

Analysis and Design of Commercial RCC Structure

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Abstract - Structural Analysis and design are important for finding out the significant threats to the integrity and stability of a structure. RCC structures are mostly used in the framing system for most of the building. They have the advantage of high compressive strength and stiffness. The principle objective of this project is to analyse and design a RCC framed structure using STAAD Pro. In this project, the plan of a G+2 commercial building, situated in Malayatoor is considered. RCC model for the structure is prepared using STAAD pro and the design involves load calculations and analysing the whole structure. The design methods used in STAAD-Pro analysis are Limit State Design following to the Indian Standard Code of Practice.

Key Words: STAAD Pro, Analysis, Design, Commercial building, RCC

1. INTRODUCTION

Structures are constructed using different types of material. Studies are carried out to find the best alternative material that can be used for the construction of structures, which can satisfy both the strength and the intended purpose. In the olden days houses were constructed using native materials like rocks, timber, leaves, etc. They were constructed without following proper guidelines or ensuring if the building was safe. The quality and the type of material used were also a major constraint. Usage of inferior quality materials resulted in the collapse of structure when there was a sudden increase in the loading conditions. This happens when there is a sudden change in the wind pattern or can even be due to seismic activities. Structural stability and safety improved with the usage of concrete and steel. RCC framed structures are constructed widely in recent days.

Structural engineering is a part of engineering that deals with the safety and integrity of a structure. A structural engineer must ensure that a design is safe to various loading conditions that the structure can encounter during its useful life, while also keeping in mind the aesthetic aspect of the structure. As the population increased and the area of space available reduced the demand for high raised structures increased. Design of such structures manually is a time consuming process. Considering the effect of wind and seismic effect makes it an even harder process. The usage of softwares like STAAD Pro, ETABS, etc makes the analysis and design of such complex structures easier. This gives an even accurate result and can also eliminate the chance for human errors.

2. SOFTWARES USED

2.1 AutoCAD

AutoCAD is a commercial computer-aided design (CAD) and drafting software application. Developed and marketed by Auto desk, auto CAD is used in industry, by architects, project managers, engineers, graphic designers, city planners and other professionals. Due to the availability of a wide range of drawing tools and features this software has been used for plotting the plan and elevation of our structures.

2.2 STAAD.ProV8i

STAAD.Pro is one of the most widely used structural analysis and design software products worldwide. It supports over 90 international steel, concrete, timber and aluminium design codes. It can make use of various forms of analysis from the traditional static analysis to more recent analysis methods like p-delta analysis, geometric nonlinear analysis, pushover analysis or a buckling analysis. It can also make use of various forms of dynamic analysis methods from time history analysis to response spectrum analysis. Due to its versatility this software has been used for the analysis of the structures using limit state design.

3. METHODOLOGY

3.1. Analysis of the structure

In this project, G+2 commercial building is considered for study. The beam and column layout of the building is shown in figure 1 and figure 2. The span between columns in RCC structures is limited. Increasing the span results in the increase of dimensions of columns and beams. This results in heavier structural members. For the RCC structure studied the maximum span is limited to less than 7m. Other relevant data is tabulated in table I:

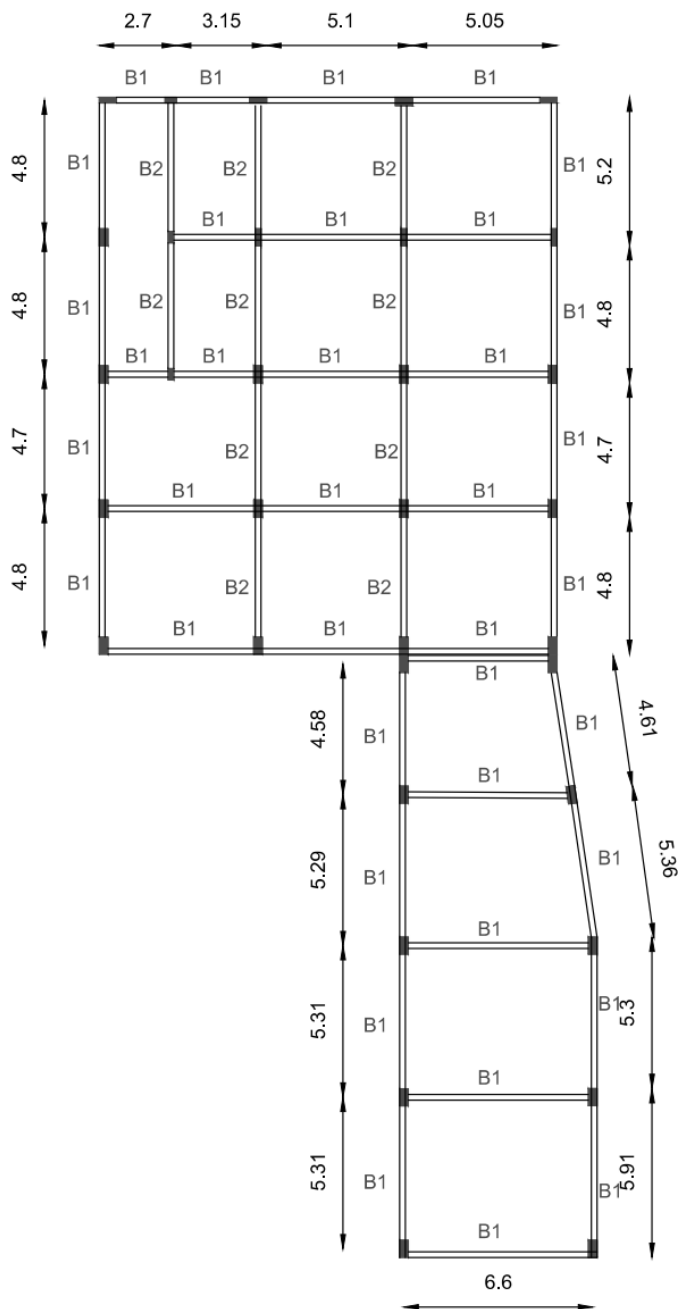


Fig-1: Beam Layout

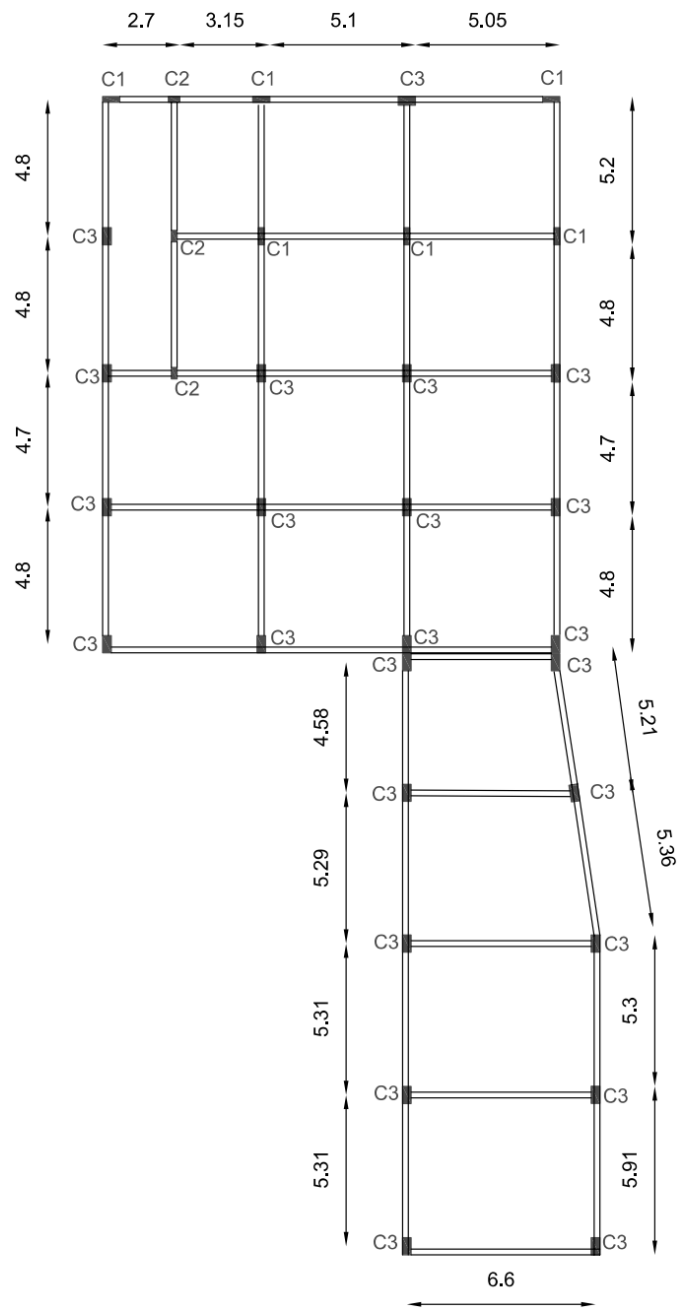


Fig-2: Column Layout

Table-I: Data for analysis

Height	Ground Floor- 4m First Floor- 3.5m Second Floor- 3.5m Stair Room- 3m
Beam	B1: 0.2m x 0.5m B2: 0.2m x 0.4m
Column	C1: 0.2m x 0.6m C2: 0.2m x 0.4m C3: 0.3m x 0.6m

Grade of concrete	M25
Grade of steel	FE415(rebar)

The modelling of the structure was carried out in STAAD pro. Figure 3 represent the 3D rendered view of the structure.

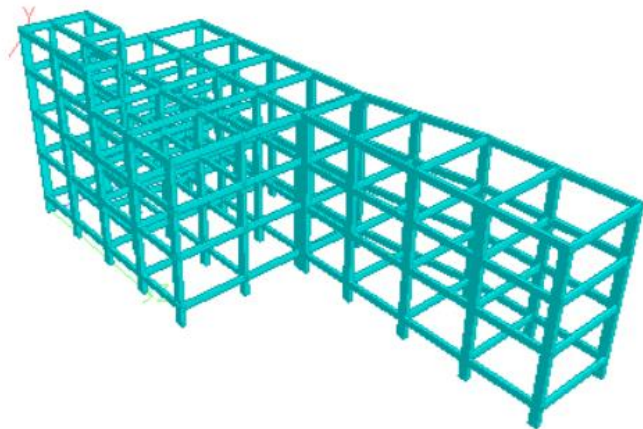


FIG-3: 3D rendered view of structure

3.2. Load Considerations

Once a design is fixed it has to be analysed to make sure that it has the sufficient strength and rigidity to perform safely. The various loads and load combinations acting on the structure are calculated from various design codes. The following are the various loads and load combination considered to act on the structure as per the Indian standards:

3.2.1 Dead Load

Dead loads are considered as per IS: 875 (Part 1) - 1987[8].

Dead load consists of the weight of different materials and loads from different parts of a structure that are not likely to change with time. It consists of the weight of beams, columns, slabs, brick walls, etc. Self-weight of different elements can be assigned automatically in STAAD by using the option self-weight. STAAD automatically calculates the weight of each of the elements. The other dead loads that are considered are shown in table II:

Table-II: Dead Load

SI No:	Item	Unit Weight	Load
1	Floor Finish	None	1 KN/m ²
2	Wall Load	17.7KN/m ³	-
	At 4m height	-	10.8 KN/m
	At 3.5m height	-	9.4 KN/m
	At 3m height	-	8.11 KN/m
3	Glass covering 10mm thickness 15cm	24.535KN/m ³	-
	At 4m height	-	0.9811 KN/m
	At 3.5m height	-	0.86 KN/m
4	Load on Terrace	None	2 KN/m ²
5	Slab of Thickness 15cm	25 KN/m ³	3.75 KN/m ²
6	Self-Weight	None	None
7	Parapet Wall	17.7 KN/m ³	-
	At 80 cm height	-	2.15 KN/m
	At 90 cm height	-	2.42 KN/m

3.2.2 Live Load

Live loads are those loads that depend on the type of occupancy and use of the structure. They include loads from human occupancy, furniture, tools, movable equipment, construction activities, etc. In STAAD the live load is assigned as uniformly varying load and as floor area load. Table III below shows the loads that are considered as per IS: 875 (Part 2) - (1987).

Table-III: Live Load

SI No:	Item	Load
1	Retail Shop	4 kN/m ²

2	Office Shop	2.5 KN/m ²
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3.2.3 Wind Load

Wind Load is used to refer to any pressure or force that the wind exerts on a structure. Wind load acting on the structure are calculated as per IS: 875 (Part 3) - 2015. The calculation of wind load is as shown below:

a) Basic Wind Speed V_b is 39m/s from figure 1 of IS: 875 (Part 3) - 2015.

b) Design Wind Speed V_z is calculated as per clause 6.3, IS: 875 (Part 3) - 2015. k_1 is the probability factor which is taken as 1 from table 1. k_2 is terrain roughness and height factor. The category is chosen as 2. The value of k_2 is obtained from table 2. Up to 10m height k_2 is taken as 1 and for height above 10m up to 14.8m k_2 is taken as 1.05. k_3 is a topographic factor calculated as per clause 6.3.3. The value is taken as 1. k_4 is an important factor for the cyclonic region (this value is neglected). Therefore, design wind speed is calculated as $V_z = V_b k_1 k_2 k_3 k_4$. Up to 10m height $V_z = 39$ m/s, and for height above 10m up to 14.8m $V_z = 40.95$ m/s.

c) Design Wind Pressure p_d is calculated as per clause 7.2, IS: 875 (Part 3) - 2015. K_d is the wind directionality factor taken as 0.9 as per clause 7.2.1. K_a is an area averaging factor which is approximately 0.85 obtained from table 4. K_c is a combination factor taken as 0.9 as per clause 7.3.3.13. From this $p_d = p_z k_a k_c k_d$, where $p_z = 0.6 v_z^2$. As per the conditions given in clause 7.2, the value of p_d is 638.82N/m² up to 10m and 704.3N/m² above 10m up to 14.8m.

d) Wind Load is calculated as per the equation $F = (C_{pe} - C_{pi}) A_p p_d$, clause 7.3.1, IS: 875 (Part 3) - 2015, where C_{pe} is external pressure coefficient, obtained from table 5. C_{pi} is internal pressure coefficient, taken as +0.2/-0.2 (for small openings) as per clause 7.3.2.1. Table IV shows the different values of C_{pe} obtained. The structure is divided into two separate structures due to the presence of expansion joints. A is the surface area of the structural element, and p_d is design wind pressure.

Table-IV: Wind Load

Structure 1				
Sl No:	Item	Direction	Cp	Nature
1	WLX1	Positive	0.5	Internal Pressure
2	WLX2	Positive	0.9	Internal Suction
3	WLX3	Negative	0.45	Internal Pressure
4	WLX4	Negative	0.05	Internal Suction
5	WLZ1	Positive	0.5	Internal Pressure
6	WLZ2	Positive	0.9	Internal Suction
7	WLZ3	Negative	-0.45	Internal Pressure
8	WLZ4	Negative	-0.05	Internal Suction
Structure 2				
Sl. No	Item	Direction	Cp	Nature
1	WLZ5	Positive	0.5	Internal Pressure
2	WLZ6	Positive	0.9	Internal Suction
3	WLZ7	Negative	0.6	Internal Pressure
4	WLZ8	Negative	0.2	Internal Suction
5	WLZ5	Positive	0.6	Internal Pressure
6	WLZ6	Positive	1	Internal Suction
7	WLZ7	Negative	0.3	Internal Pressure
8	WLZ8	Negative	0.1	Internal Suction

3.2.4 Load Combination

The following load combinations are considered for RCC framed structure as per IS: 456-2000 and IS: 800-2007

a) 1.5 (Dead Load + Live Load)

b) 1.5 (Dead Load + Wind Load X)

c) 1.5 (Dead Load + Wind Load -X)

- d) 1.5 (Dead Load + Wind Load Z)
- e) 1.5 (Dead Load + Wind Load -Z)
- f) 0.9 (Dead Load) + 1.5 (Wind Load X)
- g) 0.9 (Dead Load) + 1.5 (Wind Load -X)
- h) 0.9 (Dead Load) + 1.5 (Wind Load Z)
- i) 0.9 (Dead Load) + 1.5 (Wind Load -Z)
- j) 1.2 (Dead Load + Live Load + Wind Load X)
- k) 1.2 (Dead Load + Live Load + Wind Load -X)
- l) 1.2 (Dead Load + Live Load + Wind Load Z)
- m) 1.2 (Dead Load + Live Load + Wind Load -Z)

The analysis was carried out in STAAD Pro using the above mentioned loads and load combinations. For the given study maximum loading condition was obtained for dead load + live load combination.

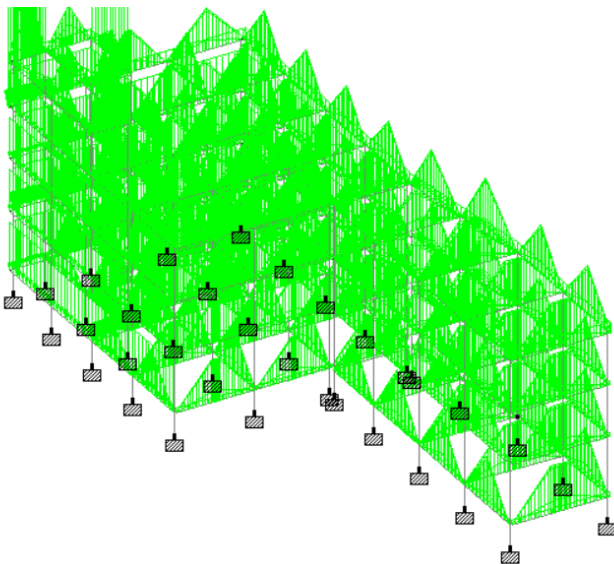


Fig-4: Dead Load + Live Load

4.3 Design of Structural Elements

4.3.1 Design of Beam

Design of beam was done manually as per IS: 456-2007. The design was carried out by taking moment and shear at various sections of the beam and calculating the desired reinforcement.

Beam 1 implies beams with 3 supports, beam 2 implies beams with 2 supports, beam 3 implies beams with 5 supports and beam 4 implies beams with 4 supports. Figure below shows the reinforcement details of RCC beams obtained for beam 1 (type 1) and beam 2 (type 1). Similarly, the calculation was done for each of the sections and they were tabulated below.

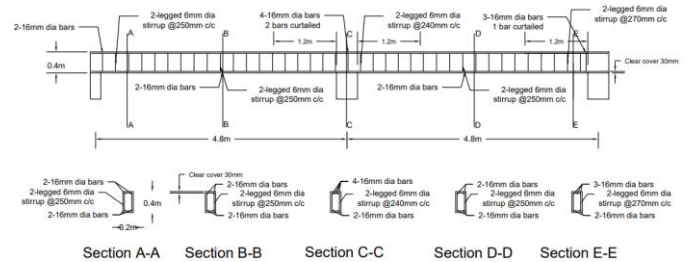


Fig-5: Beam 1 (type 1)

Beam 1:	Bottom Reinf.	Top Reinf.	Shear Reinf.
Type 1 (9.6m):			
End Support (A-A)	-	2-16mm dia bar	2L 6mm @250mm c/c
Mid span (B-B)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	4-16mm dia bar	2L 6mm @240mm c/c
Mid span (D-D)	2-16mm dia bar	-	2L 6mm @250mm c/c
End Support (E-E)	-	3-16mm dia bar	2L 6mm @270mm c/c
Type 2 (9.6m):			
End Support (A-A)	-	2-16mm dia bar	2L 6mm @250mm c/c
Mid span (B-B)	2-16mm dia bar	-	2L 6mm @300mm c/c
Intermediate Support (C-C)	-	2-16mm dia bar	2L 6mm @250mm c/c
Mid span (D-D)	2-16mm dia bar	-	2L 6mm @300mm c/c
End Support (E-E)	-	2-16mm dia bar	2L 6mm @250mm c/c

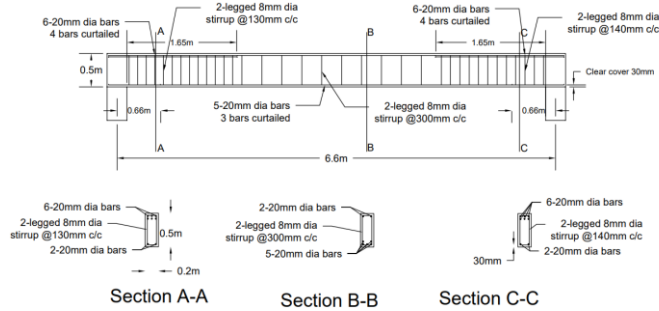


Fig-6: Beam 2 (type 1)

Beam 2:	Bottom Reinf.	Top Reinf.	Shear Reinf.
Type 1 (6.6m):			
End Support (A-A)	-	6-20mm dia bar	2L 8mm @130mm c/c
Mid span (B-B)	5-20mm dia bar	-	2L 8mm @300mm c/c
End Support (C-C)	-	6-20mm dia bar	2L 8mm @140mm c/c
Type 2 (6.6m):			
End Support (A-A)	-	5-20mm dia bar	2L 6mm @110mm c/c
Mid span (B-B)	6-20mm dia bar	-	2L 6mm @250mm c/c
End Support (C-C)	-	5-20mm dia bar	2L 6mm @120mm c/c
Type 3 (5.81m):			
End Support (A-A)	-	4-16mm dia bar	2L 6mm @190mm c/c
Mid span (B-B)	3-16mm dia bar	-	2L 6mm @250mm c/c
End Support (C-C)	-	5-16mm dia bar	2L 6mm @210mm c/c
Type 4 (5.81m):			
End Support (A-A)	-	4-16mm dia bar	2L 6mm @100mm c/c
Mid span (B-B)	4-16mm dia bar	-	2L 6mm @250mm c/c

End Support (C-C)	-	4-16mm dia bar	2L 6mm @100mm c/c
Type 5 (5.2m):			
End Support (A-A)	-	3-16mm dia bar	2L 6mm @300mm c/c
Mid span (B-B)	2-16mm dia bar	-	2L 6mm @250mm c/c
End Support (C-C)	-	3-16mm dia bar	2L 6mm @300mm c/c
Type 6 (5.2m):			
End Support (A-A)	-	2-12mm dia bar	2L 6mm @300mm c/c
Mid span (B-B)	3-12mm dia bar	-	2L 6mm @250mm c/c
End Support (C-C)	-	3-12mm dia bar	2L 6mm @300mm c/c
Type 7 (4.8m):			
End Support (A-A)	-	2-12mm dia bar	2L 6mm @250mm c/c
Mid span (B-B)	2-12mm dia bar	-	2L 6mm @300mm c/c
End Support (C-C)	-	2-12mm dia bar	2L 6mm @250mm c/c
Type 8 (3.05m):			
End Support (A-A)	-	2-12mm dia bar	2L 6mm @300mm c/c
Mid span (B-B)	2-12mm dia bar	-	2L 6mm @250mm c/c
End Support (C-C)	-	2-12mm dia bar	2L 6mm @300mm c/c

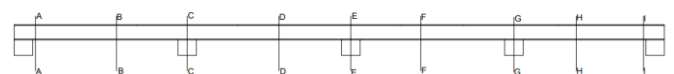


Fig-7: Beam 3

Beam 3:	Bottom Reinf.	Top Reinf.	Shear Reinf.
Type 1 (19.2m):			
End Support (A-A)	-	3-16mm dia bar	2L 6mm @180mm c/c
Mid span (B-B)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	4-16mm dia bar	2L 6mm @190mm c/c
Mid span (D-D)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (E-E)	-	4-16mm dia bar	2L 6mm @190mm c/c
Mid span (F-F)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (G-G)	-	4-16mm dia bar	2L 6mm @190mm c/c
Mid span (H-H)	2-16mm dia bar	-	2L 6mm @250mm c/c
End Support (I-I)	-	3-16mm dia bar	2L 6mm @210mm c/c
Type 2 (19.05m):			
End Support (A-A)	-	4-20mm dia bar	2L 8mm @170mm c/c
Mid span (B-B)	3-20mm dia bar	-	2L 8mm @250mm c/c
Intermediate Support (C-C)	-	4-20mm dia bar	2L 8mm @150mm c/c
Mid span (D-D)	2-20mm dia bar	-	2L 8mm @250mm c/c
Intermediate Support (E-E)	-	4-20mm dia bar	2L 8mm @210mm c/c
Mid span (F-F)	2-20mm dia bar	-	2L 8mm @250mm c/c
Intermediate Support (G-G)	-	4-20mm dia bar	2L 8mm @210mm c/c
Mid span (H-H)	2-20mm dia bar	-	2L 8mm @250mm c/c

End Support (I-I)	-	4-20mm dia bar	2L 8mm @210mm c/c
Type 3 (15.7m):			
End Support (A-A)	-	2-16mm dia bar	2L 6mm @290mm c/c
Mid span (B-B)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	2-16mm dia bar	2L 6mm @200mm c/c
Mid span (D-D)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (E-E)	-	5-16mm dia bar	2L 6mm @130mm c/c
Mid span (F-F)	3-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (G-G)	-	6-16mm dia bar	2L 6mm @110mm c/c
Mid span (H-H)	4-16mm dia bar	-	2L 6mm @250mm c/c
End Support (I-I)	-	4-16mm dia bar	2L 6mm @120mm c/c
Type 4 (15.4m):			
End Support (A-A)	-	2-16mm dia bar	2L 6mm @100mm c/c
Mid span (B-B)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	2-16mm dia bar	2L 6mm @160mm c/c
Mid span (D-D)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (E-E)	-	3-16mm dia bar	2L 6mm @220mm c/c
Mid span (F-F)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (G-G)	-	4-16mm dia bar	2L 6mm @180mm c/c

Mid span (H-H)	3-16mm dia bar	-	2L 6mm @250mm c/c
End Support (I-I)	-	3-16mm dia bar	2L 6mm @190mm c/c
Type 5 (20.59m):			
End Support (A-A)	-	3-16mm dia bar	2L 6mm @300mm c/c
Mid span (B-B)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	4-16mm dia bar	2L 6mm @220mm c/c
Mid span (D-D)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (E-E)	-	4-16mm dia bar	2L 6mm @300mm c/c
Mid span (F-F)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (G-G)	-	4-16mm dia bar	2L 6mm @300mm c/c
Mid span (H-H)	2-16mm dia bar	-	2L 6mm @250mm c/c
End Support (I-I)	-	3-16mm dia bar	2L 6mm @300mm c/c
Type 6 (20.49m):			
End Support (A-A)	-	3-16mm dia bar	2L 6mm @300mm c/c
Mid span (B-B)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	3-16mm dia bar	2L 6mm @290mm c/c
Mid span (D-D)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate Support (E-E)	-	4-16mm dia bar	2L 6mm @250mm c/c
Mid span (F-F)	2-16mm dia bar	-	2L 6mm @250mm c/c
Intermediate	-	4-16mm dia	2L 6mm

Support (G-G)		bar	@260mm c/c
Mid span (H-H)	2-16mm dia bar	-	2L 6mm @250mm c/c
End Support (I-I)	-	2-16mm dia bar	2L 6mm @300mm c/c


Fig-8: Beam 4

Beam 4:	Bottom Reinf.	Top Reinf.	Shear Reinf.
Type 1 (15.7m):			
End Support (A-A)	-	5-16mm dia bar	2L 6mm @120mm c/c
Mid span (B-B)	4-16mm dia bars	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	5-16mm dia bars	2L 6mm @100mm c/c
Mid span (D-D)	3-16mm dia bars	-	2L 6mm @250mm c/c
Intermediate Support (E-E)		5-16mm dia bars	2L 6mm @110mm c/c
Mid span (F-F)	4-16mm dia bars	-	2L 6mm @250mm c/c
End Support (G-G)	-	5-16mm dia bars	2L 6mm @130mm c/c
Type 2 (15.7m):			
End Support (A-A)	-	2-12mm dia bar	2L 6mm @300mm c/c
Mid span (B-B)	2-16mm & 2-12mm dia bars	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	1-16mm & 2-12mm dia bars	2L 6mm @300mm c/c
Mid span (D-D)	4-12mm & 4-20mm dia bars	4-12mm dia bars	2L 6mm @250mm c/c
Intermediate		2-12mm & 1-	2L 6mm

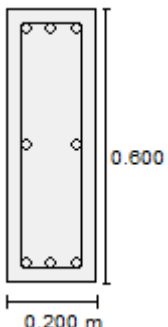
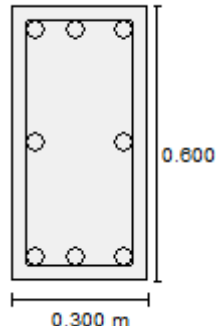
Support (E-E)		20mm dia bars	@300mm c/c
Mid span (F-F)	3-12mm dia bar -	-	2L 6mm @300mm c/c
End Support (G-G)	-	3-12mm dia bar -	2L 6mm @300mm c/c
Type 3 (15.7m)			
End Support (A-A)	-	2-16mm dia bar	2L 6mm @300mm c/c
Mid span (B-B)	2-16mm dia bars	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	3-16mm dia bars	2L 6mm @300mm c/c
Mid span (D-D)	2-16mm dia bars	-	2L 6mm @250mm c/c
Intermediate Support (E-E)		4-16mm dia bars	2L 6mm @300mm c/c
Mid span (F-F)	2-16mm dia bars	-	2L 6mm @250mm c/c
End Support (G-G)	-	2-16mm dia bars	2L 6mm @260mm c/c
Type 4 (15.7m):			
End Support (A-A)	-	4-16mm dia bar	2L 6mm @200mm c/c
Mid span (B-B)	3-16mm dia bars	-	2L 6mm @250mm c/c
Intermediate Support (C-C)	-	5-16mm dia bars	2L 6mm @170mm c/c
Mid span (D-D)	2-16mm dia bars	-	2L 6mm @250mm c/c
Intermediate Support (E-E)		4-16mm dia bars	2L 6mm @180mm c/c
Mid span (F-F)	3-16mm dia bars	-	2L 6mm @250mm c/c
End Support (G-G)	-	4-16mm dia bars	2L 6mm @210mm c/c
Type 5 (13.35m)			

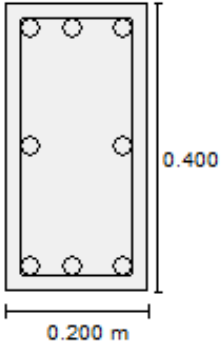
End Support (A-A)	-	2-12mm dia bar	2L 8mm @300mm c/c
Mid span (B-B)	2-12mm dia bars	-	2L 8mm @300mm c/c
Intermediate Support (C-C)	-	3-12mm & 2-16mm dia bars	2L 8mm @300mm c/c
Mid span (D-D)	4-12mm dia bars	-	2L 8mm @300mm c/c
Intermediate Support (E-E)		3-12mm & 3-20mm dia bars	2L 8mm @150mm c/c
Mid span (F-F)	3-12mm & 2-16mm dia bars	-	2L 8mm @300mm c/c
End Support (G-G)	-	2-12mm & 3-20mm dia bars	2L 8mm @170mm c/c

4.3.2 Design of Column

Design of the column is carried out using the limit state method and strictly follows the recommendations of IS: 456-2007 in STAAD Pro. Table V below shows the reinforcement details of the columns obtained.

Table V: Reinforcement detail of column.

Reinforcement Type	Reinforcement Details	No of columns
	$A_{st}: 960\text{m}^2$ Bar size:16 Bar No:8	6
	$A_{st}: 1440\text{m}^2$ Bar size:16 Bar No:8	104

	<p>$A_{st}: 640m^2$ Bar size:12 Bar No:8</p>	<p>12</p>
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4.3.3 Design of Foundation

Sloped footing was designed for the structure using the load and moments obtained from STAAD Pro. Sloped foundation is provided as it is more economical. Bending moment is critical at the face of the column and hence it requires greater depth. As we move away from the face of the column the bending moment reduces and the depth can be reduced.

Foundation is at a depth of 1.5m from the ground level and clear cover of 50mm is provided. Safe bearing capacity was taken as 250N/mm². Figure 9 shows the cross-section of the foundation provided.

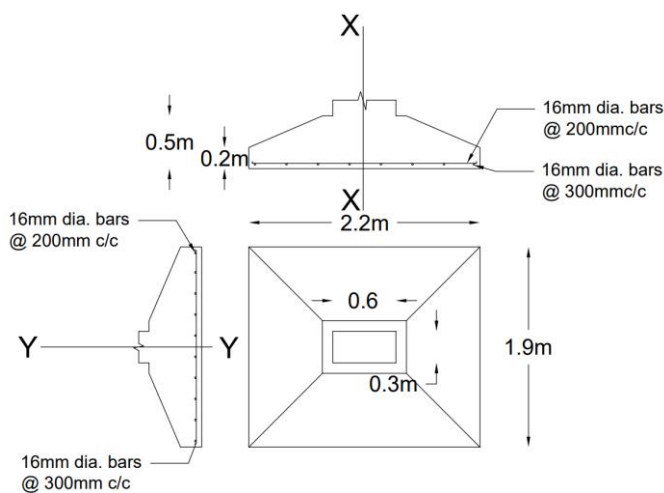


Fig-9: Foundation details

5. CONCLUSIONS

- The plan of the structure was finalised and drawn in AutoCad.
- Spacing of column and size of the sections were adjusted to obtain optimum design.
- Structural framework of the structure was modelled and analysed in STAAD. Using the software faster analysis and design of the structure could be done.

- The list of failed members can be obtained from STAAD. This helps to change the property and if required increase the dimensions of the members to obtain a safer design.
- The beams and footings were designed manually using IS: 456-2000. They are designed for the maximum loading condition that the structure can encounter during its useful life.
- The reinforcement details provided for sections in STAAD Pro are found to be greater than those obtained by manual calculation.
- The shear, bending moment and deflection pattern of the structure can be obtained.
- The safety and integrity of the structure to various loading conditions could be studied.

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