

# BIM-Based Structural Design and Quantity Estimation of Buildings

Byragoni Srinivas<sup>1</sup>, N.Sriaknth<sup>2</sup>

<sup>1</sup>PG Scholar, <sup>2</sup>Assistant Professor, Department of Civil Engineering, Chalapathi Institute of Technology(Autonomous), Abburi Raghavaiah Nagar, CITY College Rd, Mothadaka, Andhra Pradesh, India-522016.

**Abstract- — This project gives in brief, the theory behind the design of liquid retaining structure. Water tanks are storage containers for storing water. Elevated water tanks are constructed in order to provide required head so that the water will flow under the influence of gravity, the construction practice of water tanks is as old as civilized man. The water tanks project has a great priority as it serves drinking water for huge population from major metropolitan cities to the small population living in towns and villages. The main aim of this project is to understand the behavior of elevated water tank by observing the results of Bending Moment, Shear Forces, Maximum Stress, and Maximum Displacement and Design by using BIM software.**

**Keywords: Analysis of Water Tank, Loads, Bending Moment, Shear Forces, Maximum Stress and Maximum Displacement.**

## I. INTRODUCTION

A water tank is an elevated structure supporting a water reservoir constructed at a height sufficient to pressurize a water supply system for the distribution of potable water, and to provide emergency storage for fire protection. Water tanks often operate in conjunction with underground or surface service reservoirs, which store treated water close to where it will be used. Other types of water towers may only store raw (non-potable) water for fire protection or industrial purposes, and may not necessarily be connected to a public water supply. Water tanks are able to supply water even during power outages, because they rely on hydrostatic pressure produced by elevation of water (due to gravity) to push the water into domestic and industrial water distribution systems; however, they cannot supply the water for a long time without power, because a pump is typically required to refill the tower. A water tower also serves as a reservoir to help with water needs during peak usage times. The water level in the tower typically falls during the peak usage hours of the day, and then a pump fills it back up during the night. This process also keeps the water from freezing in cold weather, since the tower is constantly being drained and refilled.[citation needed] .

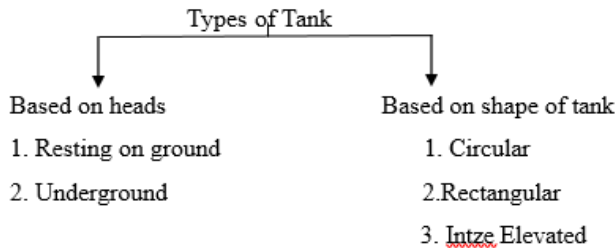
Although the use of elevated water storage tanks has existed since ancient times in various forms, the modern use of water towers for pressurized public water systems developed during the mid-19th century, as steam-pumping became more common, and better pipes that could handle higher pressures were developed. In Great Britain, standpipes, literally consisted of tall, exposed, inverted u-shaped pipes, used for pressure relief and to provide a fixed elevation for steam-driven

pumping engines which tended to produce a pulsing flow, while the pressurized water distribution system required constant pressure. Standpipes also provided a convenient fixed location to measure flow rates. Designers typically enclosed the riser pipes in decorative masonry or wooden structures. By the late 19th-Century, standpipes grew to include storage tanks to meet the ever-increasing demands of growing cities.

A variety of materials can be used to construct a typical water tower; steel and or pre stress concrete are most often used (with wood, or brick also in use), incorporating an interior coating to protect the water from any effects from the lining material. The reservoir in the tower may be spherical, cylindrical, or an ellipsoid with a minimum height of approximately 6 meters and a minimum of 4 m in diameter. A standard water tower typically has a height of approximately 40 m. Pressurization occurs through the hydrostatic pressure of the elevation of water; or every 10.20centimetres of elevation, it produces 1 kilopascal of pressure and 30 m of elevation produce roughly 300KPa, which is enough pressure to operate and provide for most domestic water pressure and distribution system requirements. The height of the tower provides the pressure for the water supply system, and it may be supplemented with a pump. The volume of the reservoir and diameter of the piping provide and sustain flow rate. However, relying on a pump to provide pressure is expensive; to keep up with varying demand, the pump would have to be sized to meet peak demands. During periods of low demand, jockey pumps are used to meet these lower water flow requirements. The water tower reduces the need for electrical consumption of cycling pumps and thus the need for an expensive pump control system, as this system would have to be sized sufficiently to give the same pressure at high flow

rates. Very high volumes and flow rates are needed when fighting fires. With a water tower present, pumps can be sized for average demand, not peak demand; the water tower can provide water pressure during the day and pumps will refill the water tower when demands are lower.

**Classification of R.C.C Water Tank**



**II. BASED ON PLACEMENT OF TANK**

These are used for clear water reservoirs, settling tanks, aeration tanks etc. These tanks directly rest on the ground. The walls of these tanks are subjected to water pressure from inside and the base is subjected to weight of water inside and soil reaction from underneath the base. The tank may be open at top or roofed. Ground water tank is made of lined carbon steel, it may receive water from water well or from surface water allowing a large volume of water to be placed in inventory and used during peak demand cycles.



Figure 2.1 Tank resting on ground

**Elevated Water Tank**



Figure 2.2 Elevated water tank

These tanks are supported on staging which may consist of masonry walls, R.C.C tower or R.C.C column braced together. The walls are subjected to water pressure from inside. The base is subjected to weight of water, weight of walls and weight of roof. The staging has to carry the entire load of entire tanks with water and is subjected to wind loads. Water tank parameters include the general design of the tanks, choice of materials of construction, as well as following:

- Location of the water tanks (indoors, outdoors, above the ground or underground) determines color and construction characteristics.
- Volume of water tank will need to hold to meet design requirements.
- Purpose for which the water tanks will be used, human consumption or industrial determines the concerns for materials that do not have side effects for human
- Temperature of area where water will be stored, may create concern freezing and delivery off setting heat.
- Delivery pressure requirements, domestic pressure range from 35-60 PSI, the demand for a given GPM (gallon per minute) of delivered flow requirements.
- How the water to be delivered to the point of use, into and out of the water tank i.e. pumps, gravity or reservoir.
- Wind and earthquake design considerations allow a design of water tank parameters to survive seismic and high wind events.

- Back flow prevention, are check valve mechanism to allow single direction of water flow.
- Chemical injection systems for algae, bacteria and virus control to allow long term storage of water.
- Algae in water tanks can be mitigated by removing sunlight from access to the water being stored.

### III. UNDERGROUND WATER TANK

These tanks are built below the ground level such as clarifier's filters in water treatment plants, and septic tanks. The walls of these tanks are subjected to water pressure from inside and earth pressure from outside. The base of the tanks is subjected to water pressure from inside and earth pressure from outside. The base of the tanks subjected to water pressure from inside and soil reaction from underneath. Always these are covered at top. These tanks should be designed for loading which gives the worst effect. The design principles of underground tank same as for the tanks resting on ground. The walls are subjected to inside a water pressure and outside earth pressure. The section of wall is designed for the earth pressure acting separately as well as acting simultaneously,. Whenever there is possibility of water table to rise, soil becomes saturated and earth. These types of tank are generally constructed of rectangular or circular in shape.

#### Based On The Shape Of Tank

##### ➤ Circular Tank

Generally circular tank rest on the ground or are elevated ones. Underground circular tanks are also constructed. The circular tanks may be designed either with flexible base connection with wall or with rigid connection between walls and base, in the former case the expansion and contraction of side walls are possible but in latter case the walls are monolithic with base. The walls of tank are subjected to hydrostatic pressure which is maximum at base and zero at top. Usually for design of circular tanks, the theory of thin cylinders is applied for design of wall thickness and for calculation of maximum hoop tension. The main reinforcement consists of circular

hoops to take care of hoop tension and is placed on both faces and wall. The distribution steel is placed vertically and is tied to main reinforcement.



Figure 2.3 Circular tank

#### Rectangular Tank

For smaller capacities circular tanks are uneconomical and their form work is costly. Rectangular tanks are constructed when small capacity tank are required. These may be resting on ground, elevated or underground. Tanks should be preferably square in plan and it is desirable that larger side should not be greater than twice the smaller side and for rectangular tanks. Walls of tanks either resting on ground or elevated are subjected to water pressure from inside and when underground they are subjected to internal water pressure and outside earth pressure. In rectangular tanks the moments are caused in two directions, Hence exact analysis is rather difficult, they are designed by approximate methods.



Figure 2.4 Rectangular Tank

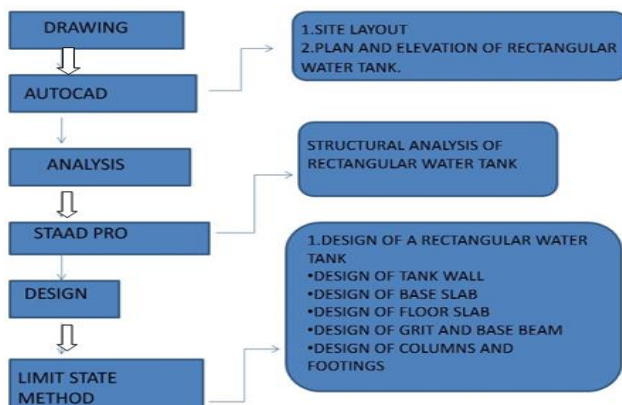
➤ **Intze Type Tank**

This is a very special type of elevated tank used for very large capacities. Circular tanks for very large capacities prove to be uneconomical when flat bottom slab is provided. Intze type tank consist of top dome supported on a ring beam which rests on cylindrical wall. The walls are supported on ring beam and conical slab. Bottom dome will also be provided which also supported by ring beam. The conical and bottom dome are made in such manner that the horizontal thrust from the conical base is balanced by that from the bottom dome. The conical and bottom domes are supported on circular beam which is in turn, supported on a number of columns. For large capacities the tank is divided in two compartments by means of partion walls supported on a circular beam.

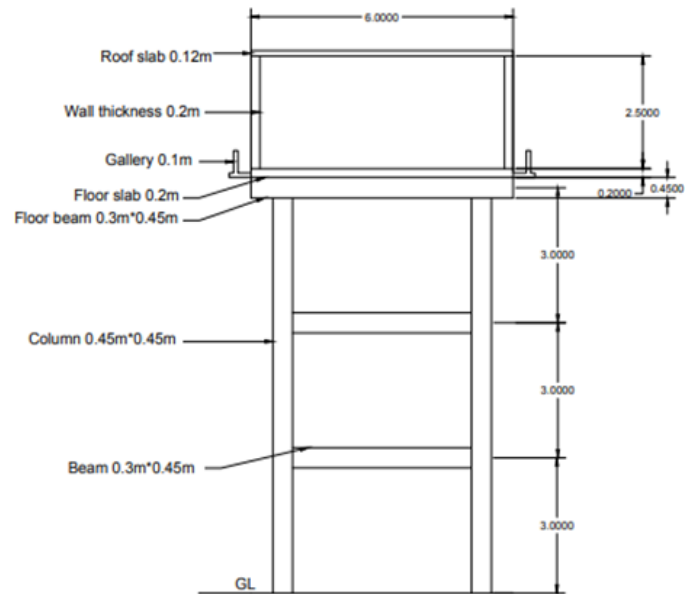


Figure 2.5 Intze type tank

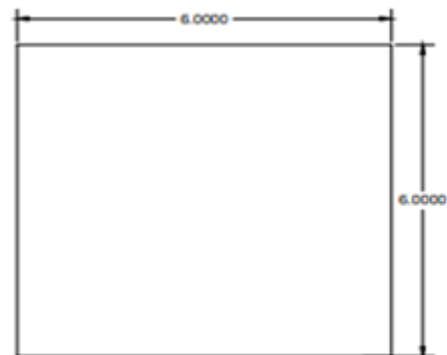
**IV. METHODOLOGY**



**Elevated Rectangular Water Tank**



SECTIONAL VIEW



PLAN

Figure.3.1 Auto Cad Plan And Sectional View

**Analysis Of The Structure**

**Outline Of Analysis:**

- The analysis of the structure that is determination of the internal forces like Bending moment, shear force, etc in the component members, for which these members have to be designed, under the action of given external loads.

- This process requires the knowledge of structural mechanics which includes mechanics of rigid bodies (i.e. mechanics of forces), mechanics of deformable bodies (i.e. mechanics of deformations) and theory of structures (i.e the science dealing with response of structural system to external loads).
- A brief review is taken of structural analysis to refresh the basic principles

### Analysis Of Wind Forces

In addition to gravity forces the tower and the tank are subjected to wind and seismic forces depending upon the location of the tank. The wind pressure at a site is determined as per IS : 875 Part III provision. The wind force on a surface is the product of pressure per unit area and projected area normal to the direction of wind. Intze tanks offer relatively smaller resistance and a reduction factor of the order 0.7 is used to arrive at effective pressure. The nature of forces and analysis procedure are discussed in the following sections.

### Classification Of Structures

The structures are classified into the following three different classes depending upon their sizes;  
 Class A – Structures and/or their components such as glazing, cladding, roofing etc., having maximum dimension(greatest horizontal or vertical dimension) less than 20m. Class B- Structures and / or their components such as glazing, cladding, roofing etc., having maximum dimension (greatest horizontal or vertical dimension) between 20m and 50m.  
 Class C- Structures and/or their components such as glazing, cladding, roofing etc., having maximum dimension (greatest horizontal or vertical dimension) greater than 50m.

### Terrain Category

There are four terrain categories. Terrain in which a specific structure stands shall be assessed as being one of the following terrain categories:

- Category 1- exposed open terrain with few or no objections in which the average height of any object surrounding the structure is less than 1.5m.
- Category 2- open terrain with well scattered obstructions having heights generally between 1.5 to 10m.
- Category 3- terrain with numerous closely spaced obstructions having the size of structure up to 10m in height with or without a few isolated tall structures.
- Category 4- terrain with numerous large high closely spaced obstructions.

### Design And Analysis

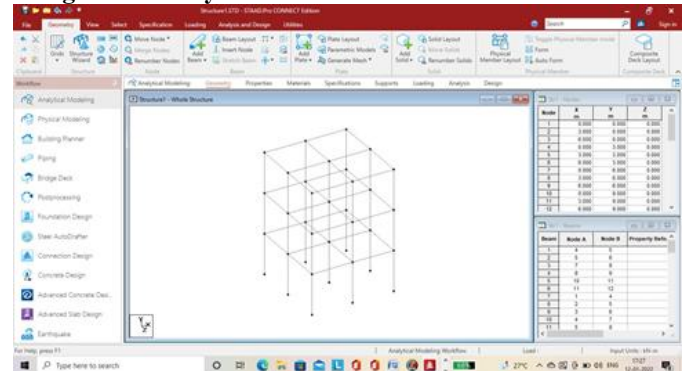


Figure.3.2 Drawing bay frame

Analytical Modelling >> Geometry >> Structure Wizard >> Frame Models >> Bay Frame

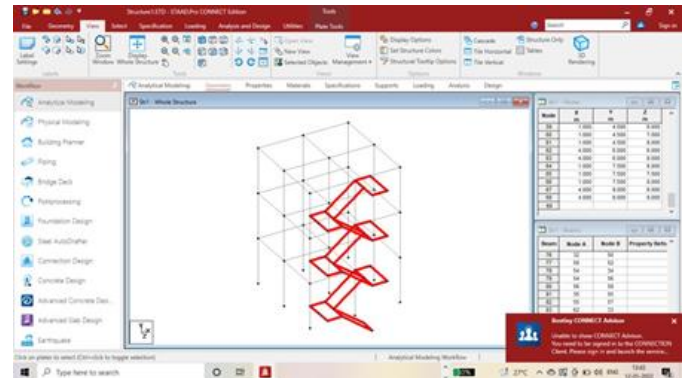
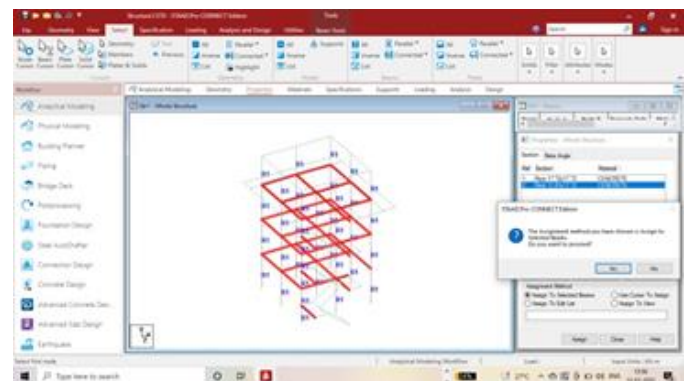


Figure.3.3 Drawing steps



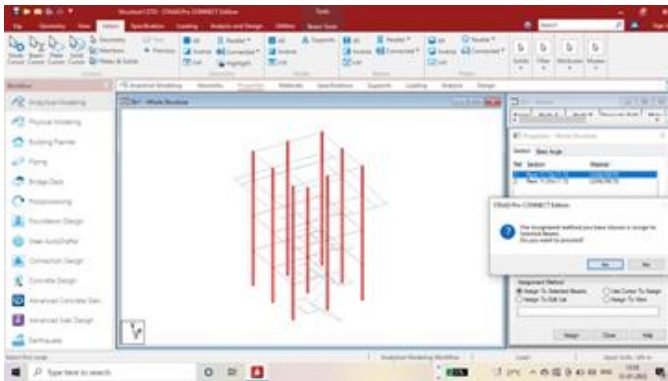


Figure.3.4 Assigning member properties to beams and columns

Using M30 and Fe 600 grade of concrete and steel for Slabs , Beams , Footings and Columns  
 $F_{ck}$ =Characteristic strength of concrete=30N/mm<sup>2</sup>  $F_y$ =yield strength of steel=600N/mm<sup>2</sup>

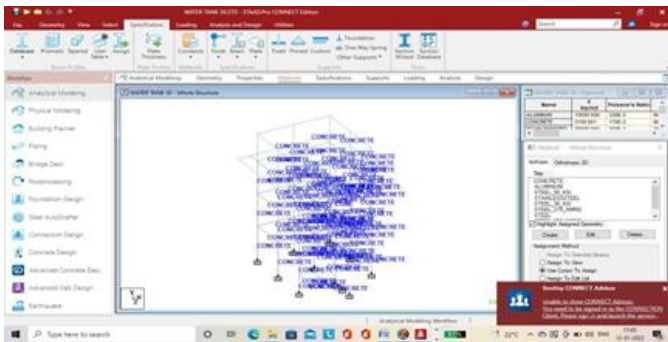


Figure.3.5 Assigning materials

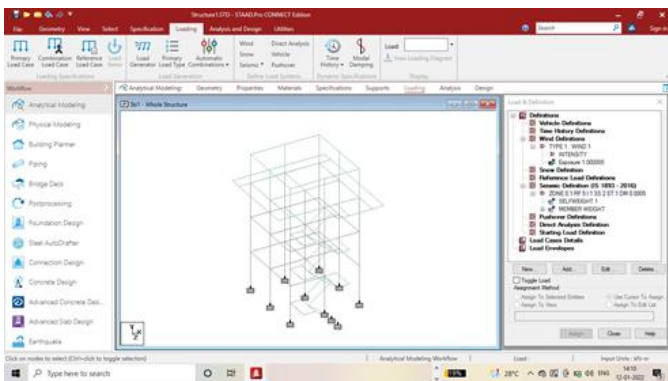


Figure.3.6 Assigning supports

**Loading on Overhead Tank:**

For overhead, the loads and loading combinations are considered for two different conditions of tanks.

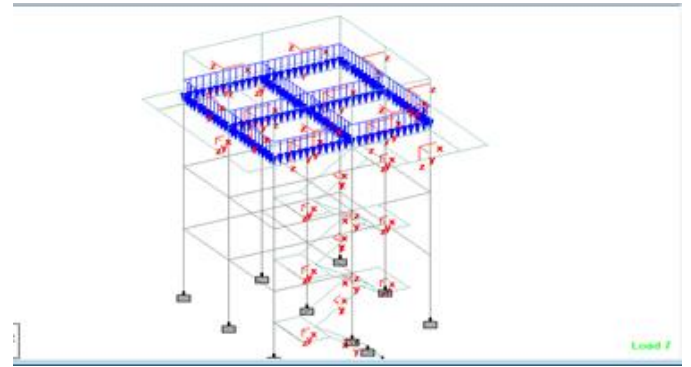


Figure.3.7 Hydrostatic pressure

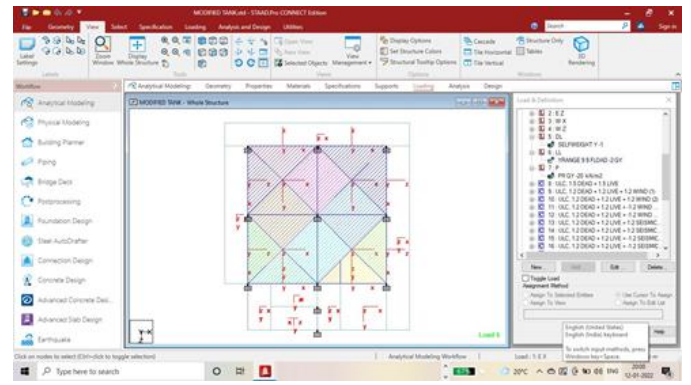


Figure.3.8 Floor and Member load

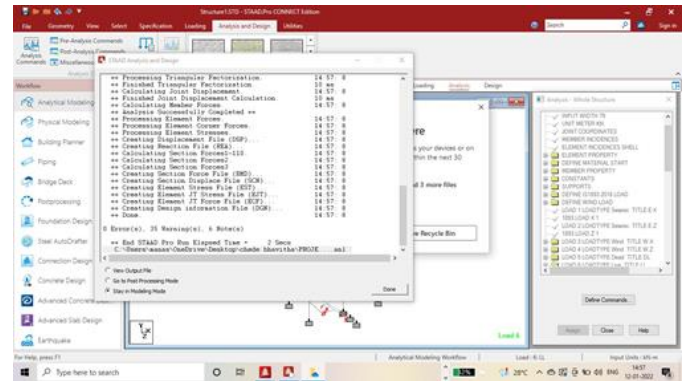


Figure.3.9 Analysis of the structure



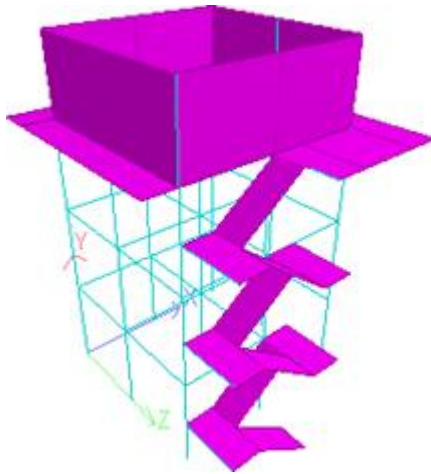
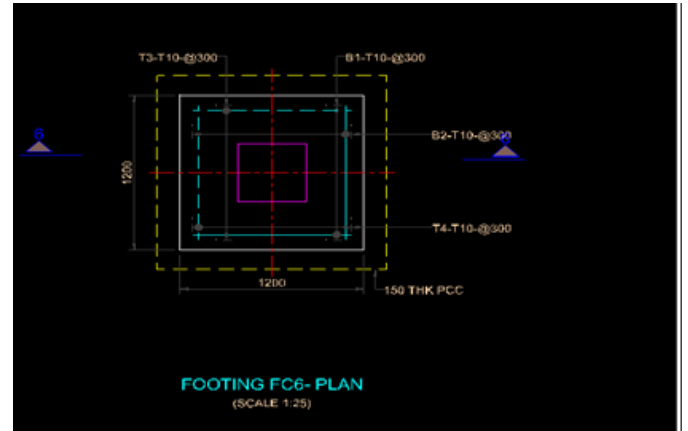


Figure.3.16.3D Rendering

Reinforcement details of footing:



Design of footing:

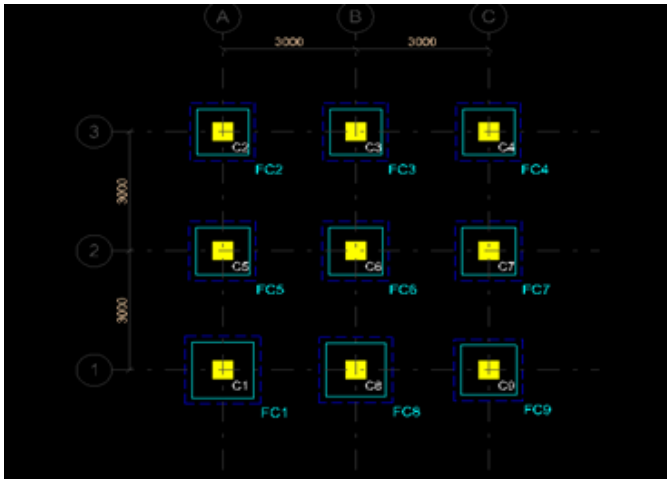


Figure.3.17 Foundation layout

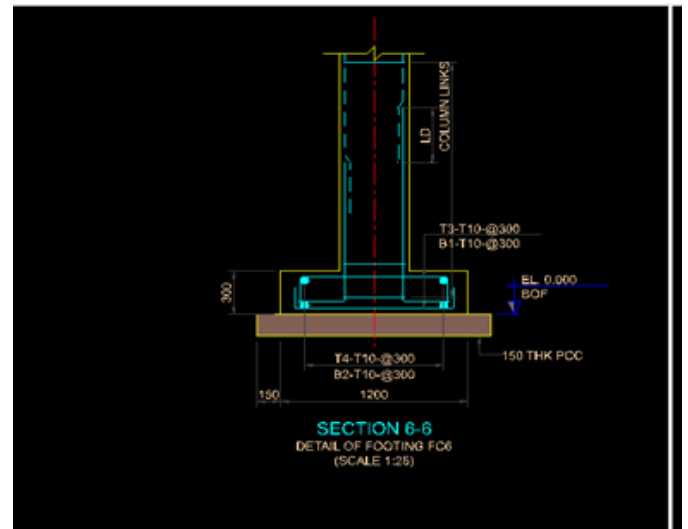


Table 3.1 Design Dimensions of the footing

Gp. No.	Footing Mark	Column Mark	Footing Type	Material Property	Column Size (mm)	Footing Size (LxBxD) (mm)	Loss contact
1	FC1	C1	Pad	M25 : Fe415	450 x 450	1400 x 1400 x 300	0
2	FC2	C2	Pad	M25 : Fe415	450 x 450	1150 x 1150 x 300	0
3	FC3	C3	Pad	M25 : Fe415	450 x 450	1150 x 1150 x 300	0
4	FC4	C4	Pad	M25 : Fe415	450 x 450	1150 x 1150 x 300	0
5	FC5	C5	Pad	M25 : Fe415	450 x 450	1200 x 1200 x 300	0
6	FC6	C6	Pad	M25 : Fe415	450 x 450	1200 x 1200 x 300	0
7	FC7	C7	Pad	M25 : Fe415	450 x 450	1200 x 1200 x 300	0
8	FC8	C8	Pad	M25 : Fe415	450 x 450	1350 x 1350 x 300	0
9	FC9	C9	Pad	M25 : Fe415	450 x 450	1250 x 1250 x 300	0

ELEVANT	BAR MARK	BAR NOS.	BAR DIA.	BAR SHAPE	CUTTING LENGTH (MM)	DIMENSIONS					
						A	B	C	D	E	R
FC6	B1	5	13		1350	150	1110	150			40
	B2	5	13		1350	150	1110	150			40
	T3	5	13		1490	220	1110	220			40
	T4	5	13		1490	220	1110	220			40

Design of Column:

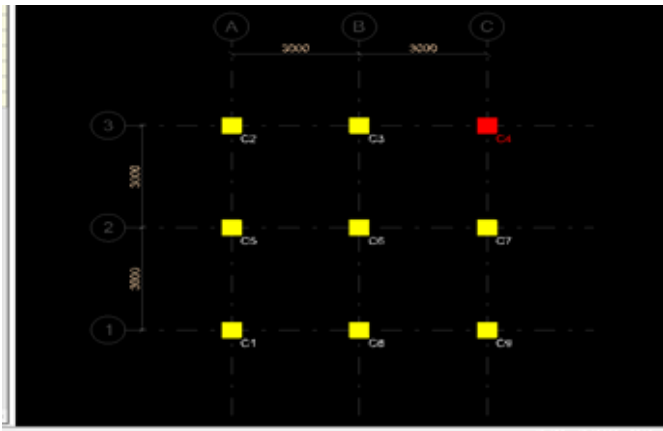


Figure.3.18 Layout of column

Table.3.2 Design dimensions of the column

Column/Beam	Level	Size	Material	Design axial load	Capacity Ratio Axial	Capacity Ratio Flexure	P/Ph (No)	Main Reinforcement	Links	Double Links
C1	3m TO 3m	400 X 400	M25, Fe415	COL, E	0.127	0.177	0.45	8T12	10 @ 175	--
C1	1.5m TO 3m	400 X 400	M25, Fe415	COL, E	0.113	0.287	0.45	8T12	10 @ 175	--
C1	3m TO 4.5m	400 X 400	M25, Fe415	COL, E	0.101	0.289	0.45	8T12	10 @ 175	--
C1	4.5m TO 6m	400 X 400	M25, Fe415	COL, E	0.086	0.339	0.45	8T12	10 @ 175	--
C1	6m TO 7.5m	400 X 400	M25, Fe415	COL, E	0.074	0.318	0.45	8T12	10 @ 175	--
C1	7.5m TO 9m	400 X 400	M25, Fe415	COL, E	0.066	0.349	0.45	8T12	10 @ 175	--
C2	1.5m TO 3m	400 X 400	M25, Fe415	COL, E	0.091	0.271	0.45	8T12	10 @ 175	--
C2	4.5m TO 6m	400 X 400	M25, Fe415	COL, E	0.077	0.271	0.45	8T12	10 @ 175	--
C2	7.5m TO 9m	400 X 400	M25, Fe415	COL, E	0.062	0.296	0.45	8T12	10 @ 175	--
C3	1.5m TO 3m	400 X 400	M25, Fe415	COL, E	0.092	0.279	0.45	8T12	10 @ 175	--
C3	4.5m TO 6m	400 X 400	M25, Fe415	COL, E	0.074	0.265	0.45	8T12	10 @ 175	--
C3	7.5m TO 9m	400 X 400	M25, Fe415	COL, E	0.057	0.311	0.45	8T12	10 @ 175	--
C4	1.5m TO 3m	400 X 400	M25, Fe415	COL, E	0.09	0.266	0.45	8T12	10 @ 175	--
C4	4.5m TO 6m	400 X 400	M25, Fe415	COL, E	0.075	0.26	0.45	8T12	10 @ 175	--
C4	7.5m TO 9m	400 X 400	M25, Fe415	COL, E	0.062	0.296	0.45	8T12	10 @ 175	--
C5	1.5m TO 3m	400 X 400	M25, Fe415	COL, E	0.103	0.253	0.45	8T12	10 @ 175	--
C5	4.5m TO 6m	400 X 400	M25, Fe415	COL, E	0.083	0.322	0.45	8T12	10 @ 175	--
C5	7.5m TO 9m	400 X 400	M25, Fe415	COL, E	0.064	0.339	0.45	8T12	10 @ 175	--
C6	1.5m TO 3m	400 X 400	M25, Fe415	COL, E	0.104	0.266	0.45	8T12	10 @ 175	--
C6	4.5m TO 6m	400 X 400	M25, Fe415	COL, E	0.082	0.317	0.45	8T12	10 @ 175	--
C6	7.5m TO 9m	400 X 400	M25, Fe415	COL, E	0.06	0.394	0.45	8T12	10 @ 175	--
C7	1.5m TO 3m	400 X 400	M25, Fe415	COL, E	0.1	0.268	0.45	8T12	10 @ 175	--
C7	4.5m TO 6m	400 X 400	M25, Fe415	COL, E	0.081	0.266	0.45	8T12	10 @ 175	--
C7	7.5m TO 9m	400 X 400	M25, Fe415	COL, E	0.063	0.289	0.45	8T12	10 @ 175	--

Design of beams:

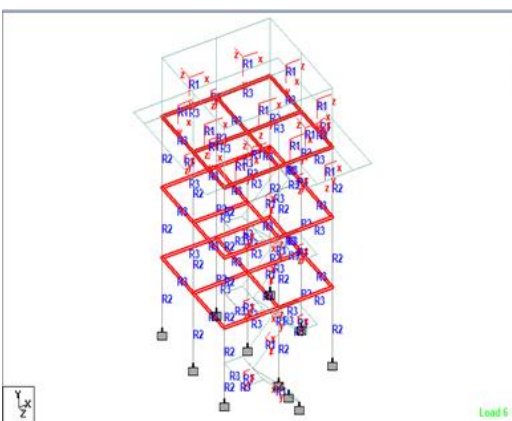


Figure.3.19 Selection of beams at 3m,6m and 9m

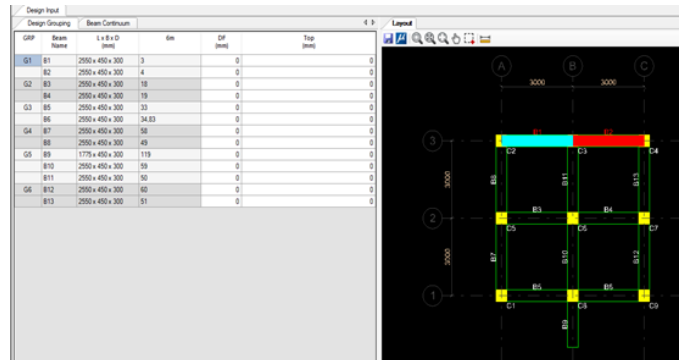


Figure.3.20 Layout of beams

Table.3.3 Design dimensions of the beams at 3m,6m and 9m

Design Input	Design Output													
Design	Design													
GPP	Beam	Type	Size	Material	Bottom Left	Bottom Mid	Bottom Right	Top Left	Top Mid	Top Right	Shear Left	Shear Mid	Shear Right	SPR
G1	B1	Reg	450x300	M25/Fe415	5T10	5T10	5T10	5T10	5T10	5T10	2L70 @ 200	2L70 @ 200	2L70 @ 200	-
G2	B3	Reg	450x300	M25/Fe415	5T10	5T10	5T10	5T10	5T10	5T10	2L70 @ 200	2L70 @ 200	2L70 @ 200	-
G3	B5	Reg	450x300	M25/Fe415	5T10	5T10	5T10	5T10	5T10	5T10	2L70 @ 200	2L70 @ 200	2L70 @ 200	-
G4	B7	Reg	450x300	M25/Fe415	5T10	5T10	5T10	5T10	5T10	5T10	2L70 @ 200	2L70 @ 200	2L70 @ 200	-
G5	B9	Cont	450x300	M25/Fe415	5T10	5T10	5T10	5T10	5T10	5T10	2L70 @ 200	2L70 @ 200	2L70 @ 200	-
G6	B12	Reg	450x300	M25/Fe415	5T10	5T10	5T10	5T10	5T10	5T10	2L70 @ 200	2L70 @ 200	2L70 @ 200	-

Figure.3.21 Selecting beams at staircases

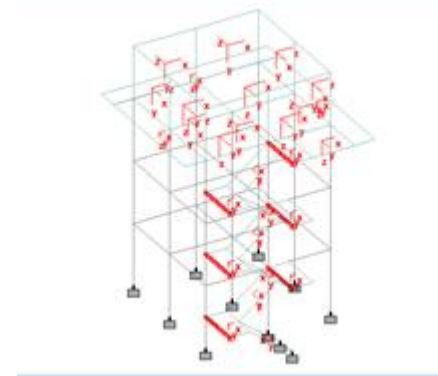


Table 3.4 Design dimensions of beams at staircases

GPP	Beam	Type	Size	Material	Bottom Left	Bottom Mid	Bottom Right	Top Left	Top Mid	Top Right	Shear Left	Shear Mid	Shear Right
G1	B1	Cont	450x300	M25/Fe415	5T10	5T10	5T10	5T10	5T10	5T10	2L70 @ 195	2L70 @ 195	2L70 @ 195

**Design of slab:**

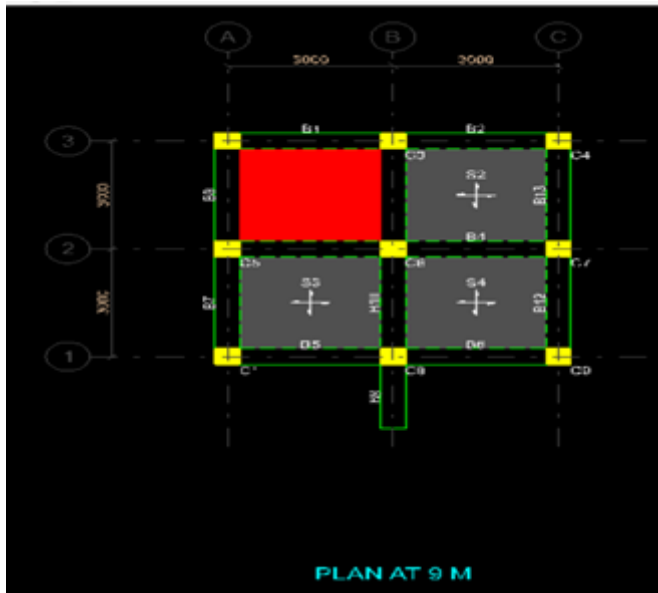


Figure.3.22 Slab layout

No	Slab	Thickness (mm)	Conc Grade	Steel Grade	Bottom @ Lx	Bottom @ Ly	Top @ Lx (Cont)	Top @ Lx (End)	Top @ Ly (Cont)	Top @ Ly (End)	Dist. Steel	Remark
S1	100	M25	Fe415	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	-	
S2	100	M25	Fe415	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	-	
S3	100	M25	Fe415	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	-	
S4	100	M25	Fe415	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	T8 @ 225	-	

Table 3.5 Design dimensions of slab

## V. MATERIALS

**Parameters for selecting Materials:**

- Materials selected for construction should be impervious.
- If iron/steel materials are taken, it should not be rusted.
- Materials should be highly resistant to fire or frost conditions.
- It can be easily repairable
- Cost of materials should be economical.

**General Consideration**

IS 3370(part 1) recommends the following measures to be considered before the construction of water tank –

➤ **Cement content :**

The concrete used for tank should be minimum of M20 grade mix so as to provide not only the strength but also higher density to prevent seepage. The cement content should not be less than 300Kg/m<sup>3</sup> to get water tightness and not more than 530Kg/m<sup>3</sup> to avoid cracking due to shrinkage of concrete. A well graded aggregate with a water- cement ratio less than 0.5 is recommended for making impervious concrete

➤ **Permissible steel requirement:**

Plain mild or HYSD steel reinforcement can be used in storage tanks. The permissible stress in reinforcement is controlled by the strain and crack widths rather by the strength. In view of complexities associated with crack widths, a simplified approach through the reduced permissible stress is recommended.

The permissible stress in steel is given below:

Types of stress in steel reinforcement	Mild steel bars (Mpa)	HYSD steel bars (Mpa)
Tensile stress in member under direct tension	115	150
Tension in steel bending or shear placed within 225mm from water face	115	150
Tension in steel placed beyond 225mm from water face; In bending, $f_{st}$	125	190
In shear, $f_{sv}$	125	175
Compression in column subjected to direct load	125	175

Table 4.1 Permissible stress in steel

➤ **Permissible Stresses in Concrete :**

To ensure uncracks condition, the permissible tensile stress in concrete in reinforcement concrete members should not exceed the values listed on table 2.2 on the liquid retaining face and also on the exterior face, for the members less than 225mm thick

Nature of stress	M20	M25	M30	M35
Direct tension, $f_{ct}$	1.2	1.3	1.5	1.6
Bending tension, $f_{cbt}$	1.7	1.8	2.0	2.2
Shear Stress, $\tau_v$	1.7	1.9	2.2	2.5

Table 4.2 Permissible stress in concrete

➤ **Cover of reinforcement:**

The minimum clear cover or nominal cover to main reinforcement in direct tension shall be 20mm diameter of the bar, whichever is greater. The minimum nominal cover is increased to 25 and 30mm for the case of tension in bending, and in the environment of alternate wetting and drying, respectively, But minimum cover should be 40mm for the surface in contact with water.

➤ **Minimum Steel:**

A minimum amount of steel shall be provided in two principle directions to minimize cracking due to shrinkage, temperature etc. The minimum HYSD reinforcement in walls, floors and roofs should be 0.35% of the surface zone cross section in either of direction of right angles.

➤ **Water proofing material:**

Primary consideration in water tanks, besides, strength is water tightness of tank. Complete water –tightness can be obtained by using high strength concrete. In addition, water proofing materials can be used to further enhance the water tightness. To make concrete leak proof or water tight, internal water proofing or water proofing linings are frequently used. In the method of internal water proofing, admixtures are used. The objects using them are to fill the pores of the concrete and to obtain a dense and less permeable concrete. Some of most commonly used admixtures are hydrated lime in quantity from 8 to 15%, by weight of cement of powdered iron fillings, which expands upon oxidation and fills in pores of concrete. Other agents like powdered chalk or talc, sodium silicate, zinc sulphate, calcium chloride etc. are also used. In water proofing linings, paints, asphalt, coal tar, waxes, resins, and bitumen are used. These materials have property to repel water.

## VI. CONCLUSION

- Based on the estimated population and prevailing water demand, the quantity of water to be supplied and stored in the tank was computed.

- The plan and other drawings for the rectangular overhead water tank was prepared using AutoCAD 2D software
- The analysis was done using BIMsoftware and the structure was analysed for self-weight, meshes for surface loads, brace properties, etc and the outputs were verified.
- The design data were acquired after due analysis. After analysis, the design data were generated.
- The design would satisfy the safety and economy norms and can be used for any village with similar population.

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