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# Design and Development of a 10 Million Liters Capacity Petroleum Product Storage Tank

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**ABSTRACT**
*In Nigeria, the demand for petroleum products are on the increase and the need for reliable and safe storage facilities is on increasing demand.This has called for indigenous design and development of these facilities to augment the existing ones, and hence, to conserve foreign exchange and enhance job creation. In this work attempt has been made to designastorage tankcapable of holding a 10 million liter of DPK, PMS and AGO.Appropriate design codes and standard are applied, an adequate design method is chosen, and material selection was donein consonance with the requirements of the recent editions of API 650 and IS 803. Design specificationsand Sketches of the storage tank are presented. Fabrication and erection procedures, examination, inspection and maintenance routine for the tank are given.It was found that, the nominal diameter is 42m without space constraint, height is 7.2 m, number of course is 4, and height of each course is 1.8m. Also, the thickness of each course of tank shell is in the order of 14mm, 12mm, 10mm and 8mm from bottom. The bottom and annular plate thickness are 10mm and 12mm respectively. Carbon steel A36 material was selected for the design. The overall weight of the tank is 541,747.10kg, which is found to be stable without anchorage.*
***Keywords**: Storage Tank, Petroleum Product, API 650, IS 803, Fixed Roof*

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## I. INTRODUCTION

Tanks are widely used for storing a range of substances in both liquid and gaseous state meantto serve industrial or domestic purpose. These tanks may usually be installed below or above the ground with a support or an appropriate foundation to hold its weight. There are numerous types of tanks designed to meet different storage needs in the industry, these tanks can be easily differentiated by their physical features like roof type, body or shell configuration, and stance position if it is either horizontally or vertically positioned. Tanks are designed using codes and standards with an appropriate design method. API 650 standards establishes minimum requirements for material, design, fabrication, erection, and testing forvertical, cylindrical, above-ground, closed-top, and open-top, welded storage tanks in various sizes, and capacities for internal pressures approximating atmospheric pressure as pointed out by Okpala and Jombo (2012).

The importance, and effect of oil and its related products, in politics, technology and especially in the global market is compelling.Samuel (2013)noted that several countries ventured into commercial exploitation of crude oil to gain competitive edge in the global market and to meet domestic demands.The estimated daily demand for petroleum products in Nigeria given by Nigerian National Petroleum Corporation (NNPC)as at 2010 with predicted growth in years to come are: petrol or premium motor spirit (PMS) is 30 million liters,kerosene or dual purpose kerosene (DPK) is 10 million liters,diesel or automobile gasoline oil (AGO) is 1.8 million liters. An analysis of the energy demand over the period 2009 to 2035 by the Energy Commission of Nigeria (ECN), using the Model for the Analysis of Energy Demand (MAED) developed by the International Atomic Energy Agency (IAEA) also indicated increasein demand for petroleum products in the country. According to Isa, et al (2009), Petroleum products accounted for the next most highly consumed energy source with 36% in 2009 and are expected to account for 61% in 2020. He conclusively noted that for Nigeria to attain its desire of Vision 2020, all effort should be geared towards attaining self-sufficiency in meeting our petroleum products demands through local refining. He further suggested that this could be achieved by properly maintaining all the local refineries and building new ones both publicly and privately. Hence the need for indigenous design and installation of bulk storage tanks in refineries and depots to effectively store these petroleum products instead of dependence on turnkey design by foreign experts.

Also, Practicing engineers face many issues and challenges when designing liquid storage tanks. These challenges are generally either in the application of the current design codes and standards, or in choosing an appropriate design method (Lisa, 2005). The design of storage tanks are influenced by economic factors, regulatory requirements, the liquid to be stored, internal pressures, external environmental forces, corrosion protection, and welding needs as pointed out by Geyer (2000).The design and safety of storage facilitieshavebecome a great concern, failures and other plight experienced by petroleum industriescan be associated to design factors or considerations not fully satisfied.Storage tank failure can also be attributed to poor design.To properly address these issues and challenges, it is recommended that appropriate design codes and standardsare applied, an adequate design method is chosen, appropriate material selection is done and stress analysis performed to ascertain the strength and reliability of the tank against failure. This work therefore strictly applied the twelfth edition of API 650 and IS 803 (Reaffirmed 2006) standard in the design.It aims at revealing the procedures involved in correctly applying the standard for welded tanks intended for oil storage andserve as a guide to prospective investors in Nigeria.

## II. METHODOLOGY

A storage tank of 10 million liters capacity that would be able to safely carry any of the three (3) major petroleum products of refineries in Nigeria,which are petrol (PMS), kerosene (DPK) and diesel (AGO) was designed to satisfy API 650, IS 803 and other relevant standards and codes. The design consideration, calculations, and the fabrication and erection procedures are presented as follows:

### *1.1 Design Consideration*

In the design of the tank, following considerations were established.

**Capacity of Storage Tank:** The Storage Capacity(C) [m$^3$] given by API 650 (Table A.1a) is defined as $C = 0.785 D^2 H$ , where, $H = H_t - \left[ (n-1) W_s \right]$ [m] is the heightfrom the bottom of course under consideration to the top of the curb angle, $D$ [m] is nominal diameter of tank, $H_t$ [m] is the height of a shell Course, $n$ is the number of shell courses required and $W_s$ [m] is thewidth of shell plate.

**Design of Tank Shell:** Tank shell design methods as per API 650 (5.6) are the One-Foot (OF) method, Variable Design-Point (VDP) method, and the Elastic Analysis (EA) method.API 650 (5.6.3.1) recommends the use of one-foot method for calculating shell thickness for diameters less than 61m, therefore this method was adopted rather than the variable design-point or elastic analysis method.

**Design of Tank Bottom:** The Bottom plates rest on the asphalted surface of the foundation. The tank bottom is designed in accordance with API 650 (5.4).The thickness of the bottom plate is usually greater than 6mm with added Corrosion Allowance (C.A) as recommended by API 650 (5.4.1).

**Design of Annular:** Annular Plates cover the periphery of the concrete foundation ring, the bottom plate and the shell of the tank rest on the annular plates. The annular plate thickness as recommended by API 650 is chosen by considering the first shell course of the shell wall.The annular is designed according to API 650 (5.5).

**Design of Tank Roof:** The tank roof is designed in accordance with API 650 (5.10). The roof design can either be a supported cone with its principal support provided by rafters and columns, or a self-supported cone or dome roof supported only at its periphery.

**Foundation Type:** A stone-pilled base with concrete ring foundation was considered to prevent soil failure due to weight of the tank. Hence, the subsoil is strengthen to absorb deformation without failing, and the reinforced concrete ring is there to enable equal weight distribution on the pilled base. Therefore, it is assumed that the soil has been well pilled to meet the requirements as outlined in Appendix B.3 and B.4 of API 650. Most tanks have their foundations done according to ACI 318, a Building Code requirement for Structural Concrete, and API 650.

**Fluid Consideration:** The Physico-chemical properties of petroleum products, as given in Odebunmi et al (2002), shows that AGO seems to have the most critical physico-chemical property given in terms of specific gravity, to ensure safe storage of any of the products. The specific gravity of water was considered instead, as this reduces the chance of tank failure due to the presence of water or other contaminants.

**Corrosion Allowance:** Corrosion allowance for the bottom and annular plates was considered to be 4mm due to the severity of degradation on these parts. The shell and roof corrosion allowance was considered to be 2mm. Added thickness to the shell in the course of design would suffice any effect of corrosion and the roof of the tank is required to be considerably light, hence choice of corrosion allowance of 2mm. All corrosion allowances conform to the requirement of API 653 (4.3 and 4.4).

**Material Selection:** Material selection was done for the shell, roof, bottom and the annular plates of the tank. API 650 (4.2) recommends carbon steel for fixed roof tank. However, ASTM carbon steel A36wasselected because of its excellent welding properties and compatibility with the fluids under consideration. Selection of Plates was done from available standard.All plates are of same dimension except that of the annular plates with varying thicknesses for the respective parts to reduce the joints to be welded. Material selection was also done for other structural members, such as rafters, rafter's girders, column supports and wind girders.

**Design Codes and Standard:** The following codes and standards given in Table 1(Appendix 1) were used for the design of the storage tank.

**Tank Fabricationand Erection:** The tank should be fabricated and erected in consonance with the requirements of API 650 (6, 7 and 9).

**Examination, Inspection and Maintenance:** All requirements regarding examination, inspection andmaintenance of the storage tank during its service life will be in accordance with recommendations of AST Operator Handbook (2003) and API 650 (7.3 and 8).

**Tank Design Details:** Refer to Table 2(Appendix 1) for this details.The Code used is of the API 650 12thEditions and IS 803(Reaffirm 2006).

### *1.2 Design Concepts and Selection*

A number of concepts was generated. However, Table 3 gives few of them that are adequate for consideration. They were all subjected to evaluation, and the selected concept given in Table 4.

### *1.3 Design Calculations*

**Determination of the Storage Tank Diameter and Height:** The storage tank capacity is defined as $C = 0.785 D^2 H$ . Given the capacity of 10,000 $m^3$ (Table 2), the tank diameter and height can iteratively be calculated by solving the design equation, $f = 0.785 D^2 H - C = 0$, using MS Excel Solver just as done to obtainAPI 650 (TableA.1a). Thus, a choice made from API 650 (Table A.1a) gives $C_s$= 9975 $m^3$, D = 42 m, and $H_t$ = 7.2 m, which satisfy the design equation. The liquid height, which is defined as $H_L = 0.785 H$ , is therefore 0.785(7.2) = 5.652 m.

**Design of Shell:** The shell design using the One-Foot method is thus presented in Table 5 (Appendix 1). The required number of jumbo plates per course was determined to be 13 plates with 20cm for allowance. The shell was initially not within safe limit according to IS 803 (6.3.3.1), against failure from hydrostatic load. Hence the shell thicknesses were adjusted (shown in Table 6, Appendix 1) to ensure the shell to adequately withstand stresses due to hydrostatic load. Also, stability of the tank shell was checked against wind to determine the appropriate height to secure tank against failure from wind especially keeping the tank shell circular. The safe height without girder was calculated to be 3.93m, which is less than the height of tank (7.2m), hence the tank was girded with one intermediate girder and top girder in accordance with IS 803 (Cl. 6.3.6.2 and Table 7). Shell development is shown in Figs1and2 (Appendix 2).

**Design of Bottom Plate:** The Bottom Plates rest on the cone-up surface of the foundation,cone-up height was considered 10cm to facilitate the easy drainage of water from the Tank bottom surface. Bottom plate thickness was calculated to be 10mm which includes the minimum bottom plate thickness of 6mm (API 650, 5.4.1) and corrosion allowance of 4mm.Bottom Plate details are given in Table 7 (Appendix 1), and bottom plates' development is presented in Fig3 (Appendix 2).

**Design of Annular Plate:** Annular parameters were calculated according to API 650 (5.5.3).The Annular plate thickness was chosen to be 12 mm as this falls within the stipulated range as recommended in API 650 (Table 5.1a). The calculated number of Annular Plates required to cover the periphery of the foundation is 22nos. Thespaces left between annular plates provide allowance for packing by offset pieces which are fully fillet-welded underneath the annular plates.Annular Plate details are given in Table 7 (Appendix 1) and annular plates' development is presented in Fig 3 (Appendix 2).

**Design of Roof:** The roof design consists of calculations for roof plates and rafters parameters. The minimum thickness for roof plate is 5mm as per API 650 (5.10.2.2), adding corrosion allowance to the minimum thickness gives 7mm. A roof plate thickness of 6mm was selected from standard due to unavailability of 7mm plate. In accordance with the requirement in API 650 (5.10.4.1) cone roof column is principally supported by rafters with a slope of 1:16 which gave a roof height of 1.3m. Also the total number of plates for roof is 77 plates.The number of rafters was iteratively determined to be 400nos at which tank is safe under bending and deflection. ISMC 150 column was selected for roof rafters. Roof Sketches are shown in Fig 3.

**Design of Structural Members:** The roof and its rafters are usually supported with girders to give static support. Pentagon and decagon formed girders at 14.43m and 28.23m respectively from the crown plate were used to support the rafters. ISHB 150 column were used for rafters girders. The roof, rafters and rafters' girders were centrally supported by a double built-in ISHB 200 column which was safe against buckling from total effective weight acting on them as recommended by IS 800 (Table 3, Cl.7.1.2.1 and Cl.7.1.2.2). Also, the overturning stability was checked using the total weight of the tank. It was determined that the stability criteria according to API (5.11.2.1) were satisfied; hence tank anchorage is not required. Sketches of columns and rafter are shown in Fig 2 (Appendix 2).

**Fittings and Appurtenance:** A complete set of fittings and appurtenance are required for the fixed roof to operate properly.Fittings and Appurtenance were determined from API 650 (5.7 and 5.8), IS 10987(Section 12) and IS: 12835 (part 1).Sketches of fittings and appurtenance are shown in Fig 1and 3 (Appendix 2).

### *1.4 Tank Fabrication and Erection*

The tank should be fabricated and erected in consonance with the requirements of API 650 (6, 7 and 9). The vertical shell joints of the storage tank shall be butt-welded with complete penetration and complete fusion attained by double welding the inside and outside weld surfaces. The horizontal shell joints shall have complete penetration and complete fusion. The bottom plates shall be lap-welded between 100mm to 300mm. The annular plates shall be butt-welded to each other, and be lap-welded to the bottom plates. The shell to bottom shall be fillet-welded.The bottom to annular shall have an overlap of 100mm with full fillet weld on the top side only. Wind girder jointsshall be full-penetration butt-welded. The roof and top-angle joints shall have continuousfull-fillet weld.The bearing plates under each support column for fixed roof tanks shall be centered and welded to the bottom plate by a continuous fillet weld of size equivalent to bottom plate thickness. For the reason of visualization, a scale model of the tank was fabricated asgiven in Fig 4 (Appendix 2).

## III. DISCUSSION OF DESIGN RESULTS

The following basic parameters for the tank were determined: the nominal diameter (42m), height (7.2m), number of shell course (4 nos.) and height of shell course (1.8m). Also the liquid height was determined using the capacity design equation. The bottom of the tank consisting of the bottom and annular plates was designed. The bottom and annular plate thickness were determined.The bottom plate dimension used was 10m x 1.8m x 10mm and the annular plate dimension 6m x 50m x 12mm (from 6m x 1.5m x 12mm plate). The difference in thickness is due to the fact that the shell of the tank rest directly on the annular plate, therefore it is under continuous load from the shell and roof weight. The shell varying thicknesses in turn were determined using the one-foot method.The design stress and hydrostatic test shell thickness was determined for each course respectively. The shell thicknesses (14mm, 12mm, 10mm and 8mm from bottom) were adopted after iterative adjustment to withstand hydrostatic load, and it was girded 3.9m from the bottom by an intermediate wind girder, and at the top by a top wind girder to ensure stability of tank against external loads like wind.
The roof plate thickness was considered to be 6mm with corrosion allowance. The cone roof has a slope of $3.58^o$ and a height of 1.3125m. The length and number of rafters (Table 7) was iteratively determined so that it will effectively support the weight, and span beneath the roof load under bending moment and deflection. A double built-in ISHB 200 column which was safe against buckling from total effective weight acting on them was used. Fittings and appurtenance for the tank were determined. Sizing for Vents, Manholes, Valves and other appurtenance were doneas recommended by standard. Table 5gives details for fitting and appurtenance sizes. The overall weight of the tank was determined (541,747.10kg). The tank was determined to the required number of anchorage due to the fact that the height to diameter ratio was small.Hence it is more economical in design resulting from same plate choice to reduce weld joints, and cost saved for anchorage design. Table 7 (Appendix 1) presentsthe design specifications.

## IV. CONCLUSION

All through the design API 650, IS 803 and other relevant standardswere successfully used to design the proposed storage tank. MS Excel spreadsheet wasused to perform design calculations. Appropriate design method and material selection were done; design factors and considerations were observed in the process of design to ensure a safe and reliable storage system. A fair assessment of the cost of the tank at as 2015 was presented. Design Specification and sketches of an indigenous design were presented to serve as a guide to prospective investors in Nigeria. A scale model of the tank was fabricated and used only for visualization purpose.

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## APPENDIX 1

**Table 1** Codes and Standards for Storage Tank Design

| Codes/Standard | Description |
|---|---|
| API 650 | Welded Steel Tanks for Oil Storage |
| API 653 | Tank Inspection, Repair, Alternation, and Reconstruction |
| IS 800 | General Construction in Steel |
| IS 803 | Vertical Mild Steel Cylindrical Welded Oil Storage tanks. |
| IS 875 (Part 3) | Code for Practice for Design Loads other than Earthquake for Building and Structures |
| IS 2007 | Method for Calibration of Vertical Oil Storage Tanks |
| IS 2008 | Method for Computation of Capacity Tables for Vertical Oil Storage Tanks |
| ASTM A36 | Standard Specification for Carbon Structural Steel |
| IS 875 (Part 1) | Code for Practice for Design Loads (Dead Load) |
| IS 6-1 | ISI Handbook for Structural Engineers –Part 1: Structural Steel Sections. |
| IS 12835 (Part 1) | Design and Installation of Fixed Foam Fire Extinguishing System |

**Table 2**: Design Details

| Design Parameter | Symbol | Data | Unit | Source of Data |
|---|---|---|---|---|
| **Input Design Data** | | | | |
| Storage Tank Capacity | $C$ | 10,000 | $m^3$ | (Tech. Specification) |
| Quantity of Tank | $Q$ | 1 | | |
| Roof (Open/Close) | | Close | | |
| Tank support (self-supported/Column-supported) | | Column supported | | |
| Type of roof (Fixed Cone/Dome roof) | | Fixed Cone | | |
| Average wind velocity | $V_b$ | 160 | $km/hr$ | |
| Operating Pressure | $P_o$ | ATM | $N/m^2$ | |
| Operating Temperature | $T_o$ | Ambient | $°C$ | |
| Design Temperature | $T_d$ | 60 | $°C$ | API 650 (4.2.10) |
| Earthquake | | Nil | | |
| Design Method | | 1-Foot Method | | API 650 (5.6.3) |
| Design Metal Temperature | $T_{dm}$ | 25 | $°C$ | Based on ambient temp. |
| Specific gravity of operating liquid | $G_L$ | 0.8504 | | Odebunmi, et al (2002) |

| | | | | |
|---|---|---|---|---|
| Design Density of water | $G_w$ | 1000 | $kg/m^3$ | |
| Design Pressure | $P_d$ | Hydrostatic Head | $mLC$ | |
| Vacuum (Internal) Pressure | $V_p$ | 63.5 | $kg/m^2$ | API 650 (5.2.1 b & c) |
| Joint Efficiency Factor | $E$ | 0.85 | | API 650 (Table AL.2) |
| Acceleration due to gravity | $g$ | 9.81 | $m/s^2$ | |

**Table 3**: Design Concepts Considered

| **Considerations** | **Design Alternatives** | | | | | **Selection** |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| Shell configuration | Horizontal cylindrical shape | Vertical cylindrical shape | Rectangular shape | Spherical shape | Spheroid shape | **B** |
| Roof Configurations | Open top | Conical roof | Dome roof | Flat roof | Floating roof | **B** |
| Bottom-plate configuration | Flat shape | Cone shape | Dome shape | ----- | ----- | **B** |
| Foundation base type | Compacted soil foundation | Crushed stone ring wall foundation | Slab foundation | Pilled support foundation | ----- | **D** |
| Foundation Configurations | Cross Shape | Square Ring | Circular Ring | Solid cylindrical Shape | Solid rectangular shape | **C** |

**Table 4**: Selected Concept with Reasons

| **Consideration** | **Selection** | **Selected Alternative** | **Reason** |
|---|---|---|---|
| Shell Configuration | B | Vertical Cylindrical Shape | It adequately account for the hydrostatic pressure exerted by the fluid on the bottom and wall of the tank. It also enables tapered wall with different values of thickness at different elevation. |
| Roof Configuration | B | Conical roof | It is relatively easy to design and fabricate. It offers adequate cover from contaminants. |
| Bottom plate Configuration | B | Cone shape | It enables easy drainage of water from its bottom, relatively easy to fabricate and maintain |
| Foundation Base Type | D | Pilled-support foundation | It adequately increases the resistance of the subsoil against the weight of tank and its content. It is more effective and quite expensive with long term advantages over other types of foundation. |
| Foundation Configurations | C | Circular Ring | It enable adequate distribution of weight of the tank and its content on the foundation |

**Table 5**: Calculation of Shell Plate Thickness

| **Design Parameter** | **Symbol/Equation** | **Value** | **Unit** | **Source of Data** |
|---|---|---|---|---|
| Total Tank Height of Shell | $H_t$ | 7.2 | $m$ | API 650 (Table A.1a) |
| Selected Diameter | $D$ | **42** | $m$ | |
| Width of Jumbo Plate | $W_s$ | 1.8 | $m$ | |
| Number of Shell Course considered | $N$ | 4 | | |
| Length of Jumbo Plate | $L_s$ | 10 | $m$ | SP 6-1 (Table VII) |
| Corrosion Allowance | $C.A$ | 2 | $mm$ | |
| Specific gravity of operating liquid(Actual) | $G_L$ | 0.8504 | | Table 3.1 |
| Density of Water | $P$ | 1000 | $kg/m^3$ | |

| | | | | |
|---|---|---|---|---|
| Specific gravity of Operating liquid (Design) | $G_w$ | 1 | | |
| Joint Efficiency Factor | $E$ | 0.85 | | |
| 1st Shell Course | $n_1$ | 1 | | |
| 2nd Shell Course | $n_2$ | 2 | | |
| 3rd Shell Course | $n_3$ | 3 | | |
| 4th Shell Course | $n_4$ | 4 | | |
| Product Design Stress | $S_d$ | 160 | $MPa$ | API 650 (Table 5.2a) |
| Hydrostatic Test Stress | $S_t$ | 171 | $MPa$ | |
| **1st Shell Course** | | | | |
| Height from Bottom to Top for 1st Course | $H_1 = H_t - [(n_1 - 1)W_s$ | **7.2** | $m$ | |
| Design Shell Thickness for 1st Course | $t_{d1} = \left[\frac{4.9D(H_1 - 0.3)G_w}{S_d E}\right]$ | **12.44** | $mm$ | API 650 (5.6.3.2) |
| Hydrostatic test Shell Thickness for 1st Course | $t_{t1} = \left[\frac{4.9D(H_1 - 0.3)G_w}{S_t E}\right]$ | **9.77** | $mm$ | |
| **2nd Shell Course** | | | | |
| Height from Bottom to Top for 2nd Course | $H_2 = H_t - [(n_2 - 1)W$ | **5.4** | $m$ | |
| Design Shell Thickness for 2nd Course | $t_{d2} = \left[\frac{4.9D(H_2 - 0.3)G_w}{S_d E}\right]$ | **9.72** | $mm$ | API 650 (5.6.3.2) |
| Hydrostatic test Shell Thickness for 2nd Course | $t_{t2} = \left[\frac{4.9D(H_2 - 0.3)G_w}{S_t E}\right]$ | **7.22** | $mm$ | |

**Table 5 (Continued):** Calculation of Shell Plate Thickness

| **Design Parameter** | **Symbol/Equation** | **Value** | **Unit** | **Source of Data** |
|---|---|---|---|---|
| **3rd Shell Course** | | | | |
| Height from Bottom to Top for 3rd Course | $H_3 = H_t - [(n_3 - 1)W_s$ | **3.6** | $m$ | |
| Design Shell Thickness for 3rd Course | $t_{d3} = \left[\frac{4.9D(H_3 - 0.3)G_w}{S_d E}\right]$ | **6.99** | $mm$ | API 650 (5.6.3.2) |
| Hydrostatic test Shell Thickness for 3rd Course | $t_{t3} = \left[\frac{4.9D(H_3 - 0.3)G_w}{S_t E}\right]$ | **4.67** | $mm$ | |
| **4th Shell Course** | | | | |
| Height from Bottom to Top for 4th Course | $H_4 = H_t - [(n_4 - 1)W_s$ | **1.8** | $m$ | |
| Design Shell Thickness for 4th Course | $t_{d4} = \left[\frac{4.9D(H_4 - 0.3)G_w}{S_d E}\right]$ | **4.27** | $mm$ | API 650 (5.6.3.2) |
| Hydrostatic test Shell Thickness for 4th Course | $t_{t4} = \left[\frac{4.9D(H_4 - 0.3)G_w}{S_t E}\right]$ | **2.12** | $mm$ | |
| **Minimum thickness check for welded tank shell** | | | | |
| Minimum acceptable thickness | $t_{min} = \left[\frac{2.6(H_t - 1)DG_w}{S_d E}\right]$ | 4.98 | $mm$ | API 653 (4.3.3.1) |
| **Comment:** The specific gravity of water was used instead of the proposed product to be stored, so as to offer the highest resistance by shell thickness against the pressure that will be experienced from products by the Storage tank. | | | | |

**Table 6**: Shell Thickness Calculation Summary by One-Foot Method

| Course | Material | Length (m) | Height (m) | Height from Bottom to Top Curb(m) | $t_d$ (mm) | $t_t$ (mm) | Previous Thickness (mm) | Adopted Thickness (mm) |
|---|---|---|---|---|---|---|---|---|
| 1 | A36 | 10 | 1.8 | 7.2 | 12.44 | 9.77 | 14 | 14 |
| 2 | A36 | 10 | 1.8 | 5.4 | 9.72 | 7.22 | 10 | 12 |
| 3 | A36 | 10 | 1.8 | 3.6 | 6.99 | 4.67 | 8 | 10 |
| 4 | A36 | 10 | 1.8 | 1.8 | 4.27 | 2.12 | 6 | 8 |

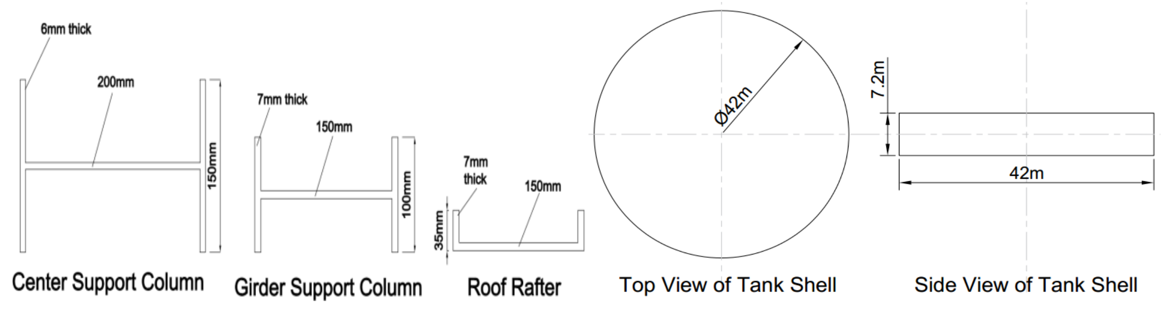
**Table 7**: Specification for Tank

| **Parameter** | **Value** | | |
|---|---|---|---|
| Design Method | One-Foot Method | | |
| Tank Diameter | 42m | | |
| Foundation Thickness | 0.30m | | |
| Total Height of Tank | 8.5125m | | |
| **Bottom Plate** | | | |
| Dimension of Bottom Plate | 10m x 1.8m x 10mm | | |
| Number of Bottom Plate | 77 | | |
| Material | ASTM A36 | | |
| **Annular Plate** | | | |
| Dimension of Annular Plate | 6m by 0.5m | | |
| Number of Annular Plate | 22 | | |
| Material | ASTM A36 | | |
| **Tank Shell** | | | |
| Height of Tank Shell | 7.2m | | |
| $1^{st}$ Shell Course | 10m x 1.8m x 14mm (13 Plates) | | |
| $2^{nd}$ Shell Course | 10m x 1.8m x 12mm (13 Plates) | | |
| $3^{rd}$ Shell Course | 10m x 1.8m x 10mm (13 Plates) | | |
| $4^{th}$ Shell Course | 10m x 1.8m x 8mm (13 Plates) | | |
| **Tank Roof** | | | |
| Type | Conical Shape | | |
| Dimension of Roof Plate | 10m x 1.8 x 6mm | | |
| Material for Roof Plate | ASTM A36 | | |
| Height of Roof | 1.3125m | | |
| Slant Height | 21.04m | | |
| Slant Height Angle | $3.58^o$ | | |
| Length of Roof Rafters | 6.9m | | |
| Number of Rafters | 400 | | |
| Number of Roof Plate | 77 | | |
| **Structural Members** | | | |
| Materials for Roof Rafters and Girders | ISMC150 | | |
| Length of Decagon Roof Girder | 8.72m (14.11m from centre column) | | |
| Length of Pentagon Roof Girder | 8.5m (7.225m from centre column) | | |
| ISMC150 Dimension | Base: 150mm | Height: 35mm | Thickness: 7mm |
| Top plate of Crown | 0.63m (10mm thick) | | |
| Base plate of Crown | 0.96m (20mm thick) | | |
| **Intermediate Wind Girder** | | | |
| Material | ASTM A36 | | |
| Dimension | Height:150mm | Base: 100mm | Thickness:6mm |
| Location distance from Tank Shell base | 3.93m | | |
| **Top Wind Girder** | | | |
| Material | ASTM A36 | | |
| Dimension | Height:100mm | Base:100mm | Thickness:10mm |

**Table 7 (Continued)**: Specification for Tank

| **Parameter** | **Value** | | |
|---|---|---|---|
| **Roof Support** | | | |
| Material for Centre Column Support | ISHB200 | | |
| Material for Supportive/Girder Column | ISHB150 | | |
| Material for Roof Rafters | ISMC150 | | |
| Dimension for ISHB200 | Base: 200mm | Height:150mm | Thickness: 6mm |
| Dimension for ISHB150 | Base: 150mm | Height:100mm | Thickness: 8mm |
| Dimension for ISMC150 | Base: 150mm | Height:35mm | Thickness: 7mm |
| Length of Centre Column | 8.5125m | 2 Nos. | |
| Length of Decagon Column | 7.64m | 10 Nos. | |
| Length of Pentagon Column | 8.06m | 5 Nos. | |
| Length of Outer Rafter | 6.90m | 225 Rafters | |
| Length of Middle Rafter | 6.90m | 125 Rafters | |
| Length of Inner Rafter | 6.885m | 50 Rafters | |
| Length of Outer Girder | 6.90m | 10 Nos. | |
| Length of Inner Girder | 6.90m | 5 Nos. | |
| **Fittings and Appurtenance** | | | |
| Parameter | Quantity | Value (mm) | |
| Shell Manhole | 2 | 600mm | |
| Product Inlet Nozzles | 1 | 250mm (10″) | |
| Product Outlet Nozzles | 1 | 200mm (8″) | |
| Foam pourer | 2 | 150mm (8″) | |
| Drain Nozzle | 1 | 100mm (4″) | |
| Level switch high Nozzle | 1 | 50mm | |
| Level switch Low Nozzle | 1 | 50mm | |
| Stairways | Cat Ladder Type | | |
| Breather Valve | 2 | 200mm (8″) | |
| Emergency Vent | 1 | 500mm (20″) | |
| Dip Hatch | 1 | 150mm | |
| Vent | 1 | 100mm | |
| Roof Manhole | 1 | 600mm | |
| Walkway | | 610mm (wide) | |
| Handrail | | 1.07m (high) | |

**APPENDIX 2**



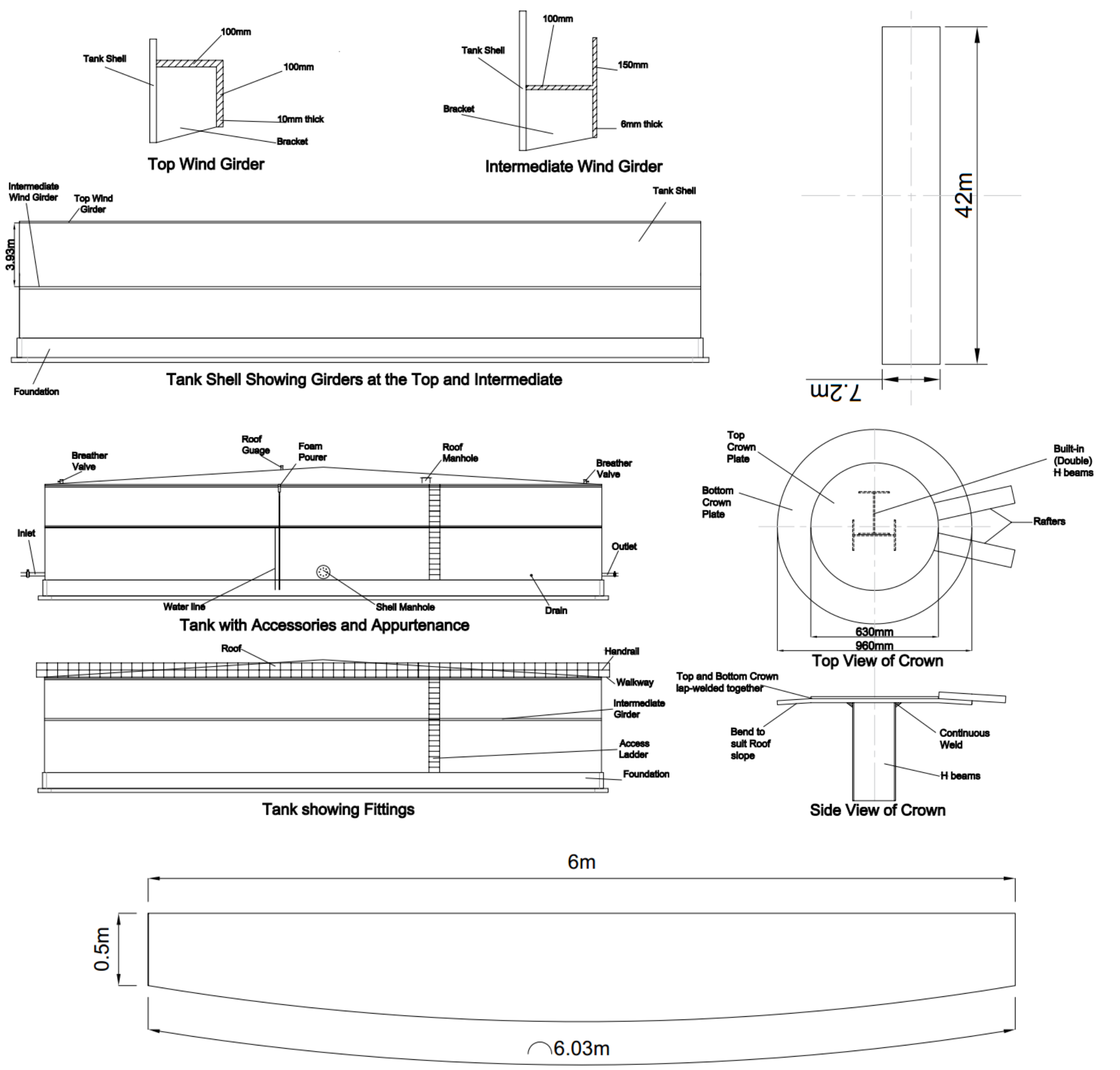
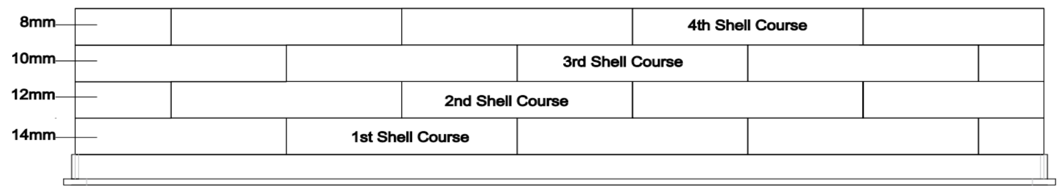
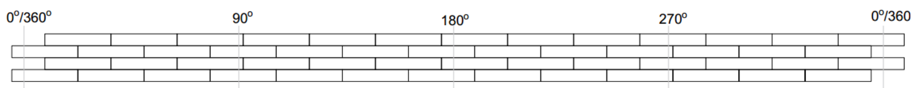


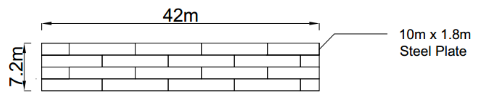

**Figure 1**: Sketches of Shell, Annular Rafters, Girders, Crown, and Fittings




Tank Shell Showing Courses and Thickness




Development of Shell Plate (View from Outside)




Front View of Tank Shell with Plates

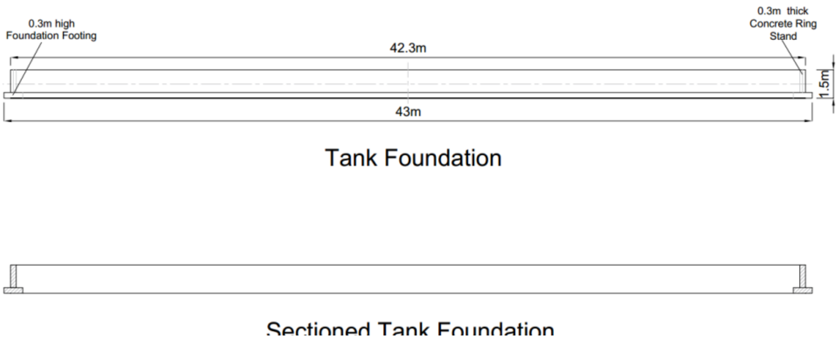



**Figure 2**: Sketches of Shell Plates, Shell and Foundation

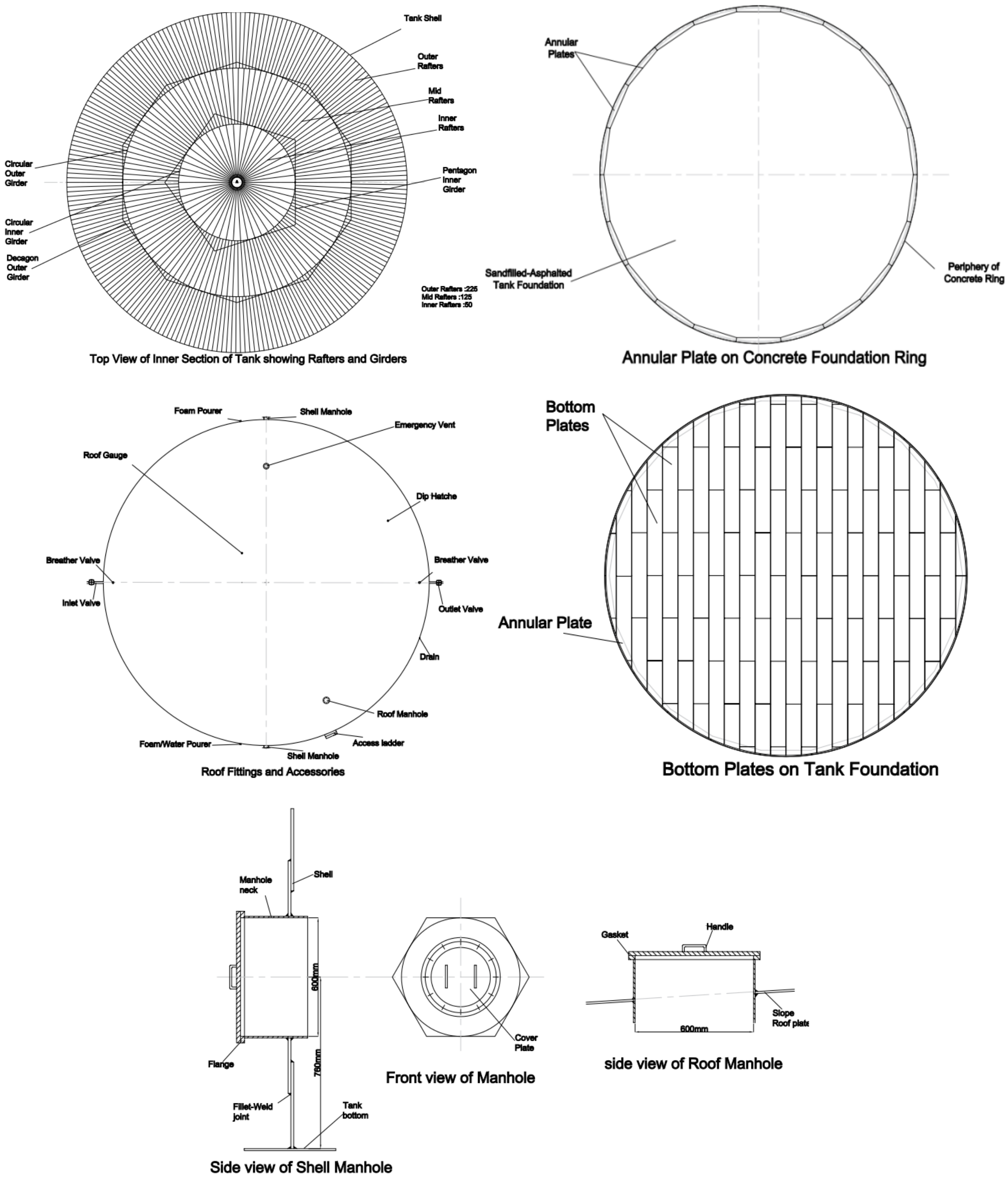



**Figure 3**: Sketches of Roof Rafters, Tank Base, Roof Accessories and Manhole

**Figure 4**: A Scale Model of the Storage Tank