**BRITISH STANDARD**

**BS EN 14620-2:2006**

# Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and –165 °C —

## Part 2: Metallic components

The European Standard EN 14620-2:2006 has the status of a British Standard

ICS 23.020.10





British Standards

# National foreword

This British Standard was published by BSI. It is the UK implementation of EN 14620-2:2006. It supersedes BS 7777-2:1993 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PVE/15, Storage tanks for the petroleum industry.

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This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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EUROPEAN STANDARD

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**EN 14620-2**

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English Version

# Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C - Part 2: Metallic components

Conception et fabrication de réservoirs en acier à fond plat, verticaux, cylindriques, construits sur site, destinés au stockage des gaz réfrigérés, liquéfiés, dont les températures de service sont comprises entre 0 °C et - 165 °C - Partie 2 : Constituants métalliques

Auslegung und Herstellung standortgefertigter, stehender, zylindrischer Flachboden-Stahltanks für die Lagerung von tiefkalt verflüssigten Gasen bei Betriebstemperaturen zwischen 0 °C und -165 °C - Teil 2: Metallische Bauteile

This European Standard was approved by CEN on 20 February 2006.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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**Management Centre: rue de Stassart, 36 B-1050 Brussels**



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# Contents

# Foreword

This European Standard (EN 14620-2:2006) has been prepared by Technical Committee CEN/TC 265 "Site built metallic tanks for the storage of liquids", the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2007, and conflicting national standards shall be withdrawn at the latest by March 2007.

EN 14620 *Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C* consists of the following parts:

— Part 1: General;

— Part 2: Metallic components;

— Part 3: Concrete components;

— Part 4: Insulation components;

— Part 5: Testing, drying, purging and cool-down.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

# 1 Scope

This European Standard specifies general requirements for the materials, design, construction and installation of the metallic components of refrigerated liquefied gas storage tanks.

This European Standard deals with the design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and –165 °C.

# 2 Normative references

The following referenced documents are indispensable for the application of this European Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 287-1, *Qualification test of welders — Fusion welding — Part 1: Steels*

EN 462-1, *Non-destructive testing — Image quality of radiographs — Part 1: Image quality indicators (wire type) — Determination of image quality value*

EN 462-2, *Non-destructive testing — Image quality of radiographs — Part 2: Image quality indicators (step/hole type) — Determination of image quality value*

EN 473, *Non-destructive testing — Qualification and certification of NDT personnel — General principles*

EN 571-1, *Non-destructive testing — Penetrant testing — Part 1: General principles*

EN 584-1, *Non-destructive testing — Industrial radiographic film — Part 1: Classification of film systems for industrial radiography*

EN 584-2, *Non-destructive testing — Industrial radiographic film — Part 2: Control of film processing by means of reference values*

EN 875, *Destructive tests on welds in metallic materials — Impact tests — Test specimen location, notch orientation and examination*

EN 970, *Non-destructive examination of fusion welds — Visual examination*

EN 1011-2, *Welding — Recommendations for welding of metallic materials — Part 2: Arc welding of ferritic steels*

EN 1092-1:2001, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 1: Steel flanges*

EN 1290, *Non-destructive testing of welds — Magnetic particle testing of welds*

EN 1418, *Welding personnel — Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials*

EN 1435:1997, *Non-destructive examination of welds — Radiographic examination of welded joints*

EN 1515-1:1999, *Flanges and their joints — Bolting — Part 1: Selection of bolting*

EN 1593, *Non-destructive testing — Leak testing — Bubble emission techniques*

EN 1712:1997, *Non-destructive testing of welds — Ultrasonic testing of welded joints — Acceptance levels*

EN 1714:1997, *Non-destructive testing of welds — Ultrasonic testing of welded joints*

EN 1759-1:2004, *Flanges and their joint — Circular flanges for pipes, valves, fittings and accessories, Class designated — Part 1: Steel flanges, NPS 1/2 to 24*

EN 1993-1-1, *Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for buildings*

ENV 1993-1-6, *Eurocode 3: Design of steel structures — Part 1-6: General rules — Supplementary rules for the strength and stability of shell structures*

ENV 1993-4-2:1999, *Eurocode 3: Design of steel structures — Part 4-2: Silos, tanks and pipelines — Tanks*

EN 1994-1-1, *Eurocode 4: Design of composite steel and concrete structures — Part 1-1: General rules and rules for buildings*

EN 10025:2004 (all parts), *Hot rolled products of non-alloy structural steels*

EN 10029:1991, *Hot rolled steel plates 3 mm thick or above — Tolerances on dimensions, shape and mass*

EN 10045-1, *Metallic materials — Charpy impact test — Part 1: Test method*

EN 10160:1999*, Ultrasonic testing of steel flat product of thickness equal or greater than 6 mm (reflection method)*

EN 10204:2004, *Metallic products — Types of inspection documents*

EN 10216-1, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 1: Non-alloy steel tubes with specified room temperature properties*

EN 10216-2, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 2: Non-alloy and alloy steel tubes with specified elevated temperature properties*

EN 10216-3, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 3: Alloy fine grain steel tubes*

EN 10216-4, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 4: Non-alloy and allow steel tubes with specified low temperature properties*

EN 10217-1, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 1: Non-alloy steel tubes with specified room temperature properties*

EN 10217-2, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 2: Electric welded non-alloy and alloy steel tubes with specified elevated temperature properties*

EN 10217-3, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 3: Alloy fine grain steel tubes*

EN 10217-4, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 4: Electric welded non-alloy steel tubes with specified low temperature properties*

EN 10217-5, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 5: Submerged arc welded non-alloy and alloy steel tubes with specified elevated temperature properties*

EN 10217-6, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 6: Submerged arc welded non-alloy steel tubes with specified low temperature properties*

EN 10220, *Seamless and welded steel tubes — Dimensions and masses per unit length*

EN 12062:1997, *Non-destructive examination of welds — General rules for metallic materials*

EN 14015:2004, *Specification for the design and manufacture of site built, vertical, cylindrical, flat-bottomed, above ground, welded, steel tanks for the storage of liquids at ambient temperature and above*

EN 14620-1:2006, *Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0°C and −165 °C — Part 1: General*

EN ISO 5817:2003, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections (ISO 5817:2003)*

EN ISO 15607:2003, *Specification and qualification of welding procedures for metallic materials — Part 1: General rules (ISO 15607:2003)*

EN ISO 15609-1:2004, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding (ISO 15609-1:2004)*

EN ISO 15614-1:2004, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys (ISO 15614-1:2004)*

ISO 261, *ISO general purpose metric screw threads — General plan*

ISO 965-2:1998, *ISO general purpose metric screw threads — Tolerances — Part 2: Limits of sizes for general purpose external and internal screw threads — Medium quality*

API 620:2004, *Design and construction of large, welded, low-pressure storage tanks*

## 3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 14620-1:2006 and the following apply.

**3.1**
**amplitude of strain**
one half of the range of strains

**3.2**
**progressive deformation**
phenomenon in which the deformations in each part of the membrane increase progressively under the cyclic loads

**3.3**
**range of strain**
difference between the maximum and minimum values in the cyclic strain curves

**3.4**
**ratcheting**
progressive incremental inelastic deformation or strain, which can occur in a component that is subject to variation of mechanical stress

**3.5**
**unstable collapse**
phenomenon in which the assessment of the process of deformation under static load becomes ambiguous

# 4 Materials

## 4.1 General

The temperature to which the steel may be exposed under all conditions is important, and shall be determined.

## 4.2 Temperatures

### 4.2.1 Minimum design temperature

The minimum design temperature shall be used as the design metal temperature for material selection of the primary and secondary liquid container.

### 4.2.2 Lodmat

The purchaser shall specify the lodmat.

### 4.2.3 Design metal temperature

When a steel component is protected from the low liquid or vapour temperature by thermal insulation, the design metal temperature shall be calculated based on the most pessimistic assumption under that loading (accidental actions included).

## 4.3 Primary and secondary liquid container

### 4.3.1 Steel selection

#### 4.3.1.1 General

The material requirements for the primary and secondary liquid container given in 4.3.1.2 have been selected primarily for their high level of toughness at the design metal temperature. For each product to be stored, specific material requirements are specified.

#### 4.3.1.2 Material requirements

##### 4.3.1.2.1 Steel classification

Plate materials shall be classified as follows:

— type I steel: low temperature carbon-manganese steel;

— type II steel: special low temperature carbon-manganese steel;

— type III steel: low nickel steel;

— type IV steel: improved 9 % nickel steel;

— type V steel: austenitic stainless steel.

For each product to be stored, the steel types shall be in accordance with Table 1.

**Table 1 — Product and steel class**

| Product | Single containment tank | Double, or full containment tank | Membrane tank | Typical product storage temperature |
|---|---|---|---|---|
| Butane | Type II | Type I | | - 10 °C |
| Ammonia | Type II | Type II | | - 35 °C |
| Propane/ Propylene | Type III | Type II | Type V | - 50 °C |
| Ethane/Ethylene | Type IV | Type IV | Type V | - 105 °C |
| LNG | Type IV | Type IV | Type V | - 165 °C |
| NOTE Service related effects, such as stress corrosion cracking, should be considered during material selection. | | | | |

#### 4.3.1.2.2 General requirements

The following general requirements shall apply:

a) **Type I steel:**

A Type I steel is a fine-grained, low carbon steel, which shall be specified for pressure purposes at temperatures down to - 35 °C. The steel shall meet the following requirements:

1) The steel shall be specified to meet the requirements of an established European Standard (e.g. EN 10028-3). Steels with a minimum yield strength greater than 355 N/mm$^2$ shall not be used.

2) The steel shall be in the normalized condition or produced by a thermo mechanical rolled process.

3) The carbon content shall be less than 0,20 %. The carbon equivalent $C_{eq}$ shall be equal to or less than 0,43 with

$$C_{eq} = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

b) **Type II steel:**

A Type II steel is a fine-grained low carbon steel, which shall be specified for pressure purposes at temperatures down to - 50 °C. The steel shall meet the following requirements:

1) The steel shall be specified to meet the requirements of an established European Standard (e.g. EN 10028-3). Steels with a minimum yield strength greater than 355 N/mm$^2$ shall not be used.

2) The steel shall be in the normalized condition or produced by a thermo mechanical rolled process.

3) The carbon content shall be less than 0,20 %. The carbon equivalent $C_{eq}$ shall be equal to or less than 0,43 with

$$C_{eq} = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

c) **Type III steel:**

A Type III steel is a fine-grained low nickel alloy steel, which shall be specified for pressure purposes at temperatures down to - 80 °C. The steel shall meet the following requirements:

1) The steel shall be specified to meet the requirements of an established European Standard (e.g. EN 10028-4);

2) The steel shall have been heat treated to obtain a fine, uniform grain size or produced by a thermo mechanical rolled process.

d) **Type IV steel:**

A Type IV steel is an improved 9 % -nickel steel, which shall be specified for pressure purposes at temperatures down to - 165 °C. The steel shall meet the following requirements:

1) The steel shall be specified to meet the requirements of an established European Standard (e.g. EN 10028-4);

2) The steel shall be quenched and tempered.

e) **Type V steel:**

Type V steel is an austenitic stainless steel according to a European Standard (e.g. EN 10028-7).

#### 4.3.1.2.3 Maximum shell plate thickness

The maximum shell plate thickness shall be:

- Types I, II and III: 40 mm;
- Types IV: 50 mm;
- Type V: no upper limit on thickness.

When material thickness is required in excess of these values, additional material investigation and testing shall be carried out to demonstrate that the same level of resistance to brittle fracture is available as would be required for the type of material and maximum thickness indicated above.

#### 4.3.1.2.4 Plate tolerances

The plate tolerances shall be:

- in accordance with EN 10029:1991, Class C, for parts where the thickness is established by calculation;
- in accordance with EN 10029:1991, Class B, for parts where the thickness is based on minimum nominal thickness considerations.

#### 4.3.2 Charpy V-notch impact test requirements

The Charpy V-notch impact test values for base material, heat-affected zone (HAZ) and weld metal shall be in accordance with Table 2.

The values specified shall be the minimum average of three specimens, with only one value less than the value specified, but not less than 70 % of the value specified.

For material thickness less than 11 mm, the largest practical sub-size specimen shall be used. The minimum Charpy V-notch impact test value for sub-size specimen shall be in direct proportion to the values specified for full size specimens.

The degradation effect due to welding shall be taken into account.

NOTE For certain materials, higher Charpy V-notch values or lower test temperatures may be needed for the base material to meet the requirements in the heat-affected zone.

Impact testing shall be carried out for each liquid containing shell plate and each completed plate from which liquid containing tank annular plates are cut. For other components, impact testing shall be carried out per heat/cast of the material.

Impact testing shall be carried out in accordance with EN 10045-1 and EN 875.

**Table 2 — Minimum Charpy V-notch impact test energy**

| Classification | Steel type | Impact test energy | Specimen orientation for plate |
|---|---|---|---|
| Type I | Low temperature carbon-manganese steel | 27 J at – 35 °C | Transverse |
| Type II | Special low temperature carbon-manganese steel | 27 J at – 50 °C | Transverse |
| Type III | Low nickel steel | 27 J at – 80 °C | Transverse |
| Type IV | Improved 9 % nickel steel | 80 J at –196 °C | Transverse |
| If nickel base weld metals are used (types II, III and IV steel) then the impact toughness energy for weld metal and heat effected zone shall be 55 J. | | | |

#### 4.3.3 Certification

For materials with a design metal temperature below 0 °C an Inspection Certificate in accordance with EN 10204:2004, type 3.1 shall be required.

### 4.4 Vapour container/outer tank

#### 4.4.1 Material for plate and structural sections

The steel of the vapour container/outer tank shall be selected in accordance with Table 3.

NOTE Alternative types of steels may be used provided equivalent properties (e.g. chemical composition and mechanical properties) can be demonstrated.

**Table 3 — Steel for vapour container/outer tank**

| Design metal temperature $T_{DM}$ °C | Thickness $e$ mm | Material grade according to EN 10025:2004 |
|---|---|---|
| $T_{DM} \geq 10$ | $e \leq 40$ | S235JRG2 or S275JR or S355JR |
| $10 > T_{DM} \geq 0$ | $e \leq 13$<br>$13 \leq e \leq 40$ | S235JRG2 or S275JR or S355JR<br>S235JO or S275JO or S355JO |
| $0 > T_{DM} \geq -10$ | $e \leq 13$<br>$13 < e \leq 40$ | S235J0 or S275J0 or S355J0<br>S235J2G3 or S275J2G3 or S355J2G3 |
| $-10 > T_{DM} \geq -20$ | $e \leq 13$<br>$13 < e \leq 40$ | S235J2G3 or S275J2G3 or S355J2G3<br>S235J2G3 or S275J2G3 or S355J2G4 |
| For design metal temperatures below -20 °C and/or for thicknesses above 40 mm, the plate shall be impact tested at a temperature not exceeding the design metal temperature and show an impact value of at least 27 J longitudinal.<br>For design metal temperatures below ) 0 °C, the impact tests of the weld metal and the HAZ of the vertical shell joint shall show at least 27 J at the design metal temperature. | | |

#### 4.4.2 Certification

For materials with design metal temperatures below 0 °C an inspection certificate in accordance with EN 10204:2004 type 3.1 shall be required.

All other materials shall be supplied with a test report in accordance with EN 10204:2004, type 2.2.

### 4.5 Other components

#### 4.5.1 Bolting

##### 4.5.1.1 Selection of bolting

Bolting shall be in accordance with EN 1515-1:1999, Table 1 and Table 2.

In selecting the material, the application, design pressure, design temperature and fluid service conditions shall be taken into account.

In the case of ferritic and martensitic steels, the bolting bar material shall have a tensile strength < 1 000 N/mm$^2$ and an elongation A5 > 14 %.

Ferritic and martensitic steels for use between –10 °C and –160 °C shall be impact tested at the design metal temperature and shall show an impact energy value of 40 J average in the longitudinal direction.

At design metal temperatures below –160 °C, the impact testing shall be performed at –196 °C.

NOTE 1 Where austenitic steel is used, bolts may relax on cooling to sub zero temperatures. This is caused by a permanent transformation of the structure from austenitic to martensitic, which results in an increase of length. The extent of transformation increases with the applied stress.

NOTE 2 Bolts that cannot be retightened after cooling should be made from steel having a stable structure, such as 25 Cr 20 Ni or nitrogen bearing austenitic steel.

#### 4.5.1.2 Studbolts

Studbolts shall be threaded over the full length. The points shall be chamfered or rounded. The height of the points shall be maximum one times the pitch of thread.

The length of studbolts shall include points. The lengths are stepped by increments of 5 mm for lengths up to 80 mm, 10 mm for lengths above 80 mm and up to 200 mm and by increments of 20 mm for lengths above 200 mm.

Threads shall be in accordance with ISO 261, tolerances shall be in accordance with class 6g of ISO 965-2:1998. Type of thread shall be either, ISO M course, or above M 39, fine thread with 4 mm pitch.

#### 4.5.1.3 Spring washers

Special spring washers shall be considered where different materials are used and different thermal contractions can take place.

### 4.5.2 Mountings

Nozzle necks, insert and reinforcing plates and permanent attachments shall have the same strength and notch ductility as the plates to which they are attached. Materials of lower strength can be used for nozzle necks provided that the neck area shall not be used as a contributing part in the area replacement calculation.

### 4.5.3 Piping components

Materials for piping components shall be in accordance with EN 1092-1:2001, EN 10216-1, EN 10216-2, EN 10216-3, EN 10216-4, EN 10217-1, EN 10217-2, EN 10217-3, EN 10217-4, EN 10217-5, EN 10217-6.

# 5 Design

## 5.1 Design theory

### 5.1.1 General

For the actions (loadings), reference is made to EN 14620-1:2006, 7.3.

The design of the steel components shall be based on either the allowable stress or limit state theory.

NOTE The inclusion of the two options recognizes that, at the present time, there is only limited experience available in the application of limit state for the design of steel storage tanks.

Since the elasto-plastic approach is used for the design of the membrane, the allowable stress/limit state criteria is not appropriate and shall be replaced with the stress/strain curve for the specified material.

### 5.1.2 Allowable stresses

#### 5.1.2.1 General

The maximum allowable tensile stress in any plate or weld metal shall be in accordance with Table 4.

**Table 4 — Determination of the maximum allowable design stress**

| **Type of steel** | **Allowable stress in service** | **Allowable stress during hydrostatic test** |
|---|---|---|
| Types I, II, III | the lesser of:<br>0,43 $f_u$ or 0,67 $f_y$ or 260 N/mm$^2$ | the lesser of:<br>0,60 $f_u$ or 0,85 $f_y$ or 340 N/mm$^2$ |
| Type IV | the lesser of:<br>0,43 $f_u$ or 0,67 $f_y$ | |
| Type V | the lesser of:<br>0,40 $f_u$ or 0,67 $f_y$ | |
| NOTES 1 $f_u$ is minimum ultimate tensile strength in N/mm² and $f_y$ is minimum yield strength in N/mm².<br>NOTES 2 For type III and IV steels, $f_y$ is equal to 0,2 % of proof stress.<br>NOTES 3 For type V steels, $f_y$ is equal to the 1 % proof stress. | | |

In case of seismic design, the allowable stress for OBE shall be 1,33 times the allowable stress for service condition. For SSE, the allowable stress shall be 1,00 $f_y$, in tension, and the critical buckling stress for compression.

#### 5.1.2.2 Tank anchorage

The tank anchorage shall be capable of resisting the tank uplift. The allowable tensile stress in the tank anchorage shall be limited to:

- normal operation: 0,50 $f_y$;
- test: 0,85 $f_y$;
- OBE: 0,67 $f_y$;
- SSE: 1,00 $f_y$.

Shell attachments and embedments shall be designed for a load corresponding to the full yield capacity of the uncoroded anchor bolts or anchor straps.

NOTE This to prevent possible tearing of the shell. For the design of the anchor bolt chairs see [14].

For Ethane/Ethylene and LNG service, anchors made from Type IV or V materials shall apply the anchor material yield stress at the temperature found in table 1 or colder.

#### 5.1.2.3 Compression area at roof-to-shell junction

The allowable compressive stress $S_c$ shall be limited to 120 N/mm$^2$.

NOTE See 5.3.1.3.5 for details of compression area.

#### 5.1.2.4 Stresses

##### 5.1.2.4.1 Butt welds

Where the load is perpendicular to the weld and in the plane of the plates, the allowable stress shall be limited to the value given in Table 4.

Where the load is parallel to the weld, the allowable shear stress shall be limited to 75 % of the value given in Table 4.

##### 5.1.2.4.2 Fillet welds

Where the load is perpendicular to the weld, the allowable shear stress shall be limited to 70 % of the value given in Table 4.

Where the load is parallel to the weld, the allowable shear stress shall be limited to 50 % of the value given in Table 4.

### 5.1.3 Limit state theory

#### 5.1.3.1 General

For the analysis, based on limit state, the following Eurocodes shall be used:

EN 1993-1-1, ENV 1993-1-6, ENV 1993-4-2:1999, and EN 1994-1-1.

The following shall be taken into account:

— simplified method in accordance with ENV 1993-4-2:1999, Clause 11 shall not be used;

— for static analysis of the roof structure, EN 1993-1-1 or EN 1994-1-1 shall be used:

— design of shells to resist external pressure shall consider the requirements of section 5.2.1.2.3. ENV 1993-1-6 does not apply in this case;

— requirements of 5.1.3.2 are not the same as the requirements of the ENV 1993-4-2:1999 but shall be followed.

#### 5.1.3.2 Primary and secondary liquid container

The partial safety factors of the primary and secondary liquid container of the single, double and full containment tanks shall be adjusted in accordance with Table 5.

NOTE The partial load factors and the material factors have been adjusted to arrive at the same shell thickness as used with allowable stress theory.

**Table 5 — Partial load and material factors for types I, II, III and IV steel**

| Operating conditions | | | Test conditions | | |
|---|---|---|---|---|---|
| $\gamma_F$ | $\gamma_M$ | | $\gamma_F$ | $\gamma_M$ | |
| 1,36 | $\alpha \geq 1{,}57$<br>1,10 | $\alpha < 1{,}57$<br>1,72/$\alpha$ | 1,06 | $\alpha \geq 1{,}42$<br>1,11 | $\alpha < 1{,}42$<br>1,57/$\alpha$ |

– NOTE $\alpha$ is the tensile to yield strength ratio $f_u/f_y$

where

$\gamma_F$ is the partial factor for actions;

$\gamma_M$ is the factor for material strength;

$f_u$ is ultimate tensile strength of steel or weld material whichever is the lesser;

$f_y$ is the yield strength of the steel or weld material whichever is the lesser.

## 5.2 Primary and secondary liquid container

### 5.2.1 Single, double and full containment tanks

#### 5.2.1.1 Bottom

##### 5.2.1.1.1 Bottom annular plates

The annular plates shall have a minimum thickness (excluding corrosion allowance), $e_a$:

$e_a$ = (3,0 + $e_1$/3), but not less than 8 mm

where

$e_1$ is the thickness of the bottom shell course, in mm.

The minimum width $l_a$, between the edge of the sketch plate and the inner side of the shell, as shown in Figure 1c shall be either:

a) as given by the following equation:

$$l_a > \frac{240}{\sqrt{H}} e_a$$

where

$e_a$ is the thickness of the annular plate, in mm;

$H$ is the maximum design liquid height, in m; or

b) 500 mm

whichever is the larger.

The following additional requirements shall apply:

— radial joints between annular plates shall be butt welded;

— shell to annular plate attachment shall be either or:

  - butt welded;
  - fillet welded at both sides with maximum 12 mm leg size fillets. Minimum leg size is the smaller of the shell or the annular plate thickness;
  - groove weld plus fillet for annular plate greater than 12 mm. The groove depth plus fillet leg shall equal the annular plate thickness;

— annular plate radial joints shall not be located within 300 mm from any vertical shell joint;

— minimum distance from outside of the shell plate to the outer edge of the annular plate shall be 50 mm.

NOTE The annular plate width and thickness may also be governed by seismic action.

#### 5.2.1.1.2 Bottom centre plates

The minimum thickness of the bottom plates, excluding corrosion allowance, shall be 5 mm.

The following requirements shall apply:

— minimum length of straight edge of sketch plate shall be 500 mm;

— bottom plates shall be joined by fillet or butt welding;

— lap joints shall have a minimum overlap of five times the thickness of the plate;

— fillet welds shall consist of at least two passes;

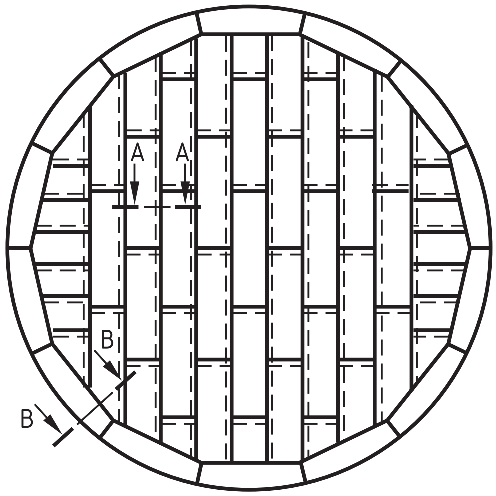
— bottom plates shall be lapped on top of the annular plates. The minimum lap shall be 60 mm;

— butt welds in bottom plates shall be welded either from both sides, or from one side using a backing strip;

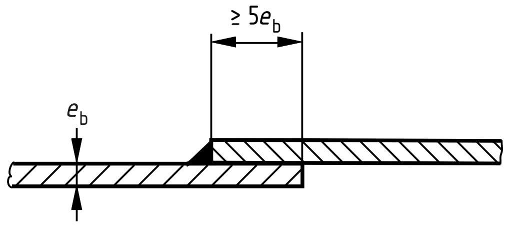
— minimum distance between individual three-plate joints shall be 300 mm.

Where reinforcing plates are fitted to the bottom, continuous fillet welds shall be used.

Layouts and details for tank bottom and annular plating shall be in accordance with Figure 1.



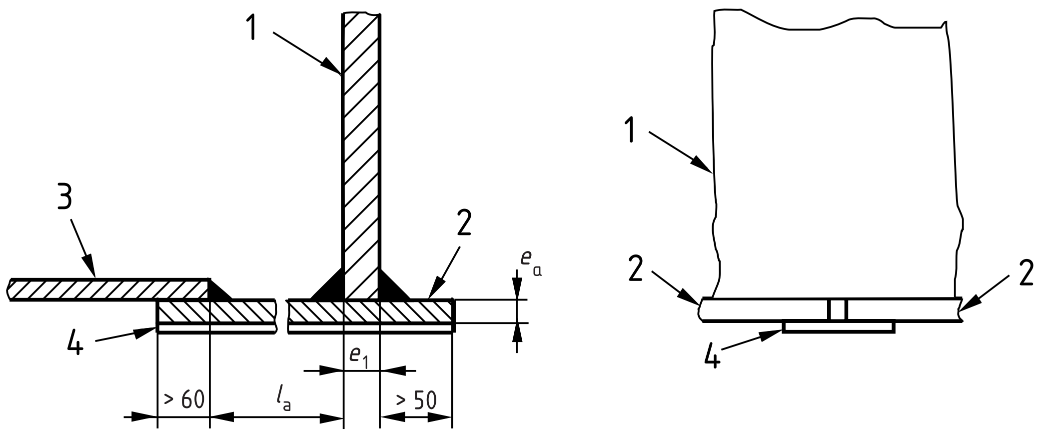

a) with annular plates at the perimeter




b) section A-A, overlap of bottom plates

**Figure 1 — Typical bottom layout**

Dimensions in millimetres




c) view B-B

**Key**

1 shell

2 annular plate

3 sketch plate

4 backing strip

**Figure 1 — Typical bottom layout** (*concluded*)

### 5.2.1.2 Shell

#### 5.2.1.2.1 Minimum shell plate thickness

The minimum shell plate thickness shall be in accordance with Table 6.

**Table 6 — Minimum shell plate thickness**

| Tank diameter<br>m | Minimum thickness<br>mm |
|---|---|
| $D \leq 10$ | 5 |
| $10 < D \leq 30$ | 6 |
| $30 < D \leq 60$ | 8 |
| $60 < D$ | 10 |
| NOTE The requirement for minimum thickness is needed for construction purposes, and may include any corrosion allowance, provided that the shell is shown by calculation to be safe in the corroded condition. | |

#### 5.2.1.2.2 Shell plate thickness

The thickness of the shell plate shall be the greatest of $e_t$, or $e$ or the minimum thickness.

a) For operating conditions:

$$e = \frac{D}{20S}[98W(H - 0{,}3) + P] + c$$

where

- $c$ is the corrosion allowance, in mm;
- $D$ is the tank inside diameter, in m;
- $e$ is the calculated plate thickness, in mm;
- $H$ is the height from the bottom of the course under consideration to the maximum design liquid level, in m;
- $P$ is the design pressure, in mbar. Zero for open top inner tank;
- $S$ is the allowable design stress, in N/mm$^2$;
- $W$ is the maximum density of the liquid under storage conditions, in kg/l.

b) for hydrostatic test condition:

$$e_t = \frac{D}{20S_t}[98\, W_t(H_t - 0{,}3) + P_t]$$

where

- $D$ is the tank inside diameter, in m;
- $e_t$ is the calculated plate thickness, in mm;

$H_t$ is the height from the bottom of the course under consideration to the test liquid level, in m;

$P_t$ is the test pressure, in mbar. Zero for open top inner tank;

$S_t$ is the allowable stress under test conditions, in N/mm$^2$;

$W_t$ is the maximum density of the test water, in kg/l.

No course shall be designed at a thickness less than that of the course above, irrespective of materials of construction, except the compression area.

#### 5.2.1.2.3 Additional requirements

a) Shell welds

All vertical and horizontal welds shall be butt welded, with full penetration and complete fusion.

b) Plate arrangement

The distance between vertical joints in adjacent courses shall be not less than 300 mm.

c) Attachments

Where attachments are made, pad plates shall be used. They shall not be located within 300 mm of a vertical weld or 150 mm of a horizontal weld.

Pad plates and reinforcing plates shall have rounded corners with a minimum radius of 50 mm.

d) External loading of inner tank shell

If applicable, the following loads shall be considered:

— insulation pressure;

— inner tank vacuum;

— pressure between the inner and outer tanks.

Biaxial stress combinations:

The shell design shall consider the combination of circumferential compressive and axial (longitudinal) stress.

Circumferential compression combined with axial stresses:

The allowable hoop compressive stress (resistance) in the absence of axial stress shall be duly reduced for any simultaneous axial compressive or tensile stress. The allowable axial compressive stress (resistance) in the absence of hoop stress shall be duly reduced for any simultaneous hoop compressive stress.

Circumferential tension combined with axial compression:

The allowable axial compressive stress (resistance) in the absence of hoop stress may be increased to account for the stabilizing effect of any simultaneous internal radial pressure.

Intermediate stiffener spacing:

The transformed shell method may be used to determine intermediate ring stiffener spacing for shells with varying shell thickness. The equivalent height (spacing) between the stiffeners is calculated as:

$$H_e = h\sqrt{\left(\frac{e_{\min}}{e}\right)^5}$$

where

$e$ is the as ordered thickness of each course in turn, in mm;

$e_{\min}$ is the as ordered thickness of the top course, in mm;

$H_e$ is the equivalent stable height of each course at $e_{\min}$, in m;

$h$ is the height of each course in turn, in m.

Each intermediate horizontal ring stiffener shall be designed for the panel loading associated with that ring, taking into account that portion of the shell considered to contribute to the stiffness of that ring.

The properties of the shell bottom corner and the top stiffener of an open top tank shall comply with the requirements for end stiffeners or bulkheads.

The stiffener shall be connected to the shell, with a continuous fillet weld on both sides. A mouse-hole shall be used at intermediate stiffener butt welds and where the stiffener crosses a vertical weld.

Stiffeners shall be located at least 150 mm from a horizontal weld.

e) External wind/vacuum loading of outer tank shell

The shell shall be designed to resist the combination of circumferential and axial (longitudinal) compressive stress. See 5.2.1.2.3 d) above. The shell shall resist a radial pressure caused by the sum of the external wind pressure and vacuum (internal negative pressure). The design wind pressure to be applied in calculations to resist radial pressure shall be based on the characteristic local wind pressure per EN 1991-1-4. The design wind pressure to be applied in calculations to resist axial stress in the shell caused by wind overturning and wind suction on the roof shall be based on overall wind pressure determined from application of appropriate shape and surface factors per EN 1991-1-4:2004.

See 5.2.1.2.3 d) for welding requirements.

### 5.2.2 Membrane tanks

#### 5.2.2.1 General

The membrane shall be made of metallic plate, minimum 1,2 mm thick. The membrane shall have a double network of corrugations, allowing free movement under all loading conditions. A folding or deep draw process shall form the corrugations. The membrane shall be fully supported by the tank insulation system.

The membrane shall be anchored into the insulation system or into the concrete outer tank so that it maintains its position throughout its lifetime. At the top of the tank, the membrane shall be arranged such that a vapour and liquid tight container is obtained (called insulation vapour space).

All the membrane components shall be designed in such a way that they can withstand all possible static and dynamic actions throughout the tank lifetime.

NOTE For typical action data, see Annex A.

The membrane and all components shall keep its form through smooth deformation or displacement. It shall be demonstrated that no progressive deformation under cyclic loading can take place and that buckling/collapse on the corrugations shall be prevented, as shall fatigue failure.

The design of the metallic membrane shall be carried out either through model tests and/or numerical analysis, see Figure 2. Whichever approach is used, the membrane shall be designed to prove its reliability under the following considerations:

— membrane shall remain stable under the assumed loads;

— membrane shall have sufficient fatigue strength for the number of cyclic loads considered.

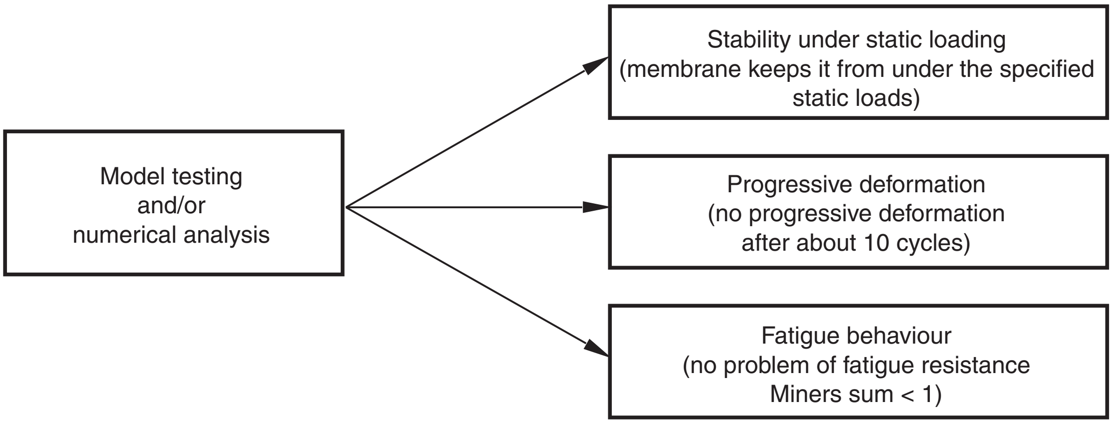



**Figure 2 — Design flowchart for membranes**

For the numerical analysis, a non-linear elasto-plastic or elasto-plastic/large displacement calculation method shall be used. The following shall be considered:

— possible asymmetrical behaviour of the membrane under thermal loads caused by the anchor system into the insulation or concrete;

— equivalent stresses shall be evaluated using either the Tresca's theory or the von-Mises' theory for both static and fatigue design;

— where appropriate the deformation produced by the thermal load shall be applied as a boundary condition;

— calculation of the maximum stress or strain shall always be based on the principal axes;

— attention shall be paid to the modelling (i.e. element sizing), of all membrane elements;

— it shall be demonstrated that the model involving the calculation theory gives a good correlation with respect to the behaviour of the real piece.

The membrane shall be designed for seismic loading. The finite element model shall include the tank structure and liquid, including liquid/structure interaction.

The anchorage system of the membrane into the insulation or concrete shall be able to withstand all assumed loads, including seismic loads.

#### 5.2.2.2 Numerical analysis

##### 5.2.2.2.1 Stress/strain curve

The stress/strain curve shall be established taking into account the following considerations:

- it shall be established for the selected material;
- part of the curve where reduction of section takes place (i.e. necking range) shall not be permitted;
- poisson's ratio ($\eta$) is different for the elastic and plastic range.

##### 5.2.2.2.2 Stability under static loading

It shall be demonstrated that the membrane keeps its form through smooth deformation under the specified static loads (a safety coefficient of 1,25 for liquid pressure). This shall confirm that the deformation of the corrugated parts shall meet the limits introduced through the stress/strain curve. Principal stresses and strains shall be used.

##### 5.2.2.2.3 Unstable collapse/buckling instability

It shall be demonstrated that no unstable collapse/buckling can occur.

NOTE For the purpose of checking the buckling stability, a buckling analysis, based on the buckling load factor analysis may be used. In such a case the following safety coefficients may be considered: 1) modelling based on laser measurement or equivalent: SF = 2,0; 2) modelling based on ideal shape : SF = 4,0. The thermal deformation may be considered as a stable state and the safety factor shall only be applied on the pressure load.

##### 5.2.2.2.4 Progressive deformation (ratcheting)

It shall be demonstrated that no progressive deformation can occur in any part of the membrane under both thermal and liquid pressure loads after ten cycles.

##### 5.2.2.2.5 Fatigue behaviour

###### 5.2.2.2.5.1 General

The biaxial stress condition shall be determined by means of an equivalent stress or strain, computed using the principal values of stress or strain respectively through Tresca or von Mises criteria.

NOTE The fatigue curve is often determined on the basis of fatigue test for uniaxial strain cycle.

###### 5.2.2.2.5.2 Strain range

The equivalent range of strains shall be assessed for all cyclic loads including the combination of each load.

The equivalent range of strain ($\Delta\varepsilon_e$) for the cyclic loads specified shall be computed assuming the plane stress condition, as the membrane is considered as a thin plate.

The effective stress and strain shall be related to the principal stresses, $\sigma_1$, $\sigma_2$, $\sigma_3$ or the principal strains $\varepsilon_1$, $\varepsilon_2$, $\varepsilon_3$ respectively, with the principal stresses and strains taken in the order $\sigma_1 > \sigma_2 > \sigma_3$ and strains $\varepsilon_1 > \varepsilon_2 > \varepsilon_3$ respectively. Therefore, inside a cycle of several loads, $\sigma_1$, $\sigma_2$, $\sigma_3$ and $\varepsilon_1$, $\varepsilon_2$, $\varepsilon_3$ shall be respectively permuted. Furthermore, since the membrane is a thin plate, the plane stress conditions shall be assumed ($\exists i \in \{1;2;3\}$, $\sigma_i = 0$). It shall be noticed even if $\sigma_i = 0$, $\varepsilon_i \neq 0$ ($i \in \{1;2;3\}$).

Therefore, the equivalent amplitude of strain, based on the Tresca's theory, shall be computed as follows:

$$\frac{\Delta \varepsilon}{2} = \text{MAX}\left\{ \left|\frac{\varepsilon_1}{2}\right|; \left|\frac{\varepsilon_2}{2}\right|; \left|\frac{\varepsilon_3}{2}\right|; \left|\frac{\varepsilon_3 - \varepsilon_1}{2}\right| \right\}$$

While, the equivalent amplitude of strain, based on the von Mises' theory, shall be computed as follows:

$$\frac{\Delta \varepsilon}{2} = C \frac{\sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2 - (\varepsilon_3 - \varepsilon_1)^2}}{2}$$

The coefficient *C* shall be as follows:

— plasticity, $\eta$ = 0,5 : $C = \frac{\sqrt{2}}{3}$;

— elasticity, $\eta$ = 0,3 : *C* = 0,544.

**5.2.2.2.5.3 Fatigue curve (SN-Curve)**

The choice of the design fatigue curve shall take into account the fact that the membrane is subjected to low cycle fatigue at low temperature, and that it locally undergoes plastic deformations.

If no fatigue curve has been obtained by means of fatigue tests on the membrane elements themselves, the fatigue curve, which will be used in the assessment of fatigue behaviour, shall be the one of the selected material and shall be submitted to the purchaser for approval.

The Miner's law shall be used as damage summation technique to determine the fatigue resistance.

NOTE 1 For examples of fatigue curves see "Recommended practice for LNG in ground storage", 7.3[16].

NOTE 2 Fatigue curves are often based on the following:

- "best fit curve". This is based on the statistic interpretation of the experimental results of fatigue. This interpretation gives the median experimental curves;

- "design curve". This is based on the "best fit curve", incorporating a correction factor defined as the most unfavourable of the value of stress divided by 2 or the number of cycles divided by 20.

These coefficients cannot be considered as safety coefficients but they shall be considered as uncertainty coefficients covering both the scattering data and the neglected effects (i.e. roughness, cutting aspects etc.). These coefficients do not take into account the local discontinuities [i.e. Stress Concentration Factor (SCF)], and therefore, it is essential that this effect shall be taken into account in the calculated stress intensity.

NOTE 3 In practice, fatigue failure usually occurs at stress concentrations. These effects should therefore be evaluated for all conditions using appropriate SCF's determined from theoretical, experimental studies of finite element stress analysis.

#### 5.2.2.2.6 Stability under seismic load

The concrete outer tank shall be able to withstand both OBE and SSE seismic loads in operating conditions.

For an OBE event, it shall be demonstrated that:

- both membrane and anchors can absorb the seismic loading;
- the pressure on the membrane is acceptable;
- the pressure on the insulation is acceptable.

For an SSE event, the outer tank, with bottom/corner protection system shall be capable of containing the liquid.

NOTE The membrane may fail.

### 5.2.2.3 Model testing

#### 5.2.2.3.1 General

When model testing is applied, the tests shall be carried out on all the components of the system. Each component shall be tested in its full size.

NOTE The test may be carried out at ambient temperature.

The number of test specimens shall be such that reliability is ensured.

The locations of measuring devices shall be determined using analysis, "reflection photoelasticity" methods etc.

The strain gauges and cements that are used shall be shown to be reliable for use on the material surface and configuration considered. Furthermore, they shall permit the computation of the stress/strains through the principal directions[1)].

The calculation of the equivalent stress or strain shall always be based on the principal axes. Therefore, the equivalent amplitude of strain, based on the Tresca's theory, shall be computed as follows:

$$\frac{\Delta \varepsilon}{2} = \mathrm{MAX}\left\{\left|\frac{\varepsilon_1}{2}\right|;\left|\frac{\varepsilon_2}{2}\right|;\left|\frac{\varepsilon_3}{2}\right|;\left|\frac{\varepsilon_1-\varepsilon_2}{2}\right|;\left|\frac{\varepsilon_2-\varepsilon_3}{2}\right|;\left|\frac{\varepsilon_3-\varepsilon_1}{2}\right|\right\}$$

While, the equivalent amplitude of strain, based on the von Mises' theory, shall be computed as follows:

$$\frac{\Delta \varepsilon}{2} = C\frac{\sqrt{(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2-(\varepsilon_3-\varepsilon_1)^2}}{2}$$

1) The principal directions correspond to the direction for which the shear stress is zero.

The coefficient *C* shall be as follows:

— plasticity, $\eta$ = 0,5 : $C = \frac{\sqrt{2}}{3}$;

— elasticity, $\eta$ = 0,3 : *C* = 0,544.

#### 5.2.2.3.2 Stability under static loading

It shall be demonstrated that no unstable collapse occurs in the membrane. A safety coefficient of 1,25 shall be taken into account when the membrane is designed for the specified loads.

#### 5.2.2.3.3 Progressive deformation (i.e. ratcheting)

When a load cycle, which simulates the operational condition, is applied, it shall be demonstrated that each part of the membrane remains stable, without progressive deformation after ten cycles.

#### 5.2.2.3.4 Fatigue behaviour

All the membrane component of the storage tank shall be tested in fatigue by:

— cyclic elongation due to thermal loading;

— cyclic pressure due to hydrostatic loading (to fully simulate the working conditions of the membrane, each component tested under cyclic pressure shall be pre-elongated to a value corresponding at least to the maximum elongation).

The “best fit curve" shall be based on the statistic interpretation, as described in the proposed ISO standard “Recommendations for fatigue design of welded joints and components”, May 1996, of the experimental results of fatigue. This interpretation gives the median experimental curves.

The experimental results of the fatigue tests shall be based on the stress or strain principal values.

The ‘design curve’ shall be determined from the ‘best fit’ curve assuming a confidence level $\gamma$= 75 % and a probability of survival, *p* = 95 %.

The design points shall be based on the following calculation:

– design point = $m - k\,\sigma$

where

$m$ is the mean of a tested population;

$\sigma$ is the standard deviation of population;

$k$ is the factor determined from Table 7.

NOTE This approach is also illustrated in Annex B.

The Miner’s law shall be used as damage summation technique to determine the fatigue resistance.

**Table 7 — k factors for S-N curves (normal distribution assumed)**

| Sample size | *k* |
|---|---|
| 3 | 3,152 |
| 4 | 2,680 |
| 5 | 2,463 |
| 6 | 2,336 |
| 7 | 2,250 |
| 8 | 2,190 |
| 9 | 2,141 |
| 10 | 2,103 |
| 11 | 2,073 |
| 12 | 2,048 |
| 13 | 2,026 |
| 14 | 2,007 |
| 15 | 1,991 |
| 16 | 1,977 |
| 17 | 1,964 |
| 18 | 1,951 |
| 19 | 1,942 |
| 20 | 1,933 |
| 21 | 1,923 |
| 22 | 1,916 |
| 23 | 1,907 |
| 24 | 1,901 |
| 25 | 1,895 |
| Confidence level of 0,75.<br>Probability of survival of 95 %. | |

## 5.3 Vapour container (outer tank)

### 5.3.1 Single, double and full containment tanks

#### 5.3.1.1 Bottom

##### 5.3.1.1.1 Annular plates

The annular plates shall be in accordance with 5.2.1.1.1.

##### 5.3.1.1.2 Bottom centre plates

The bottom centre plates shall be in accordance with 5.2.1.1.2.

#### 5.3.1.2 Shell

The minimum thickness of shell plate shall be in accordance with Table 6.

For internal pressure, the following equation shall be used:

$$e = \frac{PD}{20S} + c$$

where

| | |
|---|---|
| $c$ | is the corrosion allowance, in mm; |
| $D$ | is the container diameter, in m; |
| $e$ | is the calculated shell plate thickness, in mm; |
| $P$ | is the internal pressure, as a combination of internal gas pressure and insulation pressure, in mbar; |
| $S$ | is the allowable design stress, in N/mm$^2$. |

Design of the outer shell with intermediate ring stiffeners shall consider vertical compression in combination with circumferential compression. See 5.2.1.2.3 d).

The shell with any stiffeners shall resist all applicable loads including at least:

— vertical compression forces including:

  1) dead loads;

  2) live loads (roof live, snow);

  3) pipe loads;

  4) internal vacuum pressure;

  5) wind overturning (see 5.2.1.2.3 e);

  6) seismic overturning;

— circumferential compressive forces including:

1) wind local pressure effects (see 5.2.1.2.3 e);

2) vacuum pressure.

The amount of design load (action) by suction on roof and overturning from wind to be considered in the calculations of the allowable biaxial stress, shall depend on whether these act beneficial or adverse.

Stiffener splices shall be welded together with full penetration butt welds. A mouse-hole shall be used at stiffener butt welds and where the stiffener crosses a vertical weld. Stiffeners shall be connected to the shell, with a continuous fillet weld on both sides except when the outer shell is not designed to contain refrigerated liquid, the overhead weld may be intermittent.

The stiffener shall be located at least 150 mm from a horizontal weld.

#### 5.3.1.3 Roof

##### 5.3.1.3.1 Minimum plate thickness

The minimum roof plate thickness shall be 5 mm (exclusive of corrosion allowance).

##### 5.3.1.3.2 Roof with supporting structure

For the roof plates, one or more of the following welds shall be used:

— single sided lap weld;

— double sided lap weld;

— butt welds with or without backing straps.

The roof supporting structure shall be designed in accordance with EN 1993-1-1. Alternatively, it shall be designed according to the allowable stress theory with the following joint efficiency factors for the welds of the roof plates:

— single sided lap welds 0,35;

— double sided lap welds 0,65;

— butt welds with or without backing straps 0,70.

Lap welded roof plates shall have a minimum lap of 25 mm.

Where the roof plating is not welded to the roof support members, the roof frame shall be cross-braced in the plane of the roof surface.

##### 5.3.1.3.3 Roof without supporting structure

The roof plate thickness shall be designed for internal pressure and to resist buckling, due to external loading. The following formulae shall be used:

— for internal pressure: $e_r = P\, R_1 / 20\, S\, \eta$ (for spherical roofs);

$e_r = P\, R_1 / 10\, S\, \eta$ (for conical roofs);

— for buckling:

$$e_r = 40R_1\sqrt{\frac{10P_e}{E}}$$

where

| | |
|---|---|
| $E$ | is Young's modulus, in N/mm$^2$; |
| $e_r$ | is the roof plate thickness (excluding corrosion allowance) in mm; |
| $P$ | is the internal pressure less the weight of the corroded roof sheets, in mbar; |
| $P_e$ | is the external loading, in kN/m$^2$; |
| $R_1$ | is the radius of curvature of roof, in m; |
| $S$ | is the allowable design stress, in N/mm$^2$; |
| $\eta$ | is the weld joint efficiency factor. |

Roof plates, without supporting structure, shall be of butt-welded or double lap welded.

#### 5.3.1.3.4 Stiffened dome

For a stiffened dome roof the structure shall be designed in accordance with EN 1993-1-1.

#### 5.3.1.3.5 Compression area

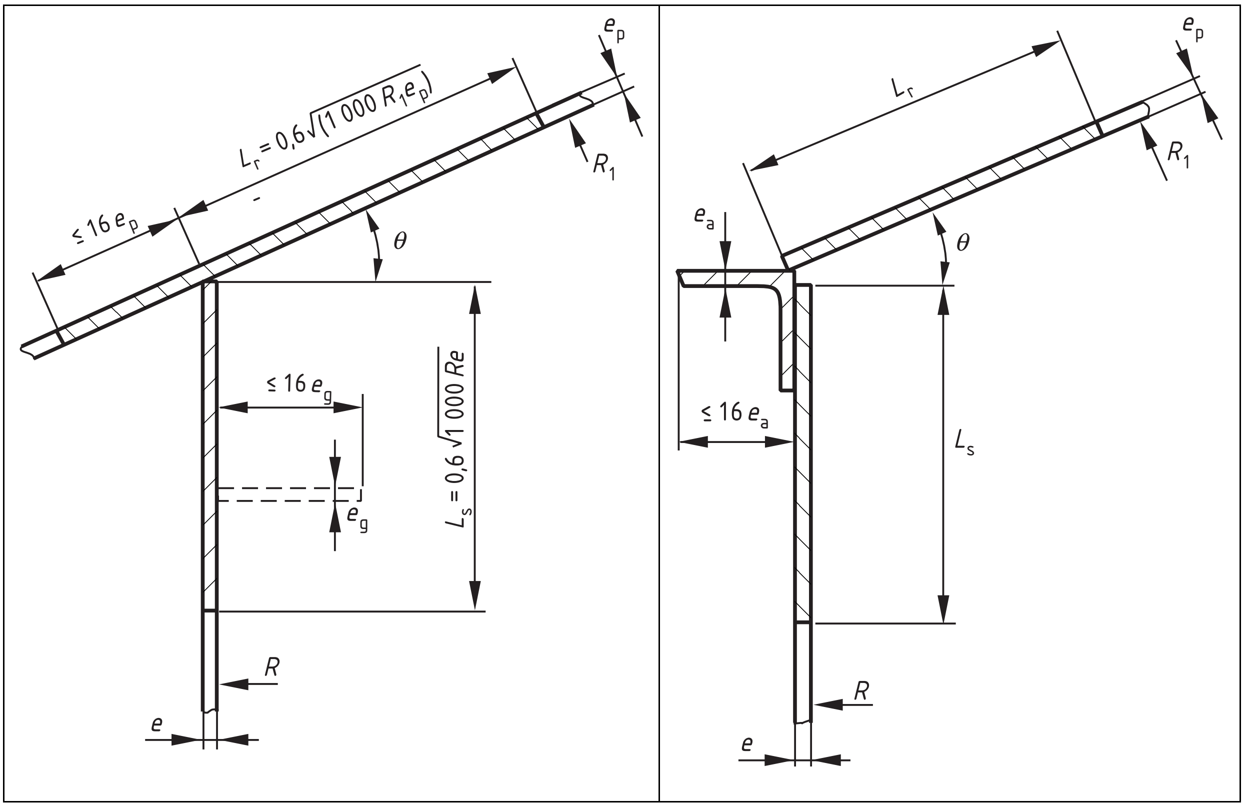
The minimum compression area, excluding any corrosion allowance, shall be determined by the following equation:

$$A = \frac{50PR^2}{S_c \tan\theta}$$

where

| | |
|---|---|
| $A$ | is the compression area required, in mm$^2$; |
| $P$ | is the internal pressure, less weight of roof sheets, in mbar; |
| $R$ | is the radius of the shell, in m; |
| $S_c$ | is the allowable compressive stress in N/mm$^2$ (see 5.1.2.3); |
| $\theta$ | is the slope of the roof meridian at roof-shell connection, in degrees. |

The effective compression area shall be made up of plates and/or sections where the maximum width is in accordance with Figure 3.




a) without corner ring

b) with corner ring

**Key**

*e* is the thickness of shell, in mm (excluding corrosion allowance);

$e_a$ is the thickness of top corner ring, in mm;

$e_g$ is the thickness of the horizontal girder, in mm;

$e_p$ is the thickness of roof plate at compression ring, in mm (excluding corrosion allowance);

$L_r$ is the effective roof length, in mm;

$L_s$ is the effective shell length, in mm;

*R* is the radius of tank shell, in m;

$R_1$ is the radius of curvature of roof, in m (for conical roofs = $R/\sin\theta$)

**Figure 3 — Typical shell-roof compression areas**

Where a top corner ring is used, the minimum size shall be in accordance with Table 8.

**Table 8 — Minimum size of top corner ring**

| Shell diameter<br>*D*<br>m | Size of corner ring<br>mm × mm × mm |
|---|---|
| $D \leq 10$ | 60 × 60 × 6 |
| $10 < D \leq 20$ | 60 × 60 × 8 |
| $20 < D \leq 36$ | 80 × 80 × 10 |
| $36 < D \leq 48$ | 100 × 100 × 12 |
| $48 < D$ | 150 × 150 × 10 |

Single lap welded roof plates shall not contribute to the compression area.

NOTE 1 Double lap welded roof plates may contribute to the compression area.

The compression area shall be proportioned such that the horizontal projection of the effective compression area has radial width of not less than 1,5 % of the horizontal radius of the tank.

The compression area shall be arranged such that the centroid of the compression area falls within a vertical distance equal to 1,5 times the average thickness of the two members intersecting at the corner, above or below the horizontal plane through the corner.

The compression area shall be checked for tension loading due to external loads (internal negative pressure included).

NOTE 2 Care should be taken to avoid excessive bending in the compression area at the connection between the roof supporting member and the compression area.

NOTE 3 For the design of the compression area, using a knuckle, see [16].

#### 5.3.2 Membrane tank

The steel parts of the roof of membrane tanks shall be in accordance with 5.3.1.3.

### 5.4 Suspended roof

A suspended roof and its supporting structure shall be designed for the minimum design temperature.

The structure shall be designed for any one hanger becoming ineffective.

The ventilation openings of the suspended roof shall be such that the pressure difference between the space below and above the suspended roof is not more than the weight of the suspended roof so that uplift cannot occur.

### 5.5 Nozzles

#### 5.5.1 General

Pipe connections to the primary or secondary liquid container shall be in accordance with EN 14620-1:2006:7.1.6.

### 5.5.2 Nozzle loads

Nozzles shall be designed to withstand the loads resulting from connected piping and attachments.

### 5.5.3 Shell nozzles

#### 5.5.3.1 O/D 80 mm and above

The nozzle details shall be in accordance with EN 14015:2004, 13.1

#### 5.5.3.2 Shell nozzles less than O/D 80 mm

The nozzle details shall be in accordance with EN 14015:2004, 13.2.

#### 5.5.3.3 Manholes

Where nozzles are used as manholes they shall have a minimum internal diameter of 600 mm.

### 5.5.4 Shell nozzle welding details

The shell nozzle welding details shall be in accordance with EN 14015:2004, 13.7.

### 5.5.5 Roof nozzles

For design pressures equal to or smaller than 60 mbar, penetrations through the roof shall be reinforced and welded in accordance with EN 14015:2004, 13.3.

For design pressures greater than 60 mbar, penetrations through the roof shall be reinforced and welded as specified for shell nozzles, see 5.5.3.

Where the opening in the roof is elliptical due to the slope or curvature of the roof, the required reinforcement shall be based on the long dimension of the elliptical opening.

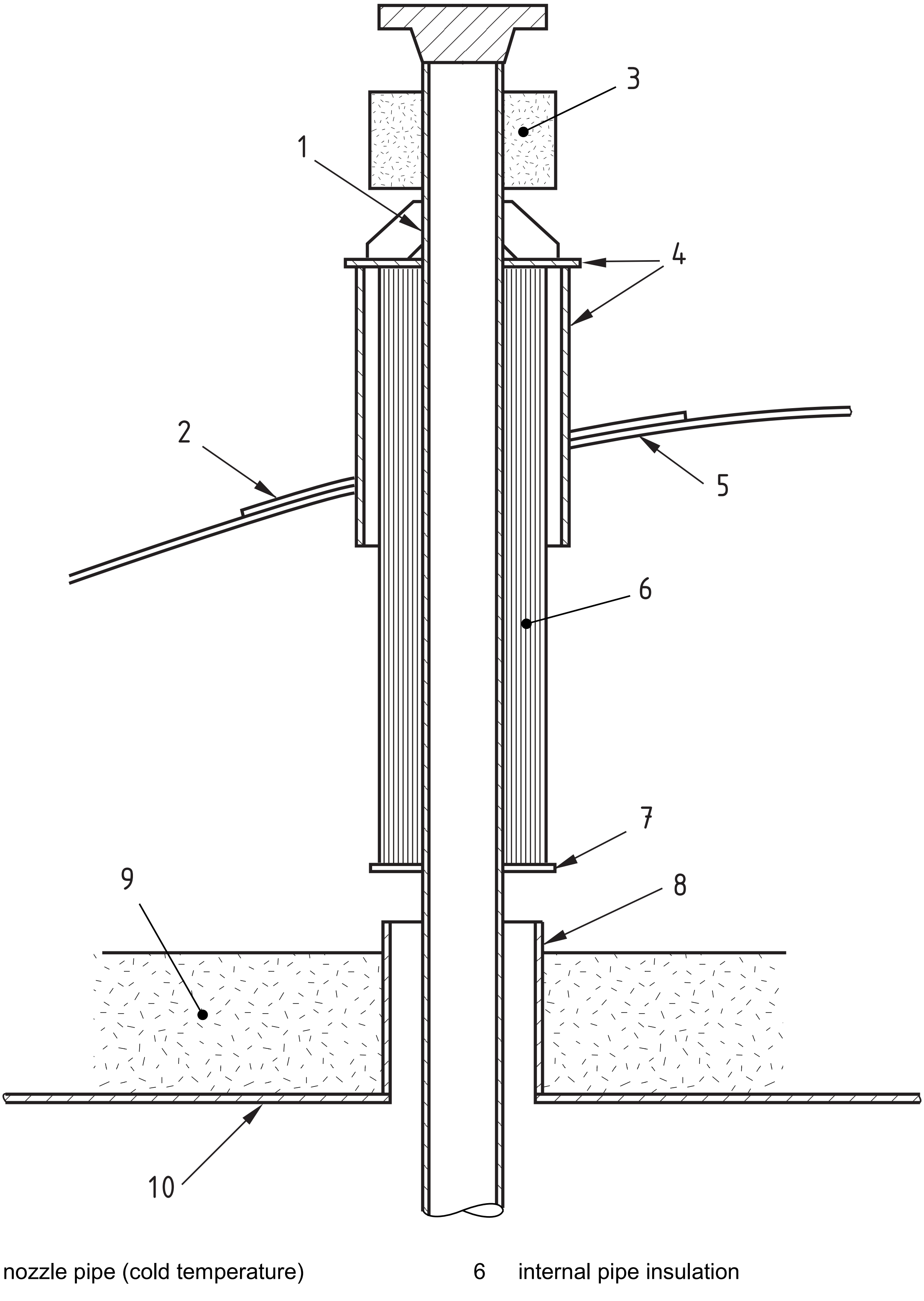
The minimum nozzle wall thickness shall be computed for the applicable loadings including piping loads. In no case shall the thickness be less than the thickness of a standard-weight pipe in accordance with EN 10220.

Roof nozzle and roof manhole flanges shall conform to class 150 of EN 1759-1:2004 or PN25 of EN 1092-1:2001, except where a higher rating has been specified by the purchaser.

NOTE 1 As an alternative, manhole flanges and covers may be made from plate and designed for a minimum pressure of 3,5 bar (g).

NOTE 2 It should be recognized that roof nozzles for cold liquid or cold vapour may need to be provided with thermal distance pieces. See Figure 4 for an example of a product inlet nozzle with thermal distance piece for a tank with suspended roof.

Roof manholes shall have a minimum nominal diameter of 600 mm.




**Key**

| | | | |
|---|---|---|---|
| 1 | nozzle pipe (cold temperature) | 6 | internal pipe insulation |
| 2 | nozzle reinforcing plate (ambient) | 7 | support ring for insulation |
| 3 | external pipe insulation | 8 | suspended roof sleeve |
| 4 | thermal distance piece (cold) | 9 | suspended roof insulation |
| 5 | dome roof (ambient) | 10 | suspended roof |

**Figure 4 — Typical roof nozzle with thermal distance piece**

#### 5.5.6 Flange drilling

The flanges of all mountings, except shell and roof manholes, shall be made and drilled in accordance with class 150 of EN 1759-1:2004, as a minimum. The orientation of mating flanges shall be checked for compatibility.

#### 5.5.7 Post-weld heat treatment of nozzles

Nozzles shall be post-weld heat treated in accordance with 8.4.

### 5.6 Primary and secondary containment, bottom connections

When primary/secondary containment bottom connections are used, the following shall be taken into account:

— differential settlement of the tank;

— differential contraction of the inner tank relative to the outer tank;

— nozzle opening shall be reinforced (doubled plate, thickened annular or sketch plate);

— unsupported area around the nozzle shall be kept to a minimum;

— space surrounding the nozzle and pipe shall be filled with suitable insulating material and sufficient localized base heating shall be applied.

### 5.7 Connections between containers

Attention shall be paid to the following:

— thermal and hydrostatic forces caused by relative movement between the inner and outer tank;

— a heat break shall be considered for the connections between the inner and outer tank;

NOTE Strain-absorbing connections (e.g. flexible loops) may be necessary to ensure that the relative movement does not induce unacceptable local stressing of the inner and/or outer tank.

— flanged joints shall not be located within inaccessible annular spaces between the inner and outer shells;

— connections between openings in the inner and outer tank roofs shall be designed to accommodate the differential movement between the roofs.

Connections passing through the suspended roof shall be able to move freely through the suspended roof, thus eliminating additional loads on either the outer roof or the suspended roof.

### 5.8 Other details

#### 5.8.1 Tank anchorage

For the anchor design the following subjects shall be considered:

— both the inner and the outer tank shall be designed independently for all combinations of actions to establish the worst conditions of uplift;

- attention shall be given to the design of the inner tank anchorage where it penetrates the outer tank bottom to ensure liquid tightness and flexibility to accommodate differential temperature movement for all design conditions;
- anchorage points shall be equally spaced over the circumference of the tank with a maximum spacing of 3 m;
- no initial tension shall be applied to the anchorage. It shall become effective only when an uplift force develops in the shell of the tank container. Measures shall be taken to ensure that anchorage bolts cannot work loose or become ineffective over the design lifetime of the tank;
- anchorage attachments to shell and foundation shall be designed for the full yield capacity of the anchor bolt or anchor strap;
- anchorage design shall allow for adjustment due to settlement prior to commissioning;
- anchorage shall be designed to take account of bending due to thermal movement;
- anchorage shall not be directly attached to shells but shall be attached to pads or brackets. Any anchor bar, bolt or strap shall have a minimum cross-sectional area of 500 $mm^2$;
- addition of a corrosion allowance of at least 1 mm shall be applied to all surfaces of anchorage bars, bolts or straps for anchors directly exposed to the atmosphere;
- need for heat-breaks. Heat transfer to the colder parts of the tank structure/foundation shall be limited such that ice formation cannot result in failure of the anchorage or tank.

### 5.8.2 Name-plate

A name-plate shall be installed on each tank giving the following information as a minimum:

- contractor's name;
- serial number;
- year of manufacture;
- design code/standard;
- tank, plant number;
- product design density and temperature;
- maximum design pressure;
- maximum design liquid level;
- storage capacity.

# 6 Fabrication

## 6.1 Handling of materials

All plates used for primary and secondary liquid containers shall be handled and stored separately in such a way that materials can't be intermixed. Adequate weather protection shall be applied. The material shall be properly marked as low-temperature materials.

Stainless steel shall be stored and handled with suitable equipment to avoid surface contamination. Any contact with zinc, galvanized tools etc. shall be prevented.

Magnetism of 9 % nickel steel shall be avoided. The residual magnetism shall not exceed 50 Gauss when delivered at site.

Welding consumables shall be protected and stored in accordance with the conditions laid down by the welding consumables standards and/or the supplier's recommendations.

Markings, on material ordered with a certificate in accordance with EN 10204:2004, type 3.1 and higher, shall remain visible after erection of the tank. In case the marking becomes obliterated during fabrication, at least one marking shall be transferred to a location that will be visible after completion of the tank.

NOTE The preferred method of marking is die-stamping, using low stress stamps with a minimum radius of 0,25 mm. However, this method is not suitable for plates less than 6 mm thick. Paint or ink marking can then be used instead.

## 6.2 Plate preparation and tolerances

### 6.2.1 Shell plates

Thermal cut edges shall be ground to bright metal and shall be free from oxide and scale.

Tolerances shall be specified based on the steel making process, shop fabrication procedures and proposed erection method. The maximum width of a shell ring shall be within 4 mm of the value used in the design.

For membrane tanks, plates shall have a cold-rolled finish without visible defects.

### 6.2.2 Annular plates

All annular plates shall have the outer edge and both short edges ultrasonically examined for a width of 150 mm after fabrication for laminations, in accordance with EN 10160:1999, level $S_2$.

### 6.2.3 Nozzles

Where nozzle necks in primary or secondary liquid container are made from rolled plate, the longitudinal weld in the nozzle neck shall be 100 % radiographically or ultra-sonically examined.

When shell nozzle necks are manufactured from carbon steel plate of thickness ≥ 25 mm, an ultrasonic examination for laminations shall be made in the area where the shell and reinforcing plate are welded to the nozzle.

If flanges are made from plate, they shall be ultrasonically tested in accordance with EN 10160:1999, to ensure freedom from laminations.

Slip-on flanges shall be welded from both sides.

All weld-neck flanges shall have full penetration butt welds.

#### 6.2.4 Reinforcement plates

The reinforcement plates shall be formed so that, when assembled, they possess the same curvature as the shell course plate on which they are welded.

All nozzle reinforcement plates shall have at least one tapped hole for inspection purposes.

### 6.3 Tolerances

#### 6.3.1 Foundation peripheral tolerances

Where a concrete ring beam is provided under the shell, the top of the ring beam shall be level to ± 3 mm in any 10 m of circumference and to within ± 6 mm in the total circumference, measured from the average elevation.

Where a concrete base slab is provided, the area 300 mm inside and 300 mm outside the shell shall comply with the concrete ring beam level tolerances.

#### 6.3.2 Other foundation surface tolerances

Any deviation, measured with a 3 m long template, shall not exceed 15 mm.

#### 6.3.3 Bottom plate tolerances

Local distortions of the bottom plates shall be minimized by controlling the welding sequences, installation of temporary stiffeners etc. They shall not exceed 75 mm over a distance less than 3 m.

#### 6.3.4 Shell to bottom connection

After assembly and welding of the first shell course to the bottom, the inside radius measured horizontally at a height of 300 mm above the bottom of the shell shall be within the limits given in Table 9. Measurements shall be made at the centre of each shell plate.

**Table 9 — Radius tolerances**

| **Diameter** <br> *D* <br> m | **Radius** <br> tolerance <br> mm |
|---|---|
| $D \leq 12$ | ± 12 |
| $12 < D \leq 46$ | ± 19 |
| $46 < D \leq 76$ | ± 25 |
| $76 < D$ | ± 30 |

#### 6.3.5 Ovality

The difference between the maximum and minimum diameter at any elevation shall not exceed 1 % of the diameter, or 300 mm, whichever is the lesser.

### 6.3.6 Local deformation in plates

Local deformation in shell plates shall be checked with a 1 m straight edge in the vertical direction and with a 1 m long template in the horizontal direction. The template for horizontal measurements shall be made to fit the design radius of the tank.

The maximum difference between the design profile and the as built profile shall be as given in Table 10.

**Table 10 — Maximum differences between the design and the as built profile**

| Plate thickness<br>*e*<br>mm | Difference<br><br>mm |
|---|---|
| $e \leq 12,5$ | 16 |
| $12,5 < e \leq 25$ | 13 |
| $25 > e$ | 10 |

### 6.3.7 Local deformation at welds

Local deformation at welds, peaking, can be internal or external to the tank centre (see Figure 5), and the tolerances shall apply to either condition.

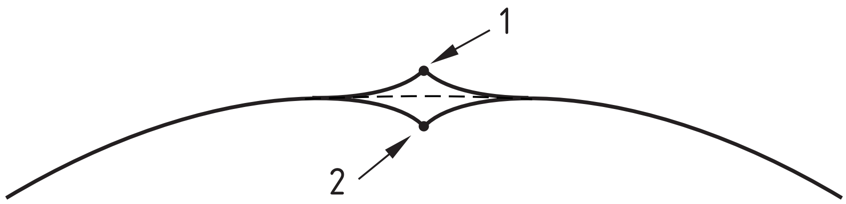
Peaking shall be measured by a gauge as shown in Figure 6. The gauge shall be set to the maximum peaking allowed (with a correction for versine) in accordance with Table 11.

Peaking shall then be acceptable until one of the outer legs lifts from the surface.

NOTE Weld peaking has a die away length which obviates use of a template notched to the weld width.

**Table 11 — Tolerance limits on local deformation in welds**

| Plate thickness<br>*e*<br>mm | Maximum<br>tolerance<br>mm |
|---|---|
| $e \leq 12,5$ | 12 |
| $12,5 < e \leq 25$ | 9 |
| $25 < e$ | 6 |




**Key**

1 outward peaking

2 inward peaking

**Figure 5 — Outward and inward peaking**

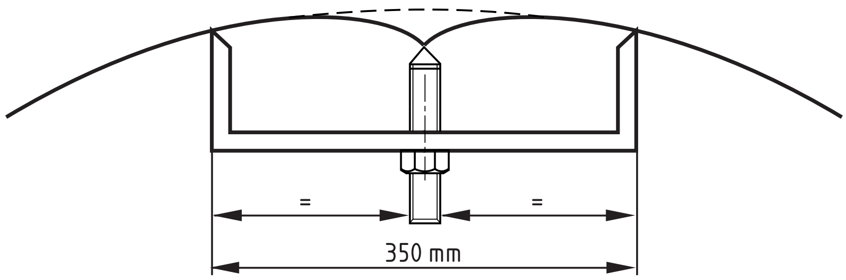



**Figure 6 — Gauge for measuring peaking**

### 6.3.8 Vertical tolerance

#### 6.3.8.1 Steel tanks

The maximum out-of-plumpness of the top of the shell relative to the bottom of the shell shall not exceed 1/200 of the total height or 50 mm whichever is less. The same tolerance shall apply to individual shell courses.

#### 6.3.8.2 Liners

The maximum out-of-plumpness of liners shall not exceed 100 mm.

### 6.3.9 Tolerances on alignment of plates

#### 6.3.9.1 Vertical joints

The misalignment of shell plates at vertical joints shall not exceed the values given in Table 12.

**Table 12 — Misalignment at vertical joints**

| Shell plate thickness<br>$e$<br>mm | Misalignment<br><br>mm |
|---|---|
| $e \leq 15$ | 1,5 |
| $15 < e \leq 30$ | 10 % of $e$ |
| $30 < e$ | 3 |

#### 6.3.9.2 Horizontal joints

The deviation between the alignment indicated on the drawing and the actual position shall not exceed 20 % of the thickness of the upper plate, with a maximum of 3 mm.

### 6.3.10 Tolerance for membrane system

The whole membrane system (membrane, insulation panels, glue, anchors etc.) shall be connected or supported by the concrete wall or concrete bottom. Therefore, the contractor shall specify the tolerances of the concrete tank, such that they shall accommodate these tolerances under all actions.

## 6.4 Roof

The method of construction shall be such that stability of the roof shall be ensured throughout the erection process.

Where a temporary supporting structure is used, the contractor shall take all necessary precautions to avoid the twisting of the support frame and rotation of the structure as a whole.

## 6.5 Temporary attachments

Temporary attachments shall be welded by the same procedure as that used for the material to which they are attached. The temporary attachment shall be removed by thermal cutting, gouging or by grinding. After thermal cutting or gouging the weld, 2 mm material shall be left and ground off to a smooth surface. Crack detection shall be performed after removal.

No temporary attachment welding shall be allowed onto the membrane.

# 7 Welding procedures

## 7.1 General

All welding, including repair and tack welding, shall have a Welding Procedure Specification (WPS) and a Welding Procedure Approval Record (WPAR) in accordance with EN ISO 15607, EN ISO 15609-1:2004 and EN ISO 15614-1.

For primary and secondary liquid containers, the welding procedures shall be approved for each new project, irrespective of previous approvals. The steel used shall be made by the same mill using the same steel making process.

In the case of pre-painted protection of the plates, which may remain in place during the welding operation, the approval of the welding procedure shall be carried out on plates with this paint.

### 7.2 WPAR requirements

A WPAR shall be generated for each of the following conditions.

One butt weld test plate shall be completed for each thickness specified below in the horizontal position for each welding process used to weld circumferential seams in the tank shell:

- for a thickness equal to or less than the minimum tank shell thickness;
- for a thickness equal to or greater than maximum tank shell thickness.

One butt weld test plate shall be completed for each thickness specified below in the vertical position for each welding process used to weld vertical (longitudinal) seams in the tank shell:

- for a thickness equal to or less than the minimum tank shell thickness;
- for a thickness equal to or greater than maximum tank shell thickness.

The thickness ranges approved in the testing conditions noted here above shall meet the EN ISO 15614-1 requirements as a minimum.

### 7.3 Impact testing

Impact testing of the weld metal and HAZ for WPAR and production testing shall be to the following and the requirements of Table 2:

- each set of specimens shall be comprised of three test specimens. One set of specimens shall be required for the weld metal and one set is required in the HAZ;
- weld metal and HAZ Charpy V-notch impact test specimens shall be sampled at a maximum of 2 mm below the surface of the parent metal and transverse to the weld. The plate rolling direction of the test plates for impact testing shall be parallel with the weld joint except for test plates for vertical joints which can be orientated with the rolling direction transverse to joint;
- V-notch shall be cut perpendicular to the surface of the weld;
- in the HAZ, the notch shall be at 1 mm to 2 mm from the fusion line and in the weld metal the notch shall be at the weld centreline.

### 7.4 9 % Nickel steel

The values of the transverse tensile test specimens required by EN ISO 15614-1 shall not be less than the value used in design for vertical welds and/or 80 % of the value for horizontal welds. If fracture occurs in the weld metal, the weld metal ultimate and yield stress (proof stress) shall be determined by:

- two all weld metal test plates shall be prepared (one each for the 1G and 3G positions) using buttered carbon steel plates;
- two all weld metal test specimens shall be prepared from each test plate.

## 7.5 Welders and welding operators

### 7.5.1 Single, double and full containment tanks

Welders shall be approved in accordance with EN 287-1. Welding operators shall be approved in accordance with EN 1418.

### 7.5.2 Membrane tanks

Welding tests shall be performed on assembly of actual membrane sheets.

As a minimum, the approval tests shall be performed in the following position and direction:

- flat position, for bottom part;
- vertical up direction, for shell part;
- horizontal direction with ledge facing up or down, for shell part.

Each test coupon shall be checked by macrographic examination.

During production, each welder or welding operator shall be evaluated periodically. The period shall be fixed in accordance with the production results obtained. As a minimum, the welders shall be tested once a month and the welding operators once a week.

## 7.6 Production test plates

### 7.6.1 Single, double and full containment tanks

For a primary and secondary liquid container, as a minimum, one production test plate shall be made from the vertical weld of the thickest and the thinnest course and for each welding process used to weld these courses.

The welding and testing of the production test plates shall be carried out as early in the tank construction as practically possible.

If the difference in thickness between the bottom and top shell courses is equal to or exceeds 20 mm, an additional production test plate shall be required for each welding process used in the vertical position on a plate thickness approximately in the middle of the thickness range between the bottom and top shell ring thicknesses. These test plates shall have a minimum width of 400 mm (200 mm each side of the joint), and shall be large enough to avoid the effects of heating on its mechanical properties.

The test plate material used for the production test plates shall be from one of the heats of steel used to build the tank.

In addition, the welding consumables used to weld the production plates shall be of the same manufacturer and type used to weld the respective production weld.

If the method of erection is such that the test plate cannot be placed at the end of a vertical weld, then it shall be welded at the site at an appropriate location using the WPS's used to weld the represented production seam.

The inspection and test requirements for the production test plates shall be the same as for the WPAR. However, only Charpy V-notch impact tests of the weld metal and HAZ shall be carried out.

Re-tests shall be allowed. In case of failure of the re-test, corrective action shall be taken. The purchaser shall be informed.

#### 7.6.2 Membrane tanks

As a minimum, one production test plate of membrane sheet shall be made from the vertical and horizontal welds of the shells and from the flat weld of the bottom.

## 8 Welding

### 8.1 Tack and temporary welds

Tack and temporary welds shall be made by approved welders.

NOTE Such welds need not be removed provided they are sound and the subsequent weld passes are thoroughly fused into the tack welds.

### 8.2 Atmospheric conditions

The contractor shall take measures to ensure that the welds are protected against moisture, rain and that wind protection shall be applied.

When the parent metal temperature is below +5 °C, the material on both sides of the joints shall be preheated. The preheating shall be carried out such that the full joint thickness of the joint is more than 5 °C.

### 8.3 Preheating

When preheating is required, it shall encompass the whole thickness of the parts to be welded for a distance of four times the plate thickness or 75 mm, whichever is the greater, in any direction before welding begins.

Preheating shall be in accordance with EN 1011-2.

### 8.4 Post-weld heat treatment

Shell nozzles and manholes shall be welded into the shell plate or thickened insert plate and the welded assembly shall be post-weld heat treated prior to installation into the tank unless one of the following exceptions applies:

— no part of the assembly has a thickness 16 mm or greater;

— no part of the assembly has a thickness 30 mm or greater and the nozzle is smaller than 300 mm in nominal diameter;

— nozzles or manholes installed in the shell of an outer tank designed for the containment of vapour only.

A heat treatment plan shall be established for the heat treatments.

NOTE 1 These requirements apply to carbon manganese steel, and do not apply to 1,5 % and 9 % Ni steel, austenitic stainless steel and non-ferrous materials.

Cold-formed 9 % Ni plates shall be post-weld heat treated (or stress relieved) when the extreme fibre strain from cold forming exceeds 3 % as determined by the following equation:

$$s = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

where

$R_o$ is the original radius (infinity for flat plat) in mm;

$R_f$ is the final radius in mm;

*s* the strain, in percent;

*t* the plate thickness in mm.

The temperature from a sufficient number of points shall be recorded continuously and automatically to ensure that the whole assembly being heat-treated is within the range specified.

The temperature of the furnace shall not exceed 400 °C at the time the assembly is placed in it.

The rate of heating above 400 °C (in degrees Celsius per h.) shall not exceed:

$\frac{5500}{e}$ with a maximum rate of 220 °C /h.,

where

*e* is the shell plate or insert plate thickness, in mm.

During the heating period, there shall be no variations in temperature throughout the assembly being heated greater than 150 °C within any 4 500 mm interval of length, and when at the holding temperature, the temperature throughout the assembly shall be within the range 580 °C to 620 °C. For quenched and tempered steels, the steel maker shall be consulted.

The furnace atmosphere shall be so controlled as to avoid excessive oxidation of the surface. There shall be no direct impingement of the flame on the assembly.

When the assembly has attained a uniform temperature as specified, the temperature shall be held constant for a period of 2,5 min. per mm thickness of the shell plate or insert plate with a minimum of 1 h.

NOTE 2 Where necessary the time/temperature combinations given in Table 13 may be used:

**Table 13 — Holding times at lower temperatures**

| Temperature °C | Holding time Minutes per mm thickness |
|---|---|
| 500 | 12,5 |
| 540 | 7,5 |
| 570 | 5,0 |

The assembly shall be cooled in the furnace to 400 °C at a rate not exceeding:

$\frac{5500}{e}$ with a maximum rate of 220 °C /h where

*e* is the shell plate or insert plate thickness, in mm.

NOTE 3 Below 400 °C, the assembly may be cooled in still air.

Fitting plates shall be suitably stiffened to retain their shape during PWHT.

# 9 Inspection

## 9.1 Qualification of NDE personnel

NDE personnel shall possess a qualification corresponding at least to the level of work they are required to carry out. This qualification shall be qualified and certified to a NDT and certification program. The program shall be based on EN 473.

NOTE ASNT SNT-TC-1A, CP189, or ACCP can also be used.

## 9.2 Inspection procedures

All NDE inspections shall be carried out by a department that is independent of the production department.

Inspection and test procedures shall be prepared. As a minimum, each procedure shall indicate:

— scope of the procedure;

— operational conditions:

1) type of equipment used;

2) type and characteristics of consumable products;

3) test parameters (duration, temperature etc.);

4) conditions for reading the results (light etc.).

## 9.3 Type of inspections

### 9.3.1 Inspection of materials

Contractor shall ensure that a material marking/identification system is maintained. The system shall be such that during construction, materials can be identified at all times.

### 9.3.2 Extent of weld inspections

#### 9.3.2.1 Primary and secondary liquid container of single, double and full containment tanks

Inspections shall be performed in accordance with Table 14.

**Table 14 — Weld inspections of primary and secondary liquid container**

| Part of tank | Type of assembly | Visual examination % | Dye penetrant examination % | Magnetic particle examination % | Vacuum box test % | Soap bubble examination % | Radiographic or ultrasonic examination % |
|---|---|---|---|---|---|---|---|
| Bottom plates | Butt weld | 100 [a] | | | 100 [a] | | |
| | Fillet weld | 100 [a] | | | 100 [a] | | |
| Bottom annular plates | Radial butt weld | 100 | | | 100 | | 100 |
| Bottom to shell | Fillet weld | 100 [b] | | | | 100 [b] | |
| Shell | Butt weld | 100 [b] | | | | | see Table 16 |
| Nozzles in shell or bottom | Longitudinal weld | 100 [c] | | | | | 100 |
| | Weld neck flange to pipe $d_n \geq 100$ mm | 100 [c] | 100 or | 100 | | | 10 |
| | Weld neck flange to pipe $d_n < 100$ mm | 100 [c d] | 100 or | 100 | | | |
| | Slip on flange to pipe fillet weld | 100 [c] | 100 or | 100 | | | |
| Nozzle to shell (insert and nozzle with reinforcing plate) | Nozzle to shell or insert weld | 100 [c] | 100 or | 100 | | | |
| | Nozzle to reinforcing plate | 100 [c] | 100 or | 100 | | | |
| | Reinforcing plate to shell | 100 [c] | | | | 100 | |
| | Insert plate to shell | 100 | | | | | 100 |
| Permanent bracket and pad plates | Fillet weld | 100 | 100 or | 100 | | | |
| Stiffening rings | Main butt welds in stiffening rings | 100 | | | | | 100 |
| | Fillet welds to shell | 100 | 100 or | 100 | | | |

[a] Before and after hydrostatic testing.
[b] At both sides.
[c] After post weld heat treatment, if required.
[d] One side.

**Table 15 — Extent of radiographic/ultrasonic examination of shell welds of primary and secondary liquid container**

| Type of examination | Welds | | |
|---|---|---|---|
| | Vertical % | Tee % [a] | Horizontal % [b] |
| Radiographic or ultrasonic | 100 | 100 | 5 |

– [a] 400 mm film to be positioned horizontally.
– [b] In addition to the Tees.

#### 9.3.2.2 Primary liquid container of membrane tanks

For the stainless steel membrane, the following weld inspections shall be performed:

- 100 % visual inspection;
- ammonia tightness test;
- dye penetrant inspection tests shall be performed each day on 5 % of each type of weld.

#### 9.3.2.3 Vapour container of single, double and full containment tanks

Inspections shall be performed in accordance with Table 16.

**Table 16 — Inspection of vapour barrier/liner**

| Part of tank | Type of assembly | Visual examination % | Dye penetrant examination % | Magnetic particle examination % | Vacuum box test % | Soap bubble examination % | Radiographic or ultrasonic examination % |
|---|---|---|---|---|---|---|---|
| Bottom plates | Butt weld | 100 | | | 100 | | |
| | Fillet weld | 100 | | | 100 | | |
| Bottom annular plates | Radial butt weld | 100 | | | 100 | | |
| Bottom to shell | Fillet weld | 100 | | | 100 | | |
| Shell | Butt weld | 100 | | | 100 | | see Table 18 |
| Compression area | Vertical and radial butt welds | 100 | 100 or | 100 | | | 25 |
| | Circumferential butt or fillet welds | 100 | 100 or | 100 | | 100 | |
| Roof | Fillet weld | 100 | | | | 100 | |
| | Butt weld | 100 | | | | 100 | |
| Nozzles in shell, bottom or roof | Longitudinal nozzle weld | 100 | | | | 100 | |
| | Flange to nozzle body | 100 | | | | 100 | |
| Nozzle to shell or insert and Nozzle with reinforcing plate | Nozzle to shell or insert weld | 100 | 100 or | 100 | | 100 | |
| | Nozzle to reinforcing plate | 100 | 100 or | 100 | | 100 | |
| | Reinforcing plate to shell | 100 | | | | 100 | |
| | Insert plate to shell | 100 | | | | | 100 |
| Temporary bracket | After removal of the bracket | 100 | 100 or | 100 | | | |
| Permanent bracket and pad plates | Fillet weld | 100 | 100 or | 100 | | | |
| Stiffening rings (Wind girder) | Main butt welds in stiffening rings | 100 | 100 or | 100 | | | |
| | Fillet welds to shell | 100 | | | | | |

**Table 17 — Extent of radiographic and ultrasonic examination of shell plate welds of vapour containers**

| Type of examination | Welds | | |
|---|---|---|---|
| | Vertical % | Tee % [a] | Horizontal % |
| Radiographic or ultrasonic | 5 | 25 | 1 |

[a] 50 % of the radiographs shall be taken with a 400 mm film positioned horizontally and 50 % with a film positioned vertically.

## 9.4 Visual inspection

A visual examination shall be conducted in accordance with EN 970 to check weld beads, shapes and dimensions, and to detect surface imperfections, both on welds and on the plates, nozzles and all accessories on the tank during its fabrication and erection.

It shall precede any other non-destructive examination or test.

## 9.5 Dye penetrant examination

Dye penetrant examination shall be conducted in accordance with EN 571-1.

All dye penetrant products used during a particular examination shall be compatible.

The contractor shall ensure that there is no risk of the products contaminating the items being examined and products which are to be stored.

## 9.6 Magnetic particle examination

The magnetic particle examination shall be conducted in accordance with EN 1290.

The method of magnetization used shall not involve feeding current into the part. A movable electromagnet with which the inspected part will form a closed magnetic circuit shall be employed.

The procedure and equipment used in the examination, and the methods used in the search for and elimination of imperfections shall be specified in a document available to the purchaser or the inspector.

The procedure shall indicate the surface quality required to enable correct interpretation to be made.

Magnetic particle inspection shall not be used on 9 % nickel steel.

## 9.7 Vacuum box examination

Vacuum box examination shall be carried in accordance with EN 1593.

The plates shall be clean and the welds shall be degreased and free of any slag or scale that might affect the quality of the examination.

The pumping system used shall guarantee a minimum vacuum of 300 mbar.

The soapy water used shall have:

- high wetting power;
- low viscosity;
- low surface tension;
- high foaming power.

## 9.8 Ammonia tightness test

An ammonia tightness test shall be carried out.

NOTE Until a European Standard becomes available NF A09-106 may be used.

## 9.9 Soap bubble examination

### 9.9.1 General

The soap bubble examination at pressure shall be conducted in accordance with EN 1593.

### 9.9.2 Shell to bottom with double fillet weld

For shell plates welded with double fillet welds to the bottom, air at a minimum pressure of 500 mbarg shall be introduced through a threaded hole provided for this purpose, into the space between the fillet welds, and shall be maintained at this pressure during the examination. Soapy water shall be applied by brush or spray to the welds. After the test, the threaded hole shall be sealed.

Care shall be taken to ensure that the test pressure between the two fillet welds is continuous around the whole perimeter of the tank shell.

### 9.9.3 Reinforcement plates

After suitable wetting of the reinforcement plate welds with soapy water, air, at a minimum pressure of 500 mbarg shall be introduced through the threaded hole. The holding time shall be not less than 30 s. After the test, the threaded hole shall be sealed.

### 9.9.4 Roof

Following the pneumatic test of the steel roof, the external fillet welds shall be wetted with soapy water. The design pressure shall be maintained during this examination.

## 9.10 Radiographic examination

The radiographic examination shall be conducted in accordance with EN 1435:1997, test category B, Table 1.

The radiation source shall be chosen depending on the thickness and areas of material to be inspected.

The films used shall be in accordance with EN 584-1 and EN 584-2.

The length of a radiographic film shall be 400 mm. The use of narrow films shall be allowed provided a strip of 10 mm of base metal, free of any film marking inscription, is visible at either side of the weld bead.

The Image Quality Indicator (IQI) shall be in accordance with EN 462-1 or EN 462-2.

The films of the weld shall be marked. The marks and positions shall be shown on a drawing, along with the identity of the welders and weld operators involved. Each film shall be marked with the tank reference and its position on the tank.

Films shall be kept in storage for interpretation for a minimum period of five years either by the contractor/erector or by the purchaser, as specified in the order.

## 9.11 Ultrasonic examination

Ultrasonic examination, used as a supplementary examination process, shall be conducted in accordance with EN 1714:1997.

Where UT examination is used in place of RT, only standardized, repeatable procedures, which produce a permanent record of the inspection, are acceptable. API 620:2004, Appendix U provides criteria that meet this requirement.

## 9.12 Acceptance criteria

### 9.12.1 Radiographic examination

Acceptance criteria for imperfections in weld seams shall be based on EN 12062:1997 and EN ISO 5817:2003 on the basis of quality level B.

### 9.12.2 Ultrasonic examination

Where UT inspection is used in place of RT, the rules of API 620:2004 shall be applied to this European Standard including the acceptance criteria for material types I through V. Where the above UT methods cannot be applied or where manual UT examination is required, manual procedures in accordance with EN 1714:1997 and acceptance levels in accordance with EN 1712:1997 shall be used for material types I through III. When manual UT examination of material types IV and V is required, special procedures shall be developed and verified.

NOTE For ultrasonic inspection, an EN standard, with fracture mechanics based acceptance criteria, is not yet available. API 620:2004 has added rules and fracture mechanics based acceptance criteria allowing ultrasonic inspection in place of radiography.

## 9.13 Unacceptable defects in horizontal welds

### 9.13.1 General

When unacceptable defect are found, weld repairs shall be carried out and the following additional inspections shall be performed.

### 9.13.2 Automatic welding

One further film shall be taken or 1 m of ultrasonic examination shall be carried out, each side of the original area.

If one of these additional films or ultrasonic examinations is rejected, then there shall be a total examination of the day's production by the machine in question.

#### 9.13.3 Manual welding

One further film shall be taken or 1 m of ultrasonic examination shall be carried out, each side of the original film.

If one of these additional films or ultrasonic examinations is rejected, then there shall be a total examination of the day's production by the welder in question.

### 9.14 Acceptable thinning after grinding

If surface imperfections have been detected, the imperfection shall be removed in its entirety by grinding and the surface shall be checked by a further examination.

Local thinning relative to the thickness shall be allowed provided the following two conditions are satisfied:

— final thickness of the plate shall not be less than 95 % of the ordered plate thickness over an area of 6*e* by 6*e* when *e* is the thickness of the plate;

— distance between any two areas affected by thinning shall be at least equal to the diameter of the circle circumscribing the largest area.

# Annex A
(informative)

# Actions on membrane

The following typical static, cyclic and accidental actions shown in Tables A.1 to A.3 should be considered:

**Table A.1 — Static action**

| | |
|---|---|
| Design pressure | Design liquid pressure plus design gas pressure |
| Thermal load | Load caused by temperature difference |
| Mechanical loads | Loads caused by external forces such as self weight, pre-stressing wall, concrete shrinkage etc. (all mechanical loads except temperature and pressure change) |

**Table A.2 — Cyclic action**

| | | |
|---|---|---|
| Liquid pressure | Difference between maximum and minimum liquid level | Number of cycles to be determined based on design lifetime of tank and estimated operating conditions |
| Thermal load | Variations of temperature during cool down.<br>Variation of temperature due to filling and emptying [a] | Number of cycles to be determined based on design lifetime of tank and estimated operating conditions |

NOTE The Owner may provide information on the operating conditions of the tank. When this is not done, then the design should be based on the following assumptions:

– one loading/unloading per week;

– decommissioning/commissioning once every two years.

[a] Curve giving the gas temperature distribution inside the tank should be submitted to the purchaser for approval.

**Table A.3 — Accidental action**

| | |
|---|---|
| Earthquake loads (no fatigue) | OBE<br>SSE |

# Annex B
(informative)

## Determination of the load and fatigue curves for membrane

The flowchart given in Figure B.1 should be followed.

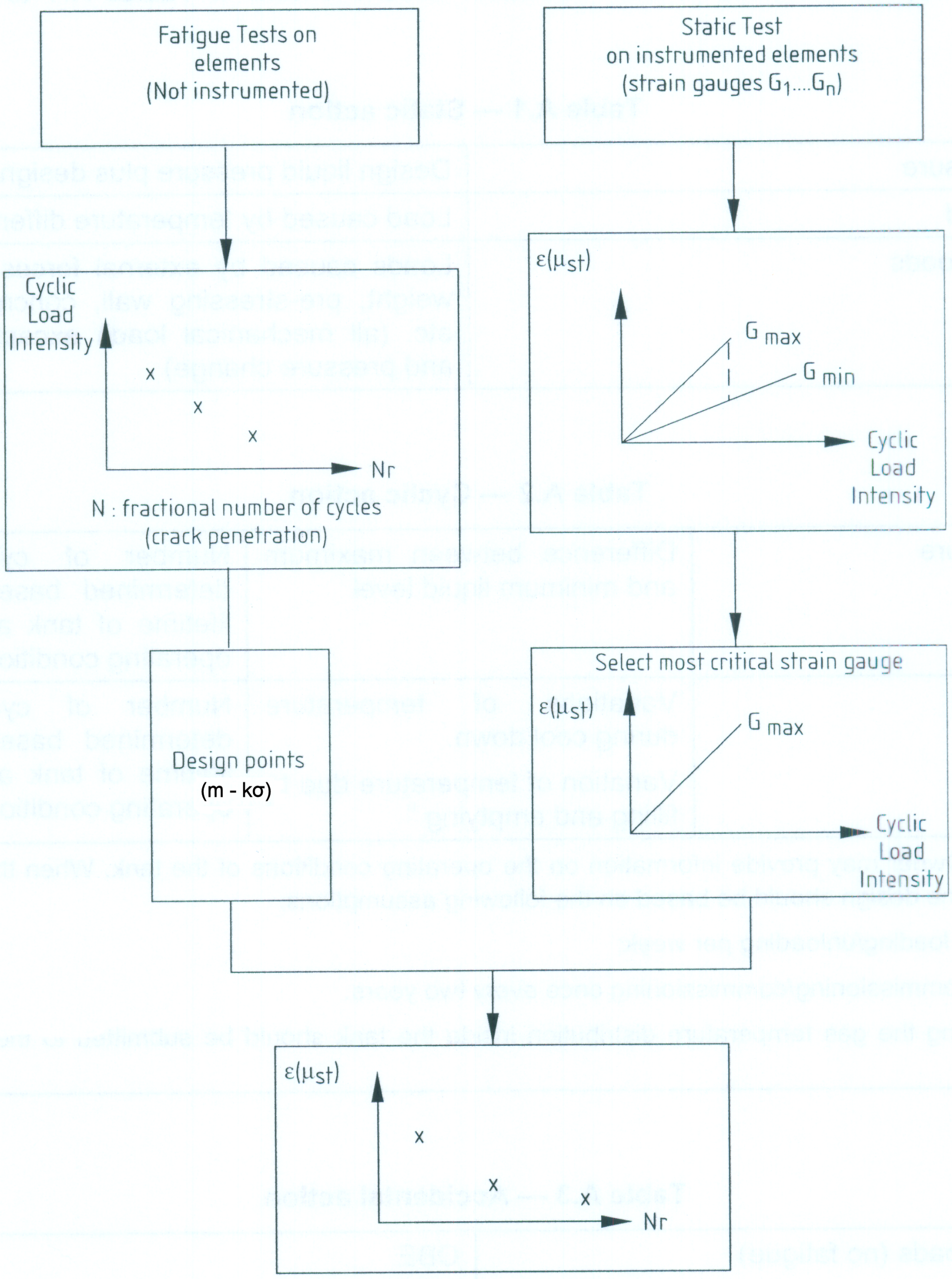



**Figure B.1 — Flowchart for membranes**

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