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Design of an MGO Storage Tank System (20,000 MT) at Thilafushi, Male

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Abstract: *In Maldives, the demand for Marine Gas Oil (MGO) are on the increase due to expansion of number of vessels on voyage and the need for reliable and safe storage facilities designed as per API 650 is on more consideration .It has found that traditional design and development of these facilities to augment the existing utilities has led to some off sets with the API 650 In this work attempt has been made to design a storage tank farm of holding a 5000 x4 MT of MGO in a single dikes enclosure that has been appropriately designed in line with the codes and standard. Material selection was done with the requirements of the recent editions of API 650, ASME B&PV Code, ASTM etc. and some adequate design method has been chosen in line with the structural stability aspect. Since one tank is having capacity of 5000MT, the 20,000MT of MGO storage utility has been designed including loading/unloading piping section as well. It was found that, the nominal diameter is 21 m without space constraint, height is 18 m, number of course is 10, and height of each course is 1.8m. Also, the thickness of each course of tank shell is in the order of 14mm, to 6mm starting from bottom. The bottom and annular plate thickness are 10mm. Carbon steel A36M/A36 material was selected for the design. The overall weight of the tank is 6055 MT, which is found to be stable with an anchorage. The structural stability was followed by the ASCE 7-02 and related studies. Fuel loading and offloading through pump house and a Conventional Buoy Moring (CBM) Station has also given in the layout. The Civil foundation was not covered in this publication with the stability checks. Finally, the Control and Instrumentation aspect has also presented in the P&ID of the system under consideration. Therefore, this attempt is an integration of basic aspects of tank farm.*
Keywords: MGO storage tank, petroleum product, API 650, fixed roof, P&ID, fire protection, piping

INTRODUCTION

Storage tanks are widely used in the industries such as petrochemical product, cements and mining, cereals and grains, fertilizers and pellets etc. The ranges of substances are solid, liquid and gaseous state to serve industrial or domestic purpose. “Aboveground storage tank” means the aboveground installation of a storage tank where at least 90% of the storage tank volume is above the floor or the ground surface, as the case may be [01]. This Marine Gas Oil

(MGO) storage is one of the industrial activities which need a tank farm at Thilafushi, Maldives. There are various types of tanks designed to meet different storage needs in the industry [02], the storage tanks could be easily differentiated by their physical features like roof type, shell configuration, and 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 for vertical, cylindrical, above-ground, closed-top, and open-top, welded storage tanks in various sizes, and capacities for internal pressures approximating atmospheric pressure [02].

Additionally, practicing engineers might face some issues and challenges when designing petroleum storage tank farms. These challenges are generally either in the application of the current design codes and standards, or in choosing an appropriate design method (Lisa, 2005). Especially when design a tank system or rather a tank farm, the design is influenced by economic factors, regulatory requirements, the liquid to be stored, internal pressures, external environmental forces, corrosion protection, and welding needs etc [7]

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Table 01. Quality specifications of MGO to be stored; BUREAU VERITAS Certificate of Quality, on 01st June 2023 for The Port of Sohar in Oman.

Property/Test	Units	Requirements	Test Method
Density at 15 ºC	Kg/m3	Maximum 820-870	ASTM D 4052
Viscosity at 40 ºC	mm2/s (cSt)	2.0 to 6.0	ASTM D 445
Sulphur content	ppm	Maximum 500	ASTM D 2622
Flash point	0ºC	Minimum 60	ASTM D 93
Cetane Index		Minimum 45	ASTM D 976
Distilled at 350 ºC	Volume %	Minimum 85	
Cloud point	ºC	Maximum 15	ASTM D 2500
Cold Fitter Plugging Point (CFPP)	ºC	Maximum 12	IP 309
Carbon Residue (Ramsbottom 10%)	Mass %	Maximum 0.2	ASTM D 524
Total Acid number,	mg KOH/g	Maximum 0.10	ASTM D 974
Ash content	Weight %	Maximum 0.01	ASTM D 482

Fuel Express Maldives (FEM) needs a properly designed MGO storage tank farm complied with API recommendations and this is based on that efforts. The specification of MGO is given in Table 01_Quality specifications of MGO to be stored BUREAU VERITAS Certificate of Quality, on 01st June 2023 for The Port of Sohar in Oman.

Storage tank could lead to failures and be attributed to poor design interpretations. In order to address these issues and challenges properly, it is recommended that appropriate design codes and standards are followed, an adequate design method is chosen. This work therefore strictly applied the 13th edition of API 650 2020 and API Recommended Practices 2350 2020 [3], [4]. The fire protection systems are designed to comply with NFPA 11; 2021, NFPA 13; 2019, NFPA 15; 2022, NFPA 16:2019 and NFPA 30:2015 [10]. The structural stability was followed by the ASCE 7 and related literature has been followed. The maximum possible attempt for revealing the procedures and interpretation involved in correctly applying the codes/standard for welded tanks for petroleum storage systems in Maldives/Sri Lanka. The layout with two diesel tanks, safety distances and CBM is presented in order to give a clear manifestation of the system configuration.

METHODOLOGY

A storage tank farm of 10,000 MT capacities (5000MTx2) together with a CBM (supplied by others) that would be able to safely carry Marine Gas Oil (MGO) imported from various parts of the world time to time. The design concepts, calculations, and the procedures are presented in the following sections.

Design Consideration

In the clause 5.2 of API 650; 2020, this term is basically interpreted as loads of the tank. The combinations of either of followings will be taken as design consideration. Dead Load (D_L), Design External Pressure (P_e), Design Internal Pressure (P_i), Hydrostatic Test Load (H_t), Minimum Live loads (L_r), Seismic Load(S), Wind Load (W) and External load and some more will be the majority of them.

Special Consideration

Foundation design, Corrosion allowance, Service conditions, weld hardness and Material Thickness are considered as the special considerations in the API 650; 2020 clause 5.3.

Initially, in the design of a tank as per API 650, following considerations have to be established. Further the stability and fire protection system and diking will be established within the tank area. Solar Lighting will be considered for the yard lighting and lastly a conventional buoy mooring unit will be integrated with a Pipe Line End Manifold (PLEM) to facilitate importation of hydro carbons in to the storage.

Capacity of A Storage Tank

The Liquid Storage Capacity(C) [m^3] given by API 650 (Table A.1a) is defined as

$$C = 0.785x\,D^2H \quad \text{.............................[Eq 01]}$$

The gross capacity of the tank will be slightly higher than the Liquid Storage Capacity because of the fact that the over fill protection criteria (API RP 2350, 2020) has to be matched with this volume. The other aspect is the density of the hydro carbon stored in the storage facility could also contribute to a bigger volume than the volumetric calculated above.

Design of Tank Shell

Design of Shell

The One-Foot method has been applied to determine tank shell design methods as the diameter is 21 m (< 61m) as given in the clause 5.6.3.1 of API 650. Therefore, this method was adopted rather than the variable design-point or elastic analysis method that are recommended and used in larger diameters than 61m.

Required minimum thickness (clause 5.6.3.2 of API 650) of shell plates are the minimum of either

$$t_d = \frac{4.9D(H-0.3)G}{S_d} + CA \text{................[Eq 02]}$$

or

$$t_t = \frac{4.9D(H-0.3)}{S_t} \text{.........................[Eq 03]}$$

Table 02. Mechanical Properties of Plates used in the Design

Plate Specification	Minimum Yield Strength (psi)	Minimum Tensile Strength (psi)	Design Stress (S_d) (psi)	Hydrostatic Test Stress (S_t) (psi)
A36	36,000	58,000	23,200	24,900

Manholes and Nozzles

Shell nozzles and manholes were determined subsequently as per the sub paragraphs given under clause 5.7 of API 650; 2020. The thickness of bolting flange of the manhole will be given by

$$t_c = D_b\sqrt{\frac{C\gamma HG}{S_d}} + CA \text{......................[Eq 04]}$$

Pressure rating of the Flanges

$$P_t = \frac{C_1 S_1}{8750} P_r \leq P_c \text{..........................[Eq 05]}$$

Wind Girders

Top wind girder (stiffener) and an intermediate wind girder have been provided. The tank shall be provided with a 75 x 75 x 6 mm (3 x 3 x 1/4 in.) top curb angle for shells more than 5 mm (3/16 in.) thick (our shell is 6mm thick), or with other members of equivalent section modulus.

Maximum Height of the intermediate wind girder is calculated using the equation below,

$$Ht = 9.47 \times t \times \sqrt{\left(\frac{t}{D^3}^{3}\right)} \times \frac{1.72}{P_{wd}} \text{...[Eq 06]}$$

Design of Tank Roof:

A supported cone with its principal support provided by rafters and columns was the configuration as clause 5.10 of API 650; 2020 doesn’t specifically state the type of roof to be used. Therefore, conical roof supported by the middle Centre column has been designed for this purpose. Although the rule of thumb is to go for external support roof for 30m, this 21 m diameter tank also has designed to accommodate some additional stability due to heavy corrosion experienced surrounds and the exposure to the sea.

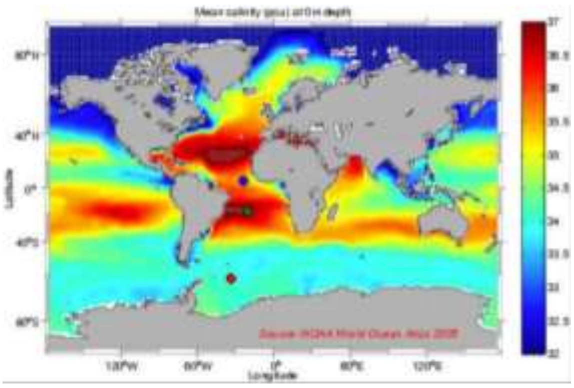

FIG 01. Map of mean salinity where Maldive is very closer to 35-36 psu at 0m.

Supported cone roof is designed in coinciding with the principle given in the clause 5.10.4 of the API 650; 2020 standard. The minimum depth of the rafters has been selected to be 400mm and the rafter spacing was calculated using equation 07.

$$b = t\left(1.5\, F_y/P\right)^{1/2} \leq 2100\text{mm} \text{……[Eq 07]}$$

Design of Tank Bottom

The foundation may be compacted sand finish or asphalt finish on which the Bottom plates are resting on. The thickness of the bottom plate designed in accordance with API 650; 2020 clause 5.4 should usually be greater than 6mm with added Corrosion Allowance (C.A) as recommended by clause 5.4.1of API 650; 2020.

Design of Annular Plate

The foundation ring will not only demarcate the limits of tanks but also it will be the load bearing of the shell of the tank. The bottom plate and the shell of the tank rest on the annular plates. The annular plate thickness as recommended by API 650 has been chosen by considering the first shell course of the shell wall. The annular plate has been designed according to clause 5.5 of API 650; 2020.

$$\text{Radial width of the annular bottom plate} = 2t_b\sqrt{\frac{F_y}{2\gamma_w GH}} \text{………………………..[Eq 08]}$$

Designing the Dike and the layout

Calculation of Dike

The rule of thumb for calculation of volume enclosed by the dike is used. 110% of the largest volume in the dike shall be equal to the volume inside the dike.

$$H_d \frac{1.1V}{(LW-\pi(\frac{D}{2})^2 n)} \text{………………[Eq 09\}}$$

Determination of Minimum Safety Distances

The separation distances are twofold. Separation distance of each tank will be considered based on diameter of the tank basically. If the diameter ≥ 10m they should not be considered as a small tank. The other aspect is whether it is a fixed roof or floating roof. In the context of Thilafushi storage, we have selected fixed roof storage. Although some studies propose irrespective of the type of fuel [09], the safety distances have been considered based on operational requirement and the generally accepted norm [02].

Tank Anchorage

Total uplift for is U and the equation 09 was used to calculate the total uplift by considering wind velocity as 57 m/s

$$U = (F_p P_i D^2 785) + (\frac{4P_{WS} H^2}{2}) - w \text{ ......[Eq 10]}$$

$$T_h = \frac{U}{N} \text{...............................[Eq 11]}$$

Diameter of the anchor bolt will be given by the following with Corrosion allowance into consideration

$$D_B = SF\sqrt{\frac{\sigma_y}{\pi T_h}} \text{..............................[Eq 12]}$$

Stability Checks against shell buckling

The stability appears to be more concentrated to the following two although the other modes (debris effect, seismic loads etc) are very less in the particular site. The pressure resistant to buckling has been determined based on the theory of elastic stability [12],[14]. The inertia pressure exerted by the liquid stored (P_l) inside the tank and the pressure exerted due to the mechanical properties of the tank (P_{cr}) together will contribute to the pressure resistance (P_r).

$$P_r = P_l + P_{cr} \text{...........................[Eq 13]}$$

Where

$$P_l = \rho_l g H \text{...............................[Eq 14]}$$

And

$$P_{cr} = \frac{2Et}{D}\left(\frac{1}{(n^2-1)\left(1+\left(\frac{2nH}{\pi D}\right)\left(\frac{2nH}{\pi D}\right)^2\right)} + \frac{t^2}{3D^2(1-\nu^2)}\left(n^2 - 1 + \frac{2n^2-1-\nu}{1+\left(\frac{2nH}{\pi D}\right)}\right)\right) \text{....[Eq 15]}$$

Against above P_r, there will be wind pressure acting on the shell, and if P_r is greater than the wind pressure developed, then the shell of the tank is safe from damaging due to buckling. The designed wind pressure is determined using the following equations

$$P_w = C_p q_z = C_p 0.613 K_z K_{zt} K_d V^2 I G_S \text{........[Eq 16]}$$

Where V is wind velocity and the other factors are constants [03]. If, $P_r > P_w$, then safe for not damaging due to buckling. The gust factor effect was taken based on the clause 6.5.8.1 of ASCE 7-02 for rigid structure [5].

General criteria for the structural stability are given by Eq 17 and Eq 18 given by the Architectural Institute of Japan [06] Allowable stress design has been applied in cylindrical metal shell against buckling. cf_{cr}, bf_{cr} and sf_{cr} Have been estimated in the procedure given by the Japanese Architectural Institute [06]

$$\frac{\sigma_c}{cf_{cr}} + \frac{\sigma_b}{bf_{cr}} \leq 1 \text{...........................[Eq 17]}$$

$$\frac{\tau}{sf_{cr}} \leq 1 \text{....................................[Eq 18]}$$

Fire Protection System

Fire water, foad and Heat Detector system has been designed by taking the appropriate values given in NFPA 11 for foam system, NFPA 13 for sprinkler system, NFPA 15 for water spray fixed system, NFPA 16 for foam water spray system and NFPA 30 flammable and combustible liquid codes [10]. Foam bladder capacity is twice the size of foam volume.

Control and Instrumentation

Overfill protection for storage tanks have been basically discussed by API Recommended Practice 2350 [4]. It is described High Level (HL) and High High Level (HHL) detector system. It is the minimum. But, highly recommend to have low level (LL) and low low level (LLL) indicators as well because of the fact that the system need a protection for pumps and other system component.

Magnetic level gauge shall be installed in every tank to confirm the manual readings with the level indications by electronic means. Motorized valves, fire detectors, automatic actuators for the total tank farm have also been considered.

MATERIAL SELECTION

Materials are selected in twofold. Firstly, the main materials of construction that are given in Table 03 and secondly, the other supplemental materials that are tabulated in Table 04.

Table 03. Main material selection

Component/ Appurtances	Description
All Plates	ASTM A36M/A36 semi killed/killed as in section 4.2.2 in page 4-2
Roof sheets	ASTM A1011 Gr 33/Gr30 or similar, other types of plates such as ASTM A515 or ASTM A 516 or ASTM A537 may be used
Castings	ASTM A216,ASTM A217 or ASTM A 352 may be used
Forgings	ASTM A105 or ASTM A110, ASTM A182 or ASTM A 350 may be used.
Piping	API 5L/ASTM A106 Gr.B,
Foam system	ASTM A 135 Gr.B or ASTM A53 Gr B or ASTM A 795 Gr B
Paint	Epoxy zinc-rich primer or similar 60 µm, Phenolic epoxy or similar product to 160 µm and Sylil Acrylate or similar paint up to 280 µm. The contractor has to select the paint scheme for forward for revive.
Galvanizing (Structural) Galvanizing (concrete reinforcements)	ASTM A123 *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products* covers the requirements for galvanizing by the hot-dip process on iron and steel products made from rolled, pressed, and forged shapes, castings, plates, bars, and strips. ASTM A767 *Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement*, covers zinc coatings applied by the hot-dip process on individual steel reinforcing bars before fabrication used in concrete

Table 04 Welding Requirements

Requirement	Applicable code or Standard
Welder/Operator Qualification (PQR and WPS)	ASME BPVC IX or ISO 9606 all parts
Welding Procedure Qualifications (WPQ)	Applicable material specifications or, where weld procedures are not covered by the material section, ISO 15609 all parts, ASME BPVC IX, or ASNI/ASMEB31.3.
Non Pressure Retaining Structural welding such as base plates or supports etc.	AWS D1.1 or ISO 10721-2
Non-destructive examination of plate edges and all weld joints.	ASME BPVC VIII DIv 1 and ASME BPVC V
Post weld heat treatment	Applicable material specification, EN13445-4, ASME BPVC VIII, DIv 1, or ASNI/ASMEB31.3.

Materials for civil foundation such as Concrete, Aggregate, Asphalts etc has not been elaborated and shall be used as in the standard practice depicted by the foundation design. The foundation design shall be incorporated with API 651 and especially cathodic protection embedded into design

DESIGN RESULTS

Following tank configuration has been made after paying attention to API 650; 2020, as the basic parameters in the tank farm.

Table 05 Volume calculation and configuration of a tanks

Diameter/ m	Height /m	Tank Diesel capacity/ MT	Tank capacity /m^3
21	18	5000	6230

After, fixing the above configuration, design consideration as interpreted by API 650;2020, was determined and following table yielded.

Table 06 Design consideration as depicted in API 650;2020

Parameter	Value	Reference section
Dead Load (D_L),	160 T of Steel	2.1. of this document
Design External Pressure (P_e),	0 kPa	5.2.1.b of API 650;2020
Design Internal Pressure (P_i),	18 kPa	5.2.1.c of API 650;2020
Hydrostatic Test Load (H_t),	166 kPa	5.2.1.d of API 650;2020
Minimum Roof Live loads (L_r),	42 T of steel	2.1 of this document
Wind Load (W)	895 T	2.1 of this document

Design results of a tank shell based on one foot method as follows taking into account that joint efficiency to be 0.7 and eq. 02 and eq. 03 were used.

Table 07 Design of Shell as per API 650:2020

shell no.	D	H	G	E	CA	t	T design	weight in kg
1	21	18.0	0.85	0.7	1	15	14	13622.9
2	21	16.2	0.85	0.7	1	13	12	12185.6
3	21	14.4	0.85	0.7	1	12	10	10748.3
4	21	12.6	0.85	0.7	1.5	11	10	9774.3
5	21	10.8	0.85	0.7	1.5	9	8	8337.0
6	21	9	0.85	0.7	2.5	8	8	7826.3
7	21	7.2	0.85	0.7	2.5	7	6	6389.0
8	21	5.4	0.85	0.7	3.5	6	6	5878.3
9	21	3.6	0.85	0.7	5.5	7	6	6294.3
10	21	1.8	0.85	0.7	5.5	7	6	6294.3
Weight of total shell								87,350.0

Design results of Tank roof, Tank bottom and annular plates.

Table 08 Design of roof structure

Parameter	Value/Unit	Reference
Maximum Bending Moment	8205 Nm at 6m from the shell	2.5 of this document
Maximum Shear force	9375 N at the center and the shell	2.5 of this document
Tank bottom plate thickness	10 mm	6mm+4mm CA

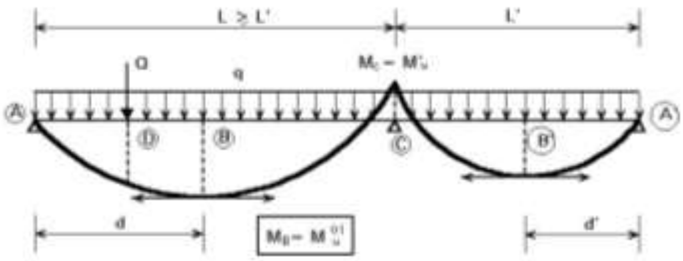

FIG 02 Bending moment diagram or the roof structure.

Design results of the manhole attached to shell and the roof is given below as per the eq.04 and Table 5.3.a, at 16m liquid height.

Table 09. Design results of bolting flange and the manhole.

Parameter	Value/Unit	Reference
Diameter of the manhole	600mm	Table 5.3 of API 650;2020
Bolting flange thickness	17 mm	Eq. 04 in this document
Bolting flange thickness	17 mm	Table 5.3.a, at 16m liquid height of API 650;2020
Thickness of manhole neck (t_n)	6 mm	Table 5.4.a, shell thickness 14 mm
Bolt Circle diameter (D_b)	768 mm	Table 5.5.a. of the API 650;2020
Cover plate diameter (D_c)	832 mm	Table 5.5.a. of the API 650;2020
Bolt size	18 mm (6.8)	600MPa Tensile strength and 800 MPa yield strength
P_t ($P_t \leq P_c$)	42	Section A.2.1. of ASME B 16.47; 2020
P_c ($P_t \leq P_c$)	48	Section A.2.1. of ASME B 16.47; 2020

Wind girders and stiffening rings are decided and presented in Table 10 bellow.

Table 10. Wind girder sizing.

Parameter	Size of the member	Reference
Top wind Girder (Curb Angle)	150x75x6 mm (16 m from the bottom)	Section 2.4.3 of this document
Intermediate wind girder	75x75x6 mm (8.00m from the bottom)	

Table 11 Design Checks against buckling

Parameter	Value/.Unit	Reference
Eq 17	0.63+0.27=1	Equation 17 and Equation 18 of this document
Eq 18	0.35	

Results of dike volume calculation are given in table 12 bellow.

Table 12 Design results of Dike enclosure.

Parameter	Value/.Unit	Reference
Length of Dike enclosure	62 m	Equation 08 in Section 2.8.1 of this document
With of Dike enclosure	40 m	
Height of Dike enclosure	3.7 m	

Results of safety distances determined from the dike wall to the nearest source of ignition are presented in Table 13 below.

Table 13. Determination of Minimum Safety Distances

Safety Distances	Generally accepted distance from a source of ignition	Reference
Class 1 (Diesel)	7.5 - 6 m	Section 2.8.2 of this document
Class 2 (Lube Oil)	10 m	
Class 3 (Gasoline/Kerosene)	15-10 m	

The results of tank anchorage calculations are presented in Table 14 below.

Table 14. Results of Anchor Details.

Parameter	Value	Reference
Uplift load	9113.25 KN	Section 2.9. of this document
Number of J Bolts	22	
Diameter of the bolt	32 mm	
Safety Factor Used	2	

Fire system components are summarized here and other accessories such as piping/tubing, control accessories will be based of manufacturers (OEM) recommendations.

Table 15 Results of Fire system details

Parameter	Per Tank (Total Farm)	Reference
Number of sprinklers apex of the tank	05 (10)	Section 2.10. of this document
Number of sprinklers at the second fire ring at the roof	16 (32)	
Number of sprinklers for shell cooling in the top ring	30 (60)	
Number of Sprinklers for the shell cooling at second ring	30 (60)	
Number of heat detectors	07 (14)	
Foam Pourers	02 (04)	
Foam Bladder tank (230 m^3)	01 (01)	

CONCLUSION

In addition to the API based design calculations, NFPA based calculations for the fire protection system, other systems such as, pump house, piping etc. were also taken in to consideration. Due to the lengthy of the document, those have not been included. Through the design API 650; 2020 and other relevant standards were used in the design the proposed storage tank farm. MS Excel spread sheet was used to perform design calculations. API 650; 2020 alone was not sufficient for a comprehensive design without other codes/standards in place. Auto CAD and Revit also were useful in formulating the models and other drawings. Design factors and considerations were observed in the process of designing to ensure a safe and reliable storage system with especially the safety distances. A Revit model of the tank farm was also given and presented only for visualization purpose of the entire system which only a part is discussed here in this article. It is not that comprehensive enough to use API 650; 2020 in designing a tank farm although it is the best standard to follow with other references.

ACKNOWLEDGEMENT

Special thanks to Fuel Express Maldives for granting the design assignment and IESL for getting this work published with a view to get some more inputs for the design process.

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APPENDIX 1

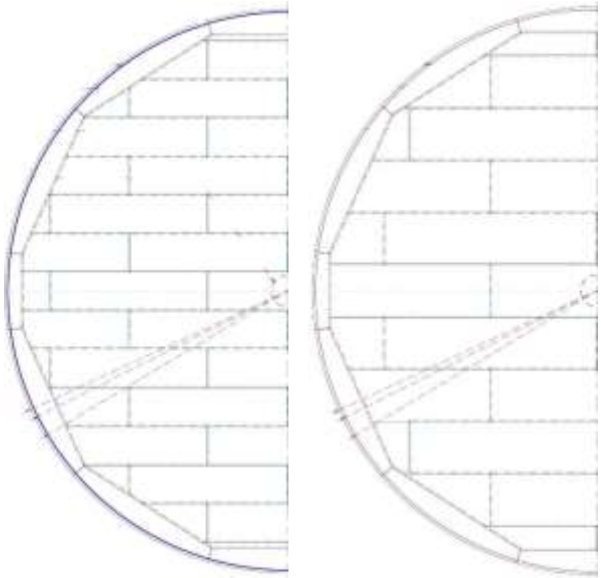
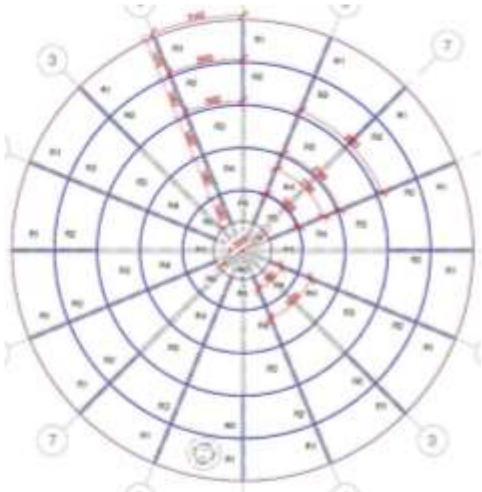
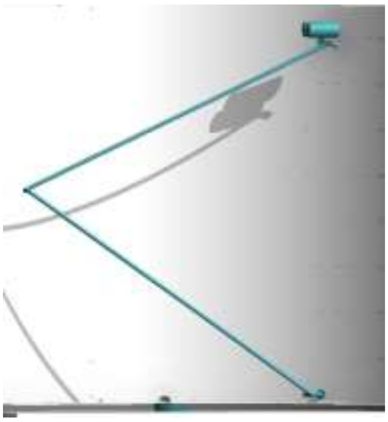
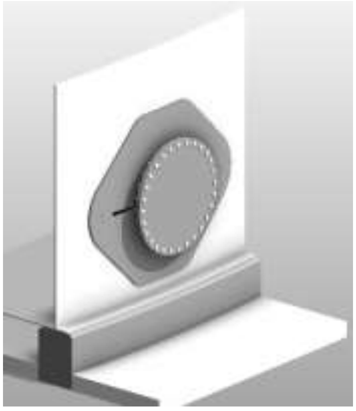
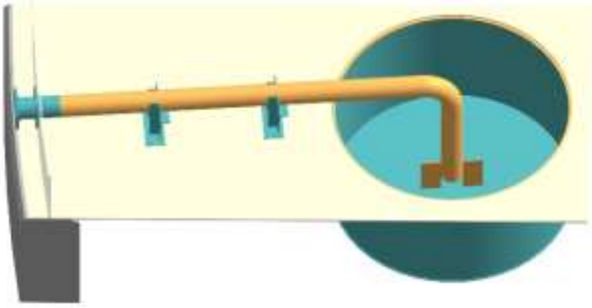
 a. Sketch of the shell	 b. Sketch of Bottom and Annular plates layout
 c. Sketch of wind Girders	 d. Sketch of roof plate layout
 e. Sketch of floating suction arm	 f. Sketch of shell manhole

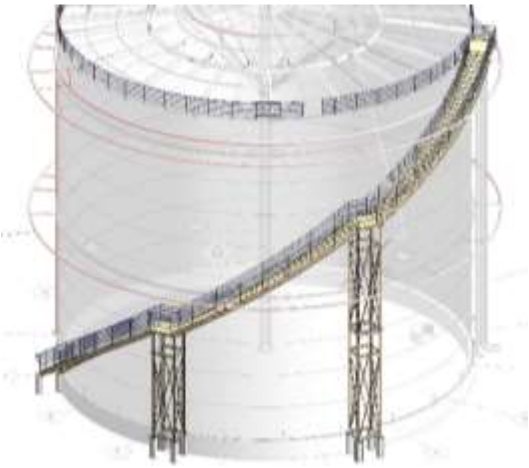
Figure 03: Sketches of Shell, Bottom and Annular Plates, Wind Girders, Roof Plate, Floating Suction and Shell Manhole.

a. Sketch of roof rafters

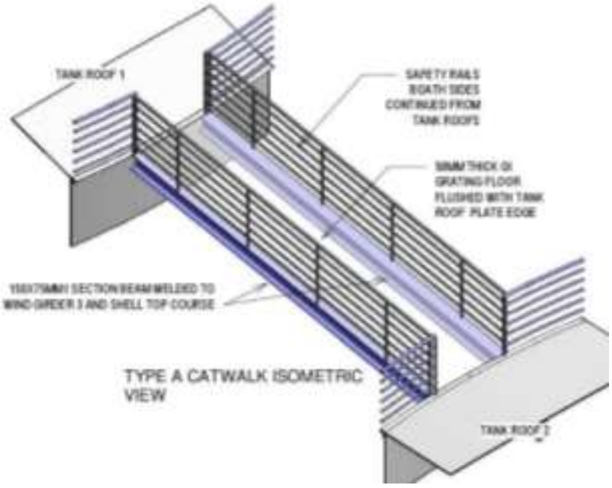
b. Centre column details



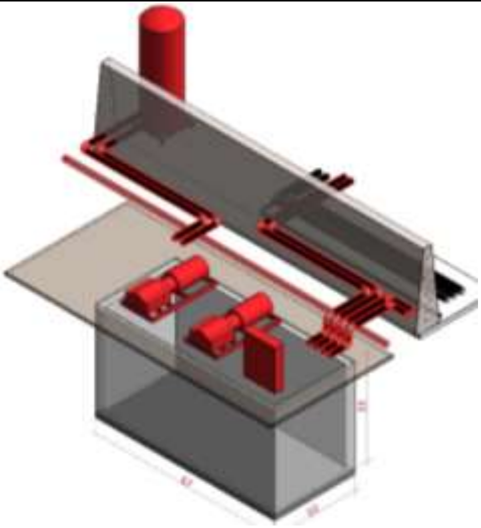
c. Draw off sump



d. Access platform



e. catwalks



f. fire water pump house

Figure 04: Sketches of Roof Rafters, Centre column details, Draw off sump, access platforms, catwalks, fire water pump house.

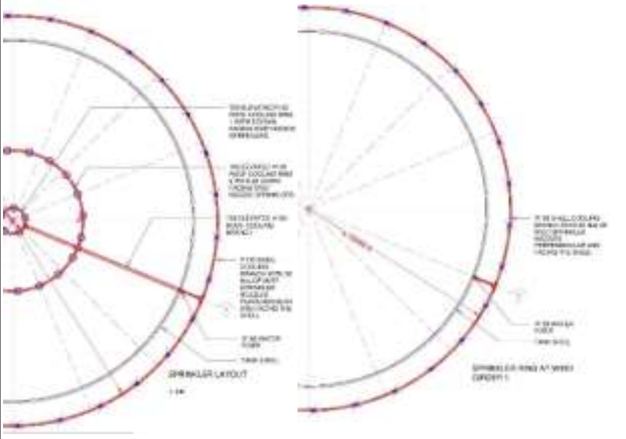
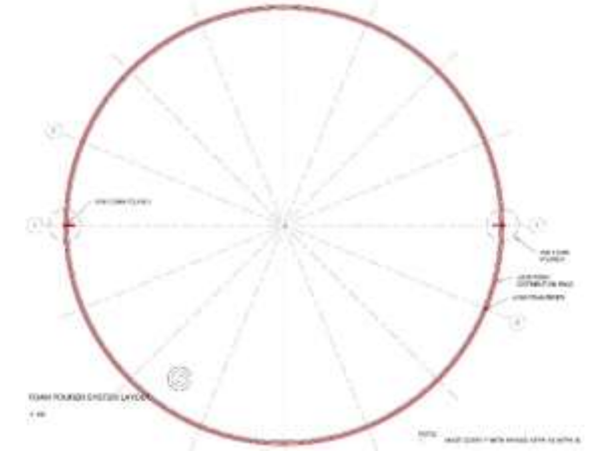
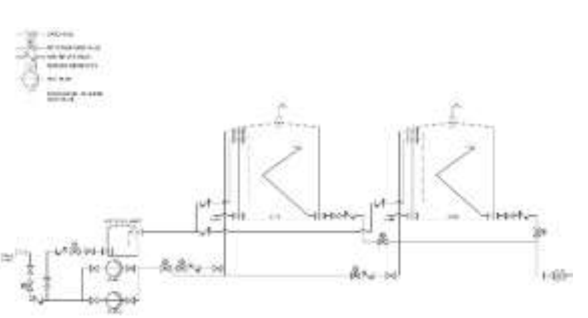
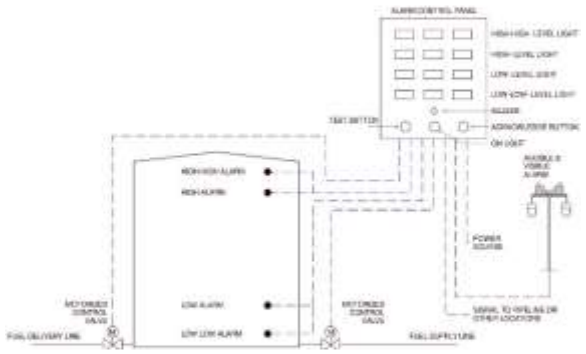
 a. Fire water layout for roof and shell cooling	 b. Foam pourers layout
 c. Sketch of P&ID	 d. Concept of C&I
 e. Site Layout	

Figure 05: fire water system, foam pourer lay out, fuel pump house, Sketch of P&ID, Concept of Control and Instrumentation, A Scale Model of the Storage Tank Farm.