

DEP SPECIFICATION

FULL CONTAINMENT REFRIGERATED LNG TANKS

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DESIGN AND ENGINEERING PRACTICE

DEM1



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the design, supply fabrication, construction, inspection and testing of Full Containment Type refrigerated Liquefied Natural Gas (LNG) Tank(s). The capacity, number and salient data pertaining to the tanks are presented in (Appendix F).

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

This is a revision of the DEP of the same number dated February 2014; see (1.5) regarding the changes.

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 authorisation 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, gas handling, oil refining, chemical processing, gasification, distribution and supply/marketing. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall 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 Abbreviations

Term	Definition
AGA	American Gas Association
ALARP	As Low As Reasonably Practicable
CCR	Central Control Room

Term	Definition
CP	Cathodic Protection
CQCE	Concrete Quality Control Engineer
DCS	Distributed Control System
EPC	Engineering Procurement and Construction
HAZ	Heat-Affected Zone
LNG	Liquefied Natural Gas
MaxNOL	Maximum Normal Operating Level
MDLL	Maximum Design Liquid Level
MinNOL	Minimum Normal Operating Level
MDR	Master List of Documents and Records register
MS	Method Statements
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 or clause number is shown in brackets (). Other documents referenced by this DEP are listed in (20).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a minor revision of the DEP of the same number dated February 2014. The following are the main, non-editorial changes.

Section/Clause	Change
3.1, Item 6	Relocated to 3.2

4.8.5	Replaced with new 4.8.5 and 4.8.6 with detail formulae
5.5.2	Formulae corrected
5.5.3	Formulae corrected
5.5.3	Formula corrected
7.1.2	Table 7.1 modified, Table 7.2 added
8.1.4	New sections added and text amended
10.4, Item 1	Text amended
References	Updated
Appendix B	Updated

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
DEP Feedback System (Users with access to Shell Wide Web)	Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal http://swwww.shell.com/standards . Select "Submit DEP Feedback", fill in the online form and submit.
DEP Standard Form (Other users)	Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at standards@shell.com .

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DUAL UNITS

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.

1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

Non-normative text is normally indented slightly to the right of the relevant DEP clause.

2. GENERAL

2.1 DESIGN PRINCIPLES

1. The tank(s) SHALL [PS] be in accordance with the "Full Containment" concept as specified in EN 14620.
2. The tanks shall meet the requirements of referenced codes and standards, unless where specifically modified by this DEP.
3. The Full Containment Tank(s) (FCT) SHALL [PS] comprise a liquid tight 9 % nickel inner tank and a liquid and vapour tight concrete outer tank. Both shall be capable of independently containing the stored product.
4. Inner tanks shall meet the requirements of API 620 Appendix Q, this DEP, and associated datasheets. The corner protection and secondary bottom shall be designed in accordance with ASME VIII-2.
5. Outer tanks shall meet the requirements of EN 14620, this DEP and associated datasheets. The roof and base of the outer tank shall be of reinforced concrete whilst the walls shall be post tensioned in both the horizontal direction and vertical directions.
6. Tanks SHALL [PS] be designed and constructed so that:
 - a. In normal service:
 - i. Accumulation of product in the inter space shall not occur.
 - ii. Vapour tightness of the secondary container is achieved through the incorporation of a metallic vapour barrier to the walls, roof and base.
 - b. In upset or emergency conditions where product accumulates in the interspace:
 - i. The outer tank and secondary bottom contains the liquid product and prevents leakage.
 - ii. Product losses due to container permeability are acceptable (under these conditions and determination of absolute rates is not required)
 - iii. Controlled venting of the product vapour to atmosphere is permitted.

2.2 TECHNICAL SCOPE INCLUSIONS

1. Design and construction of the foundation, including soil improvement, deep foundations (or otherwise) is by the Contractor.
2. A reinforced concrete base slab with under tank heating system designed to prevent frost heave and support the inner tank, outer tank and appurtenances.
3. A 9 % nickel steel open topped inner tank designed and constructed in accordance with API 620 Appendix Q (without anchor straps);
4. A concrete secondary outer container consisting of a post tensioned concrete wall rigidly connected to the outer tank concrete bottom slab and a roof constructed of reinforced concrete. The inside of the secondary container shall be lined with a carbon steel vapour barrier;
5. 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 secondary bottom shall be placed above the lower bottom insulation system consisting of cellular glass;
6. A carbon steel roof liner which forms an integral structure with the reinforced concrete roof;
7. 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;

8. A tank insulation system including insulation load bearing cellular glass insulation located between the inner tank and secondary bottoms; perlite insulation between the steel inner tank shell and the secondary container and fibreglass blanket on top of the suspended inner deck;
9. Submerged pump risers including pumps lifting mechanisms, cables from the top of the tube to the pump, and junction boxes, internal piping, etc. Spare pump to be fit tested and checked for all applicable tanks;
10. Submerged pumps shall be designed, supplied and installed by the Contractor and conform to DEP requirements;
11. Platform, staircase, stairs, walkways, caged ladders, monorails, cranes, handrails, etc.
12. Insulation space purge and monitoring system;
13. The Contractor shall supply instrumentation for level, pressure and temperature recording, leak/gas detection, and cool-down control, and any other instrumentation necessary for the completion of the works as required by the design requirements specified in the ITB documentation.
14. Pressure relief and vacuum relief valves for protection;
15. An active fire protection system consisting of fire detection and control system including nitrogen snuffing system for the pressure relief valves;
16. Firewater system for roof platform and equipment;
17. Design, installation, NDE and testing of all pipe work and pipe work insulation associated with the tank to the battery limit;
18. The Contractor shall model and design the piping systems within the scope of the tank and determine loads that the pipe supports shall accommodate. The Contractor shall consult with Principal on surge and slug design considerations when establishing piping system anchor point requirements within the battery limit. Battery limit shall be defined in the contract documentation. The Contractor shall also comply with the following:
 - a. All piping within the tank, on the tank roof and wall is within the Contractor's battery limit. Piping termination points and battery limits shall be identified within interface documentation.
19. The Contractor shall design, supply and install;
 - a. The base slab heating system including all associated control and protective devices;
 - b. Lighting, earthing and lightning protection systems on and around the tank area;
 - c. Electrical equipment and devices for MOVs, hoists and cranes;
20. The Contractor shall 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.
21. 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) shall utilise cabling trays supplied and installed by others.
22. The Contractor shall design, furnish, and install external pipe work and Insulation materials for external pipe work within the Contractor's Battery Limit and any special support components and any non-standard insulation materials required at any pipe support or guide.

23. Inspection by an independent subcontracted inspection agency for all shop fabricated sub components may be used. The qualifications of all inspectors shall satisfy the requirements of API 620, §7.2.1.

2.3 CODES AND INDUSTRY STANDARDS

Detailed list of referenced codes and standards is included in the references (20) of this Specification.

1. All codes and standards unless noted otherwise shall be the latest edition, including revision, addenda, supplements or others at the time of Invitation to Tender.

3. FOUNDATIONS, PAVING AND DRAINAGE

3.1 SOIL INVESTIGATIONS

1. Soil investigations for the tank site shall be conducted by the Principal to establish ground characteristics and variability of the underlying strata. Both factual and interpretive investigation data and reports for the LNG tank site shall be made available to the Contractor upon completion.
 - a. The available data shall be reviewed and verified by the Contractor that it is sufficient for the design and construction of the LNG Tank.
 - b. If the Contractor requires additional information on ground conditions, including ground improvement, then the Contractor shall carry out the additional work at the Contractor's own expense.
2. The final interpretation of the factual data provided to the Contractor and the factual data obtained by the Contractor shall be the Contractor's sole responsibility.
3. If Contractor identifies additional required information, then the Contractor is to bring to the attention of the Principal proposed requirements for a complementary soil investigation.
 - a. The Contractor shall carry out an assessment of the scope of the additional work and communicate this to the Principal at tender stage.
 - b. Detailed information pertaining to the Contractor's proposed foundation/ground improvement methodology shall be provided for evaluation/agreement of the Principal at the tender stage.
4. The minimum total number of exploratory holes shall be 13 configured in a 1, 4, 8 pattern; 1 at the centre, 4 evenly round circle of half diameter, plus 8 evenly distributed round the perimeter.
5. The Contractor shall, within the Tender submission, nominate the Ground Improvement Contractor and include a comprehensive Level 3 Schedule for the geotechnical works.
 - a. Specific milestones shall be included for site investigation, ground improvement, testing and handover of foundation for start of construction activities.

3.2 FOUNDATIONS

1. The Contractor shall design and build the tank foundation in such a way that, during all stages of the tank(s) lifetime (construction phases, hydro-test, operation phases and all emergency situations):
 - a. All credible combinations of loads are safely transferred to the subsoil;
 - b. Deformations including differential along any line in radial or circumferential direction are within acceptable limits from a structural and tank operational point of view;

- c. The tank foundation is to be designed in such a way that all ground and rainwater are drained away from the LNG Tank.
2. The following limiting criteria for settlement can be used by the Contractor as guidelines.
 - a. The actual settlement criteria shall be established based on the site specific geotechnical information, tank design requirements and requirements of ancillary equipment.
 - b. The predicted foundation non-uniform settlements shall not exceed the limits set out in Table 3.1.

Table 3.1 Guidelines for settlement

Type of settlement	Settlement limits
Tilt of the Tank	1: 500
Tank floor settlement along a radial line from the periphery to the tank centre	1: 300
Settlement around the periphery of the tank	1: 500 (but not exceeding the maximum settlement limit calculated for the tilt of the tank)

3. The Contractor shall select and optimise the foundation concept based on the content of the interpretive Geotechnical report.
 - a. Due consideration shall be given to the potential liquefaction of the soil in accordance with the requirements of DEP 34.11.00.12-Gen.
 - b. The allowable bearing pressure of the soil shall be determined and subject to agreement with the Principal.

4. DESIGN ACTIONS

4.1 GENERAL

1. 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.
2. The inner tank shall be capable of storing the net capacity plus the bottom ullage below the Minimum Normal Operating Liquid Level (Min.NOLL) and additional volume above Maximum Normal Operating Liquid Level (Max.NOLL) associated with the tank overfill protection, seismic sloshing wave height and freeboard.
3. The following specific design loading shall be taken into account:
 - a. Hydrotesting of the inner tank to a height based on the hydrotest pressure at the base of the inner tank being 1.25 times the Maximum Design Liquid Level (MDLL).
 - b. Normal operation of the tank containing LNG at maximum and minimum design liquid levels (MDLL, Min.NOLL).
 - c. Maximum and minimum internal pressure.
 - d. Pneumatic test of the outer tank to a pressure equal to 1.25 times the pressure for which the vapour space is designed.
 - e. OBE and SSE Earthquake as per (Appendix F).
 - f. Predicted maximum differential centre to edge settlements of the concrete bottom slab based on interpretation of the geo-technical data. The design shall

allow for total differential settlement through construction, hydro-testing and operational lifetime.

- g. Post-tensioning loads and concrete creep/shrinkage effects;
 - h. 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. Where piles are included in the design, the tank aspect ratio shall be selected so as to avoid tension in all piles under normal, OBE and SSE conditions.
 - 4. The Contractor shall be responsible for specifying purging, cool-down, and commissioning procedures.

4.2 CONSTRUCTION LOADING

- 1. All loading conditions occurring during construction including loads from equipment, personnel and due to construction sequences shall be considered in the LNG tank design.
- 2. The roof liner may be used as formwork for the construction of the concrete roof. Internal air pressure may be utilised to offset the structural demands of fresh concrete during temporary load combinations. Load and material variability factors shall reflect the temporary nature of the load and ability to control the placement and thickness of the concrete.

4.3 LIVE LOADS

- 1. Live loads shall, in general, be as per BS EN 1991-1-1. However, the following minimum live loads shall be considered in the design of structures to account for maintenance and erection.
 - a. Roof during Erection 1.5 kNm^{-2}
 - b. Corridors, passageways and staircases 4.0 kNm^{-2}
 - c. Other live load shall be as per the requirements given in BS-EN 1991-1-1.

4.4 PRESTRESS AND DIFFERENTIAL SHRINKAGE LOADS

- 1. Both short-term and long-term pre-stress loads imposed by post-tensioning shall be considered. Short-term pre-stress means pre-stress immediately after post-tensioning and long-term pre-stress means pre-stress loads after all time dependent losses such as concrete creep and shrinkage and tendon relaxation take place.
- 2. Short-term and long-term concrete differential shrinkage loads occurring due to difference in time of concrete placement for various tank components shall be considered.

4.5 WIND LOADS AND SNOW LOADS

- 1. The outer tank and associated structural components shall be designed to withstand the effects of:
 - a. Basic wind speed as per the Tank (Appendix F) and local codes.
 - b. Snow loads as per Tank (Appendix F) and local codes.

4.6 EARTHQUAKE (OBE AND SSE)

- 1. Seismic design of the inner and outer tank shall be in accordance with the requirements of API 620 Appendix L and EN 14620, respectively, and as amended herein.
- 2. The inner and outer tanks shall be designed for two levels of seismic ground motion, the Operating Basis Earthquake (OBE) and the Safe Shutdown Earthquake (SSE).

Return periods for OBE and SSE events and spectral construction shall be as per requirements of EN 14620-1, §7.3.2.2.13, §7.3.3.3 and as stated in the (Appendix F).

- a. The OBE ground motion shall be the motion represented by 5 % damped response spectra having a 10 % probability of being exceeded within a 50 year return period (mean recurrence interval of 475 years).
 - b. The SSE ground motion shall be the motion represented by a 5 % damped acceleration response spectrum having a 2 % probability of exceedance within a 50 year period (mean recurrence interval of 2,475 years).
 - c. In accordance with EN 14620 §7.3.3.3 the spectral acceleration of the SSE response spectrum shall not exceed twice the corresponding OBE spectral accelerations.
3. The complete tank system shall be designed so as to:
- a. Be re-operable after an OBE event. All components including piping, structures, attachments and appurtenances shall be designed so as to remain essentially elastic. In this regard, force reduction (ductility) shall not be permitted under the OBE event.
 - b. Survive the SSE event. In this regard, ductility is permitted as per code requirements based on the structural classification for all structural and non-structural components and attachments. Where ductility is adopted for the outer tank design including roof, wall and (where provided) piles, a detailed pushover analysis shall be undertaken to demonstrate/validate the force reduction factor selected.
4. The inner tank shall be designed for:
- a. The OBE whilst filled with LNG to the Maximum Design Liquid Level (MDLL), and
 - b. The SSE whilst filled with LNG to the Maximum Normal Operating Liquid Level (Max.NOLL).
5. Outer tank should be designed for OBE and SSE events without liquid in the secondary tank.
6. The outer tank shall also be designed to contain 100 % of the gross volume pertaining to the Max.NOLL whilst subjected to an OBE event concurrent with the product leak from the inner tank.
7. The outer tank shall be designed using dynamic lateral force procedures with due consideration of the effects of the inner tank filled to the appropriate levels as defined above, outer tank and foundation interaction. Specific combinations of components may be modelled and analysed separately.
8. For structural appendages such as platforms, etc., an appropriate analysis shall be undertaken to assess the amplification/attenuation of motion seismic action to be applied.
9. Fixed period damping ratios for the inner, outer and fluid contents shall be as per Table 4.1.

Table 4.1 Damping ratios

Component	Damping Factors in %	
	OBE	SSE
Steel	2.0	4.0
Horizontal Impulsive	2.0	5.0
Horizontal Convective	0.5	0.5
Vertical Flexible	2.0	5.0
Vertical Rigid	0.0	0.0
Prestressed Concrete	2.0	5.0
Reinforced Concrete	4.0	7.0

10. The vertical rigid component is the motion portion of the liquid that moves in phase with the ground. It shall be assumed to be at the zero period acceleration; for the purposes of the analysis, it shall be taken as 33Hz.
11. Dynamic Soil Structure Interaction (DSSI) effects shall be considered for all tank(s) not supported by a rock or rock-like foundation (shear wave velocity $V_s > 750 \text{ ms}^{-1}$).
 - a. Impedance function methods (where used) shall conform to the requirements of EN 1998-4 A7.
 - b. Maximum modal damping shall be limited to 15 % and 20 %, respectively, for the OBE and SSE horizontal modes.
 - c. The Contractor shall provide a comprehensive DSSI design basis clearly identifying the analysis methodology, i.e., impedance (frequency domain) or direct methods (time domain) along with ranges of dynamic impedances, soil constitutive models, and methodology for including far and near field effects commensurate with the requirements of (5.3.2).
12. For frequency domain methods, 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.
13. For the outer tank, individual modes (for a given excitation direction) shall be combined using the "Square Root Sum of the Squares" (SRSS) method. The total seismic demand shall be determined using a 40 % spatial combination and be the maximum of:
 - a. 100 % horizontal $\pm$ 40 % vertical
 - b. 40 % horizontal $\pm$ 100 % vertical
14. For the inner tank the impulsive and convective components shall be combined using the "absolute sum method" (for a given excitation direction). The total seismic demand in the tank shall be determined using a 40 % spatial combination (as per the above).

4.7 HEAT LEAK

1. The total heat in-leak shall be such that the boil-off rate will not exceed the percentage [as stated in (Appendix F)] of the gross tank contents per day based on pure methane. Boil-off calculations shall be based on the following information listed in the (Appendix F):
 - a. 95th percentile ambient air temperature
 - b. 5th percentile wind speed

- c. 90 % Relative Humidity
 - d. Solar radiation as per (Appendix F)
 - 2. The Contractor shall make allowances for heat gain from pumps, stilling wells and appurtenances and provide calculations during the detailed engineering phase demonstrating that the insulation fulfils the heat in-leak requirements.
 - 3. For exposed surfaces during a period of 12h, the daily global solar radiation shall be taken into account. Thermal inertia of the concrete outer tank may be considered for the effect of solar radiation on boil-off rate. The Contractor shall provide calculations during the detailed engineering phase demonstrating that the insulation fulfils the heat in-leak requirements
- 4.8 HAZARD DESIGN CONDITIONS**
- 4.8.1 LNG spill protection**
- 1. No specific provisions for spill collection are required.
- 4.8.2 Fire exposure**
- 1. In the event of a fire, the tank shall be designed to remain fully functional and continue in service with the minimum of repair.
 - 2. The outer tank roof and side walls shall be capable of withstanding fire exposure and heat radiation from the following relief valve discharge fires:
 - a. A single PRV fire may occur by ignition of vapour relieved as a result of a failed pilot system. It is assumed that remedial action to stop a single PRV fire can be taken within 2 hours. The heat radiation shall be determined based on the total design flow rate of a single PRV discharging through the tail pipe.
 - b. Multiple PRV fires may occur by ignition of vapour relieved as a result of upsets in operation. It is assumed that the fire can be stopped by operational action within 10 minutes.
 - 3. Main steel structural members, located on LNG tank roof, supporting vital equipment, shall be protected for fire.
 - 4. Requirements for the fire cases are included in (Appendix A).
- 4.8.3 LNG major leak**
- 1. The post-tensioned concrete tank wall and its connection to the base slab shall be designed to withstand the thermal effects of LNG in the annular space. An appropriate amount of intermediate liquid spill levels shall be considered in conjunction with maximum design internal pressure to ensure that the most severe design conditions are considered.
 - 2. A representative number of intermediate liquid levels sufficient to demonstrate integrity of the wall shall be considered in-conjunction with maximum design internal pressure. The Contractor shall pay particular attention to spills in the vicinity of the TCP embedment and in no instance shall the number of spill levels selected for analysis be less than six.
 - 3. It shall be demonstrated that any irreversible deformations occurring on the secondary container during the major leak or major leak plus OBE shall not impact the containers ability to meet the spillage acceptance criterion of (5.4.4).
- 4.8.4 Local cold spot**
- 1. A local cold spot of 1 m (3.3 ft) diameter at the product temperature shall be considered as acting on the walls, secondary liner and TCP. The carbon steel vapour barrier is permitted to fail under this condition.

4.8.5 High velocity Impact – Flying Valve

1. The outer tank walls and roof shall be designed to withstand the impact of a 110 kg (220 lb) projectile travelling with a velocity 45 ms^{-1} (150 fps) impacting perpendicular to surface with an impact diameter 100 mm (4 in).
2. The perforation thickness shall be determined using the modified CEA-EDF formula as presented in CEB 187 as follows;

$$V_p^2 = 1.9 f_c \rho^{1/3} \left(\frac{de^2}{M} \right)^{4/3} N^2 \left[0.35 \left(\frac{M_a}{M_{a0}} \right)^{\gamma} + 0.65 \right] \left(\frac{f_c}{f_{c0}} \right)^{-1/2}$$

- a. The maximum ratio of e/d and M_a in the above equation shall be limited to 4 and 300 kgm^{-3} respectively.
 - b. N shall be taken as 1.0 commensurate with a flat nosed object.
 - c. In order to account for uncertainty, the concrete elements shall be at least 20 % thicker than the minimum thickness required to reduce the projectile velocity to zero.
 - d. For walls with thickness smaller than twice the perforation thickness, the minimum percentage of reinforcement shall be 0.2% in each principle direction and on each member face.
2. The penetration depth shall be determined using the UKAEA formula as presented in CEB 187 follows;

$$G = 3.8 \times 10^{-5} N m V_i^{1.8} / (f_{cy}^{0.5} d^{2.8})$$

- a. Maximum values of m/d^3 and f_{cy} in the above equation shall be limited to $200,000 \text{ kgm}^{-3}$ and 44MPa respectively as per CEB 187.
 - b. N shall be taken as 1.0 commensurate with a flat nosed object.
 - c. In order to account for uncertainty, the concrete elements shall be at least 20 % thicker than the penetration depth when $z > 0.75$ and 50% thicker than the penetration depth when $z \leq 0.75$.
 - d. Where horizontal tendons are located within the penetration depth of the proximal face (with due allowance for uncertainty i.e. increasing penetration depth by 20% or 50% as required by (4.8.5.2 c)) the outer tank wall shall be designed with additional tendon redundancy to allow for a single tendon failure at any horizontal location without impairment of functional requirements.
3. The minimum depth to resist scabbing shall be determined using the UKAEA formula as presented in CEB 187 follows;

$$\frac{t_s}{d} = 5.3 (G)^{1/3}$$

Where G is determined in accordance with (4.8.5.2) above:

- a. Within the range $0.18 < d/t_s < 0.5$ the concrete elements shall be at least 40 % thicker than the minimum depth to resist scabbing;
- b. Where metallic liners are provided on the distal face the effects of scabbing need not be considered.

4.8.6 Low velocity Impact loads – Dropping objects

1. The concrete tank roof shall be designed to withstand impact of dropped objects of maximum 900 mm (3 ft) diameter weighing up to a maximum of 1000 kg (2200 lb) falling from a height of 10 m (33 ft).

2. Scabbing

- a. The conditions for scabbing or through-wall cracking to occur have been correlated by defining a scabbing number defined as presented in CEB 187 follows;

$$N_{scab} = \frac{m^{0.5} V_i d_e^{0.5} E_c^{0.5}}{d_0 e (1 + e/d) f_\tau}$$

- b. The minimum thickness to resist scabbing shall be determined from the above equation with N_{scab} equal to 50.
- c. No account should be taken of increases in compressive strength occurring after 28 days, unless corresponding increases in the tensile strength can be demonstrated.
- d. Where metallic liners are provided on the distal face the effects of scabbing need not be considered.

4.8.7 Blast loads

1. The tanks shall be designed to safely resist the effects of the blast loading specified in (Appendix F).
2. Escalation of an explosion incident shall be prevented by ensuring structures maintain their integrity when subject to specified blast wave loading.
3. Container-associated piping up to, and including, the first container shutoff valve in LNG lines and fire protection systems shall remain operational after an explosion event.
4. Blast loading shall be commensurate with the 10^{-4} overpressure as documented in (Appendix F).

5. DESIGN CONSIDERATIONS - CONCRETE COMPONENTS

5.1 GENERAL

5.1.1 General

1. Thicknesses of the bottom slab, wall, and roof are to be selected by the Contractor to meet the performance requirements documented herein. The thickness of the wall shall be selected so that in normal operating conditions the shear forces are absorbed by the wall without the need for shear reinforcement.
2. All horizontal surfaces (including plinths) that are permanently exposed to the elements shall be laid to a grade of 1:40 to generate free draining surface.
3. Design life of the concrete components shall be 50 years. It is noted that certain national codes use the design life in order to ascertain/determine design return periods for wind and earthquake. When such codes are used, checks shall be carried out to ensure that probabilities of failure are not eroded due to selection of lower 'unconventional' return periods.

5.1.2 Tank base slab

1. Tank concrete base slab/foundation design shall incorporate the recommendations of the Geotechnical report.
2. Where a temporary construction joint is provided in the slab to allow for differential movement during construction, the same shall be closed after partial post-tensioning of the wall.
3. For the base slab to wall junction, 'kicker-less' construction shall be permitted provided the Contractor can demonstrate the ability to restrain and control the wall forms during pouring. Under no circumstances shall 'pockets' or 'box outs' be used in the base to

provide securing for the formwork. Acceptable methods for securing formwork to the base slab include 'drill and fix anchors' or 'cast in place' fixings.

4. Storage tank and its foundation shall be designed to account for the maximum total and differential settlements predicted to occur during the life of the tank.
5. The bottom slab shall be of sufficient thickness to allow placement of top and bottom reinforcing mats each containing reinforcing bars in orthogonal directions, conduits for foundation heating system cables and sensors, and two inclinometer tubes embedded in the slab in orthogonal direction.
6. Heating conduits and inclinometer tubes shall maintain a minimum slope of 1/500 from the centre to the outside for water drainage. The inclinometer casings shall be cast into the slab and located at the upper most layer of the base slab. Chairs or other devices shall be used to ensure correct vertical position is maintained during pouring.

5.1.3 Tank wall

1. The wall shall be designed with monolithic connections between the base slab and wall and wall to roof.
2. The wall shall have a minimum thickness to be able to accommodate inside and outside layers of reinforcement in orthogonal directions as well as post tensioning ducts.
3. All openings used for construction purposes shall be considered within the design and limited to a height of 4.0 metres (13.12 ft) measured above the top of the base slab.
 - a. The centre of the Thermal Corner Protection (TCP) embedment shall be located a minimum of one metre above the top of any construction opening.
 - b. Openings are provided mainly for material transport and emergency escape. Generally, two temporary access openings are arranged in the wall, opposite to each other.
4. The embedment design shall consider the transient conditions under the spill condition, in particular the effects of a 'cold' embed and 'warm' wall.
5. Vertical construction joints in the outer tank wall are not permitted above an elevation equal to centre line of TCP-1m, i.e., the outer tank wall above this level shall be cast by complete 360° pours. Vertical construction joints including those required to form the temporary construction opening(s) are permitted below this level.
6. The wall shall be post-tensioned horizontally and vertically.
 - a. Post-tensioning shall be accomplished with an impermeable duct and tendon system.
 - b. Tank design shall account for effects due to the post-tensioning sequence during construction.
 - c. The outer tank shall be post-tensioned prior to hydrostatic and pneumatic testing. The minimum horizontal and vertical post-tensioning to be applied before the hydrostatic test of the outer tank shall be determined.
 - d. Pre-stressing requirements shall also be accomplished with an impermeable duct and tendon system. All pre-stressing shall occur prior to hydrostatic and pneumatic testing.
 - e. Horizontal ducts shall be constructed from 'thick plastic', i.e., polyethylene or polypropylene as provided by Manufacturer. Vertical ducts shall be constructed from welded CHS sections.
 - f. Contractor shall use 'moveable stressing platforms' for horizontal post tensioning i.e. use of scaffolding is not permitted as temporary works for stressing activities.

7. The Contractor shall determine the post-tensioning requirements, stressing sequence, location of temporary openings and methodology used to permanently seal the openings prior to pneumatic test of the outer tank. The analysis and design of the wall shall reflect the effects of reduced axial demands due to the construction sequence in the vicinity of the access opening.
8. Mechanical couplers used to connect reinforcement in the construction opening areas on the inside face affected by the cryogenic temperature at product leak, shall be qualified for LNG service temperatures. Those located on the outside face shall be qualified for the anticipated service temperatures during normal and emergency operating conditions.

5.1.4 Tank roof

1. The roof shall be spherical in shape, and made of reinforced concrete with an interior carbon steel vapour barrier (liner). The roof radius shall be selected so as to enable concrete compaction without the use of a top shutter.
2. The roof liner including the compression ring shall be anchored into the concrete.
 - a. The steel liner located on the inside of the roof may be used as formwork for concrete placement.
 - b. The concrete may be poured in two layers to limit structural demands on the roof liner. Shear links shall be provided across layers if a two layer construction method is selected.
 - c. The Contractor shall demonstrate by analysis that the roof plates and framing are adequately designed for any temporary loading scenario, including non-symmetrical loading due to wind, post-tensioning sequence and concrete pouring sequence.
3. Detailed information on proposed method for checking of metallic roof design under concrete pouring condition shall be provided for evaluation/agreement of the Principal at the tender stage. Minimum requirements shall be as follows:
 - a. The critical compressive state of steel roof will be assessed through 3D finite element modelling.
 - b. A minimum buckling safety factor will be maintained.
4. Offsetting of the reinforcement in the roof is not permitted through consideration of composite action between the roof plates and concrete. As a composite member, full transfer of horizontal shear shall be provided using properly anchored ties or headed studs. The maximum spacing of the ties or studs shall not exceed 0.6 m.
5. All roof penetrations and plinths for structural steelwork and appurtenances shall be provided with a concrete up-stand terminating a minimum height of 30 cm above the top of the roof uppermost surface. Specific details shall be included to prevent shrinkage of concrete from sleeves and maintain an adequate rainwater seal.
6. All the loads on the roof and those suspended from the steel structure (the deck and insulation) have to be supported by the concrete dome roof structure.
 - a. The roof structure shall also support the pump wells which are suspended from the roof.
 - b. The roof shall be designed to withstand a blanket loading of 1.2 kNm^{-2} (0.174 psi) projected across the whole roof area, a point load (non-concurrent) of 5 kN (1124 lbf) distributed over an area of 0.1 m^2 (1 ft^2); a uniformly distributed load considered acting on the platforms and walkways as per (4.3).

5.1.5 Ring beam under inner tank shell

1. A concrete ring beam shall be installed under the inner tank shell. The ring beam shall be designed such that the shell loads are properly distributed onto the bottom insulation under the ring beam.

2. An analysis shall be carried out to determine the ring beam structural demands. The model shall consider the effects of shell rotation and uplift (contact) of the annular plate. The width of the ring beam shall be sufficient to resist the horizontal and vertical loading from the inner tank with due consideration of annular plate deformation(s) and the localisation of stresses in the ring beam.
3. Reinforcing bars shall be suitable for use at the design minimum temperature of the product stored.
4. The design of the inner tank ring beam shall allow gas flow between the bottom insulation space and annular space, so that differential pressure resulting in uplift of the inner tank bottom cannot occur during:
 - a. Pressure testing of the tank (depressurisation) including in-situ performance testing of tank safety devices such as pressure and vacuum relief valve.
 - b. Decommissioning
5. In addition the ring beam shall be either:
 - a. Segmental ring beam: For this the gaps between annular ring concrete segments shall be minimum 25 mm (1 in) and maximum 50 mm (2 in) and filled with resilient fibreglass blanket.
 - b. Continuous ring beam: provision shall be made to promote and assure unrestricted equalisation of internal and external pressure.

5.2 DESIGN CODE

1. The reinforced and pre-stressed concrete elements of the tank wall shall be designed in accordance with the limit state philosophy of EN 1992-1. All applicable sections of the latest edition of the design code, including supplements and chapters describing precast and pre-stressed concrete, shall be followed, except where supplemented or modified by this DEP.

5.3 ANALYSIS REQUIREMENTS

5.3.1 General

1. Normal and abnormal loads structural demands shall be determined using a combination of 2D and 3D Finite Element Modelling (FEM) techniques. Local strut and tie models shall be used to determine the structural demands and equilibrium steel at discontinuities such as abutments and roof-to-wall connection.
2. Both linear and non-linear (cracking) analyses are 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 Principal review.
3. For combinations, including the major spill a non-linear analysis shall be undertaken using an axi-symmetric model. Concrete, reinforcement and prestress constitutive models used in non-linear analysis shall be in accordance with the requirements of EN 1992-1.
4. In the absence of a defined spillage rate, the Contractor shall examine the outer tank (secondary container) full with product to the maximum level along with intermediate levels to capture maximum structural demands. Particular attention shall be paid to spills in the immediate vicinity of the embedment.
5. The model(s) shall include thermal affects arising from steady state heat transfer conditions. In addition, transient thermo-mechanical analyses shall be carried out where appropriate (e.g., for liquid spill) to ensure maximum structural demands are captured prior to the establishment of steady state conditions.

Steady state conditions are defined as the thermal profiles commensurate with $t=\infty$ for any applied thermal loading.

6. The Contractor shall select soil models as necessary to determine structural demands and displacements. Loads due to pre-stressing may be simulated by axi-symmetrical loads, acting perpendicular to the tank wall. Local stress concentrations occurring at structural discontinuities such as buttresses shall be considered within the design.
7. Short term and long term loading conditions shall be considered including the effects of concrete creep and shrinkage along with pre-stress losses, relaxation and foundation stiffness (5.3.2).
8. The Finite Element Software used for modelling the tank shall be demonstrated to produce reliable results by comparison with a set of benchmark problems, i.e., those published by the UK National Agency for Finite Element Methods and Standards.
9. Where proprietary software is used by the Contractor, full validation and verification shall be provided for Principal review and approval.

5.3.2 Foundation stiffness

1. In order to generate a robust design the Contractor shall carry out a bounded analysis of the tank using upper and lower bound soil profiles, taking into account the variation in soil behaviour over the design life of the tank. This philosophy shall apply irrespective of the foundation type and method of construction.
2. All load combinations with the exception of Blast, SSE, major leak and major leak + OBE shall include for uncertainty in the Soil Structure Interaction (SSI) and Dynamic Soil Structure Interaction analyses (DSSI).
3. Uncertainty in the SSI and DSSI analyses shall be included by considering upper and lower bound stiffness considering possible variations due to the strain rate (undrained/drained), strain magnitude and load history.
4. Lower bound and upper bound estimates of the soil stiffness should be varied between the 'best estimate' value times $(1 + C_v)$ and the 'best estimate' value divided by $(1 + C_v)$; where C_v is a factor that accounts for the uncertainties in the analysis and soil properties.
5. Where sufficient/adequate soil investigation data is available, the mean and standard deviation of the low strain shear modulus should be established for each and every soil layer. The C_v shall be determined so that it covers the mean ± 1 standard deviation for every layer with a minimum value of 0.5. Where insufficient data is available to address the uncertainties in soil properties C_v shall be taken as 1.0.
6. For load combinations including Blast, SSE, major leak and major leak + OBE, the foundation stiffness shall be based on 'best estimate' shear moduli commensurate the strain rate (undrained/drained) and strain magnitude with possible variations due to the load history.
7. For all other loading combinations, the foundation stiffness shall be based on lower bound/upper bound shear moduli commensurate the strain rate (undrained/drained) and strain magnitude with possible variations due to the load history.
8. Geotechnical finite element software with an established track record shall be used to determine the time dependent settlement over the lifetime of the tank. To account for soil structure interaction, 100 % of the tank base and a minimum of 50 % of the wall shall be explicitly modelled. When necessary, 3D models shall be used to assess non-uniform settlement and tilting of the tank, due to the spatial variation of soil.
9. As a minimum, spring elements shall be used to represent the sub-soil. The Contractor shall clearly document methodology for linearisation/determination of soil springs for use in the structural analysis. The Contractor shall clearly demonstrate consistency of settlements between the geotechnical and structural analysis.
10. The static and seismic design of pile groups shall be in accordance with DEP 34.11.00.12-Gen.

5.3.3 Thermal analysis

5.3.3.1 Normal and emergency conditions

1. Structural demands due to temperature affects shall be determined from semi coupled thermo-mechanical finite element analyses using 2D axi-symmetric solid or 2D Fourier models.
2. Surface temperatures shall be determined from a heat transfer analysis. Film coefficients shall be commensurate with 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.
3. In addition, the analysis shall consider the following;
 - a. Summer and winter conditions in accordance with Table 5.1. Refer to (Appendix F) for corresponding values.
 - b. Where included solar gain shall be determined using the Solar Radiation data contained in (Appendix F). Where appropriate, solar distribution shall be scaled from ASHRAE (2009 ASHRAE Handbook—Fundamentals) or other recognised standards to determine the total gain on horizontal and vertical surfaces.
 - c. Base heating demands shall be commensurate with the condition under consideration.
 - d. The initial temperature (stress free) T_0 should be taken as the temperature of a structural element at the relevant stage of its restraint (completion).
 - i. Where necessary, upper and lower bound T_0 's shall be selected so as to maximise the differentials for 'summer' and 'winter cases'.
 - ii. Due to the construction schedule period, T_0 for the base, wall and roof may adopt different values.
 - iii. Such temperature differences shall be included within construction and test load cases.

Table 5.1 Summer and winter design cases

	Temperature	Wind	Solar Gain
Summer	95 th percentile	5 th percentile	Yes
Winter	5 th percentile	5 th percentile	No

5.3.4 Blast analysis

1. The Contractor shall consider the interaction between the incident blast wave and the dynamic response of the walls and roof which could lead to structural amplification. For quasi-static approaches the Contractor shall explicitly determine the Dynamic Load Factor (DLF) using the blast profile(s) presented in (Appendix F).
2. Time domain analysis may also be adopted using the blast profile(s) presented in (Appendix F).

5.3.5 Heat of hydration analysis

1. The Contractor shall demonstrate by analysis using test data from the proposed concrete mix that the construction sequence and environmental conditions will not cause restraint cracking in the base, wall or roof.
2. The Contractor shall measure and record the adiabatic temperature rise of the concrete mix for use in the hydration analysis. The Contractor shall provide the

analysis methodology in order to minimise cracking during construction and maintain the crack widths within the limits of (5.4.2).

5.4 LIMIT STATE CHECK AND MINIMUM REQUIREMENTS

5.4.1 General

1. The Contractor shall design the concrete structures at the Ultimate Limit State (ULS) and Serviceability Limit State (SLS) for all normal situations.
2. The Serviceability Limit State (SLS) shall be utilised to limit concrete crack widths and/or limit stresses for all load conditions including construction, testing and normal operation.
3. The Ultimate Limit State (ULS) shall be utilised to verify the strength capacity for all load conditions with the exception of those containing spill cases for which specific analysis and acceptance criterion are stated herein.
4. Material partial safety factors for SLS and ULS conditions shall be in accordance with EN 1992-1.

5.4.2 SLS limit state (SLS)

1. SLS checks shall be in accordance with the requirements of EN 1992-1.
2. For Normal operation, and construction and testing, the following shall apply:
 - a. Crack widths on inside and outside faces of pre-stressed concrete members shall be limited to $w_k < 0.2 \text{ mm}$ (0.007 in).
 - b. Crack widths on inside and outside faces of reinforced concrete members shall be limited to $w_k < 0.3 \text{ mm}$ (0.012 in).
 - c. Concrete members shall be 'directionally classified', i.e., walls pre-stressed only in the circumferential direction shall be designed to limit the crack widths to $w_k < 0.2 \text{ mm}$ (0.007 in) and 0.3 mm (0.012 in) in the circumferential and vertical directions respectively. Members pre-stressed both circumferentially and vertically shall be designed to limit crack widths to $w_k < 0.2 \text{ mm}$ (0.007 in).
3. For the OBE condition, the following shall apply:
 - a. Crack width control is not required on inside and outside faces of pre-stressed concrete and reinforced concrete members provided the tensile reinforcement stresses for crack controlling members is $\leq 300 \text{ MPa}$.
4. For the Cold Spot condition, the following shall apply:
 - a. Crack widths on inside and outside faces of pre-stressed concrete members shall be limited to $w_k < 0.3 \text{ mm}$ (0.012 in).

5.4.3 Ultimate limit state (ULS)

1. ULS checks shall be in accordance with the requirements of EN 1992-1.
2. For load caused by a relief vent fire, stresses in the pre-stressing tendons and in the reinforcing bars shall remain elastic $<$ yield stress. In addition, the compressive strain in the concrete shall be limited to $\leq \epsilon_{c1}$ to avoid crushing and spalling of the concrete. (Explosive spalling of the concrete shall be avoided).

5.4.4 Spillage acceptance criterion

1. The acceptance criterion for all spillage conditions shall be as follows:
 - a. The Residual Compression Zone (RCZ), i.e., the distance between the compressive face and the position of zero stress shall be $\geq 100 \text{ mm}$ (4 in).
 - b. The average compressive stress (RCZ_{avg}) in the RCZ shall be $\geq 1.5 \text{ MPa}$.

- c. The characteristic crack width (w_k) calculated in accordance with EN 1992-1 on the inside face of the concrete in contact with product shall be ≤ 0.2 mm. This criterion shall be applied between elevations h_1 and h_2 , where
 - h_1 = TCP centre - x
 - h_2 = TCP centre + x
 Where; x is the greater of 1 m (3.3 ft), or $2x$ the wall thickness measured at the TCP elevation.
 - d. Tensile strain in the reinforcing bars calculated on the basis of a cracked section shall be less than 1 %.
 - e. Tensile strain in the prestressed reinforcement, calculated on the basis of a cracked section, shall be $\leq f_{p0,1k}/(E_p \cdot \gamma_s)$. Where γ_s is commensurate with the accidental loading conditions (EN 1992-1-1 Table 2.1N).
 - f. Extreme compressive stress in the concrete cracked section shall be $\leq 0.85f_{ck}$.
 - g. Constitutive models for concrete and steel shall comply with the requirements of EN 1992-1 §3.1.5. Where tensile capacities are incorporated in the concrete constitutive model, upper and lower bound values pertaining to $f_{ck}0.05$ and $f_{ck}0.95$ shall be used to demonstrate compliance with the requirements of this clause.
 - h. Spillage assessments shall be carried out for short term and long term load cases using combinations of upper and lower bound soils properties.
2. Shear capacities under spillage conditions shall be verified against the requirements of EN 1992-1 ULS criterion using material variability factors commensurate with the abnormal (accidental) nature of the loading.
 3. Shear links shall be permitted to resist the shear demands under the spillage cases, and where provided, shall be of cryogenic grade.

5.5 LOAD COMBINATIONS

5.5.1 General

1. All appropriate load cases and combinations shall be incorporated in the design of the concrete outer tank.
2. The Contractor shall prepare a detailed loading summary table, to cover all phases of the tank lifetime. Favourable and unfavourable effects of all permanent, pre-stress, creep and shrinkage, temperature, hydrostatic and pressure actions shall be considered for all normal conditions including construction, normal operation and maintenance.
3. In all cases, the design shall take into account the effects of the action, shrinkage strains, and pre-stressing forces during and after tensioning with due consideration of edge restraint at the wall junctions with the base slab and roof.

5.5.2 Serviceability limit state combinations

1. Load factors for normal conditions shall be in accordance with EN 1990 and country specific National Annexes, pertaining to reversible limit states except as modified herein. Shrinkage, creep and temperature shall be included within all SLS cases including locked in stresses arising from construction and loading history.
2. For Frequent Combination

$$E_d = \sum_{j \geq 1} G_{kj} + P + Q_{sc} + Q_t + Q_f + \varphi_{1,1} Q_{k,1} + \sum_{(i > 1)} \varphi_{2,i} Q_{k,i}$$

3. Factors for $\varphi_{1,1}$ and $\varphi_{2,i}$ are presented in Table 5.2 below; $\varphi_{1,1}$ shall be taken as 1.0 for the OBE condition.

4. For Quasi permanent combination

$$E_d = \sum_{j \geq 1} G_{kj} + P + Q_{sc} + Q_t + Q_f + \sum_{(i>1)} \varphi_{2,i} Q_{k,i}$$

5. Quasi permanent combination is normally used for long-term effects (e.g., shrinkage, creep).

Table 5.2 SLS load factors

Variable actions		G_k, P, Q_{sc}, Q_T and Q_F	Leading / Main Variable factor	Accompanying Variable factor
			$\varphi_{1,1} / \varphi_{2,1}$	$\varphi_{2,i}$
Imposed load				
Frequent	Unfavourable / Favourable	1.0	0	0
Quasi – permanent	Unfavourable / Favourable	1.0	0	0
Snow load				
Frequent	Unfavourable / Favourable	1.0	0.2	0
Quasi – permanent	Unfavourable / Favourable	1.0	0	0
Wind load				
Frequent	Unfavourable / Favourable	1.0	0.2	0
Quasi – permanent	Unfavourable / Favourable	1.0	0	0

5.5.3 Ultimate limit state combinations

- Load factors for normal conditions shall be in accordance with EN 1990 and country specific National Annexes, except where modified herein. Shrinkage, creep and temperature need not be included within ULS combinations provided that they are included at Serviceability Limit State.
- For design situations with one variable action;

$$E_d = \sum_{j \geq 1} \gamma_{Gj} G_{kj} + \gamma_P P + \gamma_{sc} Q_{sc} + \gamma_t Q_t + \gamma_f Q_f + \gamma_{Q,1} Q_{k,1}$$

- Design situations with two or more variable actions shall be designed for the less favourable of following;

Equation 1 (Eq. 1)

$$E_d = \sum_{j \neq 0} \gamma_{Gj} G_{kj} + \gamma_P P + \gamma_{sc} Q_{sc} + \gamma_t Q_t + \gamma_f Q_f + \gamma_{obe} Q_{obe} + \gamma_{Q,1} \varphi_{0,1} Q_{k,1} + \sum_{(i>1)} \gamma_{Q,i} \varphi_{0,i} Q_{k,i}$$

Equation 2 (Eq. 2)

$$E_d = \sum_{j \geq 1} \varepsilon \gamma_{Gj} G_{kj} + \gamma_P P + \gamma_{sc} Q_{sc} + \gamma_t Q_t + \gamma_f Q_f + \gamma_{obe} Q_{obe} + \gamma_{Q,1} Q_{k,1} + \sum_{(i>1)} \gamma_{Q,i} \varphi_{0,i} Q_{k,i}$$

4. Factors for the above combinations, including permanent, leading, accompanying load factors are given below in Table 5.3 and Table 5.4 below. The given factors are based on Annexe to EN 1990. For country-specific load factors, refer to relevant annexes of EN 1990.

Table 5.3 ULS partial load factors for G_k , P , Q_{sc} , Q_t and Q_f actions

Action	Description of action	Factor	Unfavourable	Favourable
Permanent actions				
G_k	For (STR) limit state	γ_{Gj}	1.35	1.0
Variable Actions				
P	Pre-stressing actions	γ_P	1.2	0.9
Q_{sc}	Shrinkage and creep actions	γ_{sh}	1.2	0.0
Q_T	Temperature actions	γ_T	1.2	1.0
Q_F	Fluid actions	γ_f	1.2	1.0
$Q_{k,1}$	Leading variable action	$\gamma_{Q,1}$	See Table 5.4: for leading and accompanying variables	
$Q_{k,i}$	Accompanying variable(s) action	$\gamma_{Q,i}$		
Q_{obe}	OBE Earthquake	γ_{obe}	1.2	0.0

Table 5.4 ULS leading and accompanying load factors

Variable Action $Q_{k,i}$		Unfavourable permanent action factor ε	Leading / Main Variable factor		Accompanying Variable factor	
			$\gamma_{Q,1}$	$\varphi_{0,1}$	$\gamma_{Q,i}$	$\varphi_{0,i}$
Imposed Loads	Eq.1	1.0	1.5	0	1.5	0
	Eq.2	0.85	1.5	-	1.5	0
Snow Loads	Eq.1	1.0	1.5	0.5	1.5	0.5
	Eq.2	0.85	1.5	-	1.5	0.5
Wind Loads	Eq.1	1.0	1.5	0.6	1.5	0.6
	Eq.2	0.85	1.5	-	1.5	0.6

5. All variable actions should generally be present within a load combination, unless they have a favourable influence, in which case they are assigned a partial safety factor $\gamma_{Q,1}$ of zero. In general, unless it is clearly not a critical combination, each variable action should be considered as leading variable action, in turn.

5.5.4 Accidental load combinations

- For design situations with two or more variable actions, load factors shall be in accordance with EN 1990 and country-specific National Annex, except where modified herein:

$$E_d = \sum_{j \geq 1} (\epsilon) \cdot G_{kj} + P + Q_{sc} + Q_t + Q_f + A_d + (\varphi_{1,1} \text{ or } \varphi_{2,1}) Q_{k,1} + \sum_{i > 1} \varphi_{2,i} G_{k,i}$$

Where;

A_d - Accidental load

- Load factors and load combinations for accidental conditions shall be in accordance with Table 5.5 below.

Table 5.5 Accidental load combinations - Load factors

Permanent Load Factor	Leading Accidental Load Factor A_d			Accompanying Variable Load Factors, φ_1, φ_2		
G_k, P, Q_{sc}, Q_T, Q_F (ϵ)	SSE Spill, Impact, Blast	Spill + OBE	Fire	Imposed	Snow	Wind
Unfavourable 1.05 Favourable 1.0	1.05			0	0	0
	1.05			0	0.3	0
	1.05			0	0	0.3
		1.05		0	0	0
		1.05		0	0.3	0
		1.05		0	0	0.3
			1.05	0	0	0
			1.05	0	0.3	0
			1.05	0	0	0.3

- Multiple 'accidental load' shall not occur in the same combination, i.e., SSE or Spill or blast, etc.
- Operational loads shall be combined a single variable load and a single accidental load (as shown).

6. METALLIC COMPONENTS

6.1 GENERAL

- The inner tank, secondary bottom, Thermal Corner Protection (TCP), suspended deck, bottom liner, wall liner, and the roof liner 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 DEP.

6.2 INNER TANK

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

2. 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 (Appendix F).
 - c. Sliding shall not be permitted under the OBE and a minimum factor of safety of 1.5 shall be provided against sliding.
3. Maximum allowable stresses for the inner tank design for SSE conditions shall be in accordance with NFPA 59A 2009 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 (Appendix F).
 - c. Sliding shall not be permitted under the SSE and a minimum factor of safety of 1.0 shall be provided against sliding.
4. Shell and bottom annular plates shall be butt welded. Welding of the inner tank bottom annular plates shall comply with API 620, §Q.5.1.1. Shell to annular plate welds shall conform to API 620, §5.9.5 and §Q 7.1.1 requirements.
5. All permanent and temporary structural attachments welded directly to the 9 % nickel steel shall be of the same material as that to which they are welded.
6. Minimum plate thickness shall be in accordance with API 620.
7. Anchorage of the inner tank is not permitted under the seismic event(s); tank aspect ratio shall be modified accordingly and/or isolators introduced.
8. Attachments, including circumferential stiffeners, shall be welded with continuous fillets on all sides.
9. Stud-welded attachments shall not be used.
10. Structural attachments or appurtenances shall be located no closer than 150 mm 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, Appendix Q and Appendix R).

6.3 LINERS (VAPOUR BARRIER)

6.3.1 Bottom liner

1. 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.

6.3.2 Wall liner

1. A vapour tight metallic wall liner shall be connected to the bottom liner; the TCP embed plate and the roof liner. The wall liner above and below the TCP embed may fail in the case of the abnormal inner tank spill.
2. The wall liner shall be attached to embedded continuous strip anchors which are flush with the inside of the outer tank wall. The wall liner minimum thickness shall be 5 mm (0.2 in) unless the Contractor can demonstrate that the embedded anchor detail and welding processes are adequate to control weld heat induced plate distortion and justify a 3 mm (0.12 in) plate. Corner 'pad plate' embedments are not permitted under any circumstances for the attachment of the vapour barrier to the wall.

3. Alternatively, the wall liner shall be of butt welded construction connected to the concrete through shear studs. In this instance, no 'offsetting' of reinforcement shall be permitted when designing the concrete wall.
4. Irrespective of the vapour barrier type the wall liner and embedment materials shall have a design temperature of -20°C (-4°F) with materials in accordance with API 620, Table R-4 (or equivalent).
5. The wall liner and embedments shall be designed for the stresses and strains resulting from construction including, but not limited to, concreting operations, pre-stress loads, creep and shrinkage, temperature induced affects, internal pressure and insulation pressure loads, etc., and geometrical tolerances.
6. Where continuous strips are adopted, the Contractor shall specify the tolerance of the strips to which the liner plates are welded and the liner designed accordingly. The Contractor shall also specify the permissible void tolerance post welding of the liner to embedded anchors.

6.3.3 Roof liner

1. A vapour tight 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.
2. 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 the Contractor appropriate to the use and design considerations of the framing. Acceptable materials shall be selected from API 620, Table R-4 or equivalent.
3. The Contractor shall submit methodology for stress analysis and shear studs distribution on the roof.

6.4 SUSPENDED DECK

1. The suspended deck shall be a flat plate deck; trough decks shall not be permitted. Open vents shall be provided to ensure equilibrium of gas pressure on both sides of the suspended deck.
2. Piping penetrations through the suspended deck shall be provided with sleeves, which permit thermal movement of the suspended deck without applying load to the pipes for all load cases (including seismic).
3. The minimum plate thickness and design temperature of the deck shall be 5 mm (0.2 in) and -170°C (-274°F), respectively.
4. The suspended deck and suspension system shall be designed for the following loads.
 - a. Differential pressure produced during tank relief valve operation.
 - b. Dead loads from insulation.
 - c. Operating and dead loads from internal nozzles and platforms (if supported by the deck).
 - d. Seismic loads. The deck shall be designed to accommodate seismic induced displacements.
 - e. Construction loads including loads from people and stacking of materials.
5. The suspended deck shall be designed for a minimum live load of 0.5 kN/m^2 , or a concentrated live load of 1.5 kN at any place, or any higher load, if required for erection purposes. Walkways, where supported from the suspended deck, shall be subjected to the same loading.
6. Vents shall be provided in the suspended deck to equalise any pressure difference above and below the deck during normal and upset conditions (including roll over).

7. To enable entry into the inner tank, a removable cover to serve as an access hatch shall be installed. A deck walkway shall be provided from the outer tank roof manhole to the access hatch facilitating access to internal tank stairway.
8. The deck shall be designed for any one hanger becoming ineffective.
9. The deck shall be designed to accommodate seismic induced displacements.

6.5 SECONDARY BOTTOM AND THERMAL CORNER PROTECTION (TCP)

1. 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.
 - a. The secondary bottom shall be placed on top of the bottom insulation system.
 - b. The secondary bottom shall extend into the annular space and shall connect to the TCP.
 - c. The TCP consists of vertical shield plates with a top horizontal stub connecting to a vapour tight flush anchor plate.
2. The anchor plate is embedded in the concrete wall with anchors located on the back side of the flush anchor plate. The anchors shall control deformations of anchor plate during a spill to prevent the gap between the anchor plate and concrete exceeding the allowable crack widths shown in (5.4.4) and a possibility of cold liquid penetration behind the anchor plate.
3. The anchor plate shall extend a minimum of 300 mm (1 ft) below the attachment of the horizontal stub.
4. The connection of the annular plates to the vertical shield plates of TCP shall be made with a partial or full penetration corner weld with fillet weld.
5. Weld seams in the 9 % Ni steel thermal corner protection wall shall be complete penetration butt-welded. For vertical shield plates, single side welding is permitted with backing bars.
6. Weld seams shall be as follows:
 - a. All horizontal and vertical weld seams in the thermal corner protection sidewall shall be butt-welded.
 - b. Radial seams of bottom annular plates shall be butt-welded (backing strips may be used). At the corners, full penetration or fillet welds may be used.
 - c. Radial seams of the TCP horizontal 'stub' shall be full penetration without backing strips. The underside inside edge shall be ground flush to allow proper fit-up of the vertical shield plates for welding.
 - d. Bottom plates for the secondary tank bottom shall have a minimum of 2 pass fillet welds on the topside.
7. Width of 9 % Ni secondary annular plate shall extend inwards to overlap any gap between the concrete ring beam and the load bearing insulation. The Contractor shall investigate the need to increase the thickness of the 9 % Ni secondary annular plate to prevent weld distortion.
8. The 9 % Ni corner protection shall be designed for the loads encountered during the following scenario:
 - a. Normal conditions
 - b. Minor LNG spill into the annular space.
 - c. Major LNG spill into the annular space of the tank.
9. Contraction and expansion of the 9 % nickel plate due to inner tank leakage shall be accounted for.

10. The thermal corner protection embedment shall be designed to resist differential movement cycles in relation to internal and external temperature variations as well as pre-stressing, creep, shrinkage of concrete, and all loading occurring during the life of the tank. ASME Section VIII Div.2 shall be used for the thermal corner protection design areas which API 620 does not deal with.
11. The Contractor shall submit during tender phase its preliminary design of the thermal corner protection system as well as a description of the method of calculation, which will be carried out during the detailed design.

6.6 TANK INTERNAL AND EXTERNAL PIPING

6.6.1 General

1. The internal piping and roof nozzles shown on the P&IDs shall be designed and supplied by the Contractor. External piping shall be installed and properly supported/guided.
2. Tank mounted internal and external piping shall be designed in accordance with standard ASME B 31.3 and comply with DEP 31.38.01.11-Gen.
3. External flanges up to and including 600 mm (NPS 24) shall conform to ASME B16.5. Flanges larger than 600 mm (NPS 24) shall conform to ASME B16.47, and the design shall satisfy the requirements of API 620, §5.20.2 Roof Nozzles.
4. The Contractor shall determine the final detailed location of all internals and nozzles.
5. All piping to the inner tank shall be through the tank roof. Penetrations through the outer and inner tank wall and bottoms are not permitted.
6. All roof nozzles shall have vertical axes, with the flange boltholes straddling the north-south centreline of the nozzle and shall be designed in accordance with ASME B31.3.
7. Primary flanged connections shall be of either the welding neck or long welding neck type.
8. All roof penetrations for cold process nozzles shall be designed with stainless steel insulated sleeves for thermal breaks between the cold line temperature and the carbon steel roof liner and concrete roof. The sleeves shall be designed to be ice and condensation free for 95 % of the time. Design parameters shall be as per (9.3.10) with minimal condensation permitted outside these ranges under extreme climatic conditions.

6.6.2 Pump wells

1. The tank shall be equipped with pump wells each having a foot valve and filter box. Refer to Tank Data Sheet(s) for number of pump wells. The pump, pump wells, and foot valves shall be supplied and installed by the Contractor.
2. The pump wells shall be supported from the concrete tank roof and guided from the inner tank bottom.
 - a. Fixed anchorage from the tank bottom is not permitted.
 - b. The guide system must provide for differential movement of the pump column (well) inside the tank relative to its support point on the tank roof.
 - c. A filter box shall be made around the bottom guide to avoid debris entering the pump wells, in accordance with the pump Manufacturer's requirements.
 - d. The filter box shall be removable, to allow for hand check of pump shaft rotation before commissioning.
3. The minimum clearance between the underside of the foot-valve (in the open position) and tank bottom plate shall be as recommended by the pump Supplier and not less than 100 mm (4 in) in the warm condition.

4. The pump wells shall be sized and fabricated in accordance with the pump Manufacturer's requirements and designed for full vacuum conditions.
 - a. A vibration analysis for the pump wells shall be carried out.
 - b. The design of the pump wells, including the location of guides, shall be such that the natural frequency of the well is at least 20 % away from the harmonic operating speed.
 - c. The Contractor shall ensure that the design of the pump wells including vibration analysis is verified by the pump Supplier.
5. Pump well inside weld joints shall be flush. Welding backing rings on the inside are not permitted. Pump well construction tolerance shall be confirmed using a dummy pump supplied by the pump Supplier after installation of the pump wells.
6. The pump well dimensions including the elevations of the foot valve and the top flange shall be coordinated with the pump Supplier.
7. The pump wells and the supports shall be designed for buoyancy effects for the event in which the pump well is empty and the tank is full.
8. The pump well supports and guiding systems shall be designed for OBE and SSE design loads with the pump well full and the tank product level at both the Min.NOLL and Max.NOLL.
9. The pump wells shall be hydrostatically tested per (16.3).

6.6.3 Liquid inlets

1. All tanks shall comprise a top liquid inlet. The top fill line shall be furnished with an inclined deflector plate at the underside and be designed against horizontal forces and vibrations. The deflector plate shall be radially aligned so that flow is directly towards the tank centre.
2. Liquid inlets with roof nozzles for top and bottom filling shall be provided as per the P&ID. The top fill line shall be furnished with an inclined deflector plate at the underside and be designed against horizontal forces and vibrations.
3. The bottom fill line shall direct liquid flow over a cone and into a standpipe such that the LNG runs down the inside wall of the standpipe. The cone shall be equipped with a vapour release pipe to permit vapour entrained in liquid in the standpipe to pass into the tank vapour space.
4. A distributor shall be provided in the bottom of the standpipe with 10 slots 20° apart, directed radially outward and located on the side of the standpipe nearest the centre of the tank. The standpipe shall be self-venting at design flow rate, and be located such that it is not possible for entrained liquid in the flash vapour to pass to the tank vapour outlet.
5. Both top and bottom inlet systems should remain fully operational while the tank is filled up to its normal maximum operating level. Any exception to that principle should be justified.

6.6.4 Vapour outlets

1. No liquid entrainment shall be allowed in the vapour outlets or relief valve outlets under any circumstances.
2. The vapour outlets shall be positioned away from the deflector plate of the liquid inlet.
3. The underside of the nozzles of the relief valves shall be a minimum of 500 mm (20 in) above MDLL.

6.6.5 Cool-down line

1. The cool-down line with spray nozzles shall be designed for cool-down rates, specified in this DEP and in accordance with the Contractor's cool-down procedure.