FOREWORD

DET NORSKE VERITAS (DNV) is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

DNV service documents consist of amongst other the following types of documents:
— Service Specifications. Procedural requirements.
— Standards. Technical requirements.

The Standards and Recommended Practices are offered within the following areas:
A) Qualification, Quality and Safety Methodology
B) Materials Technology
C) Structures
D) Systems
E) Special Facilities
F) Pipelines and Risers
G) Asset Operation
H) Marine Operations
J) Cleaner Energy
O) Subsea Systems
CHANGES

• General

As of October 2010 all DNV service documents are primarily published electronically.

In order to ensure a practical transition from the “print” scheme to the “electronic” scheme, all documents having incorporated amendments and corrections more recent than the date of the latest printed issue, have been given the date October 2010.

An overview of DNV service documents, their update status and historical “amendments and corrections” may be found through http://www.dnv.com/resources/rules_standards/.

• Main changes

Since the previous edition (October 2004), this document has been amended, most recently in April 2009. All changes have been incorporated and a new date (October 2010) has been given as explained under “General.”
CONTENTS

Sec. 1 Introduction.......................................................... 7
  A. General...................................................................... 7
  A 100 Introduction......................................................... 7
  A 200 Objective............................................................. 7
  A 300 Scope and applications.......................................... 7
  A 400 Non DNV codes and standards............................ 8
  A 500 Classification....................................................... 8
B. References...................................................................... 8
  B 100 General............................................................... 8
C. Definitions..................................................................... 9
  C 100 Verbal forms......................................................... 9
  C 200 Terms.................................................................. 9
D. Abbreviations and Symbols.......................................... 11
  D 100 Abbreviations....................................................... 11
  D 200 Symbols............................................................... 11

Sec. 2 Safety Philosophy............................................... 13
  A. General...................................................................... 13
  A 100 Objective............................................................. 13
  A 200 Systematic review............................................... 13
  A 300 Safety class methodology...................................... 13
  A 400 Quality assurance................................................ 13
  A 500 Health, safety and environment......................... 13
  A 600 Qualifications of personnel............................... 13
B. Design Format............................................................ 14
  B 100 General............................................................... 14
C. Identification of Major Accidental Hazards.................. 14
  C 100 General............................................................... 14

Sec. 3 Design Documentation.................................... 15
  A. Overall Planning......................................................... 15
  A 100 General............................................................... 15
  A 200 Description of offshore concrete LNG terminal.... 15
  A 300 Meteorological and ocean conditions............... 15
  A 400 LNG terminal layout........................................... 15
  A 500 Primary functions............................................... 16
  A 600 Standards.......................................................... 16
  A 700 Documentation...................................................... 16
  A 800 Documentations required prior to construction... 16
  A 900 AS-BUILT Documentation................................... 17
  A 1000 Inspection/monitoring plans for structure in service .... 17

Sec. 4 Structural Materials........................................ 18
  A. General...................................................................... 18
  A 100 Concrete and Concrete Constituents.................... 18
  A 200 Grout and Mortar................................................. 18
  A 300 Reinforcement...................................................... 18
  A 400 Prestressing Steel and anchorage..................... 18
  A 500 Embedded Steel................................................... 18
  A 600 Repair Material.................................................... 18
  A 700 LNG Primary Containment Tank......................... 18
  A 800 Insulation........................................................... 18

Sec. 5 Loads and Analyses Requirements.................. 19
  A. Requirements to Design of Concrete Support Structure .... 19
  A 100 General............................................................... 19
  A 200 Structural requirements...................................... 19
  A 300 Design principles............................................... 20
B. Load and Load Effects.................................................. 20
  B 100 General............................................................... 20
  B 200 Environmental loads......................................... 20
  B 300 Extreme wave loads.......................................... 20
  B 400 Diffraction analysis.......................................... 20
  B 500 Additional requirements for dynamic analysis under wave load... 21
B 600 Model testing......................................................... 21
B 700 Current load.......................................................... 21
B 800 Wind loads............................................................ 21
B 900 Functional loads.................................................... 21
B 1000 Accidental loads................................................. 21
C. Load Combinations and Partial Safety Factors........... 23
  C 100 Partial load factors, \( f \)........................................... 23
  C 200 Combinations of loads........................................ 23
  C 300 Consequence of failure....................................... 23
D. Structural Analysis...................................................... 24
  D 100 General............................................................... 24
  D 200 Special load effects............................................. 24
  D 300 Analyses requirements........................................ 24
  D 400 Analysis of construction stages.......................... 25
  D 500 Transportation analysis........................................ 25
  D 600 Installation and deck mating analysis.................. 25
  D 700 In-service strength and serviceability analyses.... 25
  D 800 Fatigue analysis................................................... 25
  D 900 Seismic analysis.................................................. 26
  D 1000 Accidental and overload analyses...................... 26
  D 1100 Terminal removal/reuse...................................... 26
E. Topside Interface Design........................................... 26
  E 100 Introduction........................................................ 26

Sec. 6 Detailed Design of Offshore Concrete terminal Structures........................................ 27
  A. General...................................................................... 27
  A 100 Introduction........................................................ 27
B. Design Principles Concrete Terminal.......................... 27
  B 100 General............................................................... 27
  B 200 Limit states........................................................ 27
  B 300 Characteristic values for material strength........... 27
  B 400 Partial safety factors for materials....................... 27
  B 500 Design by testing................................................ 27
  B 600 Design material strength..................................... 28
C. Basis for Design by Calculation.................................. 28
  C 100 Concrete grades and in situ strength of concrete.... 28
  C 200 Concrete stress – strain curves for strength design... 29
  C 300 Geometrical dimensions in the calculation of sectional capacities............................................. 30
  C 400 Tension in structural members............................ 31
  C 500 Fatigue strength relationships............................. 31
  C 600 Deformation induced loads, prestressing and creep... 31
  C 700 Effect of water pressure........................................ 31
D. Design of Structural Members..................................... 31
  D 100 Design capacity in ultimate limit state (ULS)......... 31
  D 200 Capacity in fatigue limit state (FLS)..................... 31
  D 300 Design for accidental limit state (ALS)................ 31
  D 400 Design for ductility.............................................. 31
  D 500 Design in serviceability limit state (SLS)............. 32
  D 600 Design by testing................................................ 32
E. Detailing of Reinforcements......................................... 32
  E 100 General............................................................... 32
F. Corrosion Control......................................................... 32
  F 100 General............................................................... 32

Sec. 7 LNG Containment System..................................... 33
  A. Introduction............................................................. 33
  A 100 General............................................................... 33
B. Design of LNG Containment Structure........................ 34
  B 100 Design principles............................................... 34
  B 200 Design basis......................................................... 34
  B 300 Design of LNG primary tanks.............................. 34
  B 400 Containment systems........................................... 34
  B 500 Process facilities.................................................. 35
Sec. 8 Construction ................................................................. 37
A. General .............................................................................. 37
B. Specific to LNG/LPG Containment Structures .................... 37
   B 100 Construction, Commissioning and Turnaround ............ 37
   B 200 Performance testing .................................................. 37
   B 300 Inspection of independent steel containment tanks ......... 37
   B 400 Inspection of membranes of membrane tanks ............... 38
   B 500 Hydrostatic testing .................................................... 38
   B 600 Pneumatic testing ..................................................... 38
   B 700 Liners and coatings ................................................... 38
   B 800 Cool-down ............................................................. 38
   B 900 Extreme design conditions ......................................... 38
   B 1000 Painting, fire proofing and embrittlement protection ....... 39

Sec. 9 In-service Inspection, Maintenance and Conditional Monitoring of Support Structure and Tank ........................................ 40
A. General .............................................................................. 40
   A 100 Concrete Substructure ............................................... 40
B. Special for LNG containment system .................................... 40
   B 100 General ..................................................................... 40
   B 200 Gas detection .......................................................... 40
   B 300 Cold detection ........................................................ 40
   B 400 Smoke detection ...................................................... 40
   B 500 Fire detection .......................................................... 40
   B 600 Meteorological instruments ........................................ 40
   B 700 Safety control system ................................................ 40

App. A Hazard Assessment of LNG Terminals (Guidelines) ......................................................... 43
A. Hazard Assessment ............................................................. 43
   A 100 Hazards and operability study (HAZOP) ......................... 43
   A 200 Methodology .......................................................... 43
   A 300 Identification of hazards of external origin ....................... 43
   A 400 Identification of hazards of origin .................................. 43
   A 500 Hazards which are not specific to LNG/LPG ................... 43
   A 600 Hazardous area classifications ..................................... 44
   A 700 Estimation of probabilities ........................................... 44
   A 800 Estimation of consequences ......................................... 44
   A 900 Safety measures on the LNG plant ................................ 44
   A 1000 LNG terminal layout ................................................. 45
   A 1100 Emergency shutdown .............................................. 45

A 1200 Fire protection ............................................................ 45
A 1300 Seismic protection ...................................................... 45
A 1400 Confinement ............................................................. 45

App. B Hazard Definitions (Guidelines) ..................... 46
A. Hazard Definitions .............................................................. 46
   A 100 Probabilities ranges .................................................. 46
   A 200 Classes of consequence ............................................... 46
   A 300 Levels of risk ........................................................... 46

App. C General Design Principles LNG Containment Structures (Guidelines) ..................... 47
A. General Design Principles .................................................... 47
   A 100 Design considerations ................................................ 47
   A 200 General requirements ................................................ 47
   A 300 Fluid and gas tightness ............................................... 47
   A 400 Tank connections ..................................................... 47
   A 500 Thermal insulation .................................................... 47
   A 600 Operating loads ....................................................... 47
   A 700 General design rules .................................................. 47
   A 800 Liquid level ............................................................. 47
   A 900 Pressure ................................................................. 47
   A 1000 Temperature .......................................................... 47
   A 1100 Density ................................................................. 47
   A 1200 Pressure and vacuum protection ................................ 47
   A 1300 Vacuum ............................................................... 47
   A 1400 Bund wall and impounding area .................................. 47
   A 1500 Safety equipment ..................................................... 47
   A 1600 Reliability and monitoring of structure ....................... 47
   A 1700 Tank piping ........................................................... 47

App. D Detailed Structural Design of Containment System (guidelines) .............................................. 53
A. Detailed Structural Design .................................................... 53
   A 100 Introduction ............................................................ 53
   A 200 Functional requirements ............................................. 53
   A 300 Permanent actions (G) ................................................ 53
   A 400 Variable actions (Q) ................................................... 53
   A 500 Environmental loads (E) ............................................ 53
   A 600 Accidental actions (A) ................................................ 53
   A 700 Analysis ................................................................. 53
   A 800 Design criteria ........................................................ 53
   A 900 Earthquakes ............................................................. 53
   A 1000 Action combinations for design of containment tanks .... 53
   A 1100 Specific methods to determine the actions .................... 53
   A 1200 Structural detailing .................................................. 53
   A 1300 Liners ................................................................. 53
   A 1400 Insulation ............................................................. 53
   A 1500 Membrane storage vessels ....................................... 53
SECTION 1
INTRODUCTION

A. General

A 100 Introduction

101 This offshore 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.

102 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.

103 The standard shall be used together with the DNV standard DNV-OS-C502 “Offshore Concrete Structures”.

104 Design of the LNG Containment system may be designed either in accordance with the DNV Rules for Classification of Ships “Pt.5 Ch.5 – Liquified Gas Carriers” 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.

105 Guidelines for the design of containment systems based on traditional structures on land are given in Appendices A-D.

106 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.

107 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.

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

109 Floating LNG import/export terminals structures should be designed with freeboard and intact stability in accordance with DNV-OS-C301. For temporary phases the stability should be in accordance with DNV Rules for Planning and Execution of Marine Operations.

A 200 Objective

201 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.

A 300 Scope and applications

301 The standard is applicable to LNG Export and Import Terminal Structures using concrete as the structural material in the support structure as defined in 302 and 303 below.

302 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.

303 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
— vapourising
— gas quality adjustment.

304 Appendices A-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.

305 The standard is combining the design and construction experience from the fixed/ floating offshore structures DNV-OS-C502, DNV Rules for Classification of Ships Pt.5 Ch.5, 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.

306 For the detailed design of primary steel containment tanks reference is made to Rules for Classification of Ships Part 5 Chapter 5, IGC- IMO Code, EN-1473 and NFPA 59A. See Appendices C “General Design Principles LNG Containment Structures’ and 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.

307 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. The DNV Rules for Classification of Ships Part 5 Section 5 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.

308 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.

A 400 Non DNV codes and standards

401 In case of conflict between the requirements of this standard and a reference document other than DNV standard, the requirement of this standard shall prevail.

Non-DNV codes or standards may be used provided the same safety level as provided by this DNV standard, is obtained.

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

403 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.

A 500 Classification

501 Classification principles, procedures and application class notations related to classification services of offshore units are specified in the DNV Offshore Service Specifications given in Table A1.

Table A1 DNV Offshore Service Specifications

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNV-OSS-101</td>
<td>Rules for Classification of Offshore Drilling and Support Units</td>
</tr>
<tr>
<td>DNV-OSS-102</td>
<td>Rules for Classification of Floating Production and Storage Units</td>
</tr>
<tr>
<td>DNV-OSS-103</td>
<td>Rules for Classification of LNG/LPG Floating Production and Storage Units or Installations</td>
</tr>
<tr>
<td>DNV-OSS-121</td>
<td>Classification Based on Performance Criteria Determined by Risk Assessment Methodology.</td>
</tr>
<tr>
<td>DNV-OSS-309</td>
<td>Verification, Certification and Classification of Gas Export and Receiving Terminals.</td>
</tr>
</tbody>
</table>

B. References

B 100 General

101 The DNV documents in Tables B1 and B2 and recognised codes and standards in Table B3 are referred to in this standard.

102 The latest valid revision of the DNV reference documents in Tables B1 and B2 applies. These include acceptable methods for fulfilling the requirements in this standard. See also current DNV List of Publications.

103 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 Offshore Standard.

Table B1 DNV Reference Documents

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNV Rules</td>
<td>Rules for the Classification of Ships. Pt.5 Ch.5 “Liquified Gas Carriers”</td>
</tr>
<tr>
<td>DNV Rules</td>
<td>DNV Rules for Planning and Execution of Marine Operations</td>
</tr>
<tr>
<td>DNV-OS-A101</td>
<td>Safety Principles and Arrangement</td>
</tr>
<tr>
<td>DNV-OS-B101</td>
<td>Metallic Materials</td>
</tr>
<tr>
<td>DNV-OS-C401</td>
<td>Fabrication and Testing of Offshore Structures</td>
</tr>
<tr>
<td>DNV-OS-E301</td>
<td>Position Mooring</td>
</tr>
</tbody>
</table>

Table B2 DNV Offshore Object Standards for Structural Design

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNV-OSS-C101</td>
<td>Design of Offshore Steel Structures, General (LRFD Method)</td>
</tr>
<tr>
<td>DNV-OSS-C102</td>
<td>Structural Design of Offshore Ships</td>
</tr>
<tr>
<td>DNV-OSS-C103</td>
<td>Structural Design of Column-stabilised Units (LRFD method)</td>
</tr>
<tr>
<td>DNV-OSS-C104</td>
<td>Structural Design of Self-elevating Units (LRFD method)</td>
</tr>
<tr>
<td>DNV-OSS-C105</td>
<td>Structural Design of TLP (LRFD method)</td>
</tr>
<tr>
<td>DNV-OSS-C106</td>
<td>Structural Design of Deep Draught Floating Units</td>
</tr>
<tr>
<td>DNV-OSS-C502</td>
<td>Offshore Concrete Structures</td>
</tr>
</tbody>
</table>

Table B3 Other references

<table>
<thead>
<tr>
<th>Reference</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>
C. Definitions

**C 100 Verbal forms**

**101 Shall:** Indicates a mandatory requirement to be followed for fulfillment or compliance with the present standard. Deviations are not permitted unless formally and rigorously justified, and accepted by all relevant contracting parties.

**102 Should:** 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.

**103 May:** Indicates a permission, or an option, which is permitted as part of conformance with the standard.

**C 200 Terms**

**201 Accidental Limit States (ALS):** Ensures that the structure resists accidental loads and maintain integrity and performance of the structure due to local damage or flooding.

**202 Accidental Loads:** Rare occurrences of extreme environmental loads, fire, flooding, explosions, dropped objects, collisions, unintended pressure differences, leakage of LNG etc.

**203 Air Gap:** 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 sufficient large, then no wave pressure is applied to the topside structure.

**204 AS-BUILT Documentation:** 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.

**205 Atmospheric zone:** The external surfaces of the unit above the splash zone.

**206 Cathodic protection:** A technique to prevent corrosion of a steel surface by making the surface to be the cathode of an electrochemical cell.

**207 Characteristic load:** 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.

**208 Characteristic resistance:** 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.

**209 Characteristic material strength:** 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.

**210 Characteristic value:** The representative value associated with a prescribed probability of not being unfavourably exceeded during some reference period.

**211 Classification Note:** The Classification Notes cover proven technology and solutions which is found to represent good practice by DNV, and which represent one alternative for satisfying the requirements stipulated in the DNV Rules or other codes and standards cited by DNV. The classification notes will in the same manner be applicable for fulfilling the requirements in the DNV offshore standards.

**212 Coating:** Metallic, inorganic or organic material applied to steel surfaces for prevention of corrosion.

**213 Concrete Grade:** A parameter used to define the concrete strength. Concrete Grade for different characteristic values of concrete strength is provided in Sec.6, Table C1.

**214 Corrosion allowance:** Extra wall thickness added during design to compensate for any anticipated reduction in thickness during the operation.

**215 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.

**216 Cryogenic Temperature:** The temperature of the stored LNG.

**217 Deformation loads:** Loads effects on the Terminal caused by termal effects, prestressing effects, creep/shrinkage effects, differential settlements/deformations etc.

**218 Design brief:** An agreed document where owners requirements in excess of this standard should be given.

**219 Design temperature:** 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 is to be lower or equal to the lowest daily mean temperature 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.

**220 Design value:** The value to be used in the deterministic design procedure, i.e. characteristic value modified by the resistance factor or load factor.

**221 Double Containment Tanks:** 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.

**222 Driving voltage:** The difference between closed circuit anode potential and the protection potential.

**223 Ductility:** The property of a steel or concrete member to sustain large deformations without failure.

**224 Ductility level Earthquake (DLE):** The ductility level earthquake is defined probabilistically as an earthquake producing ground motion with a mean recurrence as a minimum of 10000 years.

**225 Environmental Loads:** Loads from wind, wave, tide, current, snow, ice and earthquake.

**226 Expected loads and response history:** 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.

**227 Expected value:** The most probable value of a load during a specified time period.

**228 Fatigue:** Degradation of the material caused by cyclic loading.

**229 Fatigue critical:** Structure with calculated fatigue life near the design fatigue life.

**230 Fatigue Limit States (FLS):** Related to the possibility of failure due to the effect of cyclic loading.

**231 Full Containment Tank:** 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.

**232 Functional Loads:** Permanent and variable loads, except environmental loads, to which the structure can be exposed.

**233 Hindcasting:** A method using registered meteorological data to reproduce environmental parameters. Mostly used for reproducing wave parameters.

**234 IGC-IMO Type B Independent Tank:** LNG containment tank designed, fabricated, maintained and inspected in accordance with the requirements for such tanks in IGC-IMO Rules. The design is based on the principle of detection of small quan-
tivities of LNG prior to failure of the steel support structure.

235 **Inspection:** 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.

236 **Limit State:** A state beyond which the structure no longer satisfies the requirements. The following categories of limit states are of relevance for structures:

- **ULS** = ultimate limit states
- **FLS** = fatigue limit states
- **ALS** = accidental limit states
- **SLS** = serviceability limit states.

237 **Limit State Design:** Design of the Terminal in the limit states of ULS, SLS, FLS and ALS.

238 **LNG Containment System:** The primary and secondary barrier, insulations, safety devices etc. ensuring the safe storage, handling and operation of the offshore LNG Terminal.

239 **Load and Resistance Factor Design (LRFD):** Method for design where uncertainties in loads are represented with a load factor and uncertainties in resistance are represented with a material factor.

240 **Load effect:** Effect of a single design load or combination of loads on the equipment or system, such as stress, strain, deformation, displacement, motion etc.

241 **Lowest daily mean temperature:** 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.

242 **Lowest waterline:** Typical light ballast waterline for ships, transit waterline or inspection waterline for other types of units.

243 **Membrane tank:** 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.

244 **Object Standard:** The standards listed in Table B2.

245 **Offshore Standard:** The DNV offshore standards are documents which presents the principles and technical requirements for design of offshore structures. The standards are offered as DNV’s interpretation of engineering practice for general use by the offshore industry for achieving safe structures.

246 **Offshore installation:** A general term for mobile and fixed structures, including facilities, which are intended for exploration, drilling, production, processing or storage of hydrocarbons or other related activities or fluids. The term includes installations intended for accommodation of personnel engaged in these activities. Offshore installation covers subsea installations and pipelines. The term does not cover traditional shuttle tankers, supply boats and other support vessels which are not directly engaged in the activities described above.

247 **Operating conditions:** Conditions wherein a unit is on location for purposes of production, drilling or other similar operations, and combined environmental and operational loadings are within the appropriate design limits established for such operations (including normal operations, survival, accidental).

248 **Partial Load Factor:** The specified characteristic permanent, variable, deformation, environmental or accidental loads are modified with a load factor. This load factor is part of the safety approach and varies in magnitude for the different load categories dependent on the individual uncertainties in the characteristic loads.

249 **Permanent Functional Loads:** Self-weight, ballast weight, weight of permanent installed part of mechanical outfitting, external hydrostatic pressure, prestressing force etc.

250 **Primary Tanks:** The function of the primary tank is to contain the refrigerated liquid (LNG) under normal operation of the Terminal.

251 **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.

252 **Recommended Practice (RP):** The recommended practice publications cover proven technology and solutions which have been found by DNV to represent good practice, and which represent one alternative for satisfy the requirements stipulated in the DNV offshore standards or other codes and standards cited by DNV.

253 **Robustness:** A robust structure is a structure with low sensitivity to local changes in geometry and loads.

254 **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.

255 **Reliability:** The ability of a component or a system to perform its required function without failure during a specified time interval.

256 **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.

257 **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.

258 **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.

259 **Serviceability Limit States (SLS):** Corresponding to the criteria applicable to normal use or durability.

260 **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.

261 **Specified Minimum Yield Strength (SMYS):** The minimum yield strength prescribed by the specification or standard under which the material is purchased.

262 **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.

263 **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.

264 **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.

265 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.

266 Submerged zone: The part of the unit which is below the splash zone, including buried parts.

267 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.

268 Target safety level: A nominal acceptable probability of structural failure.

269 Temporary conditions: Design conditions not covered by operating conditions, e.g. conditions during fabrication, mating and installation phases, transit phases, accidental

270 Temporary Phases: Construction, mating, transit/towing and installation phases.

271 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.

272 Transit conditions: All unit movements from one geographical location to another.

273 Unit: is a general term for an offshore installation such as ship shaped, column stabilised, self-elevating, tension leg or deep draught floater.

274 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 pre-stressing steel.

275 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.

276 Verification: Examination to confirm that an activity, a product or a service is in accordance with specified requirements.

277 Ultimate Limit States (ULS): Corresponding to the maximum load carrying resistance.

D. Abbreviations and Symbols

D 100 Abbreviations

101 Abbreviations as shown in Table D1 are used in this standard.

<table>
<thead>
<tr>
<th>Table D1 Abbreviations</th>
<th>Abbreviation</th>
<th>In full</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISC</td>
<td>American Institute of Steel Construction</td>
<td></td>
</tr>
<tr>
<td>ALS</td>
<td>accidental limit states</td>
<td></td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
<td></td>
</tr>
<tr>
<td>BS</td>
<td>British Standard (issued by British Standard Institute)</td>
<td></td>
</tr>
<tr>
<td>CN</td>
<td>classification note</td>
<td></td>
</tr>
<tr>
<td>DDF</td>
<td>deep draught floaters</td>
<td></td>
</tr>
<tr>
<td>DFF</td>
<td>design fatigue factor</td>
<td></td>
</tr>
<tr>
<td>DLE</td>
<td>ductility level earthquake</td>
<td></td>
</tr>
<tr>
<td>DNV</td>
<td>Det Norske Veritas</td>
<td></td>
</tr>
<tr>
<td>EN</td>
<td>European Norm</td>
<td></td>
</tr>
<tr>
<td>ETM</td>
<td>Event tree method</td>
<td></td>
</tr>
<tr>
<td>ESD</td>
<td>Emergency shut down</td>
<td></td>
</tr>
<tr>
<td>FLS</td>
<td>fatigue limit state</td>
<td></td>
</tr>
<tr>
<td>FM</td>
<td>Fracture mechanics</td>
<td></td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure mode effect analysis</td>
<td></td>
</tr>
<tr>
<td>FTM</td>
<td>Fault tree method</td>
<td></td>
</tr>
<tr>
<td>HAT</td>
<td>highest astronomical tide</td>
<td></td>
</tr>
<tr>
<td>HAZOP</td>
<td>Hazop and operability study</td>
<td></td>
</tr>
<tr>
<td>HISC</td>
<td>hydrogen induced stress cracking</td>
<td></td>
</tr>
<tr>
<td>HS</td>
<td>high strength</td>
<td></td>
</tr>
<tr>
<td>ID</td>
<td>Infra red detectors</td>
<td></td>
</tr>
<tr>
<td>IGIC</td>
<td>international Gas Carrier</td>
<td></td>
</tr>
<tr>
<td>IMO</td>
<td>international maritime organisation</td>
<td></td>
</tr>
<tr>
<td>ISO</td>
<td>international organisation of standardisation</td>
<td></td>
</tr>
<tr>
<td>LAT</td>
<td>lowest astronomical tide</td>
<td></td>
</tr>
<tr>
<td>LNG</td>
<td>Liquified Natural Gas</td>
<td></td>
</tr>
<tr>
<td>LRFD</td>
<td>load and resistance factor design</td>
<td></td>
</tr>
<tr>
<td>MPI</td>
<td>magnetic particle inspection</td>
<td></td>
</tr>
<tr>
<td>MSL</td>
<td>mean sea level</td>
<td></td>
</tr>
<tr>
<td>NACE</td>
<td>National Association of Corrosion Engineers</td>
<td></td>
</tr>
<tr>
<td>NDT</td>
<td>non-destructive testing</td>
<td></td>
</tr>
<tr>
<td>NS</td>
<td>Norwegian Standard</td>
<td></td>
</tr>
<tr>
<td>PWHT</td>
<td>post weld heat treatment</td>
<td></td>
</tr>
<tr>
<td>QRA</td>
<td>quantitative risk analysis</td>
<td></td>
</tr>
<tr>
<td>RP</td>
<td>recommended practise</td>
<td></td>
</tr>
<tr>
<td>SLS</td>
<td>serviceability limit state</td>
<td></td>
</tr>
<tr>
<td>SLE</td>
<td>strength level earthquake</td>
<td></td>
</tr>
<tr>
<td>SMYS</td>
<td>specified minimum yield stress</td>
<td></td>
</tr>
<tr>
<td>ULS</td>
<td>ultimate limit state</td>
<td></td>
</tr>
<tr>
<td>UV</td>
<td>Ultra violet detectors</td>
<td></td>
</tr>
</tbody>
</table>

D 200 Symbols

201 Latin characters

A Accidental Loads
a_v vertical acceleration
C Concrete Grade (normal weight concrete)
D deformation load
E environmental load
E_{cd} Design value of Young’s Modulus of concrete used in the stress-strain curve
E_{cn} Normalized value of Young’s Modulus used in the stress-strain curve
E_{rd} Design value of Young’s Modulus of reinforcement
E_{rk} Characteristic value of Young’s Modulus of reinforcement
f_{cd} Design compressive strength of concrete
f_{cn} Normalized compressive strength of concrete
f_{sd} Design strength of concrete in uni-axial tension
f_{tn} Normalized tensile strength of concrete
f_{rd} Design strength of reinforcement
f_{rk} Characteristic strength of reinforcement
F_d design load
F_k characteristic load
G permanent load
g, g_o acceleration due to gravity
h height
m moment
n number
Greek characters

\( P \) load
\( \rho \) 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

\( \delta \) deflection
\( \varepsilon \) strain

\( \gamma_c \) material coefficient concrete
\( \gamma_f \) load factor
\( \gamma_M \) material factor (material coefficient)
\( \gamma_s \) material coefficient reinforcement
\( \mu \) friction coefficient
\( \rho \) density
\( \sigma_d \) design stress

203 Subscripts

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

A. General

A 100  Objective

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

102  This section applies to Offshore Concrete LNG Terminal Structures and Containment Systems which shall be built in accordance with this standard.

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

104  The integrity of an 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 1.

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

---end-of-Guidance-note---

A 300  Safety class methodology

301  The Offshore Concrete Structure is classified into the safety class 3 based on failure consequences. For definition see Table A1.

<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>

A 400  Quality assurance

401  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.

402  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.

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

404  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.

405  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.

A 500  Health, safety and environment

501  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.

A 600  Qualifications of personnel

601  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
There should be a clear and documented link between major accidental hazards to the environment.

— significant damage to the asset
— significant damage to the environment.

The design principles are specified in Sec.2 of DNV-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.

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.

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

Requirements to materials are given in Sec.4, design of LNG Containment systems in Sec.5, loads and methods of analyses Sec.6, detailed design of the Terminal Structure in Sec.7, Construction in Sec.8 and in-service inspection, maintenance and conditioned monitoring in Sec.9.

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.

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.

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.

The basic criteria in establishing the list of critical elements is 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.

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.

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.

The above processes should consider all phases of the lifecycle of the Terminal.

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 Appendix A “Hazard Assessment of LNG Terminals”.

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

A. Overall Planning

A 100 General

101 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 fulfill the required functions.

102 The initial planning shall include determination and description of all the functions the structure shall fulfill, 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.

103 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.

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

A 200 Description of offshore concrete LNG terminal

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

202 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.

A 300 Meteorological and ocean conditions

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

302 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 lightening strikes
- relative humidity.

303 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.

---end-of---Guidance---note---

A 400 LNG terminal layout

401 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.

402 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
A 500 Primary functions

501 To provide a description of the functions of the Terminal by describing key processes; LNG Containment system; pipeline systems; and marine and helicopter operations.

502 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.
A 900  AS-BUILT Documentation

901  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).

A 1000  Inspection/monitoring plans for structure in service

1001  Plans for monitoring and inspection of the installation shall be prepared.
SECTION 4
STRUCTURAL MATERIALS

A. General

A 100 Concrete and Concrete Constituents
101 Shall be in accordance with DNV-OS-C502 Sec.4 A, B and C.

A 200 Grout and Mortar
201 Shall be in accordance with DNV-OS-C502 Sec.4 E.

A 300 Reinforcement
301 Shall be in accordance with DNV-OS-C502 Sec.4 F.
302 Reinforcement exposed to cryogenic temperature shall additionally possess ductile properties for the temperature of design exposure.

A 400 Prestressing Steel and anchorage
401 Shall be in accordance with DNV-OS-C502 Sec.4 G.
402 Prestressing steel and steel anchorages shall have ductile properties under the design temperatures of the concrete tank.

A 500 Embedded Steel
501 Embedded steel shall behave ductile for the applicable loads. The material shall be in accordance with the requirements of DNV-OS-B101.

A 600 Repair Material
601 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 DNV-OS-B101 apply.
602 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.
603 For repair of ductile joints in earthquake active areas, the repaired concrete shall be reinforced with sufficient confining reinforcement to remain ductile.

A 700 LNG Primary Containment Tank
701 The material in the primary containment tank shall be made of material remaining ductile under cryogenic temperature. Reference is made to DNV-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 Rules for the Classification of Ships (LNG Vessels), IGC-IMO Code, EN1473 or NFPA-59A. Special considerations shall be made to account for cyclic loads when applicable.

A 800 Insulation
801 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.
802 Material complying with the requirements in IGC-IMO Code, EN1473 or NFPA-59A can be used. See also Appendix C for further Guidelines.
SECTION 5
LOADS AND ANALYSES REQUIREMENTS

A. Requirements to Design of Concrete Support Structure

A 100 General

101 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.

102 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.

103 The design life of the Terminal structure shall be 100 years if not otherwise governed by local legislation.

Site related Functional Requirements

104 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

105 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.

106 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.

107 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

108 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.

109 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 person- nel and an adequate safety against damage to the structure or pollution to the environment.

A 200 Structural requirements

201 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

202 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

203 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 fulfill the requirements shall be documented.

204 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

205 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 Sections 4, 8 and 9.

Temporary Phases Requirements

206 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 DNV Rules for the Planning and Execution of Marine Operations.

207 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 weatherlight closure appliances shall be in accordance with DNV-OS-C301. Stability and freeboard under temporary conditions (construc-
tion afloat and towing) shall meet the requirements in DNV Rules for the Planning and Execution of Marine Operations.

208 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.

A 300 Design principles

General

301 The design shall be performed according to the limit state design as detailed in DNV-OS-C101 and DNV-OS-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 DNV-OS-C101 Sec.11
- the design of steel structures (supports for independent tanks, deck support structure etc.) shall be in accordance to DNV-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 DNV-OS-C101 Sec.3. See also special requirements to concrete structures in this Section
- the design for accidental limit states shall be in accordance with DNV-OS-C101 Sec.7. See also identifications of hazards in Sec.2
- the Cathodic Protection shall be designed in accordance with DNV-OS-C101 Sec.10
- stability of the structure afloat shall be calculated in accordance with DNV-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 DNV-OS-C101 and the relevant object standard DNV-OS-C102 to C106. Structural steel shall meet the requirements in DNV-OS-A105.

B. Load and Load Effects

B 100 General

101 The load and load effects shall be in accordance with DNV-OS-C502 Sec.4. The loads are generally classified as:

a) environmental, E

b) functional
   - permanent, G
   - variable, Q
   - imposed deformation, D
   - accidental, A.

102 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.

103 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.

104 Simplified methods to compute load effects may be applied if it can be verified that they produce results on the safe side.

105 If dynamic and 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.

106 Load effects from hydrodynamic and aerodynamic loads shall be determined by methods which accounts for the kinematics of the fluid 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.

107 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 is to be demonstrated by strength and, as required, ductility analyses. See Sec.3 A303 for definition of SLE and DLE.

108 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 DNV-OS-C101 Sec.11.

B 200 Environmental loads

201 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.

202 General procedures for the estimation of seismic actions are provided in DNV–OS-C101 Sec.3. For DLE, non-linear response analyses may be required. See DNV-OS-C502 for more details.

203 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 DNV-OS-C101 Sec.3.

B 300 Extreme wave loads

301 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 DNV-OS-C502 Appendix A.

B 400 Diffraction analysis

401 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 DNV-OS-C502, Appendix A.

B 500 Additional requirements for dynamic analysis under wave load

501 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.

502 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.

503 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.

B 600 Model testing

601 The necessity of model tests to determine extreme wave loads shall be determined on a case-by-case basis. See DNV-OS-C502 Appendix A for more details.

B 700 Current load

701 Currents through the depth, including directionality, shall be combined with the design wave conditions. The Characteristic current load shall be determined in accordance with DNV-OS-C101 Sec.3. For more details, see DNV-OS-C502 Appendix A.

702 If found necessary scour protection should be provided around the base of the structure. See DNV-OS-C101 Sec.11.

B 800 Wind loads

801 Wind loads may be determined in accordance with DNV-OS-C101 Sec.3 E700.

802 Wind forces on an 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 Appendix A.

B 900 Functional loads

901 Functional loads are considered to be all loads except environmental loads, and include both permanent and variable loads. The functional loads are defined in DNV-OS-C101 Sec.3, C “ Permanent Loads” and D “Variable Functional Loads”.

902 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
   — weight of permanent ballast
   — weight of permanently installed parts of mechanical outfitting, including risers, etc.
   — external hydrostatic pressure up to the mean water level
   — prestressing force (may also be considered as deformation loads).

903 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.

904 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.

905 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.

906 Potential imposed deformations are derived from sources that include:
   — thermal effects
   — prestressing effects
   — creep and shrinkage effects
   — differential settlement of foundation components.

See also D201.

B 1000 Accidental loads

1001 The Accidental Loads (A) are generally defined in DNV-OS-C101 Sec.3, G Accidental Loads. See also Sec.2 and Appendix D of this standard. The hazards identified in the hazard identification process described in Sec.2, shall be mitigated, accounted for in the design.

1002 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.

1003 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.

1004 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.

1005 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.

1006 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.

1007 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 floatels
- 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.

1008 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.

1009 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.

1010 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.

1011 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^{-1}, commonly will be most critical. See Appendix D for guidance related to combining the loads in design of the containment structure.

---end of Guidance note---

1012 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.

**C. Load Combinations and Partial Safety Factors**

101 The Load Factors for design of the Concrete terminal are specified in DNV-OS-C502 Sec.4, C “Load Combinations and Partial Safety Factors” and in Table C1.

<table>
<thead>
<tr>
<th>Combination of design loads</th>
<th>Load categories</th>
<th>G</th>
<th>Q</th>
<th>E</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td></td>
<td>1.3</td>
<td>1.3</td>
<td>0.7^a</td>
<td>1.0</td>
</tr>
<tr>
<td>b)</td>
<td></td>
<td>1.0</td>
<td>1.0</td>
<td>1.3^a</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 DNV-OS-C101 Sec.2 and C102 through C109 below.

102 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}.

103 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.

104 A load factor of 1.0 shall be applied to the weight of soil included in the geotechnical calculations.

105 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.

106 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.

107 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.

108 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 Appendix D for detailed guidance on load combinations for the design of the LNG containment tanks.

109 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.

**C 200 Combinations of loads**

201 Table B2 of DNV-OS-C101 Sec.3 B 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 Appendix D as guidelines.

202 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 Table B2 of DNV-OS-C101 for environmental loads may be considered.

203 The return conditions to be considered should be related to the duration of the operation. As a general guidance, the criteria given in Table C2 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>

**C 300 Consequence of failure**

301 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.

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

303 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.

304 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.

D. Structural Analysis

D 100 General

101 Structural analysis is the process of determining the load effects within a structure, or part thereof, in response to each significant set of loads. DNV-OS-C502 Sec.5 D 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.

D 200 Special load effects

Deformation Loads

201 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 B900.

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.

202 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 $1.0 \times 10^{-5} /{°C}$ 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°C shall require special evaluation of the temperature expansion coefficient ($\alpha$) to account for the actual temperature and relative humidity of the concrete.

203 Creep effects shall be considered where relevant. For further details, see DNV-OS-C502, Sec.6, C705.

Effect of Water Pressure

204 The effect of water pressure in the concrete is to be fully considered when relevant.

205 The effect of hydrostatic pressure on the concrete strength is to be evaluated where relevant.

206 The effect of hydrostatic forces acting on the faces of cracks is to 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

207 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

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

D 300 Analyses requirements

301 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.

302 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 DNV-OS-C502.

<table>
<thead>
<tr>
<th>Table D1 - Appropriate Types of Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
</tr>
<tr>
<td>Construction</td>
</tr>
<tr>
<td>Towing to location</td>
</tr>
<tr>
<td>Installation</td>
</tr>
<tr>
<td>In-service strength and Serviceability</td>
</tr>
<tr>
<td>Fatigue</td>
</tr>
<tr>
<td>Seismic</td>
</tr>
</tbody>
</table>
Accidental operations should 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.

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.

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.

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.

Analysis during sea tow should normally be based on a 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 DNV-OS-C502, Sec.5, D1000. The analysis of the tow shall be in accordance with the DNV Rules for Planning and Execution of Marine Operations.

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 DNV-OS-C502, Sec.5, D2000.

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.

Installation and deck mating analysis

Structural analyses 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.

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.

In-service strength and serviceability analyses

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.

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.

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.

Fatigue analysis

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.

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. The structural analysis shall include the effects of the range of sea states and directions to which the structure will be subjected.

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.

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.

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.
D 900  Seismic analysis

901  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 Sec.6, D400.

902  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.

D 1000  Accidental and overload analyses

1001  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.

1002  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.

1003  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.

1004  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.

1005  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.

D 1100  Terminal removal/reuse

1101  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.

1102  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.

1103  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.

E. Topside Interface Design

E 100  Introduction

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

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

103  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.

104  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

A. General

A 100 Introduction

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

102 Other design standards may as an alternative be used for detailed design of the Offshore Concrete Structures. An opening is made for this within DNV-OS-C502 provided the requirements to the detailed standard given in DNV-OS-C502 Appendix E “Use of Alternative Detailed Design Standard” are sufficiently covered. The level of safety shall be as required by DNV-OS-C502. The compliance with these requirements shall be documented. Special considerations for design required by this standard shall be considered.

B. Design Principles Concrete Terminal

B 100 General

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

102 Reference is made to DNV-OS-C502 which provides more details on strength and serviceability calculations of reinforced concrete structural members.

B 200 Limit states

201 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)

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

203 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.

204 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.

B 300 Characteristic values for material strength

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

302 For concrete, the 28 days characteristic compressive strength fcck is defined as a 5% fractile value (5th percentile) found from statistical analysis of testing 150 mm x 300 mm cylindrical specimens.

303 In Table C1, a normalized compressive strength, fckn, is tabulated based on this characteristic concrete cylinder strength. The normalized compressive strength of concrete, fckn, is less than the characteristic cylinder strength, fck, and considers transition of test strength into in situ strength, ageing effects due to high-sustained stresses etc.

304 For reinforcement steel, the minimum yield stress shall be taken as characteristic strength f yk, determined as the 5% defective fractile. The reinforcement shall be of quality in accordance with Sec.4, A300 Reinforcement.

305 For prestressed reinforcement the in situ strength is taken equal to the yield strength fyk or the 0.2-proof stress. The quality of prestressing steel and anchorage shall be in accordance with Sec.4, A400 Prestressing Steel and Anchorage.

306 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 DNV-OS-C101.

307 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.

308 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.

B 400 Partial safety factors for materials

401 The partial factors for the materials, γm, in reinforced concrete shall be chosen in accordance with this standard and for the limit state considered.

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

403 Foundation design shall be performed in accordance with DNV-OS-C101 Sec.11. The soil material factors shall also be in accordance with Sec.11.

B 500 Design by testing

501 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 DNV-OS-C502, Sec.5 P.
502 Characteristic resistance of structural details or structural members or parts may be verified by a combination of tests and calculations.

503 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.

B 600 Design material strength

601 The design material strength shall be taken as a normalized in-situ strength in accordance with Table B1 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 B1.

The characteristic tensile strength, \( f_{tk} \), and the normalized tensile strength, \( f_{tn} \), in the structure are defined in Table B1 and are both derived from the characteristic strength of concrete in compression.

602 In design by testing, the requirements given in DNV-OS-C502 P500 shall be applied.

603 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.

604 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.

605 Design values for the concrete are:

\[
\begin{align*}
E_{sd} & = \frac{E_{cn}}{\gamma_c} \\
f_{sd} & = \frac{f_{cn}}{\gamma_c} \\
f_{td} & = \frac{f_{tn}}{\gamma_c}
\end{align*}
\]

where

\[
\begin{align*}
E_{sd} & = \text{Design value of Young’s Modulus of concrete used in the stress-strain curve} \\
f_{sd} & = \text{Normalized value of Young’s Modulus used in the stress-strain curve} \\
f_{td} & = \text{Design compressive strength of concrete} \\
f_{td} & = \text{Normalized compressive strength of concrete} \\
f_{tn} & = \text{Design strength of concrete in uni-axial tension} \\
f_{tn} & = \text{Normalized tensile strength of concrete} \\
\gamma_c & = \text{Material strength factor concrete}
\end{align*}
\]

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, \( E_{ck} \).

\[
\frac{E_{sd}}{E_{sk}} = \frac{f_{sd}}{f_{sk}} = \frac{f_{td}}{f_{tk}}
\]

606 Design values for the reinforcement are:

\[
\begin{align*}
E_{sd} & = \frac{E_{sk}}{\gamma_s} \\
f_{sd} & = \frac{f_{sk}}{\gamma_s}
\end{align*}
\]

where

\[
\begin{align*}
E_{sd} & = \text{Design value of Young’s Modulus of reinforcement} \\
f_{sd} & = \text{Characteristic value of Young’s Modulus of reinforcement} \\
f_{sk} & = \text{Design strength of reinforcement} \\
\gamma_s & = \text{Material coefficient Reinforcement}
\end{align*}
\]

607 The material coefficient, \( \gamma_m \), for concrete and reinforcement are given in Table B1.

C. Basis for Design by Calculation

C 100 Concrete grades and in situ strength of concrete

101 The characteristic strength of concrete cylinders is defined in B300.

In Table C1, 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 light-weight aggregate concrete Grades are identified by the symbol LC. The grades are defined in Table C1 as a function of the Characteristic Compression cylinder strength of concrete, \( f_{ck} \).
102  The strength values given in Table C1 apply to lightweight aggregate concrete with the following limitations and modifications:

\[ f_{\text{cck}} \leq f_{\text{ck2}} \left( \frac{\rho_1}{\rho} \right)^2 \]

where

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

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

where:

\[ \rho = \text{Density of the lightweight concrete.} \]

For lightweight aggregate concrete with intended concrete strength \( f_{\text{ck}} > f_{\text{ck2}} \left( \frac{\rho_1}{\rho} \right)^2 \), where \( f_{\text{ck3}} = 64 \text{ MPa and } \rho_1 = 2200 \text{ kg/m}^3 \), 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.

103  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.

104  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.

105  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.

106  The characteristic tensile strength of the concrete, \( f_{\text{tk}} \), 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, \( f_{\text{tk}} \), shall be taken as 2/3 of the splitting strength determined by testing.

107  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 samples taken from the structure. For interpretation of the drilled core reference is made to DNV-OS-C502, Sec.6 C107.

C 200  Concrete stress – strain curves for strength design

201  The shape of the stress/strain relationship for concrete in compression of a specified grade is to 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 DNV-OS-C502 Sec.6 C300 can be used.

202  For normal dense concrete of grades between C25 and C55, the following simplified stress/strain diagram may be used.

![Simplified stress-strain diagram for normal density concrete of grades between C25 and C55 subject to compression](image)

\[ \sigma_c = -f_{\text{ce}} \epsilon_c \left( 2 - \frac{\epsilon_c}{\epsilon_{\text{co}}} \right) \]

\( \epsilon_{\text{co}} = -2 \% \) is strain at the point of maximum stress.

203  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

\[ \epsilon_{\text{cu}} = \epsilon_1 \left( 0.3 + 0.7 \frac{\rho}{\rho_1} \right) \]

where \( \epsilon_1 = -3.5\% \), \( \rho_1 = 2400 \text{ kg/m}^3 \) and \( \rho = \text{density of the LWA.} \)
For calculation of capacities for axial forces and bending moments, different stress distributions from those given herein (C201, C202, C203) may be applied as long as they do not result in a higher sectional capacity.

Another stress distribution than that given in C301 to C304 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.

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.

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.

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 $\varepsilon_{sy} = f_s/E_s$.

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.

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 4.

The relation between stress and short-term strain for ribbed bars at temperatures above 150°C

The diagram in Figure 4 does not include thermal strain or creep strain caused by high temperature.

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

Spiral reinforcement in columns, shear reinforcement, torsional reinforcement, and reinforcement in construction...
joints, shall be calculated in accordance with Sec.6 D, F, G and J of DNV-OS-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.

C 300 Geometrical dimensions in the calculation of sectional capacities

301 When allowing larger deviations in dimensions than those specified in Table C2, the deviations in sectional dimensions and reinforcement position shall be considered in the design. See also B607 Table B1. Smaller deviations than the specified tolerances may be considered.

<table>
<thead>
<tr>
<th>Table C2 Acceptable Deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Dimensional Deviation</td>
</tr>
<tr>
<td>Overall dimension</td>
</tr>
<tr>
<td>Cross-sectional</td>
</tr>
<tr>
<td>Perpendicularity</td>
</tr>
<tr>
<td>Inclination</td>
</tr>
<tr>
<td>Local variations (1 m measuring length)</td>
</tr>
<tr>
<td>Local variations (2 m measuring length)</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%.

302 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 B1 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.

303 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.

C 400 Tension in structural members

401 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.

C 500 Fatigue strength relationships

501 Fatigue strength relationships (S-N curves) for concrete are to 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 DNV-OS-C502, Sec.6 M.
- surrounding environment (air, submerged).

C 600 Deformation induced loads, prestressing and creep

601 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 DNV-OS-C502 Sec.6 C700.

C 700 Effect of water pressure

701 The effect of water pressure in the concrete is to be fully considered when relevant.

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

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

D. Design of Structural Members

D 100 Design capacity in ultimate limit state (ULS)

101 Detailed design of moment capacity under different magnitudes of axial loads shall be in accordance with DNV-OS-C502 Sec.6 D.

102 Slender structural Members shall be designed in accordance with DNV-OS-C502, Sec.6 E.

103 Design of shear capacity in beams, slabs and wall shall be in accordance with DNV-OS-C502, Sec.6 F.

104 Design for torsional moments in beams shall be in accordance with DNV-OS-C502, Sec.6 G.

105 Design of structural members subjected to in-plane forces shall be in accordance with the general method outlined in DNV-OS-C502, Sec.6 H.

106 Regions with discontinuity in Geometry or loads shall be designed in accordance with DNV-OS-C502, Sec.6 I.

107 Design for shear forces in construction joints shall be in accordance with DNV-OS-C502, Sec.6 J.

108 Design for bond strength and sufficient anchorage of reinforcement shall be in accordance with DNV-OS-C502, Sec.6 K.

109 Designed of partially loaded areas shall be in accordance with DNV-OS-C502. Sec.6 L.

D 200 Capacity in fatigue limit state (FLS)

201 Design for fatigue strength of members exposed to stress fluctuations shall be in accordance with DNV-OS-C502, Sec.6 M.

D 300 Design for accidental limit state (ALS)

301 Design for Accidental strength shall be in accordance with DNV-OS-C502, Sec.6 N.

D 400 Design for ductility

401 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 is to be demonstrated by strength and, as required, ductility analyses.

402 Design in SLE, using ULS load and material factors in accordance with this Standard, is to 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.

403 Design in the DLE, using ALS load and material factors, it is 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.

404 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.

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

406 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.

407 Web reinforcement of flexural members is to 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.

408 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.

D 500 Design in serviceability limit state (SLS)

501 Design in SLS shall in general be in accordance with requirements in DNV-OS-C502, Sec.6, O100.

502 The durability of the concrete structure is ensured by designing the structure in accordance with DNV-OS-C502, Sec.6, O200.

503 Design for displacement and vibration in the structure shall be in accordance with DNV-OS-C502, Sec.6, O400 and O500.

504 Tightness against leakage of fluid shall be designed in accordance with DNV-OS-C502, Sec.6, O500. 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.

505 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.

506 Crackwidth calculations shall be in accordance with the approach outlined in DNV-OS-C502. Sec.6, O700.

507 The maximum stress levels in prestressed concrete structure under SLS loading shall be limited to the values given in DNV-OS-C502, Sec.6, O800.

508 Structures exposed to repeated freeze/thaw action shall be design in accordance with the requirements in DNV-OS-C502, Sec.6, O900 and Sec.4, D306.

D 600 Design by testing

601 Concrete members can be designed by testing or by a combination of calculations and testing in accordance with DNV-OS-C502, Sec.6 P.

E. Detailing of Reinforcements

E 100 General

101 Requirements to positioning of reinforcement are provided in DNV-OS-C502, Sec.6, Q100.

102 Concrete cover to reinforcement shall be in accordance with DNV-OS-C502, Sec.6, Q200. The requirements to concrete cover is given in DNV-OS-C502, Sec.6, Q201.

103 Reinforcement shall be spliced in accordance with DNV-OS-C502, Section 6, Q300.

104 The reinforcement bars shall be bent in accordance with DNV-OS-C502, Sec.6, Q400.

105 Minimum area of reinforcement shall be provided in the structural member in accordance with DNV-OS-C502, Sec.6, Q500 and C502, Sec.6 R.

F. Corrosion Control

F 100 General

101 Corrosion control shall be carried out in accordance with DNV-OS-C502, Sec.6 S.
**SECTION 7**

**LNG CONTAINMENT SYSTEM**

---

**A. Introduction**

**A 100  General**

**101**  For the design of primary steel containment tanks (membrane or independent tanks) reference is made to DNV Rules for the Classification of ships (LNG Vessels), 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 Appendices C "General Design Principles LNG Containment Structures (Guidelines)" and 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.

**102**  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 Rules for the Classification of Ships (LNG Vessels) 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.

**103**  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.

**104**  The standards DNV Rules for the classification of Ships (LNG Vessels), 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.

---

**A 200  Storage containment systems**

**201**  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 aluminum alloy, stainless steel or 9% nickel steel.

The IHI-SPB system, currently approved has tanks, which may be constructed of aluminum, 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.

**202**  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.

**203**  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.

**204**  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.

---

DET NORSKE VERITAS
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 Section 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.

205 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.

**B. Design of LNG Containment Structure**

**B 100 Design principles**

101 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.

102 All hazards and mitigation actions to reduce the risks to an acceptable level is to be included in the design of the terminal, the layout and the containment structure.

**B 200 Design basis**

201 The design of the Primary Containment System is to be in accordance with the criteria defined in this standard.

Detailed guidelines for the design of the containment structure are provided in Appendices A - D.

202 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 state or National Authority or any other jurisdictions in the intended area of deployment and operation. Examples are several EU Directives in Europe and US Coast Guard requirements in US.

203 The complete basis for the design is to be stated in the operational manual and is to include the intended location, the envelope of environmental operational conditions and the storage capacities and throughputs of the production/re-gasification systems.

**B 300 Design of LNG primary tanks**

301 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.

302 Support structure in steel for independent LNG tanks is to comply with the requirements in DNV-OS-C101.

303 When the strength of the independent cargo tanks are designed in accordance with DNV Rules for the classification of Ships (LNG Vessels), the strength of the independent cargo tanks shall comply with the requirements in the Rules for Classification of Ships Pt.5 Ch.5 Sec.5.

Accelerations acting on the tanks shall be determined by direct calculations based on location specific environmental data with a return period of 100 years. DNV-OS-C101 replaces all references to the Rules for Classification of Ships Pt.3 Ch.1.

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 DNV-OS-C101. Cargo tanks and supporting structure subject to reduced temperature due to cargo shall comply with the requirements in the Rules for Classification of Ships Pt.5 Ch.5 Sec.2. DNV-OS-C101 replaces all references to the Rules for Classification of Ships Pt.3 Ch.1 Sec.2.

**B 400 Containment systems**

401 The LNG containment system is to be designed and constructed in accordance with the requirements of this standard, DNV Rules for the Classification of Ships (LNG Vessels), 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 Appendices A-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 is to 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 is to 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 through the base or the walls.

402 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 are to 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.

403 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.

404 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.

405 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 4.5

— 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 used 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.

406 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.

407 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.

B 500 Process facilities

The process facilities are not covered by this standard.

C. Safety Systems

C 100 General

101 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 is to provide protection against risk of fire or explosion and the secondary system is intended to reduce the consequence of fire by allowing 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 DNV-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, is to be fitted with an approved gas detection, fire detection and fire extinguishing system complying with DNV-OS-A101.

102 In addition to the DNV requirements of DNV-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.

103 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.

104 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

C 200 Cargo system and equipment
201 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.

C 300 Instrumentation and automation
301 Control and instrumentation systems are to 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.
302 Control and instrumentation systems for the process, process supports, utility and electrical systems shall be suitable for the intended application.
303 All control and safety shutdown system shall be designed for safe operation of the equipment during start-up, shutdown and normal operational conditions.
304 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 DNV-OS-D301 Sec.D104; at levels of 25% and 60% of lower explosion limit.

C 400 Gas detection systems
401 The fixed gas detection system is to comply with the requirements in DNV-OS-A101.

C 500 Emergency shutdown systems
501 Emergency shutdown shall be design in accordance with DNV-OS-A101.
SECTION 8
CONSTRUCTION

A. General

A 100 General

101 Fabrication and construction of reinforced and prestressed concrete LNG terminal shall be carried out in accordance with DNV-OS-C502, Sec. 7. The scope and definition are provided in DNV-OS-C502, Sec. 7 A.

102 The approved for construction documentation specified in DNV-OS-C502, Sec. 7 C shall be made available at the construction site, prior to start of construction.

103 A supervision and inspection activity in accordance with DNV-OS-C502, Sec. 7 D shall be implemented at the construction site in order to ensure appropriate compliance between the “For Construction Documentation” and the “As Built Structure”.

104 The construction activity shall be planned in accordance with DNV-OS-C502, Sec. 7 E prior to start of construction.

105 The constituent materials, reinforcement, prestressing systems and concrete shall be documented in accordance with DNV-OS-C502, Sec. 7 F prior to start of construction.

106 The Formworks shall be designed in accordance with DNV-OS-C502, Sec. 7 G.

107 The reinforcement, prestressing bars and embedded steel shall be placed in the formwork in accordance with the requirements given in DNV-OS-C502, Sec. 7 H.

108 The production of concrete and grout shall be in accordance with DNV-OS-C502, Sec. 7 I.

109 The transport, casting, compaction and curing of the concrete shall be in accordance with DNV-OS-C502, Sec. 7 J.

110 The prestressing system shall be stressed and completed in accordance with DNV-OS-C502, Sec. 7 K.

111 Repair of the concrete structure shall be in accordance with the requirements of DNV-OS-C502, Sec. 7 L.

112 The corrosion protection system is to be installed and tested in accordance with DNV-OS-C502, Sec. 7 M.

113 During construction as-Built construction records and As-Built documentation shall be assembled and reworked in accordance with DNV-OS-C502, Sec. 7 N.

114 The use of precast elements shall be designed for all temporary phases and its use documented in accordance with DNV-OS-C502, Sec. 7 O.

115 Geometric tolerances for the placements of reinforcement, local and global dimensions etc. shall be in accordance with DNV-OS-C502, Sec. 7 O.

B. Specific to LNG/LPG Containment Structures

B 100 Construction, Commissioning and Turnaround

101 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

102 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:

— inerting 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.

103 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.

104 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.

B 200 Performance testing

201 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.

202 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.

B 300 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
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 before any hydrotest is carried out and, if necessary, measures taken to avoid corrosion.

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.

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.

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.

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

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.

801 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.

901 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.
B 1000 Painting, fire proofing and embrittlement protection

1001 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 steel 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.

1002 Fire Proofing. Equipment and specific bulk material in LNG plants shall 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.

1003 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

A. General

A 100 Concrete Substructure

101 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 fulfil 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.

102 The scope of In-Service inspection, monitoring and maintenance shall be in accordance with DNV-OS-C502, Sec.8, A200.

103 Qualification of personnel involved in inspection planning and condition assessment shall be in accordance with DNV-OS-C502, Sec.8, A300.

104 Planning of the in-service inspection, maintenance and monitoring activities shall be in accordance with DNV-OS-C502, Sec.8, A400.

105 A programme for inspection and condition monitoring shall be prepared in accordance with DNV-OS-C502, Sec.8, A500.

106 Inspection and condition monitoring milestones and intervals shall be in accordance with DNV-OS-C502, Sec.8, A600.

107 Documentation of inspection, condition monitoring and maintenance shall be in accordance with DNV-OS-C502, Sec.8, A700.

108 Recommended items for inspection and condition monitoring are given in DNV-OS-C502, Sec.8, A800.

109 Recommendations for inspections related to corrosion control is given in DNV-OS-C502, Sec.8, A900.

110 Inspection and condition monitoring types shall be in accordance with DNV-OS-C502, Sec.8, A1000.

111 A marking system shall be established in accordance with DNV-OS-C502, Sec.8, A1100.

112 A guideline for inspection of special areas is provided in DNV-OS-C502, Sec.8, A1200.

B. Special for LNG containment system

B 100 General

101 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.

102 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.

103 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.

B 200 Gas detection

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

202 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.

203 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.

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

205 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
- vapourisers
- 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.

206 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.

B 300 Cold detection

301 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.

302 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.

303 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.

304 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.

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

B 400 Smoke detection
401 Smoke detectors can be of the following types:
- ionisation smoke detectors
- photoelectric smoke detectors
- equivalent or improved sensors.

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

403 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.

B 500 Fire detection
501 Fire detectors are installed for fast detection of fire.

502 Fire detectors can be of the following types:
- ultra-violet detectors (UV)
- infra red detectors (IR)
- equivalent or improved sensors.

503 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.

504 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.

B 600 Meteorological instruments
601 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.

B 700 Safety control system
701 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.

702 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.

703 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.

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

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

706 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).

707 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.).

708 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.

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

710 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).

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

712 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.

713 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. Hazard Assessment

A 100 Hazards and operability study (HAZOP)

101 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.

102 A HAZOP shall be conducted when the piping and instrumentation diagrams (P&IDs) are sufficiently developed and approved by the Owner.

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

104 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.

105 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.

106 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.

107 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 200 Methodology

201 The methodology of the hazard assessment can be probabilistic and/or deterministic. The probabilistic approach consists of:

— justification of the measures necessary to limit risks

202 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.

203 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 over-all procedure shall be initiated as early as possible and shall be repeated when unacceptable risks are identified during the design.

A 300 Identification of hazards of external origin

301 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 asphyxiating gas
— the impact of projectiles (ship, helicopters, plane, etc.)
— natural events (extreme waves, lightning, flooding, earthquakes, etc.)
— high energy radio waves, etc.

A 400 Identification of hazards of internal origin

401 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.
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 600 Hazardous area classifications

601 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 DNV-OS-A101 or equivalent International Standard.

602 The extent of hazardous zones shall be as given in DNV-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 DNV-OS-A101 or equivalent International Standard.

A 700 Estimation of probabilities

701 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 A200 which will determine the probability range for this hazard. The human factor shall be taken into account.

A 800 Estimation of consequences

801 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.

802 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 900 Safety measures on the LNG plant

901 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.

902 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.

903 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.

904 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 (gage) 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 1000 LNG terminal layout

1001 The layout of an LNG Terminal with respect to the surroundings shall be covered by a hazard assessment. See also DNV-OS-A101.

1002 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 offlammable materials, but they shall be located as far as possible outside hazardous areas, assuming a wind in any direction.

1003 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.

1004 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.

1005 For diesel driven fire water pumps and emergency generators the air intake shall be located outside the predicted vapour cloud envelope.

A 1100 Emergency shutdown

1101 An emergency shutdown ESD system independent from the process control system shall be provided. See DNV-OS-A101.

A 1200 Fire protection

1201 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.

1202 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.

1203 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.

1204 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.

1205 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 1300 Seismic protection

1301 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.

1302 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.

1303 The systems include the related equipment, piping, valves, instrumentaion, power supply and their supports. Structures shall be designed as for the class of the most stringent system component they are supporting.

1304 The structure shall be designed to keep their integrity in case of DLE. Heating, ventilating and air conditioning shall be designed in order to fulfill the criteria of the classified systems which are located in the structure.

1305 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 1400 Confinement

1401 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)

A. Hazard Definitions

A 100 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.).

A 200 Classes of consequence

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

202 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.

203 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.

204 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.

205 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.

206 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.

A 300 Levels of risk

301 General
Tables A1 and A2 give examples of risk levels.

302 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.

303 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.


<table>
<thead>
<tr>
<th>Table A1 Determination of level of risk inside the Boundary Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability classes</td>
</tr>
<tr>
<td>Nil Consequences</td>
</tr>
<tr>
<td>Repairable Consequences</td>
</tr>
<tr>
<td>Significant Consequences</td>
</tr>
<tr>
<td>Serious Consequences</td>
</tr>
<tr>
<td>Catastrophic consequences</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table A2 Determination of level of risk outside the Boundary Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability classes</td>
</tr>
<tr>
<td>Nil Consequences</td>
</tr>
<tr>
<td>Repairable Consequences</td>
</tr>
<tr>
<td>Significant Consequences</td>
</tr>
<tr>
<td>Serious Consequences</td>
</tr>
<tr>
<td>Catastrophic consequences</td>
</tr>
</tbody>
</table>
A. General Design Principles

100 Design considerations

The design principles outlined below are issued as guidelines for the detailed design of concrete secondary containment structures and the main load bearing structure of an LNG containment structure.

102 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.

103 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.

104 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.

105 To assure adequate safety of structures which bear high risk potentials both the event probability \( P_{\text{event}} \) and the failure probability \( P_{\text{failure}} \) must 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

106 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.

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.

107 Corresponding functional requirements are the same as for conventional design:

- load bearing
- tightening against liquids and gas
- insulating against inside and outside temperature states
- retention of the stored material
- insulating between cryogenic and environmental temperatures
- shielding against hazards

108 In view of the built-in structural resistance the choice of the appropriate protective structural system is of paramount importance. Three principle functions must be fulfilled by the structural system:

- retaining of the stored material
- insulating against inside and outside temperature states
- shielding against hazards

109 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.

110 Analytical design of storage and processing facilities has to assess and to analyse design scenarios related to

- construction
- testing
- usual operation
- hazards

111 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 Appendix 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.
112 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.

A 200 General requirements

201 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.

202 Metal storage tanks for the storage of LNG shall be designed in accordance with the requirements of Sec.7 B Design of LNG Containment Structure.

203 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 Rules for Classification of Ships Pt.5 Ch.5 Sec.5. The support concrete structure shall be designed in accordance with this standard.

204 The LNG tanks shall be designed to:

— safely contain the liquid at cryogenic temperature
— permit the boil off gas to be safely removed
— 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 Appendix 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.

A 300 Fluid and gas tightness

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

302 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)

303 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.

304 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.

305 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.

306 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 is to be assumed for calculation that the temperature of the LNG is applied directly onto the internal face, including the insulation, if any.

A 400 Tank connections

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

402 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.

403 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.

404 The design shall prevent any siphoning effects.

A 500 Thermal insulation

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

502 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.

503 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.

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

505 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.

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

507 Insulation of spherical tanks is outside the sphere and is not exposed to any hydraulic or mechanical actions.

508 External insulation shall be protected from moisture.

509 Exposed insulation shall be non-combustible.

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

511 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

512 Gas absorption

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

513 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 itself is water vapour tight.

514 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.

515 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.

516 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.

A 600 Operating loads

601 LNG Tanks shall be capable of withstanding the combinations of loads as defined in Appendix D and those resulting from changes in temperature and pressure during:

— initial cool down and warm up to ambient temperature
— filling and emptying cycles.

602 The manufacturer shall indicate the maximum rate of temperature change which the tank can withstand during cool down and warm up operations.

603 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.

A 700 General design rules

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

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

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.

### A 800 Liquid level

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

802 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.

### A 900 Pressure

901 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.

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

### A 1000 Temperature

1001 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.

### A 1100 Density

1101 Density of the LNG shall be monitored throughout the liquid depth.

### A 1200 Pressure and vacuum protection

1201 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.

1202 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.

1203 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

1204 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).

1205 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.

1206 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.

### A 1300 Vacuum

1301 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 pre-
vent permanent damage to the tank.

1302 Gas shall be injected under automatic control following too low pressure detection.

1303 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.

A 1400 Bund wall and impounding area

1401 For tank systems where individual impounding area is required as the secondary container. The impounding areas of two tanks may be adjacent.

1402 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.

1403 The need for insulation will depend on the result of the hazard assessment.

1404 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.

1405 The water shall drain to an extraction sump 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.

1406 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.

1407 Means for limiting evaporation and reducing the rate of burning of ignited spills shall be considered.

A 1500 Safety equipment

1501 Anti-rollover devices

In order to avoid rollover at least the following measures shall be taken.
- filling systems as defined in C1702
- 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.

1502 Protection against lightning

The tank shall be protected from lightning.

A 1600 Reliability and monitoring of structure

1601 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.

1602 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.

1603 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.

1604 Heating system control

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

1605 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.

A 1700 Tank piping

1701 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.

1702 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.
1703 LNG pumping

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

1704 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)

A. Detailed Structural Design

A 100 Introduction

101 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 conceivably and relevant conditions. This Appendix provides detailed guidelines for design of a containment system for import and export terminals.

102 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 Rules for Classification of Ships (LNG Vessels) are based on this approach. The special operational differences between a ship and a terminal shall be incorporated in the design.

103 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.

A 200 Functional requirements

201 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.

202 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.

203 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-liquefaction 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.

204 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.

205 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
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).

A 300 Permanent actions (G)

301 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.

302 Vapour Pressure

a) Internal vacuum
   The roof shall be designed for the internal vacuum.
   This is included in the live load specified under A400.

b) Internal pressure
   The value for the internal pressure shall be specified by the purchaser.

303 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.

304 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.

A 400 Variable actions (Q)

These are:

- [Q1]: loading during construction (scaffolding/staging, hoisting gear, partial prestressing or "Construction loading"
- [Q2]: overloads with respect to permanent actions, as deliberately applied to test strength and fluid tightness ("Overloads")
- [Q3]: hydrostatic action of LNG and fatigue through filling/emptying cycles noted "LNG"
- [Q4]: forces induced by thermal contractions or "Thermal stresses", during tank life, commissioning and decommissioning

401 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/m² of projected area and a concentrated load of 5 kN over an area of 0.1 m² 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/ m² is often used.

402 Product/Liquid Load

i) Inner tanks
   - 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 minimum product level specified or the level 0.5 m below the top of the shell, whichever is higher.
   - The inner tank and its foundation shall also be designed for the water test.

ii) Outer Tanks (double and full containment tanks only)
   - The outer tank shall be designed to contain maximum liquid content (and intermediate volumes) of the inner tank at the minimum design temperature specified.
   - Steel outer tanks and their foundations shall also be designed for the water test (see also Sec. 8 B).

iii) Concrete Structures of Membrane Tanks
   - 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.
   - The concrete tank and its foundation shall also be designed for the water test.

403 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.

A 500 Environmental loads (E)

501 These are:

- [E1]: climatic loading (hours of sunshine, daily and seasonal atmospheric temperature change, snow, ice) or "Climatic loading"
- [E2]: Strength Level Earthquake ("SLE")
- [E3]: Wind, current and Wave loads
given in Sec.4.

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

504 Wave and Current loads
The wind load shall be determined, based on local data. Reference is made to Sec. 4.

505 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.

506 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.

507 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 (Sec.3 A303, Sec.5 B107, Sec.5 D900).

b) Sloshing Effects
Sloshing pressures due to earthquake is to 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.

A 600 Accidental actions (A)

601 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").
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).

609 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.

A 700 Analysis

701 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.

702 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.

A 800 Design criteria

801 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 Sec.6 D504. For gas tightness and prevention of mitigation of moisture into the insulation, a steel membrane will normally be required in the secondary barrier.

802 In case of storage of poisonous material full tightness shall be required, to be ensured by a minimum height of the concrete compressive zone $h_c \geq 100$ 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.

803 Crack width calculations shall be carried out accounting for temperature dependency of tensile and bond strength of the concrete.

804 The crack width analysis shall be carried out in accordance with Sec.6.

805 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 Sections 5, 6 and 7 of this standard.

A 900 Earthquakes

901 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 seismic records are insufficient to expect reliable results from a probabilistic approach, deterministically.
Both horizontal and vertical ground accelerations shall be considered.
Two classes of design earth quakes shall be considered:

a) Strength Level Earthquake (SLE)
   See Sec.3 A303 for definition.
b) Ductility Level Earthquake (DLE)
   See Sec.3 A303 for definition.

902 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 (suspected 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 techniques 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.

A 1000 Action combinations for design of containment tanks

1001 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 A1 Normal actions

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testing</td>
<td>(1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earthquake</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></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 A2 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] [Q3] [Q4] [A1] [A2]</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>
</tr>
<tr>
<td>depressurisation</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>primary container leak</td>
<td></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></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<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>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Adjacent tank on fire or relief valve on fire (on the same tank)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External explosion</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A 1100 Specific methods to determine the actions

1101 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 [Q3])
— the weight of the hydrostatic test fluid (action [Q2])
— 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.

1102 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.

1103 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.

1104 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.

1105 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 is to 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.

1106 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.

A 1200 Structural detailing

1201 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 overstrength design may be appropriate also for DLE. Special consideration will be required in each case as this will be structural geometry dependent.

1202 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.

1203 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 must be resistant to liquid leakage.

1204 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.

1205 Membranes

The membrane is an impervious barrier which is separated from the concrete by the insulation. The insulation must 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 must be ductile at service temperature, is assured by profiling in the horizontal and vertical direction.

A 1300 Liners

1301 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.

1302 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.

1303 The liner must resist buckling during and after pre-
1304 A flexible zone is required at the junction wall/floor.

1305 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.

A 1400 Insulation

1401 Tank floors: 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.

1402 Tank walls: 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 must 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 must be applied in carefully controlled environmental conditions.

1403 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.

A 1500 Membrane storage vessels

1501 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

1502 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.