# CHAPTER THREE
# THE RECEARCH PROBLEM

## 3.1 Introduction

The main purpose of any structure is to carry loads over or round specified spaces and delivers them to the ground. All relevant loads and realistic load combinations have to be considered in design.

The elevated tanks they are tanks elevated from the earth and supported on towers, columns and shaft. They support vertical load (self weight and water weight) and horizontal load (wind load and water pressure on wall of tank).

## 3.2 Loads applied to water tanks

Once the dimensional requirements for a structure have been defined, it becomes necessary to determine the loads the structure must support. Often, it is the anticipation of the various loads that will be imposed on the structure that provides the basic type of structure that will be chosen for design. For example, high-rise structures must endure large lateral loadings caused by wind, and so shear wall and tubular frame systems are selected, whereas buildings located in areas prone to earthquakes must be designed having ductile frames and connections. Once the structural form has been determined, the actual design begins with those elements that are subjected to the primary loads the structure is intended to carry, and proceeds in sequence to the various supporting members until the foundation is reached. Thus, a building floor slab would be designed first, followed by the supporting beams, columns, and last, the foundation footings. In order to design a structure, it is therefore necessary to first specify the loads that act on it. The design loading for structures often specified in codes. In general, the structural engineer works with two types of codes: general building codes and design codes. General building codes specify the requirements of governmental bodies for minimum design loads on structures and minimum standards for construction.

Design codes provide detailed technical standards and are used to establish the requirements for the actual structural design. The ultimate responsibility for the design lies with the structural engineer since a structure is generally subjected to several types of loads; a brief discussion of these loadings will now be presented to illustrate how one must consider their effects in practice. Loads can act on structures can be divided into three broad categories dead loads, live loads, and environmental loads (wind, Earthquake, Snow, Rain…).

### 3.2.1Dead load

Dead loads consist of the weight of all materials of construction incorporated into the building including but not limited to, walls, floors, roofs, ceilings, stair ways, built- in partitions, finishes, cladding, and other similarly incorporated architectural and structural items and fixed service equipment including the weight of cranes.

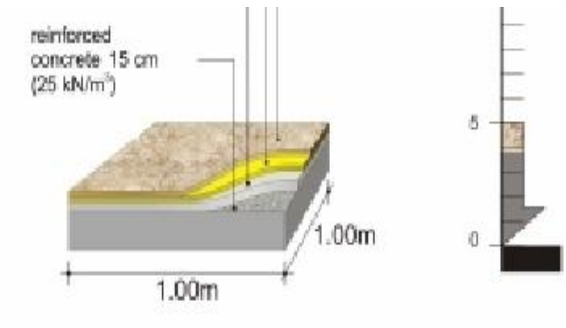



**Fig (3.1): Dead load estimation**

### 3.2.2 Live load

Live loads are loads that can change in magnitude and position which includes the weight of furniture, office equipment, partitions, people, and all moving and all moving parts The live load many are separated into two types:

-Sustained loads:

The weight of parts that do not move for long desertions, such as a file cabinet in an office, or the beds in a bedroom, which may move for several years.

-Variable load:

Such as the weight of people who move frequently (at least one time per day).the live loads may be estimated from specification code as uniform loads on the floor area of structure.

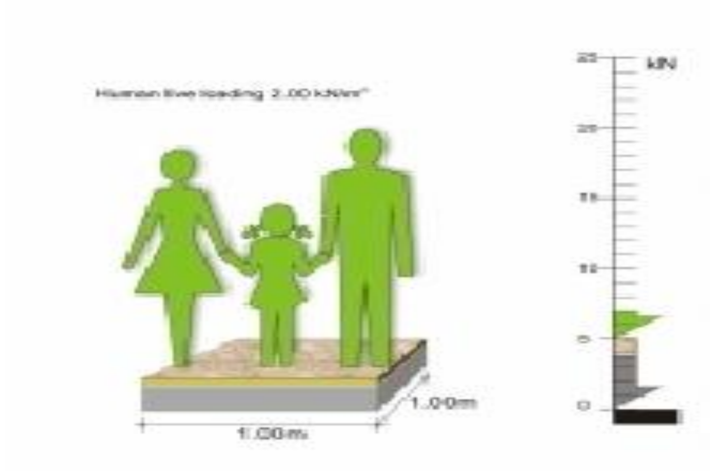



**Fig (3.2): Live load estimation**

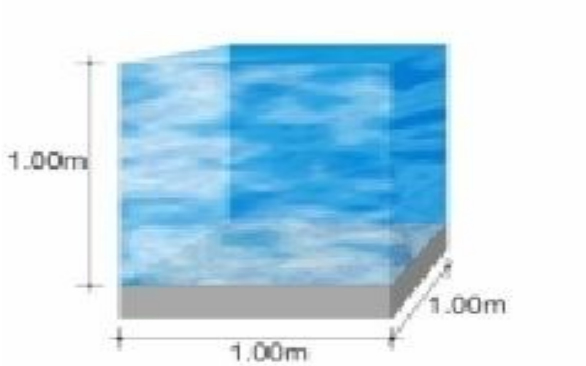



**Fig (3.3): Water weight**

### 3.2.3 Wind load

Referring to ASCE 7-05 for simplified procedure, one can notice that the simplified procedure is applicable only to building with mean roof heights less than 30 ft (9 m), which is not applicable to building of this study. The wind tunnel procedure consists of developing a small scale model of the building for testing in wind tunnel to determine the expected wind pressure etc. It is expensive and may be utilized for difficult or special situations. The analytical procedure is used in most .It is fairly systematic but some that complicated to account for various situations that can occur. Wind velocity will cause pressure on any surface. The velocity pressure depends on the height from the ground level. The following equation is recommended by ASCE 7-05 CODE of practice for calculation the velocity pressure, qz, resulting from winds:

$$qz=0.613K_z*K_{zt}*K_d*V^2*I \quad (N/m^2) \qquad (3.1)$$

Where:

V: is the basic wind speed (m/s)

$K_d$: is directionality factor from Table (3.4)

$K_{zt}$: is topographic factor

$k_{zt}$= 1 for flat ground

kz: varies with height z above the ground level obtained from Table (3.6)

I: is the importance factor obtained from Table (3.5)

$P_z = q_z G C_p$ For windward positive pressure

$P_z = q_h G C_p$ For leeward negative pressure

**External pressure coefficient $C_p$**

| Surface | $L/B$ | $C_p$ |
|---|---|---|
| Windward wall | All values | 0.8 |
| Leeward wall | 0-1 | -0.5 |
| | 2 | -0.3 |
| | $\geq 4$ | -0.2 |
| Side walls | All values | -0.7 |

**Table (3.2): Wind directionality factor, $k_d$.**

| Structure type | Directionality Factor kd |
|---|---|
| Building | |
| Main wind force resisting system | 0.85 |
| Components and cladding | 0.85 |
| Arched roofs | 0.85 |
| Chimneys, Tanks, and similar Structure | |
| Square | 0.9 |
| Hexagonal | 0.95 |
| Round | 0.95 |
| Solid sign | 0.85 |
| Open sign and lattice formwork | 0.85 |
| Trussed Towers | |
| Triangular , square , rectangular | 0.85 |
| All other cross sections | 0.95 |

**Table (3.3): Importance factor, I (wind load).**

| Category | Non - hurricane prone regions and hurricane prone regions with V=85-100 mph=37.78-44.44 m/s | Hurricane prone regions with V > 100mph V > 44.44 m/s |
|---|---|---|
| I | 0.87 | 0.77 |
| II | 1.00 | 1.00 |
| III | 1.15 | 1.15 |
| IV | 1.15 | 1.15 |

**Table (3.4): Velocity pressure exposure coefficient Kz.**

| Height above ground level z | Exposure | | | |
|---|---|---|---|---|
| | B | | C | D |
| (m) | Case1 of 2 | Case1 of 2 | Case2 | Case1 |
| 0.46 | 0.7 | 0.57 | 0.85 | 1.03 |
| 6.10 | 0.7 | 0.62 | 0.90 | 1.08 |
| 7.60 | 0.7 | 0.66 | 0.94 | 1.12 |
| 9.10 | 0.7 | 0.70 | 0.98 | 1.16 |
| 12.20 | 0.76 | 0.76 | 1.04 | 1.22 |
| 15.20 | 0.81 | 0.81 | 1.09 | 1.27 |
| 18.00 | 0.85 | 0.85 | 1.13 | 1.31 |
| 21.30 | 0.89 | 0.89 | 1.17 | 1.34 |
| 24.40 | 0.93 | 0.93 | 1.21 | 1.38 |
| 27.40 | 0.96 | 0.96 | 1.24 | 1.40 |
| 30.50 | 0.99 | 0.99 | 1.26 | 1.43 |
| 36.60 | 1.04 | 1.04 | 1.31 | 1.48 |
| 42.70 | 1.09 | 1.09 | 1.36 | 1.52 |
| 48.80 | 1.13 | 1.13 | 1.39 | 1.55 |
| 54.90 | 1.17 | 1.17 | 1.43 | 1.58 |
| 61.00 | 1.20 | 1.2 | 1.46 | 1.61 |
| 76.20 | 1.28 | 1.28 | 1.53 | 1.68 |
| 91.40 | 1.35 | 1.35 | 1.59 | 1.73 |
| 106.70 | 1.41 | 1.41 | 1.64 | 1.78 |
| 121.90 | 1.47 | 1.47 | 1.69 | 1.82 |
| 137.20 | 1.52 | 1.52 | 1.73 | 1.86 |
| 152.40 | 1.56 | 1.56 | 1.77 | 1.89 |


**Fig (3.4): Wind load effects shape.**

## 3.3 Analysis methods

### 3.3.1 Approximated method

Approximated method is depended to calculations the vertical load and approximated moment from wind load. The procedure of methods as follows:

**Rectangular water tank analysis Procedure is as follows:**

1. Calculate self weight of structure element:

- Column self weight is given by:

$$w_c = b * h * H_c * \gamma_c \quad (3.2)$$

- Bracing self weight is given by:

$$w_B = b * h * P_B * \gamma_c \quad (3.3)$$

- Bottom slab self weight is given by:

$$w_{Bs} = B * L * t * \gamma_c \quad (3.4)$$

- wall self weight is given by:

$$w_{wall} = P_{wall} * H * t * \gamma_c \quad (3.5)$$

- Top slab self weight:

$$w_{Ts} = B * L * t * \gamma_c \quad (3.6)$$

- Water weight:

$$w_w = B * L * h_w * \gamma_w \quad (3.7)$$

- **Total vertical load** = $w_c + w_B + w_{Bs} + w_{wall} + w_{Ts} + w_w$

2. Calculate vertical load due to wind load:

$$V = \frac{M_1 - \sum M}{\frac{\sum r^2}{r_1}} \quad (3.8)$$

$$\sum M = \sum w * \frac{bottom\ column\ height}{2} \quad (3.9)$$

$$\sum w = w_1 + w_2 + w_3 + w_4 + \cdots \quad (3.10)$$

$$M_1 = \sum w_i * h_i \quad (3.11)$$

3. Calculate Bracing moment:

$$M_B = (moment\ on\ top\ column + moment\ on\ bottom\ column)$$

4. Calculate bracing shear:

$$s_B = \frac{M_B}{\frac{L}{2}} \quad (3.12)$$

5. Calculate moment on each column:

$$M_c = \frac{\sum M}{N} \quad (3.13)$$

6. Calculate total vertical load (column axial load):

$$P = W_t + V \quad (3.14)$$

**Circular water tank analysis Procedure is as follows:**

1. Calculate self weight of structure element:

- Column self weight is given by:

$$w_c = \frac{\pi d^2}{4} * H_c * \gamma_c \quad (3.15)$$

- Bracing self weight is given by:

$$w_B = \pi * h * D * \gamma_c \quad (3.16)$$

- Bottom slab self weight is given by:

$$w_{Bs} = \frac{\pi D^2}{4} * t * \gamma_c \quad (3.17)$$

- wall self weight is given by:

$$w_{wall} = \pi D * H * t * \gamma_c \quad (3.18)$$

- Top slab self weight is given by:

$$w_{Ts} = \frac{\pi D^2}{4} * t * \gamma_c \quad (3.19)$$

- Water weight is given by:

$$w_w = \frac{\pi D^2}{4} * h_w * \gamma_w \quad (3.20)$$

**- Total vertical load** = $w_c + w_B + w_{Bs} + w_{wall} + w_{Ts} + w_w$ (3.21)

2. Calculate vertical load due to wind load:

$$V = \frac{M_1 - \sum M}{\frac{\sum r^2}{r_1}} \quad (3.22)$$

$$\sum M = \sum w * \frac{bottom\ column\ height}{2} \quad (3.23)$$

$$\sum w = w_1 + w_2 + w_3 + w_4 + \cdots \quad (3.24)$$

$$M_1 = \sum w_i * h_i \quad (3.25)$$

3. Calculate Bracing moment:

$$M_B = sec\theta * (moment\ on\ top\ column + moment\ on\ bottom\ column)$$

4. Calculate bracing shear:

$$s_B = \frac{M_B}{\frac{L}{2}} \quad (3.26)$$

5. Calculate moment on each column:

$$M_c = \frac{\sum M}{N} \quad (3.27)$$

6. Calculate total vertical load (column axial load):

$$P = W_t + V \quad (3.28)$$

### 3.3.2 Computer soft ware's method

With the progress in structure engineering in all types of engineering, electrical, mechanical, etc. and so on there appeared computer programming for multi uses like analysis, design, graphics, mapping and other kind of engineering parts. Moreover, from 1930 or before Second World War engineers managed to solve the problems complicated sciences with avoiding mistakes in calculations and provide short time to make decision. Also, briefing of procedures of analysis and design, which may help engineers to compress the stages of projects.

Structural programs are used for two main targets in design process. The first one is to make procedural programming that enables engineers to shorten the time of calculations in a little time by using of CAD features and to minimize the design time. The second step to use computer Intelligence techniques selection and decision making stages of the design process.

Structural programs which use CAD techniques in their process had a wide spread in engineering fields that for simplified uses in steps and learning. Also, powerful of results had merits in hand out sheet for engineers. A famous program is STAAD PRO, ETABS, SAPS, SAFE, PROKON and many programs which deferent from country to another depending on standards codes, type of analysis method, units and output of presentation or outlook for interface of the program.

The researcher in this research used SAP2000-v18.0.1 program which are familiar in engineering fields in SUDAN, easy to learn it and the researcher has an experience in this program.

The uses of structural program mainly not limit in deal with techniques of this types of program but moreover to enables with deferent engineering theorems from understanding elasticity, plasticity, finite element method passing to static and dynamic analysis Finally to the standards codes, units, materials and proprieties of the materials.

## 3.4 Soft ware's used in water tanks analysis

### 3.4.1 SAP 2000_V18

Sap200 is general-purpose civil-engineering software ideal for the analysis and design of any type of structural system. Basic and advanced systems ranging from 2D to 3D, of simple geometry to complex, may be modeled, analyzed, designed, and optimized using a practical and intuitive object-based modeling environment that simplifies and streamlines the engineering process.

### 3.4.2 ETABS V9.5 program

ETABS is used in the industry of Building Analysis and Design Software. The system was built around a physical object based graphical user interface, powered by targeted new special purpose algorithms for analysis and design. Model can include moment resisting frames, braced frames, staggered truss systems, frames with reduced beam sections or side plates, rigid and flexible floors, sloped roofs, ramps and parking structures, mezzanine floors, multiple tower buildings, and stepped diaphragm systems with complex concrete, composite or steel joist floor framing systems. Solutions to complex problems such as panel zone deformations, diaphragm shear stresses, and construction sequence loading are all available when using the ETABS. ETABS can help in designing a simple 2D frame or performing a dynamic analysis of complex high-rise structures that utilizes non-linear dampers for inter-story drift control.

### 3.4.3 Safe program

The safe program is analysis slabs by finite element .safe is ultimate integrated tool for designing reinforced and post tension concrete system.

### 3.4.4 Excel Microsoft office

Microsoft Corporation that allows users to organize, format, and calculate data with formulas using a spreadsheet system broken up by rows and columns. Microsoft Excel usually comes bundled with Microsoft Office and is compatible with other applications offered in the suite of products. The first software program similar to Excel was released in 1982 and was called Multiplan.

## 3.5 Water tank design method

Two approaches currently exist for design reinforced concrete members, strength design and allowable stress design.

The strength design method became the commonly adopted procedure for conventional buildings after 1963 revision to ACI code. Until recently the use strength design for municipal and other facilities was considered in appropriate due to lack of reliable assessment of crack width at service loads. The advances in this area of knowledge in the last two decades has led to the acceptance of the strength design method for municipal liquid retaining structures in general and concrete tanks in particular.

The latest ACI committee 350 report recommends for use of both allowable stress design and strength design for liquid retaining structures. Service state analysis of reinforcement concrete structure should include computations of crack widths and their long term effects on the structure in terms of its stability and functional performance the present state of the art of reinforced concrete design loads computations which are, at best modified from elastic analysis of the composite reinforced steel and concrete system. Due the well known effects of creep, shrinkage, temperature, all analysis of this type, in terms of computed stresses, are indices of performance of the structure and should not be construed to have any more significance than that. The load combination to determine the required strength (**U**) is requires the following tow modifications:

(1) The load factor to be used for lateral liquid pressure (**F**) is taken 1.7 rather than the value of 1.4 specified in ACI318.This value me be over conservative for some tanks, since they are filled to the top only during leak testing or because of accidental over flow. Since leak testing usually occurs only once and since most tanks are equipped with over flow pipes, some designers have considered using the load factor of 1.4 in attempt to reduce the amount of required steel which results in less shrinkage restraint. However, this publication suggests that tank designs meet ACI350 and there for recommends the use of load factor of 1.7.

(2) The members of tank must be design to meet the required strength (**U**) under ACI 318. ACI350 requires that the value of (**U**) be increased by using a multiplier called coefficient will increase the design loads to provide am one conservative design with less cracking. The increased required strength given by:

Required strength =sanitary coefficient* U

Where the sanitary coefficient equals:

1.3 For flexure

1.65 For direct tension

1.3 For shear beyond that capacity provided by the concrete.

### 3.6 Crack control

Crack widths must be minimized in tank walls to prevent leakage and corrosion of reinforcement. A criterion for flexural crack width is provided in ACI318.

This limitation is based on the Gergely-Lutz expression for crack width and is as follows:

$$z = f_s \sqrt[3]{d_c * A} \qquad (3.29)$$

Where:

Z = quantity limiting distribution of flexural reinforcement (N/mm2)

$f_s$ = calculated stress in reinforcement at service loads (N/mm2)

$d_c$ = thickness of concrete cover from extreme tension fiber to center of bar located closest there to, mm

$A$ = effective tension area of concrete surrounding the flexural tension reinforcement having the same centeriod as that reinforcement divided by numbers of bars, sq mm

The cover taking 50mm in ACI350 after that solving for the maximum spacing for given value of z gives:

$$S_{max} = z^3 / 2d^2{}_c f_s{}^3 \qquad (3.30)$$

ACI318- does not allow z to exceed 32000N/mm2/mm (180ksi/in) and 26000N/mm2/mm (145ksi/in) these value of z correspond to crack widths of 0.4mm (0.016in) and 0.33mm (0.013in) respectively.

Joints in tank walls will allow dissipation of temperature and shrinkages stresses and thereby reduce cracking. As discussed previously, the amount of temperature and shrinkage reinforcement is function of distance between shrinkage dissipating joints. Therefore, it is prudent to limit the size of concrete placement. Maximum length of wall placed at on time will usually not exceed 18m, with 9m to 15m being more common.

Water stops will be used in all joints to prevent the possibility of leakage. The cracking from temperature and shrinkage will be function of the base restraint. A sliding wall has no base fixity and this will have less restraint than tanks with fixed bases. Tanks with fixed bases tend to develop shrinkage cracks just above the slab.

## 3.7 Design procedure for elevated water tank elements

### 3.7.1 Design procedure for slab

1. Calculate effective depth **(d)**

$$d = h - cover - \frac{\emptyset_b}{2}$$

2. Calculate the initial reinforcement ratio($\boldsymbol{\rho}$)

For ductile behavior such that beam is well into the tension controlled zone, a reinforcement percentage should be chosen (50%) of $\rho_{max}$ :

$$\rho = 0.5\rho_{max}$$

$$\rho_{max} = 0.75\rho_b$$

$$\rho_b = 0.85\frac{f_{c'}}{f_y} * \beta * (\frac{600}{600 + f_y})$$

3. Find the flexural resistance factor:

$$R_u = \rho f_y(1 - \frac{\rho m}{2})$$

$$m = \frac{f_y}{0.85 f_{c'}}$$

3. Check effective depth:

$$d_{min} = \sqrt{\frac{M_u}{\emptyset b d^2}}$$

$d_{min} < d_{acual}$

4. Determine required steel are:

$A_s = \rho bd$

$$\rho = \frac{1}{m}(1 - \sqrt{1 - \frac{2R_{urev}m}{f_y}})$$

$$R_{urev} = \frac{M_u}{\emptyset bd^2}$$

5. Check for minimum steel reinforcement area:

$A_s \leq A_{Smin}$

$A_{Smin} = 0.0018\ bh$

6. Check shear:

$\emptyset V_c \geq V_u$

$\emptyset V_c = 0.17 * \emptyset\sqrt{f_{c'}} * B * d$

**3.7.2 Design procedure of rectangular wall**

a)Vertical reinforcement:

1. Calculate effective depth **(d):**

$$d = h - cover - \frac{\emptyset_b}{2}$$

2. Calculate the initial reinforcement ratio($\boldsymbol{\rho}$):

For ductile behavior such that beam is well into the tension controlled zone, a reinforcement percentage should be chosen (50%) of ρmax :

$\rho = 0.5\rho_{max}$

$\rho_{max} = 0.75\rho_b$

$$\rho_b = 0.85\frac{f_{c'}}{f_y} * \beta * (\frac{600}{600 + f_y})$$

3. Find the flexural resistance factor:

$$R_u = \rho f_y (1 - \frac{\rho m}{2})$$

$$m = \frac{f_y}{0.85 f_{c'}}$$

3. Check effective depth:

$$d_{min} = \sqrt{\frac{M_u}{\emptyset b d^2}}$$

$$d_{min} < d_{acual}$$

4. Determine required area of steel:

$$A_s = \rho b d$$

$$\rho = \frac{1}{m}(1 - \sqrt{1 - \frac{2R_{urev}m}{f_y}})$$

$$R_{urev} = \frac{M_u}{\emptyset b d^2}$$

5. Check for minimum steel reinforcement area:

$$A_s \leq A_{Smin}$$

$$A_{Smin} = 0.0018\ bh$$

<u>b) Horizontal reinforcement:</u>

1. Check shear:

$\emptyset V_c \geq V_u$

$\emptyset V_c = 0.17 * \emptyset\sqrt{f_{c\prime}} * B * d$

-If $\emptyset V_c < V_u$ then calculate $\emptyset V_s$:

$\emptyset V_s = V_u - \emptyset V_c$

-If $\frac{\emptyset V_c}{2} < \emptyset V_s < \emptyset V_c$

The section need shear reinforcement use minimum spacing from:

$(s = \frac{d}{2}, s = 600mm, \frac{3A_v f_y}{b_w}, \frac{16A_v f_y}{\sqrt{f_{c\prime}} b_w})$

-If $2\emptyset V_c < \emptyset V_s < 4\emptyset V_c$

Then (s) minimum of:

$(s = \frac{d}{4}, s = 300mm, \frac{3A_v f_y}{b_w}, \frac{16A_v f_y}{\sqrt{f_{c\prime}} b_w}, \frac{dA_v f_y}{V_s})$

-If $\emptyset V_s > 4\emptyset V_c$

Then change the section

c) Check tension stress of concrete:

$$f_c = \frac{cE_s A_s + T_{\max\,(un\,factored)}}{A_c + nA_s}$$

$c = 0.0003$

$$n = \frac{E_s}{E_c}$$

d) Calculate the maximum spacing to control cracking:

$$S_{max} = z^3 / 2d^2{}_c f_s{}^3$$

$$z = f_s \sqrt[3]{d_c * A}$$

$$A = 2d_c b_w$$

$$f_s = \frac{M}{A_s jd}$$

$$j = 1 - \frac{k}{3}$$

$$k = \sqrt{2\rho n + (\rho n)^2} - \rho n$$

If $s_{max} > reinforced\ spacing$ the section control cracking

### 3.7.3 Circular wall design procedure

a)Vertical reinforcement:

1. Calculate effective depth **(d):**

$$d = h - cover - \frac{\emptyset_b}{2}$$

2. Calculate the initial reinforcement ratio($\boldsymbol{\rho}$):

For ductile behavior such that beam is well into the tension controlled zone, a reinforcement percentage should be chosen (50%) of ρmax :

$$\rho = 0.5\rho_{max}$$

$$\rho_{max} = 0.75\rho_b$$

$$\rho_b = 0.85\frac{f_{c'}}{f_y} * \beta * (\frac{600}{600 + f_y})$$

3. Find the flexural resistance factor:

$$R_u = \rho f_y (1 - \frac{\rho m}{2})$$

$$m = \frac{f_y}{0.85 f_{c'}}$$

3. Check effective depth:

$$d_{min} = \sqrt{\frac{M_u}{\emptyset b d^2}}$$

$$d_{min} < d_{acual}$$

4. Determine required area of steel:

$$A_s = \rho b d$$

$$\rho = \frac{1}{m}(1 - \sqrt{1 - \frac{2R_{urev}m}{f_y}})$$

$$R_{urev} = \frac{M_u}{\emptyset b d^2}$$

5. Check for minimum steel reinforcement area:

$$A_s \leq A_{Smin}$$

$$A_{Smin} = 0.0018\ bh$$

<u>b) Horizontal reinforcement:</u>

1. Calculate $A_s$ from equation:

$$A_s = \frac{T_u}{0.9f_y}$$

2. Determine numbers of bars and bars spacing:

$$n = \frac{A_s}{A_b}$$

$$spacing = \frac{1000}{n}$$

3. Check shear:

$$\emptyset V_c \geq V_u$$

$\emptyset V_c = 0.17 * \emptyset\sqrt{f_{c'}} * B * d$

-If $\emptyset V_c < V_u$ then calculate $\emptyset V_s$:

$\emptyset V_s = V_u - \emptyset V_c$

-If $\frac{\emptyset V_c}{2} < \emptyset V_s < \emptyset V_c$

The section need shear reinforcement use minimum spacing from:

$(s = \frac{d}{2}, s = 600mm, \frac{3A_v f_y}{b_w}, \frac{16A_v f_y}{\sqrt{f_{c'}} b_w})$

-If $2\emptyset V_c < \emptyset V_s < 4\emptyset V_c$

Then (s) minimum of:

$(s = \frac{d}{4}, s = 300mm, \frac{3A_v f_y}{b_w}, \frac{16A_v f_y}{\sqrt{f_{c'}} b_w}, \frac{dA_v f_y}{V_s})$

-If $\emptyset V_s > 4\emptyset V_c$

Then change the section

c) Check tension stress of concrete:

$$f_c = \frac{cE_s A_s + T_{\max\,(un\,factored)}}{A_c + nA_s}$$

$c = 0.0003$

$$n = \frac{E_s}{E_c}$$

d) Calculate the maximum spacing to control cracking:

$$S_{max} = z^3 / 2d^2{}_c f_s{}^3$$

$$z = f_s \sqrt[3]{d_c * A}$$

$$A = 2d_c b_w$$

$$f_s = \frac{M}{A_s j d}$$

$$j = 1 - \frac{k}{3}$$

$$k = \sqrt{2\rho n + (\rho n)^2} - \rho n$$

If $s_{max} > reinforced\ spacing$ the section control cracking

### 3.7.4 Shear wall design procedure

1. Calculate$N_u$,$P_u$,$V_u$ from analysis output.

2. Check section capacity for compression($\emptyset P_n > N_u$):

$$\emptyset P_n = 0.55\emptyset f_{c\prime} A_g \left[1 - \left(\frac{k * L_w}{32h}\right)^2\right]$$

$$A_g = h * l_w$$

$$\emptyset = 0.65 \ \& \ k = 0.8$$

$\emptyset P_n > N_u$ o.k.

4. Check shear strength:

Calculate concrete strength of shear $V_c$and$V_c$ shall be permitted to be the lesser of the values ($\emptyset V_{c1}$ & $\emptyset V_{c2}$).

$$\emptyset V_{c1} = \emptyset \left[0.27\sqrt{f_{c\prime}} * h * d + \frac{N_u * d}{4 l_w}\right]$$

$$\emptyset V_{c2} = \emptyset \left[0.05\sqrt{f_{c\prime}} + \frac{l_w \left(0.1\sqrt{f_{c\prime}} + \frac{0.2 N_u}{l_w h}\right)}{\left(\frac{M_u}{V_u} - \frac{l_w}{2}\right)}\right] * h * d$$

Use minimum of $\emptyset V_{c1}$ & $\emptyset V_{c2}$

$\emptyset V_{c1} > V_u$

5. Calculate shear reinforcement ratio:

If $V_u < 0.5\emptyset V_c$

$\rho_t = \rho_{min} = 0.0025$

6. Calculate $A_s = \rho_t bh$

$n = \frac{A_s}{2A_b}$ Spacing =1000/n

-maximum spacing minimum of ($\frac{l_w}{5}, 3h, 450, s$)

6. Calculate vertical reinforcement ratio:

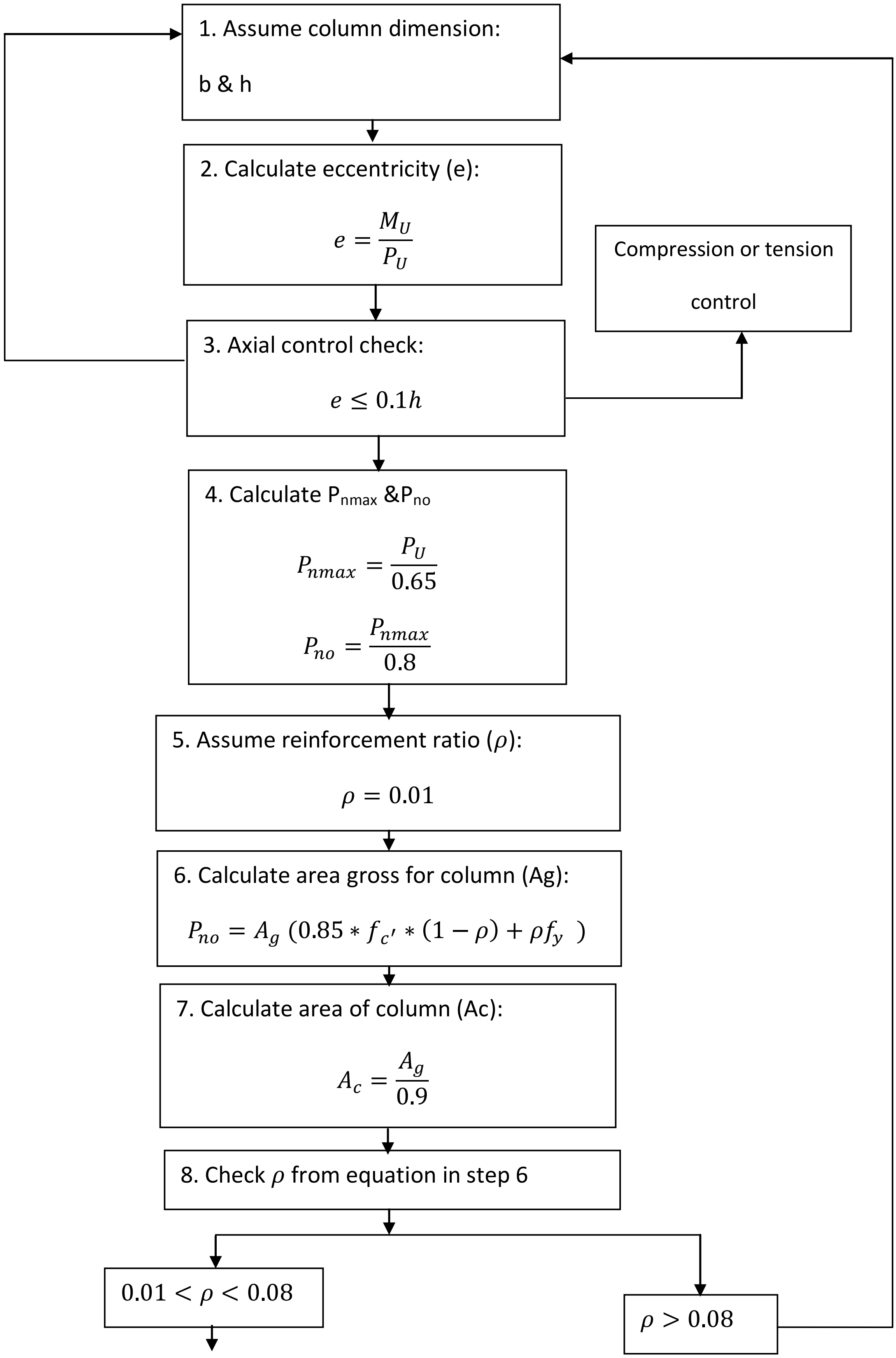
$$\rho_l = 0.0025 + 0.5\left[2.5 - \frac{h_w}{l_w}\right][\rho_t - 0.0025]$$

7. Calculate reinforcement area:

$A_s = \rho bh$

### 3.7.5 Axial column design procedure

The design procedure is summarized as alliterated in Fig(3.4)



9. Determine area of steel (As):

$$A_s = \rho * b * h$$

↓

10. Assume bar diameter and calculate bar area Ab

↓

11. Calculate number of bar:

$$n = \frac{A_s}{A_b}$$

↓

12. Calculate ties spacing minimum of:

1. $48d_t$
2. 16 $d_b$
3. Minimum b or h

**Fig (3.5): Design flow chart of column**

### 3.7.6 Beams design

**The design of beam for flexure is summarized as follows:**

1. Calculate effective depth **(d)**

$$d = h - cover - \frac{\emptyset_b}{2}$$

2. Calculate the initial reinforcement ratio($\boldsymbol{\rho}$):

For ductile behavior such that beam is well into the tension controlled zone, a reinforcement percentage should be chosen (50%) of ρmax :

$$\rho = 0.5\rho_{max}$$

$$\rho_{max} = 0.75\rho_b$$

$$\rho_b = 0.85\frac{f_{c'}}{f_y} * \beta * (\frac{600}{600 + f_y})$$

3. Find the flexural resistance factor:

$$R_u = \rho f_y(1 - \frac{\rho m}{2})$$

$$m = \frac{f_y}{0.85 f_{c'}}$$

3. Check effective depth:

$$d_{min} = \sqrt{\frac{M_u}{\emptyset b d^2}}$$

$$d_{min} < d_{acual}$$

4. Determined (a) from:

$$M_n = c * l.a$$

$$c = 0.85 f_{c\prime} * b * a$$

$$l.a = (d - \frac{a}{2})$$

4. Determine required area of steel:

-From equilibrium

$$c = T$$

$$A_s = \frac{T}{fy}$$

5. Check for minimum steel reinforcement area:

$$A_s \leq A_{Smin}$$

$$A_{Smin} = \frac{1.4}{f_y} * bh$$

**The design beam for shear is summarized as follows:**

$\emptyset V_c = 0.17 * \emptyset * \sqrt{f_{c'}} * b * d$

-Case 1:

$\frac{\emptyset V_c}{2} > V_u$

The section not need shear reinforcement.

-Case 2:

$Vu > \emptyset V_c$

Then:

Calculate$\emptyset V_s$:

$\emptyset V_s = V_u - \emptyset V_c$

-If $\frac{\emptyset V_c}{2} < \emptyset V_s < \emptyset V_c$

The section need shear reinforcement use minimum spacing from:

$(s = \frac{d}{2}, s = 600mm, \frac{3A_v f_y}{b_w}, \frac{16A_v f_y}{\sqrt{f_{c'}} b_w})$

-If $2\emptyset V_c < \emptyset V_s < 4\emptyset V_c$

Then (s) minimum of:

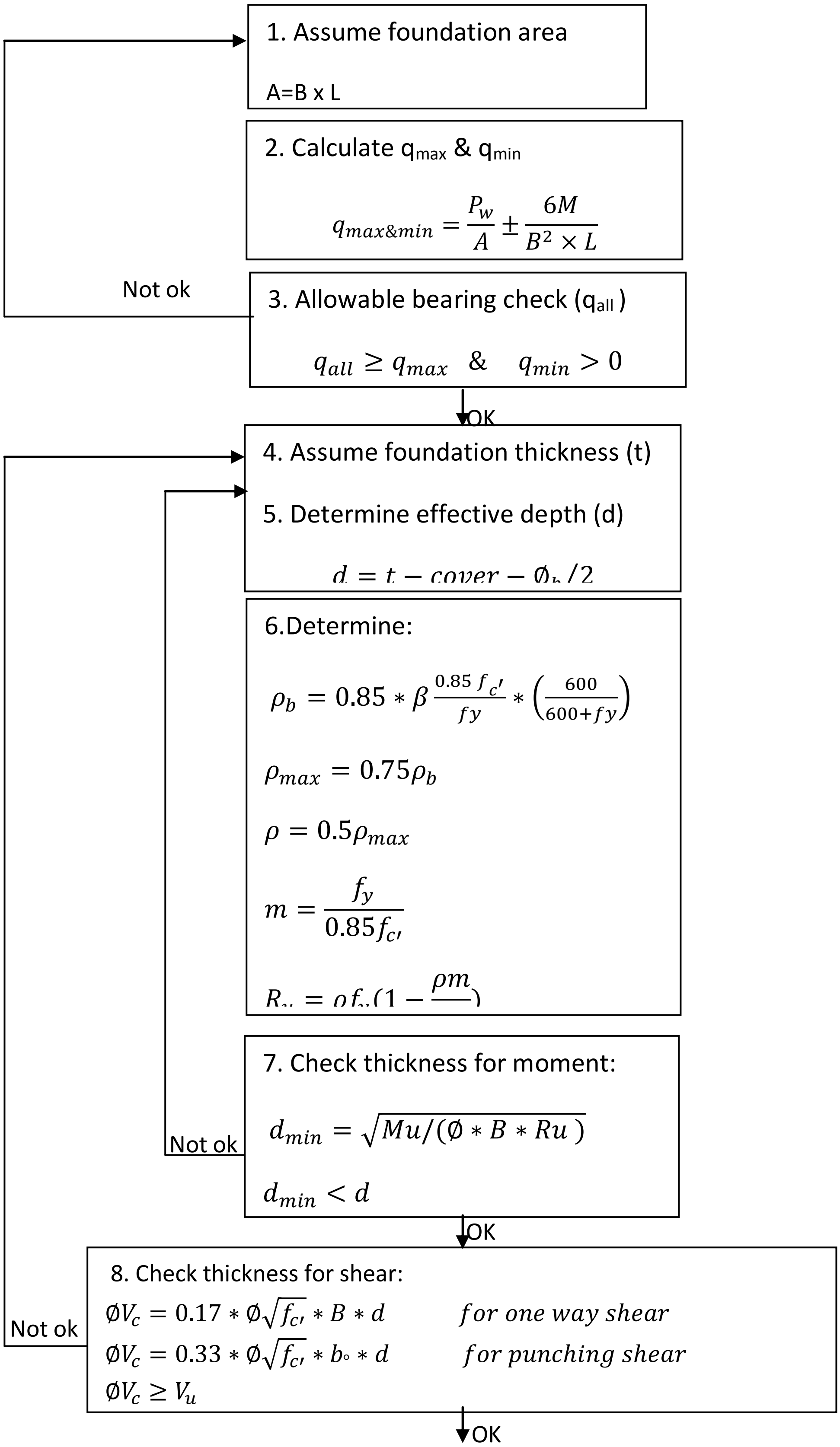
$(s = \frac{d}{4}, s = 300mm, \frac{3A_v f_y}{b_w}, \frac{16A_v f_y}{\sqrt{f_{c'}} b_w}, \frac{dA_v f_y}{V_s})$

-If $\emptyset V_s > 4\emptyset V_c$

Then change the section

### 3.7.7 Foundation design procedure

The foundation design is summarized as shown in Fig(3.5)



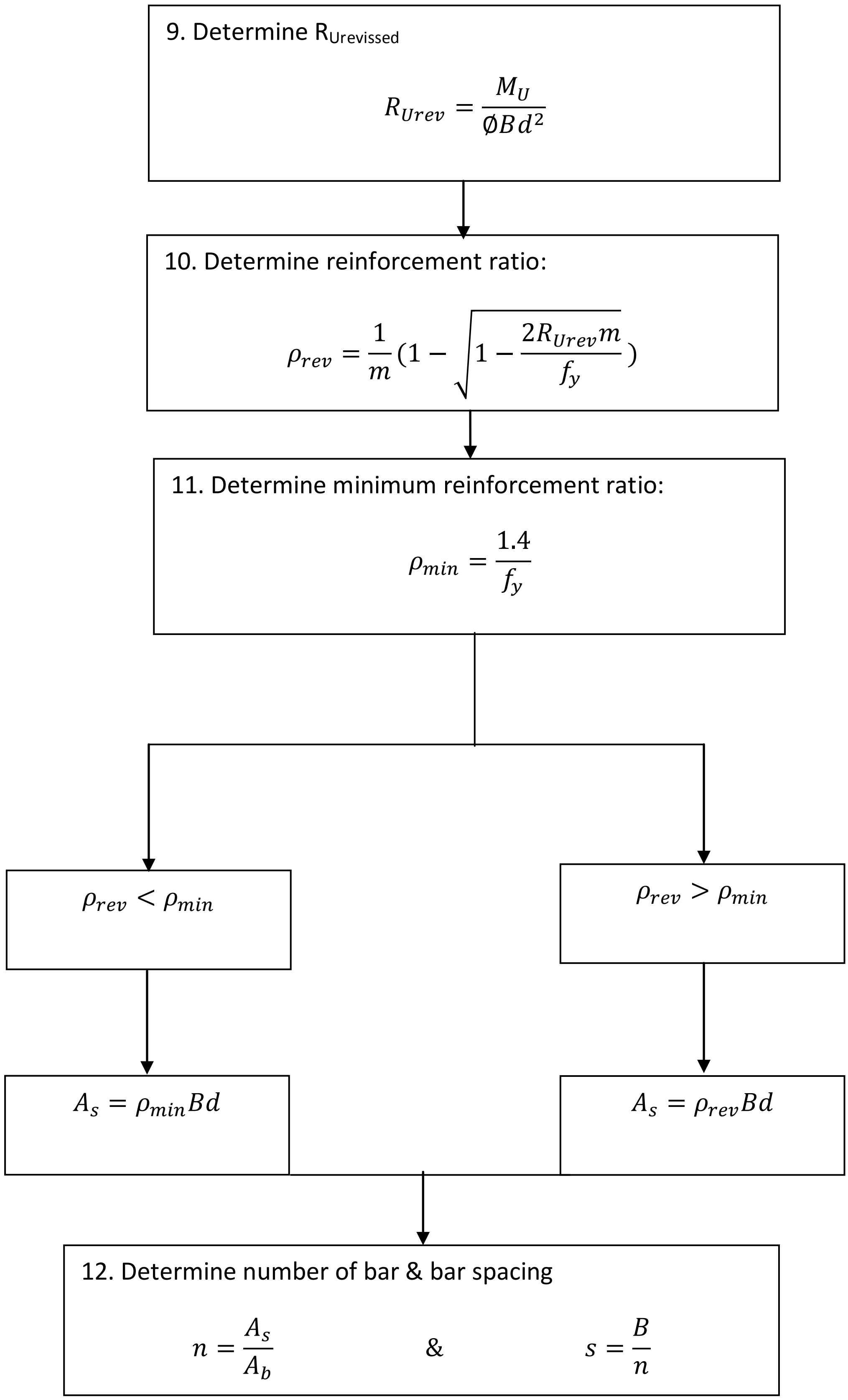



**Fig (3.6) Design flow chart of foundation**

### 3.8 Elevated water tank stability

The checks for stability for any structure are against overturning, sliding and bearing capacity failure. The factor of safety against overturning may be expressed as:

$$Fs_{(overturning)} = \frac{\sum M_R}{\sum M_o}$$

Where:

$\sum M_o$ = sum of the moments of forces tending to overturning

$\sum M_R$ = sum of the moments of forces tending to resist overturning

The factor of safety against sliding may be expressed by the equation:

$$Fs_{(sliding)} = \frac{\sum F_R}{\sum F_d}$$

$\sum F_R$ = sum of the horizontal resisting forces

$\sum F_d$ = sum of the horizontal driving forces

$$\sum F_R = \sum N \, tan\delta' + B{c_a}'$$

Where:

$\sum F_R$ = sum of vertical load

$\delta'$ = angle of friction between the soil and the base slab

${c_a}'$ = adhesion between the soil and the base slab

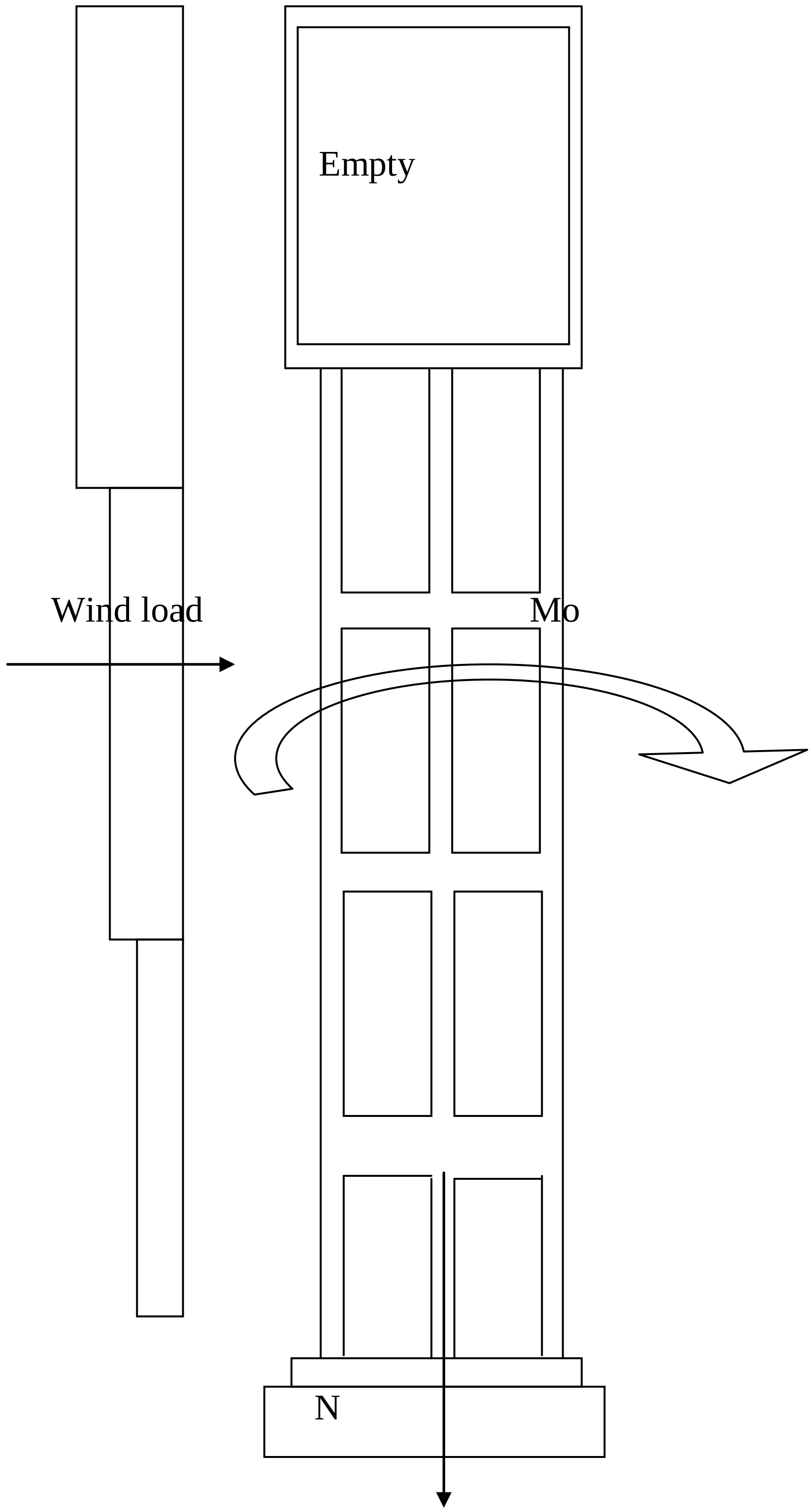



**Fig (3.7): Overturning check**

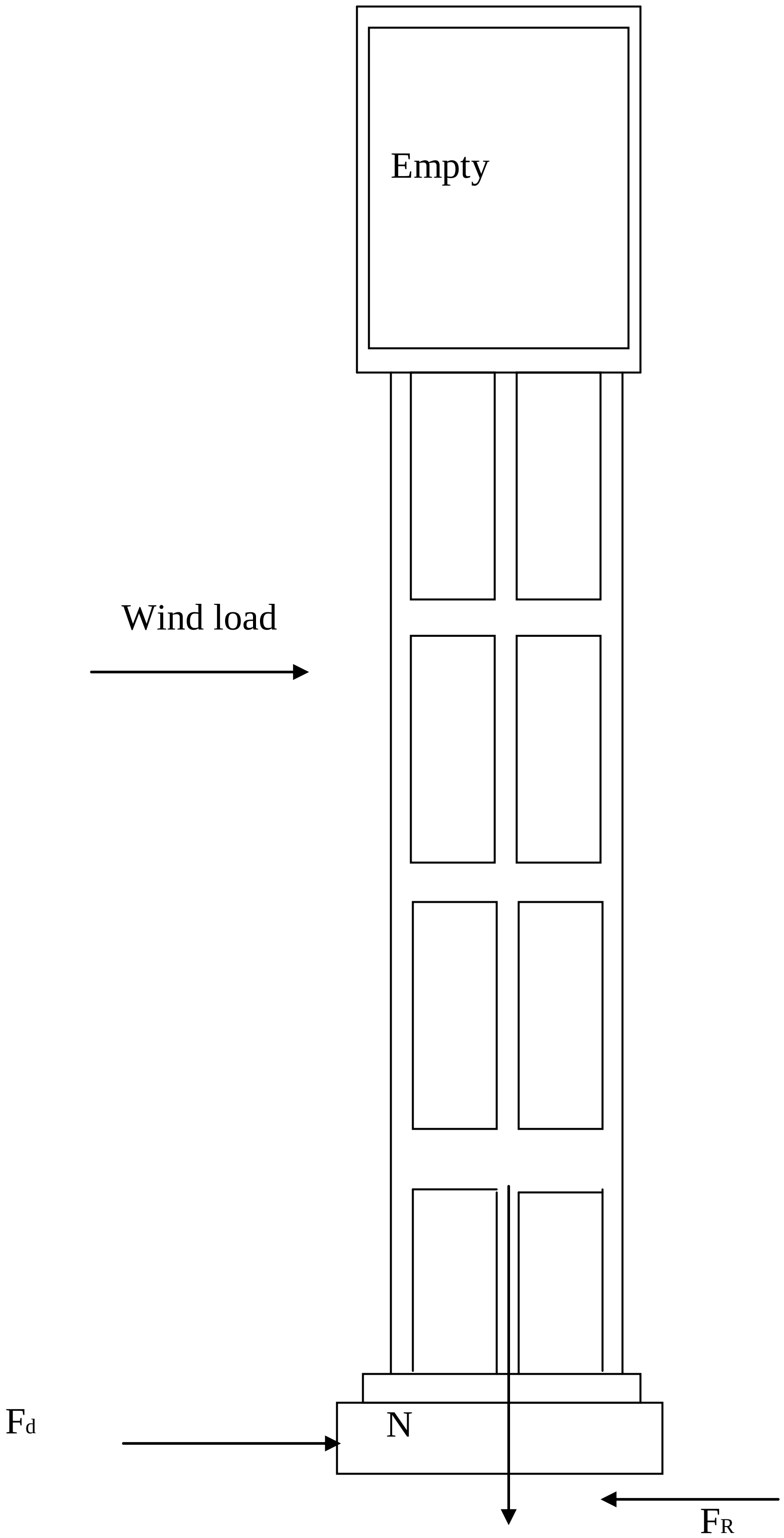



**Fig (3.8): sliding check**

## 3.9 Load applied on water tanks

The horizontal load that is load effect in structure horizontally like wind pressure, water or hydrostatic pressure and earth pressure of soil on underground water tank.

### 3.9.1 Water pressure

Water pressure is called hydrostatic pressure it depends only on the depth of water not on the water surface area. It increases in direct proportion to the depth of water. The hydrostatic pressure in continuous volume of water is the same at all points that are the same depth or elevation. The wall of tank is carry effect of water pressure and water pressure calculate by :

P=$\gamma_w * H$

$\gamma_w$ ≡Water density (10KN/m$^3$)

$H$ ≡The height of water

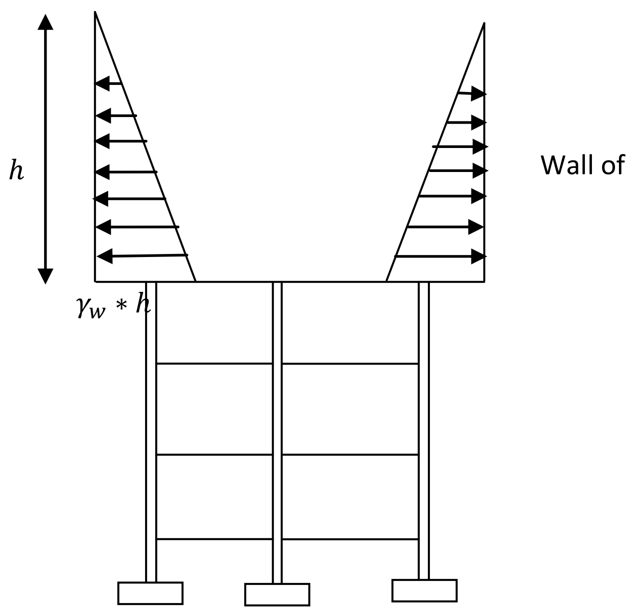



**Fig (3.9): Hydrostatic pressure in wall of tank**

### 3.9.2 Wind load

Wind velocity will cause pressure on any surface. The velocity pressure depends on the height from the ground level. The following equation is recommended by ASCE 7-05 CODE of practice for calculation the velocity pressure, qz, resulting from winds:

$$qz=0.613K_z*K_{zt}*K_d*V^2*I \qquad (N/m^2)$$

where:

V: is the basic wind speed (m/s)

$K_d$: is directionality factor from Table (3.4)

$K_{zt}$: is topographic factor

$k_{zt}$= 1 for flat ground

kz: varies with height z above the ground level obtained from

$P_z = q_z G C_p$ For windward positive pressure

$P_z = q_h G C_p$ For leeward negative pressure

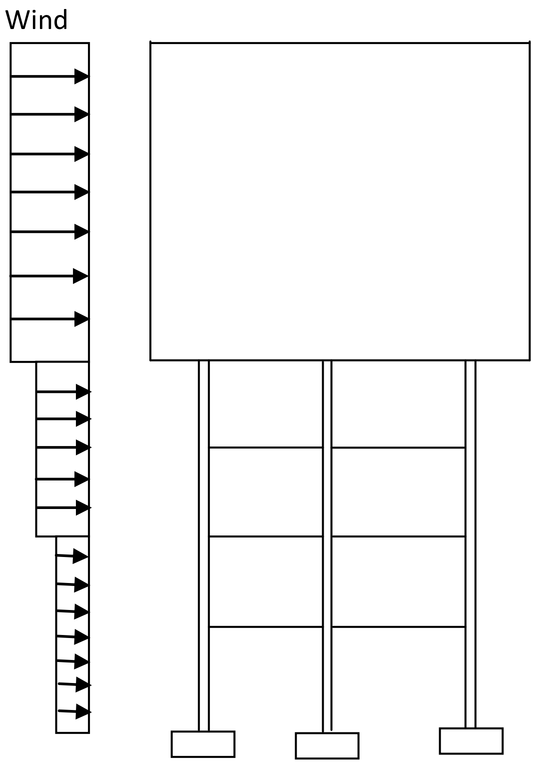



**Fig (3.10): Wind pressure**

### 3.9.3 Dead load

Dead loads consist of the weight of all materials of construction incorporated into the building including but not limited to, walls, floors, roofs, Beams, columns and footings self weight load.

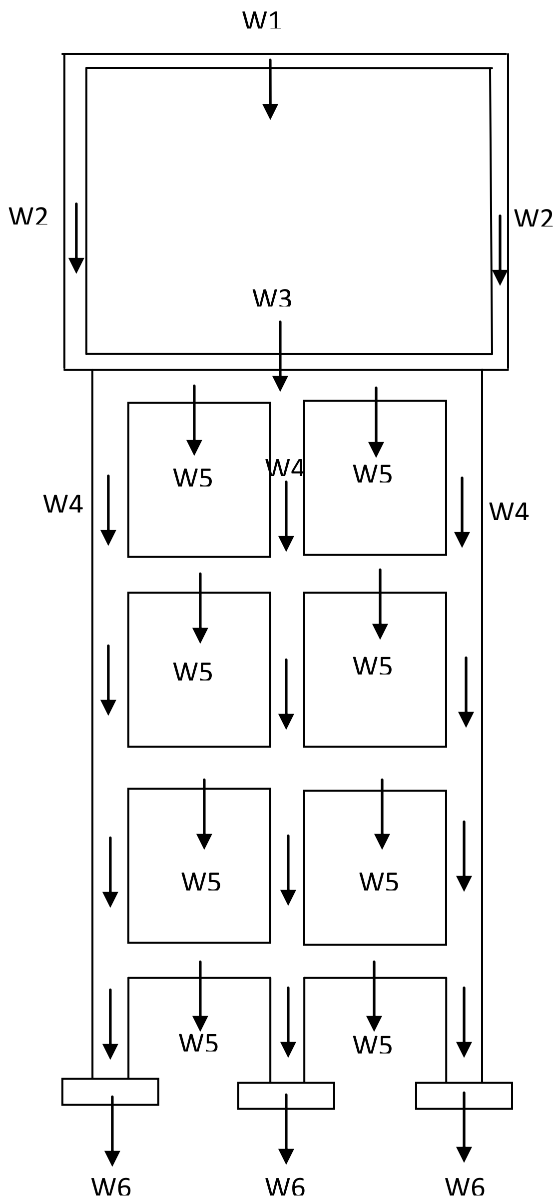



**Fig (3.11): Dead load (self weight)**

W1: weight of roof slab W2: weight of wall

W3: bottom slab weight W4: weight of column

W5: weight of beam W6: weight of footing

### 3.9.4 Water weight

The water weight acting vertically and its calculate by unit weight in meter square and depend on height of water. The maximum value of water weight in case of tank full by water and zero if tank is empty. Its calculate by equation:

Water weight = $\gamma_w * h$

h: height of water

## 3.10 Load combination

1. 1.4 DL

2. 1.2 DL+1.6 L

3. 1.2DL+W+L

4. 0.9DL+1.6L

5. D+0.75L+0.75W+F

6. D+L+W

7. 1.7F

## 3.11 load calculation for water tank

### 3.11.1Wind load calculation

-Rectangular elevated water tank:

$q_z = 0.613k_z * k_{zt} * k_d * v^2 * I$

$k_d = 0.9$

$I = 1$

$k_{zt} = 1$

$v = 47\, m/s$

$q_z = 0.613 * k_z * 1 * 1 * 47^2 * 0.9$

$q_z = 1218.7053 * k_z \quad N/m^2$

at z= 24m $\quad k_z = 0.925$ from table

at z= 15m $\quad k_z = 0.81$ from table

$q_{24} = 0.925 * 1218.705 = 1127.3\, N/m^2$

$q_{15} = 0.81 * 1218.705 = 987.15\, N/m^2$

$p_z = q_z * G * C_p$

G=0.85

$C_p = 0.8$ (Wind ward)

$C_p = -0.5$ (Leeward)

$p_{24} = 1.1273 * 0.85 * 0.8 = 0.77\, kN/m^2$ (Wind ward)

$p_{24} = 1.1273 * 0.85 * -0.5 = -0.48\, kN/m^2$ (Leeward)

Total wind pressure at 24m =$p_{24} = 1.25\, kN/m^2$

$p_{15} = 0.987 * 0.85 * 0.8 = 0.67\, kN/m^2$ (Wind ward)

$p_{15} = 0.987 * 0.85 * -0.5 = -0.42\, kN/m^2$ (Leeward)

Total wind pressure at 15m =$p_{15} = 1.09\, kN/m^2$

-Circular elevated water tank:

$q_z = 0.613 k_z * k_{zt} * k_d * v^2 * I$

$k_d = 0.95$

$I = 1$

$k_{zt} = 1$

$v = 47\, m/s$

$q_z = 0.613 * k_z * 1 * 1 * 47^2 * 0.95$

$q_z = 1286.4115 * k_z \quad N/m^2$

at z= 24m $k_z = 0.925$ from table

at z= 15m $k_z = 0.81$ from table

$q_{24} = 0.925 * 1286.4115 = 1189.931\, N/m^2$

$q_{15} = 0.81 * 1286.4115 = 1041.993\, N/m^2$

$p_z = q_z * G * C_p$

G=0.85

$C_p = 0.8$ (Wind ward)

$C_p = -0.5$ (Leeward)

$p_{24} = 1.1899 * 0.85 * 0.8 = 0.81\, kN/m^2$ (Wind ward)

$p_{24} = 1.1899 * 0.85 * -0.5 = -0.505\, kN/m^2$ (Leeward)

Total wind pressure at 24m =$p_{24} = 1.315\, kN/m^2$

$p_{15} = 1.042 * 0.85 * 0.8 = 0.708\, kN/m^2$ (Wind ward)

$p_{15} = 1.042 * 0.85 * -0.5 = -0.443\, kN/m^2$ (Leeward)

Total wind pressure at 15m =$p_{15} = 1.151\, kN/m^2$

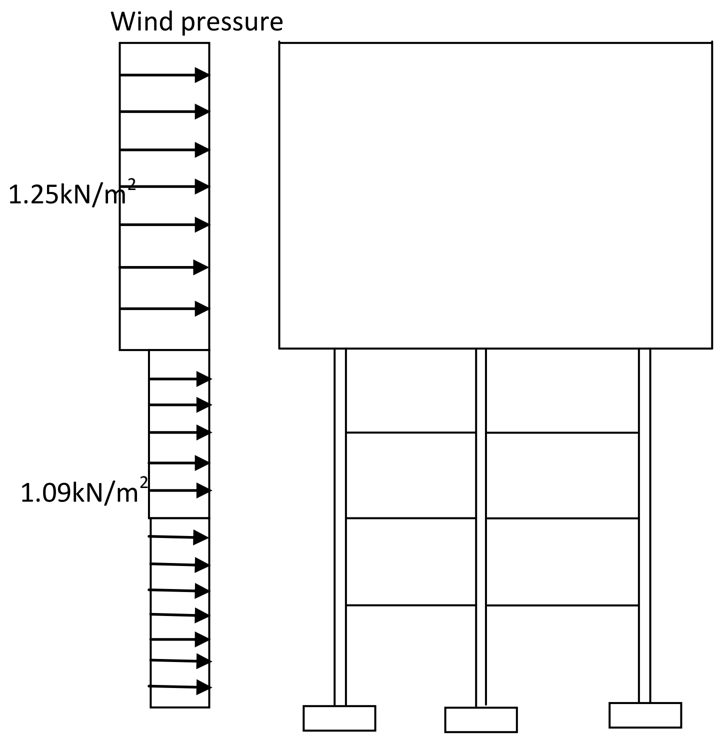



**Fig (3.12): Rectangular elevated water tank – wind pressure**

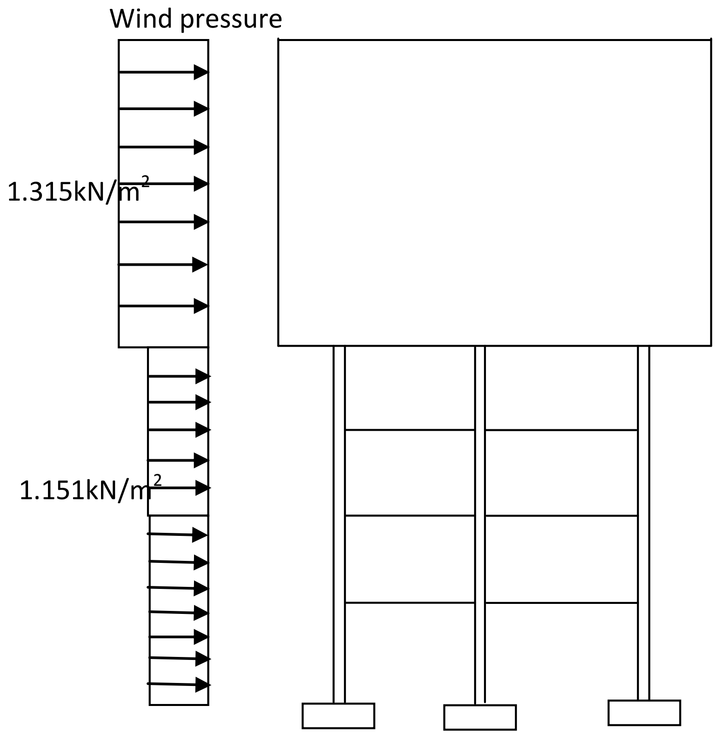



**Fig (3.13): circular elevated water tank- wind pressure**

## 3.12 Analysis data for case study

**Table (3.5): General data.**

| **parameter** | **Measure** |
|---|---|
| The height of water tank | 24m |
| Capacity of tank | $576m^3$ |
| Wind velocity | 47m/s |
| Allowable bearing capacity | $250kN/m^2$ |

**Table (3.6): Rectangular water tank data.**

| **parameter** | **Measure** |
|---|---|
| Tank dimension | 8m x 8m x 9m |
| Number of columns | 8 |
| Columns dimension | 0.5mx0.5m |
| Beams dimension | 0.4mx0.6m |
| Top slab thickness | 0.2m |
| Bottom slab thickness | 0.3m |
| Thickness of wall | 0.3m |
| Space between columns | 3.5m |

**Table (3.7): Circular water tank data.**

| parameter | Measure |
|---|---|
| Tank diameter | 9m |
| Tank height | 9m |
| Number of columns | 8 |
| Columns  diameter | 0.5m |
| Beams dimension | 0.4mx0.6m |
| Top slab thickness | 0.2m |
| Bottom slab thickness | 0.3m |
| Thickness of wall | 0.3m |
| Space between columns | 3.5m |

## 3.13Analysis methods

### 3.13.1 Approximated method analysis

The approximated analysis was done for rectangular elevated water tank show in Fig (3.14) the data analysis and result presented in Excel spread sheets as shown in table (3.8).

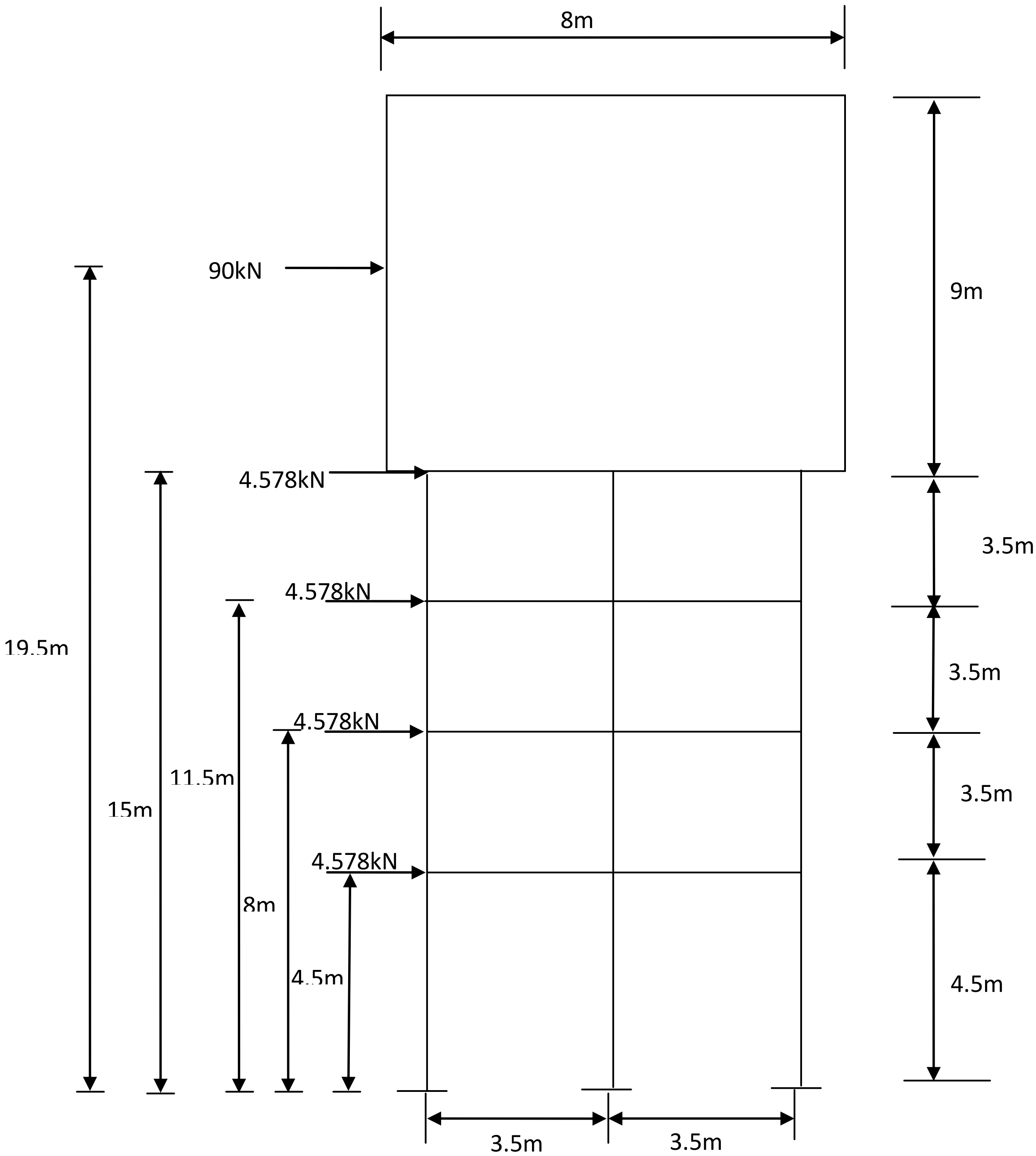



**Fig (3.14): Rectangular elevated tank**

**Table (3.8): Approximated analysis for rectangular elevated tank.**

| | | | | | |
|---|---|---|---|---|---|
| L | 8m | B | 8m | H | 9m |
| $H_1$ | 4.5m | $H_2$ | 3.5m | $H_3$ | 3.5m |
| $H_4$ | 3.5m | $H_5$ | 3.5m | $S_1$ | 3.5m |
| $S_2$ | 3.5m | $b_{column}$ | 0.5m | $b_{beam}$ | 0.5m |
| $t_{B.slab}$ | 0.3m | $h_{column}$ | 0.5m | $h_{beam}$ | 0.5m |
| $t_{T.slab}$ | 0.2m | $t_{wall}$ | 0.3m | $\gamma_{conrete}$ | 24kN/m$^3$ |
| $\gamma_{water}$ | 10 kN/m$^3$ | No.columns | 8 | Wall height | 9m |
| $P_{beam}$ | 28m | No.floor | 3 | t.c.hieght | 15m |
| $p_{z(24m)}$ | 1.25kN/m$^2$ | $p_{z(15m)}$ | 1.09kN/m$^2$ | | |

Calculations

| | | | |
|---|---|---|---|
| $w_1$ | 90kN | $w_2$ | 4.578kN |
| $w_3$ | 4.578kN | $w_4$ | 4.578kN |
| $w_5$ | 4.578kN | $h_1$ | 19.5m |
| $h_2$ | 15m | $h_3$ | 11.5m |
| $h_4$ | 8m | $h_5$ | 4.5m |
| $M_1$ | 1933.542 kN.m | $\sum M$ | 243.702 kN.m |
| | Moment & axial Due to wind | | |

| | | | |
|---|---|---|---|
| $R_{column}$ | 80.468 kN | $M_{column}$ | 30.5 kN.m |
| | Vertical load | | |
| Water weight | 5760 kN | Beams weight | 806.4 kN |
| Walls weight | 2073.6 kN | Columns weight | 720 kN |
| Top slab weight | 307.2 kN | Bottom slab weight | 460.8 kN |
| | Total weight | 10128 kN | |
| Load on each columns | **1266 kN** | Total load on each columns | **1346.469 kN** |
| | Bracing shear& Bracing Moment | | |
| $M_B$ | **60.925 kN.m** | $V_B$ | **35 kN** |

The approximated analysis was done for circular elevated water tank show in Fig (3.14) the data analysis and result presented in Excel spread sheets as shown in table (3.9).

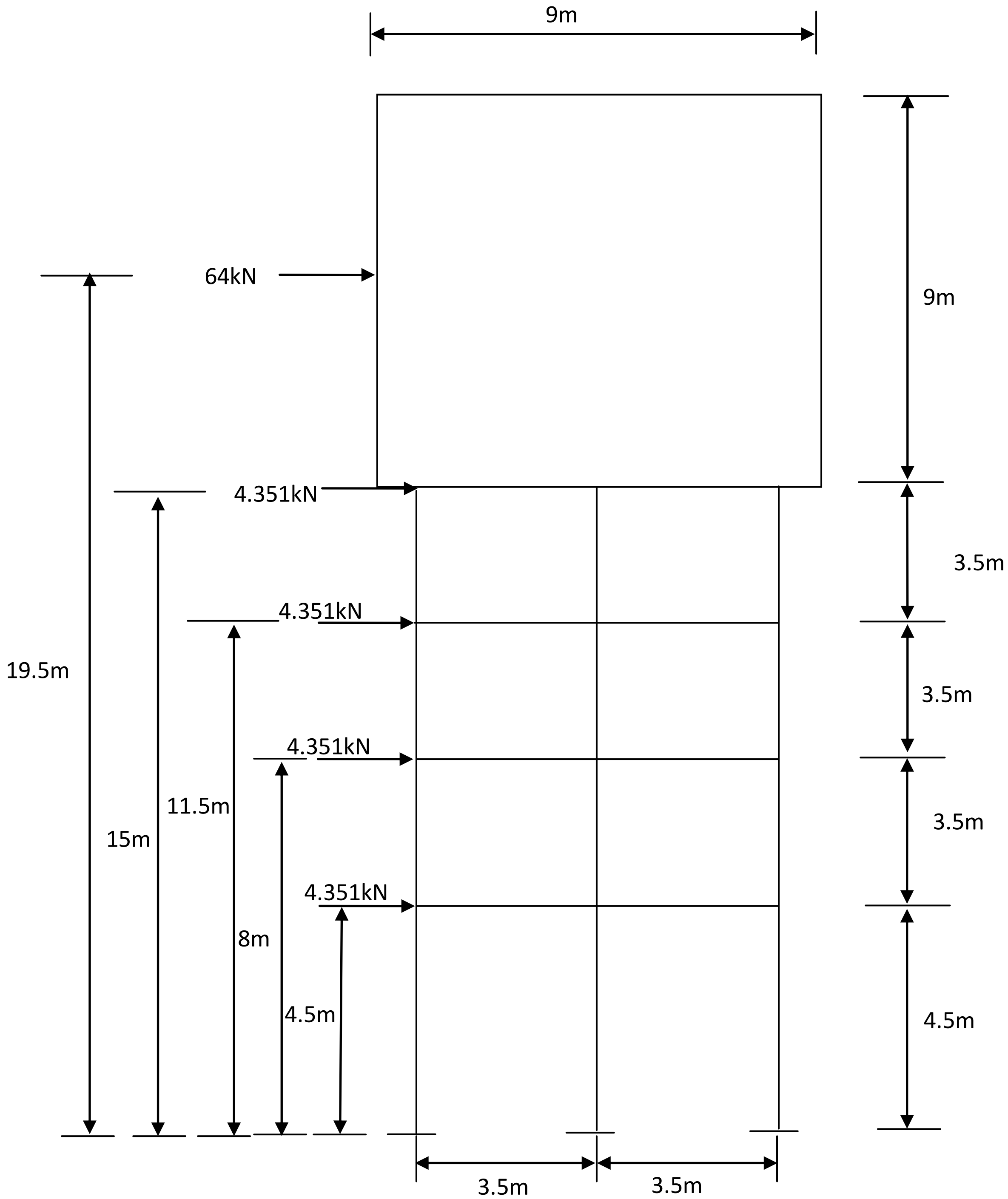



**Fig (3.15): Circular elevated tank**

**Table (3.9): Approximated analysis for circular elevated tank.**

| | | | | | |
|---|---|---|---|---|---|
| L | _ | D | 9m | H | 9m |
| $H_1$ | 4.5m | $H_2$ | 3.5m | $H_3$ | 3.5m |
| $H_4$ | 3.5m | $H_5$ | 3.5m | $S_1$ | 3.5m |
| $S_2$ | 3.5m | $D_{column}$ | 0.6m | $D_{beam}$ | 0.5m |
| $t_{B.slab}$ | 0.3m | $c_f$ | 0.6 | $L_{beam}$ | 2.475 |
| $t_{T.slab}$ | 0.2m | $t_{wall}$ | 0.3m | $\gamma_{conrete}$ | 24kN/m$^3$ |
| $\gamma_{water}$ | 10 kN/m$^3$ | No.columns | 8 | Wall height | 9m |
| $P_{beam}$ | 28m | No.floor | 3 | t.c.hieght | 15m |
| $p_{z(24m)}$ | 1.25kN/m$^2$ | $p_{z(15m)}$ | 1.09kN/m$^2$ | | |

Calculations

| | | | |
|---|---|---|---|
| $w_1$ | 63.9kN | $w_2$ | 4.351kN |
| $w_3$ | 4.351kN | $w_4$ | 4.351kN |
| $w_5$ | 4.351kN | $h_1$ | 19.5m |
| $h_2$ | 15m | $h_3$ | 11.5m |
| $h_4$ | 8m | $h_5$ | 4.5m |
| $M_1$ | 1415.934 kN.m | $\sum$M | 182.96 kN.m |
| | Moment & axial<br>Due to wind | | |

| | | | |
|---|---|---|---|
| $R_{column}$ | 88.065 kN | $M_{column}$ | 23 kN.m |
| | Vertical load | | |
| Water weight | 5760 kN | Beams weight | 574.372 kN |
| Walls weight | 1833 kN | Columns weight | 101.736 kN |
| Top slab weight | 305.36 kN | Bottom slab weight | 458.1 kN |
| | Total weight | 8998.068 kN | |
| Load on each columns | **1124.76 kN** | Total load on each columns | **1214 kN** |
| | Bracing shear& Bracing Moment | | |
| $M_B$ | **65.1 kN.m** | $V_B$ | **48.75 kN** |

### 3.13.2 Program analysis

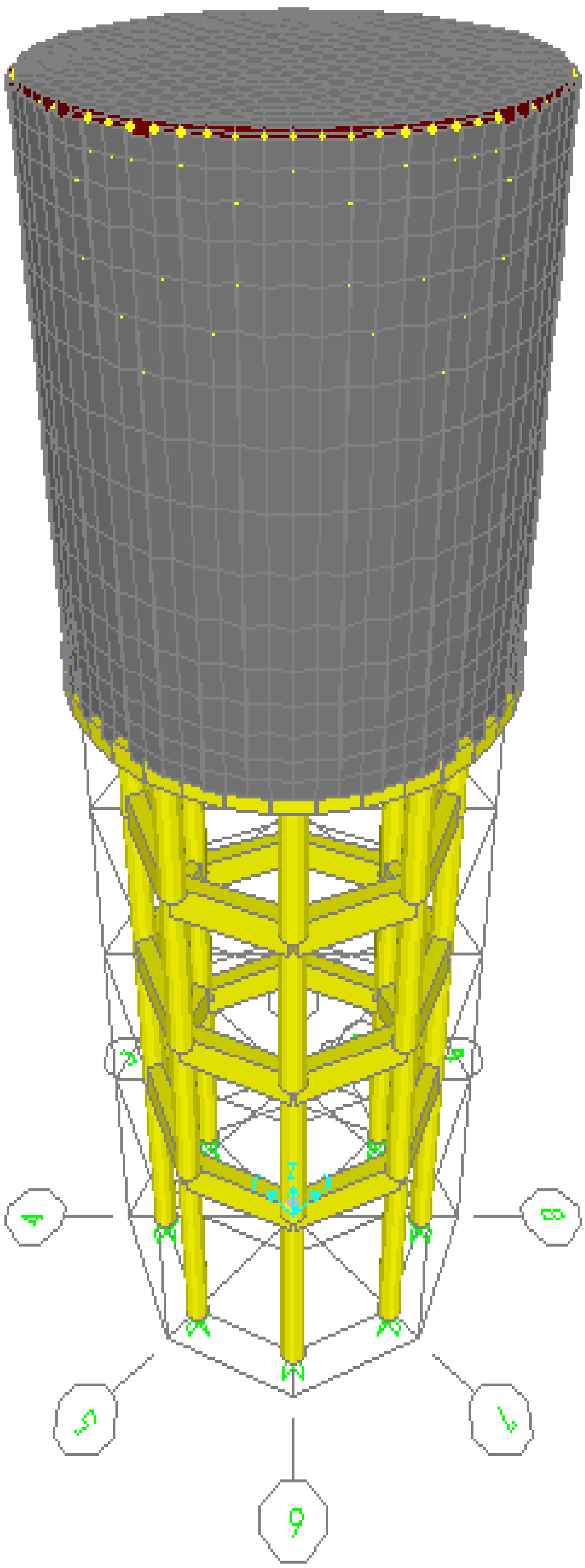


**Fig (3.16): Circular elevated tank model**

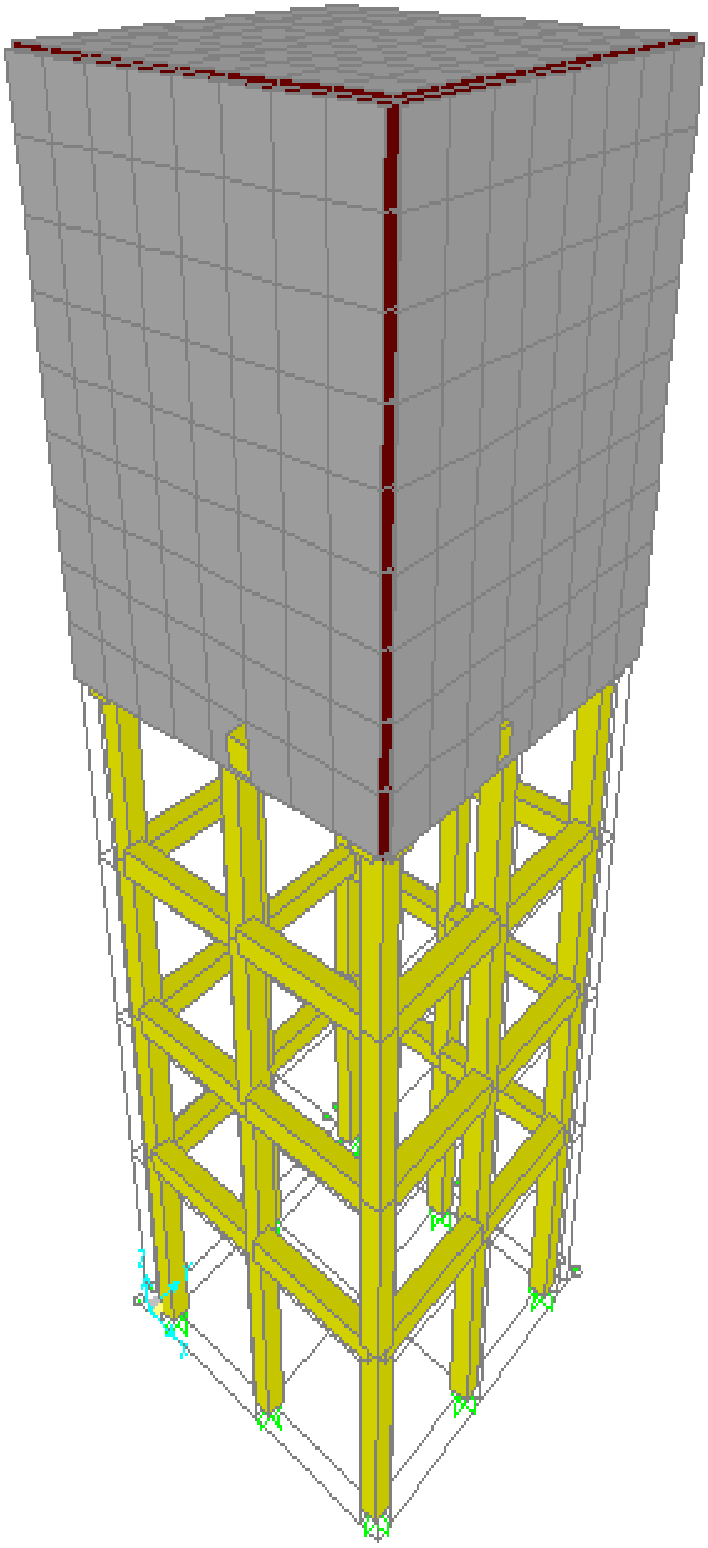
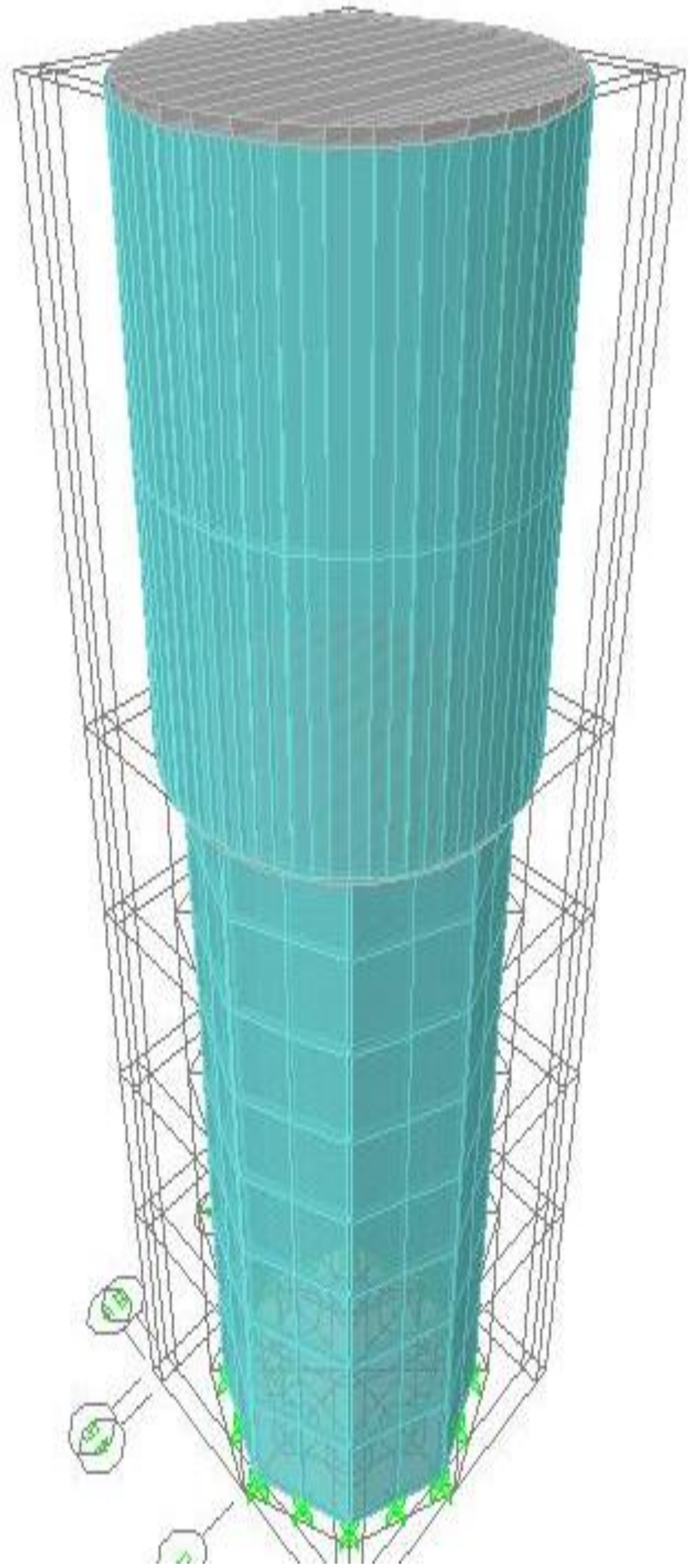


**Fig (3.17): Rectangular elevated tank model**

**Fig (3.18): Circular elevated tank supporting in walls model**



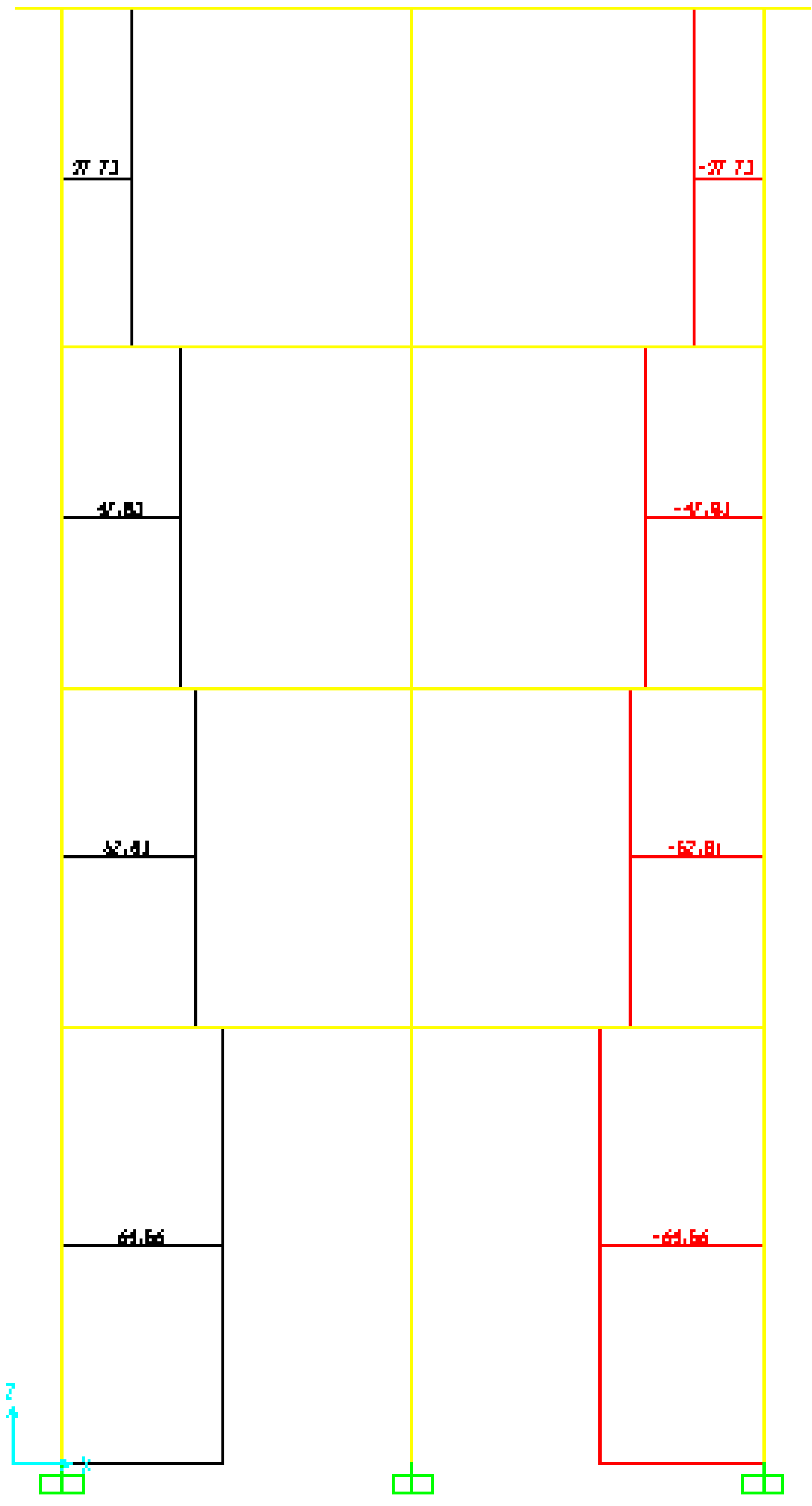


**Fig (3.19): Rectangular elevated water tank – columns axial due to wind load**

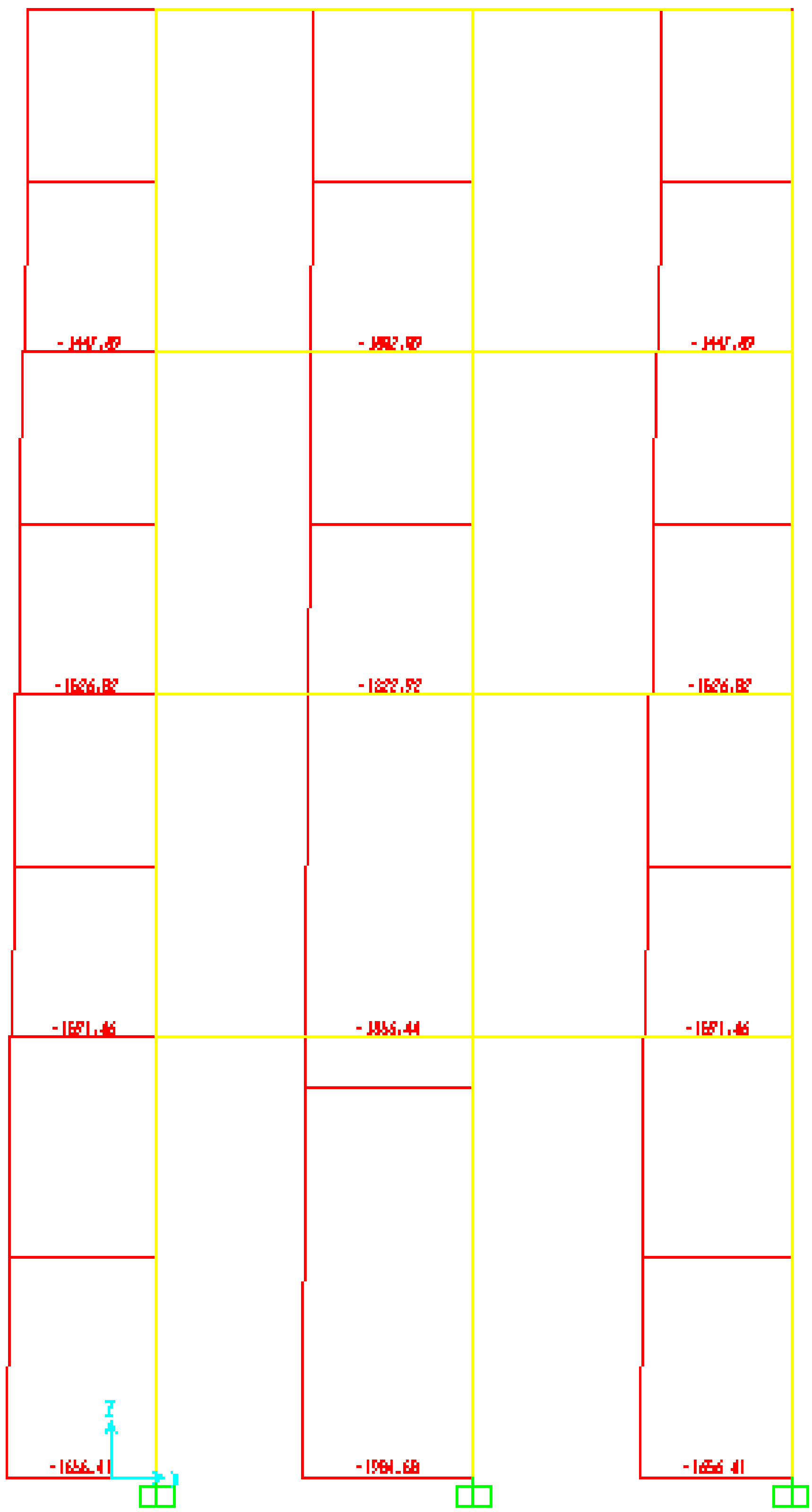



**Fig (3.20): Rectangular water tank - columns axial load due to Combination (2)**

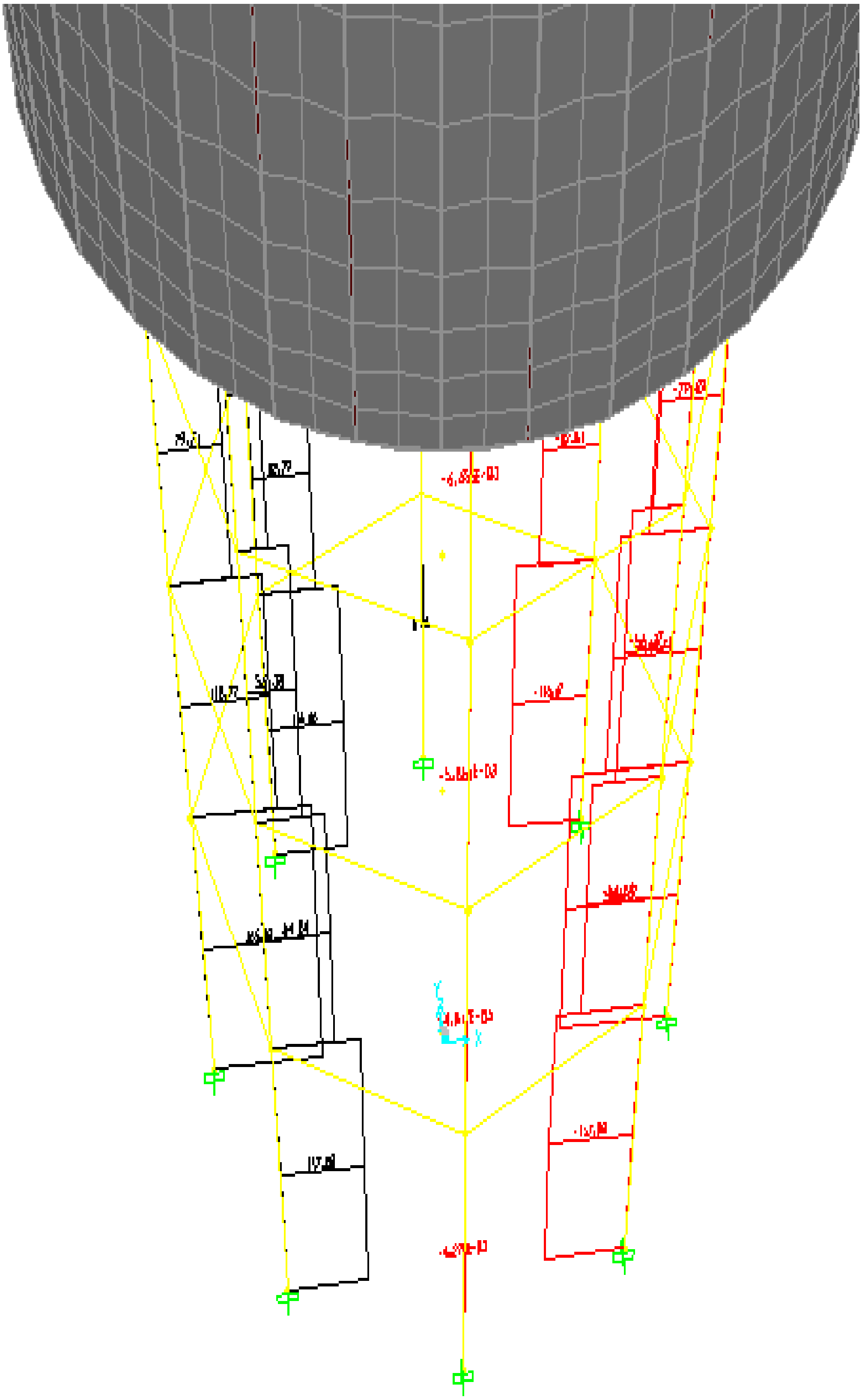


**Fig (3.21): Circular water tank-columns axial load due to wind load**

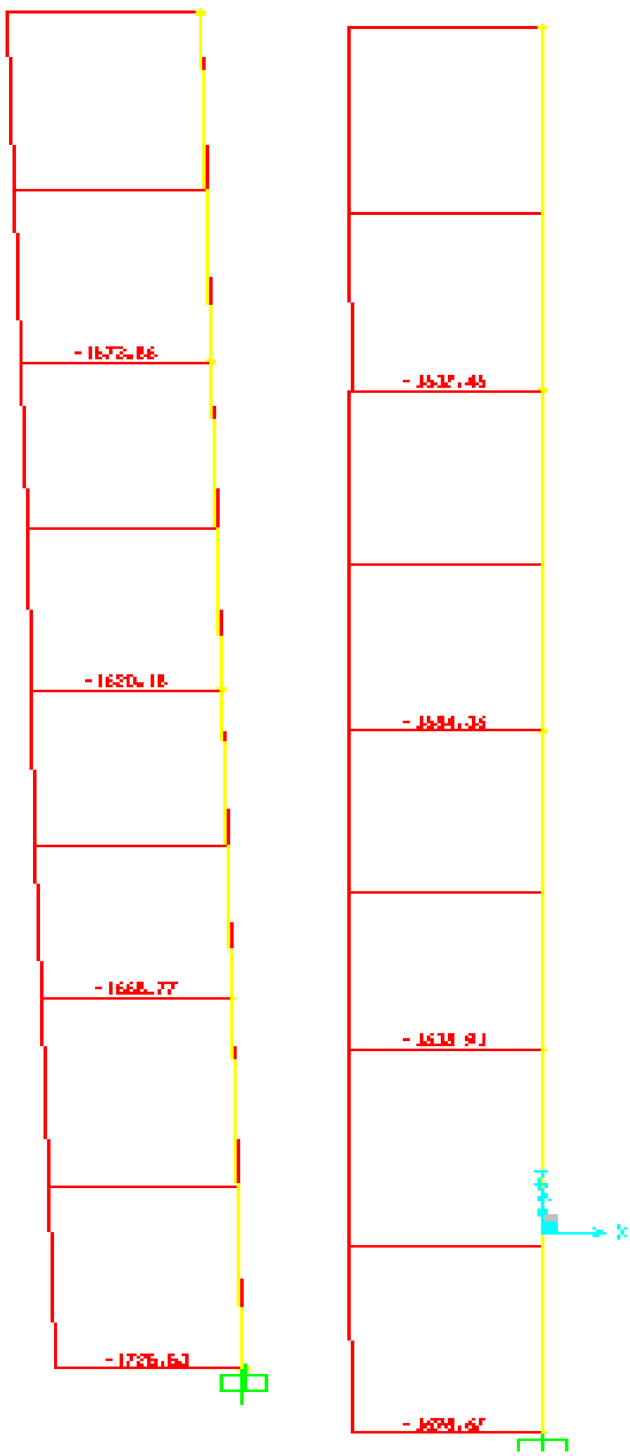


**Fig (3.22): circular water tank-columns axial load due to combination (2)**

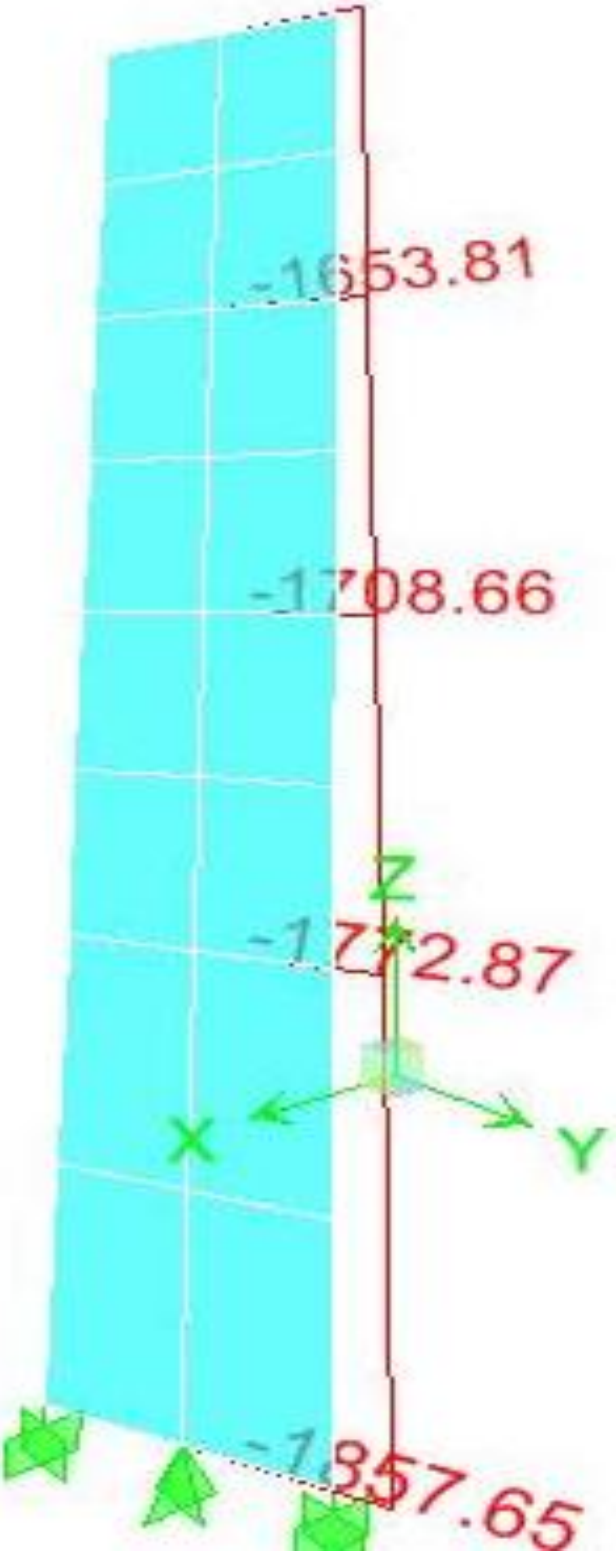



**Fig (3.23): circular water tank- wall axial due to combination (2)**

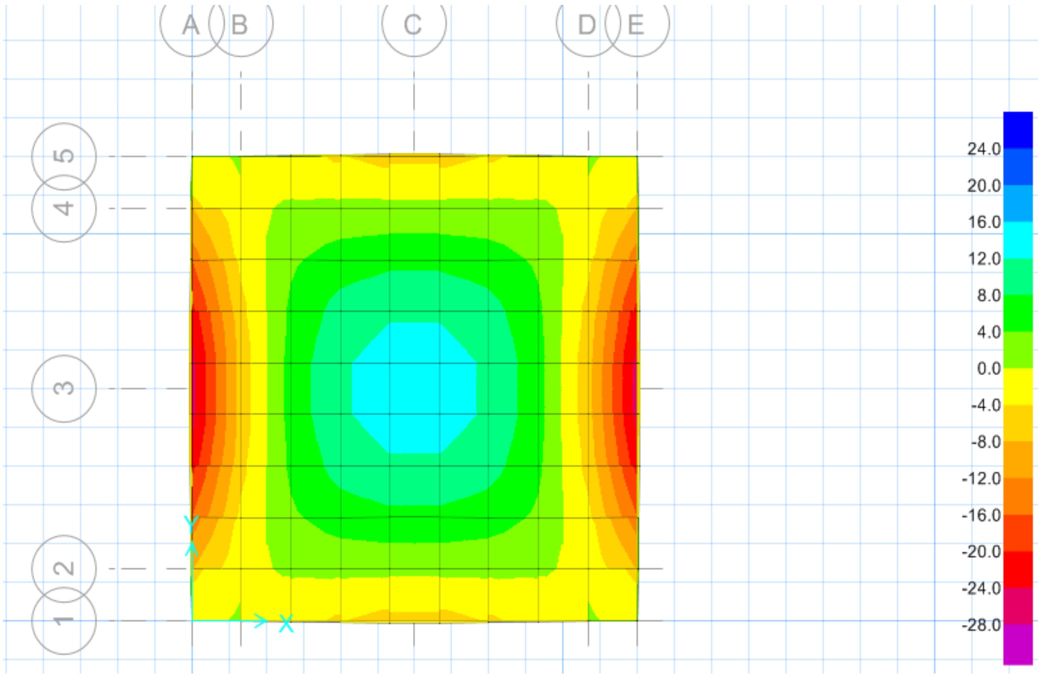



**Fig (3.24): Rectangular water tank-top slab moment (M11)**

**Safe program**

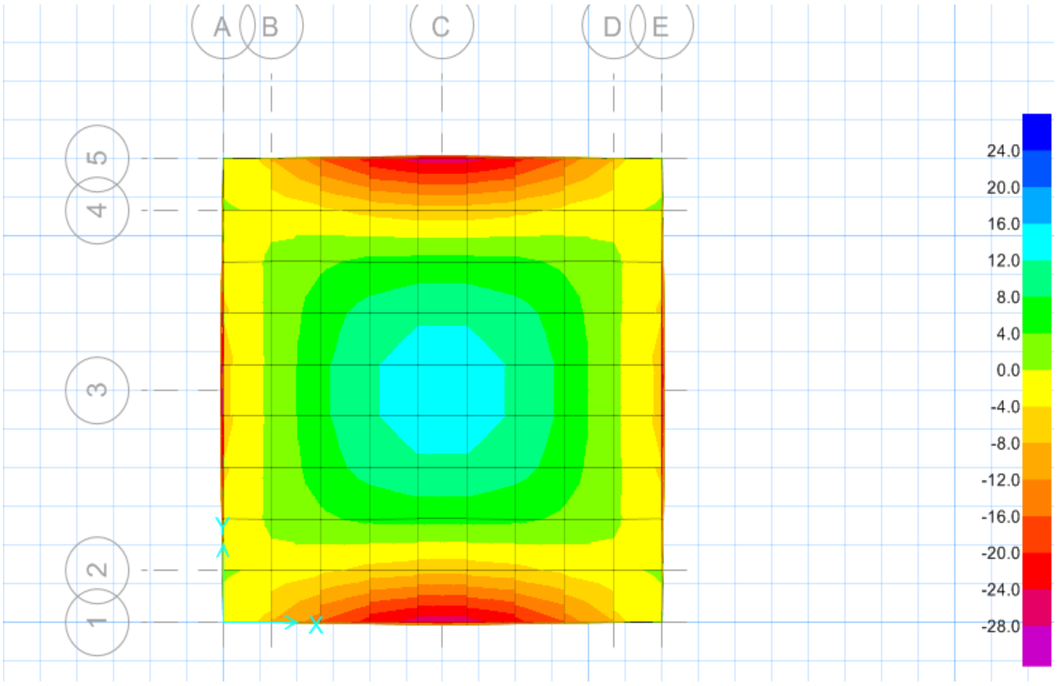



**Fig (3.25): Rectangular water tank-top slab moment (M22)**

**Safe program**

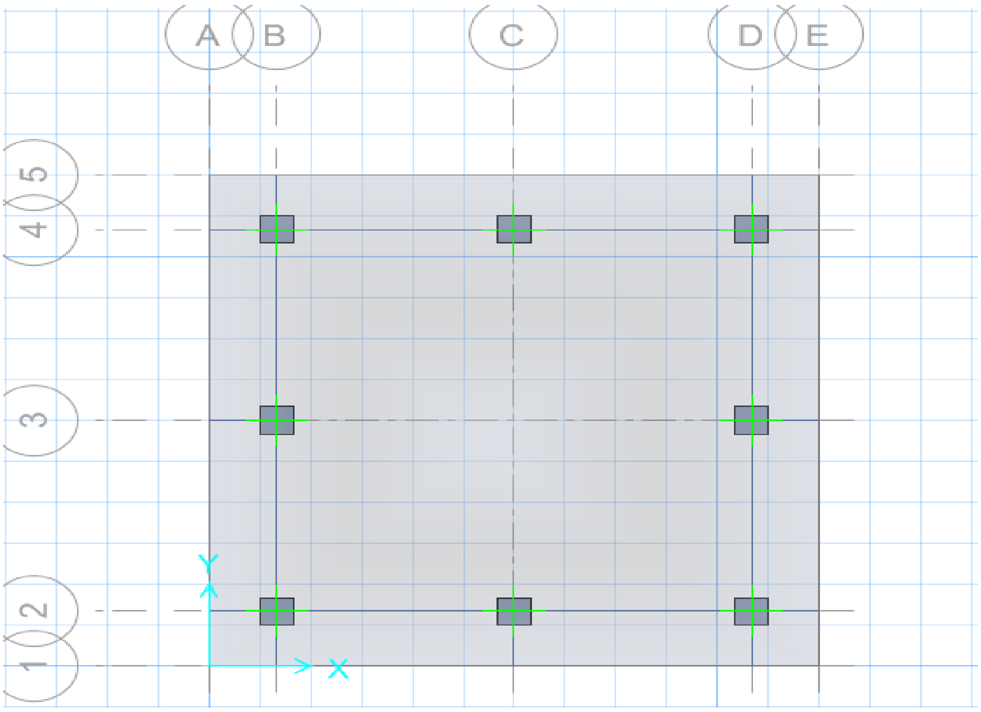



**Fig (3.26): Rectangular water tank-bottom slab**

**Safe program**

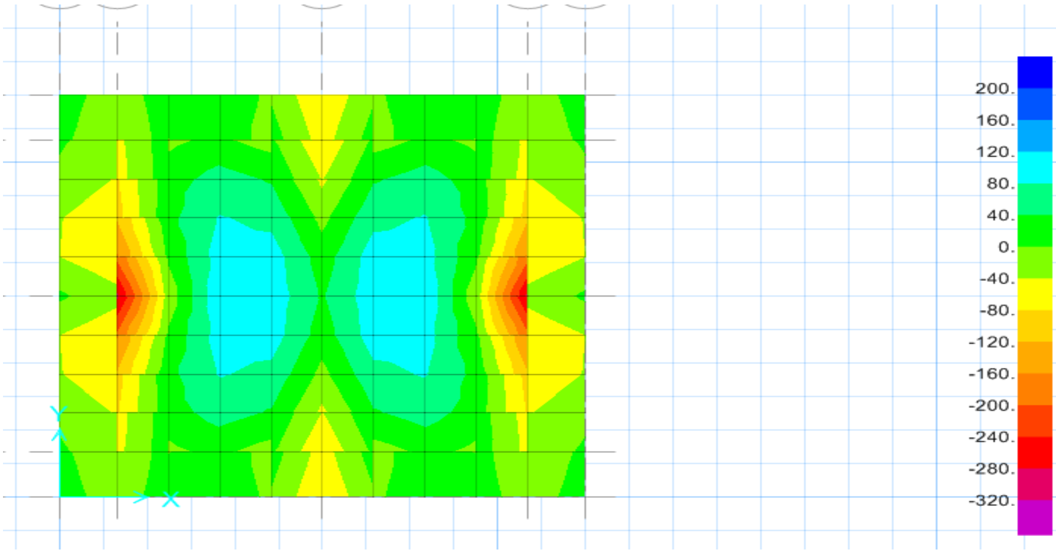



**Fig (3.27): Rectangular water tank-bottom slab moment (M11)**

**Safe program**

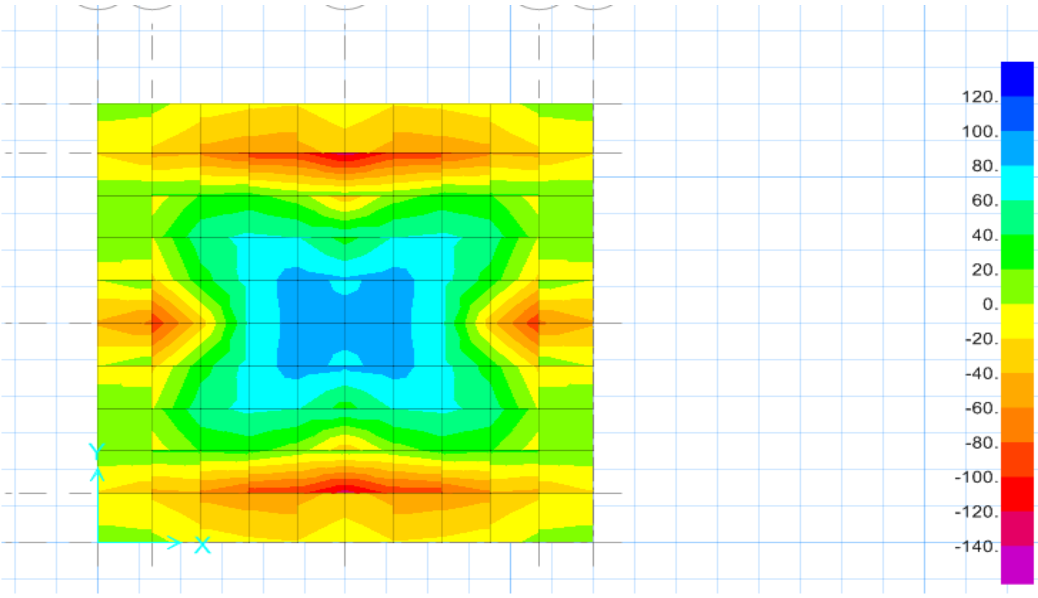



**Fig (3.28): Rectangular water tank-bottom slab moment (M22)**

**Safe program**

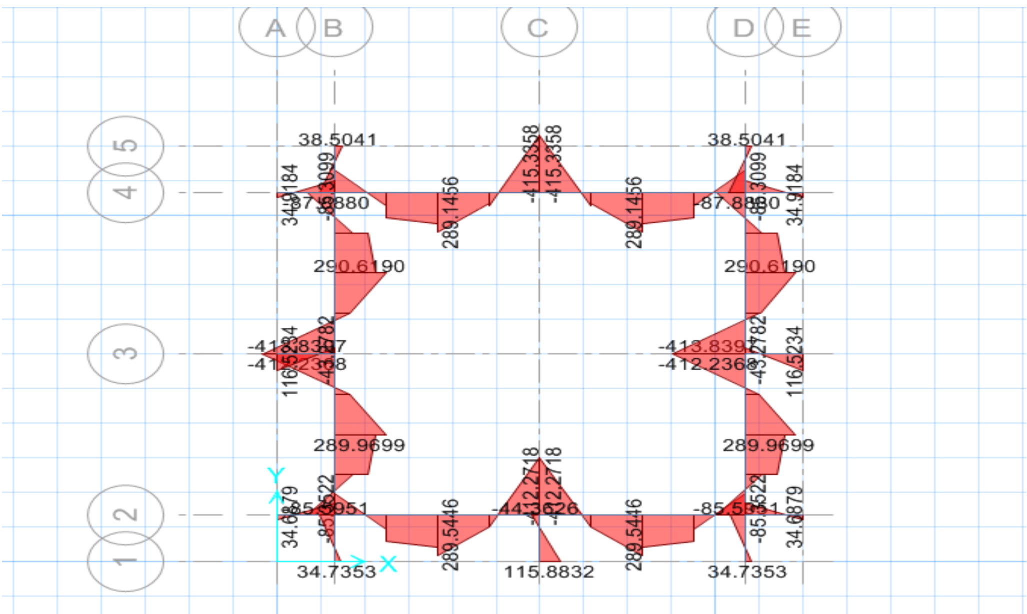



**Fig (3.29): rectangular water tank-top beams moment**

**Safe program**

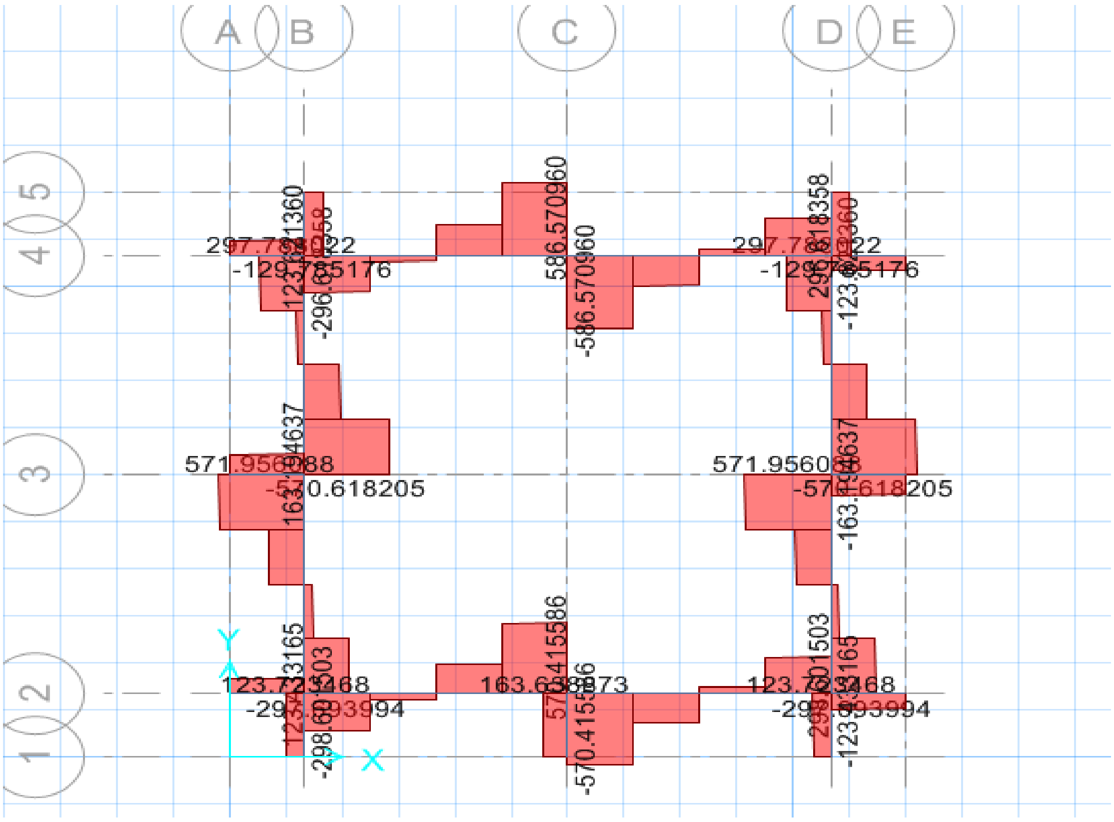



**Fig (3.30): Rectangular water tank-top beams shear**

**Safe program**

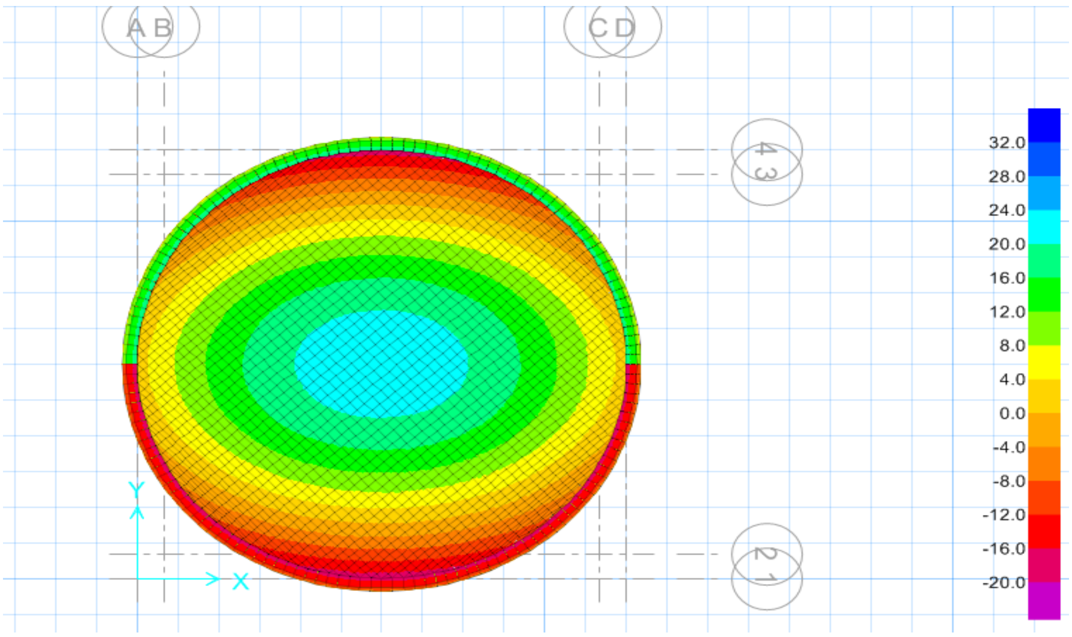



**Fig (3.31): Circular water tank-top slab moment due to combination 4**

**Safe program**

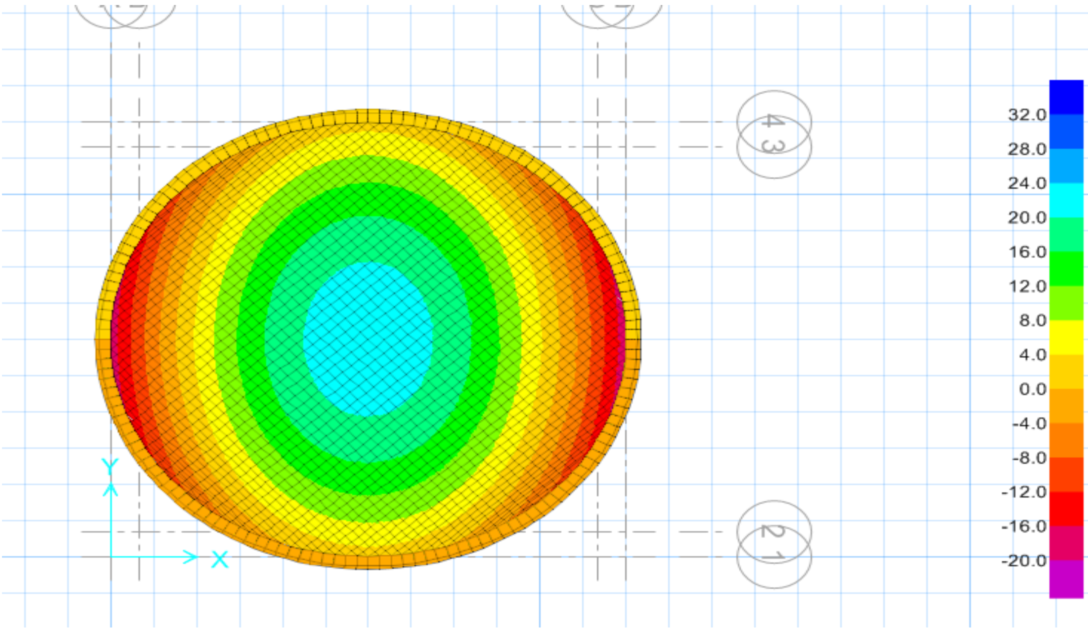



**Fig (3.32): Circular water tank-top slab moment due to combination 4**

**Safe program**

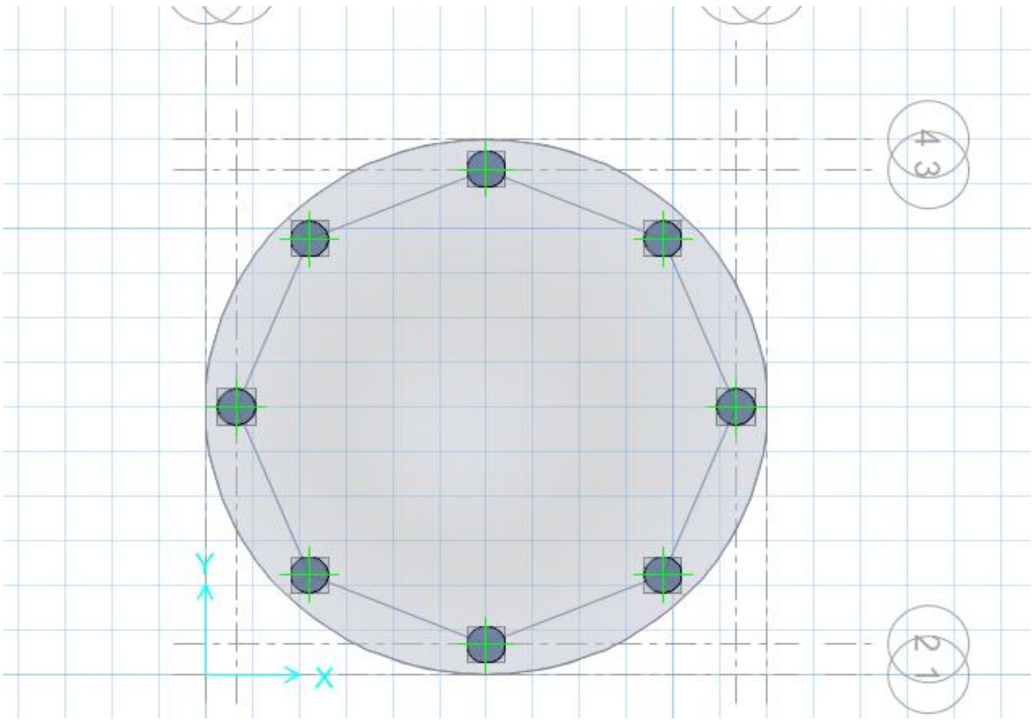



**Fig (3.33): Circular water tank-bottom slab**

**Safe program**

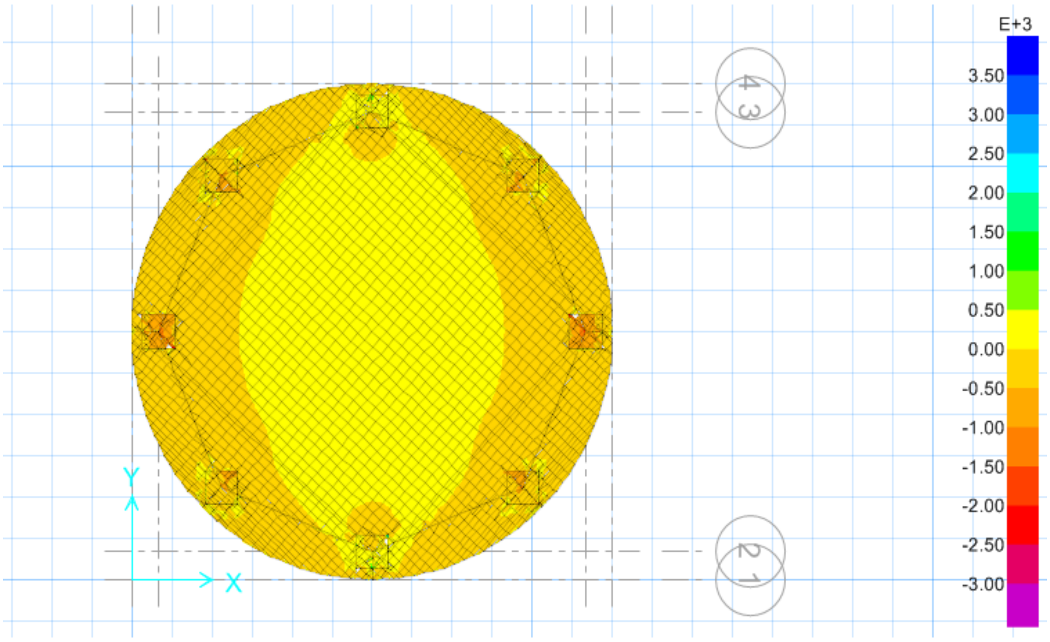



**Fig (3.34): Circular water tank-bottom slab moment (M11) due to Combination (4) Safe program**

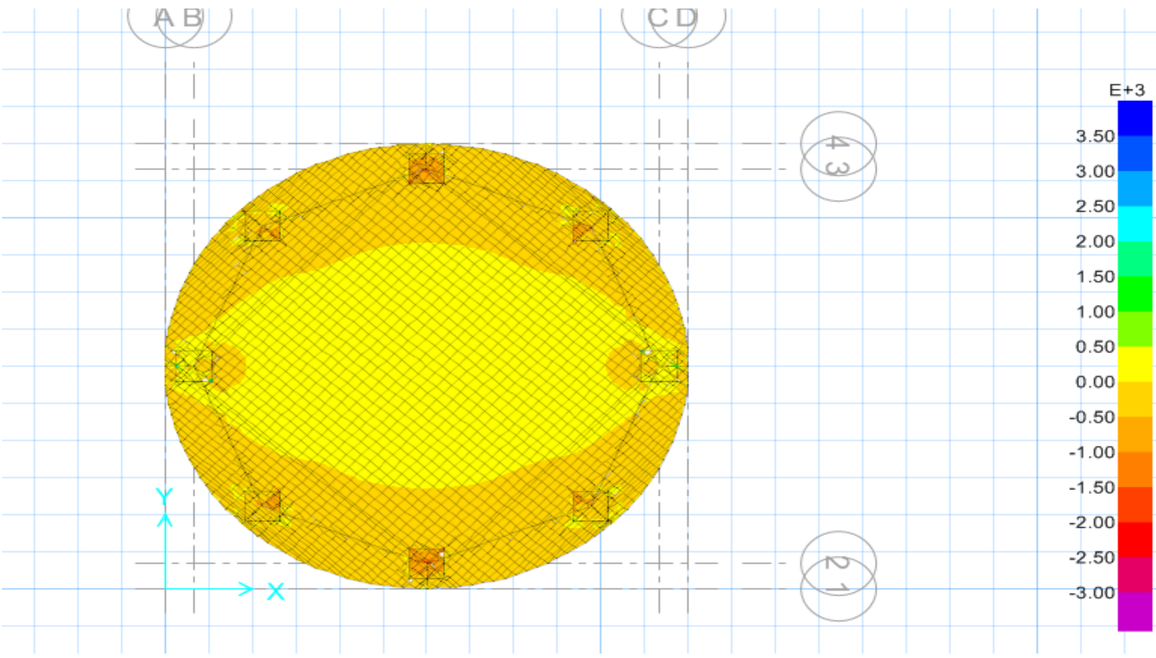



**Fig (3.35): Circular water tank-bottom slab moment (M22) due to Combination (4) Safe program**

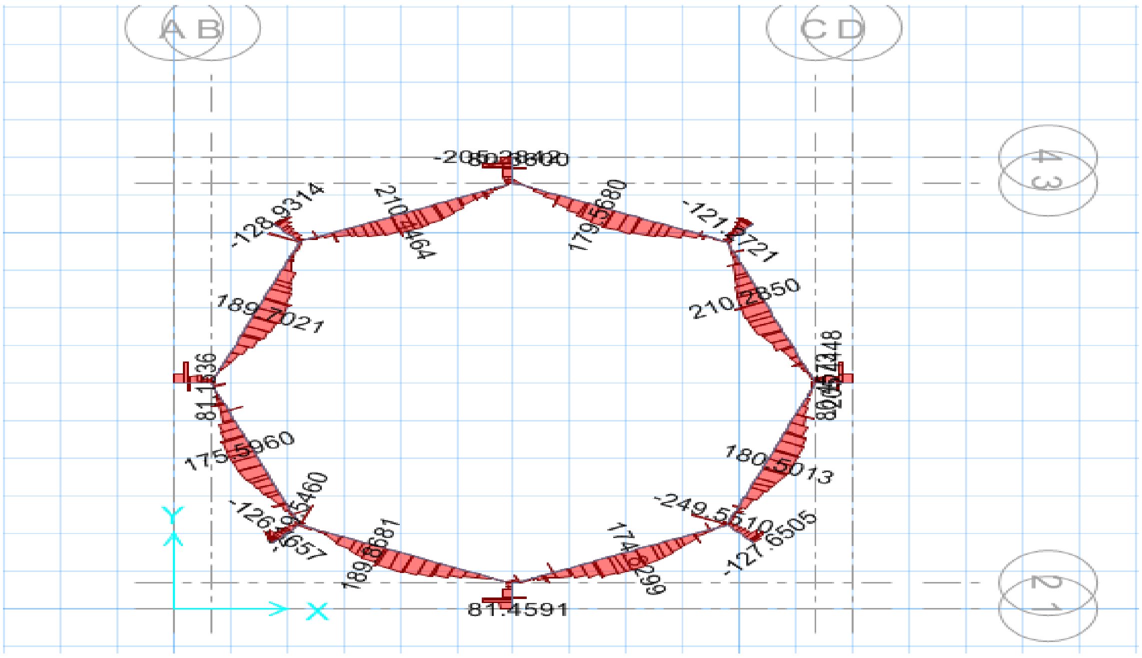



**Fig (3.36): Circular water tank-top beam moment**

**Safe program**

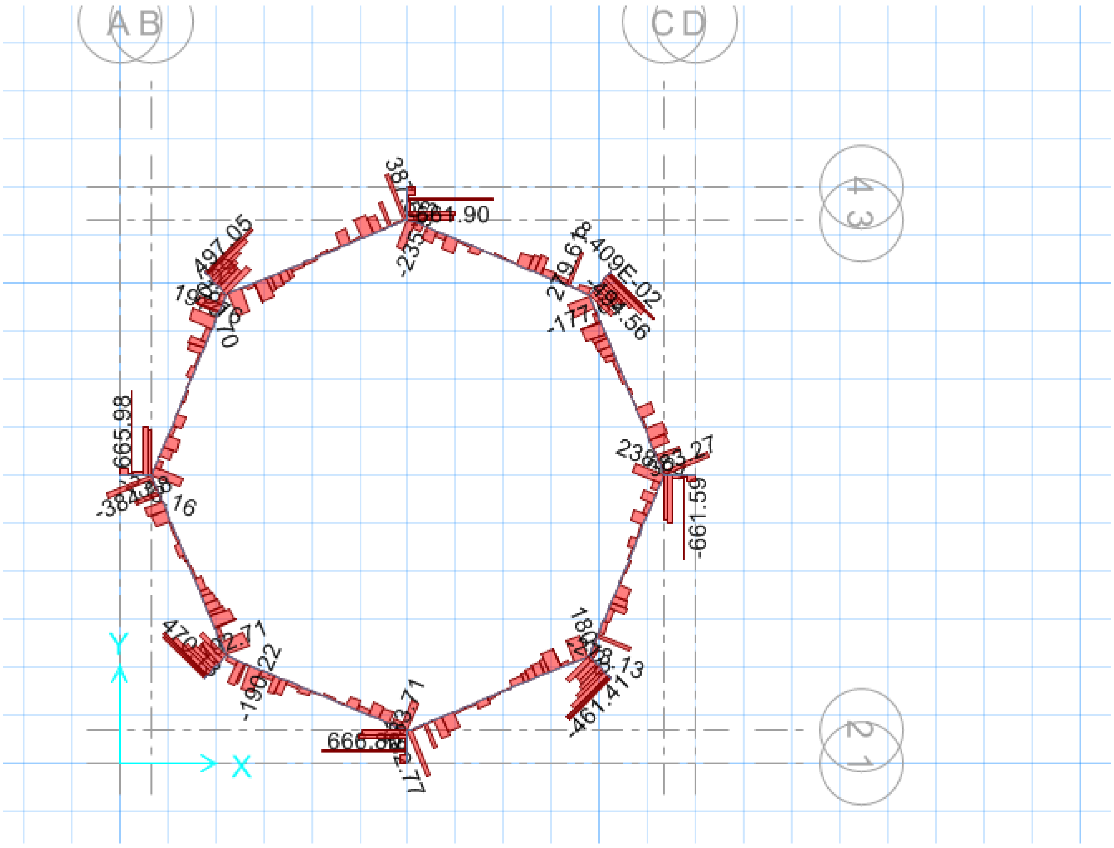



**Fig (3.37): Circular water tank-top beam shear**

**Safe program**

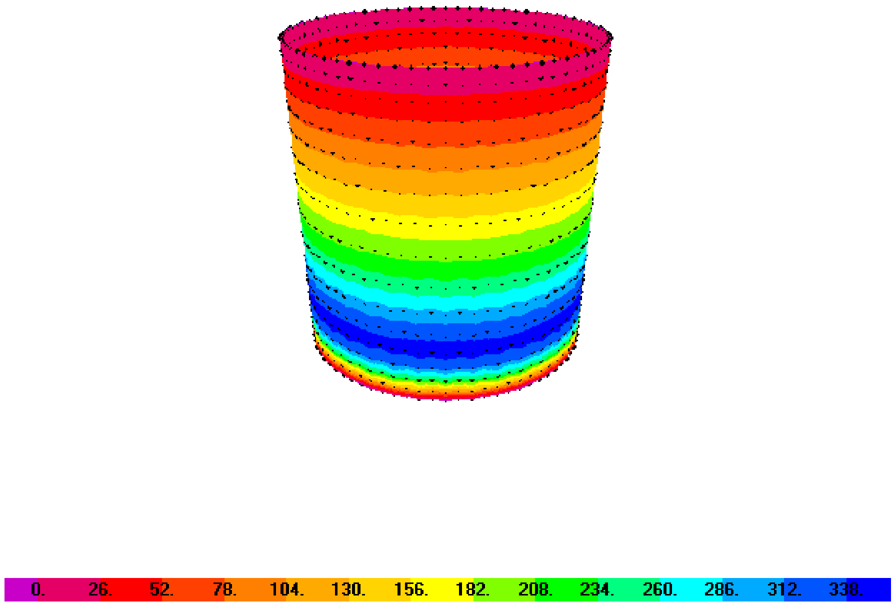



**Fig (3.38): Circular water tank wall ring tension**

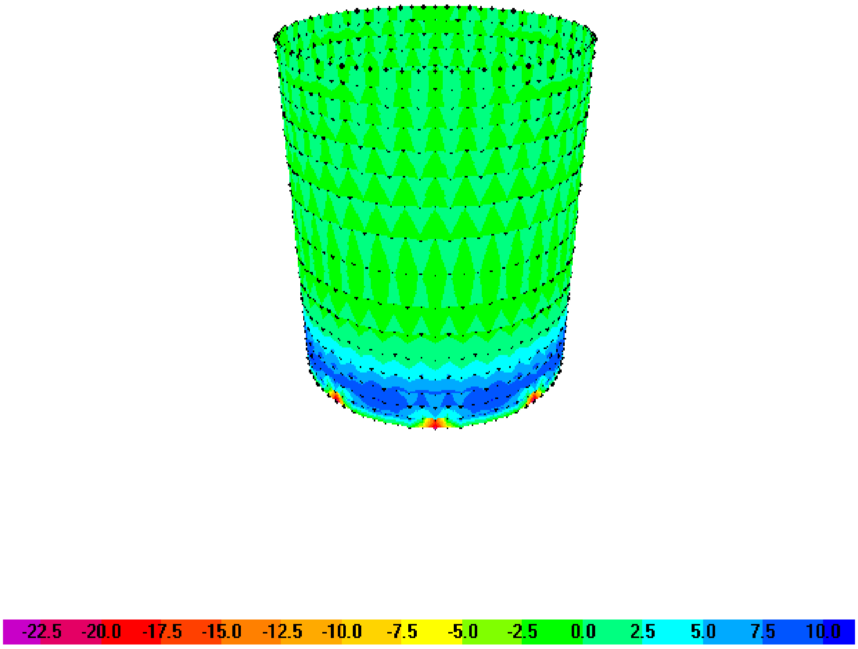



**Fig (3.39): Circular water tank wall - moment**

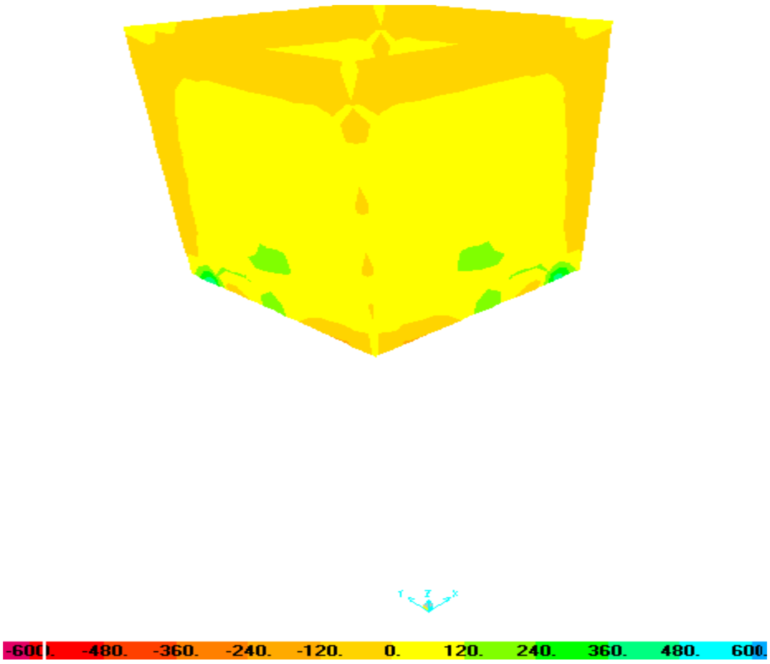



**Fig (3.40): Rectangular water tank wall moment**

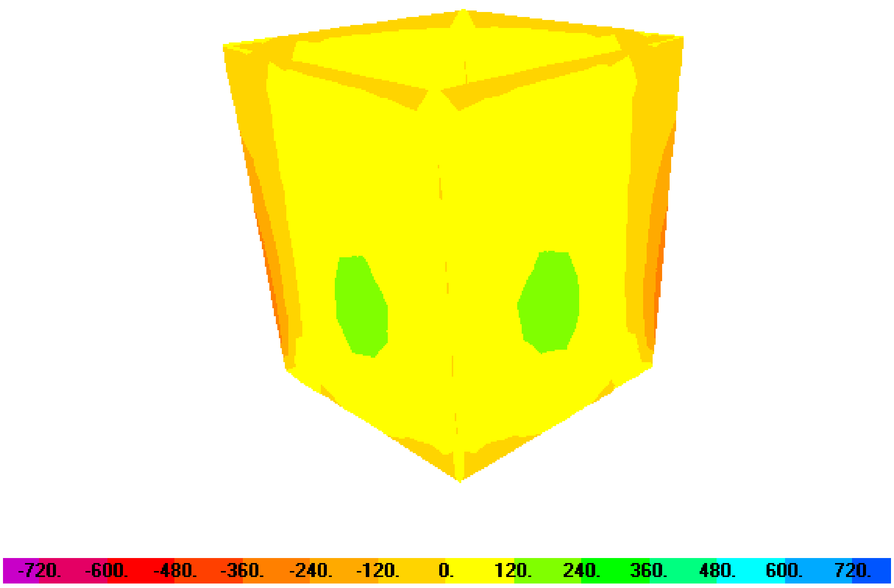



**Fig (3.41): Rectangular water tank wall moment**

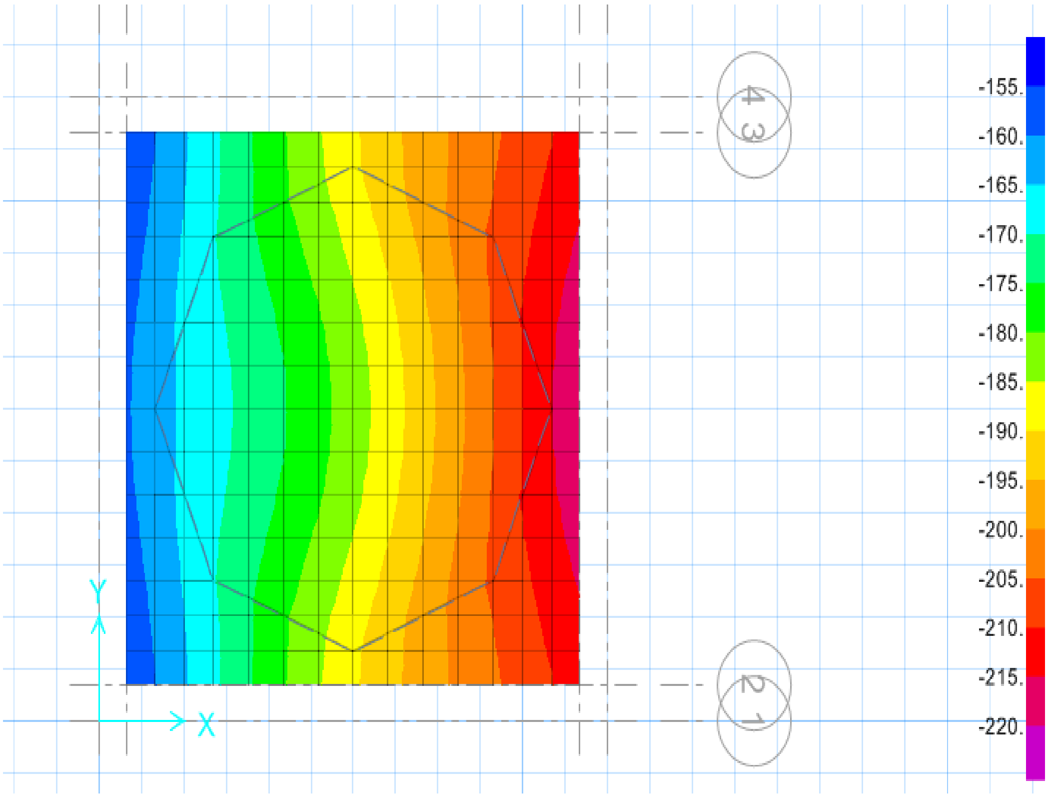



**Fig (3.42): Raft foundation soil pressure diagram**

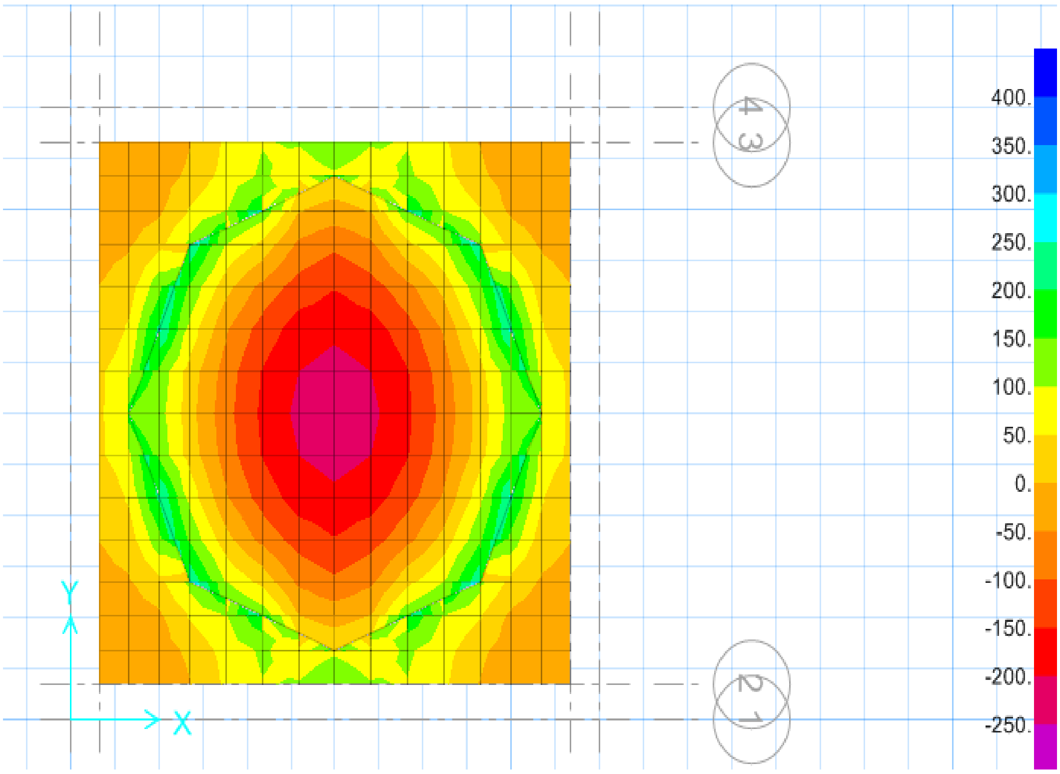



**Fig (3.43): Raft foundation moment diagram (M11)**

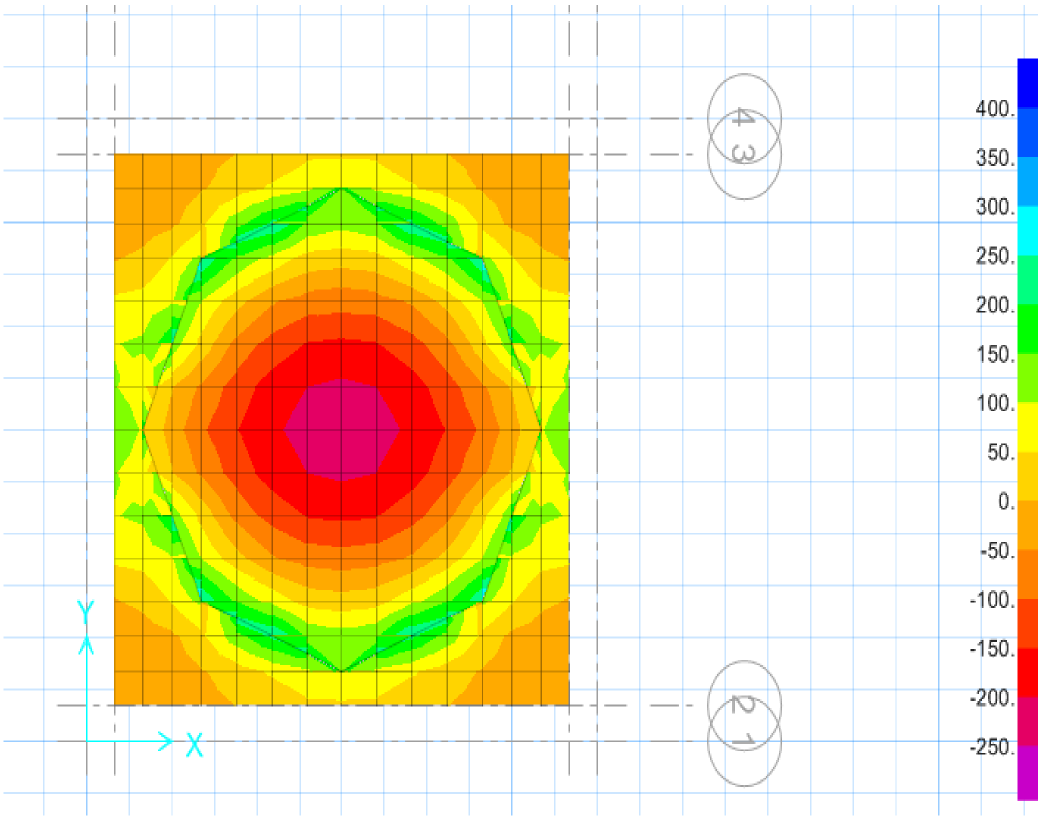



**Fig (3.44): Raft foundation moment diagram (M22)**

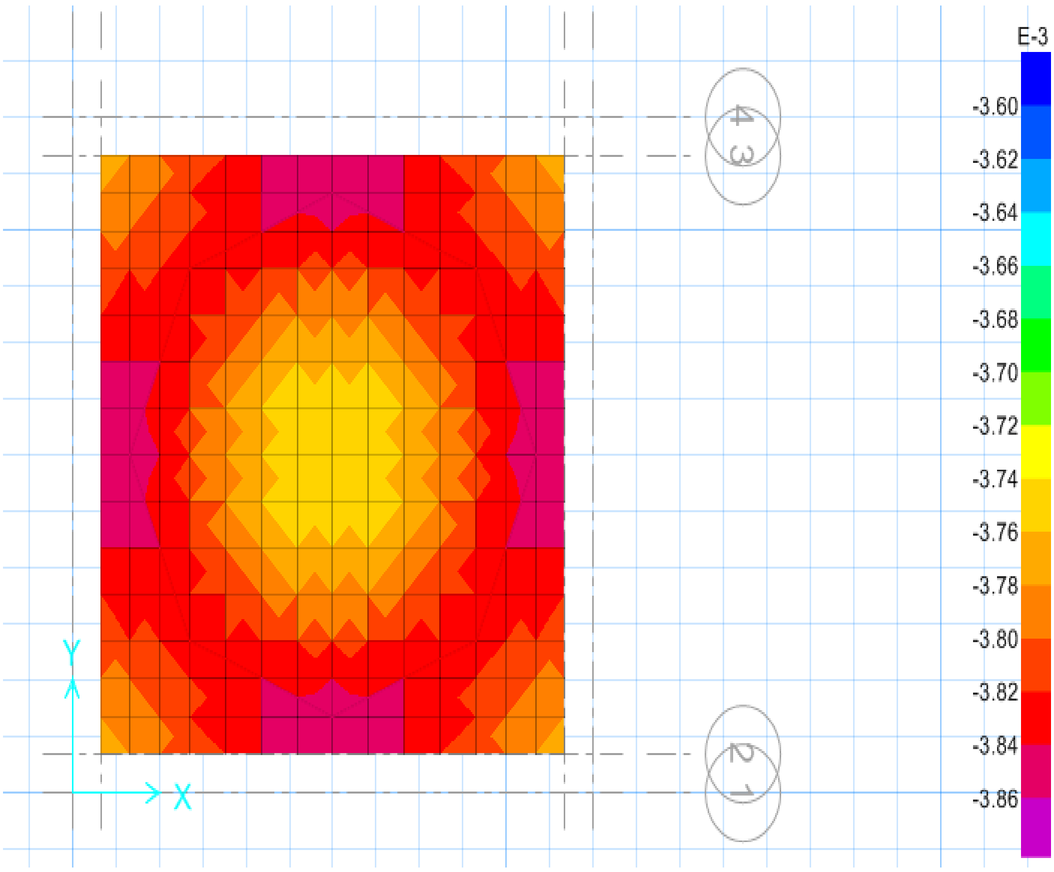



**Fig (3.45): Raft foundation deformed shape.**

**Table (3.10): Rectangular and circular column results.**

| Tank ID | Ultimate axial load(kN) | Ultimate moment (kN.m) | Working axial load (kN) | Working moment (kN.m) |
|---|---|---|---|---|
| Rectangular tank column | 1904.6 | 60.47 | _ | _ |
| Circular tank column | 1733.8 | 61.64 | _ | _ |
| Rectangular tank foundation | 1904.6 | 60.473 | 1109.46 | 45.35 |
| Circular tank foundation | 1733.8 | 61.64 | 1144.17 | 45.35 |

**Table (3.11): Beams and slab results.**

| Tank ID | shear | Negative moment | Positive moment |
|---|---|---|---|
| Rectangular tank top slab | 14.3 | 22 | 23.6 |
| Rectangular tank bottom slab | 603.97 | 288.6 | 133.5 |
| Rectangular tank girder | 586.57 | 415.34 | 289.456 |
| Circular tank girder | 235.32 | 128.93 | 210.464 |
| Rectangular tank beam | 22.21 | 39.6 | 35.4 |
| Circular tank beam | 74.71 | 81.97 | 69.016 |

**Table (3.12): Circular tank –slab results.**

| Tank ID | Radial negative moment | Radial positive moment | Tangential negative moment | Tangential positive moment |
|---|---|---|---|---|
| Top circular slab | 19.8 | 23.9 | 20 | 22 |
| Bottom circular slab | 396 | 323 | 396 | 323 |

**Table (3.13): Circular tank –wall results.**

| Negative moment<br>kN.m | Positive moment<br>kN.m | Ring tension<br>kN |
|---|---|---|
| 22.5 | 11.6 | 338 |

**Table (3.14): Rectangular tank-wall results.**

| Negative moment<br>kN.m | Positive moment<br>kN.m | Shear<br>kN |
|---|---|---|
| 480 | 369 | 425.6 |

**Table (3.15): Circular slab design.**

| | | | |
|---|---|---|---|
| $f_{c'}$ | 28 N/mm$^2$ | $f_y$ | 420 N/mm$^2$ |
| $L$ | 9 m | $h$ | 300mm |
| $V_u$ | 14.3 kN | $\gamma_{con}$ | 24 kN/m$^3$ |
| $M_{negative}$ | 19.8 kN.m/m | $M_{postive}$ | 23.9 kN.m/m |
| **Negative Moment design** | | | |
| $h_{min} = \frac{L}{36}$ | 213.7mm | $\rho_b$ | 0.0284 |
| $\rho_{max}$ | 0.02125 | $\rho$ | 0.0106 |
| $m$ | 17.647 | $R_u$ | 4.035 N/mm2 |
| $d_{min}$ | 80.564 mm | Say d | 162mm |
| $\therefore h$ | 220mm | $R_{u\,rev}$ | 0.9991 N/mm2 |
| $\rho_{rev}$ | 0.00243 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 410.83 mm2 | n | 3.63 |
| Use $\emptyset 12mm$ | | $A_b$ | 113 mm2 |
| spacing | 250mm | | |
| Use $\emptyset 12mm$ @$250mm\ c/c$ | | | |
| **Positive moment** | | | |
| M positive | 22 kN.m | Say d | 162mm |
| $\therefore h$ | 220mm | $R_{u\,rev}$ | 0.975 N/mm2 |

| | | | |
|---|---|---|---|
| $\rho_{rev}$ | 0.00242 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 410.83 mm2 | Use $\emptyset 12mm$ | |
| $A_b$ | 113 mm2 | spacing | 250mm |
| Use $\emptyset 12mm\ @250mm\ c/c$ | | | |

**Table (3.16): Rectangular slab design.**

| | | | |
|---|---|---|---|
| | | | |
| $f_{c'}$ | 28 N/mm2 | $f_y$ | 420 N/mm2 |
| $L$ | 8 m | $h$ | 200mm |
| $V_u$ | 12 kN | $\gamma_{con}$ | 24 kN/m3 |
| $M_{negative}$ | 25.4 kN.m/m | $M_{postive}$ | 18.58 kN.m/m |
| **Negative Moment design** | | | |
| $h_{min} = \frac{L}{28}$ | 228.7mm | $\rho_b$ | 0.0284 |
| $\rho_{max}$ | 0.02125 | $\rho$ | 0.0106 |
| $m$ | 17.647 | $R_u$ | 4.035 N/mm2 |
| $d_{min}$ | 83.4 mm | Say d | 162mm |
| $\therefore h$ | 220mm | $R_{u\,rev}$ | 1.072 N/mm2 |
| $\rho_{rev}$ | 0.00261 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 439.4 mm2 | | |
| Use $\emptyset 12mm$ | | $A_b$ | 113 mm2 |

| | | | |
|---|---|---|---|
| spacing | 250mm | | |

Use $\emptyset 12mm$ @$250mm\ c/c$

**Positive moment**

| | | | |
|---|---|---|---|
| M positive | 25.4 kN.m | Say d | 162mm |
| $\therefore h$ | 220mm | $R_{u\ rev}$ | 1.072 N/mm2 |
| $\rho_{rev}$ | 0.00261 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 439.4 mm2 | Use $\emptyset 12mm$ | |
| $A_b$ | 113 mm2 | spacing | 250mm |

Use $\emptyset 12mm$ @$250mm\ c/c$

**Table (3.17): Rectangular slab design.**

| | | | |
|---|---|---|---|
| $f_{c'}$ | 28 N/mm2 | $f_y$ | 420 N/mm2 |
| $L$ | 3.5 m | $h$ | 300mm |
| $V_u$ | 603.97 kN | $\gamma_{con}$ | 24 kN/m3 |
| $M_{negative}$ | 288.6 kN.m/m | $M_{postive}$ | 133.5 kN.m/m |

**Negative Moment design**

| | | | |
|---|---|---|---|
| $h_{min} = \frac{L}{24}$ | 145mm | $\rho_b$ | 0.0284 |
| $\rho_{max}$ | 0.02125 | $\rho$ | 0.0106 |
| $m$ | 17.647 | $R_u$ | 4.035 N/mm2 |

| | | | |
|---|---|---|---|
| $d_{min}$ | 281.91 mm | Say d | 290mm |
| $\therefore h$ | 325mm | $R_{u\,rev}$ | 3.81N/mm2 |
| $\rho_{rev}$ | 0.0099 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 2871 mm2 | | |
| Use $\emptyset 16mm$ | | $A_b$ | 201.0619 mm2 |
| spacing | 75mm | | |

Use $\emptyset 16mm\ @75mm\ c/c$

**Shear check**

| | | | |
|---|---|---|---|
| $V_u$ | 603.97 kN | $\emptyset V_c$ | 195.65 kN |
| $\emptyset V_s$ | 408.32 | | |

Check thickness for shear reinforcement

$$V_u \leq \emptyset(V_c + 0.66\sqrt{f_{c'}}bd)$$

| | | | |
|---|---|---|---|
| $\emptyset(V_c + 0.66\sqrt{f_{c'}}bd)$ | 955.24 kN | $V_u$ | 603.97 kN |

$2\emptyset V_c < \emptyset V_s < 4\emptyset V_c$ *Then spacing use minimum of*

| | | | |
|---|---|---|---|
| $\frac{d}{4}$ | 72.5mm | $\frac{3A_v f_y}{b_w}$ | 190.5 mm |
| $\frac{16A_v f_y}{\sqrt{f_{c'}}b_w}$ | 191.4 mm | $s$ | 300 mm |

**Positive moment**

| | | | |
|---|---|---|---|
| | | Say d | 290mm |
| $\therefore h$ | 325mm | $R_{u\,rev}$ | 1.764 N/mm2 |

| | | | |
|---|---|---|---|
| $\rho_{rev}$ | 0.0044 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 1267 mm2 | Use $\emptyset 16mm$ | |
| $A_b$ | 201.0619 mm2 | spacing | 158.1mm |

Use $\emptyset 16mm$ @$150mm\ c/c$

**Distribution reinforcement**

| | | | |
|---|---|---|---|
| $A_{s\,min}$ | 585 mm2 | (Use $\emptyset 12$) $A_b$ | 113mm2 |
| spacing | 193.16 mm | | |

Use $\emptyset 12mm$@$180mm\ c/c$

**Table (3.18): Circular slab design.**

| | | | |
|---|---|---|---|
| $f_{c\prime}$ | 28 N/mm2 | $f_y$ | 420 N/mm2 |
| $L$ | 3.5 m | $h$ | 350mm |
| $V_u$ | 603.97 kN | $\gamma_{con}$ | 24 kN/m3 |
| $M_{negative}$ | 323 kN.m/m | $M_{postive}$ | 245 kN.m/m |

**Negative Moment design**

| | | | |
|---|---|---|---|
| $h_{min} = \frac{L}{24}$ | 145mm | $\rho_b$ | 0.0284 |
| $\rho_{max}$ | 0.02125 | $\rho$ | 0.0106 |
| $m$ | 17.647 | $R_u$ | 4.035 N/mm2 |
| $d_{min}$ | 281.91 mm | Say d | 290mm |

| | | | |
|---|---|---|---|
| $\therefore h$ | 350mm | $R_{u\,rev}$ | 3.81N/mm2 |
| $\rho_{rev}$ | 0.0104 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 3120 mm2 | | |
| Use $\emptyset 20mm$ | | $A_b$ | 314 mm2 |
| spacing | 100mm | | |

Use $\emptyset 20mm$ @$100mm\ c/$

**Positive moment**

| | | | |
|---|---|---|---|
| | | Say d | 300mm |
| $\therefore h$ | 245mm | $R_{u\,rev}$ | 3.0246 N/mm2 |
| $\rho_{rev}$ | 0.007 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 2310 mm2 | Use $\emptyset 20mm$ | |
| $A_b$ | 314 mm2 | spacing | 135mm |

Use $\emptyset 20mm$ @$135mm\ c/c$

**Table (3.19): Rectangular wall design.**

| | | | |
|---|---|---|---|
| | | | |
| $f_{c'}$ | 28 N/mm2 | $f_y$ | 420 N/mm2 |
| $L$ | 9 m | $h$ | 300mm |

| | | | |
|---|---|---|---|
| $V_u$ | 425.6 kN | $\gamma_{con}$ | 24 kN/m3 |
| $M_{negative}$ | 250 kN.m/m | $M_{postive}$ | 130 kN.m/m |

**Negative Moment design(internal face)**

| | | | |
|---|---|---|---|
| $h = 300$ | 145mm | $\rho_b$ | 0.0284 |
| $\rho_{max}$ | 0.02125 | $\rho$ | 0.0106 |
| $m$ | 17.647 | $R_u$ | 4.035 N/mm2 |
| $d_{min}$ | 262.5 mm | Say d | 265mm |
| $\therefore h$ | 325mm | $R_{u\,rev}$ | 3.96N/mm2 |
| $\rho_{rev}$ | 0.0104 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 2756 mm2 | | |
| Use $\emptyset 20mm$ | | $A_b$ | 314 mm2 |
| spacing | 100mm | | |

Use $\emptyset 20mm\ @100mm\ c/c$

**Shear check (horizontal reinforcement)**

| | | | |
|---|---|---|---|
| $V_u$ | 425.6 kN | $\emptyset V_c$ | 178.8 kN |
| $\emptyset V_s$ | 246.81 kN | | |

Check thickness for shear reinforcement

$$V_u \leq \emptyset(V_c + 0.66\sqrt{f_{c'}}bd)$$

| | | | |
|---|---|---|---|
| $\emptyset(V_c + 0.66\sqrt{f_{c'}}bd)$ | 955.24 kN | $V_u$ | 425.6 kN |

$\emptyset V_c < \emptyset V_s < 2\emptyset V_c$ *Then spacing use minimum of*

| | | | |
|---|---|---|---|
| $\frac{d}{2}$ | 125mm | $\frac{3A_v f_y}{b_w}$ | 190.5 mm |
| $\frac{16A_v f_y}{\sqrt{f_{c'}} b_w}$ | 191.4 mm | $s$ | 300 mm |

Use $\emptyset 10mm$ @$125mm\ c/c$

**Positive moment (external face)**

| | | | |
|---|---|---|---|
| | | Say d | 265mm |
| $\therefore h$ | 325mm | $R_{u\,rev}$ | 2.056 N/mm2 |
| $\rho_{rev}$ | 0.00513 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 1359.45 mm2 | Use $\emptyset 16mm$ | |
| $A_b$ | 201.0619 mm2 | spacing | 135mm |

Use $\emptyset 16mm$ @$135mm\ c/c$

**Check stress and crack width**

| | | | |
|---|---|---|---|
| $E_s$ | $200 \times 10^3 Mpa$ | $E_c$ | 24870.06 Mpa |
| $n$ | 8 | $A_s$ | 3140 mm2 |
| $T_{max}$ | 812.467 kN | $C$ | 0.0003 |
| $f_c$ | 2.79 N/mm2 | $f_{c\,chek}$ | 2.8 N/mm2 |
| $f_c < f_{c\,check}$ | O.K | $d_c$ | 50mm |
| $A$ | 100000 mm2 | M | 147 kN |
| $k$ | 0.333 | $j$ | 0.889 |
| $d$ | 265mm | $f_s$ | 198.71 Mpa |

| | | | |
|---|---|---|---|
| $z$ | 33978.9 Mpa | Use z | 20384.2 |

**The maximum spacing control cracking $s_{max}$**

| | | | |
|---|---|---|---|
| $s_{max}$ | 215.571 mm | $s_{max} > 130mm$ | O.K |

**Table (3.20): Circular wall design.**

| | | | |
|---|---|---|---|
| | | | |
| $f_{c'}$ | 28 N/mm2 | $f_y$ | 420 N/mm2 |
| $L$ | 9 m | $h$ | 300mm |
| $V_u$ | 38.4 kN | $\gamma_{con}$ | 24 kN/m3 |
| $M_{negative}$ | 22.5 kN.m/m | $M_{postive}$ | 11.6 kN.m/m |

**Distribution reinforcement**

**Moment design (vertical reinforcement)**

| | | | |
|---|---|---|---|
| $h$ | 300mm | $\rho_b$ | 0.0284 |
| $\rho_{max}$ | 0.02125 | $\rho$ | 0.0106 |
| $m$ | 17.647 | $R_u$ | 4.035 N/mm2 |
| $d_{min}$ | 78 mm | Say d | 240mm |
| $\therefore h$ | 300mm | $R_{u\,rev}$ | 3.96N/mm2 |
| $\rho_{rev}$ | 0.00104 | $\rho_{min}$ | 0.0018 |
| $A_s$ | 540 mm2 | | |

| | | | |
|---|---|---|---|
| Use $\emptyset 16mm$ | | $A_b$ | 201mm2 |
| spacing | 300mm | | |

Use $\emptyset 16mm$ @$300mm\ c/c$ external &eternal face

**Shear check**

| | | | |
|---|---|---|---|
| $V_u$ | 38.8 kN | $\emptyset V_c$ | 178.8 kN |
| $V_u < \emptyset V_c$ | O.K | | |

Check thickness for shear reinforcement

$$V_u \leq \emptyset(V_c + 0.66\sqrt{f_{c'}}bd)$$

| | | | |
|---|---|---|---|
| $\emptyset(V_c + 0.66\sqrt{f_{c'}}bd)$ | 955.24 kN | $V_u$ | 38.8 kN |

**Main reinforcement**

**Ring tension (horizontal reinforcement)**

| | | | |
|---|---|---|---|
| $T_{un\ factored}$ | 338 kN | $T_u$ | 948.09 kN |
| $A_s$ | 2508.175 mm2 | $use\emptyset 20mm$ | |
| $A_b$ | 314 mm2 | spacing | 125mm |

Use $\emptyset 20mm$ @$125mm\ c/c\ \ int\&ext$

**Check stress and crack width**

| | | | |
|---|---|---|---|
| $E_s$ | $200 \times 10^3 Mpa$ | $E_c$ | 24870.06 Mpa |
| $n$ | 8 | $A_s$ | 2512 mm2 |
| $T_{max}$ | 338 kN | $C$ | 0.0003 |

| | | | |
|---|---|---|---|
| $f_c$ | 1.53 N/mm2 | $f_{c\ chek}$ | 2.8 N/mm2 |
| $f_c < f_{c\ check}$ | O.K | $d_c$ | 50mm |
| $A$ | 100000 mm2 | M | 22.5 kN |
| $k$ | 0.07 | $j$ | 0.889 |
| $d$ | 240mm | $f_s$ | 38.23 Mpa |
| $z$ | 5633.6 Mpa | | |

**The maximum spacing control cracking $s_{max}$**

| | | | |
|---|---|---|---|
| $s_{max}$ | 651 mm | $s_{max} > 125mm$ | O.K |

**Table (3.21): Rectangular water tank bracing design.**

| | | | |
|---|---|---|---|
| $b_w$ | 400 mm | $h$ | 400mm |
| $V_u$ | 22.121 kN | $M_{negative}$ | 39.6 kN.m |
| $M_{positive}$ | 35.4 kN.m | $d$ | 367 mm |
| $a$ | 11.52 mm | $c$ | 109670.4 |
| $A_{s\ negative}$ | 238.41 mm2 | Use 2$\emptyset 16mm$ | |
| $A_{s\ positive}$ | 232.32 mm2 | Use 2$\emptyset 16mm$ | |
| $V_u$ | 22.21 kN | $\emptyset V_c$ | 99.06 kN |
| $V_u < \frac{\emptyset V_c}{2}$ | O.K | | |

**Table (3.22): Rectangular water tank girder beam design.**

| | | | |
|---|---|---|---|
| $b_w$ | 400 mm | $h$ | 700mm |
| $V_u$ | 586.57 kN | $M_{negative}$ | 415.34 kN.m |
| $M_{positive}$ | 289.456kN.m | $d$ | 667 mm |
| $a$ | 52.73 mm | $c$ | 501989.6 N |
| $A_{s\,positive}$ | 1091.281 mm2 | Use Ø16 $Ab = 201.0619\ mm2$ | |
| $n$ | 5.429 bars | Say | 6 bars |
| $a_{negitive}$ | 77.138 mm | $c$ | 734353.76 N |
| $A_{s\,negitive}$ | 1596.42 mm2 | Use Ø16 $Ab = 201.0619\ mm2$ | |
| $n$ | 7.94 bars | Say | 8 bars |

**Shear check**

| | | | |
|---|---|---|---|
| $V_u$ | 586.57 kN | $\emptyset V_c$ | 180 kN |
| $V_u > \emptyset V_c$ | | $\emptyset V_s$ | 406.57 |

$$2\emptyset V_c < \emptyset V_s < 4\emptyset V_c \ \ Then\ spacing\ use\ minimum\ of$$

| | | | |
|---|---|---|---|
| $\frac{d}{4}$ | 166.75mm | $\frac{3A_v f_y}{b_w}$ | 541.65 mm |
| $\frac{16A_v f_y}{\sqrt{f_{c'}} b_w}$ | 545.93 mm | $s$ | 300 mm |

Use Ø$10mm@150c/c(1m\ length)$

| | | | |
|---|---|---|---|
| $V_u$ | 244.9 kN | $\emptyset V_c$ | 180 kN |
| $V_u > \emptyset V_c$ | | $\emptyset V_s$ | 64.9 kN |

$\frac{\emptyset V_c}{2} < \emptyset V_s < \emptyset V_c$ *Then spacing use minimum of*

| | | | |
|---|---|---|---|
| $\frac{d}{2}$ | 333 mm | $\frac{3A_v f_y}{b_w}$ | 541.65 mm |
| $\frac{16A_v f_y}{\sqrt{f_{c'}} b_w}$ | 545.93 mm | $s$ | 600 mm |

**Use $\emptyset 10mm@300c/c(1.5m$ length on the middlle of beam$)$**

**Table (3.23): Circular water tank bracing design.**

| | | | |
|---|---|---|---|
| $b_w$ | 400 mm | $h$ | 400mm |
| $V_u$ | 69.016 kN | $M_{negative}$ | 74.71 kN.m |
| $M_{positive}$ | 81.97 kN.m | $d$ | 367 mm |
| $a$ | 27.066 mm | $c$ | 257669.878 |
| $A_{s\ negative}$ | 560 mm2 | Use3$\emptyset 16mm$ | |
| $A_{s\ positive}$ | 560 mm2 | Use 3$\emptyset 16mm$ | |
| $V_u$ | 69.016 kN | $\emptyset V_c$ | 99.06 kN |
| $V_u > \frac{\emptyset V_c}{2}$ | | | |
| $s = \frac{d}{2}$ | 180mm | | |

Use $\emptyset 10mm@180c/c$

**Table (3.24): Circular water tank girder beam design.**

| | | | |
|---|---|---|---|
| $b_w$ | 400 mm | $h$ | 700mm |
| $V_u$ | 235.32 kN | $M_{negative}$ | 128.93 kN.m |
| $M_{positive}$ | 210.464 kN.m | $d$ | 667 mm |
| $a$ | 37.9 mm | $c$ | 360808N |
| $A_{s\,positive}$ | 784.365 mm2 | Use Ø16 $Ab = 201.0619\ mm2$ | |
| $n$ | 3.9 bars | Say | 4 bars |
| $a_{negitive}$ | 22.96 mm | $c$ | 218579.2 N |
| $A_{s\,negitive}$ | 475.172 mm2 | Use Ø16 $Ab = 201.0619\ mm2$ | |
| $n$ | 2.36 bars | Say | 3 bars |

**Shear check**

| | | | |
|---|---|---|---|
| $V_u$ | 235.32 kN | $\emptyset V_c$ | 180 kN |
| $V_u > \emptyset V_c$ | | $\emptyset V_s$ | 55.32 kN |

$$\frac{\emptyset V_c}{2} < V_u \ \ Then\ spacing\ use\ minimum\ of$$

| | | | |
|---|---|---|---|
| $\frac{d}{2}$ | 300mm | $\frac{3A_v f_y}{b_w}$ | 541.05 mm |
| $\frac{16A_v f_y}{\sqrt{f_{c'}} b_w}$ | 545.93 mm | $s$ | 600 mm |

Use $\emptyset 10mm@300c/c(all\ length)$

**Table (3.25): Rectangular column design.**

| | | | |
|---|---|---|---|
| $P_u$ | 1904.6 kN | $M_u$ | 60.47 kN.m |
| $e$ | 31.749 | $b$ | 400 mm |
| $\rho$ | 0.01 | $h$ | 400 mm |
| $P_{n\ max}$ | 2930.153 kN | $P_{n^\circ}$ | 3662.7 kN |
| $A_g$ | 131932.1375mm2 | $A_c$ | 146591.27mm2 |
| $b$ | 382.8 mm | Say | 400 mm |
| $\rho$ | 0.01 | $A_s$ | 1600 mm2 |
| Use $\emptyset 16$ | $A_b = 201.0619$ | $n$ | 7.96 bars |
| say | 8 bars | | |

**Ties use minimum of**

| | | | |
|---|---|---|---|
| $48d_t$ | 480mm | $16d_b$ | 256mm |
| $bor\ h$ | 400mm | | |

Use $\emptyset 10mm@250mm\ c/c$

| | | | |
|---|---|---|---|
| $P_u$ | 1831.701 kN | $M_u$ | 39.05 kN.m |
| $e$ | 21.318mm | $b$ | 400 mm |
| $\rho$ | 0.01 | $h$ | 400 mm |

| | | | |
|---|---|---|---|
| $P_{n\,max}$ | 2818.1kN | $P_{n°}$ | 3522.6 kN |
| $A_g$ | 125083.45mm2 | $A_c$ | 138981.6069mm2 |
| $b$ | 373 mm | Say | 400 mm |
| $\rho$ | 0.01 | $A_s$ | 1600 mm2 |
| Use Ø16 | $A_b = 201.0619$ | $n$ | 7.96 bars |
| say | 8 bars | | |

**Ties use minimum of**

| | | | |
|---|---|---|---|
| $48d_t$ | 480mm | $16d_b$ | 256mm |
| $bor\ h$ | 400mm | | |

Use $Ø10mm@250mm\ c/c$

**Table (3.26): Circular column design.**

| | | | |
|---|---|---|---|
| $P_u$ | 1733.79 kN | $M_u$ | 61.64 kN.m |
| $e$ | 35.55 mm | $D$ | 450 mm |
| $\rho$ | 0.01 | | |
| $P_{n\,max}$ | 2667.37 kN | $P_{n°}$ | 3334.21 kN |
| $A_g$ | 118393.58mm2 | $A_c$ | 131548.4mm2 |
| $D$ | 382.8 mm | Say | 450 mm |
| $\rho$ | 0.01 | $A_s$ | 1590.43 mm2 |
| Use Ø16 | $A_b = 201.0619$ | $n$ | 7.91 bars |

| | | | |
|---|---|---|---|
| say | 8 bars | | |

**Ties use minimum of**

| | | | |
|---|---|---|---|
| $48d_t$ | 480mm | $16d_b$ | 256mm |
| $bor\ h$ | 450mm | | |

Use $\emptyset 10mm@250mm\ c/c$

| | | | |
|---|---|---|---|
| $P_u$ | 1655.78 kN | $M_u$ | 58.67 kN.m |
| $e$ | 35.43 mm | $D$ | 450 mm |
| $\rho$ | 0.01 | | |
| $P_{n\,max}$ | 2547.35 kN | $P_{n^\circ}$ | 3184.192 kN |
| $A_g$ | 113066.96 mm2 | $A_c$ | 125629.97 mm2 |
| $D$ | 400.05 mm | Say | 400 mm |
| $\rho$ | 0.01 | $A_s$ | 1256 mm2 |
| Use $\emptyset 16$ | $A_b = 201.0619$ | $n$ | 6.2 bars |
| say | 8 bars | | |

**Ties use minimum of**

| | | | |
|---|---|---|---|
| $48d_t$ | 480mm | $16d_b$ | 256mm |
| $bor\ h$ | 400mm | | |

Use $\emptyset 10mm@250mm\ c/c$

**Table (3.27): Rectangular water tank foundation.**

| | | | |
|---|---|---|---|
| $\gamma_{con}$ | 24 kN/m3 | $f_y$ | 420 Mpa |
| $h$ | 600 mm | $f_{c'}$ | 28 Mpa |
| $B$ | 2.2 m | $L$ | 2.2m |
| $P_w$ | 1109.46 kN | $P_u$ | 1904.5 kN |
| $M_w$ | 45.35 kN.m | $M_u$ | 60.473 kN.m |
| $q_{max}$ | 254.781 kN/m2 | $q_{min}$ | 203.673 kN/m2 |
| $q_{all}$ | 300 kN/m2 | $q_{max} < q_{all}$ | O.K |
| $q_{u\,max}$ | 427.58 kN/m2 | $q_{u\,min}$ | 359.42 kN/m2 |
| $d$ | 520 mm | $m$ | 19.328 |
| $R_u$ | 3.906 N/mm2 | $M_u$ | 537.256 kN.m |
| $d_{min}$ | 263.56 mm | $d_{min} < d_{acual}$ | O.K |

**One way shear**

| | | | |
|---|---|---|---|
| $V_u$ | 285.681 kN | $\emptyset V_c$ | 771.819 kN |
| $\emptyset V_c > V_u$ | O.K | | |

**Punching shear check**

| | | | |
|---|---|---|---|
| $V_u$ | 1904.51 kN | $\emptyset V_c$ | 2729.514 kN |
| $\emptyset V_c > V_u$ | O.K | | |

**Moment reinforcement**

| | | | |
|---|---|---|---|
| $R_{u\,rev}$ | 1.0034 N/mm2 | $\rho_{rev}$ | 0.0023 |

| | | | |
|---|---|---|---|
| $\rho_{min}$ | 0.0033 | $\rho_{rev} < \rho_{min}$ | Use $\rho_{min}$ |
| $n$ | 11.3 bars | spacing | 194 mm |

Use $\emptyset 16mm@150mm\ c/c$

**Table (3.28): Circular water tank foundation.**

| | | | |
|---|---|---|---|
| $\gamma_{con}$ | 24 kN/m$^3$ | $f_y$ | 420 Mpa |
| $h$ | 600 mm | $f_{c\prime}$ | 28 Mpa |
| $B$ | 2.2 m | $L$ | 2.2m |
| $P_w$ | 1144.17 kN | $P_u$ | 1733.8 kN |
| $M_w$ | 46.325 kN.m | $M_u$ | 61.64 kN.m |
| $q_{max}$ | 262.502 kN/m$^2$ | $q_{min}$ | 210.502 kN/m2 |
| $q_{all}$ | 300 kN/m2 | $q_{max} < q_{all}$ | O.K |
| $q_{u\,max}$ | 392.95 kN/m2 | $q_{u\,min}$ | 323.49 kN/m2 |
| $d$ | 520 mm | $m$ | 19.328 |
| $R_u$ | 3.906 N/mm2 | $M_u$ | 475.682 kN.m |
| $d_{min}$ | 267.06 mm | $d_{min} < d_{acual}$ | O.K |

**One way shear**

| | | | |
|---|---|---|---|
| $V_u$ | 220.66 kN | $\emptyset V_c$ | 771.82 kN |
| $\emptyset V_c > V_u$ | O.K | | |

**Punching shear check**

| | | | |
|---|---|---|---|
| $V_u$ | 1733.8 kN | $\emptyset V_c$ | 2396.224 kN |
| $\emptyset V_c > V_u$ | O.K | | |

**Moment reinforcement**

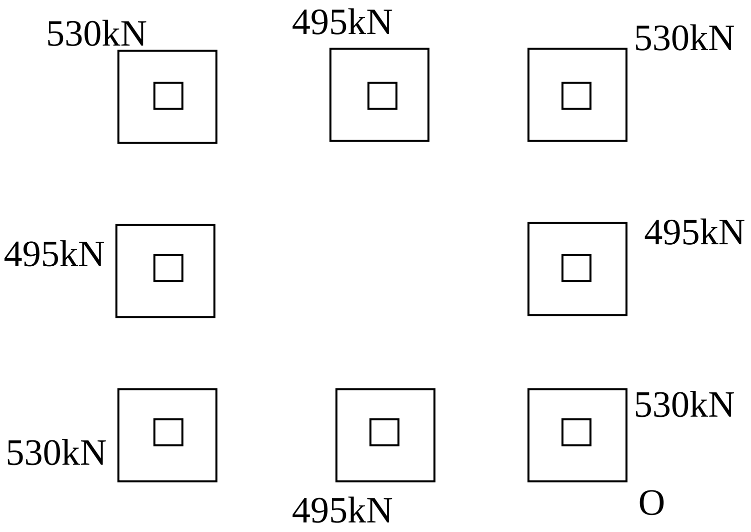
| | | | |
|---|---|---|---|
| $R_{u\,rev}$ | 1.0303 N/mm2 | $\rho_{rev}$ | 0.002095 |
| $\rho_{min}$ | 0.0033 | $\rho_{rev} < \rho_{min}$ | Use $\rho_{min}$ |
| $n$ | 11.294 bars | spacing | 194 mm |

Use $\emptyset 16mm@150mm\ c/c$

### 3.14 Stability check

**- Rectangular water tank**

- overturning check:



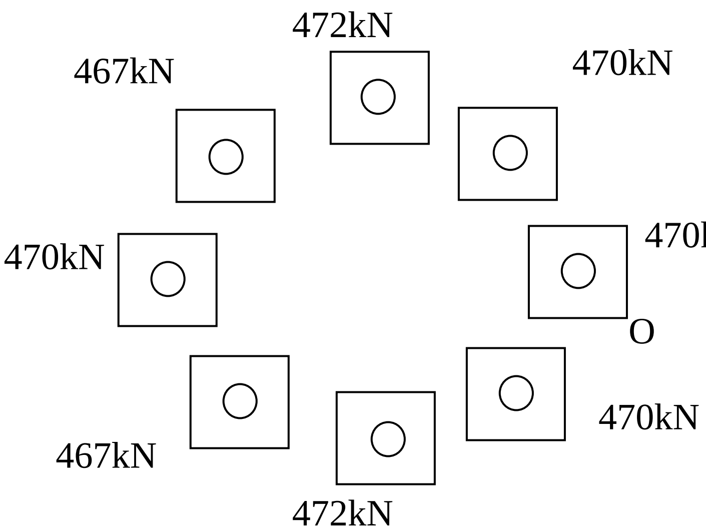

$$M_R = (530 + 495 + 530) * 1.1 + (495 * 2 * 4.6) + (530 + 530 + 495) * 8.1 = 18860 KN.m$$

$$M_o = 1933.54\ kN.m$$

$$F.S = \frac{M_R}{M_o} = \frac{18860}{1933.54} = 9.75 \gg 1.5\ \ O.K$$

**-Circular water tank**

- overturning check:



$$M_R = 470 * 8.1 + (467 * 2 * 7.07) + 472 * 2 * 4.6 + 470 * 2 * 2.13$$
$$= 17271.98 KN.m$$

$$M_o = 1417.689\ kN.m$$

$$F.S = \frac{M_R}{M_o} = \frac{17271.98}{1417.689} = 12.183 \gg 1.5\ \ O.K$$

**4.8.2Circular water tank with wall**

- overturning check:

$$M_R = 4584 * 4 = 18336 KN.m$$

$$M_o = 1648.373\ kN.m$$

$$F.S = \frac{M_R}{M_o} = \frac{18336}{1648.373} = 11.124 \gg 1.5\ \ O.K$$