

DEP SPECIFICATION

FULL CONTAINMENT REFRIGERATED LNG TANKS

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(DEP Circular 41/11 has been incorporated)

(DEP Circular 58/12 has been incorporated)

DESIGN AND ENGINEERING PRACTICE

DEM1



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1. INTRODUCTION

1.1 SCOPE

This new DEP specifies requirements and gives recommendations for the technical requirements pertaining to the design, supply, fabrication, erection, inspection, testing and commissioning of field erected Full Containment Refrigerated Liquefied Natural Gas (LNG) tank(s).

This DEP supplements and amends the applicable design standards referenced herein.

Unless noted otherwise all requirements stated herein shall be applicable to tanks located at export and import facilities.

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual DEM 1 – Application of Technical Standards

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorised access to DEPs does not for that reason constitute an authorization to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to oil and gas production and gas handling. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process should be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

1.3.2 Specific abbreviations

Term	Definition
AGA	American Gas Association

Term	Definition
ALARP	As Low As Reasonably Practicable
CCR	Central Control Room
DCS	Distributed Control System
EPC	Engineering Procurement and Construction
HAZ	heat-affected zone
LNG	Liquefied Natural Gas
OBE	Operating Base Earthquake. See EN 1473
PAS	Process Automation System (combination of SIS, DCS and other systems)
PLC	Programmable Logic Controller
PRV	Pressure Relief Valves
RCRV	Reserve Capacity Relief Valves
SIS	Safety Instrumented System
SLS	Serviceability Limit State
SRSS	Square Root Sum of the Squares
SSE	Safe Shutdown Earthquake, See EN 1473
TCP	Thermal Corner Protection
TMS	Tank Monitoring System
TPI	Third Party Inspection
ULS	Ultimate Limit State
VCE	Vapour Cloud Explosion
WPQ	Welding Procedure Qualification
WPQR	Welding Procedure Qualification Record
WPS	Welding Procedure Specification
XLPE	Cross Linked Polyethylene.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (25).

1.5 COMMENTS ON THIS DEP

Comments on this DEP may be sent to the Administrator at standards@shell.com, using the DEP Feedback Form. The DEP Feedback Form can be found on the main page of “DEPs on the Web”, available through the Global Technical Standards web portal <http://www.shell.com/standards> and on the main page of the DEPs DVD-ROM.

1.6 DUAL UNITS

**Amended per
Circular 58/12**

Dual units have been incorporated throughout this DEP.

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

2. GENERAL

2.1 DESCRIPTION OF THE TANKS

The tanks SHALL [PS] be "Full Containment"¹ double wall type as described in EN 1473 and designed and constructed as per the requirements specified herein.

The Full Containment Tank(s) SHALL [PS] comprise a liquid tight 9% nickel inner tank and a liquid and vapor tight concrete secondary container. Both SHALL [PS] be capable of independently containing the stored product.

The inner tank shall [PS] be as per API 620 Appendix Q and the requirements of this specification and associated datasheets.

The outer tank SHALL [PS] be constructed from concrete respectively in accordance with the requirements of EEMUA 207 and the requirements of this specification and associated tank data sheets. The roof and base of the secondary container SHALL [PS] be reinforced concrete whilst the walls SHALL [PS] be post tensioned in accordance with the requirements of EEMUA 207.

In accordance with API 620 the inner tank shall be designed for all specified loading conditions/combinations that may occur during construction, testing, commissioning, operation, emergency, de-commissioning and maintenance.

The tanks SHALL [PS] be designed and constructed so that:

- i. In normal service:
 - Accumulation of product within the interspace is not permitted.
 - Vapour tightness of the secondary container is achieved through the introduction of a metallic vapour barrier to the walls, roof and base.
- ii. In upset or emergency conditions where product accumulates in the interspace:
 - the secondary container contains the liquid product and prevent leakage.
 - Product losses due to container permeability are acceptable under these conditions and determination of absolute rates is not required.
 - Controlled venting of the product vapour is permitted.

2.2 CONTRACTORS SCOPE OF WORK

The site location for the tanks will be graded to a rough finish grade.

Design and construction of the foundation, including soil improvement, deep foundations (or other wise) is by the Contractor.

A reinforced concrete base slab with under tank heating system designed to prevent frost heave and support inner tank, outer tank and appurtenances.

A 9% nickel steel open topped inner tank designed and constructed in accordance with API620 Appendix Q.

A concrete outer tank consisting of a post tensioned concrete wall rigidly connected to the outer tank concrete bottom slab, with a roof constructed of reinforced concrete. The inside of the concrete outer tank shall be lined with a carbon steel vapour barrier.

A 9% Nickel steel Secondary Bottom and 9% Nickel steel Insulated "Thermal Corner Protection". These shall be linked together and the top of the Thermal Corner Protection anchored into the pre-stressed concrete wall, approximately 5 m above the base slab. The

¹ Membrane tanks are considered as equivalent to Full Containment tanks and maybe substituted as an alternate to Full Containment Tanks.

Secondary Bottom shall be placed above the lower system of Cellular Glass bottom insulation.

A carbon steel roof liner which forms an integral structure with the reinforced concrete roof.

A flat plate suspended inner deck, supported by hangers from the concrete roof and roof liner constructed of aluminium., stainless steel, or 9% nickel steel.

A tank insulation system including insulation under the inner tank bottom (below the secondary bottom, and if required, between the secondary bottom and the inner tank bottom), insulation between the steel inner tank shell and the concrete outer tank, and insulation on top of the suspended inner deck.

Submerged pump risers including pumps lifting mechanisms, cables from the top of the tube to the pump, and junction Boxes, internal piping, etc, as indicated on the referenced drawings or data Sheets, and other accessories as stated in this specification, referenced drawings and data Sheets

Platform, staircase, stairs, walkways, caged ladders, monorails, cranes, handrails, etc as indicated on the Referenced Drawings.

Instrumentation for level, pressure and temperature recording, leak/gas detection, and cool-down control, and any other instrumentation specified for supply by the Contractor.

Valves for pressure and vacuum protection.

A fire detection and control system for the relief valves.

Design, installation, NDE and testing of all pipework and pipework insulation associated with the tank. to the Battery Limit near the base of the tank.

Contractor shall model and design the piping systems within his scope of the tank and determine pipe loads that the anchors must accommodate.

Contractor's Battery Limit is as generally defined in the Project Area Drawings and P&ID's. Contractor shall also comply with the following:

- a) Piping: All piping in the tank or on the tank roof or wall is within the Contractor's Battery Limit. Wall piping termination point will be near the base of the wall at the top of the elbows where piping turns horizontally on the adjacent rack.
- b) Electrical: For the pump power cables, the Contractor will supply and install the cables from grade to a Junction Box (JB or JB's) at the top of the Pumpwells. For other electrical items, Contractor will supply, detail, locate, and install all electrical components or equipment in or on the tank, and between the tank and the nearest JB, Substation, or Auxiliary Room as designated for each component.
- c) Instrumentation: Contractor will supply, detail, locate, and install all instrumentation and its associated wiring and components which are in or on the tank, and from the tank to the nearest JB or designated termination point for each component.
- d) All Trays, Racks, Supports, etc for the Electrical and Instrumentation are within the scope of the Contractor when in or on the tank or tank wall, but for cabling exiting the tank area, the Contractor (if required) will utilise cabling trays supplied and installed by others.

The Contractor will design, furnish, and install external pipework and Insulation materials for external pipework within the Contractor's Battery Limit and any special support components and any non-standard insulation materials required at any pipe support or guide.

2.3 CODES AND INDUSTRY STANDARDS

Detailed list of applicable codes and standards is included in Appendix A of this document. All codes and standards unless noted other wise shall be the latest edition, including revision addenda, supplements or others at the time of Invitation to Tender.

3. TANK DESIGN

3.1 GENERAL

Each tank shall consist of two liquid containers. Each container shall be capable of holding the gross liquid volume of cryogenic liquid without liquid leakage.

The Contractor shall be responsible for specifying purging, cool-down, and commissioning procedures.

3.2 SERVICE CONDITIONS

The inner and outer tank shall be designed for all specified loading conditions/combinations which may occur during construction, testing, commissioning, operation, de-commissioning, and maintenance of the tank.

The following specific design loading shall be taken into account:

- a) Hydrotest of the inner tank to the water level specified herein
- b) Normal operation of the tank containing LNG at maximum design product level.
- c) OBE and SSE Earthquake as per Tank Datasheets.
- d) Predicted maximum differential centre to edge settlements of the concrete bottom slab based on interpretation of the geo-technical data at each tank site. The design must allow for total differential settlement through construction, hydro-testing and operational lifetime.

The external pressure on the inner tank shell, exerted by the perlite insulation in the annular space, in particular for the situation of an empty tank.

3.3 CONSTRUCTION LOADING

The roof liner may be used as form work for the construction of the concrete roof and, consequently, shall be designed to support loads from the fresh concrete. Roof structural in combination with internal air pressure may be utilised to support the liner and fresh concrete weight during construction of a concrete roof.

3.4 WIND LOADS AND SNOW LOADS

Wind loads and Snow loads shall be in accordance with the Tank Data Sheet.

3.5 EARTHQUAKE

Seismic design of the inner and outer tank shall be in accordance with EN 1473. Implementation of EN 1473 requirements shall be as described in the Seismic Hazard Assessment Report.

The LNG container and its impounding system shall be designed for two levels of seismic ground motion, the Operating Basis Earthquake (OBE) and the Safe Shutdown Earthquake (SSE) as defined in EN 1473 section 4.2.4.

Inner Tank: Earthquake loading shall be per the Seismic Assessment Report. The inner tank shall be designed using the methods in API 620 Appendix L and the additional requirements of this specification. In addition, the Operating Base Earthquake (OBE) and Safe Shutdown Earthquake (SSE) criteria specified in EN 1473 shall be used. It shall be assumed that the inner tank is filled with LNG to its maximum operating level. When designing for the SSE condition, allowable stresses shall be determined in accordance with NFPA-59A, 4.1.3.6.

Outer Tank: The outer tank shall be designed using a dynamic lateral force procedure, utilising a finite element model. The overall model shall include the inner tank, inner tank contents, outer concrete tank and foundation all modelled as a single multi-degree of freedom complex system. Specific combinations of components may be modelled and analysed separately.

Load Conditions and Combinations

- a) The horizontal and vertical response spectra for both the OBE and SSE shall be input to the model as acceleration spectra. The responses of the composite tank structure for each mode shape shall be determined from the appropriate response spectrum, modal frequency and composite damping.
- b) Modal damping ratios and limitations on maximum damping for OBE and SSE shall be in accordance with EN14620.
- c) Modal combination shall be by "Square Root Sum of the Squares" (SRSS) method, spatial combination shall be the maximum of
 - i. 100% horizontal + 30% vertical
 - ii. 30% horizontal + 100% vertical
- d) Allowable stresses for the SSE condition shall be determined in accordance with NFPA-59A, 4.1.3.6.

The corresponding earthquake loads experienced by the bottom insulation shall be incorporated in the design, taking into account the safety factors as stated in API 620.

3.6 HEAT LEAK

The total heat in-leak shall be such that the boil-off rate will not exceed the percentage of the gross tank contents per day based on pure methane as specified in the Data Sheet(s). Boil-off calculations shall be based on the maximum ambient temperature, wind speed, relative humidity, and the average daily global solar radiation listed in the Data Sheet(s).

Contractor shall provide calculations during the contract detailed engineering phase demonstrating that the insulation fulfils the heat in-leak requirements.

Contractor shall make allowances for heat gain from pumps, stilling wells and appurtenances.

3.7 HAZARD DESIGN CONDITIONS

Heat Radiation/Fire Exposure: The outer tank roof and side walls shall be capable of withstanding fire exposure and heat radiation from a relief valve discharge fire with the relief valves discharging at the maximum relieving rate.

LNG Spill Conditions: In addition to the specified service loading, the post-tensioned concrete tank wall and its connection to the base slab shall be designed to withstand the thermal shock of LNG in the annular space. The outer tank shall be capable of containing the full inner tank contents. Intermediate liquid levels shall be considered as required to represent the controlling worst condition and combined with maximum internal pressure. The temperature gradient shall be analysed for critical steady state spill levels. Since the annular space is assumed to fill gradually, there is no specified leakage rate.

Combination of Loading Conditions:

The inner 9% nickel steel container and outer post-tensioned concrete tank shall be designed for all specified service and hazard loading conditions. Combinations of loading conditions that produce the most severe design case(s) shall be considered. Hazard loading conditions may be considered as separate events; combinations of hazard conditions in addition to service loading cases are not required (except as noted above).

Impact Loads due to projectiles from external explosions shall be as specified in the Tank Data Sheet(s). Resistance and acceptance criterion shall be as per EEMUA 207.

Blast loads from external Vapour Cloud Explosions (VCE's) shall be as specified in the Tank Data Sheet(s).

The impounding system (the outer concrete tank wall and bottom) shall, as a minimum, be designed to withstand an SSE while empty and an OBE while holding the volume, which is

equal to the full inner tank contents with vapour pressure at design pressure. After an OBE or an SSE, there shall be no loss of containment capability.

3.8 HAZARD PROTECTION REQUIREMENTS

3.8.1 LNG Spill Protection

Contractor shall design and install splash plates under flanges to protect the surrounding steelwork and enable vaporisation of product.

3.8.2 Flammable Gas Detection:

Two flammable gas detectors (infrared flame detectors) shall be installed under the roof platform near flanged piping connections that have spill protection systems. An audible alarm, which is clearly marked as a fire and gas alarm system, shall be installed at the outside periphery of the platform. The warning system shall also activate in the Central Control Room (CCR).

3.8.3 Heat Detection

Heat detection shall be provided wherever water spray is used on the tank roof for protection of equipment or accessories. The detection system shall be configured with two sensors such that both sensors must register and send an alarm to the CCR. The sensors shall consist of double loop air pressurized black PVC tubes.

3.8.4 Manual Call Points

Manual call points are required on the stairway providing access to the tank roof platform, and on the roof platform. These manual call points shall be configured so that they may be used to activate local and remote audible and visual alarms and also activate fire water pumps or a spray system on the roof platform.

3.8.5 Water Protection of Equipment and Accessories on Roof Platform

A fire water system including firewater piping to the top of the LNG Tank Roof Platform shall be designed and provided by Contractor capable of producing spray coverage for the entire platform. Design parameters shall be as specified in the Tank Data Sheet. In the PRV area, spray nozzles shall be positioned to protect the PRV's in the event of a relief stack fire.

3.8.6 Relief Valve Discharge Lines

Tailpipes of relief valves discharging to atmosphere shall be provided with a nitrogen connection for a hand operated valve from grade snuffing system. Contractor shall supply the snuffing system.

4. CONCRETE TANK DESIGN

4.1 GENERAL DESIGN REQUIREMENTS

4.1.1 General

Contractor shall carry out detailed design of the concrete outer tank based on the requirements of this DEP and the principal dimensions of the tank. Thickness of the bottom slab, wall, and roof are to be selected by Contractor. Inner Tank Diameter and height dimensions shall be selected to suit Project constraints.

4.1.2 Tank Bottom

Tank concrete base slab/foundation design shall incorporate the recommendations of the Geotechnical report. Concrete compressive strength requirements shall be as per this specification.

During construction of the wall, a temporary construction joint in the slab located just inside the concrete wall, may be made to allow differential settlements /movements between the wall area and the inner slab area. The joint shall be closed after partial post-tensioning of the wall.

Kickerless construction shall be permitted provided the Contractor can demonstrate the ability to restrain and control the forms.

4.1.3 Tank Wall

The wall shall be designed to be LNG tight with a monolithic connection to the base slab. A monolithic connection shall be made between the wall and concrete roof.

The tank wall shall be made of post-tensioned concrete with a characteristic strength per this Specification. Pre-stressing shall be accomplished with an impermeable duct and tendon system.

Contractor shall design the pre-stressed concrete wall for Service, Abnormal Loadings, and Temperatures to assure that the load carrying ability is maintained for all applicable design conditions. Design shall be in accordance with this specification. Determination of a need for cryogenic rebar at the inside of the wall shall be made by Contractor and subject to approval by Company.

Temporary openings in the wall for construction purposes may be considered in the design. This opening(s) shall be located so that they pass through the wall below the anchorage area of the TCP system, and should be limited to approximately 3.5 metres in height. Contractor shall determine post-tensioning arrangements for the location of temporary openings and for the method used to permanently seal the openings before pressure test of the outer tank.

Thermal Corner Protection anchorage shall be centred a minimum of one metre above the top of the Temporary Opening described above.

Above the top level of the 9%Ni thermal corner protection (TCP) Company require the concrete of the outer tank wall be cast by complete 360° pours. Vertical construction joints in the wall will be allowed only below this level, including those required to form the temporary construction opening(s).

4.1.4 Tank Roof

The roof shall be spherical in shape, and made of reinforced concrete with an interior carbon steel vapour barrier (liner).

The characteristic strength of concrete shall be as given in this specification. It may be poured in layers to restrict loading on the liner. The roof liner including the compression ring shall be anchored into the concrete. The steel liner located on the inside of the roof may be used as formwork for concrete placement. Contractor shall demonstrate by analysis that the roof plates and framing are adequately designed for non-symmetrical loading due to the concrete pouring sequence.

4.1.5 Ringbeam under Inner Tank Shell

A concrete ringbeam shall be installed under the inner tank shell. The ringbeam shall be designed such that the shell loads are properly distributed onto the bottom insulation under the ringbeam. Horizontal forces caused by possible movements of the annular plate, shall be taken into account.

The concrete ringbeam shall be reinforced with cryogenic rebar, or carbon steel rebar if designed in accordance with EEMUA 207.

4.2 CONCRETE TANK DESIGN CODE

The design of the prestressed concrete outer tank shall be in accordance EN 1992 part 1 and 3 (also known as EC2). All applicable sections of the latest edition of the design code, including supplements and chapters describing precast and prestressed concrete, shall be followed except when supplemented or modified by provisions of this specification.

Loads on outer tank shall be in accordance with EEMUA 207 where not specified in Tank Data Sheet(s).

4.3 DESIGN/ANALYSIS

4.3.1 Tank Wall Design Method

The concrete slab and pre-stressed concrete wall shall be designed for the following two Limit States:

- a) Serviceability Limit State (SLS) – Includes construction, normal operating, OBE and spill load conditions. This design state shall be utilised to determine concrete crack widths for construction and normal operating loads, and liquid tightness of the wall for the spill condition. All partial safety factors shall be taken as 1.0.
- b) Ultimate Limit State (ULS) – Includes all load conditions. This design state shall be utilised to determine concrete section adequacy per the strength requirements, material partial safety factors in Table 1 and the load partial safety factors in EEMUA 207 except that for the OBE event, a load factor of 1.5 shall be used.

All appropriate load cases and combinations shall be incorporated in the design of the concrete outer tank. A detailed loading summary table, as contained in EEMUA 207 shall be prepared to cover all phases of the tank life.

Seismic load combinations shall consider all possible combinations of the sum of 100% of the effect in one direction (horizontal or vertical) and 30% of the effect in the other direction.

Adverse and beneficial effects of the prestress and shrinkage loads shall be considered for construction, maintenance, and normal operating load conditions. A reduced ULS load factor of 1.0 shall be used for prestress and shrinkage loads when they are determined to be beneficial in strength evaluation of concrete design sections.

In all cases the design shall take into account the effects of the loads, shrinkage strains, and pre-stressing forces during and after tensioning, and conditions of edge restraint at the wall junctions with the base slab and roof.

The design shall meet the acceptance criteria of this specification.

4.3.2 Tank Modelling & Analysis

The concrete tank shall be analysed for service and abnormal loads using a combination of 2D and 3D finite element modelling and analysis techniques. The model shall also include both heat transfer and non-linear thermal effects. The overall model shall include the foundation stiffness effects (soil-structure interaction), the concrete base slab, the concrete wall, the outer tank roof, the inner tank, the suspended deck, the insulation system and allowance for piping and tank top structures

Summer and winter design temperatures shall be commensurate with 95th and 5th percentile temperatures as per EEMUA 207.

Solar gain shall be considered as additional to the (Summer) Design Maximum temperature.

- a) Solar gain shall be determined using the Solar Radiation data contained in tank datasheet.
- b) Correlations shall be made using ASHRAE (2009 ASHRAE Handbook—Fundamentals) or other recognised standards to determine the total gain on horizontal and vertical surfaces.
- c) Surface temperatures shall be determined from a heat transfer analysis. Film coefficients shall be correlated to the surface temperatures, object size and flow characteristics. For the purpose of analysis the tank shell shall be considered as a cylinder in cross flow subjected to a wind speed of 4ms⁻¹.

Spring elements shall be used as a minimum to model the sub-soil. Contractor shall determine the spring stiffness's from the soil investigation commensurate with short term and long term behaviour.

Alternatively, more advanced models of the sub-soil may be used in order to adequately represent the foundation behaviour.

Where appropriate to the loadcase under consideration the model shall take into account reduced stiffness of the structure as a result of crack formation in the concrete using established industry standard constitutive models. (e.g. for liquid spill, cold spot and fire conditions).

Loads due to prestressing may be simulated by axi-symmetrical loads, acting perpendicular to the tank wall. Stress distributions arising from discontinuities shall be examined.

Creep and shrinkage of the concrete, as well as relaxation of the prestressing steel, shall be taken into account;

Steady-state thermo-mechanical analyses shall be carried out in order to design the tank for conditions involving thermal loads. In addition, transient thermo-mechanical analyses shall be carried out where appropriate (e.g. for liquid spill);

The Finite Element Method software, which will be used for modelling of the concrete tank, shall be demonstrated to produce reliable results by comparison with a set of benchmark problems (e.g. those published by the UK National Agency for Finite Element Methods and Standards), relevant for the type(s) of analysis carried out for the tank model.

Where proprietary software is used by the Contractor verification and validation documentation shall be supplied to the Company for review and approval.

4.3.3 Foundation Stiffness

Long term and short Foundation flexibility shall be explicitly included in the finite element model to determine upper bound and lower bound demands.

Where piles are provided specific considerations shall be given to the representation of foundation flexibility and determination accurate prediction of pile loading.

Where 'smeared' stiffness's are used in the finite element model benchmarking shall be provided to demonstrate accuracy of the final pile loadings. This phenomenon occurs when representing the orthogonal pile layout in an axis symmetric space.

4.3.4 Thermal Analysis

Structural demands due to temperature affects shall be determine from semi or fully coupled thermo-mechanical finite element analyses using 2D Axi-symmetric solid or 2D Fourier models.

The upper and lower bound surface temperatures shall be determined from heat transfer analyses with film coefficients commensurate with a cylinder is cross flow subjected to the following:

- a) Windspeed for the determination of film coefficients shall be the 5th percentile mean hourly wind speed.
- b) Maximum and minimum solar gain along with maximum and minimum (5th and 95th percentile) temperatures. Where appropriate Solar distribution shall be scaled from ASHRAE (2009 ASHRAE Handbook—Fundamentals).
- c) Base heating demands shall be commensurate with the condition under consideration.
- d) Short term and long term foundation stiffnesses shall be considered in the mechanical model.

4.3.5 2D and 3D Global linear Elastic Analyses

2D and 3D Elastic analysis shall be used to determine global symmetric and non symmetric demands in the outer tank. Local models shall be used to determine the impact of structural discontinuities such as buttresses and where relevant non-axisymmetric piling layouts.

- a) Where necessary the stress analysis shall take into account the non-linear behaviour of the concrete; i.e. reduced stiffness due to cracking.
- b) Long term and short soil affects along with upper and lower bound determination of soil parameters.
- c) The pre-load effects due to post-tensioning (including relaxation), creep and shrinkage of the concrete shall also be considered.
- d) Predicted edge to centre differential settlements shall be included inherently in all load cases through the use of appropriate foundation analogues.

4.3.6 2D and 3D Cracked analyses

Nonlinear (cracking) analyses is permitted for the determination of structural demands for SLS and ULS combinations. Where cracked analyses are adopted by the Contractor full verification (of software/method) shall be provided for company review. Determination of crack widths shall be in accordance with EN 1992 and no credit shall be taken for tension stiffening when this is included in the constitutive model.

4.3.7 Acceptance Criteria

The following acceptance criteria are required for load conditions as applicable:

- a) Strength Criteria, Concrete strength criteria per EN 1992 shall be satisfied for all load conditions using the material and load factors as applicable.
- b) Shear links in the wall shall not be permitted for normal operation loadcases

Crack Control, for normal operating conditions, concrete crack widths in the wall shall be limited to 0.2 mm (0.007 in) for prestressed zones and crack widths in the slab and roof shall be limited to 0.3 mm (0.012 in). Additional requirements for crack widths shall be as per EEMUA 207.

4.3.8 Wall Liquid Tightness (Applies to Inner Tank Spill Condition Only)

Spillage conditions shall examine critical combinations of maximum and minimum external temperatures/pressures, long term and short term affects including prestressing, creep and shrinkage so as to determine the critical positions at the TCP position.

The product shall be prevented from migrating behind the TCP embedment through the control of compressive zones and crack widths within a zone extending $\pm$ twice the wall thickness measured above and below the top of the embedment. Within this zone;

- a) The compression shall not be less than 80mm (3.15 in)
- b) Crack widths shall be less than $<0.1\text{mm}$ (0.004 in) be determined in accordance with EN 1992 using the strains from the nonlinear analysis. Where tension stiffening

is included within the constitutive model then this shall be removed from the subsequent determination of crack widths whereby avoiding 'double dipping'.

Where explicit nonlinear methods are used constitutive models for concrete and steel shall comply with EN 1992. Other methods of analysis maybe permitted subject to Company approval.

Where proprietary software is proposed by the contractor full validation and verification shall be provided for company review and approval.

Both transient and steady state effects shall be whereby maximising the structural demands on both the concrete and embedment. The effects of a 'cold' embed and warm wall should be explicitly considered.

In the absence of a predefined spillage the contractor shall examine the secondary container full to the maximum level along with intermediate level top capture the structural demands. Particular attention shall be paid to spills in the immediate vicinity of the embedment

5. COMPONENT DESIGN OF THE METAL TANK

5.1 GENERAL

The following components shall be designed, fabricated, supplied, erected, inspected and tested in accordance with the standards, guidelines, specifications, documents specified herein and additional requirements as given in this specification. The inner tank, secondary bottom plus the thermal corner protection (TCP), suspended deck, bottom liner, wall liner, and the roof liner.

5.2 INNER TANK

Maximum allowable stresses for the inner tank design for normal and testing conditions shall be in accordance with API 620 Appendix Q.

Maximum allowable stresses for the inner tank design for OBE conditions shall be in accordance with API 620 Appendix L.4.2.5.

- a) Response at the OBE level shall be essentially elastic and the force reduction factor shall be taken as 1.0.
- b) Earthquake definition for the OBE shall be as per Tank datasheet.

Maximum allowable stresses for the inner tank design for SSE conditions shall be in accordance with NFPA 59A with the force reduction factor taken as 1.0.

- a) Force reduction factors greater than 1.0 shall be demonstrated explicitly via a pushover analysis or similar approved analysis.
- b) Earthquake definition for the SSE shall be as per the Tank Datasheet.

Shell and bottom annular plates shall be butt welded. Welding of the inner tank bottom annular plates shall comply with API 620 Q 7.1.1. Shell to annular plate welds shall conform to API 620 sections 5.9.5 and Q 7.1.1 requirements.

Temporary access through the inner tank shell, using 'door sheets' or manways, is permitted.

All permanent structural attachments welded directly to the 9% nickel steel shall be of the same material as that to which they are welded.

Minimum plate thickness: per API 620.

Anchorage of the inner tank is not permitted under the seismic event(s), tank aspect ratio shall be modified accordingly and/or isolators introduced.

Attachments, including circumferential stiffeners, shall be welded with continuous fillets on all sides.

Stud-welded attachments are not permitted

Structural attachments or appurtenances shall be located no closer than 150 mm (6 in) to all vertical and horizontal weld seams and any other attachment welds or discontinuities (except for circumferential stiffening rings at vertical shell joints as shown in API 620, Appendices Q and R).

5.3 LINERS (VAPOUR BARRIER)

5.3.1 Bottom Liner

A vapour tight bottom liner, connected to the wall liner, shall be provided. The design shall account for stresses, strains, and thermal considerations. The bottom liner minimum thickness shall be 5 mm (0.2 in), and it may be lap welded. The design temperature shall be -20°C (-4°F). Acceptable materials shall be selected from API 620, Table R-4 or equivalent.

5.3.2 Wall Liner

A vapour tight wall liner which is connected to the bottom liner, the TCP embed plate and the roof liner shall be provided. The wall liner above and below the TCP embed may fail in the case of the abnormal inner tank spill. The wall liner shall be attached to embedded anchors which are flush with the inside of the outer tank wall. The wall liner minimum thickness shall be 3 mm (0.12 in). The wall liner and embedment material shall have a design temperature of -20°C (-4°F). Acceptable materials shall be selected from API 620, Table R-4 or equivalent.

The wall liner and embedded anchors shall be designed for the stresses and strains resulting from prestress loads and geometrical tolerances of construction of the liner and embedded anchors.

The tolerance of the strips to which the liner plates are welded, shall be specified by Contractor and the liner shall be designed accordingly.

The anchors of the strips shall be designed for shear resulting from prestressing loads.

5.3.3 Roof Liner

A carbon steel roof liner shall be installed at the inside face of the concrete roof. The liner shall function as an integral part of the concrete roof using shear anchors for load transfer.

The roof liner may be used as formwork for the concrete during construction. The liner shall be at least 5 mm (0.2 in) thick. The design temperature shall be -20°C (-4°F). A structural framing design temperature shall be selected by Contractor appropriate to the use and design considerations of the framing. Acceptable materials shall be selected from API 620, Table R-4 or equivalent.

5.4 SUSPENDED DECK

The suspended deck shall be a flat plate deck, trough decks shall not be permitted.

The suspended deck shall be provided with open vents to ensure equilibrium of gas pressure on both sides of the suspended deck.

The minimum plate thickness of the deck shall be 5 mm (0.2 in).

The minimum design temperature of the deck shall be -170°C (-274°F).

The suspended deck shall be designed for:

- a) a minimum live load of 0.5 kN/m², or
- b) a concentrated live load of 1.5 kN at any place of the suspended deck, or
- c) walkways where supported from the suspended deck

5.5 SECONDARY BOTTOM AND THERMAL CORNER PROTECTION (TCP)

The secondary bottom shall consist of minimum 5 mm (0.2 in) thick 9% nickel steel lap welded inner bottom plates and annular plates at the perimeter. The secondary bottom shall be placed on top of the bottom insulation system or between groups of insulation when insulation is also utilised above the secondary bottom. The secondary bottom shall extend into the annular space and shall connect to the TCP. (The TCP consists of vertical shield plates with a top horizontal stub connecting to a vapour tight flush anchor plate. The anchor plate is embedded in the concrete wall with anchors located on the back side of the flush anchor plate). The annular plates shall be butt welded (backing strips may be used). The connection of the annular plates to the vertical shield plates of TCP shall be made with a partial penetration corner weld with fillet.

Contraction/ expansion of the secondary bottom and vertical shield plates due to operating conditions or thermal shock caused by leakage shall be taken into account and included in the design of these plates. Consideration may be given to the increased material strength that occurs at cryogenic temperatures when calculating stresses and strains for this emergency condition.