10.7 Flat ends of non-circular or annular shape ................................................................. 145
11 Flanges ........................................................................................................................... 148
11.1 Purpose ...................................................................................................................... 148
11.2 Specific definitions .................................................................................................... 148
11.3 Specific symbols and abbreviations .......................................................................... 149
11.4 General ...................................................................................................................... 150
11.5 Narrow face gasketed flanges .................................................................................. 154
11.6 Full face flanges with soft ring type gaskets ............................................................. 169
11.7 Seal welded flanges .................................................................................................. 172
11.8 Reverse narrow face flanges ..................................................................................... 173
11.9 Reverse full face flanges .......................................................................................... 175
11.10 Full face flanges with metal to metal contact ......................................................... 179
12 Bolted domed ends ...................................................................................................... 182
12.1 Purpose ...................................................................................................................... 182
12.2 Specific definitions .................................................................................................... 182
12.3 Specific symbols and abbreviations .......................................................................... 182
12.4 General ...................................................................................................................... 182
12.5 Bolted domed ends with narrow face gaskets ......................................................... 182
12.6 Bolted domed ends with full face joints ................................................................... 184
13 Heat Exchanger Tubesheets ....................................................................................... 187
13.1 Purpose ...................................................................................................................... 187
13.2 Specific definitions .................................................................................................... 187
13.3 Specific symbols and abbreviations .......................................................................... 188
13.4 U-tube tubesheet heat exchangers ........................................................................... 190
13.5 Fixed tubesheet heat exchangers ............................................................................. 205
13.6 Floating tubesheet heat exchangers ........................................................................ 234
13.7 Tubesheet characteristic .......................................................................................... 253
13.8 Maximum permissible tube to tubesheet joint stress .............................................. 260
13.9 Maximum permissible longitudinal compressive stress for tubes ......................... 261
13.10 Design of tubesheet flange extension with a narrow face gasket ......................... 264
13.11 Design of tubesheet flange extension with a full face gasket ................................. 269
13.12 Special tube-to-tubesheet welded joints ............................................................... 272
14 Expansion bellows ...................................................................................................... 275
14.1 Purpose ...................................................................................................................... 275
14.2 Specific definitions .................................................................................................... 275
14.3 Specific symbols and abbreviations .......................................................................... 277
14.4 Conditions of applicability ...................................................................................... 278
14.5 U-shaped unreinforced bellows ............................................................................. 281
14.6 U-shaped reinforced bellows .................................................................................. 295
14.7 Toroidal bellows ...................................................................................................... 299b
14.8 Fabrication ............................................................................................................... 299h
14.9 Inspection and testing............................................................................................... 299i
14.10 Bellows subjected to axial, lateral or angular displacements ............................... 300
15 Pressure vessels of rectangular section ...................................................................... 306
15.1 Purpose ...................................................................................................................... 306
15.2 Specific definitions .................................................................................................... 306
15.3 Specific symbols and abbreviations .......................................................................... 306
15.4 General ...................................................................................................................... 308
15.5 Unreinforced vessels .............................................................................................. 308
15.6 Reinforced vessels ................................................................................................... 314
15.7 Openings .................................................................................................................. 323
16 Additional non-pressure loads .................................................................................. 325
16.1 Purpose ...................................................................................................................... 325
16.2 Specific definitions .................................................................................................... 325
16.3 Specific symbols and abbreviations .......................................................................... 326
16.4 Local loads on nozzles in spherical shells ............................................................... 328
16.5 Local loads on nozzles in cylindrical shells ............................................................. 338
16.6 Line loads .................................................................................................................. 349
16.7 Lifting lugs ............................................................................................................... 356
Foreword


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 and EN 13445-3:2002/A6:2006 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. EN 13445-3:2002/A8:2006 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2006, and conflicting national standards shall be withdrawn at the latest by October 2006. EN 13445-3:2002/A10:2008 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2007, and conflicting national standards shall be withdrawn at the latest by December 2007. EN 13445-3:2002/A16:2008 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2009, and conflicting national standards shall be withdrawn at the latest by June 2009.


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, O, R and S are informative.

This European Standard consists of the following Parts:

— Part 1: General.
— Part 2: Materials.
— Part 3: Design.
— Part 4: Fabrication.
— Part 6: Requirements for the design and fabrication of pressure vessels and pressure parts constructed from spheroidal graphite cast iron.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, 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 764-3:2002, Pressure equipment — Part 3: Definition of parties involved

EN 837-1, Pressure gauges – Part 1: Bourdon tube pressure gauges - Dimensions, metrology, requirements and testing

EN 837-3, Pressure gauges –Part 3: Diaphragm and capsule pressure gauges - Dimensions, metrology, requirements and testing

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


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

EN 10222-1:1998, Steel forgings for pressure purposes — Part 1: General requirements for open die forgings


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
22 Circular flat ends with radial reinforcement ribs

22.1 Purpose

The purpose of the rules in this Clause is to allow the design of circular flat ends reinforced by radial ribs, with or without uniformly distributed peripheral bending moment, subject to pressure.

The components considered in this Clause consist of a circular flat end, reinforced by radial uniformly spaced ribs; the height of the ribs is generally constant, however their profile may be slightly inclined at the outer edge (see Figures 22.2-1, 22.2-2, 22.2-3 and 22.2-4).

The ribs shall be connected with each other at the centre of the end; this may be obtained either by welding them together, or by welding them to a central ring or to a rigid plug. The number of the ribs should be neither smaller than 3 nor greater than 24.

These rules do not deal with the calculation for leak tightness of the connection between the end and the corresponding flange on the vessel; in case the leak tightness has to be assured, the required thickness of the end might be greater than the thickness required by the static calculation, at least in the area of the gasket and relevant bolting.

This kind of construction is not recommended in case of cyclic loadings or in case of external corrosion.

22.2 Specific definitions

The following definitions are in addition to those in Clause 3.

22.2.1 reinforcing rib
rectangular plate located along the radius of a circular flat end, located perpendicularly to its plane and welded to it from both sides

22.2.2 continuous weld
weld between the rib and the end, located on both sides of the rib, for its entire length

22.2.3 intermittent weld
weld between the rib and the end, located on both sides of the rib, composed by different segments interesting only a portion of its length.
Figure 22.2-1 Welded ends with ribs

Figure 22.2-2 Welded end with ribs (Ribs welded to a protruding shell)

Figure 22.2-3 Bolted end with ribs and additional peripheral bending moment
22.3 Specific symbols and abbreviations

The following symbols and abbreviations are in addition to those in clause 4.

- $d_1$: diameter of central plug or ring
- $d_2$: diameter subject to pressure
- $d_3$: diameter of bolt circle
- $d_4$: outside diameter of end
- $e$: thickness of end
- $e_R$: thickness of reinforcing ribs
- $e_C$: thickness of central circular ring
- $f$: nominal design stress of end at design temperature
- $f_R$: nominal design stress of rib at design temperature
- $f_B$: nominal design stress of bolts at design temperature
- $f_C$: nominal design stress of central ring at design temperature

**NOTE**  Design temperature means the temperature of the condition to be assessed (bolting-up, operating or testing).

- $g_o$: minimum required throat thickness of the weld between end and reinforcing rib
- $g_1$ $\ldots$ $g_i$: throat thicknesses of the intermittent welds between end and reinforcing ribs (Figure 22.7-1)
- $h$: height of reinforcing ribs
length of reinforcing ribs

\( l \)

in case of intermittent welds is the length of the most external weld between end and reinforcing rib

\( l_i \) lengths of the intermittent welds between end and reinforcing ribs

\( n_v \) number of reinforcing ribs

maximum allowable pressure in operating or testing conditions

\( p_A \)

spacing between two consecutive ribs calculated on the diameter \( d_2 \)

\( W \) total bolt load in the different conditions (bolting-up, operating and testing) as defined in Clause 11

\( z_R \) joint efficiency of the weld between the end and the reinforcing ribs

\( z_C \) joint efficiency of the weld in the central ring

\( \beta \) angle of the circular sectors free of openings

### 22.4 Ends without additional peripheral bending moment

#### 22.4.1 Maximum allowable pressure

The maximum allowable pressure shall be the smaller of the values calculated with the following equations:

\[
\begin{align*}
P_{\text{max}} &= \left( \frac{e}{C \cdot d_2} \right)^2 f \\
P_{\text{max}} &= \frac{0.25}{K} \left( \frac{h}{T} \right)^2 - u + \left( \frac{h}{T} - u \right)^2 + 4 \left( \frac{h}{T} \right)^2 f_R \left( \frac{e_R}{d_2} \right)
\end{align*}
\]

where \( C \) and \( K \) are taken from Figure 22.4-1 and 22.4-2 respectively, while \( u \) is equal to 0.5 for continuous welds between the end and the ribs; when these welds are intermittent as in Figure 22.7-1, and are composed by \( m \) segments having each one the length \( l_i \), \( u \) shall be calculated with the following equation:

\[
u = 0.9 - \frac{1}{2l} \sum_{i=1}^{m} l_i
\]

#### NOTE 1 The length \( l \) of the reinforcing ribs shall be extended, whenever possible, up to the external diameter \( d_4 \), in any case at least up to the diameter \( d_3 \).

#### NOTE 2 When a central ring as in Figure 22.2-4 is provided, this one shall comply with the provisions of Clause 7.4.2.
22.4.2 Minimum Dimensions

The minimum end thickness $e$ and the minimum height $h$ of the ribs shall be calculated with the following equations:

$$e = C \frac{P}{\sqrt{f}}$$  \hspace{1cm} (22.4-4)

$$h = 0.5 \frac{d_z}{d_z} \sqrt{Z + \frac{u}{Z}}$$  \hspace{1cm} (22.4-5)

where $Z$ is given by:

$$Z = \frac{2K d_z P}{f_R e_R}$$  \hspace{1cm} (22.4-6)

in the above equations $C$, $K$ and $u$ shall be determined according to the preceding paragraph.
22.5 Ends with additional peripheral bending moment

The minimum end thickness $e$ and the minimum height $h$ of the ribs shall be calculated with the following equations:

\[ e = C_0 \cdot d_2 \cdot \sqrt{\frac{P}{f}} \quad (22.5-1) \]

\[ h = 0.5 \cdot d_2 \cdot \sqrt{Z_0 \cdot \frac{Z_0 + u}{Z_0 + 1}} \quad (22.5-2) \]

where $Z_0$ is given by:

\[ Z_0 = \frac{2K_o \cdot d_2 \cdot P}{f_R \cdot \sigma_R} \quad (22.5-3) \]

In the above equations $u$ shall be determined with formula 22.4-3, while $C_0$ and $K_0$ shall be taken from Figures 22.5-1 and 22.5-2 after determining the parameter $x$ as follows:

\[ x = \frac{4W}{P \cdot d_2^2 \cdot \pi} \left( \frac{d_3 - d_2}{d_2} \right) \quad (22.5-4) \]
Figure 22.5-2 Factor $K_0$ for ends with peripheral bending moment

By the graph in Figure 22.5-1 it is possible to check if there is an advantage in increasing the number of ribs: for high values of $x$ the coefficient $C_0$ remains constant (it cannot be lower than the minimum values determined by the curve labelled with ‘S’); therefore a number of ribs higher than 5 is ineffective if $x \geq 0.25$, a number higher than 4 is ineffective if $x \geq 0.37$, a number higher than 3 is ineffective if $x \geq 0.55$.

NOTE 1 The first term of equation 22.5-4 is the ratio between the total bolt load and the total pressure load over the end, which is normally higher than 1 in operating and testing conditions (because the bolts shall develop a reaction higher than the pressure load in order to keep the gasket compressed); since the second term is normally much smaller than 1, the resulting values of $x$ in these conditions are generally lower than 0.6; for higher values of $x$ the ribs are not effective, and a normal unstayed flat end would be recommended.

NOTE 2 The above method is not adequate for the bolting-up condition, where the pressure is 0 and the value of $x$ would become infinite; in order to verify the end also in this condition an equivalent plate thickness shall be calculated with the formula:

$$e_{EQ} = \sqrt{\frac{e^3 + \frac{eR^2h^4}{t^2e} + \frac{eRh}{t} \left(4e^2 + 4h^2 + 6eh\right)}{e + h}}$$

(22.5-5)

where $t$ is given by:

$$t = \frac{\pi d_2}{n_v}$$

(22.5-6)

in the calculation of $e_{EQ}$ all the negative tolerances for corrosion and fabrication shall be taken into account.
The reinforced end is able to withstand the bolting-up load $W$ if:

$$e_{EQ} \geq \frac{3(d_3 - d_2)}{\pi d_2} \left(\frac{W}{f_{MIN}}\right)$$

(22.5-7)

In the above equation $f_{MIN}$ is the lower of the nominal design stress of the end and the nominal design stress of the ribs.

### 22.6 Openings

The openings shall be located at a reasonable distance from the ribs, the welds, the central radius of each sector and the periphery of the end; this condition is satisfied if the angle $\beta$ in Figure 22.6-1 complies with 22.6-1:

$$\beta \geq \frac{360}{8n_v}$$

(22.6-1)

If the above condition is verified, no additional calculation for opening reinforcement will be required; otherwise an alternative design method shall be used (e.g. Design by Analysis).

### 22.7 Welds

Continuous welds between end and reinforcing ribs shall be calculated with equation 22.7-1; if the welds are intermittent, the conditions provided by equations 22.7-2, 22.7-3 and 22.7-4 shall also be met.

$$g_o = \frac{0.3(2l + d_1)}{(n_v + 1)\left(\frac{h}{2l + d_1}\right)^2 + 0.6\left(\frac{h}{2l + d_1}\right)} \cdot \frac{P}{f_{MIN}z_R}$$

(22.7-1)

In the above equation $f_{MIN}$ is the lower of the nominal design stress of the end and the nominal design stress of the ribs.
\[ l_0 \geq 0.2l \quad (22.7-2) \]

\[ \sum_{i=1}^{m} (l_i a_i) \geq 2l_0 a_0 \quad (22.7-3) \]

**NOTE**  The throat thickness to be used in the above equation is the minimum thickness calculated by (22.7-1)

\[ l_0 \leq \sum_{i=1}^{m} l_i \leq 0.8l \quad (22.7-4) \]

When the throat thicknesses obtained by equation 22.7-1 for a continuous weld is very small, the use of intermittent welds can be considered, unless other considerations (e.g. cyclic loading) would not make it advisable. For fillet or partially penetrated welds without NDT the value of \( z_R \) shall not be taken higher than 0.7.

![Figure 22.7-1 Intermittent welds between end and reinforcing rib](image)

### 22.8 Central Ring

The central ring shall satisfy the following equation:

\[
P \leq P_{\text{max}} = \frac{4 \pi}{K n_v} \frac{e_c h^2}{d_3^3} \frac{z_c f_c}{1 + \left( \frac{h}{n_v e_c} \right)^2} \quad (22.8-1)\]

where \( K \) shall be taken from Figure 22.4-2 for ends without peripheral bending moment; for ends with peripheral bending moment, \( K \) shall be replaced by \( K_o \) to be taken from Figure 22.5-2.

When \( d_1 - 2e_c \geq \frac{2d_4}{n_v} \), the central portion of the end (with diameter \( d_1 - 2e_c \)) shall be verified according to the following formula:

\[
e = 0.41(d_1 - 2e_c) \sqrt{\frac{P}{f}} \quad (22.8-2)\]

For fillet or partially penetrated welds without NDT the value of \( z_C \) shall not be taken higher than 0.7.
Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of the EU Pressure Equipment Directive (97/23/EC)

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Pressure Equipment Directive (97/23/EC).

Once this standard is cited in the Official Journal of the European Communities under that Directive and has been implemented as a national standard in at least one Member State, compliance with the clauses of this standard given in Table ZA.1 confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding Essential Requirements of that Directive and associated EFTA regulations.

Table ZA.1 — Correspondence between this European Standard and Pressure Equipment Directive (97/23/EC)

<table>
<thead>
<tr>
<th>Clause(s)/subclause(s) of this EN</th>
<th>Essential Requirements (ERs) of Pressure Equipment Directive (97/23/EC)</th>
<th>Qualifying remarks/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>All clauses</td>
<td>2.2</td>
<td>Design for adequate strength</td>
</tr>
<tr>
<td>5</td>
<td>2.2</td>
<td>Calculation method</td>
</tr>
<tr>
<td>5</td>
<td>2.2.3</td>
<td>DBF</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>Quantitative requirements</td>
</tr>
<tr>
<td>7 to 19, 21 and 22</td>
<td>2.2.3</td>
<td>Calculation method - DBF</td>
</tr>
<tr>
<td>20</td>
<td>2.2.2 – 2.2.4</td>
<td>Design by experimental method</td>
</tr>
<tr>
<td>Annex A</td>
<td>2.2.3</td>
<td>Calculation method - DBF</td>
</tr>
<tr>
<td>Annex E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex J</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annex B, Annex C</td>
<td>2.2.3</td>
<td>Calculation method - Design by Analysis</td>
</tr>
</tbody>
</table>

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.