Beam No. 123 M25(concrete) Fe415 (Main bar) Fe415 (Secondary bar) Length: 5000mm Size: 300x350mm Cover: 25mm			
Schedule of provided reinforced bars			
Section	0.0mm	2500mm	5000mm
Top reinforcement	13@12mm ϕ 2 layers	3@12mm ϕ 1 layer	13@12mm ϕ 2 layers
Bottom reinforcement	5@10mm ϕ 1 layer	7@10mm ϕ 1 layer	5@10mm ϕ 1 layer
Shear reinforcement	2 legged 8mm ϕ @130mm c/c	2 legged 8mm ϕ @130mm c/c	2 legged 8mm ϕ @130mm c/c

Table 4: Reinforcement detailing of beam no. 123

H. Concrete design of column:

Concrete design results for the column of maximum axial force (i.e. column no. 28);

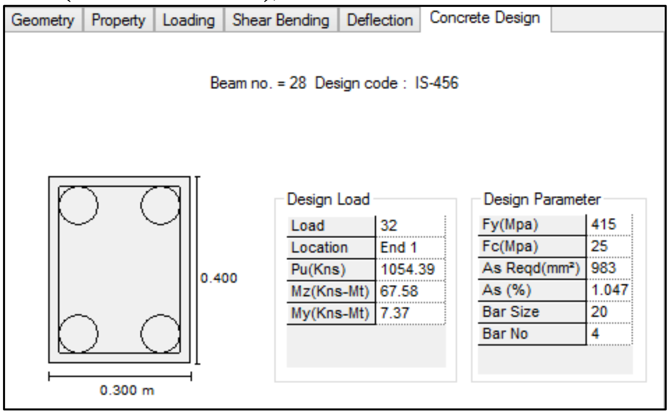

Fig. 17: Concrete design of column no. 28

Design Results of Column No. 28 M25(concrete) Fe415 (Main bar) Fe415 (Secondary bar) Length: 2000mm Size: 300x400mm Cover: 40mm	
Type of column	Short column
Required steel area	983.47 mm^2
Required concrete area	119016.53 mm^2
Main reinforcement provided	4@20mm ϕ =1256.64mm^2 (i.e. 1.05%, between 0.8% to 6% of cross section area)

Tie reinforcement	8mm ϕ rectangular ties @300mm c/c
Axial force based on reinforcement provided	P_{UZ}= 1726.99 KN

Table 5: Reinforcement detailing of column no. 28

I. Concrete design of isolated footing:

STAAD.foundation V8i (Release 5.3) is used for designing of isolated footing. The foundation shape, size & reinforcement detailing described below is for footing located at the centre of the structure (i.e. footing for node no. 27).

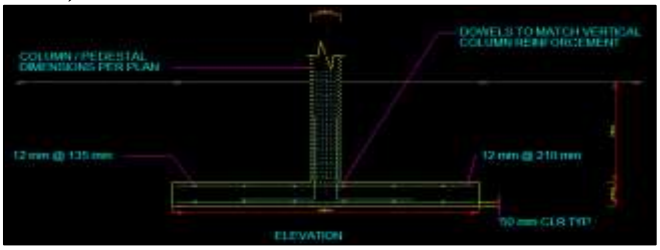

Fig. 18: Shape of isolated footing with reinforcement schedule

Design results of Isolated Footing for Node no. 27 Length:3900mm Width:3900mm Thickness:355mm	
Reinforcement schedule	
Bottom reinforcement(M_Z)	12mm ϕ @ 120mm c/c
Bottom reinforcement(M_X)	12mm ϕ @ 105mm c/c
Top reinforcement(M_Z)	12mm ϕ @ 210mm c/c
Top reinforcement(MX)	12mm ϕ @ 135mm c/c

Table 6: Isolated footing dimensions & reinforcement schedule

J. Required quantity of concrete & reinforced steel:

Quantity of concrete and reinforcing steel required for beams and columns are:

Total volume of concrete = 83.2 m^3

Total quantity of reinforcing steel for different dia. bars= 84241 N (= 8590.19 Kg approx.)

Bar Dia. (in mm)	Weight (in N)
8	19115
10	9148
12	16756
16	9666
25	3931
Total	84241

Table 7: Quantity of reinforcing steel

Total actual self-wt. of structure due to beams and columns = 1959.45 KN

VI. CONCLUSION

1) Drafting of plan using Auto CAD is simpler, more accurate than the manual work
2) Modelling using Revit Architecture is less time taking and helps in actual 3D visualisation of structure.
3) STAAD. Pro gives more accurate results with all the design checks required for safety purpose.
4) Overall structure is safe, design & analysis of beams, columns & footings is successful and there is no error.

5) Lateral load due to earthquake is much more than wind load hence proper arrangement have to be done to make the structure earthquake resistant.
6) Earthquake load with combination of dead load is responsible for maximum shear force and bending moment.
7) If the analysis shows warning like "Section is not adequate, reinforcement % exceeds maximum limit" then increase the size of beams.

Acknowledgment

I wish to express my gratitude and sincere appreciation to my brother and colleagues for their encouragement & guidance.

References

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[5] IS 875 (Part-2) - 1987 code for calculation of live load.
[6] IS 875 (Part-3) - 1987 code for calculation of wind load.
[7] IS 1893 – 2002/2005 code for calculation of seismic load.