Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2017, 4(8):318-329**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Design of a Floating Roof Crude Oil Storage Tank of 100,000 BPD Capacity and Prototype Fabrication

Emenike N. Wami[1], Welis Mike Onunwor[2], Owhor Sampson Chisa[2], Jimmy Dorcas Etim[3]

[1]Faculty of Engineering and Technology, Federal University Wukari, Taraba State, Nigeria
[2]Mechanical / Production Engineering, Federal University Wukari, Taraba State, Nigeria
[3]Petroleum Engineering, Rivers State University of Science and Technology, Port-Harcourt, Nigeria

Abstract Storage tanks are widely used in many industries particularly in the oil, petroleum refining and petrochemical industries. There are different types of storage tanks such as the fixed roof type, open roof type, external and internal floating roof type, etc. Floating roof tank is that which the roof floats directly on top of the product, with no vapor space and eliminating the possibility of flammable atmosphere. This study commenced with extensive literature review of the available codes and standards for designing storage tanks, these were compiled and categorized for use in parameter calculations. Many data gathering trips were undertaken to crude oil storage tank farms and facilities and relevant information, including geotechnical data and metrological peculiarities of the areas were recorded and compared with similar data available for the site chosen for the tank location.

A floating roof crude oil storage tank of 100,000 BPD capacity was designed taking into consideration the available geotechnical and meteorological information of the location site. The tank functional parameters such as diameter, height, etc were calculated using basic design equations; detailed calculations were also carried out for mechanical and structural components of the tank and roof fittings to ensure tank stability, using API standard codes, equations and procedures. For a tank of 100,000 BPD working capacity with allowance made for overfill and overflow (vapor emission) volume, the calculated designed height of the tank was obtained as 20.7m at a tank diameter of 39.0m, which from the ratio of D/H shows that the designed storage tank is a short floating roof type. The design incorporated adequate safety precautionary measures by taking into consideration risk of fire hazards, hydrate formation and tank failure due to corrosion. A prototype of the designed tank was fabricated and successfully tested.

Keywords Floating roof Crude oil Storage Tank, Design codes and Standards, Tank Dimensions, seismic factors, Tank Design parameters, Roof Design, fluid flow equations

1. Introduction

Large capacity storage tanks are essential facilities in the petroleum industry, ranging from crude oil production, refining processes to product distribution and consumption.

They are important for many reasons in custody transfer operations and others viz: market process of demand and supply will require it, for strategic reserve creations, for use whenever necessary in case of any processing problems occurrence; as a part of the separation process for further flash vaporization at atmospheric pressure and gravity settling; to avoid exposure to waste through evaporation or spillage which would be very hazardous to the environment. It is a vital tie-in point between the upstream and downstream operations [1].

Crude oil storage tanks are large capacity specially designed vessel reservoirs, which can be constructed with various types of materials, for storing crude oil [2].

Storage tank assembly includes its integral piping and its entire components, including dispensing systems, spill containment devices, stage II vapor recovery devices, and overfill protection devices, secondary containment systems and any associated release detection equipment [2].

Storage tanks are of different classifications, types, sizes and shapes. Components (fittings) incorporated, design criteria, material of construction, and protection and maintenance systems are based on their uses and type of fluid to be stored [3]. They can be designed in accordance with design standards and codes [4]. Tank Shell design as per *API 650* can be done by several methods [5]. Engineers or storage tank designers who do the preliminary and detail design are normally not familiar or not exposed to the actual site conditions. Their models and designs are basically based on the codes and standard requirements and basic theory from reference books or only rely on the commercial software for the basic design; they have limited knowledge of the actual technical details of the environments where such tanks are expected to be located. Often times in their designs, the geotechnical and seismic factors are not always given adequate considerations by simply assuming that not all are prone to these factors. These had resulted in lots of floating roof failures in the industry. Hence the industry, tank farm owners as well as the tank designers need to have simple rules and formulae to ensure that the floating roof storage tanks are adequately designed and strong enough for the various loading during operation. Beside the procedures and rules, understanding of how the stresses behave in the tank material is essential for tank stability and complete safe design.

This work presents design equations calculating different tank dimensions - taking into consideration the geological and seismic safety factor; calculation of tank shell design by 1-foot method, other sections and design parameters of 100,000bpd capacity floating roof crude oil storage tank.

2. Floating Roof Crude Oil Storage Tank: Design Methodology

2.1. Design Approach

Data on design of storage tanks are generated from variation of literature sources including field information from designing companies, design standards and code such as *API 650, 2007, API 2000, ASME 2007,* etc.

The tank capacity and its parameters, shell and shell stress design analysis such as hydrostatic pressure, wind and seismic loading were calculated evaluation and design of the different types of floating roofs and roof fittings (accessories); safety and other design parameters, was carried out.

2.2. Storage Tank Design Equations

2.2.1. Tank Section Heights and Capacity [5]

- **Tank allowance height**, $\mathbf{H_A} = H_1+H_2+H_3$

Where;

Tank minimum fill height, $\mathbf{H_1} = H_2 = \frac{\beta}{2.5} H_{Net}$.

Tank minimum overfill height, $\mathbf{H_2} = H_1$

Tank overfill height, $\mathbf{H_3} = 0.5H_1 = 0.5H_2$.

Therefore, $\mathbf{H_A} = H_1+H_2+H_3 = 2.5H_1$

- **Tank fluid storage height (Net capacity)**, $\mathbf{H_{Net}} = \frac{V_{Net}}{\pi r^2}$.
- **Tank maximum height**, $\mathbf{H_T} = H_{Net} + H_A = (1+\beta)H_{Net}$.

$\boldsymbol{\beta} = (H_A/H_{Net})$ = Fraction of H_{Net}.

- **Maximum Tank Volume**, $\mathbf{V_{Max}}$

$$= \frac{\pi D^2}{4} H_T = \frac{\pi D^2}{4}(1+\beta)H_{Net}.$$

2.2.2. Seismic Design [5]

The seismic design of the storage tank is accordance to *API 650 (2007)*.

2.2.2.1. Parameters required for seismic design

Convective (sloshing) period,

$$\mathbf{Tc} = 1.8K_S.\sqrt{D},$$

- Sloshing period coefficient, $K_S = \frac{0.578}{\sqrt{\tanh\left(\frac{3.68H}{D}\right)}}$.
- Regional-dependent transition period for longer period ground motion, T_L= 4sec
- Scaling factor, **Q** = 1.0
- Acceleration-based site coefficient, **Fa** at 0.2sec for site class of D and Ss=2.5Sp, Sp=0.3g, Ss=0.75, was determined directly from table [API 650, 2007] as 1.2.

Velocity-based site coefficient, **Fv** at 1sec was obtained from table as 1.65

Three major analyses performed in the seismic design are:

2.2.2.2. Overturning Stability check is resistance against wind load, the anchorage and number of anchor bolts required and ring wall moment.

2.2.2.3. Maximum base shear force, V is the shear stress at the base (bottom) of the storage tank to avoid tearing and or collapsing.

2.2.2.4. Freeboard requirement, δ_S is to ensure the roof sael remain within the height of the tank shell.

2.2.2.5. Site geometry design data for seismic design

Seismic peak ground acceleration, Sp=0.3g, Importance factor, I=1.50, Site class = D, Seismic group, SUG = III.

Ss = 2.5Sp for 5% damped spectral response acceleration parameter at period of 0.2sec.

S1 = 1.25Sp at periods 1sec for 5% damped spectral response acceleration parameter.

2.2.2.6. Overturning Stability

2.2.2.6.1. Ring wall moment, M_{rw} is the portion of the total overturning moment that acts at the base of the tank shell perimeter, is used to determine loads on ring wall foundation, anchorage force and check longitudinal shell compression to avoid bulking [5].

$$= \sqrt{[A_i(W_I X_i + W_s X_s + W_r X_r)]^2 + [A_c(W_c X_c)]2}.$$

Where;

Design Impulsive spectral acceleration Parameter, $A_i = S_{DS}\left(\frac{I}{R_{wi}}\right) = 2.5Q.F_a.S_O\frac{I}{R_{wi}}$.

Design Convictive spectral acceleration Parameter, A_C

$$= KS_{DI}\left(\frac{T_L}{T_C^2}\right)\left(\frac{I}{R_{WC}}\right) = 2.5K.Q.Fa.So\left(\frac{T_S T_L}{T_C^2}\right)\left(\frac{I}{R_{WC}}\right)$$

Design effective impulsive weight, **Wi** $= \frac{\tanh\left(0.866\frac{D}{H}\right)}{0.866}W_P$, when D/H ≥ 1.333, i.e. short tank.

Design effective convection weight, **Wc**

$= 0.230\frac{D}{H}\tanh\left(\frac{0.367\,H}{D}\right).W_P$.

Center of action for effective lateral impulsive force, **Xi** = 0.375H, when D/H≥1.333.

Center of action for effective lateral convection force, X_c

$= \left[1.0 - \frac{\cosh\left(\frac{3.67H}{D}\right)-1}{\frac{3.67H}{D}\sinh\left(\frac{3.67H}{D}\right)}\right]H.$

Total weight of the tank shell, W_s= 3,5E5N.

Total weight of tank roof, W_r= 0N.

Height from the bottom of the tank shell to the shell's center of gravity, X_s= 10.350m.

Height from the bottom of the tank shell to the roof and roof appurtenances center of gravity, X_r = 0 m.

2.2.2.6.2. Resistance to Overturning

There are three resisting components to resist against the overturning due to seismic;

2.2.2.6.2.1. Anchorage requirement is checked by the anchorage ratio, J and the J criteria table from *API 650, 2007*.

$\mathbf{J} = \frac{M_{rw}}{D^2[wt(1-0.4A_V) + wa - 0.4w_{int}]}$

Where;

wt = $\frac{W_S}{\pi.D}$ + wrs

wa= 7.9ta$\sqrt{Fy.H.Ge} \leq$ 1.28 H. D. Ge

Ge=G. (1 - 0.4 Av); G = 1, Specific gravity

2.2.2.6.2.1.1. Anchorage Design [5]**:** If the tank was found to be structurally unstable and is not self anchored for the design load; it will use anchor bolts to provide minimum anchorage resistance. The design uplift load on the anchor bolts due to the seismic is $\mathbf{W_{AB}} = \left(\frac{1.273 M_{rw}}{D^2} - w_t(1 - 0.4Av)\right) + W_{int}$.

2.2.2.6.2.2. Annular plate requirement

L= 0.01723.$t_a\sqrt{\frac{Fy}{H.Ge}}$. (450≤L≤0.035D) **2.2.2.6.2.3 Shell compression,** $\boldsymbol{\sigma_c}$[5]=$[W_t(1 + 0.4A_V) +$ *1.237MrwD211000ts.*

$F_C = \frac{83ts}{2.8D} + 7.5\sqrt{(G.H)}$, When $\frac{GHD^2}{t^2}$ <44

2.2.2.7. Base shear force, V: the seismic base shear is defined as the SRSS combination of the impulsive and convective components.

V =$\sqrt{V_i^2 + V_C^2}$, $V_i = A_i(W_S + W_r + W_f + W_i)$

$$V_C = A_C + W_C$$

2.2.2.8. Freeboard, $\boldsymbol{\delta_S} = 0.5D.A_f$.

$$A_f = K.S_{D1}\frac{T_L}{T_C^2} = 2.5K.S_o.F_a.Q.\left(\frac{T_L T_S}{T_C^2}\right)$$

2.2.3. Shell Design

Design shell thickness, t=$\frac{4.9\ D\ (H-0.3).G}{Sd}$ + C.A

Hydrostatic Test shell thickness, t_t=$\frac{4.9\ D\ (H-0.3)}{St}$

2.2.4. Other areas and design parameters [3-7]**:** This covers all the parameters with their equations that are not mentioned above such as;

- Top stiffener and intermediate and top wind girder design.
- Overturning stability against wind load.
- Roof and roof fittings and accessories design.
- Protection and maintenance systems.
- Flow equation.
- Data sheet.
- Design calculation sheet.
- Process flow diagram

2.2.5. Fabrication of Prototype Tank

An automated prototype of the storage tank was fabricated.

2.2.6. Input Data

The design parameters are computed with the following input data (Table 1):

Table 1: Input Data Sheet

STORAGE TANK DATA SHEET	
ITEM No.	T- 3514D
SERVICE	CRUDE OIL STORAGE
ROOF TYPE	FLOATING ROOF
HAZARD CATEGORY	MINIMAL
INTERNAL FLOATING ROOF TYPE	SINGLE DECK PONTOONFLOATING ROOF
AMOUNT OF ITEMS REQUIRED	1
SHELL DESIGN METHOD	1-FOOT METHOD
NET CAPACITY	100,000bbl = 15,898.95m^3
NORMAL CAPACITY	155,611bbl = 24,739.103m^3
NORMINAL CAPACITY VOLUME	24,736.103m^3

INSIDE DIAMETER	39,006mm
NORMINAL DIAMETER (NEW)	39,028mm
NORMINAL DIAMETER (CORRODED)	39,031mm
HEIGHT (MAX.DESIGN LIQ.LEVEL)	20700mm
SPECIFIC GRAVITY(ACTUAL/DESIGN)	0.790 / 1.00
DESIGN CODE	API 650
OPERATING PRESSURE	0.763 bar
OPERATING TEMPERATURE	33℃
DESIGN PRESSURE (UPPER&LOWER)	0.00mbar
DESISN TEMPT. (UPPER&LOWER)	(70 & -17)℃
PRODUCT STORED	CRUDE OIL
DENSITY	745.6 kg/m^3
FLASH POINT	< 100 ℃ (67℃)
FLOWRATE IN	20,361 bpd
FLOWRATE OUT	10,000 bpd
BLANKETING VALVE SET POINT	11.0 psig
DE-PAD VALVE SET POINT	12.0 psig/0.83 bar
PRESSURE SAFETY VAL. SETPOINT	14.0 psig/0.99 bar
ROOF LEG TYPE	PONTOON&CENTER DECK SUPPORT LEG
PROTECTION SYSTEM TYPE	FIRE PROTECTION
FIRE PROTECTION	SECOND ROOF SEAL SYSTEM&VENTING

TANK NOZZLES				
TAG	SERVICE	SIZE	RATING	FACING
N1	TANK LIQUID INLET	6”	150#	RF
N2	TANK LIQUID OUTLET	6”	150#	RF
N3a	PRESSURE SAFETY VALVES	4”	150#	RF
N3b	VACUUM VALVES	6”	150#	RF
N4	TANK BLANKETING	4”	150#	RF
N5a/b/c/d	FOAM CHAMBERS	6”	150#	RF
N6	VENT	4”	150#	RF
N7	SAMPLING POINT	2”	150#	RF
N8a/b/c/d	DRAINS	4”	150#	RF
N9	EMERGENCY FIRE CASE VENT	24”	150#	RF
M1	MANHOLE	24”	150#	RF
M2	MANHOLE	24”	150#	RF
CN1	LEVEL INDICATOR TRANSMITTER	4”	150#	RF
CN2	PRESSURE TRANSMITTER	2”	150#	RF
CN3a/b	LSLL	4”	150#	RF
CN4	LSHH	4”	150#	RF
N10	PRESSURE GUAGE	2”	150#	RF
N11	MINIMUM RECIRCULATION LINE	2”	150#	RF
NC	NOZZLE FOR CLEANING	24” x 24”		
NOTE	The nozzles positions are indicated in the attached sketch (attachment 1)			

3. Results

3.1. Tank Capacity

Taking D = 39m,β= 0.56,V_{Net}= 100,000bbl(15,898m³), from above equations, we have; H_1=H_2=2.959m, H_3=1.4795m, H_A=7.397m, H_{Net}=13.303m, H_T=20.7m and V_{Max}=155623.2bbl (24739.103m³). From ratio of D/H=1.88 and ≥1.33, shows a short tank [1]

3.2. Shell design

The 1-foot method in API 650, 2007 used gave the minimum shell wall thickness at the bottom course as 28mm, which reduces to 11mm at the upper top course in accordance with the liquid static head.

Table 2 show Shell Wall Design Thickness Summary

Course No	Width (mm)	Height (mm)	t.design (mm)	t.hydro (mm)	t.min (mm)	tsc. (mm)				
1	2440	20,700	27.30	21.60	27.30	28				
2	2440	18,260	24.40	19.02	24.40	25				
3	2440	15,820	21.45	16.43	21.49	22				
4	2440	13,380	18.58	13.85	18.58	19				
5	2440	10,940	15.67	11.26	15.67	16				
6	2440	8,500	12.77	8.68	12.77	13				
7	2020	6,060		9.86		6.10	11	11		
8	2020	4,040			7.45			3.96	11	11
9	2020	2020			5.04			1.82	11	11

Where,

t.design = Minimum required thickness due to design condition,

t.hydo. = Minimum required thickness due to hydrostatic test,

t.min = The greater value of t.design and t.hydro, and

tsc = Actual thickness used.

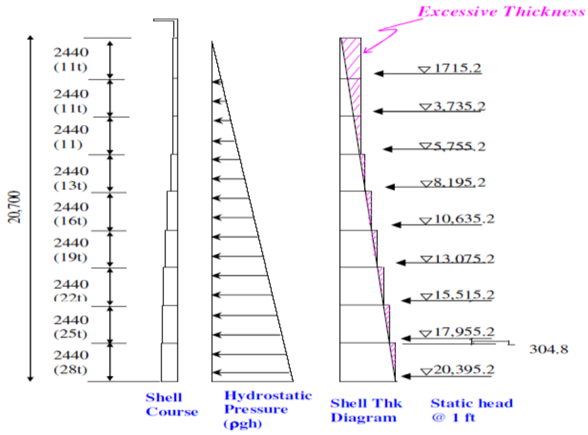

Figure 1: Illustrates Diagrammatical Sketch of Shell Wall with Design Thickness

From the 1-Foot equation, it can be seen that the minimum required shell thickness is directly proportional to the liquid static height; hence the shell thickness diagram shall follow the same shape profile with the hydrostatic pressure due to the design liquid height as shown in Figure 1. However it is impractical to construct the tank with the taper thickness, therefore different shell course with different thickness is used. The use of courses with diminishing thickness will has the effect that, at the joint between two adjacent courses, the thicker lower course provides some stiffening to the top, thinner course and this cause an increase in stress in the upper part of the lower course and a reduction in stress in the lower part of the upper course.

3.3. Top Stiffener / Top Wind Girder

$Z = 1007140mm^3$

From the design calculation, a fabricated Tee-girder of size T 825x250x8x10 with toe plate length 250mm, web plate length 825mm, toe plate thickness 10mm and web plate thickness 8mm is used.

3.4. Intermediate Wind Girder

H_T= 9.182m OR = 9182mm and Z = 225,812.032mm^3

3.5. Overturning Stability against Wind Load

<u>Criteria 1:</u> $0.6Mw + M_{pi} < \frac{M_{DL}}{1.5}$ = 4,345,020,578Nmm < 41,767,668,251Nmm

<u>Criteria2</u>: $M_W + 0.4M_{Pi} < \frac{(M_{DL}+M_F)}{5}$ = 7,241,700,964<108,035,440,779Nmm

The summarized calculation result for the overturning stability against wind load shows that both uplift criteria are met and the tank will be structurally stable even without anchorage.

3.6. Seismic Design

Seismic design is beyond API 650, 2007 scope and will be challenging to analyze the effect on the floating roof. But three (3) MAJOR analyses were done in order to perform and achieve the seismic design, which are **overturning stability (M_{rw}), maximum base shear (V) and freeboard (δs) required for the sloshing wave height.**

3.7. Overturning Stability

M_{rw} = 3.81453E+11Nmm or 38143029.8Nm.

This overturning moment is important for the mechanical design, to design the anchorage requirement and determine the minimum the number and size of the anchor bolt for the storage tank. It is also important to the civil engineer to design the tank foundation in which the tank is being supported.

3.8. Design Spectral Acceleration

***Impulsive spectral acceleration A_i** = 0.34%g

***Convective spectral acceleration parameter, *Ac*:**

For $T_C > T_L$, = 0.0633%g

3.9. Effective Weight of Product W

Using equations 3.8a and 3.8b, the following results are obtained;

*****For Effective impulsive weight

When D/H ≥ 1.333

W_i = 137,636,499.10N

*****For Effective convection weight

W_C = 100,998,137.14N

3.10. Center of Action for Effective Lateral Force

***For Impulsive force**

When D/H≥ 1.333,

X_i = 7762.5mm

Since D/H in this project is 1.884, which is > 1.333, then X_i = 7.762m, therefore the height from the bottom of the tank shell to the center of action of the lateral seismic forces is related to the **convective liquid force** for ring wall moment,

***For Convective force**

X_C = 12.72255m

3.11. Base Shear Force

The seismic base shear was defined as the combination of the impulsive and convective components,

V = 48,326,902.75N

Since the tank is a floating roof crude oil storage tank and the roof floats on the liquid, W_r becomes zero (W_r = 0) and the total weight of the tank is added to the weight of the tank content (crude oil). Figure 3.3 in Chapter 3.2.3.3.8 also illustrates this.

3.12. Resistance to Overturning

The following resisting components were analyzed using Table 4 and equation above, thereby proving the tank to be structurally stable.

***Anchorage requirement/Ratio j** = 2.17

The anchorage ratio calculated is 2.17 which are greater than I.54; therefore the designed floating roof crude oil storage tank cannot be self anchored and needs to be mechanically anchored by anchor bolt which is been designed and sized up, further below.

*Annular plate requirement

L = 1.10857m

The maximum width of annulus for determining the resisting force, Ls = 0.035 D = 1.36609m

Since L < 0.035 D which is the minimum annular width and was calculated to be = 1,108.57mm and the actual width used is 1,200mm. And Ls>L, the bottom/ annular plate width is satisfactory and hence sufficient for the seismic loading

. ***Shell compression, σc**

σc = 12.67N/mm²

F_C = 57.94N/mm²

$\frac{GHD^2}{t^2} = 40.22$

Since the maximum longitudinal shell compression stress, sc is 12.67N/mm², $\frac{GHD^2}{t^2}$ is 40.22 which is less than 44; and F_C is found to be 57.94 N/mm² which is less than 0.5 times the minimum specific yield stress of the bottom shell, Fty, the tank is structurally stable.

3.13. Anchorage Design

$\boldsymbol{W_{AB}}$ = 36,592,019 N OR 36.592KN

σ_b $161.04N/mm^2$

S_y for SA 320 Gr. L7 = 551.5N/mm^2 And 0.8Sy = 441.2N/mm²

Since W_{AB} is calculated to be 36.592KN, the tensile stresses in the anchor bolt which the uplift load applied on have to be check against the allowable tensile strength, which is 0.8 time its specify yield stress, *Sy*. The material used for the anchor bolts is the high strength bolt SA 320 Gr.L7, with the minimum specific yield stress of 551.5N/mm², and the allowable tensile strength for the bolt will be 0.8Sy = 441.2N/mm². Total 86 numbers of M64 bolts are pre-selected for the design, and hence the tensile stress on each of the anchor bolt can be determine by $\sigma_b = \frac{W_{AB}}{N.Ab}$ and found to be 161.04N/mm², hence proving that the selected number (N) and the anchor bolt size (Ab) is sufficient.

3.14. Freeboard

δS = 1,647mm.

A_f In seismic group SUG III for cases where $T_C > T_L$ is = 0.0845

A_f Was found to be 0.0845 and δs found to be 1,647mm. According to *API 650 (2007),* the minimum required freeboard for the SUG III tanks shall be equal to the sloshing wave height, δs

3.15. Roof Design

This consists of five (5) design parameters which are;

3.15.1. Roof type selection

In view of this project with tank diameter of 39m, and the cost effectiveness, where the insulation effect due to the air gap between the decks plate in the double deck floating roof is not favorable for the climatic condition of the tank site, the single deck floating roof is selected.

3.15.2. Buoyancy design (Pontoon and Center deck design)

*The **pontoon** is design to have sufficient buoyancy to remain on the product by having inoperative of roof drain rainfall, deck plate, etc. While

*The center is design with a nominal thickness of 8mm.

3.15.3. Roof stress design

*Dead load only – No flooding in center deck, where by

Unit lateral pressure = $\frac{w(deck) - Fb}{Deak\ Area}$

*Dead load + 250mm of accumulation, where by

Unit lateral pressure = $\frac{W(deck) + W(rain) - Fb}{Deck\ area}$

3.16. Effect of large deflection on center deck

For $\frac{q\alpha^4}{Et^4} = 11.11.1$

For $\frac{\sigma\alpha^4}{Et^2} = 11.11.2$

The maximum deflection and the stresses for the both cases are summarized the Table 3 below;

Table 3: Summary Result for Maximum Deflection and Stresses in Center Deck

	LOAD CASE 1		**LOAD CASE 2**	
	DECKCENTER	**DECK EDGE**	**DECKCENTER**	**DECK EDGE**
Max. Deflection, y (mm)	215.81		214.38	
σ Total(N/mm²)	35.92	62.84	33.94	59.37
σ bending(N/mm²)	3.52	5.41	3.34	5.14
σdiaphragm(N/mm²)	32.40	57.43	30.00	54.38

3.17. Pontoon stability – Pontoon ring design

Rh = 459.44N

Nlp = 107,593.27

Angle α = 0.001673

***At Mid-point**

Bending moment, mm = 1.50735E11N

Circumferential tensile force = 7,881,429.1N

***At Load-point**

Bending moment, mm = 9.169891E13N

Circumferential tensile force = 7,867,296.2N

Table 4: Summary Results for Pontoon Ring stability

RING STABILITY CHECK	LOAD CASE 1		LOAD CASE 2	
	MID – POINT	LOAD – POINT	MID - POINT	LOAD - POINT
Bending moment(Nmm)	19.14	-38.29		
Circ. Force(N)	7867429	7867429	7867429	7867429
Bending stress(N/mm²)	0.0000007	-0.000001	0.0000007	-0.000001
Circ. Stress(N/mm²)	159.98	159.98	151.07	151.07
Allow. bending stress(N/mm²)	183	183	183	183
Allow. Axial stress(N/mm²)	165	165	165	165
Unity Check	0.97	0.97	0.92	0.92
Condition	OK	OK	OK	OK

3.18. Fitting and Accessories Design

3.18.1 Roof seal system

Two roof seal systems are adopted;

(1) Primary roof seal system, in which the Scissor Hanger type Mechanical (metallic) shoe roof seal system was selected for its highly reputed performance, lower cost and simple installation. To minimize vapor loss, rain fall from rim gap and centralize the floating roof.

(2) Secondary roof seal system which reduces vapor loss and provides environmental protection with fewer odors, compliance with the air standards, saves cost, enhances safety by protection against rim fires and **significantly** reduces amount of rainfall entering the tank.

3.18.2 Roof seal materials

From the recommendation tables *[EEMUA 2003, vol.1, p118]*, the fluoropolymers, urethane and nitrile seal materials such as **vition ® (FPM)/nylon (PA)** and the **Teflon ® (PTFE)/glass** seal materials are selected because of their high crude oil storage ability and their very good resistance against hydrocarbon and ultraviolet and retardant to flame. The hydrocarbon resistance material is installed at bottom section while the ultraviolet resistance at the top section.

3.18.3 Roof support leg

A total number of 22 (twenty-two) pontoon support legs and 30 (thirty) for deck support legs, with size 4” pipe schedule 80 is designed.

For the pontoon support leg, 1leg/6m of tank circumference was approximated, and for the centre deck support leg, for tanks diameter up to 60m, 1leg/34m² of center deck area is approximated.

The complete stress design calculation for the roof support leg and the summary stress results are shown in Table 5 and it shows that the actual stresses of all the legs are less than the allowable stress hence proving that the pre-selected number and size of the support legs are sufficient.

Table 5: Summary result for Roof support legs

Leg at radius	**No. of Legs**	**Actual stress(N/mm²)**	**Allowable stress(N/mm²)**	**Result**
4267.00	5.00	25.18	75.08	OK
8839.00	10.00	24.70	75.08	OK
13716.00	15.00	21.59	75.08	OK
18541.00	22.00	31.33	74.62	OK

3.18.4. Venting system

The automated bleeder vent in accordance to *API 2000, 1998* is selected and designed for which leg to the N_{vent} $= \frac{A_{vent\ req.}}{A_{vent}}$ = 1 minimum number of vent required.

The bleeder vents were sized up to (Ø 200 mm) 8" schedule standard pipe; minimum number of 1 (one) is required but a total number of 2 (two) are installed because 1 (one) of it is designed for standby (alternative) purpose such as one fails as a result of malfunctioning or blockage (plugging). Namely;

(1) Vacuum Venting (In-breathing)
(2) Pressure Venting (In-breathing)

3.18.5 Roof drain system

Flexible drain pipe system was selected for the roof drain system and a minimum number of 2 (two) with size 4" schedule 80 (Ø 100 mm) is required. This is necessary to prevent contamination of the fluid (crude oil) stored and is accurately achieved through the following;

(1) Drain Pipe selection = Flexible Drain pipe.
(2) Drain pipe design

Total Head, H = 1.275m. Total Head loss, h = 1.2075m

Flow velocity, V = 1.15m/s. Flow rate per drain pipe, Q = 23.30m³/h

$N_{REQ.} = 1.97 \simeq 2$

3.19. Rolling ladder and guager platform

A rolling ladder and track with length of the same height (to match) with the minimum and maximum roof height is installed. A guager platform for accessibility and maintenance of the tank, allowing of instrumentations and guide pole are installed.

3.20. Fire fighting system and Foam dam

Multiple foam chamber method is selected and is shown below;

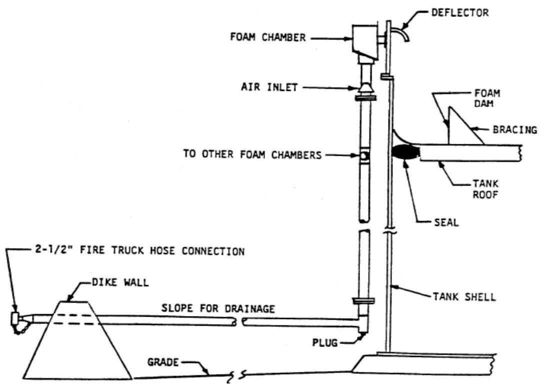

Figure 2: Illustrates Fire Protection system for a Floating Roof Storage Tank [NFPA 11, 2005]

3.21. Fabricated Prototype Liquid Flow Regulatory Tank

A prototype of the above designed floating roof crude oil storage tank is fabricated. This chapter gives a summary the materials used, how they were sourced for, the procedures for fabrication, the safety measures and precautions taken and how it was assembled together.

The automatic reservoir tank was designed to be operated by Electricity to power all the mechanism.

The following under listed items were used for the prototype fabrication: were sourced locally:

1. 500 liter capacity tank
2. Float with Brass link mechanism
3. Inlet auto control valve.
4. Auto control valve outlet
5. Power float switch
6. Lower and upper sensor chips
7. Length of 1inch. Plastic pipe.
8. Wiring cable
9. Control switch.

The choice of the materials is born out of careful investigation on the compliance of each component based on the state of the volume of the liquid response upon agitation mechanically and further consideration was given to their easy accessibility, cost effectiveness/affordability, durability handling and transportation.

A standard sheet of 4'x8' Aluminum material was procured and used for the construction of the Dome and its accessories as follows:

1. Marking out the dimensions for the Dome development, its Recess, the Pivot and Pivot Guide

2. The construction of the Dome, Pivot and Pivot Guide was given serious attention especially on their stability as the Dome moves up and down to avoid the slightest restriction.
3. The Pivot Guide was constructed with a clearance of about 1mm. round about the Pivot, this clearance made it possible for the Pivot with the Dome to move without time "lag" or "lead" due to the differential state of the fluid levels.

The Aluminum Dome was carefully developed, the Recess was marked out exactly the size of the circumference of the Dome and was fixed by means of lip folding and not riveted for the avoidance of increase in weight, and then the Cylindrical Pivot was constructed and fixed in the same method of lip folding.

The Pivot Guide was developed to add credence to the steady state of the Dome and the Pivot on the float without being kicked out of position.

The float link mechanism which houses a flapper valve internally was fixed at the intake port of the tank, the rod is made of Brass material to withstand atmospheric reactions, the float control the volume of the intake of the fluid that gets into the tank reservoir.

The power unit was fixed on the body of the tank for easy operation and power supply; the Sensors are simulated by the power source.

The Automatic Outlet Valve is fitted below the tank so as to open at a predetermined volume when the fluid gets to its maximum level as to supply to desiring areas.

3.21.1. Safety Precaution

1. While assembling the various units the power source must be shut out completely.
2. The Aluminum components must be handled with minimal pressure being exerted on them as any form of deformation will create misalignment during assemblage.
3. The float should not be allowed to puncture or crack while fixing.
4. There should be no restriction, no matter how minimal, in the up and down movement of the Dome and Pivot.

4. Conclusion

100,000bpd capacity floating roof storage Tank has been designed for storing crude oil. Throughout the design process, the design code - API 650 (2007) was strictly followed together with other standard such as API 2000 (1998), ASME 7 Standards (2005, 2007), BS 2654 (1989, 1989), NFPA 11 (2005), NFPA 15 (2007), Petronas Technical Specification (PTS), etc. The following designs and protection system for the tank were completed in accordance with design standards:

- Shell Stress Analysis.
- Roof Stress Design.
- Selection of roof fitting.
- Sizing of roof fitting.
- Seal, venting and evaporation control for fire and other protection system.

In the shell stress analysis, the 1-foot method in API 650 (2007) was used and this gave the minimum shell wall thickness at the bottom course as 28 mm, and the thickness reduced to 11 mm at the upper top course in accordance with the liquid static head. Although the crude oil storage tank was found to be structurally stable without anchorage during the wind load; however it was structurally unstable for the seismic, hence anchorage was taken into consideration and was designed for.

In the roof stress design, the roof buoyancy for the pontoon volume and the pontoon stresses were checked for and found structurally stable. A total number of 22 (twenty-two) pontoon support legs and 30 (thirty) for deck support legs, with size (Ø 100 mm) 4" pipe schedule 80 are designed. The bleeder vents were sized up to (Ø 200 mm) 8" schedule 80 standard pipe; minimum number of 1 (one) is required but a total of 2 (two) are used since 1 (one) of it was designed for standby (alternative) purpose. Flexible drain pipe system was selected for the roof drain system and a minimum number of 2 (two) with size (Ø 100 mm) 4" schedule 80are required. The Scissor Hanger type in the metallic mechanical Shoe Seal was selected for the primary seal in the roof seal system.

An automated prototype reservoir tank to be operated by electricity to power the mechanism that depicts the designed floating roof crude oil storage tank of large capacity was fabricated.

In summary, 100,000bpd capacity Floating Roof Crude oil Storage Tank with dimensions of 39m diameter and 20.7m high has been successfully designed using basic design guidelines and standard codes.

Acknowledgement
I wish to especially express my profound gratitude and heartfelt thanks to all whose valuable contributions helped in accomplishing this assignment.
Firstly, I sincerely thank Prof. Geoffrey Obitor Okogbaa, the Vice Chancellor, Federal University Wukari and the Management of the University for pounding the enabling academic environment for this work.
I also want to thank the Research Grant Committee of the University for approving this project, while my special thanks goes to TETFUND for providing the funds for the research.
My appreciation also goes to all my colleagues in the Faculty of Engineering and Technology, Federal University Wukari, for their cooperation throughout the durations of this work, especially the Technologists (Welis, Mike Onunwor and Owhor, Sampson Chisa) for their technical assistance in fabricating the prototype of the storage tank.
Lastly, I wish to thank Dorcas E. Jimmy, my Research Assistant from the Department of Petroleum Engineering, Rivers State University of Science and Technology, who did most of the field trips to numerous Storage Tank Farms and facilities, for data collection and as well as did most of the calculations.
To God be all the Glory.

References

[1]. Jimmy, Dorcas Etim (2014): "Design of a Floating Roof Crude Oil Storage Tank of 100,000BPD Capacities", Proceedings of the 44th NSChE Annual Conference, Owerri, 2014. Pp. 210-239.
[2]. Ankur Sharma (2013): *Student Master of Industrial Hygiene and Safety, I.S.T, June 29, 2013.*
[3]. EEMUA Publication No. 159:2003 (2003): *Users' Guide to the Inspection Maintenance and Repair of Aboveground Vertical Cylindrical Steel Storage Tanks. Vol.1,3rd Edition, The Engineering Equipment and Materials Users' Association.*
[4]. Khanna Amit (2013): *Engineering Design Guide for Storage Tanks (Storage Tank Presentation).*
[5]. API Standard 650 (2007): *Welded steel tanks for Oil Storage.*11thEdition, American Petroleum Institute.
[6]. Housner G. W. (2005): Earthquake Pressures on Fluid Containers and tank capacity and sizing.
[7]. Other API, AISC, ANSI, ASME, BS, NFPA, PTS Standard codes and Publishers. See project reference page.