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Unfired pressure vessels - Part 3: Design

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Foreword

This document (EN 13445-3:2002, EN 13445-3:2002/A4:2005 and EN 13445-3:2002/A5:2006) has been prepared by Technical Committee CEN/TC 54 "Unfired pressure vessels", the secretariat of which is held by BSI.

EN 13445-3:2002 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2002, and conflicting national standards shall be withdrawn at the latest by November 2002. EN 13445-3:2002/A4:2005 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2006, and conflicting national standards shall be withdrawn at the latest by January 2006. EN 13445-3:2002/A5:2006 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2006, and conflicting national standards shall be withdrawn at the latest by August 2006.

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.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive 97/23/EC.

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

In this standard the Annexes A, B, C, E, F, G, J, P and Q are normative and the Annexes D, H, I, K, L, M, N and O are informative.

This European Standard consists of the following Parts:

— Part 1: General.

— Part 2: Materials.

— Part 3: Design.

— Part 4: Fabrication.

— Part 5: Inspection and Testing.

— Part 6: Requirements for the design and fabrication of pressure vessels and pressure parts constructed from spheroidal graphite cast iron.

CR 13445-7, *Unfired pressure vessels - Part 7: Guidance on the use of conformity assessment procedures.*

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 Part of this European Standard specifies requirements for the design of unfired pressure vessels covered by EN 13445-1:2002 and constructed of steels in accordance with EN 13445-2:2002.

EN 13445-5:2002, Annex C specifies requirements for the design of access and inspection openings, closing mechanisms and special locking elements.

NOTE This Part applies to design of vessels before putting into service. It may be used for in service calculation or analysis subject to appropriate adjustment.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies (including amendments).

EN 286-2:1992, *Simple unfired pressure vessels designed to contain air or nitrogen — Part 2: Pressure vessels for air braking and auxiliary systems for motor vehicles and their trailers.*

EN 288-8:1995, *Specification and approval of welding procedures for metallic materials — Part 8: Approval by a pre-production welding test.*

prEN 764-1:2001, *Pressure equipment — Terminology — Part 1: Pressure, temperature, volume, nominal size*

EN 764-2:2002, *Pressure equipment — Part 2: Quantities, symbols and units*

EN 764-3:2002, *Pressure equipment — Part 3: Definition of parties involved*

EN 1092, *Flanges and their joints. Circular flanges for pipes, valves, fittings and accessories, PN-designated.*

EN 1591-1:2001, *Flanges and their joints - Design rules for gasketed circular flange connections – Calculation method.*

EN 1708-1:1999, *Welding - Basic weld joint details in steel – Part 1: Pressurized components*

EN ISO 4014:2000, *Hexagon head bolts — Product grades A and B (ISO 4014:1999).*

EN ISO 4016:2000, *Hexagon head bolts — Product grade C (ISO 4016:1999).*

ISO 261:1998, *ISO general purpose metric screw threads — General plan.*

3 Terms and definitions

For the purposes of this Part of this European Standard, the terms and definitions given in EN 13445-1:2002, EN 13445-2:2002 and the following apply:

3.1
action
imposed thermo-mechanical influence which causes stress and/or strain in a structure, e.g. an imposed pressure, force, temperature

3.2
analysis thickness
effective thickness available to resist the loadings in corroded condition

9.2.9
set-on nozzle
nozzle which is welded only to the outside of the shell (see Figure 9.4-7)

9.2.10
shell
cylinder, sphere, cone or dished end

9.2.11
shell discontinuity
junction between any two of the following: cylinder, cylinder on a different axis, cone, dished head, spherical end, flange or flat head

9.2.12
small opening
isolated opening which satisfies the condition of equation (9.5-18)

9.3 Specific symbols and abbreviations

The following symbols, subscripts and abbreviations apply in addition to those in clause 4.

9.3.1 Subscripts

The following subscripts apply to the symbols listed in 9.3.2.

a refers to the analysis thickness of a component;

b refers to a nozzle or branch;

c refers to the mean value of a dimension;

e refers to the outside or external dimension;

i refers to the inside or internal dimension;

L refers to a ligament check;

O refers to an overall check;

o refers to a possible maximum or minimum value; among different values;

p refers to a reinforcing plate;

r refers to a reinforcing ring;

s refers to the shell;

w refers to the area of fillet weld which may *be* taken in account for reinforcement;

φ refers to additional pressure loaded area for an oblique nozzle connection;

1 refers to the first of two adjacent openings;

2 refers to the second of two adjacent openings.

9.3.2 Symbols

Symbol	Description	Unit
a	Distance taken along the mid-thickness of the shell between the centre of an opening and the external edge of a nozzle or a ring; or, if no nozzle or ring is present, *a* is the distance between the centre of the hole and its bore.	mm
a_1 , a_2	Values of *a* on the ligament side of the opening (Figures 9.6-2 and 9.6-3).	mm
a'_1 , a'_2	Values of *a* on the opposite side of the opening to the ligament (see Figure 9.6-5).	mm
Af	Stress loaded cross-sectional area effective as reinforcement.	mm^2
Af_{Ls}	Af of the shell contained along the length L_b (see Figures 9.6-1 to 9.6-4).	mm^2
Af_{Os}	Af of the shell contained along the length L_{b1} (see Figures 9.6-5 to 9.6-6).	mm^2
Af_w	Cross-sectional area of fillet weld between nozzle (or plate) and shell (see 9.5.2.3.3 and Figures 9.4-4 and 9.5-1).	mm^2
Ap	Pressure loaded area.	mm^2
Ap_{Ls}	Ap of the shell for the length L_b (see Figures 9.6-1 to 9.6-4).	mm^2
Ap_{Os}	Ap of the shell for the length L_{b1} (see Figures 9.6-5 to 9.6-6).	mm^2
Ap_φ	Additional pressure loaded area for oblique nozzle connection, function of angle φ (see Figures 9.5-1 to 9.5-2).	mm^2
d	Diameter (or maximum width) of an opening on shell without nozzle.	mm
d_{eb}	External diameter of a nozzle fitted in a shell.	mm
d_{ib}	Internal diameter of a nozzle fitted in a shell.	mm
d_{ip}	Internal diameter of a reinforcing plate.	mm
d_{er}	External diameter of a reinforcing ring.	mm
d_{ir}	Internal diameter of a reinforcing ring.	mm
d_{ix}	Internal diameter of extruded opening.	mm
D_c	Mean diameter of a cylindrical shell at the junction with another component.	mm
D_e	External diameter of a cylindrical or spherical shell, the cylindrical part of a torispherical or an elliptical dished end, a conical shell at the centre of an opening.	mm
D_i	Internal diameter of a cylindrical or spherical shell, the cylindrical part of a torispherical or an elliptical dished end, a conical shell at the centre of an opening.	mm
e_1	Minimum required thickness of a cylindrical shell at the junction with another component (see Figures 9.7-6 and 9.7-10).	mm
e_2	Minimum required thickness of a conical shell at the junction with a cylindrical shell (see Figures 9.7-6 and 9.7-10).	mm
e_b	Effective thickness of nozzle (or mean thickness within the external length l_{bo} or internal length l_{bio}) for reinforcement calculation.	mm
$e_{a,b}$	Analysis thickness of nozzle (or mean analysis thickness within the length l_b external or internal by the shell).	mm
$e_{a,m}$	Average thickness along the length l_o for reinforcing rings (see Equation (9.5-47))	mm

Symbol	Description	Unit
$e_{c,s}$	Assumed shell thickness of shell wall (see equation (9.5-2) for checking of reinforcement of an opening. The thickness may be assumed by designer between the minimum required shell thickness e and the shell analysis thickness $e_{a,s}$. This assumed thickness shall then be used consistently in all requirements. NOTE For $e_{c,s}$ the shell analysis thickness may be used always, but sometimes it may be advantageous to use a smaller assumed value to obtain smaller distances from adjacent shell discontinuities.	mm –
e_p	Effective thickness of reinforcing plate for reinforcement calculation.	mm
$e_{a,p}$	Analysis thickness of reinforcing plate.	mm
e_r	Effective thickness of reinforcing ring for reinforcement calculation.	mm
$e_{a,r}$	Analysis thickness of reinforcing ring.	mm
$e_{a,s}$	Analysis thickness of shell wall or mean analysis thickness within the length l'_s and excluding the thickness of the reinforcing pad if fitted.	mm
e'_s	Length of penetration of nozzle into shell wall for set-in nozzles with partial penetration.	mm
f_b	Nominal design stress of the nozzle material.	MPa
f_p	Nominal design stress of the reinforcing plate material.	MPa
f_s	Nominal design stress of shell material.	MPa
h	Inside height of a dished end, excluding cylindrical skirt.	mm
k	Reduction factor for f_s (used for overall check in 9.6.4).	_
l_b	Length of nozzle extending outside the shell.	mm
l'_b	Effective length of nozzle outside the shell for reinforcement	mm
l_{bi}	Length of nozzle extending inside the shell (i.e.: protruding nozzle)	mm
l'_{bi}	Effective length of nozzle inside the shell for reinforcement	mm
l_{bo}	Maximum length of nozzle outside the shell for reinforcement	mm
l_{cyl}	Length of cylindrical shell given by equation (9.7-3) and used in the strength assessment of a junction (see Figure 9.7-6) between a cylinder and: — the small end of a conical shell with same axis; — a spherical shell convex towards the cylinder; — a cylindrical shell with convergent axis.	mm
l_{con}	Length of conical shell given by equation (9.7-7) and used in the strength assessment of a junction between the small end of a cone and a cylindrical shell, (see Figure 9.7-6).	mm

Symbol	Description	Unit
l_n	Distance between the centre line of a shell butt-weld and the centre of an opening near or crossing the butt-weld.	mm
l_o	Maximum length of ring and shell wall in reinforcing rings for reinforcement	mm
l_p	Width of reinforcing plate.	mm
l_{pi}	Width of reinforcing plate between two adjacent openings (Figure 9.6-5).	mm
l'_p	Effective width of reinforcing plate for reinforcement.	mm
l_r	Width of reinforcing ring.	mm
l'_r	Effective width of reinforcing ring for reinforcement.	mm
l_s	Length of shell, from the edge of an opening or from the external diameter of a nozzle, to a shell discontinuity.	mm
		mm
l'_s	Effective length of shell for opening reinforcement.	mm
l_{so}	Maximum length of shell contributing to opening reinforcement, taken on the mean surface of the shell wall.	mm
L_b	Centre-to-centre distance between two openings or nozzles taken on the mean surface of the shell (see Figure 9.6-2).	mm
L_{b1}	Length of cross sectional area of shell including the whole section of two adjacent openings taken on the surface of the shell.	mm
r_{is}	Inside radius of curvature of the shell at the opening centre.	mm
R	Inside radius of a hemispherical end or of the crown of a torispherical end.	mm
w	Distance between an opening and a shell discontinuity (see Figures 9.7-1 to 9.7-11).	mm
w_{min}	Required minimum value for w.	mm
w_p	Minimum value for w which has no influence on l_s from shell discontinuities	mm
α	Half apex angle of a conical shell.	degrees
θ	For a nozzle having a longitudinal weld, angle between the plane containing the nozzle axis and the longitudinal weld line, and the plane containing the nozzle axis and the shell generatrix passing through the center of the opening.	degrees
φ	obliquity angle in the longitudinal or transversal cross-section, measured between the normal to the wall at the opening centre and the projection of the nozzle axis on the considered cross-section.	degrees
φ_e	Projection of φ in the plane in which L_b lies for ligament check of multiple openings.	radians
Φ	Angle between the centre-to-centre line of two openings or nozzles and the generatrix of a cylindrical or conical shell ($0° \leq \Phi \leq 90°$) (see Figure 9.6-1).	degrees
Ω	- for isolated openings, angle between shell generatrix and axis of major diameter - for adjacent openings, angle between the plane containing the opening centres and the axis of major diameter.	degrees

9.4 General

9.4.1 A shell containing an opening shall be adequately reinforced in the area adjacent to the opening. This is to compensate for the reduction of the pressure bearing section. The reinforcement shall be obtained by one of the following methods:

a) increasing the wall thickness of the shell above that required for an unpierced shell (see Figures 9.4-1 and 9.4-2);

b) using a reinforcing plate (see Figures 9.4-3 and 9.4-4);

c) using a reinforcing ring (see Figures 9.4-5 and 9.4-6);

d) increasing the wall thickness of the nozzle (see Figures 9.4-7 and 9.4-8) above that required for the membrane pressure stress;

e) using a combination of the above (see Figures 9.4-9 to 9.4-13).

9.4.2 The dimensions of the reinforcement area at an opening shall be assumed and the design shall be verified by the method laid down in the following subclauses.

The method is based on ensuring that the reactive force provided by the material is greater than, or equal to, the load from the pressure. The former is the sum of the product of the average membrane stress in each component and its stress loaded cross-sectional area (see Figures 9.4-1 to 9.4-13). The latter is the sum of the product of the pressure and the pressure loaded cross-sectional areas. If the reinforcement is insufficient, it shall be increased and the calculation repeated.

Reinforcement and strength may vary around the axis of an opening. Reinforcement shall be shown to be sufficient in all planes.

9.4.3 The design method is applicable when the opening is located at a minimum distance from a shell discontinuity. Rules for determining this minimum distance are given in 9.7.

9.4.4 Elliptical or obround openings

Elliptical or obround openings resulting from a circular nozzle oblique to the shell wall shall be calculated according to 9.5.2.4.5.

For all other elliptical or obround openings the ratio between the major and minor diameter shall not exceed 2.

9.4.4.1 Elliptical or obround openings reinforced by increased shell wall thickness, reinforcing plate or reinforcing ring (see 9.4.1 a), b) or c))

In cylindrical or conical shells the diameter d of the opening for reinforcing calculations shall be taken:

— along the generatrix of the shell for isolated openings

— in the plane containing the centres of the openings