

PD CEN/TR 13445-102:2015



BSI Standards Publication

Unfired pressure vessels

Part 102: Example of application of vertical vessel with bracket supports

bsi.

...making excellence a habit.
AVA Documents™
Document Sharing Hub

National foreword

This Published Document is the UK implementation of CEN/TR 13445-102:2015.

The UK participation in its preparation was entrusted to Technical Committee PVE/1, Pressure Vessels.

A list of organizations represented on this committee can be obtained on request to its secretary.

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

© The British Standards Institution 2015. Published by BSI Standards Limited 2015

ISBN 978 0 580 87643 1

ICS 23.020.30

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 September 2015.

Amendments issued since publication

Date	Text affected
------	---------------

TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

CEN/TR 13445-102

May 2015

ICS 23.020.30

English Version

**Unfired pressure vessels - Part 102: Example of application of
vertical vessel with bracket supports**

Unbefeuerte Druckbehälter - Beispiel 2: Stehende Behälter
mit Tragpratzen

This Technical Report was approved by CEN on 10 February 2015. It has been drawn up by the Technical Committee CEN/TC 54.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

© 2015 CEN All rights of exploitation in any form and by any means reserved
worldwide for CEN national Members.

Ref. No. CEN/TR 13445-102:2015 E

AVA Documents
Document Sharing Hub

Contents

Page

Foreword.....	3
Introduction	4
3.1 Drawing of the vessel.....	5
3.2 Calculation model	6
3.3 Operating conditions.....	7
3.4 Comments on the operating conditions provided by the User.....	7
4.1 General.....	8
4.2 Is EN13445 applicable to the vessel?	8
4.3 Warning of Annex A of reference [1]	8
4.4 Prerequisites of Annex A of reference [1]	8
5.1 Permitted materials.....	10
5.2 Requirements given in 4.2 of reference [2]	11
5.3 Requirements given in 4.3 of reference [2]	11
5.4 Requirements given in 4.4 of reference [2]	11
5.5 Materials selected for the vessel example 2	12
6.1 General.....	15
6.2 Basic design.....	15
6.3 Fatigue calculations	15
6.4 Determination of test pressures of the vessel in Annex C.....	17
6.5 Determination of the deformation according to EN 13445-4 reference [4], Clause 9 in Annex C	19
6.6 Data used in example 2	19
6.7 Conditions of applicability of calculations	20
7.1 General.....	20
7.2 Material traceability	20
7.3 Manufacturing tolerances	20
7.5 Welding, as in 8 of reference [4].....	26
7.6 Manufacture and testing of welds – Production test, as in 8 of reference [4].....	26
7.7 Forming of pressure parts, as in 9 of reference [4].....	27
7.8 Post weld heat treatment (PWHT), as in 10 of reference [4].....	27
8.1 Generality	27
8.2 Non destructive testing, as in 4.3 of reference [5]	27
8.3 Determination of extent of non-destructive testing, as in 6.6.2 of reference [5].....	28
Annex A (informative) Drawing of example 2	29
Annex B (informative) Nameplate of example 2	30
Annex C (informative) Design calculation of example 2.....	31

Foreword

This document (CEN/TR 13445-102:2015) has been prepared by Technical Committee CEN/TC 54 “Unfired pressure vessels”, the secretariat of which is held by BSI.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

Introduction

Harmonized standards under Pressure Equipment Directive (97/23/EC) have been adopted over the past few years on the basis of mandate M 071. These standards give appropriate solutions for designing and building safe pressure equipment complying with the pressure equipment directives.

Although the main standards for the major product groups are now available, further action is needed to ensure a take-up by industry of these standards.

A recent public consultation on the use of EN Standards in the field of pressure equipment has shown that better knowledge of content and better usability are the more substantial aspects to encourage the use of the harmonized European standards (document CEN/PE/AN N 220).

The Pressure equipment Migration Help Desk, EN 13445/MHD, was created in August 2002 to give to the standard users a central point where raising questions and obtaining authorized answers. From the questions it received, the help desk has identified the publication of examples of application as a key issue and has developed rules of procedure for their publication as CEN deliverables (document CEN/PE/AN N 128).

Examples of application is an efficient way to help the standard user to correctly understand and apply the requirements of the standard and to be aware of the permissible deviations, possible alternatives, use of normative reference documents, etc. It can also assist training organization and software developers.

The project, in its efforts to broaden the application of the European Standards harmonized for PED, will support the actions of the European Commission in the field of safety of pressure equipment.

It will also promote the use of these European Standards on the global market.

1 Scope

This Technical Report details the design, manufacturing, inspection and testing of a steel vessel submitted to pressure cycles, using the EN 13445 series for "Unfired pressure vessels", to guide the user of these standards in sequential decision making, together with some alternative choices.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13445-1:2009_Issue 5, *Unfired pressure vessels – Part 1: General* [1]

EN 13445-2:2009_Issue 5, *Unfired pressure vessels – Part 2: Materials* [2]

EN 13445-3:2009_Issue 5, *Unfired pressure vessels – Part 3: Design* [3]

EN 13445-4:2009_Issue 5, *Unfired pressure vessels – Part 4: Fabrication* [4]

EN 13445-5:2009_Issue 5, *Unfired pressure vessels – Part 5: Inspection and testing* [5]

EN 10028-2:2003, *Flat products made of steels for pressure purposes – Part 2: Non-alloy and alloy steels with specified elevated temperature properties* [6]

3 The vessel and its operating conditions

3.1 Drawing of the vessel

The technical drawing of the vessel and vessel details is represented in Annex A:

A note in the introduction of EN 13445-1, clearly says that "In EN 13445 the term pressure vessel includes the welded attachments up to and including the nozzle flanges, screwed or welded connections".

The briefed lay-out is given as in Figure 1.

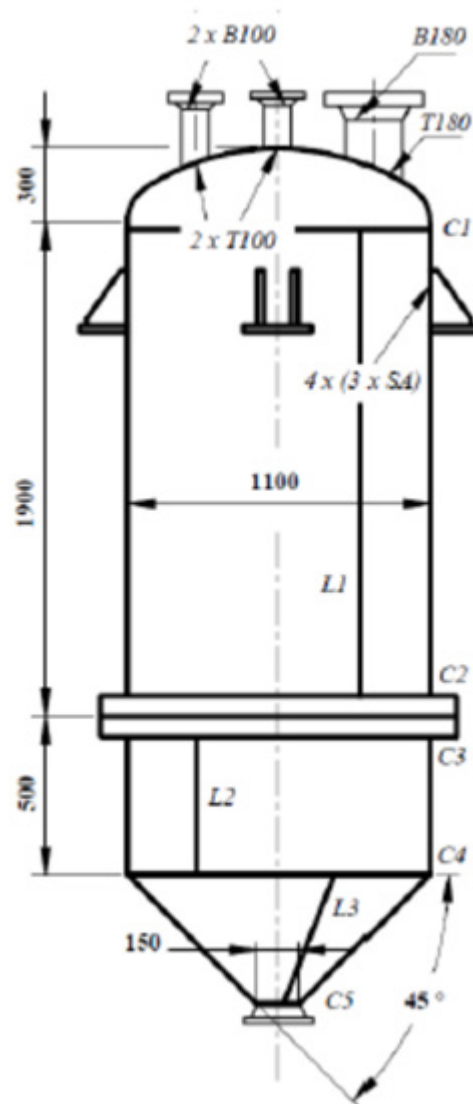


Figure 1 — Briefed lay-out

3.2 Calculation model

The calculation model is presented in 3D in Figure 2.



Figure 2 — Calculation model

3.3 Operating conditions

The general characteristics given by the user are reproduced below:

- a) content: gas group 1, density of 0,48;
- b) internal pressure: 18 bar / 0,5 bar;
- c) temperature: 20 °C/260 °C;
- d) number of expected full pressure cycles: 1200.

3.4 Comments on the operating conditions provided by the User

The gas group 1 is a dangerous fluid according to Council Directive 67/548/EEC of 27 June 1967 on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances.

See also:

<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31967L0548:en:NOT>

and further information on

<https://osha.europa.eu/nl/legislation/directives/exposure-to-chemical-agents-and-chemical-safety/osh-related-aspects/58>

In the contract 1 200 pressure cycles from 18 bar (1,8 MPa) to 0,5 bar (0,05 MPa) are expected. A design pressure of 1,8 MPa will not be used to avoid a short duration pressure surge at each cycle (See Pressure

Equipment Directive, *Annex I*, clause 2.11.2 *Pressure limiting devices*). Therefore the safety valve will be set at 2 MPa (pressure higher than 1,8 MPa + 10 %) and the design pressure of 2 MPa will be used in design calculations for static loadings.

4 Application of EN 13445-1 [1]

4.1 General

This part contains general information on the scope of the standard as well as terms, definitions, quantities, symbols and units which are applied throughout the standard.

Before designing and manufacturing the vessel according to the standard, the manufacturer shall verify the applicability of the standard EN 13445 and perform a number of prerequisites.

4.2 Is EN13445 applicable to the vessel?

The answer is yes, since the vessel does not belong to the vessels mentioned in Clause 1 of reference [1] which are:

- Vessels of riveted construction;
- Vessels of lamellar cast iron or any material not included in part 2, 6 or 8 of the standard;
- Multilayered, autofrettaged or pre-stressed vessels.

4.3 Warning of Annex A of reference [1]

The standard EN 13445 is harmonized under the Pressure Equipment Directive (97/23/EC). This means that if the vessel meets the requirements of this standard, it can be presumed to conform to those essential safety requirements which are listed in the Annexes ZA of each individual part.

In this connection, it should be understood that the standard is indivisible. The design and manufacturing of the vessel requires application of all relevant parts of the standard, in this case of Part 1 General [1], Part 2 Materials [2], Part 3 Design [3], Part 4 Fabrication [4] and Part 5 Inspection and testing [5], since the vessel is a steel vessel.

Part 7 and Part 9 are not mandatory parts in this sense.

4.4 Prerequisites of Annex A of reference [1]

4.4.1 Operating conditions

Operating conditions provided by the User will be used in the design calculations, but a design pressure of 2 MPa will be used in calculations for static loadings, as it is mentioned in 4.3.

4.4.2 Actions to be considered according to the list in 5.3.1 of EN 13445-3 reference [3]

- a) internal pressure;
- b) maximum static head of contained fluid;
- c) weight of the vessel;
- d) maximum weight of contents under operating conditions;

- e) weight of water under hydraulic pressure test conditions;
- f) wind, snow, and ice loading (not present);
- g) earthquake loading (negligible);
- h) other loads supported by or reacting on the vessel, including loads during transport and installation (negligible);
- i) stresses caused by supporting lugs, ring, girders, saddles, internal structures or connecting piping or intentional offsets of median lines on adjacent components. (Only stresses caused by bracket supports will be considered);
- j) shock loads caused by water hammer or surging of the vessel contents (not present);
- k) bending moments caused by eccentricity of the centre of the working pressure relative to the neutral axis of the vessel (not present);
- l) stresses caused by temperature differences including transient conditions and by differences in coefficients of thermal expansion (Not requested by the User);
- m) stresses caused by fluctuations of pressure, temperature and external loads (Stresses caused by fluctuations of pressure and temperature will be considered);
- n) stresses caused by the decomposition of unstable fluids (not present).

4.4.3 Classification of load cases

4.4.3.1 Normal load cases

Normal load cases are those acting on the pressure vessel during normal operation, including start-up and shutdown. They result of combination of actions mentioned in 5.3.2.

4.4.3.2 Exceptional load cases

Exceptional load cases are those corresponding to events of very low probability requiring the safe shutdown and inspection of the vessel or plant. No such exceptional load case is expected.

4.4.3.3 Testing load cases

Testing load cases include testing load cases for final assessment and testing load cases in service. Only the hydraulic test for final assessment will be considered.

4.4.4 The Category of the vessel as defined in the Pressure Equipment Directive (PED)

Taking into consideration:

- The maximum allowable pressure PS: 20 bar
- The fluid group: 1
- The volume of the vessel: 2.656 L
- The potential energy content product $PS.V = 53.120 \text{ bar.L}$

The vessel category is IV (See Figure 3, Excerpt from Table 1 of *Annex II* of the PED where the case is represented by a red dark dot or see Figure A-1 of CR 13445-7).

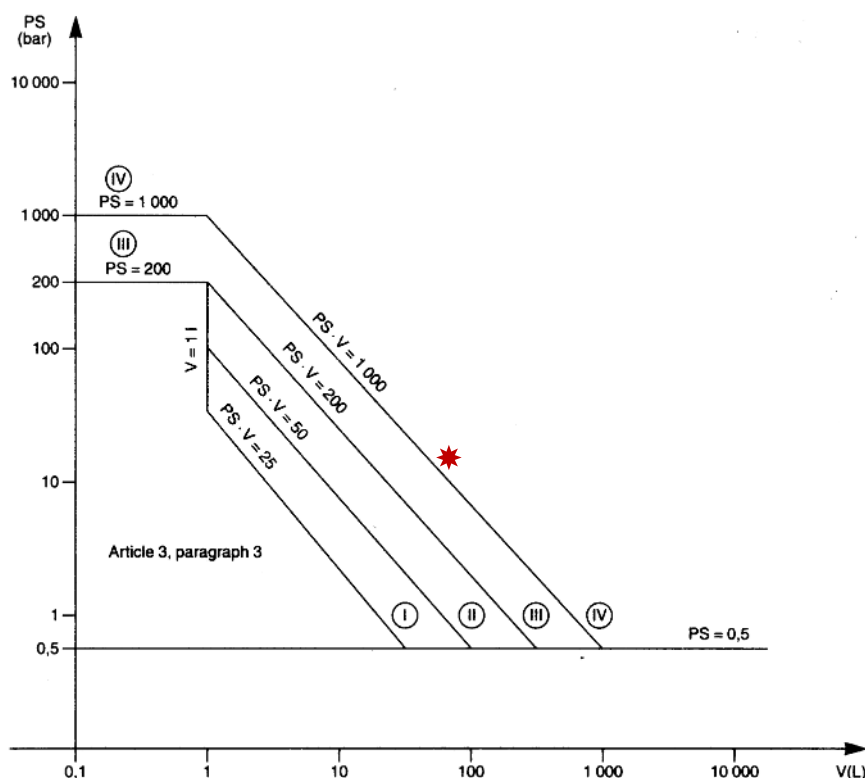


Figure 3 — Vessel category

4.4.5 The Conformity Assessment Module to be used

Applicable modules of Category IV are B+D, B+F, G, H1. Module G is used throughout this example (this is according to the drawing Example 2).

5 Application of EN 13445-2 [2]

5.1 Permitted materials

5.1.1 General

Clause **A.4 Materials** of reference [1] recalls the principles.

Specific requirements apply to materials for pressure-bearing parts. They are given in 4.1, 4.2, 4.3 and 4.4 of reference [2].

5.1.2 Requirements given in 4.1 of reference [2]

- Materials shall be selected to be compatible with anticipated fabrication steps and to be suitable for internal fluid and external environment
- Materials shall be accompanied by inspection documents in accordance with EN 10204:2004

NOTE 1 This is not properly speaking a design requirement, but a means to inspect material properties.

- Materials shall be free from surface and internal defects which can impair their intended usability
- Steels shall have a specified minimum elongation after fracture: 14 %
- Steels shall have a specified minimum impact energy measured on a Charpy V-notch impact test specimen greater or equal to 27 J for ferritic steels, etc.
- The chemical composition of ferritic steels intended for welding and forming shall not exceed 0,25 % C, 0,035 % P, 0,025 % S.

Only materials which are qualified for pressure equipment may be used. Qualification of materials can be made in three different ways:

- Materials from European harmonized Standards, see 4.3.1 of reference [2]. Certain materials supplied in accordance with European material Standards are accepted as qualified for use in pressure-bearing parts. These materials are enumerated in Table E.2-1 of reference [2].
- Materials with a European Approval for materials (EAM), see 4.3.2 of reference [2]. Materials with an EAM, which states that they can be used for products under the PED, are qualified for use in relevant products according to this standard. EAMs are published in the Official Journal, and the European Commission maintains a list of EAMs on their web site.

NOTE 2 This web site is presently accessible under the address

http://ec.europa.eu/enterprise/pressure_equipment/ped/materials/published_en.html.

- Materials with a Particular Material Appraisal (PMA), see 4.3.3 of reference [2]. Materials, which have been subject to a PMA are qualified. This appraisal is carried out by the manufacturer (and in certain cases checked by a Notified Body).

NOTE 3 The European Commission and Member States have in November 2006 agreed on "Guiding Principles for the contents of Particular Materials Appraisals". The document is published on:

http://ec.europa.eu/enterprise/pressure_equipment/ped/materials/index_en.html.

5.2 Requirements given in 4.2 of reference [2]

Materials for example 2 are high temperatures steels for which the requirements of **4.2.2 Design temperature above 20 °C** apply.

In **4.2.5** specific requirements are given for steels for **fasteners** (bolts, nuts, etc.).

5.3 Requirements given in 4.3 of reference [2]

4.3 addresses **Technical delivery conditions** for steels and welding consumables. For example 2, the **European standards** for plates, tubes, and forgings will be used. European standards will also be used for welding consumables.

Table E.2-1 of reference [2] provides an overview on materials for pressure purposes. This Table will be used for example 2.

5.4 Requirements given in 4.4 of reference [2]

4.4 addresses **Marking**. This marking ensures traceability between the product and the inspection documents.

NOTE Marking has no incidence on design calculations.

5.5 Materials selected for the vessel example 2

Characteristics of the steels, fasteners and gaskets selected for the vessel are given in Table 1 and reproduced in Annex C to this report.

P355 GH of the European harmonized standard EN 10028-2 [6] was selected for the shell (upper, lower), dished end and cone elements of the vessel (also support brackets). This steel was preferred to P295GH to have a smaller weight (approximately 15 % or 120 kg for all plate made materials) with a slightly higher price (approximate price difference in Western Europe is 100 € per metric ton).

P280 GH of the European harmonized standard EN 10222-2 was selected for the main flange upper and lower side.

Table 1 — Materials and main material characteristics in example 2

Vessel part	Material	Material designation	EN 13445-2 reference	Dimensions (mm) (see also Annex C)	Material group to CR ISO 15608	Main material characteristics				
						Tensile min/max MPa	Min yield MPa	Min elong A5 at room temp	Min impact energy KV, J at - 20 °C	Min impact energy KV, J at +20 °C
Cylindrical shell upper, lower	Ferritic steel plate for high temperature service	EN 10028-2 P355 GH (1.0473)	See Table E.2-1 of EN 13445-2	$e < 16$ mm $e_n = 12$ for lower part, $e_n = 10$ for upper part	1.2	510-650	355	20	27	40
Conical shell	Ferritic steel plate for high temperature service	EN 10028-2 P355 GH (1.0473)	See Table E.2-1 of EN 13445-2	$e < 16$ mm $e_n = 12$	1.2	510-650	355	20	27	40
Dished end	Ferritic steel plate for high temperature service	EN 10028-2 P355 GH (1.0473)	See Table E.2-1 of EN 13445-2	$e < 16$ mm $e_n = 14$	1.2	510-650	355	20	27	40
Main flange upper and lower side	Forging	EN 10222-2 P280 GH (1.0426)	See Table E.2-1 of EN 13445-2	$50,00 < t < 160$ mm $e_n = 95$ for lower part, $e_n = 103$ for upper part	1.2	490-610	280-305	22		27
Bolts(fasteners) main flange:	25CrMo4(+QT)	EN 10269 (dia.< 100 mm)	See Table E.2-1 of EN 13445-2	Number=68 M22x2,5 M22x2,5	— a)	800-950	Upper 0,2%600	15		27-32
Gasket	Spirally wound mineral filled stainless steel -Monel			Gasket parameters $m=3$, $y=69$ MPa	— a)					

Table 1 — Materials and main material characteristics in example 2 (*continued*)

Vessel part	Material group	Material designation	EN 13445-2 reference	Dimensions (mm) (see also Annex C)	Material group to CR ISO 15608	Main material characteristics				
						Tensile min/max MPa	Min yield MPa	Min elong A5 at room temp.	Min impact energy KV, J at -20°C	Min impact energy KV, J at +20°C
Nozzle N3 (DN200)	Standard XS	EN 10216-2 P265GH (1.0425)	See Table E.2-1 of EN 13445-2	Deb=219,10 eb=12,70	1.1	410-570	265 ^{b)}	23	28	—
Nozzle N4 DN150	Standard XS	EN 10216-2 (1.0425)	See Table E.2-1 of EN 13445-2	Deb=168.3 eb=10,97	1.1	410-570	265 ^{b)}	23	28	—
LWN Flange at N1/N2 (DN 100)	PN25	EN 10222-2 P280GH (1.0477)	See Table E.2-1 of EN 13445-2	25 bar rating 235/102,3 eb=19,85	1.2	460-580	280	21		27
Standard flange pos. at N3 (DN 200)	PN25	EN 10222-2 P280GH (1.0477)	See Table E.2-1 of EN 13445-2	25 bar rating 235/102,3 eb = 19,85	1.2	460-580	280	21		27
Standard flange pos. at N4 (DN 150)	PN25	EN 10222-2 P280GH (1.0477)	See Table E.2-1 of EN 13445-2	25 bar rating 235/102,3 eb = 28	1.2	460-580	280	21		27
Brackets and reinforcement plates	Ferritic steel plate for high temperature service	EN 10028 -2 P355 GH 1.0477 (1.0473)	See Table E.2-1 of EN 13445-2	T < 16 mm web e _n =15, base plate e _n =20 reinforcing plate e _n =10	1.2	510-650	355	20	27	40

a) not applicable

b) at 100 °C

6 Application of EN 13445-3 [3]

6.1 General

General definitions and general requirements are in Clauses 1 to 6 of **reference [3]**. Design requirements for the various components are contained in the relevant clauses of **reference [3]**. Specific design requirements for the simplified fatigue analysis are contained in Clause 17.

In this document, the principles of the calculations are presented. For details, it is recommended to examine the calculation sheets obtained by software. Each calculation sheet follows step by step the paragraphs of the relevant clause of reference [3].

The calculations sheets are gathered in pages 7 to 58 of Annex C to this report. Main results of the calculations are in pages 1 to 6.

6.2 Basic design

6.2.1 Verification of thicknesses

The first step is the verification of the thicknesses of the various components or parts composing the pressure vessel under the design loading:

$$P = 2 \text{ MPa}$$

$$T = 260 \text{ °C}$$

This is done successively for the cylindrical shells and their flanges, the ellipsoidal head and the attached nozzles, the conical shell, the cylindrical shell, the nozzle N4 and the brackets.

6.2.2 Determination of the maximum permissible pressure $P_{\max}$

Then the maximum permissible pressure defined in 3.16 is calculated for each component or vessel part using the formula given in the column entitled Maximum permissible pressure $P_{\max}$ of Table 17-1 of reference [3].

For example, for cylindrical shells $P_{\max}$ is given in Clause 7 of reference [3] by Formula (7.4.3).

As explained in 17.6.1, $P_{\max}$ will be used in the fatigue calculations.

6.3 Fatigue calculations

6.3.1 General

Fatigue calculations of example 2 are performed using the formulae of Clause 17 of **reference [3]**. This is done in six steps.

6.3.2 Determination of fatigue sensitive locations

These locations are:

- Welded zones
- Unwelded zones with stress concentration

For guidance, see Table 17-1 of reference [3].

6.3.3 Determination of pseudo-elastic stress range $\Delta\sigma$

$\Delta\sigma$ shall be calculated from the pressure range ΔP as follows:

$$\Delta\sigma = \frac{\Delta P}{P_{\max}} \cdot \eta \cdot f \quad (17.6-1)$$

where

- $P_{\max}$ is the maximum permissible pressure of the component or vessel part under consideration as defined in Clause 4, except for dished ends where a specific definition of $P_{\max}$ applies (see NOTE 2 of Table 17-1)
- f is the nominal stress of the component or vessel part under consideration, at calculation temperature.
- The value of η is obtained from Table 17-1 for each weld detail. It is an upper bound of the following ratio:

$$\frac{\text{maximum structural stress in detail under consideration under pressure } P_{\max}}{\text{nominal design stress at calculation pressure}}$$

Where $\Delta\sigma > 3f$, $\Delta\sigma$ shall be increased according to the rule given in 18.8 to account for elastic-plastic cyclic conditions.

6.3.4 Stress factors η and associated maximum permissible pressures

Stress factors η and associated permissible pressure are given in Table 17-1 for each component or vessel part. Stress factors η depend on shape imperfections.

6.3.5 Fictitious stress range

6.3.5.1 General

The fictitious stress range is used for determination of the allowable number of cycles. It includes the thickness and temperature corrections: C_e and C_T at a welded joint or vessel part and also the effective stress concentration factor K_f for notch effect at an unwelded part. These factors are defined in 17.6.2

6.3.5.2 At a welded joint

$$\Delta\sigma^* = \left(\frac{\Delta\sigma}{C_e \cdot C_T} \right) \quad (17.6-9)$$

6.3.5.3 At a unwelded region

$$\Delta\sigma^* = \left(\frac{\Delta\sigma}{C_e \cdot C_T} \right) \cdot K_f \quad (17.6.10)$$

6.3.6 Determination of the allowable number of cycles

6.3.6.1 General

The allowable number of cycles is obtained by introducing $\Delta\sigma^*$ in the appropriate fatigue design curve among the curves of Figure 17-4 Total fatigue damage index.

6.3.6.2 Classification of welded joints

The welded joints shall be allocated to the classes given in Table 17-4 which are testing group dependent. For example 2, only the column testing group 3 is to consider.

6.3.6.3 Unwelded regions

For unwelded regions, the class UW fatigue design curve in Figure 17-4 applies.

6.3.7 Fatigue results

All fatigue damage index computed in Annex C are acceptable since they are less than 1. The maximum value 0,157 is reached at the longitudinal butt weld of the shell upper portion.

There is no critical area as defined in 17.2.16.

NOTE This point is important for future Non-Destructive Testing. See Clause 8 of this report.

6.3.8 Total fatigue damage index

The total fatigue damage index is calculated using Formula (17.7-1)

$$D = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \text{etc...} = \sum_i^k \frac{n_i}{N_i} \quad (17.7-1)$$

6.3.9 Fatigue results

All fatigue damage index computed in Annex C are acceptable since they are less than 1. The maximum value 0,157 is reached at the longitudinal butt weld of the shell upper portion.

There is no critical area as defined in 17.2.16.

NOTE This point is important for future Non-Destructive Testing. See Clause 9 of this report.

6.4 Determination of test pressures of the vessel in Annex C

6.4.1 Principle

In **Annex C**, the test pressure of the vessel is computed, as explained in Clause 10 of **EN 13445-5**, reference [5]. It is the greater of:

$$P_t = 1,25 \cdot P_d \cdot \frac{f_a}{f_{T_d}} \quad (10.2.3.3.1-1)$$

or

$$P_t = 1,43 \cdot P_s \quad (10.2.3.3.1-2)$$

where:

P_t is the test pressure measured at the highest point of the chamber of the vessel in the test position;

P_d and T_d are the coincident design pressure and design temperature values for the maximum pressure load case;

P_s is the maximum allowable pressure of the vessel;

f_a is the nominal design stress for normal operating load cases of the material of the part under consideration at the test temperature;

f_{T_d} is the nominal design stress for normal operating load cases of the material of the part under consideration at temperature T_d ;

Since the ratio $\frac{f_a}{f_{T_d}}$ depends on the material of the part under consideration, the value $\frac{f_a}{f_{T_d}}$ to be used for

calculation of P_t shall not be less than the **smallest ratio** obtained considering the different materials of the main pressure bearing parts (e.g. shells, ends, tubesheets of heat exchangers, tube bundles, main flanges but **ignoring bolting associated to main flanges**). Main pressure bearing parts **do not include** pressure rated standard flanges and bolting designed without calculation according to the rules of 11.4.2 of EN 13445-3:2009.

6.4.2 Procedure followed in Annex C for example 2

The test pressure is determined in five steps:

6.4.2.1 Step 1

List the main components of the vessel using the criteria given above in 7.3.1 (e.g. shells, ends, etc.).

6.4.2.2 Step 2

Compute for each of them the pressure P_{t_1} using the formula $P_{t_1} = 1,25 \cdot P_d \cdot \frac{f_a}{f_{T_d}}$

6.4.2.3 Step 3

Compute the pressure $P_{t_2} = 1,43 \cdot P_s$

6.4.2.4 Step 4

Compute the test pressure of the component using the formula $P_t = \max(P_{t_1}, P_{t_2})$

6.4.2.5 Step 5

Compute the test pressure of the vessel: it is the smallest of the test pressures of the main components.

6.4.3 Results of the calculations

In page 3 of Annex C the test pressures of the main components are gathered. The test pressure of the vessel is the smallest of the test pressures of the main components.

For example 2, the test pressure of the vessel is equal to 2,95 MPa. It is limited to 2,95 MPa by the test pressure of the main flange which is greater than 2,86 MPa ($1,43 \cdot P_s$).

6.5 Determination of the deformation according to EN 13445-4 reference [4], Clause 9 in Annex C

The deformations of the cylindrical and conical shells and the deformation of the ellipsoidal head are computed in Annex C using formulae of Clause 9 of reference [4].

The most important deformation is in the ellipsoidal head manufactured in one piece: 21,6 %. Deformation is limited to 1 % in upper and lower cylindrical shells and to 7,4 % in the conical shell.

These values are important for heat treatment during manufacturing (see Clause 7 of this report).

6.6 Data used in example 2

6.6.1 Materials

Materials have been selected in Clause 5 of this document. For the main parts of the vessel, they belong to the material group 1.2.

A corrosion allowance $c = 1$ mm has been introduced for the inner wall. No corrosion allowance has been introduced for the outer wall.

6.6.2 Material nominal design stresses

Nominal design stresses have been determined from material data included in material standards using the formulae of Clause 6 of EN 13445-3, reference [3].

6.6.3 Selection of testing group and weld joint factor

Table 6.6.1-1 of EN 13445-5, reference [5], shows that the testing group 3B is applicable since the material group is 1.2.

For governing joints (See 5.6 of EN 13445-3), the corresponding weld joint factor is $z = 0,85$.

6.6.4 Design load case (determination of thicknesses), reference [3]

The following values have been used:

- The calculation pressure as defined in 5.3.10;
- The nominal design stress at calculation pressure as defined in 6.1.3;
- The analysis thickness as defined in 5.2.3;
- The joint efficiency factor $z = 0,85$.

NOTE As it is conservative, the possibility of using the higher yield stress R_e has not been utilized in this example.

6.6.5 Operating load case (simplified fatigue analysis), reference [3]

The following parameters have been used for the calculation of the stress range $\Delta\sigma$ of Formula (17.6.1) of Clause 17 and the calculation of the fictitious stress range:

- The pressure range given in the data of example 2;
- The maximum permissible pressure as defined in 3.16, using the analysis thickness $e_a = e_n - c$;
- The nominal stress of the component at calculation temperature;
- The η factor obtained from the Table 17-1 for the weld detail or vessel part taking in consideration the tolerances which shall not exceed those permitted in **reference [4]**.

6.6.6 Testing load case for final assessment, reference [5]

The following parameters have been used for the calculation of the test pressure:

- The nominal design stress of the material at test temperature;
- The nominal thickness (no corrosion allowance);
- The joint efficiency factor $z = 1$.

6.7 Conditions of applicability of calculations

The validation of the fatigue calculations necessitates the respect of the following limitations:

- Design requirements for welded joints of Annex A of reference [3] are satisfied (see Clause 7 of this document);
- Manufacturing tolerances of Clause 5 of reference [4] are satisfied (see Clause 7 of this document);
- For weld seams, the Manufacturer shall assume certain tolerances and derive the corresponding stress factors to be used for fatigue assessment (See Table 17-1.). Then the assumed tolerances should be checked and guaranteed after manufacturing (see 17.4.6 of reference [3]).
- Testing requirements given in reference [5] are satisfied (see Clause 8 of this document).

7 Application of EN 13445-4, reference [4]

7.1 General

Most of the requirements for manufacturing are to be found in EN 13445-4:2009 for pressure vessels and vessel parts made from steel.

7.2 Material traceability

The vessel manufacturer shall have and maintain an identification system for materials used in fabrication.

NOTE This is without influence on design calculations.

7.3 Manufacturing tolerances

7.3.1 Principle

For example 2, the designer shall verify that the tolerances used in design calculations are less than the maximum manufacturing tolerances permitted by Clause 5 of reference [4] for **dynamic and cyclic loads**.

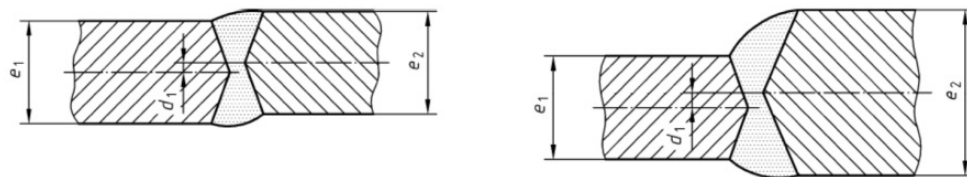
These tolerances can be inferior to those for predominantly non cyclic loads. This is the case for peaking on longitudinal butt welds.

7.3.2 Surface geometry of welds, as in 5.1 of reference [4]

The surface geometry of welded butt and fillet joints shall meet the requirements of EN 13445-5, reference [5].

7.3.3 Middle line alignment, as in 5.2 of reference [4]

Middle line alignment is represented on the Figure 4.



a) Middle line alignment d_1 at equal thickness $e_1 = e_2$ b) Middle line alignment d_1 at different thickness $e_1 \leq e_2$

Figure 5.2-1 — Middle line alignment d_1

Figure 4 — Abstract from EN 13445-5:2009

For longitudinal welds in the cylindrical shells and the conical shell, the maximum misalignment given by Table 5.2.1 is $e_1/10$.

For example 2, this means a maximum misalignment of 1,2 mm for the cylindrical lower shell. The value used in the fatigue calculation was **0,60 mm**.

For circular welds in the cylindrical shells and the conical shell, the maximum misalignment given by Table 5.2.3 is $e_1/10 + 1$.

For example 2, this means a maximum misalignment of 2,2 mm for the cylindrical lower shell. The value used in the fatigue design calculations was **0,60 mm**.

NOTE A similar approach has been applied to the other shells.

7.3.4 Surface alignment, as in 5.3 of reference [4]

The transition across the weld between parts of the same thickness shall be smooth and gradual with a slope of 1 in 4 over the width of the weld.

Where different thicknesses are being joined, a taper shall be produced in accordance with **Annex A** of **EN 13445-3**, reference [3]

NOTE In the calculations, it was supposed that these transitions had been done.