Concrete LNG terminal structures and containment systems
FOREWORD

DNV GL standards contain requirements, principles and acceptance criteria for objects, personnel, organisations and/or operations.

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Any comments may be sent by e-mail to rules@dnvgl.com

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CHANGES – CURRENT

General

This document supersedes the October 2010 edition of DNV-OS-C503. The purpose of the revision of this service document is to comply with the new DNV GL document reference code system and profile requirements following the merger between DNV and GL in 2013. Changes mainly consist of updated company name and references to other documents within the DNV GL portfolio.

Some references in this service document may refer to documents in the DNV GL portfolio not yet published (planned published within 2017). In such cases please see the relevant legacy DNV or GL document. References to external documents (non-DNV GL) have not been updated.

Editorial corrections

In addition to the above stated changes, editorial corrections may have been made.
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SECTION 1 INTRODUCTION

1.1 General

1.1.1 Introduction

1.1.1.1 This standard provides principles, technical requirements and guidelines for the design, construction and in service inspection of LNG export/import concrete terminal structures and containment systems. The terminal structures may be a floating or gravity based structure.

1.1.1.2 The standard covers the design of the concrete structure supporting the LNG tanks of different storage types and identifies different hazards of importance for the design of the concrete structure from such storage.

1.1.1.3 The standard shall be used together with the DNV GL standard DNVGL-ST-C502 Offshore concrete structures.

1.1.1.4 Design of the LNG Containment system may be designed either in accordance with the DNV GL rules for classification of ships DNVGL-RU-SHIP Pt.5 Ch.7 Liquified gas tankers or relevant standards for the design of the containment system.

Special considerations are required for the application of above standards in an offshore terminal structure.

1.1.1.5 Guidelines for the design of containment systems based on traditional structures on land are given in App.A to App.D.

1.1.1.6 LNG containment structures on land are generally designed using a double barrier system. Prestressed concrete can be used both as primary and secondary barrier with provision of a gas tight barrier. This barrier may be of carbon steel if located on the inner surface of the secondary barrier.

1.1.1.7 A carbon steel membrane may also be required for LNG terminals using concrete as secondary barrier in order to protect the insulation from external humidity caused by the mitigation of moisture through the concrete secondary barrier.

1.1.1.8 The insulation shall also be protected against all forms of humidity caused by condensation of water on the cold surfaces.

1.1.1.9 Floating LNG import/export terminals structures should be designed with freeboard and intact stability in accordance with DNVGL-OS-C301 Stability and watertight integrity. For temporary phases the stability should be in accordance with DNVGL-ST-N001 Marine operations and marine warranty.

1.1.2 Objective

1.1.2.1 The objectives of this standard are to:

— provide an international standard for the design, construction and in-service inspection of offshore concrete terminal structures with an acceptable level of safety by defining minimum requirements for design, construction control and in-service inspection
— serve as a contractual reference document between supplier and purchasers related to design, construction and in-service inspection
— serve as a guideline for designer, supplier, purchasers and regulators.
1.1.3 Scope and applications

1.1.3.1 The standard is applicable to LNG export and import terminal structures using concrete as the structural material in the support structure as defined in [1.1.3.2] and [1.1.3.3] below.

1.1.3.2 LNG export terminal structures
LNG export terminals are, by nature, located near the coast and are designed to liquefy the natural gas which will then be loaded onto LNG carriers. An LNG export terminal generally includes:
— an incoming natural gas metering and receiving station, including in the case of a two phase incoming pipeline, a slug catcher
— condensate stabilisation and storage
— gas treatment units in which any acid gases, water, heavier hydrocarbons and, if appropriate, mercury which might be present in the incoming gas are extracted
— liquefaction units which produce LNG and within which, ethane, propane, commercial butane, heavier hydrocarbons and nitrogen can be extracted. A proportion of the extracted hydrocarbons can be used as refrigerant make up. A liquefaction unit uses very specific equipment such as cryogenic spool-wound or brazed plate-fin exchangers and high-powered turbo compression units. Two refrigerant cycles in cascade are usually employed
— LNG storage tanks and the relevant loading plants for filling LNG carriers
— generation and/or purchase and distribution of the utilities necessary for the plant to operate (electricity, steam, cooling water, compressed air, nitrogen, fuel gas etc.)
— general off-site installations, (gas and liquid flare systems, effluent treatment, fire fighting systems etc.).

Most of the gas treating steps can be commonly found in gas treatment plant for the production of sales gas. e.g. acid gas removal, dehydration, hydrocarbon dew point and liquid natural gas (LNG) recovery.

1.1.3.3 LNG import terminals
LNG import terminals are designed to receive LNG from LNG carriers, to unload, store and convert it into the gaseous phase for sending it out to the gas network or gas consumers.
Thus an LNG receiving terminal provides several essential functions which are:
— unloading
— storage
— LNG recovery and pressurising
— vaporising
— gas quality adjustment.

1.1.3.4 App.A - App.D are appended to the standard. These appendices contain guidelines for the design of terminals in accordance with approach for land LNG terminal structures in accordance with the approach used for the design of land LNG terminal structures modified with the environmental condition of an offshore terminal.

1.1.3.5 The standard is combining the design and construction experience from the fixed/floating offshore structures DNVGL-ST-C502 Offshore concrete structures, DNVGL-RU-SHIP Pt.5 Ch.7 Liquefied gas tankers, IMO - IGC Code The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk and the experience from design and construction of land based storage tank for LNG as presented in EN-1473 and NFPA 59A.

1.1.3.6 For the detailed design of primary steel containment tanks reference is made to DNVGL-RU-SHIP Pt.5 Ch.7 Liquefied gas tankers, IGC- IMO Code, EN-1473 and NFPA 59A.
See App.C General design principles LNG containment structures and App.D Detailed structural design of containment system for guidelines for the design of the primary steel containment tanks in accordance with conventional tanks at land. The environmental impact on offshore terminals are included in these guidelines.
1.1.3.7 On ships, the IGC-IMO type B independent tanks are widely used. These tanks are designed, constructed and inspected in accordance with the requirements in the IGC - IMO Code. *DNVGL-RU-SHIP Pt.5 Ch.7 Liquefied gas tankers* gives detailed requirements for the design of Independent tanks Type B. Site specific data shall be considered in the design of terminal structures and containment systems.

1.1.3.8 The development and design of new concepts for LNG terminals requires a systematic hazard identification process in order to mitigate the risk to an acceptable risk level. Hazard identification is therefore a central tool in this standard in order to identify hazards and mitigate these to an acceptable risk level.

1.1.4 Non DNV GL codes and standards

1.1.4.1 In case of conflict between the requirements of this standard and a reference document other than DNV GL standard, the requirement of this standard shall prevail. Non-DNV GL codes or standards may be used provided the same safety level as provided by this DNV GL standard, is obtained.

1.1.4.2 Where reference is made to non-DNV GL codes, the valid revision shall be taken as the revision which is current at the date of issue of this standard, unless otherwise noted.

1.1.4.3 In addition to the requirements mentioned in this standard, it is also the responsibility of the designer, owner and operator to comply with additional requirements that may be imposed by the flag state or the coastal state or any other jurisdictions in the intended area of deployment and operation.

1.1.5 Classification

1.1.5.1 Classification principles, procedures and application class notations related to classification services of offshore units are specified in the DNV GL rules for classification documents given in Table 1-1.

Table 1-1 DNV GL rules for classification of offshore units documents

<table>
<thead>
<tr>
<th>Document code</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNVGL-RU-OU-0101</td>
<td>Offshore drilling and support units</td>
</tr>
<tr>
<td>DNVGL-RU-OU-0102</td>
<td>Floating production, storage and loading units</td>
</tr>
<tr>
<td>DNVGL-RU-OU-0103</td>
<td>Floating LNG/LPG production, storage and loading units</td>
</tr>
</tbody>
</table>

1.2 References

1.2.1 General

1.2.1.1 The DNV GL documents in Table 1-2 and Table 1-3 and recognised codes and standards in Table 1-4 are referred to in this standard.

1.2.1.2 The latest valid revision of the DNV GL reference documents in Table 1-2 and Table 1-3 applies. These include acceptable methods for fulfilling the requirements in this standard. See also current DNV GL list of publications.
1.2.1.3 Other recognised codes or standards may be applied provided it is shown that they meet or exceed the level of safety of the actual DNV GL offshore standard (DNVGL-OS) or the actual DNV GL standard (DNVGL-ST).

Table 1-2 DNV GL reference documents

<table>
<thead>
<tr>
<th>Document code</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNVGL-RU-SHIP Pt.5 Ch.7</td>
<td>Rules for classification of ships Pt.5 Ship types, Ch.7Liquified gas tankers</td>
</tr>
<tr>
<td>DNVGL-ST-N001</td>
<td>Marine operations and marine warranty</td>
</tr>
<tr>
<td>DNVGL-OS-A101</td>
<td>Safety principles and arrangements</td>
</tr>
<tr>
<td>DNVGL-OS-B101</td>
<td>Metallic materials</td>
</tr>
<tr>
<td>DNVGL-OS-C401</td>
<td>Fabrication and testing of offshore structures</td>
</tr>
<tr>
<td>DNVGL-OS-E301</td>
<td>Position mooring</td>
</tr>
<tr>
<td>DNVGL-RP-C201</td>
<td>Buckling strength of plated structures</td>
</tr>
<tr>
<td>DNVGL-RP-C202</td>
<td>Buckling strength of shells</td>
</tr>
<tr>
<td>DNVGL-RP-C203</td>
<td>Fatigue strength analysis of offshore steel structures</td>
</tr>
<tr>
<td>DNVGL-RP-C205</td>
<td>Environmental conditions and environmental loads</td>
</tr>
<tr>
<td>DNVGL-RP-E301</td>
<td>Design and installation of fluke anchors</td>
</tr>
<tr>
<td>DNVGL-RP-E302</td>
<td>Design and installation of plate anchors in clay</td>
</tr>
<tr>
<td>DNVGL-CG-0128</td>
<td>Buckling (former DNV Classification Note 30.1)</td>
</tr>
<tr>
<td>DNVGL-RP-C212</td>
<td>Offshore soil mechanics and geotechnical engineering (former DNV Classification Note 30.4)</td>
</tr>
<tr>
<td>DNVGL-RP-C211</td>
<td>Structural reliability analysis (former DNV Classification Note 30.6)</td>
</tr>
<tr>
<td>DNVGL-CG-0129</td>
<td>Fatigue assessments of ship structures (former DNV Classification Note 30.7)</td>
</tr>
</tbody>
</table>

Table 1-3 DNV GL offshore standards (DNVGL-OS) and DNV GL standards (DNVGL-ST)

<table>
<thead>
<tr>
<th>Document code</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNVGL-OS-C101</td>
<td>Design of offshore steel structures, general - LRFD method</td>
</tr>
<tr>
<td>DNVGL-OS-C102</td>
<td>Structural design of offshore ships</td>
</tr>
<tr>
<td>DNVGL-OS-C103</td>
<td>Structural design of column stabilised units - LRFD method</td>
</tr>
<tr>
<td>DNVGL-OS-C104</td>
<td>Structural design of self-elevating units - LRFD method</td>
</tr>
<tr>
<td>DNVGL-OS-C105</td>
<td>Structural design of TLPs - LRFD method</td>
</tr>
<tr>
<td>DNVGL-OS-C106</td>
<td>Structural design of deep draught floating units - LRFD method</td>
</tr>
<tr>
<td>DNVGL-OS-C502</td>
<td>Offshore concrete structures</td>
</tr>
</tbody>
</table>
### Table 1-4 Other references

<table>
<thead>
<tr>
<th>Document code</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGC-IMO Code</td>
<td>International Code for the Construction and Equipment of Ships Carrying Liquified Gases in Bulk</td>
</tr>
<tr>
<td>EN 1473</td>
<td>Installation and Equipment for Liquified Natural Gas. Design of Onshore Installations.</td>
</tr>
<tr>
<td>NFPA 59A</td>
<td>A Standard for Production, Storage and Handling of Liquified Natural Gas.</td>
</tr>
<tr>
<td>ISO 13819-1</td>
<td>Petroleum and natural gas industries – Offshore structures – Part 1: General requirements</td>
</tr>
<tr>
<td>NORSOK</td>
<td>N-003 Actions and Action Effects</td>
</tr>
<tr>
<td>NORSOK</td>
<td>N-004 Design of Steel Structures</td>
</tr>
</tbody>
</table>

### 1.3 Definitions

#### 1.3.1 Verbal forms

**Table 1-5 Definitions of verbal forms**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>shall</td>
<td>indicates a mandatory requirement to be followed for fulfilment or compliance with the present standard. Deviations are not permitted unless formally and rigorously justified, and accepted by all relevant contracting parties</td>
</tr>
<tr>
<td>should</td>
<td>indicates a recommendation that a certain course of action is preferred or particularly suitable. Alternative courses of action are allowable under the standard where agreed between contracting parties but shall be justified and documented</td>
</tr>
<tr>
<td>may</td>
<td>indicates a permission, or an option, which is permitted as part of conformance with the standard</td>
</tr>
</tbody>
</table>

#### 1.3.2 Terms

**Table 1-6 Definitions of terms**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>accidental limit states (ALS)</td>
<td>ensures that the structure resists accidental loads and maintain integrity and performance of the structure due to local damage or flooding</td>
</tr>
<tr>
<td>accidental loads</td>
<td>rare occurrences of extreme environmental loads, fire, flooding, explosions, dropped objects, collisions, unintended pressure differences, leakage of LNG etc.</td>
</tr>
<tr>
<td>air gap</td>
<td>free distance between the 100 year design wave and the underside of a topside structure supported on column supports allowing the wave to pass under the topside structure. When air gap is sufficiently large, then no wave pressure is applied to the topside structure</td>
</tr>
<tr>
<td><strong>Term</strong></td>
<td><strong>Definition</strong></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>as-built documentation</td>
<td>documentation of the offshore terminal as finally constructed. Includes design basis/design brief documents, updated designed calculations, updated construction drawings, construction records and approved deviations reports</td>
</tr>
<tr>
<td>atmospheric zone</td>
<td>the external surfaces of the unit above the splash zone</td>
</tr>
<tr>
<td>cathodic protection</td>
<td>a technique to prevent corrosion of a steel surface by making the surface to be the cathode of an electrochemical cell</td>
</tr>
<tr>
<td>characteristic load</td>
<td>the reference value of a load to be used in the determination of load effects The characteristic load is normally based upon a defined fractile in the upper end of the distribution function for load.</td>
</tr>
<tr>
<td>characteristic resistance</td>
<td>the reference value of structural strength to be used in the determination of the design strength The characteristic resistance is normally based upon a 5% fractile in the lower end of the distribution function for resistance</td>
</tr>
<tr>
<td>characteristic material strength</td>
<td>the nominal value of material strength to be used in the determination of the design resistance The characteristic material strength is normally based upon a 5% fractile in the lower end of the distribution function for material strength.</td>
</tr>
<tr>
<td>characteristic value</td>
<td>the representative value associated with a prescribed probability of not being unfavourably exceeded during some reference period</td>
</tr>
<tr>
<td>coating</td>
<td>metallic, inorganic or organic material applied to steel surfaces for prevention of corrosion</td>
</tr>
<tr>
<td>concrete grade</td>
<td>a parameter used to define the concrete strength. Concrete Grade for different characteristic values of concrete strength is provided in Table 6-2</td>
</tr>
<tr>
<td>corrosion allowance</td>
<td>extra wall thickness added during design to compensate for any anticipated reduction in thickness during the operation</td>
</tr>
<tr>
<td>cryogenic concrete tank</td>
<td>a cryogenic concrete tank is either a double containment tank or a full containment tank. For this type of tanks, the walls of the primary and secondary containers are both of prestressed concrete</td>
</tr>
<tr>
<td>cryogenic temperature</td>
<td>the temperature of the stored LNG</td>
</tr>
<tr>
<td>deformation loads</td>
<td>loads effects on the Terminal caused by thermal effects, prestressing effects, creep/shrinkage effects, differential settlements/deformations etc.</td>
</tr>
<tr>
<td>design brief</td>
<td>an agreed document where owners requirements in excess of this standard should be given</td>
</tr>
<tr>
<td>design temperature</td>
<td>the design temperature for a unit is the reference temperature for assessing areas where the unit can be transported, installed and operated The design temperature shall be lower or equal to the lowest daily mean temperature in air for the relevant areas. For seasonal restricted operations the lowest daily mean temperature in air for the season may be applied. The cargo temperature shall be taken into account in the determination of the structural temperature.</td>
</tr>
<tr>
<td>design value</td>
<td>the value to be used in the deterministic design procedure, i.e. characteristic value modified by the resistance factor or load factor</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>double containment tanks</td>
<td>a double containment tank is designed and constructed so that both the inner self-supporting primary container and the secondary container are capable of independently containing the refrigerated liquid stored</td>
</tr>
<tr>
<td>driving voltage</td>
<td>the difference between closed circuit anode potential and the protection potential</td>
</tr>
<tr>
<td>ductility</td>
<td>the property of a steel or concrete member to sustain large deformations without failure</td>
</tr>
<tr>
<td>ductility level earthquake (DLE)</td>
<td>the ductility level earthquake is defined probabilistically as an earthquake producing ground motion with a mean recurrence as a minimum of 10000 years</td>
</tr>
<tr>
<td>environmental loads</td>
<td>loads from wind, wave, tide, current, snow, ice and earthquake</td>
</tr>
<tr>
<td>expected loads and response history</td>
<td>expected load and response history for a specified time period, taking into account the number of load cycles and the resulting load levels and response for each cycle</td>
</tr>
<tr>
<td>expected value</td>
<td>the most probable value of a load during a specified time period</td>
</tr>
<tr>
<td>fatigue</td>
<td>degradation of the material caused by cyclic loading</td>
</tr>
<tr>
<td>fatigue critical</td>
<td>structure with calculated fatigue life near the design fatigue life</td>
</tr>
<tr>
<td>fatigue limit states (FLS)</td>
<td>related to the possibility of failure due to the effect of cyclic loading</td>
</tr>
<tr>
<td>full containment tank</td>
<td>a tank designed and constructed so that both the primary container and the secondary container are capable of independently containing the refrigerated liquid stored and one of them its vapour</td>
</tr>
<tr>
<td>functional loads</td>
<td>permanent and variable loads, except environmental loads, to which the structure can be exposed</td>
</tr>
<tr>
<td>hindcasting</td>
<td>a method using registered meteorological data to reproduce environmental parameters. Mostly used for reproducing wave parameters</td>
</tr>
<tr>
<td>IGC-IMO type B independent tank</td>
<td>LNG containment tank designed, fabricated, maintained and inspected in accordance with the requirements for such tanks in IGC-IMO rules</td>
</tr>
<tr>
<td></td>
<td>The design is based on the principle of detection of small quantities of LNG prior to failure of the steel support structure.</td>
</tr>
<tr>
<td>inspection</td>
<td>activities such as measuring, examination, testing, gauging one or more characteristics of an object or service and comparing the results with specified requirements to determine conformity</td>
</tr>
<tr>
<td>limit state</td>
<td>a state beyond which the structure no longer satisfies the requirements. The following categories of limit states are of relevance for structures:</td>
</tr>
<tr>
<td></td>
<td>─ ULS = ultimate limit states</td>
</tr>
<tr>
<td></td>
<td>─ FLS = fatigue limit states</td>
</tr>
<tr>
<td></td>
<td>─ ALS = accidental limit states</td>
</tr>
<tr>
<td></td>
<td>─ SLS = serviceability limit states</td>
</tr>
<tr>
<td>limit state design</td>
<td>design of the Terminal in the limit states of ULS, SLS, FLS and ALS</td>
</tr>
<tr>
<td>LNG containment system</td>
<td>the primary and secondary barrier, insulations, safety devices etc. ensuring the safe storage, handling and operation of the offshore LNG terminal</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>load and resistance factor design (LRFD)</td>
<td>method for design where uncertainties in loads are represented with a load factor and uncertainties in resistance are represented with a material factor</td>
</tr>
<tr>
<td>load effect</td>
<td>effect of a single design load or combination of loads on the equipment or system, such as stress, strain, deformation, displacement, motion, etc.</td>
</tr>
<tr>
<td>lowest daily mean temperature</td>
<td>the lowest value on the annual mean daily average temperature curve for the area in question. For temporary phases or restricted operations, the lowest daily mean temperature may be defined for specific seasons. Mean daily average temperature: the statistical mean average temperature for a specific calendar day. Average: average during one day and night.</td>
</tr>
<tr>
<td>lowest waterline</td>
<td>typical light ballast waterline for ships, transit waterline or inspection waterline for other types of units</td>
</tr>
<tr>
<td>membrane tank</td>
<td>the membrane tank consists of thin (barriers) of either stainless steel, GRP/aluminium foil composite, or invar that are supported through the insulation by the boundary structure of the cargo tank itself</td>
</tr>
<tr>
<td>object standard</td>
<td>the standards listed in Table 1-3</td>
</tr>
<tr>
<td>DNV GL offshore standard (DNVGL-OS)</td>
<td>contains technical requirements, principles and acceptance criteria related to classification of offshore units</td>
</tr>
<tr>
<td>DNV GL standard (DNVGL-ST)</td>
<td>contains requirements, principles and acceptance criteria for objects, personnel, organisations and/or operations</td>
</tr>
<tr>
<td>DNV GL class guideline (DNVGL-CG)</td>
<td>contains methods, technical requirements, principles and acceptance criteria related to classed objects as referred to from rules</td>
</tr>
<tr>
<td>DNV GL rules for classification (DNVGL-RU)</td>
<td>contains procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the Society as basis for classification</td>
</tr>
<tr>
<td><strong>Term</strong></td>
<td><strong>Definition</strong></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>permanent functional loads</td>
<td>self-weight, ballast weight, weight of permanent installed part of mechanical outfitting, external hydrostatic pressure, prestressing force etc.</td>
</tr>
<tr>
<td>primary tanks</td>
<td>the function of the primary tank is to contain the refrigerated liquid (LNG) under normal operation of the terminal</td>
</tr>
</tbody>
</table>
| quality plan                         | a plan implemented to ensure quality in the design, construction and in-service inspection/maintenance
An interface manual shall be developed defining all interfaces between the various parties and disciplines involved to ensure that the responsibilities, reporting routines and information routines are established. |
| recommended practice (DNVGL-RP)     | contains sound engineering practice and guidance                                                                                                                                                              |
| robustness                           | a robust structure is a structure with low sensitivity to local changes in geometry and loads                                                                                                               |
| redundancy                           | the ability of a component or system to maintain or restore its function when a failure of a member or connection has occurred
Redundancy may be achieved for instance by strengthening or introducing alternative load paths.                                                                                                               |
| reliability                          | the ability of a component or a system to perform its required function without failure during a specified time interval                                                                                      |
| risk                                 | the qualitative or quantitative likelihood of an accidental or unplanned event occurring considered in conjunction with the potential consequences of such a failure. In quantitative terms, risk is the quantified probability of a defined failure mode times its quantified consequence |
| secondary tanks                      | the secondary tanks shall contain the refrigerated liquid (LNG) if there is a failure in the primary containment system
The secondary tank shall be designed capable of containing the leaked contents for an agreed period of time consistent with the approval scenarios for safe disposal of the same. |
| service temperature                  | service temperature is a reference temperature on various structural parts of the unit used as a criterion for the selection of steel grades or design for crackwidth etc. in SLS                                                                                 |
| serviceability limit states (SLS)    | corresponding to the criteria applicable to normal use or durability                                                                                                                                             |
| slamming                             | impact load on an approximately horizontal member from a rising water surface as a wave passes
The direction of the impact load is mainly vertical. Slamming can also occur within the LNG tanks due to LNG.                                                                                            |
<p>| specified minimum yield strength (SMYS) | the minimum yield strength prescribed by the specification or standard under which the material is purchased                                                                                               |
| specified value                      | minimum or maximum value during the period considered. This value may take into account operational requirements, limitations and measures taken such that the required safety level is obtained |</p>
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
</table>
| splash zone                               | the external surfaces of the unit that are periodically in and out of the water  
The determination of the splash zone includes evaluation of all relevant effects  including influence of waves, tidal variations, settlements, subsidence and vertical  motions.                                                      |
| stability                                  | the ability of the floating structure to remain upright and floating when exposed to  
small changes in applied loads  
The ability of a structural member to carry small additional loads without buckling.                                                                                                                   |
| strength level earthquake (SLE)            | the strength level earthquake is defined probabilistically as an earthquake  
producing ground motion with a mean recurrence at a minimum interval of 100 years                                                        |
| submerged zone                             | the part of the unit which is below the splash zone, including buried parts                                                                                                                                  |
| survival condition                         | a condition during which a unit may be subjected to the most severe  
environmental loadings for which the unit is designed  
Drilling or similar operations may have been discontinued due to the severity of  
the environmental loadings. The unit may be either afloat or supported on the sea  
bed, as applicable.                                                                                                 |
| target safety level                        | a nominal acceptable probability of structural failure                                                                                                                                                    |
| temporary conditions                       | design conditions not covered by operating conditions, e.g. conditions during  
fabrication, mating and installation phases, transit phases, accidental                                                          |
| temporary phases                           | construction, mating, transit/towing and installation phases                                                                                                                                              |
| tensile strength                           | minimum stress level where strain hardening is at maximum or at rupture for  
steel. For concrete it is the direct tensile strength of concrete                                                                                                                                   |
| transit conditions                         | all unit movements from one geographical location to another                                                                                                                                           |
| unit                                       | is a general term for an offshore installation such as ship shaped, column  
stabilised, self-elevating, tension leg or deep draught floater                                                                                                                                         |
| utilisation factor                         | the fraction of anode material that can be utilised for design purposes  
For design of terminal structures, the utilisation factor also means the ratio of  
used strength to failure strength of concrete, reinforcement or prestressing steel.                                                                                                                  |
| variable functional loads                  | weight and loads caused by the normal operation of the terminal  
Variable functional loads may vary in position, magnitude and direction during  
the operational period and includes modules, gas weight, stored goods, pressure  
of stored components, pressures from stored LNG, temperature of LNG, loads  
occurring during installation, operational boat impacts, mooring loads etc.                                                                 |
| verification                               | examination to confirm that an activity, a product or a service is in accordance  
with specified requirements                                                                                                                                                                           |
| ultimate limit states (ULS)                | corresponding to the maximum load carrying resistance                                                                                                                                                      |
1.4 Abbreviations and symbols

1.4.1 Abbreviations

Abbreviations as shown in Table 1-7 are used in this standard.

**Table 1-7 Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISC</td>
<td>American Institute of Steel Construction</td>
</tr>
<tr>
<td>ALS</td>
<td>accidental limit states</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>BS</td>
<td>British Standard (issued by British Standard Institute)</td>
</tr>
<tr>
<td>CN</td>
<td>classification note</td>
</tr>
<tr>
<td>DDF</td>
<td>deep draught floaters</td>
</tr>
<tr>
<td>DFF</td>
<td>design fatigue factor</td>
</tr>
<tr>
<td>DLE</td>
<td>ductility level earthquake</td>
</tr>
<tr>
<td>EN</td>
<td>European Norm</td>
</tr>
<tr>
<td>ETM</td>
<td>event tree method</td>
</tr>
<tr>
<td>ESD</td>
<td>emergency shut down</td>
</tr>
<tr>
<td>FLS</td>
<td>fatigue limit state</td>
</tr>
<tr>
<td>FM</td>
<td>fracture mechanics</td>
</tr>
<tr>
<td>FMEA</td>
<td>failure mode effect analysis</td>
</tr>
<tr>
<td>FTM</td>
<td>fault tree method</td>
</tr>
<tr>
<td>HAT</td>
<td>highest astronomical tide</td>
</tr>
<tr>
<td>HAZOP</td>
<td>hazard and operability study</td>
</tr>
<tr>
<td>HISC</td>
<td>hydrogen induced stress cracking</td>
</tr>
<tr>
<td>HS</td>
<td>high strength</td>
</tr>
<tr>
<td>ID</td>
<td>Infra red detectors</td>
</tr>
<tr>
<td>IGC</td>
<td>international gas carrier</td>
</tr>
<tr>
<td>IMO</td>
<td>international maritime organisation</td>
</tr>
<tr>
<td>ISO</td>
<td>international organisation of standardisation</td>
</tr>
<tr>
<td>LAT</td>
<td>lowest astronomic tide</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquified natural gas</td>
</tr>
<tr>
<td>LRFD</td>
<td>load and resistance factor design</td>
</tr>
<tr>
<td>MPI</td>
<td>magnetic particle inspection</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------------------------------------------</td>
</tr>
<tr>
<td>MSL</td>
<td>mean sea level</td>
</tr>
<tr>
<td>NACE</td>
<td>National Association of Corrosion Engineers</td>
</tr>
<tr>
<td>NDT</td>
<td>non-destructive testing</td>
</tr>
<tr>
<td>NS</td>
<td>Norwegian standard</td>
</tr>
<tr>
<td>PWHT</td>
<td>post weld heat treatment</td>
</tr>
<tr>
<td>QRA</td>
<td>quantitative risk analysis</td>
</tr>
<tr>
<td>RP</td>
<td>recommended practise</td>
</tr>
<tr>
<td>SLS</td>
<td>serviceability limit state</td>
</tr>
<tr>
<td>SLE</td>
<td>strength level earthquake</td>
</tr>
<tr>
<td>SMYS</td>
<td>specified minimum yield stress</td>
</tr>
<tr>
<td>ULS</td>
<td>ultimate limit state</td>
</tr>
<tr>
<td>UV</td>
<td>ultra violet detectors</td>
</tr>
</tbody>
</table>

1.4.2 Symbols

1.4.2.1 Latin characters

A accidental loads
a\textsubscript{v} vertical acceleration
C concrete grade (normal weight concrete)
D deformation load
E environmental load
E\textsubscript{cd} design value of Young’s modulus of concrete used in the stress-strain curve
E\textsubscript{cn} normalized value of Young’s modulus used in the stress-strain curve
E\textsubscript{sd} design value of Young’s modulus of reinforcement
E\textsubscript{sk} characteristic value of Young’s modulus of reinforcement
f\textsubscript{cd} design compressive strength of concrete
f\textsubscript{cn} normalized compressive strength of concrete
f\textsubscript{td} design strength of concrete in uni-axial tension
f\textsubscript{tn} normalized tensile strength of concrete
f\textsubscript{sd} design strength of reinforcement
f\textsubscript{sk} characteristic strength of reinforcement
\( F_d \) design load  
\( F_k \) characteristic load  
\( G \) permanent load  
\( g, g_0 \) acceleration due to gravity  
\( h \) height  
\( M \) moment  
\( n \) number  
\( P \) load  
\( p \) pressure  
\( p_d \) design pressure  
\( Q \) variable functional load  
\( R \) radius  
\( r_c \) radius of curvature  
\( R_d \) design resistance  
\( R_k \) characteristic resistance  
\( S_d \) design load effect  
\( S_k \) characteristic load effect  

### 1.4.2.2 Greek characters

\( \delta \) deflection  
\( \varepsilon \) strain  
\( \gamma_c \) material coefficient concrete  
\( \gamma_l \) load factor  
\( \gamma_M \) material factor (material coefficient)  
\( \gamma_s \) material coefficient reinforcement  
\( \mu \) friction coefficient  
\( \rho \) density  
\( \sigma_d \) design stress  

### 1.4.2.3 Subscripts

\( d \) design value  
\( k \) characteristic value  
\( p \) plastic  
\( y \) yield. 
SECTION 2 SAFETY PHILOSOPHY

2.1 General

2.1.1 Objective

2.1.1.1 The purpose of this section is to present the safety philosophy and corresponding design format applied in this standard.

2.1.1.2 This section applies to offshore concrete LNG terminal structures and containment systems which shall be built in accordance with this standard.

2.1.1.3 This section also provides guidance for extension of this standard in terms of new criteria etc.

2.1.1.4 The integrity of a offshore concrete LNG terminal structures and containment systems designed and constructed in accordance with this standard is ensured through a safety philosophy integrating different parts as illustrated in Figure 2-1.

2.1.1.5 An overall safety objective shall be established, planned and implemented, covering all phases from conceptual development until abandonment.

![Figure 2-1 Safety philosophy structure](image)

2.1.2 Systematic review

2.1.2.1 As far as practical, all work associated with the design, construction and operation of the offshore concrete terminal structure shall be such as to ensure that no single failure will lead to life-threatening situations for any person, or to unacceptable damage to the terminal or the environment.

2.1.2.2 A systematic review or analysis shall be carried out for all phases in order to identify and evaluate the consequences of single failures and series of failures in the offshore concrete terminal, such that necessary remedial measures can be taken. The extent of the review or analysis shall reflect the criticality of the offshore concrete terminal, the criticality of a planned operation, and previous experience with similar systems or operations.
**Guidance note:**

A methodology for such a systematic review is quantitative risk analysis (QRA). This may provide an estimation of the overall risk to human health and safety, environment and assets and comprises:

- hazard identification,
- assessment of probabilities of failure events,
- accident developments, and
- consequence and risk assessment.

It should be noted that legislation in some countries requires risk analysis to be performed, at least at an overall level to identify critical scenarios that might jeopardise the safety and reliability of a Terminal. Other methodologies for identification of potential hazards are failure mode and effect analysis (FMEA) and hazard and operability studies (HAZOP).

---end---of---guidance---note---

### 2.1.3 Safety class methodology

#### 2.1.3.1

The offshore concrete structure is classified into the safety class 3 based on failure consequences. For definition see Table 2-1.

### Table 2-1 Safety classes

<table>
<thead>
<tr>
<th>Class for consequences of failure</th>
<th>Safety class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor seriousness</td>
<td>1</td>
</tr>
<tr>
<td>Serious</td>
<td>2</td>
</tr>
<tr>
<td>Very Serious</td>
<td>3</td>
</tr>
</tbody>
</table>

### 2.1.4 Quality assurance

#### 2.1.4.1

The safety format within this standard requires that gross errors (human errors) shall be controlled by requirements for organisation of the work, competence of persons performing the work, verification of the design, and quality assurance during all relevant phases.

#### 2.1.4.2

For the purpose of this standard, it is assumed that the owner of the offshore concrete LNG terminal has established a quality objective. The owner shall, in both internal and external quality related aspects, seek to achieve the quality level of products and services intended in the quality objective. Further, the owner shall provide assurance that intended quality is being, or will be, achieved.

#### 2.1.4.3

The quality system shall comply with the requirements of ISO 9000 and specific requirements quoted for the various engineering disciplines in this standard.

#### 2.1.4.4

All work performed in accordance with this standard shall be subject to quality control in accordance with an implemented quality plan. The quality plan should be in accordance with the ISO 9000 series. There may be one quality plan covering all activities, or one overall plan with separate plans for the various phases and activities to be performed.

#### 2.1.4.5

The quality plan shall ensure that all responsibilities are defined. An interface manual should be developed that defines all interfaces between the various parties and disciplines involved, and ensure that responsibilities, reporting and information routines as appropriate are established.
2.1.5 Health, safety and environment

2.1.5.1 The objective of this standard is that the design, materials, fabrication, installation, commissioning, operation, repair, re-qualification, and abandonment of the offshore concrete LNG terminal structures and containment systems are safe and conducted with due regard to public safety and the protection of the environment.

2.1.6 Qualifications of personnel

2.1.6.1 All activities that are performed in the design, construction, transportation, inspection and maintenance of offshore structures according to this Standard shall be performed by skilled personnel with the qualifications and experience necessary to meet the objectives of this standard. Qualifications and relevant experience shall be documented for all key personnel and personnel performing tasks that normally require special training or certificates.

2.1.6.2 National provisions on qualifications of personnel such as engineers, operators, welders, divers, etc. in the place of use apply. Additional requirements may be given in the project specification.

2.2 Design format

2.2.1 General

2.2.1.1 The design format within this standard is based upon a limit state and partial safety factor methodology, also called load and resistance factor design format (LRFD). The design principles are specified in DNVGL-OS-C101. The design principle is based on LRFD, but design may additionally be carried out by both testing and probability based design.

The aim of the design of the terminal and its elements are to:
— sustain loads liable to occur during all temporary operating and damaged conditions if required
— maintain acceptable safety for personnel and environment
— have adequate durability against deterioration during the design life of the terminal.

2.2.1.2 The design of a structural system, its components and details shall, as far as possible, account for the following principles:
— resistance against relevant mechanical, physical and chemical deterioration is achieved
— fabrication and construction comply with relevant, recognised techniques and practice
— inspection, maintenance and repair are possible.

2.2.1.3 Structures and elements thereof, shall possess ductile resistance unless the specified purpose requires otherwise.

2.2.1.4 Requirements to materials are given in Sec.4, design of LNG containment systems in Sec.7, loads and methods of analyses Sec.5, detailed design of the terminal structure in Sec.6, Construction in Sec.8 and in-service inspection, maintenance and conditioned monitoring in Sec.9.
2.3 Identification of major accidental hazards

2.3.1 General

2.3.1.1 The standard identified common accidental hazards for an offshore concrete LNG terminal structures and containment systems. The designer shall ensure itself of its completeness by documenting through a hazard identification and risk assessment process that all hazards which may be critical to the safe operation of the offshore concrete LNG terminal have been adequately accounted for in design. This process shall be documented.

2.3.1.2 Criteria for the identification of major accident hazards shall be:
— significant damage to the asset
— significant damage to the environment.
There should be a clear and documented link between major accident hazards and the critical elements.

2.3.1.3 The following inputs are normally required in order to develop the list of critical elements:
— description of Terminal and mode(s) of operation, including details of the asset manning
— equipment list and layout
— hazard identification report and associated studies
— safety case where applicable.

2.3.1.4 The basic criteria in establishing the list of critical elements shall be to determine whether the system, component or equipment which – should they fail – have the potential to cause, or contribute substantially to, a major accident. This assessment is normally based upon consequence of failure only, not on the likelihood of failure.

2.3.1.5 The following methodology should be applied for confirming that prevention, detection, control or mitigation measures have been correctly identified as critical elements:
— identify the major contributors to overall risk,
— identify the means to reduce risk,
— link the measures, the contributors to risk and the means to reduce risk to the assets’ systems – these can be seen to equate to the critical elements of the asset.

2.3.1.6 The record of critical elements typically provides only a list of systems and types of equipment or structure etc. In order to complete a meaningful list, the scope of each element should be clearly specified such that there can be no reasonable doubt as to the precise content of each element.

2.3.1.7 The above processes should consider all phases of the lifecycle of the terminal.

2.3.1.8 The hazard assessment shall consider, as a minimum the following events:
— damage to the primary structure due to:
  — extreme weather
  — ship collision
  — dropped objects
  — helicopter collision
  — exposure to unsuitable cold/warm temperature
  — exposure to high radiation heat.
  — earthquake
  — fire and explosion
— loss of primary liquid containment (duration shall be determined based on an approved contingency plan)
— LNG leakage
— release of flammable or toxic gas to the atmosphere or inside an enclosed space
— roll over (thermodynamic instability due to LNG stratification)
— loss of stability
— loss of any single component in the station keeping/mooring system
— loss of ability to offload LNG or discharge gas ashore
— loss of any critical component in the process system
— loss of electrical power.

More details of hazards related to LNG storage are provided as guidelines in App.A *Hazard assessment of LNG terminals*.

2.3.1.9 The results of the hazard identification and risk assessment shall become an integral part of the structural design of the offshore concrete structure.
SECTION 3 DESIGN DOCUMENTATION

3.1 Overall planning

3.1.1 General

3.1.1.1 A fixed/floating concrete offshore LNG terminal structures and containment systems shall be planned in such a manner that it can meet all requirements related to its functions and use as well as its structural safety and durability requirements. Adequate planning shall be done before actual design is started in order to have sufficient basis for the engineering and by that obtain a safe, workable and economical structure that will fulfil the required functions.

3.1.1.2 The initial planning shall include determination and description of all the functions the structure shall fulfil, and all the criteria upon which the design of the structure are based. Site-specific data such as water depth, environmental conditions and soil properties shall be sufficiently known and documented to serve as basis for the design. All functional and operational requirements in temporary and service phases as well as robustness against accidental conditions that can influence the layout and the structural design shall be considered.

3.1.1.3 All functional requirements to the Terminal affecting the layout and the structural design, shall be established in a clear format such that it can form the basis for the engineering process and the structural design.

3.1.1.4 Investigation of site-specific data such as seabed topography, soil conditions and environmental conditions shall be carried out in accordance with requirements of DNVGL-OS-C101, ISO 19901-1 and ISO 19901-4.

3.1.2 Description of offshore concrete LNG terminal

3.1.2.1 The objective is to provide an overview of the LNG terminal, highlighting key assumptions and operational phases of the development.

3.1.2.2 The overview should be presented in three sections:
— overview of LNG terminal
— development bases and phases
— staffing philosophy and arrangements.
Cross-references to data sources, figures etc. should be provided.

3.1.3 Meteorological and ocean conditions

3.1.3.1 The objective is to summarise key design parameters with cross-references to key technical documents.

3.1.3.2 The metocean/climatology conditions section should cover at least the following:
— storm/wave/current conditions
— wind
— seawater/air temperature
— earthquakes
— cyclones
— other extreme conditions
— seabed stability
— tsunami
— atmospheric stability
— range and rates of changes of barometer pressure
— rainfall, snow
— corrosive characteristics of the air
— frequency of lightning strikes
— relative humidity.

3.1.3.3 Seismology for gravity based LNG terminal in seismic active zones:
An earthquake is defined by the horizontal and vertical accelerations of the ground. These accelerations are described by their:
— frequency spectrum
— amplitude.

A site specific earthquake analysis shall be performed. This analysis shall be reported in a seismic report where geological and seismic characteristics of the location of the gravity based facilities and the surrounding region as well as geotectonic information from the location have to be taken into account. As a conclusion this report shall recommend all seismic parameters required for the design.

The potential of earthquake activity in the vicinity of the proposed site is determined by investigating the seismic history of the region (320 km radius) surrounding the site, and relating it to the geological and tectonic conditions resulting from the soil survey.

These investigations involve thorough research, review and evaluation of all historically reported earthquakes that have affected, or that could reasonably be expected to have affected the site.

The geological, tectonic and seismological studies help to establish:
— strength level earthquake (SLE)
— ductility level earthquake (DLE).

Guidance note:
SLE and DLE shall be established as either:
— probabilistically, as those that produce ground motions with the mean recurrence as a minimum interval of 10 000 years for the DLE and 100 years for the SLE, and/or
— deterministically, assuming that earthquakes which are analogous to maximum historically known earthquakes are liable to occur in future with an epicentre position which is the most severe with regard to its effects in terms of intensity on the site, while remaining compatible with geological and seismic data. In this case, the SLE accelerations shall be one-half those determined for the DLE.

3.1.4 LNG terminal layout

3.1.4.1 The objective is to provide a description of the LNG terminal, its unique features (if any), equipment layout for all decks, and interaction with existing offshore/onshore facilities.

3.1.4.2 This section should include a description of at least the following (where applicable):
— general:
  — terminal
  — geographical location
  — water depth.
— layout:
  — terminal orientation
— elevation/plan views
— equipment
— escape routes
— access to sea deck
— emergency assembly area etc.
— structural details, including modelling of structure and loadings.

— interaction with existing facilities:
  — physical connections
  — support from existing facilities.

— interaction with expected facilities (where applicable).

3.1.5 Primary functions

3.1.5.1 To provide a description of the functions of the terminal by describing key processes; LNG containment system; pipeline systems; and marine and helicopter operations.

For design of the LNG terminal structure, this information is required as background information essential for identification of structural hazards of importance for the design of the structural load bearing structure of the terminal.

3.1.5.2 The primary functions section should include a description of at least the following (where applicable):

Process systems:
  — process description (overview)
  — process control features
  — safety control systems for use during emergencies e.g. controls at the TR or emergency assembly area.

LNG containment system:
  — primary barrier system
  — secondary barrier system
  — insulation systems
  — piping
  — layout
  — electrical
  — monitoring.

Pipeline and riser systems:
  — location, separation, protection
  — riser connect/disconnect system.

Utility systems:
  — power generation and distribution
  — communications
  — other utility systems (e.g. instrument air, hydraulics, cranes).

Inert gas systems:
  — safety features (e.g. blow-out prevention systems)
  — integration with platform systems

Workover and wireline systems:
  — extent and type of activity planned
— integration with platform systems.

Marine functions/systems:
— supply
— standby vessels
— diving
— ballast and stability systems
— mooring systems
— LNG offloading system
— LNG vessel mooring system.

Helicopter operations:
— onshore base
— capability of aircraft
— helicopter approach.

3.1.6 Standards

3.1.6.1 A design brief document shall include references to standards and design specifications.

3.1.7 Documentation

3.1.7.1 Documentation shall be prepared for all activities that are to be performed in the design, construction, transportation and installation of offshore concrete LNG terminal structures and containment systems. Documentation shall also be prepared showing records of all inspection and control of materials used and execution work performed that has an impact on the quality of the final product. The documentation shall be to a standard suitable for independent verification.

3.1.7.2 Necessary procedures and manuals shall be prepared to ensure that the construction, transportation, installation and in-service inspection are performed in a controlled manner in full compliance with all assumptions of the design.

3.1.7.3 The most important assumptions, on which the design, construction and installation work is based with regard to the offshore concrete LNG terminal structures and containment systems, shall be presented in a summary report. The summary report shall be available and suitable for use in connection with operation, maintenance, alterations and possible repair work. The summary report will normally be based on the documentation identified in [A.1.8] and [A.1.9].

3.1.8 Documentation required prior to construction

3.1.8.1 The technical documentation of concrete LNG terminal structures and containment systems, available prior to construction, shall comprise:
— design calculations for the complete structure including individual members
— project specification and procedures
— drawings issued for construction and approved by design manager.

3.1.8.2 All technical documentation shall be dated, signed and verified.

3.1.8.3 The project specification shall comprise:
— construction drawings, giving all necessary information such as geometry of the structure, amount and position of reinforcing and prestressing steel and for precast concrete elements, tolerances, lifting devices, weights, inserts, etc.
— description of all products to be used with any requirements to the application of the materials. This information should be given on the drawings and/or in the work description. Material specifications, product standards, etc., shall be included
— work description (procedures) related to the construction activity.

3.1.8.4 The work description should also include all requirements to execution of the work, i.e. sequence of operation, installation instructions for embedment plates, temporary supports, work procedures, etc.

3.1.8.5 The work description shall include an erection specification for precast concrete elements comprising:
— installation drawings consisting of plans and sections showing the positions and the connections of the elements in the completed work
— installation data with the required materials properties for materials applied at site
— installation instructions with necessary data for the handling, storing, setting, adjusting, connection and completion works with required geometrical tolerances.
— quality control procedures.

3.1.9 As-built documentation

3.1.9.1 The as-built documentation shall comprise:
— quality records
— method statements
— sources of materials, material test certificates and/or suppliers' attestation of conformity, Mill Certificate, approval documents
— applications for concessions and responses
— as-built drawings or sufficient information to allow for preparation of as-built drawings for the entire structure including any precast elements
— a description of non-conformities and the results of possible corrective actions
— a description of accepted changes to the project specification
— records of possible dimensional checks at handover
— a diary or log where the events of the construction process are reported
— documentation of the inspection performed.
— geotechnical design report (GDR).

3.1.10 Inspection/monitoring plans for structure in service

3.1.10.1 Plans for monitoring and inspection of the installation shall be prepared.
SECTION 4 STRUCTURAL MATERIALS

4.1 General

4.1.1 Concrete and concrete constituents

4.1.1.1 Shall be in accordance with DNVGL-ST-C502.

4.1.2 Grout and mortar

4.1.2.1 Shall be in accordance with DNVGL-ST-C502.

4.1.3 Reinforcement

4.1.3.1 Shall be in accordance with DNVGL-ST-C502.

4.1.3.2 Reinforcement exposed to cryogenic temperature shall additionally possess ductile properties for the temperature of design exposure.

4.1.4 Prestressing steel and anchorage

4.1.4.1 Shall be in accordance with DNVGL-ST-C502.

4.1.4.2 Prestressing steel and steel anchorages shall have ductile properties under the design temperatures of the concrete tank.

4.1.5 Embedded steel

4.1.5.1 Embedded steel shall behave ductile for the applicable loads. The material shall be in accordance with the requirements of DNVGL-OS-B101.

4.1.6 Repair material

4.1.6.1 Repair material exposed to LNG shall have ductile properties under the design temperatures of the concrete tank. For repair using steel as structural material, the provisions of DNVGL-OS-B101 apply.

4.1.6.2 Concrete and grout material exposed to cryogenic temperature are considered applicable for cryogenic exposure under normal conditions. The repair shall be design for the actual temperature exposure expected in the remaining lifetime in accordance with this standard.

4.1.6.3 For repair of ductile joints in earthquake active areas, the repaired concrete shall be reinforced with sufficient confining reinforcement to remain ductile.

4.1.7 LNG primary containment tank

4.1.7.1 The material in the primary containment tank shall be made of material remaining ductile under cryogenic temperature. Reference is made to DNVGL-OS-B101 and/or alternatively, the material shall comply with the requirements in the standard used for the design of the primary containment tank, i.e. Either DNV
GL rules for classification DNVGL-RU-OU-0103 *Floating LNG/LPG production, storage and loading units*, IGC-IMO Code, EN1473 or NFPA-59A. Special considerations shall be made to account for cyclic loads when applicable.

4.1.8 Insulation

4.1.8.1 The insulation used in LNG containment structures shall be made of material remaining its functions under repeated cycles of temperature cycles down to cryogenic temperature and also provide required insulation effect under the applied loads.

4.1.8.2 Material complying with the requirements in IGC-IMO Code, EN1473 or NFPA-59A can be used. See also App.C for further guidelines.
SECTION 5 LOADS AND ANALYSES REQUIREMENTS

5.1 Requirements to design of concrete support structure

5.1.1 General

5.1.1.1 The engineering/design of a fixed/floating offshore concrete LNG terminal structures and containment systems shall be carried out in such a way that all functional and operational requirements relating to the safety of the installation and its operation are met, as well as those requirements relating to its functions as an offshore facility.

5.1.1.2 The functional requirements will affect the layout of the terminal including the loading scenarios that will have to be considered in the design of the terminal. The functional requirements will be related to both the site-specific conditions as well as the requirements related to the use of terminal for import and export of LNG.

5.1.1.3 The design life of the terminal structure shall be 100 years if not otherwise govern by local legislation.

Site related functional requirements

5.1.1.4 The terminal shall be positioned and oriented on site such that it takes account of other terminals, governing wind directions, accessibility of ships and helicopters and safety in case of fire or leakages of hydrocarbons.

Environmental considerations

5.1.1.5 There shall be a site-specific evaluation of all types of environmental conditions that can affect the layout and design of the structure, including rare events with a low probability of occurrence.

5.1.1.6 If relevant, the deck elevation shall be determined in order to give an adequate air gap, based on site-specific data, allowing the passage of extreme wave crests under the deck, higher than the design wave crest and taking due account of possible interacting ice or icebergs. Interaction with deck supports and underwater caisson effects shall be considered. For barge type structures, the deck elevation is governed by the freeboard, stability calculations and wave pressure on the deck structure.

5.1.1.7 The water depth used in establishing layout and in the design shall be based on site-specific data taking due account of potential settlements, subsidence, etc.

Facility operational requirements

5.1.1.8 The functional requirements of the terminal shall be considered related to the production/operational system are such as:

a) layout
b) storage volume, compartmentation, densities, temperatures, etc. in case of stored products
c) safeguards against spillage and contamination
d) access requirements both internal and external, both for operation, inspection and condition monitoring, etc.
e) interface to topsides/plant
f) installations for LNG vessels and other vessels servicing the terminal.

5.1.1.9 All hazard scenarios that can be associated with the operations/maloperations and the functions of the Terminal shall be established and evaluated, such as fire, explosions, loss of intended pressure differentials, flooding, leakages, rupture of pipe systems, dropped objects, ship impacts, etc. The Terminal
shall be designed to give adequate safety to personnel and an adequate safety against damage to the structure or pollution to the environment.

5.1.2 Structural requirements

5.1.2.1 Structures and structural members shall perform satisfactorily during all design conditions, with respect to structural strength, mooring, stability, ductility, durability, displacements, settlements and vibrations. The structure and its layout shall be such that it serves as a safe and functional base for all mechanical installations that are needed for the facility to operate. Adequate performance shall be demonstrated in design documentation.

Structural concept requirements

5.1.2.2 The structural concept, details and components shall be such that the structure:

a) has adequate robustness with small sensitivity to local damage
b) can be constructed in a controlled manner
c) provides simple stress paths that limit stress concentrations
d) is resistant to corrosion and other degradation
e) is suitable for condition monitoring, maintenance and repair
f) remains stable in a damaged condition
g) fulfils requirements for removal if required.

Materials requirements

5.1.2.3 The materials selected for the terminal shall be suitable for the purpose and in accordance with Sec.4. The material properties and verification that these materials fulfil the requirements shall be documented.

5.1.2.4 The materials, all structural components and the structure itself shall be ensured to maintain the specified quality during all stages of construction. The requirement to quality assurance is given in Sec.2.

Execution requirements

5.1.2.5 Requirements to execution, testing and inspection of the various parts of the structure shall be specified on the basis of the significance (risk level) of the various parts with regard to the overall safety of the completed and installed LNG terminal structures and containment systems as well as the terminal in temporary conditions. See Sec.4, Sec.8 and Sec.9.

Temporary phases requirements

5.1.2.6 The structure shall be designed for all stages with the same intended reliability as for the final condition unless otherwise agreed. This applies also for moorings or anchorage systems applied for stages of construction afloat. Reference is made to DNVGL-ST-N001 Marine operations and marine warranty.

5.1.2.7 For floating structures and all floating stages of the marine operations and construction afloat of fixed installations, sufficient positive stability and reserve buoyancy shall be ensured. Both intact and damaged stability should be evaluated on the basis of an accurate geometric model. Adequate freeboard shall be provided. One compartment damage stability should normally be provided except for short transient phases. Intact and damaged stability, watertight Integrity, freeboard and weathertight closure appliances shall be in accordance with DNVGL-OS-C301.

Stability and freeboard under temporary conditions (construction afloat and towing) shall meet the requirements in DNVGL-ST-N001 Marine operations and marine warranty.

5.1.2.8 Weight control required for floating structures and temporary phases of fixed installations should be performed by means of well-defined, documented, robust and proven weight control. The system output should be up-to-date weight reports providing all necessary data for all operations.
5.1.3 Design principles

5.1.3.1 General
The design shall be performed according to the limit state design as detailed in DNVGL-OS-C101 and DNVGL-ST-C502. The design shall provide adequate strength and tightness in all design situations such that the assumptions made are complied with:

— the design of concrete structures shall be in accordance to this standard
— the foundation design shall be in accordance DNVGL-OS-C101
— the design of steel structures (supports for independent tanks, deck support structure etc.) shall be in accordance to DNVGL-OS-C101
— the possible interface between any steel structure and the support concrete structure shall be included in the design
— the design for load and load effects shall be in accordance with DNVGL-OS-C101. See also special requirements to concrete structures in this Section
— the design for accidental limit states shall be in accordance with DNVGL-OS-C101 Ch.2 Sec.7. See also identifications of hazards in DNVGL-OS-C101
— the cathodic protection shall be designed in accordance with DNVGL-OS-C101
— stability of the structure afloat shall be calculated in accordance with DNVGL-OS-C301.
— this standard is primary addressing containment systems and terminals built in concrete. In cases where the load carrying support terminal is constructed in steel, the design of structural members shall be designed in accordance with DNVGL-OS-C101 and the relevant object standard DNVGL-OS-C102 to DNVGL-OS-C106. Structural steel shall meet the requirements in DNVGL-OS-B105.

5.2 Load and load effects

5.2.1 General

5.2.1.1 The load and load effects shall be in accordance with DNVGL-ST-C502. The loads are generally classified as:

a) environmental, E
b) functional
   — permanent, G
   — variable, Q
   — imposed deformation, D
   — accidental, A.

5.2.1.2 The loads shall include the corresponding external reaction. The level of the characteristic loads shall be chosen according to the condition under investigation:

— under temporary conditions (construction, towing and installation)
— during operation
— when subject to accidental effects
— in a damaged condition.

5.2.1.3 The load effects shall be determined by means of recognized methods that take into account the variation of the load in time and space, the configuration and stiffness of the structure, relevant environmental and soil conditions, and the limit state under examination.

5.2.1.4 Simplified methods to compute load effects may be applied if it can be verified that they produce results on the safe side.
5.2.1.5 If dynamic or non-linear effects are of significance as a consequence of a load or a load effect, such dynamic or non-linear effects shall be considered.

5.2.1.6 Load effects from hydrodynamic and aerodynamic loads shall be determined by methods which accounts for the kinematics of the liquid or air, the hydrodynamic load, and the interaction between liquid, structure and soil. For calculation of global load effects from wind, simplified models may normally suffice.

5.2.1.7 Seismic load effect analyses shall be based on characteristic values described by an applicable seismic response spectrum or a set of carefully selected real or artificially simulated earthquake time histories. A combination of these methods may be used if such combination will produce a more correct result. The analysis shall account for the effects of seismic waves propagation through the soil, and the interaction between soil and structure.

Terminals located in seismically active area shall be designed to possess adequate strength and stiffness to withstand the effect of strength level earthquake (SLE) as well as sufficient ductility to remain stable during the rare motions of greater severity associated with ductility level earthquake (DLE). The sufficiency of the structural strength and ductility shall be demonstrated by strength and, as required, ductility analyses. See [3.1.3.3] for definition of SLE and DLE.

5.2.1.8 The soil-structure interaction shall be assessed in the determination of the soil reactions used in the calculation of load effects in the structure. Parameters shall be varied with upper and lower bound values to ensure that all realistic patterns of distribution are enveloped, considering long and short term effects, unevenness of the seabed, degrees of elasticity and plasticity in the soil and, if relevant, in the structure. See DNVGL-OS-C101.

5.2.2 Environmental loads

5.2.2.1 Wind, wave, tide and current are important sources of environmental loads (E) on many structures located offshore. In addition, depending on location, seismic or ice loads or both can be significant environmental loads.

5.2.2.2 General procedures for the estimation of seismic actions are provided in DNVGL-OS-C101. For DLE, non-linear response analyses may be required. See DNVGL-ST-C502 for more details.

5.2.2.3 The computation of ice loads is highly specialized and location dependent and is not covered in detailed by this standard. Ice loads shall be computed by skilled personnel with appropriate knowledge in the physical ice environment in the location under consideration and with appropriate experience in developing loads based on this environment and the load return periods in accordance with DNVGL-OS-C101.

5.2.3 Extreme wave loads

5.2.3.1 Wave loads from extreme conditions shall be determined by means of an appropriate analysis procedure supplemented, if required, by a model test program. Global loads on the structure shall be determined. In addition, local loads on various appurtenances, attachments and components shall be determined. For more details see DNVGL-ST-C502 App.A.

5.2.4 Diffraction analysis

5.2.4.1 Global loads on large volume bodies shall generally be estimated by applying a validated diffraction analysis procedure. In addition, local kinematics, required in the design of various appurtenances, shall be evaluated including incident, diffraction and (if appropriate) radiation effects. For more details, see DNVGL-ST-C502 App.A.
5.2.5 Additional requirements for dynamic analysis under wave load

5.2.5.1 In cases where the structure can respond dynamically, such as in the permanent configuration (fixed or floating), during wave load or earthquakes or in temporary floating conditions, additional parameters associated with the motions of the structure shall be determined. Typically, these additional effects shall be captured in terms of inertia and damping terms in the dynamic analysis.

5.2.5.2 Ringing can control the extreme dynamic response of particular types of concrete gravity structure. A ringing response resembles that generated by an impulse excitation of a linear oscillator: it features a rapid build up and slow decay of energy at the resonant period of the structure. If it is important, ringing is excited by non-linear (second, third and higher order) processes in the wave loading that are only a small part of the total applied environmental load on a structure.

5.2.5.3 The effects of motions in the permanent configuration such as those occurring in an earthquake, floating structures or in temporary phases of fixed installations during construction, tow or installation, on internal fluids such as ballast water in tanks, shall be evaluated. Such sloshing in tanks generally affects the pressures, particularly near the free surface of the fluid.

5.2.6 Model testing

5.2.6.1 The necessity of model tests to determine extreme wave loads shall be determined on a case-by-case basis. See DNVGL-ST-C502 App.A for more details.

5.2.7 Current load

5.2.7.1 Currents through the depth, including directionality, shall be combined with the design wave conditions. The Characteristic current load shall be determined in accordance with DNVGL-OS-C101. For more details, see DNVGL-ST-C502 App.A.

5.2.7.2 If found necessary scour protection should be provided around the base of the structure. See DNVGL-OS-C101.

5.2.8 Wind loads

5.2.8.1 Wind loads may be determined in accordance with DNVGL-OS-C101.

5.2.8.2 Wind forces on a offshore concrete terminal (OCT) will consist of two parts:
— wind forces on topside structure
— wind forces on concrete structure above sea level.
For more details, see App.A.

5.2.9 Functional loads

5.2.9.1 Functional loads are considered to be all loads except environmental loads, and include both permanent and variable loads. The functional loads are defined in DNVGL-OS-C101.

5.2.9.2 Permanent loads (G) are loads that do not vary in magnitude, position or direction during the time period considered. These include:
— self weight of the structure
5.2.9.3 Variable functional loads (Q) originate from normal operations of the structure and vary in position, magnitude, and direction during the period considered. They include loads from:

- personnel
- modules, parts of mechanical outfitting and structural parts planned to be removed during the operation phase
- weight of gas and liquid in pipes and process plants
- stored goods, tanks, etc.
- weight and pressure in storage compartments and ballasting systems
- temperatures in storages, etc. (may also be considered as deformation loads)
- loads occurring during installation and drilling operations, etc.
- ordinary boat impact, rendering and mooring.

5.2.9.4 The assumptions that are made concerning variable loads shall be reflected in a Summary Report and shall be complied with in the operations. Possible deviations shall be evaluated and, if appropriate, shall be considered in the assessment of accidental loads.

5.2.9.5 Certain loads, which can be classified as either permanent or variable, may be treated as imposed deformations (D). Load effects caused by imposed deformations shall be treated in the same way as load effects from other normal loads or by demonstration of strain compatibility and equilibrium between applied loads, deformations, and internal forces.

5.2.9.6 Potential imposed deformations are derived from sources that include:

- thermal effects
- prestressing effects
- creep and shrinkage effects
- differential settlement of foundation components.

See also [5.4.2.1].

5.2.10 Accidental loads

5.2.10.1 The accidental loads (A) are generally defined in DNVGL-OS-C101. See also Sec.2 and App.D of this standard. The hazards identified in the hazard identification process described in Sec.2, shall be mitigated/ accounted for in the design.

5.2.10.2 Accidental loads can occur from extreme environmental conditions, malfunction, mal operation or accident. The accidental loads to be considered in the design shall be based on an evaluation of the operational conditions for the structure, due account taken to factors such as personnel qualifications, operational procedures, installations and equipment, safety systems and control procedures.

5.2.10.3 Primary sources of accidental loads include:

- rare occurrences of extreme environmental loads
- fires
- flooding
- explosions
- dropped objects
- collisions
— unintended pressure difference changes.
— leakage of LNG through primary barrier or couplings etc.

5.2.10.4 Rare occurrences of extreme environmental loads
This will include extreme environmental loads such as the extreme seismic action, DLE, and all other extreme environmental loads when relevant.

5.2.10.5 Fires
The principal fire and explosion events are associated with hydrocarbon leakage from flanges, valves, equipment seals, nozzles, etc.
The following types of fire scenarios (relevant for LNG terminals) should among others be considered:
— fire related to loading/unloading or process equipment, or storage tanks; including jet fire and fire ball scenarios
— burning oil/gas on sea
— fire in equipment or electrical installations
— pool fires on deck or sea
— fire jets.
The fire load intensity may be described in terms of thermal flux as a function of time and space or, simply, a standardized temperature-time curve for different locations.
The fire thermal flux may be calculated on the basis of the type of hydrocarbons, release rate, combustion, time and location of ignition, ventilation and structural geometry, using simplified conservative semi-empirical formulae or analytical/numerical models of the combustion process.

5.2.10.6 Explosions
The following types of explosions should be considered:
— ignited gas clouds
— explosions in enclosed spaces, including machinery spaces and other equipment rooms as well as oil/gas storage tanks.
The overpressure load due to expanding combustion products may be described by the pressure variation in time and space. It is important to ensure that the rate of rise, peak overpressure and area under the curve are adequately represented. The spatial correlation over the relevant area that affects the load effect, should also be accounted for. Equivalent constant pressure distributions over panels could be established based on more accurate methods.
The damage due to explosion should be determined with due account of the dynamic character of the load effects. Simple, conservative single degree of freedom models may be applied. When necessary non-linear time domain analyses based on numerical methods like the finite element method should be applied.
Fire and explosion events that result from the same scenario of released combustibles and ignition should be assumed to occur at the same time, i.e. to be fully dependent. The fire and blast analyses should be performed by taking into account the effects of one on the other.
The damage done to the fire protection by an explosion preceding the fire should be considered.

5.2.10.7 Collisions
The impact loads are characterised by kinetic energy, impact geometry and the relationship between load and indentation. Impact loads may be caused by:
— vessels in service to and from the installation including supply vessels
— LNG vessels serving the terminal
— ships and fishing vessels passing the installation
— floating installations, such as flotels
— aircraft on service to and from the field
— dropped or sliding objects
— fishing gear  
— icebergs or ice.

The collision energy can be determined on the basis of relevant masses, velocities and directions of ships or aircraft that may collide with installation. When considering the installation, all traffic in the relevant area should be mapped and possible future changes in vessel operational pattern should be accounted for. Design values for collisions are determined based on an overall evaluation of possible events. The velocity can be determined based on the assumption of a drifting ship, or on the assumption of uncontrolled operation of the ship. See Sec. 2.

In the early phases of terminal design, the mass of supply ships should normally not be selected less than 5000 tons and the speed not less than 0.5 m/s and 2 m/s for ULS and ALS design checks, respectively. A hydrodynamic (added) mass of 40% for sideways and 10% for bow and stern impact can be assumed.

The most probable impact locations and impact geometry should be established based on the dimensions and geometry of the terminal and vessel and should account for tidal changes, operational sea-state and motions of the vessel and Terminal which has free modes of behaviour. Unless more detailed investigations are done for the relevant vessel and terminal, the impact zone for supply vessel on a fixed Offshore Concrete LNG Terminal should be considered to be between 10 m below LAT and 13 m above HAT.

Special considerations shall be made with respect to impact energy and impact zone for LNG vessels serving the LNG terminal.

5.2.10.8 Dropped objects

Loads due to dropped objects should for instance include the following types of incidents:
— dropped cargo from lifting gear  
— failing lifting gear  
— unintentionally swinging objects  
— loss of valves designed to prevent blow-out or loss of other drilling equipment.

The impact energy from the lifting gear can be determined based on lifting capacity and lifting height, and on the expected weight distribution in the objects being lifted.

Unless more accurate calculations are carried out, the load from dropped objects may be based on the safe working load for the lifting equipment. This load should be assumed to be failing from lifting gear from highest specified height and at the most unfavourable place. Sideways movements of the dropped object due to possible motion of the structure and the crane hook should be considered.

The trajectories and velocity of objects dropped in water should be determined on the basis of the initial velocity, impact angle with water, possible reduction in energy as the object hit the water surface, possible current velocity effects and effects of hydrodynamic resistance.

The impact effect of long objects such as pipes should be subject to special consideration.

5.2.10.9 Unintended pressure difference changes

Changes in intended pressure differences or buoyancy caused for instance by defects in or wrong use of separation walls, valves, pumps or pipes connecting separate compartments as well as safety equipment to control or monitor pressure, shall be considered.

Unintended distribution of ballast due to operational or technical faults should also be considered.

5.2.10.10 Floating structure in damaged condition

Floating structures, which experience buoyancy loss, will have an abnormal floating position. The corresponding abnormal variable and environmental loads should be considered.

Adequate global structural strength should be documented for abnormal floating conditions considered in the damage stability check, as well as tightness or ability to handle potential leakages in the tilted condition.

5.2.10.11 Combination of accidental loads

When accidental loads occur simultaneously, the probability level (10^-4) applies to the combination of these loads. Unless the accidental loads are caused by the same phenomenon (like hydrocarbon gas fires and
explosions), the occurrence of different accidental loads can be assumed to be statistical independent. However, due attention shall be taken to the result of any quantitative risk assessment.

**Guidance note:**
While in principle, the combination of two different accidental loads with exceedance probability of $10^{-2}$ or one at $10^{-3}$ and the other at a $10^{-1}$ level, correspond to a $10^{-4}$ event, individual accidental loads at a probability level of $10^{-4}$, commonly will be most critical. See App.D for guidance related to combining the loads in design of the containment structure.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.2.10.12 Accidental leakage of LNG through the primary barrier shall be considered in design. In the case of a concrete secondary barrier, the potential local change in temperature shall be considered in the design of the tightness control under this condition. For a containment structure supported by a steel support structure, the leakage has to be small and controlled, or the secondary barrier is placed within the secondary barrier or the main structure is built using steel with cryogenic properties as may be required.

### 5.3 Load combinations and partial safety factors

#### 5.3.1 Partial load factors, $\gamma_f$

**5.3.1.1** The load factors for design of the concrete terminal are specified in DNVGL-ST-C502 and in Table 5-1.

**Table 5-1 Recommended partial factors for loads for the ultimate limit state (ULS) Load combinations (from DNVGL-OS-C101)**

<table>
<thead>
<tr>
<th>Combination of design loads</th>
<th>Load categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$G$</td>
</tr>
<tr>
<td>a)</td>
<td>1.3</td>
</tr>
<tr>
<td>b)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Load categories are:
- $G =$ permanent load
- $Q =$ variable functional load
- $E =$ environmental load
- $D =$ deformation load

$^a$ Factor may have to be amended for areas with other long term distribution functions than North Sea conditions.

For description of load categories, see DNVGL-OS-C101, [5.3.1.2] through [5.3.1.9] below.

**5.3.1.2** The loads shall be combined in the most unfavourable way, provided that the combination is physically possible and permitted according to the load specifications. Loading conditions that are physically possible but not intended or permitted to occur in expected operations, shall be included by assessing probability of occurrence and accounted for as either accidental conditions in the accidental damage limit state (ALS) or as part of the ordinary design conditions included in the ULS. Such conditions may be omitted in case where the annual probability of occurrence can be assumed to be less than $10^{-4}$.

**5.3.1.3** For permanent loads, a load factor of 1.0 in load combination a) shall be used where this gives a more unfavourable load effect. For external hydrostatic pressure, and internal pressures from a free surface, an load factor of 1.2 may normally be used provided that the load effect can be determined with normal accuracy. Where second order effects are important, a load factor of 1.3 shall be used.
5.3.1.4 A load factor of 1.0 shall be applied to the weight of soil included in the geotechnical calculations.

5.3.1.5 Prestressing loads may be considered as imposed deformations. Due account shall be taken of the time dependent effects in calculation of effective characteristic forces. The more conservative value of 0.9 and 1.1 shall be used as a load factor in the design.

5.3.1.6 The definition of limit state categories is valid for foundation design with the exception that failure due to cyclic loading is treated as an ULS limit state, alternatively as an ALS limit state, using load and material coefficients as defined for these limit state categories.

The load coefficients are in this case to be applied to all cyclic loads in the design history. Lower load coefficients may be accepted if the total safety level can be demonstrated to be within acceptable limits.

5.3.1.7 Where a load is a result of high counteracting and independent hydrostatic pressures, the pressure difference shall be multiplied by the load factor. The pressure difference shall be taken as no less than the smaller of either one tenth of the highest pressure or 100 kPa. This does not apply when the pressure is balanced by direct flow communication. The possibility of communication channel being blocked shall then be part of the risk assessment.

5.3.1.8 For LNG containment tanks, the load factor for LNG loads (Q, pressure from LNG containment on primary barrier and secondary barrier) shall be taken as 1.6. The loads from the LNG containment tanks shall be combined with other loads in the most unfavourable way, provide that the combination is physically possible and permitted according to the specification. See App.D for detailed guidance on load combinations for the design of the LNG containment tanks.

5.3.1.9 In the ALS, the load factor shall be 1.0 for all loads. For structures exposed to DLE and the in-plane shear walls may be design using a strength design in stead of a ductility design approach. In this case a sufficient earthquake load increase factor shall be identified and applied in design. This factor shall not be less than 1.1.

5.3.2 Combinations of loads

5.3.2.1 DNVGL-OS-C101 gives a more detailed description of how loads shall be combined. When environmental and accidental loads are acting together, the given probabilities apply to the combination of these loads. For combination of loads in design of LNG containment structure, see App.D as guidelines.

5.3.2.2 For temporary phases, where a progressive collapse in the installation does not entail the risk of loss of human life, injury, or damage to people or the environment, or of significant financial losses, a shorter return period than that given in DNVGL-OS-C101 for environmental loads may be considered.

5.3.2.3 The return conditions to be considered should be related to the duration of the operation. As a general guidance, the criteria given in Table 5-2 may be applied:

<table>
<thead>
<tr>
<th>Duration of use</th>
<th>Environmental criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 3 days</td>
<td>Specific weather window</td>
</tr>
<tr>
<td>3 days to 1 week</td>
<td>More than 1 year, seasonal</td>
</tr>
<tr>
<td>1 week to 1 month</td>
<td>10 years return, seasonal</td>
</tr>
<tr>
<td>1 month to 1 year</td>
<td>100 years return, seasonal</td>
</tr>
<tr>
<td>More than 1 year</td>
<td>1000 years return, all year</td>
</tr>
</tbody>
</table>
5.3.3 Consequence of failure

5.3.3.1 Structures can be categorised by various levels of exposure to determine criteria that are appropriate for the intended service of the structure. The levels are determined by consideration of life safety and consequences of failure.

5.3.3.2 Life safety considers the manning situation in respect of personnel on the terminal when the design environmental event would occur.

5.3.3.3 Consequences of failure consider the potential risk to life of personnel brought in to react to any incident, the potential risk of environmental damage and the potential risk of economic losses.

5.3.3.4 LNG terminal structures and containment systems are classified as structures with high consequence of failure and shall be designed in accordance with the requirements of this standard for environmental and functional loads including accidental loads.

Inspection during construction shall be extended inspection in accordance with this standard.

5.4 Structural analysis

5.4.1 General

5.4.1.1 Structural analysis is the process of determining the load effects within a structure, or part thereof, in response to each significant set of loads. DNVGL-ST-C502 specifies requirements for the various forms of structural analysis necessary to define the response of the structure during each stage of its life. Load effects calculated by structural analysis shall be used as part of the design documentation.

5.4.2 Special load effects

Deformation loads

5.4.2.1 Deformation induced loads created by imposed deformations in the structure, are loads to be treated as either deformation loads (D) or as functional loads. See [5.2.9].

Examples of such loads may be:
— differential settlement
— temperature effects
— shrinkage
— loads in flexible members connected to stiff members may in some cases be seen as deformation induced loads
— changes in strain due to absorption.

For Terminals with a ductile mode of failure, and where second order effects are negligible, the effect of deformation loads may normally be neglected.

A typical example of a ductile mode of failure is a flexural failure provided sufficient rotational capacity exists. Verification of sufficient rotational capacity may in most cases be based on simplified considerations.

5.4.2.2 Imposed deformations normally have a significant influence on the shear resistance of a section, and shall be duly considered in the design.

The characteristic value of deformation imposed loads is normally evaluated on the basis of defined maximum and minimum values for the parameters governing its magnitude.

An accurate calculation of deformation loads caused by temperature effects can only be obtained from a non-linear analysis, reflecting realistic material properties of reinforced concrete. In practice, effects due to
imposed deformations may be calculated using a linear elastic model, and a constant modulus of elasticity throughout the structure. Possible reductions due to cracking may be estimated separately.

The temperature expansion coefficient (\( \alpha \)) may be taken as \( 1.0 \cdot 10^{-5} \, ^\circ\text{C}^{-1} \) for concrete. Where the temperature induced loads are significant testing is normally to be carried out to determine (\( \alpha \)). Concrete members exposed to temperature below \(-60^\circ\text{C}\) shall require special evaluation of the temperature expansion coefficient (\( \alpha \)) to account for the actual temperature and relative humidity of the concrete.

5.4.2.3 Creep effects shall be considered where relevant. For further details, see DNVGL-ST-C502.

Effect of water pressure

5.4.2.4 The effect of water pressure in the concrete shall be fully considered when relevant.

5.4.2.5 The effect of hydrostatic pressure on the concrete strength shall be evaluated where relevant.

5.4.2.6 The effect of hydrostatic forces acting on the faces of cracks shall be taken into account in the analytical models used for prediction of concrete strength. This effect is also to be taken into account when actual load effects are evaluated.

Loss of intended underpressure

5.4.2.7 For structures designed with an intended underpressure, relative to external pressure, a design condition, where the intended underpressure is lost, shall be evaluated. This load effect may be categorized as an accidental load effect. Load combinations, and load and material factors shall be taken according to ALS criteria.

More stringent criteria may be specified by the client for this situation (e.g. increased material factor, load factors etc.) due to e.g. costly and excessive repair.

Weight of concrete

5.4.2.8 The long-term effect of water absorption shall be considered in the estimation of concrete weights. This is especially important for floating concrete structures.

5.4.3 Analyses requirements

5.4.3.1 All structural analyses performed shall simulate, with sufficient accuracy, the response of the structure or component for the limit state being considered. This may be achieved by appropriate selection of the analysis type with due regard to the nature of loads applied and the expected response of the structure.

5.4.3.2 The following table gives general guidance as to the type of analysis that shall be adopted for each design condition for the structure. Further details are provided in DNVGL-ST-C502.

Table 5-3 Appropriate types of analysis

<table>
<thead>
<tr>
<th>Condition</th>
<th>Appropriate types of analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>Linear static analysis is generally appropriate.</td>
</tr>
<tr>
<td>Towing to location</td>
<td>Linear static analysis is generally appropriate. Dynamic effects may be significant in response to hydrodynamic motions. These can normally be simulated by pseudo-static analysis.</td>
</tr>
<tr>
<td>Installation</td>
<td>Linear static analysis is generally appropriate.</td>
</tr>
<tr>
<td>In-service strength and serviceability</td>
<td>Linear, static or pseudo-static analysis is generally appropriate for global load path analysis. Analyses of temperature distribution within structure as input to strength analysis in ULS, SLS and FLS.</td>
</tr>
</tbody>
</table>
Condition | Appropriate types of analysis
--- | ---
Fatigue | Linear analysis is generally appropriate. Dynamic effects may be significant for short period waves. A pseudo-static deterministic approach is normally acceptable.
Seismic | Dynamic analysis is normally required, where seismic ground motion is significant. Non-linear effects might need to be considered for ductility level earthquakes.
Accidental | Non-linear analysis is normally required for significant impacts. Dynamic response can be significant. Temperature analyses will be required to predict temperature distribution and following temperature stresses in case of accidental leakage of LNG through the primary containment. This applies for containment systems where the concrete is designed to act as secondary containment structure.
Removal/reuse | As per transportation and installation.

5.4.4 Analysis of construction stages

5.4.4.1 Sufficient analyses shall be performed on components of the structure during construction to ensure their integrity at all significant stages of the construction and assembly process and to assess built-in stresses from restrained deformations. Construction stages shall include onshore and inshore operations.

5.4.4.2 Consideration shall be given to the sequence of construction in determining load effects and to the age of the concrete in determining resistance. Specific consideration shall be given to the stability of components under construction. Adequate support for temporary loads, such as crane footings, shall be provided in the analysis.

5.4.4.3 Assessment of the structure during construction stages may normally be performed using static analysis. However, dynamic response to wind turbulence might need to be calculated for tall, slender structures and consideration shall be given to other possible dynamic load effects, such as earthquakes, occurring during the construction phase.

5.4.5 Transportation analysis

5.4.5.1 Analysis of a fixed concrete structure shall include the assessment of structural integrity during significant stages of the sea tow of the structure, whether it is self-floating, barge supported or barge assisted. The representation of the structure during such operations shall be consistent with the stage being represented, incorporating the correct amount of ballast and simulating only those components of the topsides actually installed.

5.4.5.2 Analysis during sea tow should normally be based on linear static analysis, representing the motion of the concrete structure by peak heave, sway, surge, pitch and roll accelerations as predicted by hydrodynamic analysis. For such analysis to be valid, it shall be demonstrated that motions in the natural periods of major components of the structure, will not be significantly excited by this global motion. If dynamic effects are deemed important, they shall be incorporated in accordance with DNVGL-ST-C502. The analysis of the tow shall be in accordance with the DNV GL standard DNVGL-ST-N001 Marine operations and marine warranty.

5.4.5.3 Fatigue damage can result from extreme tow duration in heavy seas. If this is significant, fatigue damage accrued shall be accumulated together with that calculated for in-service conditions in accordance with DNVGL-ST-C502.

5.4.5.4 Consideration shall be given to possible damage scenarios during sea tow. Sufficient structural analyses should be performed to ensure adequate integrity of the structure, preventing complete loss in the
event of collision with tugs or other vessels present during the transportation stage. In particular, progressive collapse due to successive flooding of compartments shall be prevented.

5.4.6 Installation and deck mating analysis

5.4.6.1 Structural analysis shall be performed at critical stages of the deck mating (if applicable) and installation stages. Such analyses shall, as a minimum, cover times of maximum pressure differential across various components of concrete structure. The configuration of the structure at each stage of the setting down operation should reflect the planned condition and inclination of the structure and the associated distribution of ballast.

5.4.6.2 Deck mating, ballasting down and planned setting down on the sea floor shall normally be analysed by a linear static approach. As these phases normally represent the largest external water heads, implosion or buckling should be analysed. The effect of unevenness in the seabed shall be considered in assessing seabed reactions in an ungrouted state.

5.4.7 In-service strength and serviceability analyses

5.4.7.1 At least one global analysis of the structure shall be performed in its in-service configuration suitable for subsequent strength and serviceability assessment. The structure shall also be analysed for extreme wave effects using ALS load factors, unless it can be conclusively demonstrated that this limit state is always less onerous than the corresponding ULS condition.

5.4.7.2 Local analysis shall be performed to assess secondary structure and details that appear from the global analysis to be heavily loaded or that are complex in form or loading. Such analyses may be based on non-linear methods if these are more appropriate to the component behaviour.

5.4.7.3 It is generally acceptable to base all strength analysis of an in-service concrete platform on deterministic analysis, predicting response to specific extreme waves. Sufficient wave periods, directions and wave phases shall be considered to obtain maximum response in each type of component checked. Consideration shall be given to waves of lower than the maximum height if greater response can be obtained due to larger dynamic effects at smaller wave periods.

5.4.8 Fatigue analysis

5.4.8.1 When required, detailed fatigue analysis shall be based on a cumulative damage assessment performed over the proposed lifetime of the structure. The analysis shall include transportation stages, if significant, and should consider the effects of the range of sea states and directions to which the structure will be subjected.

5.4.8.2 A linear representation of the overall structure is generally acceptable for the evaluation of global load paths for fatigue analysis. The structural analysis shall include the effects of permanent, live, hydrostatic and deformational loads. It shall be justifiable to use reduced topside and other loads in the fatigue analysis, on the basis that typical rather than extreme loads through its life are required. Significant changes in static load through the lifetime of the structure shall be analysed separately and fatigue damage shall be accumulated over each phase. For details in fatigue life prediction, see [6.4.2].

5.4.8.3 Dynamic amplification is likely to be more significant for the relatively short wave periods causing the majority of fatigue damage. Fatigue analysis shall therefore consider the effects of dynamic excitation in appropriate detail, either by pseudo-static or by dynamic response analysis. Deterministic or stochastic types of analysis are both permissible, subject to the following provisions.
5.4.8.4 For deterministic analysis, the selected individual waves to which the structure is subjected shall be based on a representative spread of wave heights and periods. For structures that are dynamically sensitive, these shall include several wave periods at or near each natural period of the structure, to ensure that dynamic effects are accurately assessed. Consideration shall also be given to the higher frequency content in larger waves that may cause dynamic excitation.

5.4.8.5 Sufficient wave cases shall be analysed for probabilistic analysis to adequately represent the stress transfer functions of the structure. Non-linear response of the structure shall be incorporated into the analysis using appropriate methods, if significant.

5.4.9 Seismic analysis

5.4.9.1 Two levels of seismic loading on an offshore concrete structure shall be considered:
— strength level earthquake (SLE), which shall be assessed as a ULS condition
— ductility level earthquake (DLE), for which ductile behaviour of the structure assuming extensive plasticity is permissible provided the structure survive.

LNG containment structures shall be designed for both the SLE and DLE earthquakes. Systems which is vital for the plant system shall remain operational following both a SLE and a DLE. No leakage of LNG is acceptable from a DLE. For further details see [6.4.4].

5.4.9.2 The load effects on components that are simulated as linear elastic in either SLE or DLE analyses shall be evaluated and used to confirm that these components satisfy ULS criteria. Components that demonstrate ductile response shall be so designed, and assessed against acceptance criteria relevant for the actual limit state with respect to all relevant response parameters. Ductility of reinforced concrete structures in seismic active areas is ensured by sufficient confinement of the concrete by stirrup reinforcements.

5.4.10 Accidental and overload analyses

5.4.10.1 Analysis of the structure under accidental conditions, such as ship collision, helicopter impact or iceberg collision, shall consider the following:
— local behaviour of the impacted area
— global strength of the structure against overall collapse
— explosions
— local cold spots in concrete secondary barrier due to local leakage in primary barrier
— post-damage integrity of the structure.

5.4.10.2 The resistance of the impact area may be studied using local models. The contact area and perimeter shall be evaluated based on predicted non-linear behaviour of the structure and of the impacting object. Non-linear analyses may be required since the terminal will generally deform substantially under the accidental loads. Appropriate boundary conditions shall be provided far enough away from the damaged region for inaccuracies to be minimized.

5.4.10.3 Global analysis of the terminal under accidental loads may be required to ensure that a progressive collapse is not initiated. The analysis should include the weakening effect of damage to the structure in the impacted area. If ductile response of the structure is likely for the impact loads determined global non-linear analysis may be required to simulate the redistribution of load effects as section resistances are exceeded. The global analysis may be based on a simple representation of the structure sufficient to simulate progressive collapse. Deflection effects shall be included, if significant.
5.4.10.4 Energy absorption of the structure will arise from the combined effect of local and global deformation. Sufficient deformation of the structure to absorb the impact energy from the collision not absorbed by the impacting object shall be documented.

5.4.10.5 Analysis of the structure in its damaged condition may normally be performed using linear static analysis. Damaged components of the structure shall be removed from this analysis, or appropriately weakened to simulate their reduced strength and stiffness.

For accidental case of local leakage in the primary barrier, it will be required to carry out special temperature analyses to determine the temperature distribution and the resulting stress distribution from this load case.

5.4.11 Terminal removal/reuse

5.4.11.1 Analysis of the structure for removal shall accurately represent the structure during this phase. The analysis shall have sufficient accuracy to simulate pressure differential effects that are significant during this stage. The analysis shall include suction forces that shall be overcome prior to separation from the sea floor, if appropriate. Suitable sensitivity to the suction coefficient shall be incorporated. The possibility of uneven separation from the seabed and drop-off of soil or underbase grout shortly after separation shall be considered and structural response to subsequent motions shall be evaluated.

5.4.11.2 Weights of accumulated debris and marine growth shall also be considered if these are not to be removed. Items to be removed from the structure, such as the topsides, conductors, and risers, shall be omitted from the analysis.

5.4.11.3 The condition of the concrete and reinforcement should account for degradation of the materials during the life of the platform. If the analysis is carried out immediately prior to removal, then material degradation shall take account of the results from recent underwater surveys and inspections.

5.5 Topside interface design

5.5.1 Introduction

5.5.1.1 The design of the interface between a steel topsides structure and a concrete substructure requires careful consideration by both the topsides and substructure designers.

5.5.1.2 Particular attention shall be paid to ensure that all relevant information is exchanged between the topsides and substructure design teams.

5.5.1.3 If topside and substructure construction are separate contracts, special care shall be taken to handle the interface responsibility. It shall be clear who is responsible for input to and from the topside engineering contractor as part of a technical coordination procedure.

5.5.1.4 For a barge type structure, the deck structure supporting the topside modules will normally be constructed as an integral part of the terminal structure. This simplifies the topside interface design.
SECTION 6 DETAILED DESIGN OF OFFSHORE CONCRETE TERMINAL STRUCTURES

6.1 General

6.1.1 Introduction

6.1.1.1 The detailed design of prestressed/reinforced concrete shall be carried out in accordance with DNVGL-ST-C502. This standard is generally making references to this standard.

6.1.1.2 Other design standards may as an alternative be used for detailed design of the offshore concrete structures. An opening is made for this within DNVGL-ST-C502 provided the requirements to the detailed standard given in DNVGL-ST-C502 App.E are sufficiently covered. The level of safety shall be as required by DNVGL-ST-C502. The compliance with these requirements shall be documented. Special considerations for design required by this standard shall be considered.

6.2 Design principles concrete terminal

6.2.1 General

6.2.1.1 Design in compliance with this standard can be based either on calculations or on testing, or a combination of these.

6.2.1.2 Reference is made to DNVGL-ST-C502 which provides more details on strength and serviceability calculations of reinforced concrete structural members.

6.2.2 Limit states

6.2.2.1 Structures shall satisfy the requirements in the following limit states:
   — ultimate limit state (ULS)
   — accidental limit state (ALS)
   — fatigue limit state (FLS)
   — serviceability limit state (SLS).

6.2.2.2 In ULS and ALS, the capacity is demonstrated by testing or by calculation based on the strain properties and design material strengths.

6.2.2.3 In FLS, it shall be demonstrated that the structure can sustain the expected load cycles at the applied load levels for the intended service life.

The documentation shall include:
   — bending moment
   — axial force
   — shear force
   — torsional moment
   — anchorage of reinforcement
   — partial loading
   and combinations of these.
6.2.2.4 The design in SLS shall demonstrate that the structure, during its service life, will satisfy the functional requirements related to its use and purpose. Serviceability limit state requirements shall also ensure the durability and strength of the structure. The documentation shall include:
- cracks
- tightness/leakage
- strains
- displacements
- dynamic effects
- concrete stress level
- compression zone.

6.2.3 Characteristic values for material strength

6.2.3.1 The characteristic strength of materials shall be determined according to design standards and recognized standards for material testing.

6.2.3.2 For concrete, the 28 days characteristic compressive strength $f_{ck}$ is defined as a 5% fractile value ($5^{th}$ percentile) found from statistical analysis of testing 150 mm x 300 mm cylindrical specimens.

6.2.3.3 In Table 6-2, a normalized compressive strength, $f_{cn}$, is tabulated based on this characteristic concrete cylinder strength. The normalized compressive strength of concrete, $f_{cn}$, is less than the characteristic cylinder strength, $f_{ck}$, and considers transition of test strength into in situ strength, ageing effects due to high-sustained stresses etc.

6.2.3.4 For reinforcement steel, the minimum yield stress shall be taken as characteristic strength $f_{ck}$, determined as the 5% defective fractile. The reinforcement shall be of quality in accordance with [4.1.3] Reinforcement.

6.2.3.5 For prestressed reinforcement the in situ strength is taken equal to the yield strength $f_{sy}$ or the 0.2-proof stress. The quality of prestressing steel and anchorage shall be in accordance with [4.1.4] Prestressing steel and anchorage.

6.2.3.6 For geotechnical analyses, the characteristic material resistance shall be determined so that the probability of more unfavourable materials occurring in any significant extent is low. Any deteriorating effects during the operation phase shall be taken into consideration. See DNVGL-OS-C101.

6.2.3.7 For the fatigue limit state FLS, the characteristic material strength shall be determined statistically as a 2.5% fractile for reinforcement, prestressing assemblies, couplers, welded connections, etc. unless other values are specified in the reference standard for that design. For concrete, design reference strength shall be used. For soil, the characteristic strength shall be used. For other materials, acceptance criteria shall be specified which offer a safety level equivalent to that of the present provision.

6.2.3.8 Where high resistance of a member is unfavourable (e.g. in weak link considerations), an upper value of the characteristic resistance shall be used in order to give a low probability of failure of the adjoining structure. The upper value shall be chosen with the same level of probability of exceedance as the probability of lower values being underscored. In such cases, the material factor shall be 1.0 in calculating the resistance that is applied as a load on adjoining members.
6.2.4 Partial safety factors for materials

6.2.4.1 The partial factors for the materials, $\gamma_m$, in reinforced concrete shall be chosen in accordance with this standard and for the limit state considered.

6.2.4.2 For structural steel members, the material factor shall be in accordance with DNVGL-OS-C101.

6.2.4.3 Foundation design shall be performed in accordance with DNVGL-OS-C101. The soil material factors shall also be in accordance with DNVGL-OS-C101.

6.2.5 Design by testing

6.2.5.1 If the loads acting on a structure, or the resistance of materials or structural members cannot be determined with reasonable accuracy, model tests can be carried out. Reference is made to DNVGL-ST-C502.

6.2.5.2 Characteristic resistance of structural details or structural members or parts may be verified by a combination of tests and calculations.

6.2.5.3 A test structure, a test structural detail or a test model shall be sufficiently similar to the installation to be considered. The results of the test shall provide a basis for a reliable interpretation, in accordance with a recognized standard.

6.2.6 Design material strength

6.2.6.1 The design material strength shall be taken as a normalized in-situ strength in accordance with Table 6-1 divided by a material coefficient $\gamma_m$.

The design strength in compression, $f_{cd}$, is found by dividing the normalized compressive strength $f_{cn}$ by the material coefficient, $\gamma_c$, in Table 6-1.

The characteristic tensile strength, $f_{tk}$, and the normalized tensile strength, $f_{tn}$, in the structure are defined in Table 6-1 and are both derived from the characteristic strength of concrete in compression.

6.2.6.2 In design by testing, the requirements given in DNVGL-ST-C502 shall be applied.

6.2.6.3 If a high design strength is unfavourable, a special appraisal of the material coefficients and the nominal value of the in-situ strength, shall be performed. An example is the design of a potential plastic hinge as part of the ductility design of a structure in a seismic active area.

6.2.6.4 The material coefficients, $\gamma_m$, take into account the uncertainties in material strength, execution, cross-sectional dimensions and the theory used for calculation of the capacity. The material coefficients are determined without accounting for reduction of capacity caused by corrosion or mechanical deterioration.

6.2.6.5 Design values for the concrete are:

$$\begin{align*}
E_{cd} &= E_{cn} / \gamma_c \\
 f_{cd} &= f_{cn} / \gamma_c \\
 f_{td} &= f_{tn} / \gamma_c
\end{align*}$$

where:
\[ E_{cd} = \text{design value of Young’s modulus of concrete used in the stress-strain curve} \]
\[ E_{cn} = \text{normalized value of Young’s modulus used in the stress-strain curve} \]
\[ f_{cd} = \text{design compressive strength of concrete} \]
\[ f_{cn} = \text{normalized compressive strength of concrete} \]
\[ f_{td} = \text{design strength of concrete in uni-axial tension} \]
\[ f_{tn} = \text{normalized tensile strength of concrete} \]
\[ \gamma_c = \text{material strength factor concrete} \]

In the ultimate limit state and the accidental limit state, the Young’s modulus for concrete, \( E_c \), is taken equal to the normalized value, \( E_{cn} \), in the serviceability limit state.

In the fatigue limit state, the Young’s modulus for concrete, \( E_c \), is taken equal to the characteristic value, \( E_{ck} \).

**6.2.6.6** Design values for the reinforcement are:

\[ E_{sd} = \frac{E_{sk}}{\gamma_s} \]
\[ f_{sd} = \frac{f_{sk}}{\gamma_s} \]

where:

\[ E_{sd} = \text{design value of Young’s modulus of reinforcement} \]
\[ E_{sk} = \text{characteristic value of Young’s modulus of reinforcement} \]
\[ f_{sd} = \text{design strength of reinforcement} \]
\[ f_{sk} = \text{characteristic strength of reinforcement} \]
\[ \gamma_s = \text{material coefficient reinforcement} \]

**6.2.6.7** The material coefficient, \( \gamma_m \), for concrete and reinforcement are given in Table 6-1.

<table>
<thead>
<tr>
<th>Limit state</th>
<th>Ultimate limit state</th>
<th>Accidental and fatigue limit state</th>
<th>Serviceability limit state</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reinforced concrete</strong></td>
<td>( \gamma_c )</td>
<td>( \frac{1.25}{1.40} )</td>
<td>( \frac{1.10}{1.20} )</td>
</tr>
<tr>
<td><strong>Reinforcement. ( \gamma_s )</strong></td>
<td>( \frac{1.15}{1.25} )</td>
<td>( \frac{1.00}{1.10} )</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Plain Concrete</strong></td>
<td>( \gamma_c )</td>
<td>( \frac{1.50}{1.75} )</td>
<td>( \frac{1.25}{1.50} )</td>
</tr>
</tbody>
</table>

1) When the design is to be based on dimensional data that include specified tolerances at their most unfavourable limits, structural imperfections, placement tolerances as to positioning of reinforcement, then these material coefficients can be used. When these coefficients are used then any geometric deviations from the approved for construction drawings shall be evaluated and considered in relation to the tolerances used in the design calculations.

2) Design with these coefficients allows for tolerances in accordance with [6.3.3] or alternatively on cross sectional dimensions and placing of reinforcements that do not reduce calculated resistance by more than 10 percent. If specified tolerances are in excess of those given in [6.3.3] or the specified tolerances lead to greater reductions in calculated resistance, the excess tolerances or the reduction in excess of 10 percent shall be accounted for in resistance calculations. Alternatively, material coefficients may be taken according to those given under 1.
### 6.3 Basis for Design by Calculation

#### 6.3.1 Concrete grades and in situ strength of concrete

**6.3.1.1** The characteristic strength of concrete cylinders is defined in [6.2.3].

In Table 6-2, normalized values for in situ strength of concrete are given. The given tensile strength is valid for concrete in uni-axial tension.

The values are specific for concrete, not exposed to cryogenic temperatures.

Normal weight concrete has grades identified by C and lightweight aggregate concrete grades are identified by the symbol LC. The grades are defined in Table 6-2 as a function of the characteristic compression cylinder strength of concrete, $f_{ck}$.

**Table 6-2 Concrete grades and structural strength (MPa).**

<table>
<thead>
<tr>
<th>Strength</th>
<th>Concrete grade (MPa) 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- / C15 / LC15 / C25 / LC25 / C35 / LC35 / C45 / LC45 / C55 / LC55 / C65 / LC65 / C75 / LC75 / C85 / LC85 / C95 / C105</td>
</tr>
<tr>
<td>Characteristic comp. cube strength, $f_{ck}$</td>
<td>15 / 25 / 35 / 45 / 55 / 65 / 75 / 85</td>
</tr>
<tr>
<td>Characteristic comp. cylinder strength, $f_{ck}$</td>
<td>12 / 20 / 28 / 36 / 44 / 54 / 64 / 74 / 84 / 94</td>
</tr>
<tr>
<td>Norm. structural comp. strength, $f_{cn}$</td>
<td>11.2 / 16.8 / 22.4 / 28 / 33.6 / 39.2 / 44.8 / 50.4 / 56 / 61.6</td>
</tr>
<tr>
<td>Characteristic tensile strength, $f_{tk}$ 2)</td>
<td>1.55 / 2.10 / 2.55 / 2.95 / 3.30 / 3.65 / 4.00 / 4.30 / 4.60 / 4.90</td>
</tr>
<tr>
<td>Norm. structural tensile strength, $f_{tn}$</td>
<td>1.00 / 1.40 / 1.70 / 2.00 / 2.25 / 2.50 / 2.60 / 2.70 / 2.70 / 2.70</td>
</tr>
</tbody>
</table>

1) Concrete grades are related to the characteristic compressive cylinder strength and is denoted by C for normal dense aggregate concrete and LC for lightweight aggregate concrete. The grades are defined in this Table.

2) The given tensile strength applies to concrete subjected to uni-axial tension.

**6.3.1.2** The strength values given in Table 6-2 apply to lightweight aggregate concrete with the following limitations and modifications:

$$f_{ck} < f_{ck2} (\rho_1)^2$$

where:

$f_{ck2} = 94 \text{ MPa}$ and $\rho_1 = 2200 \text{ kg/m}^3$

Tensile strength, $f_{tk}$, and in situ strength, $f_{tn}$, shall be multiplied by the factor $(0.15 + 0.85 \rho/\rho_1)$

where:

$\rho_1 = 2200 \text{ kg/m}^3$ if the tensile strength is not determined by testing

$\rho = \text{Density of the lightweight concrete.}$
For lightweight aggregate concrete with intended concrete strength $f_{cck} > f_{cck3} (\rho / \rho_1)^2$, where $f_{cck3} = 64 \text{ MPa}$ and $\rho_1 = 2200 \text{ kg/m}^3$, it shall be shown by test samples that a characteristic strength, 15% higher than the intended, can be achieved. The test shall be carried out on concrete samples with the same material composition as intended used.

6.3.1.3 For normal density concrete of grade higher than C85 and lightweight aggregate concrete of all grades, it shall be documented by testing that the concrete satisfies the requirements on the characteristic compressive cylinder strength. This also applies if the regular compliance control of the concrete production is performed by testing the compressive cube strength.

6.3.1.4 For concrete at high temperatures for a short period (fire), it may be assumed, provided more accurate values are not known, that the compressive strength reduces linearly from full value at 350°C to zero at 800°C. The tensile strength may be assumed to decrease from full value at 100°C to zero at 800°C. If the concrete is exposed to temperatures above 200°C for a longer period of time, the strength properties of the concrete shall be based on test results.

6.3.1.5 For concrete exposed to temperatures below -60°C, the possible strength increase in compressive and tensile strength may be utilized in design for this conditions provided the strength are determined from relevant tests under same conditions (temperature, humidity) as the concrete in the structure. An increase in tensile strength of concrete caused by low temperatures will generally tend to increase the distance between the cracks, hence increase the crackwidth.

6.3.1.6 The characteristic tensile strength of the concrete, $f_{tk}$, may be determined by testing of the splitting tensile strength for cylindrical specimens at 28 days in accordance with ISO 4108. The characteristic tensile strength, $f_{tk}$, shall be taken as $2/3$ of the splitting strength determined by testing.

6.3.1.7 By rehabilitation or by verifying the capacity in structures where the concrete strength is unknown, the strength shall be determined on the basis of drilled core specimens taken from the structure. For interpretation of the drilled core reference is made to DNVGL-ST-C502.

6.3.2 Concrete stress – strain curves for strength design

6.3.2.1 The shape of the stress/strain relationship for concrete in compression of a specified grade shall be chosen such that it results in prediction of behavioural characteristics in the relevant limit states that are in agreement with results of comprehensive tests. In lieu of such data, the general relationship given DNVGL-ST-C502 can be used.

6.3.2.2 For normal dense concrete of grades between C25 and C55, the following simplified stress/strain diagram may be used.
For lightweight aggregate concrete of grades between LC15 and LC45, a simplified bilinear stress – strain diagram may be applied for calculation of capacities. The maximum strain limit for LWA concrete in compression is

\[ \varepsilon_{cu} = \varepsilon_1 + \frac{0.7 \rho}{\rho_1} \]

where \( \varepsilon_1 = -3.5\% \), \( \rho_1 = 2400 \text{ kg/m}^3 \) and \( \rho = \text{density of the LWA} \).
6.3.2.4 For calculation of capacities for axial forces and bending moments, different stress distributions from those given herein ([6.3.2.1], [6.3.2.2], [6.3.2.3]) may be applied as long as they do not result in a higher sectional capacity.

6.3.2.5 Another stress distribution than that given in [6.3.1] to [6.3.4] may be assumed when calculating the capacity for axial force and bending moment, provided this will not give a larger capacity for the cross section.

6.3.2.6 For reinforcement, a relationship between force and strain which is representative for the type and make in question shall be used.

The stress-strain diagram for design is found by dividing the steel stress $\sigma_s$ by the material coefficient $\gamma_s$.

Any deviating properties in compression shall be considered.

6.3.2.7 Where the assumed composite action with the concrete does not impose stricter limitations, the strain in the reinforcement shall be limited to 10 ‰. For prestressed reinforcement the prestressing strain is added to this limit.

6.3.2.8 For reinforcement in accordance with Sec.4, the steel stress may be assumed to increase linearly from 0 to $f_{sd}$ when the strain increases from 0 to $\varepsilon_{sy} = f_{sk}/E_{sk}$.

The reinforcement stress may be assumed to be equal to $f_{sd}$ when the strain varies between $\varepsilon_{sy}$ and $\varepsilon_{su}$. The strain $\varepsilon_{su}$ shall not exceed 10 ‰.

The steel can be assumed to have the same strain properties and yield stress in both compression and tension.

![Stress-strain diagram for reinforcement in accordance with Sec.4.](image)

**Figure 6-3 Stress-strain diagram for reinforcement in accordance with Sec.4.**

6.3.2.9 For temperatures above 150°C, the stress-strain diagram for ribbed bars in accordance with Sec.4 can be assumed to be in accordance with Figure 6-4.
The diagram in Figure 6-4 does not include thermal strain or creep strain caused by high temperature.

6.3.2.10 Reinforcement exposed to low temperature shall remain ductile under the applicable temperature range.

6.3.2.11 Spiral reinforcement in columns, shear reinforcement, torsional reinforcement, and reinforcement in construction joints, shall be calculated in accordance with DNVGL-ST-C502. The utilized stress shall not be higher than the stress corresponding to 2.5 ‰ strain. For prestressed reinforcement, the prestressed strain is added.

For confinement of the concrete compression zone in DLE design, special considerations shall be made.

### 6.3.3 Geometrical dimensions in the calculation of sectional capacities

6.3.3.1 When allowing larger deviations in dimensions than those specified in Table 6-3, the deviations in sectional dimensions and reinforcement position shall be considered in the design. See also Table 6-1. Smaller deviations than the specified tolerances may be considered.

#### Table 6-3 Acceptable deviations.

<table>
<thead>
<tr>
<th>Type of dimensional deviation</th>
<th>Maximum tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall dimension</td>
<td>± 25 mm</td>
</tr>
<tr>
<td>Cross-sectional</td>
<td>± 8%</td>
</tr>
<tr>
<td>Type of dimensional deviation</td>
<td>Maximum tolerance</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Perpendicularity</td>
<td>8 ‰</td>
</tr>
<tr>
<td>Inclination</td>
<td>3 ‰</td>
</tr>
<tr>
<td>Local variations (1 m measuring length)</td>
<td>8 mm</td>
</tr>
<tr>
<td>Local variations (2 m measuring length)</td>
<td>12 mm</td>
</tr>
</tbody>
</table>

For structures of special shapes and geometry alternative tolerances may be specified from a strength point of view provided the capacity calculated, based on the specified tolerances, does not reduce the capacity with more than 10%.

6.3.3.2 If the most unfavourable combinations of specified tolerances for section's dimensions and reinforcement positions are considered and conformity control verifies that the actual deviations do exceed those specified, then the increased material coefficients in accordance with Table 6-1 may be used. Should the as-built documentation show that the intended deviation in tolerances are not met, then the section shall be re-evaluated in all relevant limit states.

6.3.3.3 For structures cast under water, the outer 100 mm of concrete at horizontal construction joints and in the contact area between the ground and the concrete shall not be taken into account as effective cross section for transfer of forces. If the structure is set at least 100 mm into rock, the entire concrete section can be calculated as effective for transfer of forces to the ground.

6.3.4 Tension in structural members

6.3.4.1 Tensile forces shall be provided for by reinforcement with the following exceptions:

— tension caused by shear force, anchorage or splicing of reinforcement, and by partially loaded areas, may be assumed transferred by the concrete for design purposes in accordance with this standard.

6.3.5 Fatigue strength relationships

6.3.5.1 Fatigue strength relationships (S-N curves) for concrete shall take into account all relevant parameters, such as:

— concrete quality
— predominant load effect (axial, flexural, shear, bond or appropriate combinations of these)
— state of stress (cycling in pure compression or compression/tension)
— formulas for prediction of fatigue life for concrete are provided in DNVGL-ST-C502.
— surrounding environment (air, submerged).

6.3.6 Deformation induced loads, prestressing and creep

6.3.6.1 Deformation induced loads created by imposed deformations in the structure, are loads to be treated as deformation loads (D), and not as a force which requires equilibrium. For more details reference is made to DNVGL-ST-C502.
6.3.7 Effect of water pressure

6.3.7.1 The effect of water pressure in the concrete shall be fully considered when relevant.

6.3.7.2 The effect of hydrostatic pressure on the concrete strength shall be evaluated where relevant. (For lightweight aggregate concrete, this effect may be significant.)

6.3.7.3 The effect of hydrostatic forces acting on the faces of cracks shall be taken into account in the designs for ULS, SLS, ALS and FLS.

6.4 Design of structural members

6.4.1 Design capacity in ultimate limit state (ULS)

6.4.1.1 Detailed design of moment capacity under different magnitudes of axial loads shall be in accordance with DNVGL-ST-C502.

6.4.1.2 Slender structural Members shall be designed in accordance with DNVGL-ST-C502.

6.4.1.3 Design of shear capacity in beams, slabs and wall shall be in accordance with DNVGL-ST-C502.

6.4.1.4 Design for torsional moments in beams shall be in accordance with DNVGL-ST-C502.

6.4.1.5 Design of structural members subjected to in-plane forces shall be in accordance with the general method outlined in DNVGL-ST-C502.

6.4.1.6 Regions with discontinuity in Geometry or loads shall be designed in accordance with DNVGL-ST-C502.

6.4.1.7 Design for shear forces in construction joints shall be in accordance with DNVGL-ST-C502.

6.4.1.8 Design for bond strength and sufficient anchorage of reinforcement shall be in accordance with DNVGL-ST-C502.

6.4.1.9 Designed of partially loaded areas shall be in accordance with DNVGL-ST-C502.

6.4.2 Capacity in fatigue limit state (FLS)

6.4.2.1 Design for fatigue strength of members exposed to stress fluctuations shall be in accordance with DNVGL-ST-C502.

6.4.3 Design for accidental limit state (ALS)

6.4.3.1 Design for accidental strength shall be in accordance with DNVGL-ST-C502.

6.4.4 Design for ductility

6.4.4.1 Terminals located in seismically active areas shall be designed to possess adequate strength and stiffness to withstand the effect of strength level earthquake (SLE) as well as sufficient ductility to remain stable during the rare motions of greater severity associated with ductility level earthquake (DLE). The
sufficiency of the structural strength and ductility shall be demonstrated by strength and, as required, ductility analyses.

6.4.4.2 Design in SLE, using ULS load and material factors in accordance with this standard, shall demonstrate that the structure is adequately designed for strength to withstand this loading without damage. The earthquake loading shall be combined with other environmental loads at a magnitude shown likely to occur at the same time as the strength level earthquake.

6.4.4.3 Design in the DLE, using ALS load and material factors, shall to be demonstrated that the structure has the capability of absorbing the energy associated with the ductility level earthquake without reaching a state of incremental collapse. The distortion should be, at least, twice as severe as those resulting from the SLE earthquake. This applies to seismic active areas. The stored LNG shall be contained in the containment structure after the DLE.

6.4.4.4 In United States’ offshore regions, reference is be made to the API RP 2A for design criteria for earthquake. In other seismically active locations around the world, a seismic report may be prepared that presents the seismic design parameters in a manner consistent with the approach taken in the RP 2A.

6.4.4.5 The compressive strain in the concrete at its critical sections (including plastic hinges locations) shall be limited to 0.3%, except when greater strain may be accommodated by confinement steel.

6.4.4.6 For structural members or sections subjected to flexural bending or to load reversals, where the percentage of tensile reinforcement exceed 70% of the reinforcement at which yield stress in the steel is reached simultaneously with compressive failure in the concrete, special confining reinforcement and/ or compressive reinforcement shall be provided to prevent brittle failure in the compressive zone of the concrete.

6.4.4.7 Web reinforcement of flexural members shall be designed for shear forces which develop at full plastic bending capacity at end sections. In addition
- the diameter of rods used as stirrups is not to be less than 10 mm
- only closed stirrups (stirrup ties) shall be used
- the spacing of stirrups is not to exceed the lesser of d/2 or 16 bar diameters of compressive reinforcement, where d is the distance from the extreme compression fibre to the centroid of tensile reinforcement. Tails of stirrups shall be anchored within a confined zone, i.e. turned inward.

6.4.4.8 No splices are allowed within a distance d from a plastic hinge. Lap splices shall be at least 30 bar diameters long, but not less than 460 mm.

6.4.5 Design in serviceability limit state (SLS)

6.4.5.1 Design in SLS shall in general be in accordance with requirements in DNVGL-ST-C502.

6.4.5.2 The durability of the concrete structure is ensured by designing the structure in accordance with DNVGL-ST-C502.

6.4.5.3 Design for displacement and vibration in the structure shall be in accordance with DNVGL-ST-C502.

6.4.5.4 Tightness against leakage of fluid shall be designed in accordance with DNVGL-ST-C502. For structural concepts, where concrete acts as secondary barrier for LNG leakage and insulation may become saturated by the permeability of the concrete, then a metal membrane is required. This metal membrane may not possess cryogenic properties, if the purpose of the membrane is to protect the insulation from getting saturated and shall not be exposed to cryogenic temperature during normal operation.
6.4.5.5 Concrete is not gas tight and special measures shall be taken to ensure a gas tight concrete structure, when this is required. An example is concepts where the concrete wall is designed to be part of the primary containment system.

6.4.5.6 Crackwidth calculations shall be in accordance with the approach outlined in DNVGL-ST-C502.

6.4.5.7 The maximum stress levels in prestressed concrete structure under SLS loading shall be limited to the values given in DNVGL-ST-C502.

6.4.5.8 Structures exposed to repeated freeze/thaw action shall be design in accordance with the requirements in DNVGL-ST-C502.

6.4.6 Design by testing

6.4.6.1 Concrete members can be designed by testing or by a combination of calculations and testing in accordance with DNVGL-ST-C502.

6.5 Detailing of reinforcements

6.5.1 General

6.5.1.1 Requirements to positioning of reinforcement are provided in DNVGL-ST-C502.

6.5.1.2 Concrete cover to reinforcement shall be in accordance with DNVGL-ST-C502. The requirements to concrete cover is given in DNVGL-ST-C502.

6.5.1.3 Reinforcement shall be spliced in accordance with DNVGL-ST-C502.

6.5.1.4 The reinforcement bars shall be bent in accordance with DNVGL-ST-C502.

6.5.1.5 Minimum area of reinforcement shall be provided in the structural member in accordance with DNVGL-ST-C502.

6.6 Corrosion control

6.6.1 General

6.6.1.1 Corrosion control shall be carried out in accordance with DNVGL-ST-C502.
SECTION 7 LNG CONTAINMENT SYSTEM

7.1 Introduction

7.1.1 General

7.1.1.1 For the design of primary steel containment tanks (membrane or independent tanks) reference is made to DNV GL rules for classification DNVGL-RU-OU-0103 Floating LNG/LPG production, storage and loading units, IMO - IGC Code The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk and EN-1473 and NFPA 59A as the general design standard for the LNG Containment System. See also guidelines for design of LNG containment systems in App.C General design principles LNG containment structures (guidelines) and App.D Detailed structural design of containment system(Guidelines). In applying the above referenced standards the special impact of the marine environment on safety shall be especially evaluated.

7.1.1.2 For vessels, the IMO type B independent tanks are widely used. These tanks are designed, constructed and inspected in accordance with the requirements in the DNV GL rules for classification DNVGL-RU-OU-0103 Floating LNG/LPG production, storage and loading units and the IMO- IGC Code. These tanks are designed under the principle of minimum leak detection of LNG before failure of the steel support structure.

7.1.1.3 LNG containment structures on land are generally designed using a double barrier system. Prestressed concrete may be used both as primary and secondary barrier with provision of a gas tight barrier. This barrier may be of carbon steel if located on the inner surface of the secondary barrier. The use of a concrete primary barrier of concrete will require a special design minimizing the temperature stresses.

7.1.1.4 The standards DNV GL rules for classification DNVGL-RU-OU-0103 Floating LNG/LPG production, storage and loading units, IGC – IMO Code, EN-1473 and NFPA-59A shall not be interchanged in the design of the primary containment system. The same standards shall be used throughout.

Guidance note:
In mixing of standards, use of other design standards, methods and modifications the same overall safety level as this standard shall be documented.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.1.2 Storage containment systems

7.1.2.1 IGC-IMO Type b TANKS
Under the category of Type B independent tanks, there are currently two approved systems:
— the Moss spherical tank system
— the IHI self-supporting prismatic type B (IHI-SPB) system

The Moss spherical tank system is most widely used on ships. The spherical, single containment tank system consists of an unstiffened, sphere supported at the equator by a vertical cylinder. The cylinder is monolithically connected to the tank by a profile in the tank wall. Both sphere and outer shell may be made in aluminium alloy, stainless steel or 9% nickel steel.
The IHI-SPB system, currently approved has tanks, which may be constructed of aluminium, stainless steel or 9% nickel steel. The IHI-SPB prismatic tanks would be supported by a system of chocks, which in addition to the chocks supporting the vertical weight of the tank, incorporate lower and upper rolling chocks to cater for the dynamic behaviour of the tank system under different loading conditions.
The tanks are designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. IGC Code has special requirements to material documentation, construction supervision, detection system, monitoring system and in-service inspection which shall be followed for these tanks. A partial secondary barrier is use by which the cargo tanks insulation system contains any leakage of LNG and directs it to the drip trays located around the support chocks. The support structure for the tank either floating or fixed gravity platform shall be designed in accordance with this standard. The difference in dynamic performance of the two platforms types shall be accounted for in the design of the containment structure.

7.1.2.2 Double containment tank
A double containment tank is designed and constructed so that both the inner self supporting primary container and the secondary container are capable of independently containing the refrigerated liquid stored. To minimise the pool of escaping liquid, the secondary container should be located at a distance not exceeding 6 m from the primary container. The primary container contains the refrigerated liquid under normal operating conditions. The secondary container is intended to contain any leakage of the refrigerated liquid, but it is not intended to contain any vapour resulting from this leakage.

7.1.2.3 Full containment tank
A tank designed and constructed so that both self supporting primary container and the secondary container are capable of independently containing the refrigerated liquid stored and for one of them its vapour. The secondary container can be 1 m to 2 m distance from the primary container. The primary container contains the refrigerated liquid under normal operating conditions. The outer roof is supported by the secondary container. The secondary container shall be capable both of containing the refrigerated liquid and of controlled venting of the vapour resulting from product leakage after a credible event.

7.1.2.4 Membrane tank
The membrane tank consists of thin layers (barriers) of either stainless steel, GRP/aluminium foil composite, or invar that are supported through the insulation by the boundary structure of the cargo tank itself. A membrane tank should be designed and constructed so that the primary container, constituted by the membrane, is capable of containing both the liquefied gas and its vapour under normal operating conditions and the concrete secondary container, which supports the primary container, should be capable of containing all the liquefied gas stored in the primary container and of controlled venting of the vapour resulting from product leakage of the inner tank. The vapour of the primary container is contained by a steel roof liner which forms with the membrane an integral gastight containment. The action of the liquefied gas acting on the primary container (the metal membrane) is transferred directly to the prestressed concrete secondary container through the load bearing insulation. Different types of membranes are available in the marked as the insulation may contain both a primary and a secondary barrier or alternatively only a primary barrier, the concrete supporting structure acting as the secondary barrier. For steel vessels it is normal to have the primary and secondary barrier built into the insulation. For a concrete terminal either floating or gravity based, the concrete hull may be used as secondary barrier based on an appropriate hazard identification and risk evaluation of the layout. The design of the membrane tanks shall be done incorporating the possible deformation of the concrete structure from environmental response in accordance with Sec.4. Sloshing effects in the membrane tanks shall be carefully examined. Fatigue approval of the membrane design itself is another area that needs careful consideration at the system approval stage and during design approval. The fatigue capability of key weld connections in the containment systems barriers, are dependent upon the global stress level of the concrete structure.
The stress variation in a gravity base/fixed concrete platform is considered to be less severe than in a steel vessel.

The membrane may be designed in accordance with NFPA 59A and EN-1473. Environmental load effects and terminal structure responses shall be included in the design.

**7.1.2.5 Cryogenic concrete tank**

A cryogenic concrete tank is either a double containment tank or a full containment tank. For this type of tanks, the walls of the primary and secondary containers are both of prestressed concrete.

For more details of possible cryogenic concrete tanks on land, see EN1473. For land structures, the primary containment will be made from cryogenic prestressed concrete, the base being made from cryogenic material (nickel steel, aluminium or stainless steel) and a cryogenic prestressed concrete secondary container.

No concepts have currently been developed using concrete as primary barrier for offshore terminals. It is, however, anticipated that such containment structures may be developed. One of the main challenges is the handling of temperature stresses. Material properties shall be derived for the temperature range to which the material is exposed.

Several combinations are possible for the use of prestressed reinforced concrete in the cryogenic storage due to the good performance of prestressed concrete under cryogenic temperature.

Concrete at cryogenic temperature has increased strength in tension and compression, increased Young’s modulus, increased conductivity dependent on moisture content, increased thermal conductivity, increased specific heat and a coefficient of thermal expansion which is reduced at cryogenic temperature (dependent of moisture content).

Reinforced concrete is not gas tight and a membrane is required to ensure gas tightness. The membrane may be located on the inside of the secondary barrier. In the latter case, the application of the gas barrier can be made from carbon steel.

Reinforcement and prestressed steel exposed to cryogenic temperature shall be ductile under the cryogenic temperature.

In the design of a cryogenic tank system, temperature effects on the tank systems shall be accounted for. Temperature stresses caused by constraints may control the prestressing level to ensure the required liquid tightness.

**7.2 Design of LNG containment structure**

**7.2.1 Design principles**

7.2.1.1 The minimum recurrence interval used to establish the magnitude of the design environmental condition is 100 years, except where use of a shorter recurrence interval produces higher magnitude load effects. As applicable, when a National Authority having jurisdiction over the LNG terminal specifies the use of a lower return period, this shall be specially considered.

7.2.1.2 All hazards and mitigation actions to reduce the risk to an acceptable level shall be included in the design of the terminal, the layout and the containment structure.

**7.2.2 Design basis**

7.2.2.1 The design of the primary containment system shall be in accordance with the criteria defined in this standard.

Detailed guidelines for the design of the containment structure are provided in App.A to App.D.

7.2.2.2 In addition to the above requirements mentioned, it is also the responsibility of the designer, owner and operator to comply with additional requirements that may be imposed by the flag state or the coastal
7.2.2.3 The complete basis for the design shall be stated in the operational manual and shall include the intended location, the envelope of environmental operational conditions and the storage capacities and throughputs of the production/re-gasification systems.

7.2.3 Design of LNG primary tanks

7.2.3.1 The structural strength design shall take into account necessary strengthening of support structures for equipment applied in and forces introduced by the production facilities and operation.

7.2.3.2 Support structure in steel for independent LNG tanks shall comply with the requirements in DNVGL-OS-C101.

7.2.3.3 When the strength of the independent cargo tanks are designed in accordance with DNV GL rules for classification DNVGL-RU-OU-0103 Floating LNG/LPG production, storage and loading units, the strength of the independent cargo tanks shall comply with the requirements in the DNV GL rules for classification DNVGL-RU-SHIP Pt.5 Ch.7 Liquefied gas tankers.

Accelerations acting on the tanks shall be determined by direct calculations based on location specific environmental data with a return period of 100 years. DNVGL-OS-C101 replaces all references to the DNV GL rules for classification DNVGL-RU-SHIP Pt.3 Hull.

The containment systems shall be designed to withstand the loads referred to in 303 at all loading conditions. Material selection shall comply with the requirements in DNVGL-OS-C101. Cargo tanks and supporting structure subject to reduced temperature due to cargo shall comply with the requirements in the DNV GL rules for classification DNVGL-RU-SHIP Pt.5 Ch.7 Liquefied gas tankers. DNVGL-OS-C101 replaces all references to the DNV GL rules for classification DNVGL-RU-SHIP Pt.3 Hull.

7.2.4 Containment systems

7.2.4.1 The LNG containment system shall be designed and constructed in accordance with the requirements of this standard, DNVGL-RU-OU-0103 Floating LNG/LPG production, storage and loading units, IGC-IMO Code, NFPA 59A or EN-1473. The application of NFPA 59A and EN-1473 requires special considerations in handling environmental loading and the marine environment. See also App.A to App.D.

The design shall incorporate the following features:

— a secondary containment system such if there is a failure in the primary system, the secondary system shall be capable of containing the leaked contents for an agreed period of time consistent with the approval scenarios for the safe disposal of same (special considerations for IMO Type B Independent tanks)
— there shall be a minimum of two independent means of determining the liquid level in the LNG storage tanks
— means to fill the tank from both the top and bottom to avoid stratification
— independent high and high-high level alarms
— at least one pressure gauge connected to the vapour space
— two independent overpressure protection devices
— devices for measuring the liquid temperature at the top, middle and bottom tank
— a gas detection system which will alarm high gas concentrations in the space between the primary and secondary barrier
— no pipe penetrations though the base or the walls.

7.2.4.2 Tanks together with their supports and fixtures shall be designed with considerations of appropriate combinations of the following loads:
— internal pressure
— external pressure
— dynamic loads due to motion of the floating terminal
— seismic loads
— thermal loads
— sloshing
— loads corresponding to vessel deflection on floating units
— loads corresponding to global deformation in gravity based structures
— tank and cargo weight with corresponding reactions in way of the supports
— insulation weight
— loads in way of towers and other attachments.

The sloshing loads shall consider any level of filling in each tank.

On floating terminal structures, the loads on the supports, are also to consider the terminal structure inclined up to the worst angle of inclination resulting from flooding consistent with the terminal's damage stability criteria up to an angle of 30 degrees.

7.2.4.3 For containment systems designed in accordance with IGC-IMO Code, the containment system shall be fully design, constructed and inspected during the service life in accordance with IGC –IMO Code. Special conditions apply to IMO Type B Independent tanks.

Guidance note:
Documented inspection regimes with the same safety levels as achieved by the IDC-IMO Code may be applied.

7.2.4.4 For containment systems designed in accordance with the principles outlined in NFPA 59A or EN-1473, the containment system shall be fully design, constructed and inspected during the service life in accordance with this standard, NFPA 59A or EN-1473. The effect of sloshing and other effects from the marine environment shall be accounted for in the design. Such load effects are not accounted for in the above standards.

7.2.4.5 The IGC-IMO Code Type B independent tanks are designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. The following references to IGC-IMO shall be noted:
— the requirements to analysis of such tanks are defined in IGC –IMO Code Clause 4.4.5
— the limitations in stress level is defined in IGC –IMO Code Clause 4.5.1.4
— requirements to secondary Barrier in accordance with IGC -IMO Code Clauses 4.7.3 and 4.7.4
— requirements to insulation in IGC –IMO Code Clause 4.8
— requirements to materials IGC-IMO Code Clause 4.9
— construction and testing IGC-IMO Code Clause 4.10
— survey procedure in IGC-IMO Code Clause 1.5
— a partial secondary barrier is use by which the cargo tanks insulation system contains any leakage of LNG and direct it to the drip trays located around the support chocks.

IGC-IMO Type B independent tanks designed, constructed and maintained in accordance with the requirement of the IGC-IMO Code can be used in both floating and gravity based concrete terminals.

7.2.4.6 Design of containment structures using concrete as a structural material shall be in accordance with this standard. Relevant material properties for the concrete for the exposure temperature shall be documented.

7.2.4.7 Prestressed concrete may be used as secondary barrier in a membrane tank system, the design, construction and in-service inspection shall be in accordance with this code.
7.2.5 Process facilities
The process facilities are not covered by this standard.

7.3 Safety systems

7.3.1 General

7.3.1.1 The safety systems are intended to protect life, property and the environment and are applicable to the entire installation, including the loading and off-loading arrangement for gas, LNG and LNG Vapour. The overall safety system should be comprised of subsystems providing two levels of protection; primary and secondary. The primary system shall provide protection against risk of fire or explosion and the secondary system is intended to reduce the consequence of fire by affording protection to the people and the facility and reducing the risk of fire spread. The primary and secondary safety measures required consist of both active and passive systems as described in DNVGL-OS-A101. The effectiveness of this system should be established by conducting a fire and explosion hazard analysis.

Each space is considered a fire risk, such as the process equipment, cargo deck area, spaces containing gas processing equipment such as compressors, heaters, etc. and the machinery equipment of category *A* as defined by SOLAS, shall be fitted with an approved gas detection, fire detection and fire extinguishing system complying with DNVGL-OS-A101.

7.3.1.2 In addition to the DNV GL requirements of DNVGL-OS-A101, depending on the flag of registry of the unit and the area of operation, the flag state and the coastal state may have additional requirements or regulations which may need to be complied with.

7.3.1.3 Primary systems

Many of the products being handled on board an offshore LNG terminal are highly flammable and therefore examples of some of the measures that may be necessary to protect against fire or explosion risks are as follows:

— avoid the possibility of liquid or gas escaping where there is a source of vapour ignition
— provide fixed gas detection comprised of two different types of elements, which will activate an audible alarm at a manned control station to alert of a gas release before the gas can mitigate to an unclassified area
— a low temperature detection system in and around the LNG tank storage facility to sound and alarm at a manned station to alert in the event of a liquid or vapour leak
— a multi-tiered emergency shutdown system capable of isolating an upset condition with local system or single train shutdowns before the conditions requires a complete platform shutdown
— maintain integrity of the containment boundary at all times to reduce the possibility of a controlled discharge of LNG or LNG vapour. Where, it is possible for LNG to leak in the event of a failure, such as a joint, valve, or similar connection, a spill tray immediately underneath these components should be provided
— maintain a positive separation between process areas, cargo storage, cargo handling area and area containing source of vapour ignition
— eliminate direct access from the space containing process equipment to the spaces containing machinery such as electrical equipment, fire equipment, or other similar equipment which may be considered an ignition source.

7.3.1.4 Secondary system

The secondary systems are systems which are employed to prevent the spread of fire and may be categorized as follows:

— fire detection system
— fire extinguishing systems
— water deluge system
— personnel protection and life saving appliances
— structural fire protection.

7.3.2 Cargo system and equipment

7.3.2.1 The requirements given by the Rules for Classification of Ships Pt.5 Ch.5, shall be complied with as referenced below:
— piping systems in cargo area (Pt.5 Ch.5 Sec.6 A, B and C)
— cargo pressure or temperature control (Pt.5 Ch.5 Sec.7 A)
— cargo heating arrangements (Pt.5 Ch.5 Sec.7 B)
— insulation for tanks, hold spaces and piping (Pt.5 Ch.5 Sec.7 C)
— marking of tanks, pipes and valves (Pt.5 Ch.5 Sec.8)
— gas-freeing and venting of cargo tanks and piping systems (Pt.5 Ch.5 Sec.9)
— tests after installation onboard (Pt.5 Ch.5 Sec.14, see below)
— gas operated propulsion machinery (Pt.5 Ch.5 Sec.16)
— filling limits for cargo tanks (Pt.5 Ch.5 Sec.17).
Reference to Pt.5 Ch.5 Sec.14 includes only A104 and A106. A106 shall read: The hull shall be inspected for cold spots.

7.3.3 Instrumentation and automation

7.3.3.1 Control and instrumentation systems shall provide an effective means for monitoring and controlling pressures, temperatures, flow rates, liquid levels and other process variables for a safe and continuous operation of the process and storage facilities.

7.3.3.2 Control and instrumentation systems for the process, process supports, utility and electrical systems shall be suitable for the intended application.

7.3.3.3 All control and safety shutdown system shall be designed for safe operation of the equipment during start-up, shutdown and normal operational conditions.

7.3.3.4 The requirements given in the Rules for Classification of Ships Pt.5 Ch.5 Sec.13 shall be complied with. These requirements are supplemented as follows:
— the alarm shall be so that the operator will have sufficient time to stop the flow without exceeding the maximum permissible filling level.
— the automatic shut off valve shall be operated as part of the shutdown logic for the emergency shutdown system or process shutdown system integrating the process systems.
— alarm levels for gas detections are covered by DNVGL-OS-D301; at levels of 25% and 60% of lower explosion limit.

7.3.4 Gas detection systems

7.3.4.1 The fixed gas detection system shall comply with the requirements in DNVGL-OS-A101.

7.3.5 Emergency shutdown systems

7.3.5.1 Emergency shutdown shall be design in accordance with DNVGL-OS-A101.
SECTION 8 CONSTRUCTION

8.1 General

8.1.1 General

8.1.1.1 Fabrication and construction of reinforced and prestressed concrete LNG terminal shall be carried out in accordance with DNVGL-ST-C502. The scope and definition are provided in DNVGL-ST-C502.

8.1.1.2 The approved for construction documentation specified in DNVGL-ST-C502 shall be made available at the construction site, prior to start of construction.

8.1.1.3 A supervision and inspection activity in accordance with DNVGL-ST-C502 shall be implemented at the construction site in order to ensure appropriate compliance between the for construction documentation and the as built structure.

8.1.1.4 The construction activity shall be planned in accordance with DNVGL-ST-C502 prior to start of construction.

8.1.1.5 The constituent materials, reinforcement, prestressing systems and concrete shall be documented in accordance with DNVGL-ST-C502 prior to start of construction.

8.1.1.6 The Formworks shall be designed in accordance with DNVGL-ST-C502.

8.1.1.7 The reinforcement, prestressing bars and embedded steel shall be placed in the formwork in accordance with the requirements given in DNVGL-ST-C502.

8.1.1.8 The production of concrete and grout shall be in accordance with DNVGL-ST-C502.

8.1.1.9 The transport, casting, compaction and curing of the concrete shall be in accordance with DNVGL-ST-C502.

8.1.1.10 The prestressing system shall be stressed and completed in accordance with DNVGL-ST-C502.

8.1.1.11 Repair of the concrete structure shall be in accordance with the requirements of DNVGL-ST-C502.

8.1.1.12 The corrosion protection system shall be installed and tested in accordance with DNVGL-ST-C502.

8.1.1.13 During construction as-built construction records and as-built documentation shall be assembled and reworked in accordance with DNVGL-ST-C502.

8.1.1.14 The use of precast elements shall be designed for all temporary phases and its use documented in accordance in accordance with DNVGL-ST-C502.

8.1.1.15 Geometric tolerances for the placements of reinforcement, local and global dimensions etc. shall be in accordance with DNVGL-ST-C502.
8.2 Specific to LNG/LPG containment structures

8.2.1 Construction, commissioning and turnaround

8.2.1.1 Acceptance tests: Equipment installed on the plant shall be tested in accordance with the relevant codes and standards especially for:
— high pressure pipework
— pressure vessels.

8.2.1.2 Preparation at start-up and shutdown: The presence of hydrocarbons and of low temperatures, requires special commissioning and shutdown procedures. These include, before start up:
— inverting in order to eliminate oxygen to obtain a maximum oxygen content of 8 mol %
At the time of any shutdown for servicing which requires opening of a circuit, it is necessary to:
— eliminate liquid hydrocarbons
— defrost (or derime) by circulating warm dry gas and inert by scavenging with nitrogen before being able to open up to atmosphere.

8.2.1.3 Commissioning and decommissioning of LNG/LPG storage tanks should not be regarded as a normal operational requirement and should not be attempted on any routine basis.

8.2.1.4 LNG/LPG facilities should be designed to ensure that commissioning, de-commissioning and re-commissioning can be carried out in a controlled and safe manner. In this respect, special attention should be given to the following:
— purge connections
— instrumentation for monitoring and recording of gaseous and liquid content during emptying and purging operations.
— sufficient monitoring and/or control devices to ensure that the inner and outer tanks are not subjected to positive or negative pressures beyond the design limits during the purge (in particular, upheaval of the bottom centre of the tank should be prevented).
— instrumentation to permit regular sampling and monitoring of the atmosphere in the tank during inspection and repair to ensure absence of hydrocarbons or any combustible/toxic gases.
— instrumentation and piping for a controlled cool-down.

The tank contractor has to supply a detailed procedure for commissioning and decommissioning of the tank, to ensure that the design criteria are not exceeded.

8.2.2 Performance testing

8.2.2.1 Generally the adequacy of the tank design shall be demonstrated by means of engineering calculations and proven material properties, supplemented with adequate quality assurance and quality control procedures.

8.2.2.2 Performance aspects, however, which cannot be fully ensured, shall be verified by means of testing the LNG/LPG tank or parts thereof. Tests may include material testing under extreme conditions, structural details of tank, parts of storage system and/or the entire tank.
8.2.3 Inspection of independent steel containment tanks

**Guidance note:**
It is recommended that the following steps are carried out:

1) material identification
2) approval and qualification of weld procedures
3) qualification of welding operators
4) NDT requirements for liquid containing steel and outer tanks. Radiographic techniques and interpretation acceptance standards must be included in the specification.
   a) 100% radiography of all bottom annular plate butt welds
   b) 100% radiography of all vertical seam welds
   c) 100% radiography of all horizontal seam welds
   d) 100% radiography of butt welds of shell stiffeners
   e) 100% crack detection shall be made to the following areas:
      i) shell to floor fillet welds
      ii) shell to roof annular fillet welds
      iii) all shell and roof attachments including fittings and penetrations
      iv) all ground areas after removal of welded temporary attachments.
   f) vacuum box testing shall be carried out at the following areas of both inner and outer tanks prior to and where applicable also after the hydrotest:
      i) all floor lap welds
      ii) all floor butt welds
      iii) welds in outer tank floor.
   g) leak testing of possible outer steel roof.

---end---of---guide---note---

8.2.4 Inspection of membranes of membrane tanks

**8.2.4.1** The tightness of a corrugated membrane should be inspected by means of dye penetrant tests and an ammonia test should be carried out on all welded joints.

**Guidance note:**
The ammonia test is performed as follows; all the welds are painted with a very sensitive reagent which changes colour when in contact with ammonia. Ammonia gas mixed with air is injected in the insulation space under a low pressure. The control of the ammonia/air ratio is performed at some calibrated leaks. Possible leaks are detected and repaired. Then, the test is repeated.

---end---of---guide---note---

8.2.5 Hydrostatic testing

**8.2.5.1** To verify liquid tightness, strength of the tank, bottom insulation and tank foundation and for reasons of stress relieving of steel tanks, the primary tanks of an IMO Type B independent tank shall be water tested.

**8.2.5.2** The composition of the test water shall be determined before any hydrotest is carried out and, if necessary, measures taken to avoid corrosion.
Primary tanks shall be water-tested to a level equal to the maximum product level specified or the level 0.5 m below the top of the shell, whichever is higher. The ullage for earthquake sloshing need not be included in the design water test height.

8.2.5.3 Measurements during hydrotesting.

**Guidance note:**
- During filling and emptying of the tank, deformation of the inner tank shall be carefully monitored at various locations. The frequency of the measurements depends on the deformation behaviour. As a minimum, surveys shall be carried out at water levels of 25, 50, 75 and 100% of the full water test height.
- If unpredicted deformations are observed, water filling shall be stopped and the cause investigated.
- When the full water test height has been reached, the water shall be left in the tank for at least 48 hours, whereafter a visual inspection shall be carried out for evidence of leaks, e.g. water leaking through welds or seeping out of the foundation ring supporting the inner tank shell, etc.
- Inspect the bottom insulation for cracks and or damage where possible.
- Inspect anchor bolts for buckling/slack.

---end---of---guidance---note---

After hydrostatic testing it is recommended to vacuum-box test the primary tank bottom again.

8.2.6 Pneumatic testing

8.2.6.1 The tank shall be pneumatically tested. This can be done in accordance with the relevant BS or API codes.

8.2.7 Liners and coatings

8.2.7.1 Concrete can not be considered fully vapour tight. Therefore, the inside surface of concrete outer tanks of full containment tanks and of membrane tanks should be provided with a vapour tight liner to ensure gas tightness during normal operation. Such liner should also reduce the ingress of water vapour into the tank which could reduce the insulation capacity of the insulation system.

8.2.7.2 The internal surface of the concrete (dome) roof is usually provided with a carbon steel liner, which serve also as formwork during casting of the roof. Concrete walls and bottoms slabs are usually provided with either a carbon steel liner or with a mastic or other non-metallic coating. Reinforced concrete outer tank bottoms are sometimes provided with a secondary low temperature steel bottom to ensure liquid tightness after a leakage from the inner tank.

8.2.7.3 Non-metallic liners such as special coatings with a low permeability for methane and water vapour should have a good adhesion to the concrete and should have crack bridging properties (to bridge cracks in concrete) which ensures the sealing capacity during normal operating conditions.

8.2.7.4 Steel liners are usually checked for vapour tightness by means of vacuum box testing.

8.2.7.5 Testing of non-metallic liners: As part of the selection procedure of a suitable non-metallic liner, the required properties for gas and water vapour permeability and crack bridging capabilities should be verified. Inspection of non-metallic liners occurs visually during and after installation.

8.2.8 Cool-down

8.2.8.1 A gradual and equal cool down of a non-restrained primary tank will result only in shrinkage of the inner tank without stress generation in the tank material. A local cool-down (resulting in temperature differences), however, will result in abnormal shrinkage and stress. These stresses combined with those
already existing from fabrication and welding may result in cracking at location of stress concentration. Therefore, the cool-down of the tank shall be done very carefully. Special cool-down skin thermocouples should be connected to the inner tank bottom and inner tank shell. The permissible temperature difference between adjacent thermocouples should be established by the designer.

The use of nitrogen in cool-down may result in sub-cooling of the tank below its design temperature e.g. butane to -45°C, propane to -70°C and LNG to -180°C. This sub-cooling should always be avoided by the careful introduction of refrigerated gas into the tank, a slow cool-down and frequent, proper temperature monitoring.

8.2.9 Extreme design conditions

8.2.9.1 Subjecting an LNG tank or parts of it to extreme design conditions should be avoided as it implies testing of the structure to its ultimate design condition with inevitably some degree of damage.

8.2.10 Painting, fire proofing and embrittlement protection

8.2.10.1 Painting: Protective coating of metal surfaces of equipment, pipelines and metallic structures in an LNG installation is required. Concrete structures may also be coated to protect them from wear and tear. The coating system shall primarily protect metal surfaces against corrosion at operating conditions in the actual environment of the LNG plant location. Saliferous or aggressive atmospheres have to be taken into account.

Before any coating special preparation of the surface shall be carried out. Coating usually consists of various layers starting with primer coat, intermediate and finish coat on carbon ste low alloy steel with less than 12% Cr and austenitic stainless steel surfaces. High quality hot-dip galvanising is required on all platform and platform support steel work, stairway and handrail assemblies, ladder side rails and cages, plates, stair treads and open grid flooring etc. unless impracticable.

Galvanised surfaces shall normally be left unpainted except for marine environment for which additional painting is recommended. Galvanised metal jackets used to cover insulation of piping or equipment can receive further anti corrosion coating. It is recommended that galvanised surfaces are located so as to avoid the possibility of molten zinc contaminating stainless steel piping and equipment in the event of a fire possibly leading to inter granular corrosion and brittle failure.

For safety reasons all equipment and piping in LNG installations shall have a specific colour or marking for identification of the contents.

All painting, galvanising, colour coding and marking shall be designed and executed in accordance with local rules.

8.2.10.2 Fire proofing: Equipment and specific bulk material in LNG plants shall to be protected from the effects of heat input from fires.

Supports for equipment and bulk material have to be protected in such a way that their function and form are not adversely affected during a certain period of fire.

Fire proofing is also required on control equipment and cables in order to maintain their operability in case of fire.

Fire proofing can be provided by:
— preformed or sprayed concrete
— plate material made of mineral fibre, ceramic calcium silicate or cellular glass
— intumescent coatings.

Fire proofing shall be designed and executed in accordance with the appropriate International standards.
8.2.10.3 Embrittlement protection: Equipment and specific bulk material which could be affected by an LNG leak (for example from flanges) shall be protected from brittle failure.

Such a protection shall be achieved by an appropriate material selection (concrete, stainless steel, etc.) or by a tagging with material that will protect the equipment and specific bulk material from the cold shock.

This layer shall be designed and installed in accordance with appropriate standards. Provision shall be taken to protect their outer surface from wear and tear due to outdoor conditions.

Equipment and specific bulk material have to be protected in such a way that their function and form are not adversely affected during the plant operation.
SECTION 9 IN-SERVICE INSPECTION, MAINTENANCE AND CONDITIONAL MONITORING OF SUPPORT STRUCTURE AND TANK

9.1 General

9.1.1 Concrete substructure

9.1.1.1 The purpose of this section is to specify requirements and recommendations for in-service inspection, maintenance and condition monitoring of offshore concrete LNG terminal structures and containment systems and to indicate how these requirements and recommendations can be achieved. Alternative methods may also fulfill the intent of these provisions and can be applied provided they can be demonstrated and documented to provide the same level of safety and confidence.

9.1.1.2 The scope of in-service inspection, monitoring and maintenance shall be in accordance with DNVGL-ST-C502.

9.1.1.3 Qualification of personnel involved in inspection planning and condition assessment shall be in accordance with DNVGL-ST-C502.

9.1.1.4 Planning of the in-service inspection, maintenance and monitoring activities shall be in accordance with DNVGL-ST-C502.

9.1.1.5 A programme for inspection and condition monitoring shall be prepared in accordance with DNVGL-ST-C502.

9.1.1.6 Inspection and condition monitoring milestones and intervals shall be in accordance with DNVGL-ST-C502.

9.1.1.7 Documentation of inspection, condition monitoring and maintenance shall be in accordance with DNVGL-ST-C502.

9.1.1.8 Recommended items for inspection and condition monitoring are given in DNVGL-ST-C502.

9.1.1.9 Recommendations for inspections related to corrosion control is given in DNVGL-ST-C502.

9.1.1.10 Inspection and condition monitoring types shall be in accordance with DNVGL-ST-C502.

9.1.1.11 A marking system shall be established in accordance with DNVGL-ST-C502.

9.1.1.12 A guideline for inspection of special areas is provided in DNVGL-ST-C502.

9.2 Special for LNG containment system

9.2.1 General

9.2.1.1 A gas detection system shall be installed. The detection system shall give warning of leakage of LNG or natural gas or other flammable refrigerants or noxious vapours from the LNG plant, and indicate the presence of smoke or flames in the event of the outbreak of fire. The detection systems provided for each equipment item shall be specified in the description of the installation.
9.2.1.2 The level of back-up required for safety equipment depends on the risk acceptability level of the event which can result from failure of that equipment.

9.2.1.3 Up to a certain level of risk, it is not necessary to duplicate every piece of detection equipment, but the detection system installed shall ensure detection of an event. The level of acceptability is arrived as follows:

— potential leakage zones are identified
— the maximum tolerable time of leakage corresponding to the risk acceptability level in question is determined for each zone that leakage time depends on the following, in particular:
  — the maximum leakage flow rate which can be envisaged
  — the existence of a retention system.
— failure of a sensor is tolerated if with the other sensors in service, the safety system as a whole allows the leak to be sealed off within the period of time laid down.

9.2.2 Gas detection

9.2.2.1 Gas detectors are installed for fast detection of gas, which can be present because of gas leaks or LNG leaks which evaporate.

9.2.2.2 Gas detectors should be of the following types:

— catalytic combustion sensors
— semi-conductor sensors
— thermal conductivity sensors
— equivalent or improved sensors.

These detectors shall be conform to EN 50054 and EN 50057 or equivalent standards.

9.2.2.3 The gas detectors which will be used in an LNG plant shall be calibrated to a value equal to or less than 25% of the lower flammability limit in air of the gas monitored.

9.2.2.4 The range of gas concentrations to be measured shall be between 0% and the lower flammability limit.

9.2.2.5 Gas detectors shall be installed in an LNG plant as a result of the hazard assessment and particularly near to the following units:

— throughout the liquefaction plant
— loading/unloading areas
— vaporisers
— at the inlet of burners of vaporisers, air compressors, diesel engines, gas turbines and gas engines
— LNG pumps
— flanges
— points of possible concentration of LNG in any impounding basins
— boil off gas compressors.
— buildings and enclosed spaces where gas can accumulate
— at the inlet of building heating, venting and air conditioning systems.

9.2.2.6 The detectors shall be installed taking into account the specific gravity of the gas, ventilation, the atmospheric conditions and the results of the dispersion calculations. Their location shall allow fast and accurate detection of possible leaks.
9.2.3 Cold detection

9.2.3.1 Cold detectors are installed for the detection of LNG leaks. They can be of the following types
— fibre optic systems
— temperature probes (thermocouples, resistance type probes, etc.)
— equivalent or improved sensors.

9.2.3.2 The detectors shall be chosen for optimum efficiency at LNG temperatures. They shall be insensitive
to long term environmental changes. Their mechanical characteristics shall allow simple installation and
maintenance.

9.2.3.3 Unlike other detection systems, fibre optic systems allow distributed detection for which the
minimum necessary equipment shall be a self check unit for checking the correct operation of the system at
fixed intervals. At the same time a second unit shall check the correct operation of the self check unit. An
alarm shall be connected to these units.

9.2.3.4 The use of cold detectors is recommended in LNG storage tank impounding areas, if any, in LNG
impounding collection basins, around LNG pumps and in LNG spillage collection channels, if any.

9.2.3.5 They shall be installed at low points where LNG is likely to collect. Their location shall allow fast and
accurate detection of possible leaks.

9.2.4 Smoke detection

9.2.4.1 Smoke detectors can be of the following types:
— ionisation smoke detectors
— photoelectric smoke detectors
— equivalent or improved sensors.

9.2.4.2 It is recommended to choose detectors that are capable of stabilising their sensitivity with respect to
variation in pressure, moisture and temperature.

9.2.4.3 It is recommended that the detectors are installed in areas containing electrical cubicles and
cabinets. Within these buildings they shall be installed at points where smoke is most likely to concentrate.

9.2.5 Fire detection

9.2.5.1 Fire detectors are installed for fast detection of fire.

9.2.5.2 Fire detectors can be of the following types:
— ultra-violet detectors (UV)
— infra red detectors (IR)
— equivalent or improved sensors, e.g. thermal detectors.

9.2.5.3 These devices can give false alarms. Sources of false detection for UV detectors are, for
example, X rays and arc welding. IR detectors are sensitive to solar radiation and infrared sources such as
hot equipment commonly found in an LNG plant. UV/IR detectors are recommended.
9.2.5.4 Depending on the reliability-needed the detectors can be equipped with self checking devices. It is recommended that these detectors be installed in close proximity to places where leaks and ignition are most likely, i.e.:

— loading-unloading areas
— in any impounding basins
— all other positions appropriate to the installation.

9.2.6 Meteorological instruments

9.2.6.1 A meteorological station shall be installed in LNG liquefaction plants and receiving terminals in order to measure:

— air temperature
— barometric pressure
— humidity
— wind direction
— wind velocity
— wave heights.

The measurements obtained shall enable the deployment of active fire protection equipment to be determined. The required reliability shall be determined in accordance with the hazard assessment.

9.2.7 Safety control system

9.2.7.1 The safety control system shall be designed for loss prevention:

— detection of loss of containment:
  — LNG spillage
  — natural gas leakage
  — fire
— activation of ESDs
— monitoring and control of protection equipment.

This system shall permit automatic detection of unsafe conditions and shall activate automatically and/or manually the appropriate ESD, for example:

— loading or unloading
— send out
— liquefaction.

9.2.7.2 Emergency shut down (ESD): The emergency shut down system can include some process shut down functions. For the purpose of this clause, only the primary safety functions are described.

9.2.7.3 In respect with the hazard assessment, a cause and effect matrix shall be established in order to perform the right ESD as a function of the location and nature of abnormal conditions detected.

9.2.7.4 Additionally, when an operator in the control room or on-site presses an ESD push button, the corresponding ESD shall be performed.

9.2.7.5 Fire and gas detectors are located so as to be able to handle the incidents determined in the hazard assessment. See Sec.2.

9.2.7.6 The safety control system shall be designed to:
— monitor and control the protection equipment, for example:
  — water curtains
  — foam generators
  — fixed powder-extinguishers
  — pressurisation of dedicated rooms.
— monitor and control the protection auxiliaries, for example:
  — fire pumps
  — fire water system valves
  — foam agent pumps
  — emulsifier or foam agent network valves (if any).
— inform the operator of any incident
— activate automatically the appropriate ESD
— activate automatically the appropriate protection equipment
— inform the process control system of ESD activation and activate PSD (if applicable).

9.2.7.7 Data acquisition: The safety control system detection may be based on the following types of detectors:
— specific point gas detectors
— linear gas detectors
— smoke detectors
— flame detectors
— specific point cold detectors
— linear cold detectors.
The safety control system shall collect:
— information of each detector
— ambient temperature, the wind direction and its velocity
— information from the protection equipment, the protection auxiliaries and the safety process equipment
  (LNG valves, blow down valves, pressure switches, etc.).

9.2.7.8 Monitoring and control: The safety control system shall enable the operator in the control room to:
— monitor and control protection equipment
— monitor and control protection auxiliaries
— activate any ESD with the corresponding push button
— inhibit the automatic activation of any ESD with a key.
The safety control system shall give the operator in the control room:
— the status of each detector
— the status of protection equipment
— the status of protection auxiliaries
— the meteorological parameters
— the list of all the detectors that have detected an incident.
and it shall be able to print reports and save data.

9.2.7.9 The system shall automatically start pumps to prevent the fire water system pressure from dropping below a set value.

9.2.7.10 In addition, the safety control system can automatically activate in case of incident:
a general procedure to open all emergency exits
— an external audible alarm (siren or klaxon).

9.2.7.11 Furthermore, in case of computerised control system, critical alarms shall be hard wired to the special alarm annunciator in the main control room.

9.2.7.12 The reliability of the system shall be consistent with the safety level of the plant. An ESD shall always be performed even in case of dysfunction of the safety control system.

9.2.7.13 Access control system: Access points for entering inside the plant boundary shall be controlled through separate, specially adapted barriers.
The opening of these barriers shall be authorised through a specific access control which shall be able to:
— verify the level of authorisation
— count the number of people going through an opened door
— automatically open all the barriers, including fire fighting and emergency access roads, as part of a plant evacuation procedure following an incident.

Depending on the size of the plant, access to process zones where gas is stored, piped or processed can be controlled. Such control can be limited to process zones or extended to a wider area. Control of access can be put into practice either by security guards or by using a physical device (lock, magnetic badge, etc.).
APPENDIX A HAZARD ASSESSMENT OF LNG TERMINALS (GUIDELINES)

A.1 Hazard assessment

A.1.1 Hazards and operability study

A.1.1.1 All LNG/LPG projects shall be subjected to a preliminary process hazard review at process flow sheet definition stage, for example to minimise the number of equipment items and the total inventory of hazardous materials.

A.1.1.2 A hazard and operability study (HAZOP) shall be conducted when the piping and instrumentation diagrams (P&IDs) are sufficiently developed and approved by the owner.

A.1.1.3 The HAZOP shall be developed to identify and eliminate or minimise hazards.

A.1.1.4 The HAZOP shall be conducted by a multi-disciplinary team who shall systematically address the piping and instrumentation diagrams (P&IDs) and identity credible events caused by deviations from the design intent.

A.1.1.5 The analysis shall include the following principles:
— be systematic, following a proven approach based on piping and instrumentation diagrams (P&IDs), applied to all normal modes of operation, to commissioning, to start-up, to emergency shutdown and to normal shutdown
— be conducted by a review panel to be chaired by an experienced and competent engineer, and including other persons competent in design and operation. At least one member of the team should have intimate knowledge of this type of installation
— the review panel shall be given sufficient resources, for example in terms of time and access to specialist knowledge
— give rise to a formal written report describing the findings and recommendations concerning the changes to plant design or operating procedures
— proper follow up leading to the resolution of all points shall be documented.

A.1.1.6 New facilities shall be analysed before start-up. To allow the necessary modifications to be made without compromising the start-up schedule, a full analysis shall normally be performed before the approved for construction issue. A review and approval procedure shall be established for the management of change during construction, with if necessary a full and final analysis based on as built drawings.

A.1.1.7 Operating facilities shall be analysed following a plant modification, with if necessary a full and final analysis before restart. A review and approval procedure shall be established for the management of minor change during normal operating periods.

A.1.2 Methodology

A.1.2.1 The methodology of the hazard assessment can be probabilistic and/or deterministic. The probabilistic approach consists of
— collection of failure rate data,
— list of potential hazards of external and internal origin
— determination and classification of the probability of these hazards
— determination of the consequences of each hazard and their allocation into classes of consequence
— classification of accidents in accordance with their consequences and probability criteria in order to determine the level of risk
— verification that no hazard comes within the unacceptable risk category
— justification of the measures necessary to limit risks.

A.1.2.2 The deterministic approach consists in:
— list of potential hazards of external and internal origin,
— establishment of credible hazards
— determination of the consequences necessary
— justification of the necessary safety improvement measures to limit the risks.

A.1.2.3 The hazard assessment can be based on conventional methods such as:
— hazard and operability study (HAZOP)
— failure mode effect analysis (FMEA)
— event tree method (ETM)
— fault tree method (FTM).

Implementation of the overall procedure shall be initiated as early as possible and shall be repeated when unacceptable risks are identified during the design.

A.1.3 Identification of hazards of external origin

A.1.3.1 The studies of the natural, urban and industrial environment and also of external communication routes enable hazards arising from outside the plant to be listed. Such hazards can be caused by:
— LNG carriers and ships at berth or when manoeuvring
— heat radiation (fire)
— clouds of flammable, toxic or asphyxiant gas
— the impact of projectiles (ship, helicopters, plane, etc.)
— natural events (extreme waves, lightning, flooding, earthquakes, etc.)
— high energy radio waves, etc.

A.1.4 Identification of hazards of internal origin

A.1.4.1 Hazard arising from LNG/LPG
Possible loss of containment of LNG shall be listed for all items of equipment including the loading or unloading of LNG carriers. To simplify the study, scenarios may be established.

The following events shall as a minimum be considered:
— loss of primary liquid containment (for a duration to be determined based on an approved contingency plan)
— LNG release
— release of flammable or toxic gas to the atmosphere or inside an enclosed space
— roll over (thermodynamic instability due to LNG stratification).

These scenarios shall be defined in terms of:
— the probability of the hazard
— the location of the leak
— the nature of the fluid (LNG or gas, specifying the temperature thereof)
— the rate and the duration of the leakage
— weather conditions (wind speed and direction, atmospheric stability, ambient temperature, relative humidity)
— for spillage of LNG, the effect of the environment (including any impounding area) and the effect on the properties of structural steelwork leading to brittle failure due to low or cryogenic temperatures.

A.1.5 Hazards which are not specific to LNG/LPG

A.1.5.1 The following causes of hazards which are not specific to LNG shall be considered:
— damage to the primary structure due to extreme weather, impact/collision, dropped objects, helicopter collision, exposure to unsuitable cold temperatures, exposure to high radiant heat
— fire and explosion
— LPG and heavier hydrocarbon storage
— poor communication between ship and terminal
— leakage of other hazardous substances, in particular flammable refrigerant
— pressurised and steam raising equipment
— rotating machinery
— utilities, catalysts and chemicals (fuel oil, lubricating oils, methanol, etc.)
— electrical installations
— docking installations associated with the LNG plant.
— loss of any single component in the station keeping/mooring system
— loss of ability to offload LNG or discharge gas ashore
— loss of stability.

A.1.6 Hazardous area classifications

A.1.6.1 All installations shall be subjected to an hazardous area analysis. The terms of reference for such an analysis shall be laid down in accordance with DNVGL-OS-A101 or equivalent International Standard.

A.1.6.2 The extent of hazardous zones shall be as given in DNVGL-OS-A101 or equivalent International Standard. The selection of equipment for use in particular locations shall be determined by the hazardous zone classification of these locations in accordance with DNVGL-OS-A101 or equivalent International Standard.

A.1.7 Estimation of probabilities

A.1.7.1 The estimation of the probability associated with a given hazard, where utilised, shall be based on reliable data bases which are suitable for the LNG industry or on recognised methods as in [A.1.2] which will determine the probability range for this hazard. The human factor shall be taken into account.

A.1.8 Estimation of consequences

A.1.8.1 The consequences of each scenario will depend on the characteristics of LNG and other phenomena. For the consequences of leakage or spillage of fluids other than LNG reference shall be made to their material safety data sheets.

A.1.8.2 Evaporation of spilled LNG
The phenomenon of instantaneous vaporisation (flash) shall be taken into account. Calculation of evaporation due to heat transfer shall be carried out using appropriate validated models.
The model shall, as a minimum, take the following into account:
— the LNG flow rate and duration
— the LNG composition
— the temperature of the water
— the atmospheric conditions (ambient temperature, humidity, wind velocity)
— the atmospheric stability or temperature gradient.

A.1.9 Safety measures on the LNG plant

A.1.9.1 Leaks of LNG and refrigerants produce flammable vapour clouds denser than air. The terminal shall therefore be designed to eliminate or minimise the quantity and frequency of accidental and planned emissions of these fluids.

A.1.9.2 This shall be achieved by that the best available rules of technology are implemented. Particular consideration shall be given to the following:
— design pressures and temperatures of piping and equipment shall be selected to cover all anticipated normal and upset conditions
— wherever possible plant and equipment containing flammable fluid shall be located in the open, however, maintenance and climatic conditions will affect this decision
— plant layout shall be designed to avoid congestion
— appropriate piping flexibility to suit all operating conditions
— the number of flanges in pipe runs shall be minimised by using welded inline valves where practical. Where flanges are used they should be oriented so that if a leak occurs the jet stream shall not impinge on nearby equipment
— the orientation of flanges and relief valve tail pipes shall be such as to minimise hazard
— design pressures shall leave a sufficiently wide margin above operating pressures so as to minimise the frequency of the lifting of relief valves
— pumps with high integrity seals or submerged pumps and motors shall be used for LNG and LPG
— structures supporting piping and equipment handling flammable fluids shall be designed to withstand the ultimate limit state
— techniques for industrial risk management shall be employed from the design through to start up, operation, during maintenance and modifications.

A.1.9.3 Internal overpressure protection
Safety devices shall be provided to cover all internal overpressure risks including those due to fire.
It is recommended that the discharge from conventional safety devices (safety valves, relief valves), unless those from tanks and vaporisers, are routed to the flare/vent system or the storage tank.
In fact, the temperature and the height of the discharge of the released gas from tanks and vaporisers allow a good atmospheric dispersion. This point shall be confirmed by the hazard assessment. In addition, this measure avoids pressure drop and/or obstruction inside the flare system and consequently reduces the risk.
If the hazard assessment shows that the consequences of the discharge directly to atmosphere are acceptable, then connection to the flare/vent system is not necessary.

A.1.9.4 Emergency depressurising
If no appropriate protection is installed such as fire insulation, water deluge system etc., it is recommended that automatic or semi-automatic depressurising systems are provided when a BLEVE risk due to overpressure and elevated wall temperature is present (see EN 1160).
The intention of this measure is to:
— reduce the internal pressure
— reduce the effect in case of leakage
— avoid the risk of failure of LNG or gas filled pressure vessels and piping from external radiation including those due to fire.
Devices for depressurising high pressure equipment shall allow the pressure of one or more than one item of equipment to be reduced quickly. Reduction from the design pressure to 50% of the design pressure, or 7 bar (gauge) if that value is higher than 50% of the design pressure, in 15 min., should generally be provided for. The gases thus extracted shall be sent to the flare system which shall be capable of handling the low temperatures generated during depressurise.

Isolating valves, activated from the control room or other remote location shall be provided so that the unit can be isolated into several sub-systems and where it is required to isolate sensitive equipment. This will make it possible to depressurise only one part of the plant, while limiting the entry of hydrocarbons into a fire containing zone.

A.1.10 LNG terminal layout

A.1.10.1 The layout of an LNG terminal with respect to the surroundings shall be covered by a hazard assessment. See also DNVGL-OS-A101.

A.1.10.2 The prevailing wind direction shall be considered in LNG terminal layout. Where practicable, control rooms, accommodation area and ignition sources shall not be downwind of accidental and planned releases of flammable materials, but they shall be located as far as possible outside hazardous areas, assuming a wind in any direction.

A.1.10.3 The LNG terminal shall be laid out to provide safe access for construction, operation, maintenance and for fire fighting:
  — separation distances shall take into account, in particular
  — radiation flux levels
  — lower flammability limit contours
  — noise
  — blast effects.

A.1.10.4 The LNG Terminal main control room shall be located outside hazardous areas. Furthermore, it shall be designed to suit explosive atmospheres resulting from gas dispersion. and to resist overpressure created by explosions. The control room shall be designed to protect the occupants for as long as necessary to effectuate the emergency procedures and then allow them to safely escape from the incident.

A.1.10.5 For diesel driven fire water pumps and emergency generators the air intake shall be located outside the predicted vapour cloud envelope.

A.1.11 Emergency shutdown

A.1.11.1 An emergency shutdown ESD system independent from the process control system shall be provided. See DNVGL-OS-A101.

A.1.12 Fire protection

A.1.12.1 Equipment, including ESD valves and vessels containing quantities of liquid hydrocarbon which can cause an escalation of an incident shall be protected from thermal radiation. Piperack supports and vessel skirts and ESD valves which can receive thermal radiation resulting from an ignited leak shall be provided with at least 90 min. protection.

A.1.12.2 Fire protection in the form of insulation or water deluge shall be provided for pressure vessels which can receive thermal radiation fluxes from external sources in excess of allowable thermal radiation flux inside the boundary / EN1473 4.3.1/. This to prevent such vessels failing and releasing superheated liquid, which can result in a BLEVE.
A.1.12.3 It shall be recognised that pressure vessels subject to radiation in excess of that defined in / EN1473 4.3.1/ from a major incident such as an LNG tank fire shall require protection for much more than 90 min. This is not likely to be achieved by insulation and a water deluge system is necessary.

A.1.12.4 The calculation of water deluge, insulation for fire protection of structures etc. as protection against fires shall be performed for the fluid which gives rise to the highest radiation flux. Adaption of methods proposed elsewhere in this European Standard for LNG may be used.

A.1.12.5 Protection of the tanks and safety equipment against radiation from fire in the retaining basin, if any, of adjacent tanks shall be taken into account.

A.1.13 Seismic protection

A.1.13.1 The following systems shall withstand actions resulting from earthquake:
— systems for which rupture can create a hazard for the plant
— protection systems for which operation is required to keep a minimum safety level.

A.1.13.2 For earthquake design purpose, the plant systems and their components shall be classified on basis of their importance, from a safety point of view, such classification being analysed during hazard assessment:
— Class A: systems which are vital for the plant safety. They shall remain operational for both SLE and DLE.
— Class B: systems performing vital functions for the plant operation or for which collapse could cause a major impact on the environment or could lead to additional hazard. These systems shall remain operational after SLE and shall keep their integrity in case of DLE. Class B shall include as a minimum the secondary containment of all LNG tanks.
— Class C: other systems. These systems shall remain operational after SLE and shall not fall on or impact other systems classes and components after DLE.

A.1.13.3 The systems include the related equipment, piping, valves, instrumentation, power supply and their supports. Structures shall be designed as for the class of the most stringent system component they are supporting.

A.1.13.4 The structure shall be designed to keep their integrity in case of DLE. Heating, ventilating and air conditioning shall be designed in order to fulfil the criteria of the classified systems which are located in the structure.

A.1.13.5 The most commonly used methods for qualification are hereafter listed:
— time history analysis
— modal spectral analysis
— load coefficient method
— spacing chart.
They range from the most sophisticated one (time history analysis), containing the least undue conservatism, to the most coarse (spacing chart), including a very high degree of conservatism. When it is estimated that qualification by analysis is unfeasible, qualification by test shall be performed.

A.1.14 Confinement

A.1.14.1 Confined or partially confined zones shall be avoided as far as possible, in particular the space situated under the base slab of raised tanks, if any, shall be sufficiently high to allow air to circulate.
APPENDIX B HAZARD DEFINITIONS (GUIDELINES)

B.1 Hazard definitions

B.1.1 Probabilities ranges

Range 1: Frequent or quasi-certain event.
This corresponds, in quantitative terms, to a probability of occurrence of more than $10^{-2}$/Year.

Range 2: Possible but not very frequent event.
Probability of occurrence lying between over $10^{-2}$ up to $10^{-4}$/Year.

Range 3: Rare event.
Probability of occurrence lying between over $10^{-4}$ up to $10^{-6}$/Year.

Range 4: Extremely rare event.
Probability of occurrence lying between over $10^{-6}$ up to $10^{-8}$/Year.

Range 5: Improbable event.
Probability less than $10^{-8}$/Year.

Range 6: Event of non-quantifiable probability (failing of meteorite, attempt on life or property, etc.).

B.1.2 Classes of consequence

B.1.2.1 Classes of consequence take into account the extent of injury and damage.

B.1.2.2 Class 1: Catastrophic or major consequences
— total stoppage of the plant and
— one or more than one person dead or
— one or more than one external system damaged or destroyed or
— the quantity of the LNG concerned is greater than 60 m$^3$ or
— the cost of the damage is greater than 10% of the new value of the installation.

B.1.2.3 Class 2: Serious or critical consequences:
— total stoppage of the plant and
— the quantity of the LNG concerned is greater than 6 m$^3$ and lower than 60 m$^3$ or
— one or more than one system destroyed inside the plant or
— the cost of the damage is greater than 1% and lower than 10% of the new value of the installation.

B.1.2.4 Class 3: Significant consequences:
— there is appreciable degradation of the system which could bring about interruption of the plant. There are only limited material losses and not any irreversible damage of the system
— the quantity of the LNG concerned is greater than 0.6 m$^3$ and lower than 6 m$^3$ or
— the cost of the damage is greater than 0.1% and lower than 1% of the new value of the installation.

B.1.2.5 Class 4: Minor or repairable consequences:
— there is no appreciable degradation of performance likely to jeopardise the task of the plant or
— the quantity of the LNG concerned is lower than 0.6 m$^3$ or
— the cost of the damage is lower than 0.1% of the new value of the installation.
### B.1.2.6 Class 5: Nil consequences:
This concerns events which arise during day to day operation of the system, the quantity of the LNG concerned is lower than 0.06 m$^3$.

### B.1.3 Levels of risk

#### B.1.3.1 General

Tables B-1 and Table B-2 give examples of risk levels.

#### B.1.3.2 Level 1: Situation which is undesirable and therefore refused. (Not acceptable).
Arrangements for processes, procedures and items of equipment shall be provided as quickly as possible.

#### B.1.3.3 Level 2: Situation which shall be improved.
A level at which it shall be demonstrated that the risks is made as low as reasonably practical.

#### B.1.3.4 Level 3: Normal situation. (Acceptable).

**Table B-1 Determination of level of risk inside the Boundary Plant**

<table>
<thead>
<tr>
<th>Probability classes</th>
<th>5 Nil consequences</th>
<th>4 Repairable consequences</th>
<th>3 Significant consequences</th>
<th>2 Serious consequences</th>
<th>1 Catastrophic consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Non quantifiable</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>5 Entirely improbable (&lt; 10$^{-8}$/year)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4 Extremely rare (10$^{-6}$ to 10$^{-4}$/year)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3 Rare (10$^{-4}$/year to 10$^{-2}$/year)</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2 Possible (10$^{-2}$/year to 10$^{-0}$/year)</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1 Frequent (&gt; 10$^{-2}$)</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table B-2 Determination of level of risk outside the boundary plant**

<table>
<thead>
<tr>
<th>Probability classes</th>
<th>5 Nil consequences</th>
<th>4 Repairable consequences</th>
<th>3 Significant consequences</th>
<th>2 Serious consequences</th>
<th>1 Catastrophic consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Non quantifiable</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>5 Entirely improbable (&lt; 10$^{-8}$/year)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Probability classes</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
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</tr>
<tr>
<td>Nil consequences</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repairable consequences</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Significant consequences</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Serious consequences</td>
<td></td>
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<tr>
<td>Catastrophic consequences</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4 Extremely rare (10^{-8} to 10^{-6} /year)</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3 Rare (10^{-6} /year to 10^{-4} /year)</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2 Possible (10^{-4} /year to 10^{-3} /year)</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1 Frequent (&gt; 10^{-2})</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
C.1 General design principles

C.1.1 Design considerations

C.1.1.1 The design principles outline below is issued as guidelines for the detailed design of concrete secondary containment structures and the main load bearing structure of a LNG containment structure.

C.1.1.2 The design of retaining and processing facilities of explosive or poisonous materials includes:
— the conceptional design resulting in the final configuration of the plant
— the final shaping of the individual structure
— the detailed design resulting in the assessment of the structural performance
— the safety verifications
— the detailing of the structural components for the practical construction.

The structural design should take into account all relevant stages of the structure from erection, testing to operation. For safety reasons this includes the consideration of possible accidents and the assessment of the structural performance under corresponding hazard scenarios.

C.1.1.3 The verification of the required structural performance under construction, testing, operation and during accidents shall be based on limit state design. For action scenarios resulting from construction testing and operation. It is of primary importance to assure appropriate service behaviour.

This requires a design in relevant serviceability limit states (SLS), (for example deformation limit states, limit states of crack width etc.) and in relevant ultimate limit states (ULS) concerning resistance, stability and eventually deformability.

It should be noted that very often serviceability limit states (SLS) govern the final dimensioning and detailing of the concrete structures.

C.1.1.4 For action scenarios resulting from possible hazards design shall assure that the damages liable to occur during these hazards are limited. The acceptable damage levels depend on conditions imposed by the necessary protection of persons, of the environment and of properties. In general all safety considerations are governed by the required limitation of damage consequences in the case of accidents.

C.1.1.5 To assure adequate safety of structures which bear high risk potentials both the event probability \(P_{\text{event}}\) and the failure probability \(P_{\text{failure}}\) shall be limited. Limitation of the event probability means active safety measures aiming at reducing the hazard initiating event probabilities.

These measures comprise among others:
— adequate decisions concerning the location of the facility
— adequate choices concerning tank layout and spacing
— active fire protection
— active protection to limit the probability of explosions and impacts
— provision for pressure and vacuum reliefs
— provision of alarm systems indicating leakage and spillage
— provision of protective systems against lightning.

C.1.1.6 Passive safety measures which limit the failure probability to acceptable levels. These measures comprise:
— lay-out and site studies
— the appropriate choice of protective structural systems
— the identification and assessment of relevant testing operation and hazard scenarios
— the modelling of these scenarios in terms of design combinations of actions
— the limit state design against the action effects resulting from these combinations
— appropriate structural detailing in view of cross-sections,
— definition of critical regions.

C.1.1.7 Corresponding functional requirements are the same as for conventional design:
— load bearing
— tightening against liquids and gas
— insulating against inside and outside temperature states.

However, different from conventional design are the required performances during a hazard. Since the design objective is the limitation of damage, the limit states to be verified may allow for damages which are not acceptable under usual operation. For example tightness requirements during a hazard may allow for a controlled loss of the stored material unless the consequences of this loss are unacceptable.

C.1.1.8 In view of the built-in structural resistance the choice of the appropriate protective structural system is of paramount importance. Three principle functions shall be fulfilled by the structural system:
— retaining of the stored material
— insulating between cryogenic and environmental temperatures
— shielding against hazards.

C.1.1.9 The appropriate choice of structural systems includes that these functions are clearly assigned to corresponding structural elements. Furthermore redundancy of the operating and protective performance should be assured in the event of the failure of those structural elements which are important to guarantee trouble-free operation and adequate protection.

Redundancy during operation will generally be assured by appropriate process engineering, redundancy during hazards requires the design of appropriate shielding barriers. The degree of redundancy during hazards depends on the damage level which is acceptable as a consequence of a failing structural element. Such acceptable damage levels should be chosen in view of the pertaining event probability.

C.1.1.10 Analytical design of storage and processing facilities has to assess and to analyse design scenarios related to
— construction
— testing
— usual operation
— hazards.

C.1.1.11 The structural requirements to be met during construction, testing, operation and hazard scenarios are related to tightness, load bearing, shielding and insulating. Verification of the required structural performance is based on limit state design. Corresponding design limit states are defined in App.D Detailed design structural design of containment system and comprise fire resistance, cold spot and shock resistance, energy dissipation, ultimate load bearing, structural integrity and repairability, fluid tightness and insulation capacity.

C.1.1.12 The material factors for concrete, structural steel, reinforcing and prestressing steel and the factors to apply to the prestressing force for verifications of ultimate (ULS) and serviceability limit states (SLS) under permanent, transient and accidental action combinations are those specified in Sec.5 for the design of the concrete barriers and support structure.
C.1.2 General requirements

C.1.2.1 Equipment for which the design pressure is more than 500 mbar shall meet the requirements of applicable standards or codes used for the design of pressure vessels.

C.1.2.2 Metal storage tanks for the storage of LNG shall be designed in accordance with the requirements of [7.2] Design of LNG containment structure.

C.1.2.3 IMO type B independent tanks designed, constructed and inspected in-service in accordance with the requirements of IGC - IMO Code can be used for offshore terminals provided the independent tanks are fully designed in accordance with the IGC-IMO Code and DNV GL rules for classification DNVGL-RU-SHIP Pt.5 Ch.7 Liquefied gas tankers. The support concrete structure shall be designed in accordance with this standard.

C.1.2.4 The LNG tanks shall be designed to:
— safely contain the liquid at cryogenic temperature
— permit the safe filling and removal of LNG
— permit the boil off gas to be safely removed
— prevent the ingress of air and moisture except as a last resort to prevent unacceptable vacuum conditions in the vapour space
— minimise the rate of heat leak, consistent with operational requirements
— withstand the damage leading to loss of containment due to credible external factors as defined in App.A
— operate safely between the design maximum and minimum (vacuum) pressures
— withstand the number of filling and emptying cycles and the number of cool down and warming operations which are planned during its design life
— withstand deformations from the support structure caused by environmental conditions.

C.1.3 Fluid and gas tightness

C.1.3.1 The tank shall be gas and liquid tight in normal operation. See Sec.7 for liquid tightness of prestressed concrete structures.

C.1.3.2 The degree of resistance to leakage required in the event of external overloads such as impact damage, thermal radiation and blasts shall be defined in the hazard assessment (See Sec.2)

C.1.3.3 LNG tightness of the primary container shall be ensured by a continuously welded plate, membrane or cryogenic concrete prestressed with cryogenic reinforcement and crack control in accordance with Sec.5.

C.1.3.4 LNG tightness of the secondary container shall be ensured by:
— continuously welded plate
— prestressed concrete with lining
— other proven suitable material
— crack control in accordance with Sec.5.

C.1.3.5 The outer envelope of the tank which is exposed to the atmosphere (metallic or concrete) shall be designed in such a way as to prevent all water penetration, whether this is sea water, surface water, firewater, rainwater or atmospheric humidity. The humidity may introduce corrosion problems, deterioration of the insulation and of the concrete which shall be covered by the design.

C.1.3.6 To contain liquid in case of LNG leakage the following requirement shall be followed
— for double and full containment tanks where the secondary container is made of metal, it shall be of cryogenic grade
when the secondary container is made of prestressed concrete, the temperature of the prestress cables shall remain compatible with the strength of the maximum hydrostatic head. It shall be assumed for calculation that the temperature of the LNG is applied directly onto the internal face, including the insulation, if any.

C.1.4 Tank connections

C.1.4.1 External connections shall be designed to accept loads imposed from the external piping and internal piping, if any.

C.1.4.2 The fluid and gas transfer pipelines which penetrate the container shall satisfy the following requirements:
— Penetrations shall not give rise to excessive heat input.
— Where penetrations are subject to thermal contraction and expansion which can be rapid if necessary the internal connections shall be strengthened and the external connections shall be designed to transmit external piping loads to a thermal expansion compensating system.
— There shall be no penetrations of the primary and secondary container walls or base. Overflow pipes are not recommended. If overflow pipes cannot be avoided, the associated additional risk shall be included in the hazard assessment.
— If needed, connections shall be provided for nitrogen into the annular space between the inner tank and the outer containment to enable air to be purged out before commissioning and LNG to be purged out after emptying for maintenance.

C.1.4.3 The absence of wall or base penetrations requires the use of submerged pumps. A platform on the roof shall be provided to allow pumps to be removed for maintenance.

C.1.4.4 The design shall prevent any siphoning effects.

C.1.5 Thermal insulation

C.1.5.1 Materials used for thermal insulation shall be documented suitable for its use.

C.1.5.2 The minimum thermal conductivity of insulating materials shall be specified. The installed insulation systems shall be free from contaminants which can corrode or otherwise damage the pressure-containing components with which they come into contact.

C.1.5.3 Insulation and heating system may be installed beneath the primary container base to reduce cold heat transfer into the foundation and the sea. Likewise, all parts of the side walls below the water level may have to be insulated and heated by air to avoid freezing of the sea. The final solution should require a detailed temperature study as the solution will be concept dependent.

C.1.5.4 Base and side wall insulation shall be designed and specified to be able to withstand any kind of action combinations as defined in App.D.

C.1.5.5 The thermal expansion of components shall be taken into account therefore insulation installed outside the primary container, when it is made up of expanded perlite, can be protected from settling, for example, by glass wool padding which absorbs variations in the diameter of the primary container.

C.1.5.6 The thermal insulation of a membrane tank shall withstand the hydrostatic load, both static and dynamic behaviour.

C.1.5.7 Insulation of spherical tanks is outside the sphere and is not exposed to any hydraulic or mechanical actions.
C.1.5.8 External insulation shall be protected from moisture.

C.1.5.9 Exposed insulation shall be non-combustible.

C.1.5.10 The quality of insulation shall be such that no single point of the external envelope of the tank will remain at a temperature below 0°C by an air temperature above or equal to 5°C.

C.1.5.11 Fire behaviour
When selecting insulation materials and designing insulation systems made of several products such as the insulation materials themselves, mastics, coatings, metal jacketing, it is important to take their fire behaviour into consideration. Insulation systems, as a whole, likely to be in contact with fire, shall not cause the fire to spread.
Fire behaviour of insulation systems shall be documented

C.1.5.12 Gas absorption
For obvious safety reasons, porous insulation products likely to absorb gaseous methane shall be avoided.

C.1.5.13 Moisture resistance
Moisture present in insulation systems very quickly impairs the performance of the insulation materials. For example, 1% moisture in volume contained in an insulation material reduces its thermal efficiency by 20 to 30%.
Water can penetrate into an insulation material in 2 different ways:
— either in the liquid state
— or as water vapour which condenses within the insulation material.
Some insulation materials are waterproof to a certain extent, but most of them are permeable to gases and thus to water vapour.
In order to avoid water vapour ingress, an efficient vapour barrier shall be provided and placed around the insulation material, except when the insulation is itself is water vapour tight.

C.1.5.14 Differential movements
A water vapour tight system should be achieved. It shall thus be designed to remain gas tight even after undergoing the anticipated differential movements between the pipe and the various products that make up the insulation system (including the vapour barrier(s), coatings, cell fillers, metal jackets).
The joints, mostly contraction joints, shall be designed to resist differential movement cycles in relation to both internal and external temperature variations. Global displacement due to stress variations in the load carrying structure shall be accounted for.

C.1.5.15 Surface condensation
The consequences of condensation are (examples):
— in temperate or cold zones, outside surface condensation can turn into ice, which can lead to premature ageing of the vapour barriers or protective coatings
— in humid regions, a large quantity of condensation can cause corrosion and has a negative influence on plant, algae and micro-organism proliferation, which in turn would accelerate ageing of the vapour barriers or external coatings.
In order to avoid outside surface condensation on the insulation system, the difference between the ambient external temperature and the surface temperature shall be limited, to ensure that the outside surface temperature is higher than the dew point temperature for about 75% of the time when it is not raining.

C.1.5.16 Thermal conductivity
The thickness depends on the thermal conductivity of the material(s) at temperatures ranging from the fluid temperature to ambient temperature.
As far as plastic foams are concerned, this value heavily depends on several factors such as:

— density
— blowing
— moisture
— ageing.

All materials permeable to water vapour are sensitive to moisture. Consequently, the thermal conductivity correction applied on the measured values to take this into account shall be greater than in the case of temperatures close to ambient conditions, as the moisture intake is much greater.

The thermal conductivity value used for thickness calculation will need to take account of the following:

— selection of insulation material
  — water vapour tightness
  — dimensional changes at cryogenic temperatures, especially in expansion loops
  — deterioration
— selection and application of the vapour barrier:
  — film or coatings
  — single layer on the outside or multiple layers
  — longitudinal partitioning or not
  — quality of the products and source of supply
  — reinforcement or not
  — risks of deterioration and, if the equipment has been damaged, study of the risk of local or widespread damage
  — resistance to maintenance activity
— climatic conditions:
  — dry, temperate or tropical zones
  — risk of outside thaw
— risk of mechanical damage:
  — foot traffic on piping or equipment
  — design and quality of critical points such as tees, elbows, supports, flanges, valves, etc.
  — maintenance quality
— qualification of the insulation contractor:
  — quality of workmanship
  — jobsite protection in case of bad weather
— operating temperature
— variable or constant service temperature
— job complexity:
  — number of elbows, connections, valves, etc.

**C.1.6 Operating loads**

**C.1.6.1** LNG tanks shall be capable of withstanding the combinations of loads as defined in App.D and those resulting from changes in temperature and pressure during

— initial cool down and warm up to ambient temperature
— filling and emptying cycles.
C.1.6.2 The manufacturer shall indicate the maximum rate of temperature change which the tank can withstand during cool down and warm up operations.

C.1.6.3 For double and full containment tanks, the primary container shall be designed to withstand the maximum differential pressure which could occur during all operating phases and a system shall be provided to prevent lifting of the floor.

C.1.7 General design rules

C.1.7.1 The structures of the tank shall be designed to withstand at least the combination of actions defined in Sec.4.

C.1.7.2 In addition, structures and structural elements shall:
— perform satisfactorily during normal conditions, with regard to degradation, displacement, settlement and vibration
— have adequate safety with regard to resisting fatigue failure
— show optimum ductile properties and little sensitivity to local damage
— be simple to make
— provide simple stress paths with small stress concentrations
— be suitable for simple condition monitoring, maintenance and repair.

C.1.7.3 The materials selected for the load bearing structures shall be suitable for the purpose. The quality of the materials shall be documented.

C.1.7.4 Requirements for the fabrication, testing and control shall be determined on the basis of the significance of the various parts with regard to the overall safety of the structure.

C.1.8 Liquid level

C.1.8.1 High accuracy and independent level devices are recommended as the means for protection against overflow in preference to overflow-pipes.

C.1.8.2 The tank shall be fitted with instruments which enable the level of LNG to be monitored and which enable protective action to be taken. These instruments shall in particular allow:
— continuous measurement of the fluid level from at least two separate systems (except for peak shaving tanks), of suitable reliability each system shall include high level alarms and high high level alarms
— detection of high high level based on instrumentation of suitable reliability which is independent of the above mentioned continuous measurements of level detection shall initiate the ESD function for feed pumps and valves in feed and recirculation lines.

C.1.9 Pressure

C.1.9.1 The tank shall be fitted with instruments, permanently installed and properly located which enable the pressure to be monitored as follows:
— continuous pressure measurement
— detection of too high pressure, by instrumentation which is independent of the continuous measurement
— detection of too low pressure (vacuum) by instrumentation, which is independent of the continuous measurement. Following vacuum detection, the boil off compressors and pumps shall be stopped and if necessary, vacuum breaker gas injected under automatic control
— if the insulated space is not in communication with the internal container, differential pressure sensors between the insulation space and the internal container or separate pressure sensors in the insulation space shall be installed.

C.1.9.2 For energy saving purposes, to reduce the boil off it is recommended that a constant absolute pressure be maintained inside the tank.

C.1.10 Temperature

C.1.10.1 The tank shall be fitted with properly located, permanently installed instruments which enable the temperature to be monitored as follows:
— the liquid temperature shall be measured at several depths the vertical distance between two consecutive sensors shall not exceed two metres
— gaseous phase temperature
— the wall and the bottom temperature of the primary container
— the wall and the bottom temperature of the secondary container except for the impounding area.

C.1.11 Density

C.1.11.1 density of the LNG shall be monitored throughout the liquid depth.

C.1.12 Pressure and vacuum protection

C.1.12.1 The various reference flow rates of gaseous discharges which shall be taken into consideration Sufficient margin shall be provided between the operating pressure and the design pressure of the tank to avoid unnecessary venting.

C.1.12.2 Irrespective of the means for recovery of boil off gas which might exist elsewhere (e.g. reliquefaction, compression), the vapour space of the tank shall be connected to a flare/vent, safety valve, or possibly a rupture disc which is capable of discharging flow rates from any likely combination of the following:
— evaporation due to heat input
— displacement due to filling
— flash at filling
— variations in atmospheric pressure
— the recirculation from a submerged pump.

C.1.12.3 The tank shall be fitted with at least two over pressure valves. The valves shall be linked to the flare network or vent system. Sizing of valves shall be on the assumption that one of them is out of service. The maximum flow to be discharged, at maximum operating pressure, is either the gas flow due to the heat input in the event of a fire or any likely combination of the following flow due to:
— evaporation due to heat input
— displacement due to filling
— flash at filling
— variations in atmospheric pressure
— the recirculation from a submerged pump
— control valve(s) failure
— rollover, in case of no other device is envisaged.
C.1.12.4 If the calculation of the overpressure valves or the flare/vent system does not take into account the rollover, a rupture disc or equivalent shall be installed whatever the other measures taken (for example, stock management policies, various filling lines).

C.1.12.5 A rupture disk can be used to protect the tank from overpressure. This device which is regarded as a last resort makes it possible to retain overall tank integrity without interrupting plant operation by temporarily sacrificing gas tightness.

C.1.12.6 The rupture disc shall be designed in such a way that:
— it can be replaced in operation following failure
— fragments will not fall into the tank
— fragments will not damage any other part of the tank.
Rupture of the disk shall cause all boil off gas compressors to trip automatically.

C.1.13 Vacuum

C.1.13.1 The tank shall be prevented from going into negative pressure beyond the permissible limit, by timely automatic shutdown of pumps and compressors and by two vacuum breaker systems:
— a gas or nitrogen injection system which shall act first
— vacuum relief valves which allow air into the tank as introduction of air can bring about a flammable mixture, this safety device shall act only as a last resort in order to prevent permanent damage to the tank.

C.1.13.2 Gas shall be injected under automatic control following too low pressure detection.

C.1.13.3 The tank shall be fitted with at least two vacuum relief valves. Sizing of valves shall be on the assumption that one of them is out of service. The flow to be admitted at maximum negative pressure to 1, 1 times that required to mitigate any likely combination of the following causes:
— the variation of the atmospheric pressure
— pump suction
— boil off gas compressor suction.

C.1.14 Bund wall and impounding area

C.1.14.1 For tank systems where individual impounding area is required as the secondary container. The impounding areas of two tanks may be adjacent.

C.1.14.2 Retention system materials shall be impermeable to LNG. The thermal conductivity of the material affects the rate of evaporation following a spill which is an important factor in the hazard assessment.

C.1.14.3 The need for insulation will depend on the result of the hazard assessment

C.1.14.4 Impounding areas for LNG in which rain or firewater can collect shall include a means for removing it to ensure that the required volume is maintained and to prevent flotation of the tank.

C.1.14.5 The water shall drain to an extraction sump within the impounding basin within the impounding area and be removed by pumping or by gravity flow. A reliable method shall be provided for preventing spilled LNG from being transferred from the pond.

C.1.14.6 The dimensions of each impounding area shall be such that its equivalent capacity will be at least 100% of the maximum volume which can be stored in the tank.
C.1.14.7 Means for limiting evaporation and reducing the rate of burning of ignited spills shall be considered.

C.1.15 Safety equipment

C.1.15.1 Anti-rollover devices
In order to avoid rollover at least the following measures shall be taken.
— filling systems as defined in [C.1.17.2]
— a recirculation system
— monitor boil off rate
— temperature/density measurements throughout LNG depth.
Other preventive measures can be used, such as:
— avoiding storing significantly different qualities of LNG in the same tank; appropriate
— filling procedure considering. the respective densities of the LNG
— nitrogen content of LNG at failing below 1 mol.
These measures lead to the practical elimination of stratification of LNG.

C.1.15.2 Protection against lightning
The tank shall be protected from lightning.

C.1.16 Reliability and monitoring of structure

C.1.16.1 Reliability
LNG tanks are structures which shall have high reliability.
This requires a design which ensures that changes in the structural condition of the tank are slow and limited, on the one hand, and permits monitoring of representative parameters of this condition, on the other.
The level of reliability which it is necessary to achieve as required can lead to the back-up of certain components of the structure; the dual hydraulic barrier (primary container and then secondary container) concept forms part of this type of back-up.

C.1.16.2 Monitoring of structure
Devices for monitoring the general condition of the structure, including the foundation, shall be designed in such a way as to leave sufficient time for action if anomalies are detected.
The monitored values shall be interpreted in terms of predefined
— normal values
— alarm values
— critical values.
The parameters which are deemed to be representative of the general condition of the structure are stated below.

C.1.16.3 Temperature sensors
Three sets of temperature sensors shall be considered
— on the outer skin of the primary container wall and bottom, to monitor cool down and warm up, except for membrane tanks
— on the warm side of the insulation (wall and bottom) to detect any leakage and to monitor any deterioration of the insulation due for example to settling
— on the outer surface of concrete wall of full containment tanks and/or membrane tanks and on the outer surface of concrete raft or point of support for all types of tanks to monitor the temperature gradient.

Plots from all sensors shall be recorded in the control room and any confirmation of leakage shall sound the alarm. The covering of sensors shall be sufficient to ensure that any leakage is detected and the temperature gradient is monitored.

**C.1.16.4 Heating system control**

In the case of tanks which have a heating system, consumption of power by the system shall be continuously recorded.

**C.1.16.5 Primary container leak detection**

For all tanks where the insulation space is not in communication with the primary container, a system shall be provided for nitrogen circulated within the insulation space. Monitoring of the tightness of the primary container is then possible by detection of hydrocarbons in the nitrogen purge.

**C.1.17 Tank piping**

**C.1.17.1 Cool down piping**

A system for cool down shall be provided to prevent cold liquid from failing onto the bottom of a warm tank. It can terminate for example, in a spray nozzle or a perforated ring.

The pipe used for filling by spraying can also be used for cool down.

**C.1.17.2 Filling piping**

Filling shall be able to be carried out, as a function of the LNG quality, both from the roof and at the lower part by a line going to the bottom of the tank.

For the bottom filling, at least one of the following features shall be provided (except for tanks used for peak shaving):

— jet nozzles placed at the bottom of the tank and oriented toward the surface
— a vertical pipe perforated for part or for all of its length
— a jet breaker, located at the extremity of a pipe for spray filling.

**C.1.17.3 LNG pumping**

Transfer of LNG from the tank and LNG recirculation shall be done with electrically driven submerged pumps.

**C.1.17.4 Overflow**

The overflow pipe, if envisaged as a last resort and authorised by the hazard assessment, shall be sized to handle a flow corresponding to the maximum flow rate of the filling pumps. The overflow pipe crosses the side sheet of the primary container at a height at least equal to the level of the high high level alarm. It shall be equipped at its base with one or more rupture disks with a burst pressure determined from the hydrostatic head of the liquid in the overflow pipe. One or more valves shall allow maintenance of the disk(s) without releasing gas. A temperature alarm shall detect the presence of liquid in the lower portion of the overflow pipe.

The design of this pipe shall take account of the movements due to differential temperatures between the two walls.
APPENDIX D DETAILED STRUCTURAL DESIGN OF CONTAINMENT SYSTEM (GUIDELINES)

D.1 Detailed structural design

D.1.1 Introduction

**D.1.1.1** Liquefied natural gas (LNG) storage tanks are designed to contain liquefied gases at atmospheric pressure and low temperatures during their service life for a range of conceivable and relevant conditions. This Appendix provides detailed guidelines for design of a containment system for import and export terminals.

**D.1.1.2** LNG containment systems on ships are designed using the IGC-IMO Code. The IMO Type B Independent Tank system is of particular interest. For application of this tank system in a floating or gravity based concrete terminal, the provisions of IGC-IMO Code shall be followed with respect to material selection and documentation, design documentation, construction and in-service inspection. The DNV GL rules for classification DNVGL-RU-OU-C0103 Floating LNG/LPG production, storage and loading units are based on this approach. The special operational differences between a ship and a terminal shall be incorporated in the design.

**D.1.1.3** LNG containment systems on land are designed using EN1473 or NFPA 59A. These standards can be used for the design of the containment system provided the added influence of the marine environment is included in the design. This appendix is based on principles as outlined in EN1473 and NFPA 59A. The special operational differences between a land based concept and a terminal located either floating or fixed to the bottom as a gravity platform shall be accounted for in the design.

D.1.2 Functional requirements

**D.1.2.1** Liquid tightness

LNG storage systems are designed to provide full liquid tightness under normal operating conditions. IMO Type B tanks, double wall, full containment, and membrane type tanks shall also be liquid tight under emergency conditions.

Under normal operating conditions, liquid tightness is provided by the inner tank of a single wall, double wall or full containment tank, and by the corrugated membrane of a membrane type tank.

In this respect, the need for attention to design aspects to minimize the risk of leakage (e.g. by avoiding connections on a liquid containing tank below the maximum liquid level) is highlighted.

By definition, the outer tank of a double wall and full containment tank are designed liquid tight. Also, the concrete structure of a membrane tank shall be designed for liquid tightness. This to avoid leakage of product into the environment after the exceptional event of a leak from the inner tank or membrane.

Leakage from an inner tank or a membrane may lead to a uniform built up of refrigerated product in the annular space (between inner and outer tank), or in the insulation space (between membrane and concrete tank) respectively. In particular, the wall-to-bottom connection is vulnerable for the effects of low temperatures due to such leakage and, therefore, special attention should be given in the design to guarantee the liquid tightness of the wall-to-bottom connection under such conditions.

Also, leakage of the inner tank or membrane may lead to local cold spots on the concrete (outer) wall and bottom.

Both the above mentioned loading cases shall be considered in the tank design.

Overfill of the inner container is not a design requirement of this appendix, provided that multiple independent facilities (i.e. at least 2 independent level gauges with alarms and an independent instrument with high and high-high level alarms with automatic cut-off arrangement) are installed to prevent overfill.
Overfill would lead to refrigerated product in the annular space of a full containment tank, and to exposure to refrigerated product of the roof of a single wall, and membrane tank.

**D.1.2.2 Gas tightness**

In case of vapour leakages, a hazardous situation may be created in view of possible formation of a flammable or explosive vapour cloud (e.g. in case of methane, ethane, propane or butane), or a poisonous vapour cloud (e.g. for ammonia). Vapour leakages are, therefore, unacceptable and consequently LNG tanks shall be designed gas tight for normal operating conditions.

Under emergency conditions such as nearby fires, explosions and extreme earthquakes, or a leaking inner-tank/membrane, the owner may consider to accept limited vapour leakages.

As concrete in itself cannot be considered vapour tight, normally a vapour barrier coating or steel liner is provided at the inner surface of the concrete outer tank. Such liner or vapour barrier coating should also sufficiently limit the migration of water from the outside, through the concrete structure into the tank.

For membrane tanks, the possibility of product vapour leakage is generally further reduced under normal operating conditions as the insulation space between membrane and concrete structure should be continuously purged with nitrogen when concrete is designed as the secondary barrier.

**D.1.2.3 Boil-off**

The owner or operator of the storage system should specify the allowable maximum boil-off in order to design the insulating capacity. For tanks in exporting terminals the optimum boil-off follows from considerations of product loss, re-liquification costs and insulation costs.

For import terminals the boil-off requirements may be less stringent than for export terminals because boil-off gas may be sent directly into the distribution grid.

**D.1.2.4 Heating system.**

LNG tanks of which the base (and wall) are in direct contact with the soil/sea water may be provided with a base (and wall) heating system.

The heating system, in combination with the insulation, shall prevent the zero isotherm from penetrating into the soil/water.

The control of the heating system is obtained by temperature sensors which are strategically located over the heated area.

**D.1.2.5 Pressure and vacuum relief**

LNG tanks are protected against overpressures and vacuum.

The following facilities/control are normally used for over pressure protection.

1) Boil-off compressor.
2) Relief to safe location, e.g. flare or vent.
3) Closure of liquid inlet.
4) Emergency relief valves, relieving directly to atmosphere (for ultimate protection).

The following facilities/control are normally used for vacuum (gauge) protection.

1) Supply of hot liquid/gas.
2) Trip of boil-off compressor and shut-down liquid outlet flow from the tank.
3) Opening of vacuum relief valves to allow entrance of air into the tank (ultimate protection).

**D.1.3 Permanent actions (G)**

**D.1.3.1** The permanent actions [G] are:

— prestress (the probable value of the prestressing, if any)
— own weight (on raft, foundations)
— weight of items of equipment (pipe work and fittings)
— gaseous pressure
— thrust of thermal insulating material (for example in the case of perlite insulation)
— external hydrostatic pressure up to mean water level
— soil pressure on foundation and/or on the tank.

D.1.3.2 Vapour pressure
a) Internal vacuum
   The roof shall be designed for the internal vacuum.
   This is included in the live load specified under [D.1.4].
b) Internal pressure
   The value for the internal pressure shall be specified by the purchaser.

D.1.3.3 Pressure from insulation
The loose perlite powder in the annular space between the inner and outer shells will exert a pressure on the inner tank shell. The presence of resilient blankets, which allow movements of the tank shell, will reduce these pressures. The compressive load acting on the inner tank shell shall be determined by the tank contractor based on investigations and test work.

D.1.3.4 Prestressing
The effects of prestress induced by prestressing cables shall be incorporated. Eccentricity, anchor slip, friction losses and relaxation of stress in prestressing cables, as well as creep and shrinkage of concrete, shall be taken into account.

D.1.4 Variable actions (Q)
These are:

\[ Q_1 \] : loading during construction (scaffolding/staging, hoisting gear, partial prestressing or construction loading

\[ Q_2 \] : overloads with respect to permanent actions, as deliberately applied to test strength and fluid tightness (overloads)

\[ Q_3 \] : hydrostatic action of LNG and fatigue through filling/emptying cycles noted LNG

\[ Q_4 \] : forces induced by thermal contractions or thermal stresses, during tank life, commissioning and decommissioning

D.1.4.1 Live load
a) Roof
   A uniformly distributed load and a concentrated load shall be specified for the roof.
   Usually, for steel roofs a uniformly distributed load of 1.2 kN/m$^2$ of projected area and a concentrated load of 5 kN over an area of 0.1 m$^2$ placed at any location on the roof are specified. In general, concrete roofs are capable of carrying higher concentrated loads.
b) Platforms and access ways
   A uniformly distributed load of 5kN/ m$^2$ is often used.

D.1.4.2 Product/liquid load
a) Inner tanks
   i) The inner tank shall be designed for a liquid load at the specified minimum design temperature, including sloshing and possible movement of the floating structure or global deformation of the concrete support structure due to global response.
The design product level shall be the maximum product level specified or the level 0.5 m below the top of the shell, whichever is higher.

ii) The inner tank and its foundation shall also be designed for the water test

b) Outer tanks (double and full containment tanks only)

i) The outer tank shall be designed to contain maximum liquid content (and intermediate volumes) of the inner tank at the minimum design temperature specified.

ii) Steel outer tanks and their foundations shall also be designed for the water test (see also [8.2]).

c) Concrete structures of membrane tanks

i) The concrete tank shall be designed for the combination of the hydrostatic load resulting from tank contents and a temperature loading following from a leak in the membrane.

ii) The concrete tank and its foundation shall also be designed for the water test.

D.1.4.3 Settlements
The storage tank and its foundations shall be designed taking account of the predicted maximum total and differential settlements that can occur during the life of the tank.

a) Cone down

The maximum expected difference between the average displacement along the circumference of the tank and the displacement of the bottom centre (cone down) shall be determined. Its effect in terms of membrane tension in the tank bottom and moments in the wall-to-bottom connection shall be taken into account.

b) Circumferential displacement

Differential displacement along the circumference of the tank may lead to high bending moments in the wall-to-bottom junction and the roof-to-wall junction. The effect of maximum expected differential displacement shall be incorporated in the design.

c) Local soft spots

For tanks on a raft foundation the effects of local soft spots shall be considered in the design of the concrete tank.

D.1.5 Environmental loads (E)

D.1.5.1 These are:

― \([E_1]\) : climatic loading (hours of sunshine, daily and seasonal atmospheric temperature change, snow, ice) or climatic loading

― \([E_2]\) : strength level earthquake (SLE)

― \([E_3]\) : wind, current and wave loads

D.1.5.2 General

The environmental conditions shall be collected and specified by the owner. In general, local codes provide guidelines for the determination of environmental loads (actions) such as wind, snow, temperatures, earthquakes, etc. The owner should verify whether the statistical basis of these guidelines is commensurate with the required level of reliability. More details are given in Sec.4.

D.1.5.3 Wind load

The wind load shall be determined, based on local data (wind speed records or codes).

D.1.5.4 Wave and current loads

The wind load shall be determined, based on local data. Reference is made to Sec.4.

D.1.5.5 Snow load
The snow load shall be in accordance with local requirements. Also, the case with only half the roof area loaded should be considered.

**D.1.5.6 Ambient temperatures**

The maximum and minimum ambient temperatures shall be specified by the owner.

The effect of seasonal variation in ambient temperatures shall be taken into account. Sun radiation and other short term variations of temperature should also be taken into account for structural detailing. For structures exposed to sea water, the effect of the sea temperature shall also be included in the design.

**D.1.5.7 Earthquakes**

The effect of earthquakes is three fold. It causes acceleration of the tank structure resulting in horizontal and vertical loads, sloshing of the liquid contents and it results in deformation of the subgrade for fixed platforms.

a) Seismic loads

For the assessment of effects of seismic loads, a distinction can be made between a static and a dynamic analysis of the tank structure.

A (pseudo) static approach is often used for preliminary concrete tank designs for areas with high seismicity or for detailed designs for areas with low seismicity.

For the detailed design of tanks exposed to more severe seismic loads, a dynamic analysis (e.g. by means of modal analysis or direct integration technique) may be used. The input for such calculation is a time-ground acceleration history or a design response spectrum. They are based on a certain recurrence interval (See [3.1.3.3], [5.2.1.7], [5.4.9]).

b) Sloshing effects

Sloshing pressures due to earthquake shall be predicted based on the results from the dynamic analyses.

c) Subgrade deformation

The deformation of the subgrade follows from shear waves and compression waves progressing along the surface of the earth. They can be magnified if a soft subgrade covers the hard stratum. In such case a site investigation should be carried out to determine ground accelerations and subgrade deformation.

**D.1.6 Accidental actions (A)**

**D.1.6.1** These are:

[A₁] over pressure (one cause of which can be rollover) (over pressure)

[A₂] negative pressure (negative pressure)

[A₃] primary container leakage, including the thermal shock on the secondary container (leak action)

[A₄] over-filling (over-filling)

[A₅] ductility level earthquake (DLE)

[A₆] impact of a projectile (impact)

[A₇] radiation due to fire (radiation)

[A₈] Blast due to external (blast).

**D.1.6.2 General**

In view of the high consequences an uncontrolled release of hazardous products might have for life, property and environment, due attention should be given to extreme design conditions, i.e. hazard loads and hazard or accident scenario’s.

Hazards can be classified into three categories:

A. Internal hazards

Definition:
Any internal situation of either technical, physical or operational nature, that might jeopardize the functioning, strength or stability of the liquid retaining component of the storage system and might give rise to a thermal, physical, and/or mechanical loading of the concrete protective structure.

Internal hazards are:
1) roll over
2) overfilling
3) inner tank failure
   — local failure; cold spot
   — overall failure; whether or not in a zipping mode.

B. External hazards
Definition:
Any external action resulting from natural phenomena or nearby industrial or anyhow man-made accidents.
Relevant external hazards are:
1) blast
2) impact
3) fire
4) earthquake
5) hurricanes
6) flood
7) lightning.

D.1.6.3 Roll over
Precautions shall be taken to prevent stratification and subsequent roll over.

D.1.6.4 Overfilling
Precautions in the form of multiple independent measuring devices shall be installed to prevent overfilling of the inner tank. If nevertheless overfilling does occur, the scenario for inner tank failure shall be considered.

D.1.6.5 Leakage of an inner tank or membrane may result in a local drop in temperature of the concrete protective structure (cold spot) or, if leakage continues, to gradual filling up of the annular space between inner and outer structure with cold liquid, in which case the outer structure is submitted to a thermal and hydrostatic load (inner tank failure). A consistent failure scenario shall reveal whether, for the storage system in view, a cold spot loading case shall be considered as an intermediate stage prior to an inner tank failure.

D.1.6.6 In case an inner tank fails in a sudden mode, the resulting load case is indicated as zipping.

D.1.6.7 The extent and duration of a cold spot shall be established on the basis of consistent and realistic leakage scenario's.
In case of a pipe-break just on the roof of the tank (caused by, for example, an external explosion), the possibility of an externally induced cold spot shall be considered.

D.1.6.8 In a consistent failure scenario the following points shall be considered:
— rate and height of filling of the annular space
— the role of the insulating system in the calamity stage
— the effect of excessive evaporation when the concrete protective outer structure is filled with cold liquid (built-up of overpressure).

Thermal and structural analysis shall be carried out for intermediate and final stages of the accident. Thermal loads, hydrostatic pressure and eventual overpressure due to excessive evaporation shall be combined with relevant operational loads (dead weight).
D.1.6.9 Classification of industrial explosions

Industrial explosions can be classified into:

1) physical explosions
   - exploding steam boilers
   - rapid face transformation (e.g. nuclear power plants) - exploding pressure vessels (BLEVE)

2) chemical explosions
   - explosive charges (incl. sabotage)
   - gas cloud explosions.

For each individual project in inventory shall be made up of the blast potentials. Blast potentials which stem from adjacent plants shall be considered as well.

D.1.7 Analysis

D.1.7.1 Thermal analysis

Thermal analysis shall be carried out making allowance for temperature dependency of thermal material properties. Due attention shall be given to the transient state; non-linear temperature fields give rise to eigen-stresses, which stresses significantly influence the crack pattern (crack distance and crack width). For further details, see Sec.5.

D.1.7.2 Structural analysis

The outer tank shall be designed to contain maximum liquid content of the inner tank at the minimum design temperature specified.

Structural analysis shall be carried out accounting for temperature dependency of mechanical and rheological material properties. Adopted material properties shall be based on tests or applicable literature data. The effect of cracking on the distribution of forces shall be considered. Local plasticity is acceptable as long as overall stability is assured and provided that crack width and leakage requirements remain fulfilled. For further details, see Sec.5.

D.1.8 Design criteria

D.1.8.1 Crack width criteria shall ensure that possible leakage of gas or liquid through cracks shall neither give rise to an escalation of a calamity nor constitute an additional hazard for life and property beyond what is considered to be acceptable. See [6.4.5.4]. For gas tightness and prevention of mitigation of moisture into the insulation, a steel membrane will normally be required in the secondary barrier.

D.1.8.2 In case of storage of poisonous material full tightness shall be required, to be ensured by a minimum height of the concrete compressive zone \( h_x \geq 100 \text{ mm} \). In view of high consequences leakage of poisonous material through through-cracks might have, even narrow through~cracks may not be considered to be tight for the duration of the calamity and shall, therefore, either be avoided or be sealed off by an internal liner. The functioning of the liner shall be checked for all relevant cryogenic load cases. The tightness criteria shall be in accordance with Sec.5.

D.1.8.3 Crack width calculations shall be carried out accounting for temperature dependency of tensile and bond strength of the concrete.

D.1.8.4 The crack width analysis shall be carried out in accordance with Sec.6.

D.1.8.5 For the determination of the load bearing capacity (shear, flexure, membrane forces) the temperature dependency of material properties of steel and concrete shall be taken into account.
Partial safety factors shall allow for uncertainties in modelling of the loading, in adopted material properties and response calculations. The detailed design shall be in accordance with Sec.5, Sec.6 and Sec.7 of this standard.

D.1.9 Earthquakes

D.1.9.1 Seismic loads

Data on seismic activity of a particular site shall be obtained from local records. If no reliable records are available, data (response spectra) shall be determined either probabilistically or, if statistic data are insufficient to expect reliable results from a probabilistic approach, deterministically. Both horizontal and vertical ground accelerations shall be considered.

Two classes of design earthquakes shall be considered:

a) Strength level earthquake (SLE)
   See [3.1.3.3] for definition.

b) Ductility level earthquake (DLE)
   See [3.1.3.3] for definition.

D.1.9.2 Seismic analysis

A full dynamic analysis shall be carried out (see Sec.5), making allowance for:

— material damping
— soil characteristics
   Soil characteristics (stiffness, damping, susceptibility to liquefaction) significantly affect the dynamic response of the structure. A parametric sensitivity study is recommended to investigate the effect of scatter in soil characteristics. This particularly in view of the intensity of liquid-structure interaction (sloshing)
— sloshing of the liquid
   Sloshing effect shall be dealt with according to up-to-date calculation procedures. Eventual damage to roof insulation (suspended roof), the possibility and consequences of overfill and suction forces a non-load bearing membrane might be subjected to, shall be duly considered.

Due attention shall be given to the modelling of the interaction between inner and outer tank, i.e. to the dynamic properties of the load bearing bottom insulation. Anchoring of the inner tank in order to ensure horizontal and vertical stability of the inner tank shall thoroughly be investigated.

A dynamic response obtained with a model analysis will generally yield sufficiently accurate results. For higher accuracy direct integration technics are more suitable. In the early stage of the project a quasi static analysis may be helpful for a preliminary estimation of the seismic behaviour of the structure and of the soil-structure interaction. Design values for structural forces (moments, shear forces, etc.) to be used for dimensioning of cross sections, amounts of reinforcement etc. shall be obtained from the full dynamic analysis.

In the dynamic analysis the adopted materials properties shall refer to temperatures under operational conditions.

If the concrete protective structure is required to withstand the hydrostatic and thermal loading resulting from a possible failure of the inner tank in an earthquake, a consistent scenario shall demonstrate whether an additional dynamic loading associated with the failure of the inner tank has to be considered or not.
D.1.10 Action combinations for design of containment tanks

D.1.10.1 The actions listed above shall be combined to create normal actions and augmented actions at least as severe as those indicated in the tables below, taking into account load coefficients. It shall be noted that the accidental actions are assumed not to be simultaneous.

**Table D-1 Normal actions**

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<tbody>
<tr>
<td>Building</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>(1)</td>
<td>(2)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Operation</td>
<td>x</td>
<td>-</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>(2)</td>
</tr>
<tr>
<td>Earthquake</td>
<td>x</td>
<td>-</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>(1)</td>
</tr>
</tbody>
</table>

(1) Taking into account the pressure test of 1,0 times the maximum operating gauge pressure.
(2) Taking into account hydrostatic pressure test at a minimum pressure of 1,0 times the operating gauge pressure under normal filling conditions.

**Table D-2 Accidental action combinations**

<table>
<thead>
<tr>
<th>Augmented actions</th>
<th>Permanent action</th>
<th>LNG</th>
<th>Thermal stresses</th>
<th>Over pressure</th>
<th>Negative Pressure</th>
<th>Leak action</th>
<th>Overfilling</th>
<th>DLE</th>
<th>Impact</th>
<th>Radiation</th>
<th>Blast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over pressure</td>
<td>[G]</td>
<td>[Q₃]</td>
<td>[Q₄]</td>
<td>[A₁]</td>
<td>[A₂]</td>
<td>[A₃]</td>
<td>[A₄]</td>
<td>[A₅]</td>
<td>[A₆]</td>
<td>[A₇]</td>
<td>[A₈]</td>
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<tr>
<td>depressurisation</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>primary container leak</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overfilling</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Earthquake</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missile impact</td>
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<td>x</td>
<td>x</td>
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<td></td>
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</tr>
</tbody>
</table>
**D.1.11 Specific methods to determine the actions**

**D.1.11.1 Hydrostatic action of fluid**

The hydrostatic action shall be calculated taking into account the weight of the highest of the following values:

- the weight of LNG which completely fills the primary container (action \([Q_3]\))
- the weight of the hydrostatic test fluid (action \([Q_2]\))
- any sloshing effect from liquid in the tank
- any pressure variation or sloshing effect from hull movements.

The hydrostatic test is usually carried out with water, the density of which is approximately twice as high as that of LNG. Therefore, according to the height of the water during the test, the hydrostatic action can be up to twice that encountered under normal operating conditions. The nature of the fluid, which will be used for the hydrostatic test, and the level of fluid which will be required shall be known at the design stage. Minimum test conditions are described in Sec.6, but the owner can have particular requirements.

In a tank with a self-supporting primary container, by definition the primary container shall take up forces generated by the hydrostatic action of the fluid.

The secondary container (including impounding area if required) wall shall also be able to withstand that action in the event of internal tank leakage.

**D.1.11.2 Effect of fire radiation on prestressed concrete**

The thickness of the concrete shall be sufficient to ensure that, in the event of an external fire, the temperature of the prestress cables is kept low enough to maintain the integrity of the LNG tank and its enclosure with full contents and at maximum design pressure. If no water deluge system is installed, the integrity of the design of the tank shall be guaranteed during the time needed to provide fire water in sufficient quantities from an external source.

To determine this minimum concrete thickness recognised methods and appropriate models which have been validated shall be used.

**D.1.11.3 Deformable projectile impacts**
Deformable projectiles are non rigid objects which are assumed to be incapable of deforming a harder surface on impact. The impact of planes or helicopters on a prestressed concrete wall, if required in the hazard assessment, shall be taken into account on this basis except for the impact of the engine which is considered to be an indeformable projectile.

The resulting effect is the application of a force on a portion of the surface, that is, of a pressure, whose value varies over time. By retaining the maximum value of this pressure, the calculation of the required resistance to impact may be reduced to one based on a statically applied pressure.

The calculation of this pressure can be carried out from the following elements:

— it may be assumed that a mass that impacts the hard surface, instantly reaches a nil velocity; splinters shall also have a nil velocity
— knowing the distribution of mass within the projectile, the application of dynamics allows the calculation of the instantaneous value of the resulting force on the wall
— the resulting pressure is obtained by dividing the force thus obtained by the area of the instantaneous contact surface area of the projectile with the wall.

D.1.11.4 Indeformable projectile impacts

Indeformable projectiles (for example aircraft engines) are those assumed to be harder than the surface encountered. The absorption of their momentum is through deformation and breaking of the wall.

Actions shall be calculated using recognised models.

D.1.11.5 Explosions

If flammable products stored or transported near the tank, were accidentally released into the atmosphere, they could create an explosion generating an over pressure wave to which the tank would be submitted.

Recognised methods and models which have been validated shall be used to calculate the over pressure. In this case it will be assumed that:

— a detonating or deflagrating explosion near the tank creates an over pressure wave that shall be applied, as a worst case assumption, to half the perimeter of the tank
— the effects on the structure are reduced to a static calculation.

The method, widely used because of its simplicity, of the TNT equivalent which assimilates the gas explosion to a TNT detonating explosion is considered too conservative when applied to unconfined natural gas clouds.

D.1.11.6 Earthquakes

The reactions of the fluid mass and the mass of the tank as such shall be studied separately dynamically.

Critical dampening percentages shall be covered by the soil report.

Study of the fluid mass shall enable the following to be determined for tanks:

— pressure distribution on the walls
— the height of the wave at the surface of the fluid
— tangential shearing stresses within the tank
— vertical tensile stresses at the base of the tank (sizing of anchorage within the raft)
— vertical compressive stresses at the base of the tank (resistance to buckling)
— overturning moment, which includes the effects of dynamic pressures on the bottom.

D.1.12 Structural detailing

D.1.12.1 Toughness

The assumed magnitude and distribution of the loads as well as the calculations of the cross section forces are approximations only with a considerable range of variation for hazard load cases. A sufficient toughness for the reduction of elastic stress peaks and a sufficient capacity for the redistribution to less stressed areas and therefore prevention of a brittle fracture are the most important requirements in the design of the outer
tank. For dynamic hazards like earthquake, vapour cloud explosion, external impact, internal fluid impact, a sufficient energy dissipation is required to absorb the introduced energy.

A measure for the compliance with all these requirements is the toughness of a cross-section and of a structure. Toughness is required to limit the damages after hazards. For a concrete secondary barrier, this requirement is fulfilled with a sufficient minimum longitudinal reinforcement in both directions and, if necessary, by reinforcing the wall in the areas base slab/wall and dome/wall with stirrups sufficient to prevent brittle shear fracture.

If the cross-section dimensions are sufficient to exclude brittle fracture resulting from failure of the concrete pressure zone, an increase in reinforcement is preferable to an increase in the concrete cross-section, taking all factors into consideration.

Ductility of reinforced concrete sections are provided by appropriate inclusion of confining reinforcement in the concrete section.

For ductility requirement of structural members in in-plane shear, special considerations may be required. If ductility design in form of plastic hinges becomes unrealistic, an over-strength design may be appropriate also for DLE. Special consideration will be required in each case as this will be structural geometry dependent.

D.1.12.2 Fire resistance, external fire

If the sprinkler system fails the shielding tank has to resist the thermal radiation of an adjacent burning tank or of a burning spill for a limited time. Structural integrity and serviceability of a concrete container are maintained if the prestressing tendons in the wall are covered sufficiently with concrete, considering the march of temperature and the critical temperature of the prestressing steel, and if the reinforcement on the inside of the wall is sufficient for crack distribution.

Examination of the system as a whole for non-uniform temperature distribution can result in decisive bending moments and forces.

D.1.12.3 Cold resistance, cold spot resistance

With regard to the risk of cracking and penetration of liquid to the surface of the concrete wall, an insulation liner is efficient only for the reduction of the boil off rate and for cold spot resistance.

If the safety theory of the outer tank requires a cryogenic wall or bottom slab, the material properties shall be chosen considering the temperature of the stored liquid.

For the design of a cryogenic liner the effects of thermal shock on anchors, shear studs and the like shall be investigated. If the liner for operating conditions is not cryogenic the concrete structure shall be resistant to liquid leakage.

D.1.12.4 Liquid and gas tightness

If complete liquid tightness for protection of the insulation or gas tightness is necessary for double wall systems, a steel liner is required.

D.1.12.5 Membranes

The membrane is an impervious barrier which is separated from the concrete by the insulation. The insulation shall be selected in such a manner that it can transfer the liquid pressure to the concrete as a permanent load. The flexibility of the approx. 1 mm thick metal membrane, which shall be ductile at service temperature, is assured by profiling in the horizontal and vertical direction.

D.1.13 Liners

D.1.13.1 Liners are in dispensable in the design of concrete components as an impervious barrier to make the components liquid tight on the long run or gas tight and to prevent the penetration of water into the insulation.
D.1.13.2 Liners are in contact with and act usually compositely with the concrete. The standard design is a lining located at the inner surface of the outer concrete wall.

D.1.13.3 The liner shall resist buckling during and after prestressing (including the effects of creep and shrinkage of the concrete wall). In the case of leakage of the inner tank the liner may experience contraction and thermal shock which is sufficient to overcome the prestress. Consideration should also be given to the rate of strain under these conditions. The effects of thermal shock on any anchors, shear studs, and the like connecting the liner with the concrete shall also be considered.

D.1.13.4 A flexible zone is required at the junction wall/floor.

D.1.13.5 Whether a cryogenic liner is required for the outer tank depends upon the design philosophy. Under operating conditions the liner is protected by the insulation so that the gas tightness can be assured by a non-cryogenic liner. In the event of failure of the inner tank the cryogenic liner is only necessary when it has to assure the liquid tightness.

D.1.14 Insulation

Tank floors
D.1.14.1 Foamed glass blocks are commonly employed, stacked in layers with filled and staggered vertical joints and interleaved with bitumenous or felt layers. The material is brittle, and its strength is limited. Other types of insulant used in tank floor construction include pvc and polyurethane, though the long term creep characteristics of the latter should be taken into account in determining its suitability and limiting compressive stress.

The insulation immediately below the wall of the inner tank may be subjected to load intensifies in excess of the safe working capacity of foamed glass; in this zone, it is therefore usual to install a ring beam of perlite concrete which may be cast in place but more usually is of precast oven dried and sealed blocks.

Other lightweight concretes including cellular concrete and an insulating concrete incorporating polystyrene beads have also been used, as have blocks of laminated balsa wood. The width of this ring beam should extend at least 100 mm beyond the inner edge of the annular plate of the inner tank bottom.

Tank walls
D.1.14.2 The most widely used forms of insulation are powdered perlite in double wall systems, and either foamed glass or polyurethane slabs in single wall designs. Perlite is provided as a loose powder which is subject to settlement and consolidation, and therefore required to be contained. This is usually done by filling the space between the inner and outer walls, and a nylon or similar seal is often provided at the wall to roof junction to prevent the perlite from being carried over into the stored liquid.

For metallic inner tanks a resilient layer in the form of a fibre glass blanket, about 100 mm thick, is placed around the inner tank, to prevent the pressure of the perlite powder from building up following consolidation and thermal cycles, since such pressure increases could lead to buckling of the tank.

Foamed glass and polyurethane blocks are commonly attached to the wall by means of a suitable adhesive. They shall be fully protected from the ingress of moisture, which can disrupt the adhesive and cause a loss of insulation,-and from ultraviolet attack.

There are also insulations of sprayed polyurethane foam which are used both as insulation and as temporary membranes for the reduction of the boil off rate and for cold spot resistance, because of their impervious nature. A resin bonded fibre glass reinforcing layer may be incorporated near the exposed face of the foam, to prevent cracks temporarily from penetrating to the liner. Systems employing sprayed insulation shall be applied in carefully controlled environmental conditions.

D.1.14.3 Tank roofs: These are usually insulated by means of perlite, fibre glass blankets, mineral wool, or polyurethane, placed on top of a suspended inner roof.
D.1.15 Membrane storage vessels

D.1.15.1 The insulation of a membrane storage is in charge of two additional functions which are:
— tightness in the case of a damaged membrane
— transmitting the load bearing forces to the supporting structure.

D.1.15.2 For these purposes the two following systems may be employed:
— Panels made of polyvinyl chloride (PVC) bonded together, and covered with a plywood sheet which provides adequate support for the membrane. The joints between the insulation panels are staggered and filled with glass-wool. In case of a liquid penetration behind the primary barrier, the tightness of this insulation system protects the concrete from being submitted to any thermal shock.
— Bonded planks of polyurethane foam reinforced in three orthogonal directions with fiber-glass yarns. The system is tight (totally bonded) which eliminates any free flow path. In addition, LNG gradually penetrating into the insulation because of a damaged membrane is stopped from reaching the outer tank by a gas barrier formed within the insulation.
CHANGES – HISTORIC

There are currently no historical changes for this document.
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SAFER, SMARTER, GREENER