SLOVENSKI STANDARD
SIST EN 13445-3:2014/A8:2019

01-maj-2019

Neogrevane (nekurjene) tlačne posode - 3. del: Konstruiranje - Dopolnilo A8

Unfired pressure vessels - Part 3: Design

Unbefeuerte Druckbehälter - Teil 3: Konstruktion

Récipients sous pression non soumis à la flamme - Partie 3 : Conception

Ta slovenski standard je istoveten z: EN 13445-3:2014/A8:2019

ICS:

23.020.32 Tlačne posode Pressure vessels

SIST EN 13445-3:2014/A8:2019 **en,fr,de**

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 13445-3:2014/A8

April 2019

ICS 23.020.30

English Version

Unfired pressure vessels - Part 3: Design

Récipients sous pression non soumis à la flamme - Partie 3 : Conception

Unbefeuerte Druckbehälter - Teil 3: Konstruktion

This amendment A8 modifies the European Standard EN 13445-3:2014; it was approved by CEN on 19 November 2018.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for inclusion of this amendment into the relevant national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This amendment 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 CEN-CENELEC Management Centre has the same status as the official versions.

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, Serbia, 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: Rue de la Science 23, B-1040 Brussels

Ref. No. EN 13445-3:2014/A8:2019 E

Contents

Page

European foreword

This document (EN 13445-3:2014/A8:2019) has been prepared by Technical Committee CEN/TC 54 “Unfired pressure vessels”, 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 October 2019, and conflicting national standards shall be withdrawn at the latest by October 2019.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN 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(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of EN 13445-3:2014.

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, 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, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Modifications to Clause 2, Normative references

Add a footnote number “1” *after the reference* “EN 1991-1-4:2005” *and the corresponding footnote at the bottom of the page:*

“1 EN 1991-1-4:2005 is impacted by the stand-alone amendment EN 1991-1-4:2005/A1:2010 and the corrigendum EN 1991-1-4:2005/AC:2010.”.

In the reference to EN 1991-1-6, replace "EN 1991-1-6" *with* “EN 1991-1-6:2005”.

Add the following new reference at the appropriate place:

“EN 12195-1:2010, *Load restraining on road vehicles — Safety — Part 1: Calculation of securing forces*”.

2 Modification to 5.3.1, Actions

Add the following note at the end of the subclause:

“

NOTE The combination of actions is given in 5.3.2.4.”.

3 Addition of a new Subclause 5.3.2.4, Load combinations

Insert the following new subclause:

“

5.3.2.4 Load combinations

5.3.2.4.1 General

Load combinations of non-pressure loads in Table 5.3.2.4-1 are used in connection with calculations according to Clause 16 and Annex C (linear elastic behaviour). The basic calculation of pressure envelope by design pressures and temperatures shall be made before Clause 16 (or Annex C) calculations. The load combinations in Table 5.3.2.4-1 are minimum to be taken into account, if they are relevant. There may also be other loads.

5.3.2.4.2 Specific definitions

5.3.2.4.2.1 Dead loads

Maximum dead load (G_{max}) is the weight of the whole un-corroded vessel with all internals (trays, packing, etc.), attachments, insulation, fire protection, piping, platforms and ladders.

Corroded dead load (G_{corr}) is defined as G_{max} but with the weight of the corroded vessel.

Minimum dead load (G_{min}) is the weight of the un-corroded vessel during the installation phase, excluding the weight of items not already mounted on the vessel before erection (e.g. removable internals, platforms, ladders, attached piping, insulation and fire protection).

NOTE A scaffold is normally self-supported. In this case, the weight of the scaffold is not included in the vessel weight.

Transport dead load (G_{trans}) is the case, when vessel has the removable internals and insulation already mounted on the vessel in the workshop.

5.3.2.4.2.2 Live loads

Live loads (L) used in this clause are weight loads of the contents (fluids or solids in the bottom of the vessel, on trays and in packing) and traffic loads on platforms and ladders by personnel and machinery.

5.3.2.4.2.3 Wind loads

Wind loads (W) are horizontal global pressure loads caused by wind and acting on the projected area of the vessel and its attachments, as influenced by the force coefficients (see 22.4.4).

5.3.2.4.2.4 Earthquake loads

Earthquake loads (E) are quasi-static horizontal forces on the vessel sections caused by seismic accelerations at the base of vessel calculated by the “lateral force method of analysis” (see 22.4.5).

5.3.2.4.2.5 Forces from attached external piping

Reaction forces from attached external piping are forces resulting from weight (G), wind (W), earthquake (E) and other additional forces (F) as far as they influence the global equilibrium of the vessel (see 22.4.6 for columns).

NOTE Forces and moments on nozzles and supports on the vessel caused by attached external piping can act as internal and/or external loads. Internal loads are those that cause local loads only and have no influence on the global equilibrium because they are self-compensating. Furthermore, attached pipes can either load the vessel or restrain it depending on their layout. Consideration of these aspects is given in the recommendations in 22.4.6.

5.3.2.4.3 Specific symbols and abbreviations

The following specific symbols and abbreviations are used in Table 5.3.2.4-1 in addition to those in Clause 4:

E earthquake load (see 5.3.2.4.2.4)

F additional loads from piping (thermal expansion loads) (see 5.3.2.4.2.5)

$f_{B,op}$ nominal design stress for operation conditions for anchor bolts, see Formula (6.7–1)

G_{min} minimum dead loads (see 5.3.2.4.2.1)

G_{max} maximum dead loads (see 5.3.2.4.2.1)

G_{corr} corroded dead loads (see 5.3.2.4.2.1)

G_{trans} transport dead loads (see 5.3.2.4.2.1)

L live loads of each loading case (contents, etc.) (see 5.3.2.4.2.2)

P_i internal calculation pressure as defined in 5.3.10 for $P > 0$ (including hydrostatic pressure)

P_e external calculation pressure as defined in 5.3.10 for $P < 0$ (e.g. vacuum)

W wind load (Clause 22 and EN 1991-1-4)

$\sigma_{c,all}$ maximum allowable compressive stress for operation conditions in accordance with 16.14.8, with σ_e as defined in 8.4 and with a safety factor of 1,5 in Formula (16.14–29)

$\sigma_{c,all,test}$ maximum allowable compressive stress for test conditions in accordance with 16.14.8, with σ_e as defined in 8.4 and with safety factor 1,05 in Formula (16.14–29)

& operator which means: superposition of the different load types for the axial and lateral forces, the bending moments and the resulting shear and longitudinal stresses using the beam theory for non-pressure loads and the membrane theory for pressure loads

Table 5.3.2.4–1 — Load combinations

Load Case	Types of load included	Load combination including weighting factors	Allowable tensile stress for shells	Allowable compressive stress for shells	Allowable tensile stress for anchor bolts	Explanations
LC0	P_i, G_{max}	P_i and G_{max}	f_d	$\sigma_{c,all}$	$f_{B,op}$	Operation with internal pressure
LC1	P_i, G_{max}, L, F, W	$0{,}9 \cdot P_i$ and G_{max} and L and F and $1{,}1 \cdot W$[b]	f_d	$\sigma_{c,all}$	$f_{B,op}$	Operation with internal pressure and wind
LC2	P_e, G_{max}, L, F, W	P_e and G_{max} and L and F and $1{,}1 \cdot W$	f_d	$\sigma_{c,all}$	$f_{B,op}$	Operation with external pressure and wind
LC3	G_{max}, L, F, W	G_{max} and L and F and $1{,}1 \cdot W$	f_d	$\sigma_{c,all}$	$f_{B,op}$	Operation without pressure but with wind
LC4	G_{corr}, W	G_{corr} and $1{,}1 \cdot W$	f_d	$\sigma_{c,all}$	$f_{B,op}$	Shut down (no pressure, contents and thermal reactions)
LC5	G_{min}, W	G_{min} and $0{,}7 \cdot W$	f_d	$\sigma_{c,all}$	$f_{B,op}$	Installation
LC6	P_i, G_{max}, L, E	$0{,}9 \cdot P_i$ and G_{max} and L and E	f_{exp}[c]	$\sigma_{c,all,test}$	$1{,}2 \cdot f_{B,op}$	Operation with internal pressure and earthquake
LC7	P_e, G_{max}, L, E	P_e and G_{max} and L and E	f_{exp}[c]	$\sigma_{c,all,test}$	$1{,}2 \cdot f_{B,op}$	Operation with external pressure and earthquake
LC8	G_{max}, L, E	G_{max} and L and E	f_{exp}[c]	$\sigma_{c,all,test}$	$1{,}2 \cdot f_{B,op}$	Operation without pressure but with earthquake
LC9	P_{test}, G_{max}, L_{test}, W	P_{test} and G_{max} and L_{test} and $0{,}6 \cdot W$	f_{test}	$\sigma_{c,all,test}$	$f_{B,op}$	Test with test pressure, test filling and wind
LC10	G_{max}	$\geq 1{,}5 * G_{max}$	f_{test}	$\sigma_{c,all,test}$	N/A	Lifting (Crane)
LC11	G_{trans}	[a]	f_{test}	$\sigma_{c,all,test}$	N/A	Transport

[a] Transport load case shall be taken into account on basis of manufacturer's risk analysis for the vessel, if it proves to be critical for the vessel depending on the transport way (road, ship or train). If no special regulations are specified the following transport loads shall be considered: downwards: $1{,}4\ G_{trans}$, sidewards and upwards: $0{,}5 * G_{trans}$ driving

direction: 0,8*G_{trans}. The transport loads shall be agreed with transport company so that the transport will not damage the vessel (see EN 12195-1).
[b] Real operating pressure may be used instead of 0,9*P_i, if it is limited either naturally (e.g. steam temperature) or by safety related control and instrumentation system.
[c] After exceptional load case the vessel shall have re-inspection.

Remarks

For LC1 and LC2: If more than one combination of coincident design pressure and design temperature exists then all combinations shall be investigated. Alternatively a single combination of the maximum pressure and maximum temperature of all the cases may be used. It is not certain that the governing condition of coincident pressure and temperature is also governing for the load combinations.

For LC1 and LC6: The factor 0,9 is applied to the internal calculation pressure P_i because the internal operating pressure is normally 10 % below PS due to the pressure limiting device.

For LC3 and LC8: These load cases are not required when both loading cases LC1 and LC2, or LC6 and LC7 are applicable, i.e. internal and external pressure are applied.

For LC5: The wind load in this case depends on configuration at this time (with or without scaffold, platforms, insulation). The reduced factor for the wind load is in accordance with EN 1991-1-6:2005 for duration times < 12 months.

For LC9: The reduced factor for the wind load is in accordance with EN 1991-1-6:2005 for duration times < 3 d.

In calculation of allowable bending stress $\sigma_{b,all}$ for transport and lifting cases according to 16.6.6, the nominal design stress f_{test} can be used instead of f and K_2 shall be set equal 1,05.

The global effect of additional piping loads on shell stresses or anchoring shall be taken into account by designer, if considered relevant.”.

4 Addition of a new Subclause 6.7, Nominal design stress of anchor bolting

Insert the following new subclause:

"

6.7 Nominal design stress of anchor bolting

The nominal design stress for the anchor bolts for the operation condition shall be calculated as follows:

$$f_{B,op} = \min\left\{\frac{R_{p0,2/TB}}{1,65} ; \frac{R_{m/20}}{2,062\,5}\right\} \quad (6.7\text{-}1)$$

where

TB is design temperature for anchor bolts

NOTE In most cases the design temperature TB of the anchor bolts will be 20 °C and will generally be much lower than the design temperature of the vessel.".

5 Modifications to 8.4, General

Replace the first sentence of 8.4.2 with the following one:

"

8.4.2 For shells made in non-austenitic steels, excluding ferritic, martensitic and precipitation hardened stainless steels in material group 7 and austenitic ferritic stainless steels in material group 10, the nominal elastic limit shall be given by:".

Replace the first sentence of 8.4.3 with the following one:

"

8.4.3 For shells made in austenitic steels, ferritic, martensitic and precipitation hardened stainless steels and austenitic ferritic stainless steels, the nominal elastic limit shall be given by:".

6 Modification to Subclause 16.4, Local loads on nozzles in spherical shells

Replace Subclause 16.4 with the following one:

"

16.4 Local loads on nozzles in spherical shells

16.4.1 Purpose

This clause provides a method for the design of a spherical shell with a nozzle subjected to local loads and internal pressure.

In cases where the loads are unknown see Annex V.

16.4.2 Additional specific symbols and abbreviations

The following symbols and abbreviations are in addition to those in Clause 4 and 16.3:

d is mean nozzle diameter;

d_i is inside nozzle diameter;

d_e	is outside nozzle diameter;
d_2	is outside diameter of a reinforcing plate;
e_c	is analysis thickness of the combined shell and reinforcing plate;
e_{eq}	is equivalent shell thickness;
e_b	is nozzle thickness;
f_b	is allowable design stress of nozzle material;
F_S	is nozzle shear force;
F_Z	is axial nozzle force (positive when force is tensile or radially outwards);
$F_{Z,max}$	is maximum allowable axial force on the nozzle;
L	is width of the reinforcing plate;
M_B	is bending moment in the nozzle at the junction with the shell;
$M_{B,max}$	is maximum allowable bending moment in the nozzle at the shell junction;
M_Z	is torsional nozzle moment
R	is mean shell radius at the nozzle;
scf_P, scf_Z and scf_M	are stress factors due to pressure, nozzle axial load and moment respectively;
$\Delta\sigma_P$	is stress range due to pressure;
$\Delta\sigma_{FZ}$	is stress range due to axial nozzle load range;
$\Delta\sigma_{MB}$	is stress range due to moment range;
κ	is reinforcement rate factor;
λ_S	is a geometric parameter applicable to nozzles in spheres;
τ	is the shear stress in shell;
τ_F	is the shear stress in shell caused by shear force;
τ_Z	is the shear stress caused by torsional moment;
Φ	is load ratio.

16.4.3 Conditions of applicability

The following conditions apply:

a) $0{,}001 \le e_a / R \le 0{,}1$;

NOTE Values of $e_a / R < 0{,}001$ are acceptable provided that the shell wall deflection does not exceed half the wall thickness.

b) distances to any other local load in any direction shall be not less than $\sqrt{R \cdot e_c}$;

c) nozzle thickness shall be maintained over a distance of $l \ge \sqrt{d \cdot e_b}$.

16.4.4 Summary of design procedure

The design procedure is as follows:

a) calculate the basic dimensions e_c and L from the following:

1) at the nozzle outside diameter, when a reinforcing plate is fitted:

$$e_c = e_a + e_2 \cdot \min\left(\frac{f_2}{f};1\right) \quad (16.4\text{-}1)$$

2) at the outside edge ($d = d_2$) of a reinforcing plate, or when no reinforcing plate is fitted:

$$e_c = e_a \quad (16.4\text{-}2)$$

Width L of the reinforcing pad given by:

$$L = 0{,}5\left(d_2 - d_e\right) \quad (16.4\text{-}3)$$

b) calculate the maximum allowable individual loads (see 16.4.5);

c) check the load ratios and the interaction of the loads (see 16.4.6);

d) if no reinforcing plate or a reinforcing plate with $L \geq \sqrt{R\,(e_a + e_2)}$ is fitted, go to step 6;

e) calculate the maximum allowable individual loads at the edge of the reinforcing plate ($d = d_2$ and $e_c = e_a$), and check the load ratios and the interaction of the loads using 16.4.5 and 16.4.6;

f) calculate the equivalent shell thickness e_{eq} (see 16.4.7.2) and check the combined stress range (see 16.4.7) in cases only where one of the ranges for pressure ΔP, force ΔF_Z or moment ΔM_B (calculated according to Formulae (16.4-16) to (16.4-18) in 16.4.7.1) is larger than the extreme absolute values of the pressure P, the force F_Z or the moment M_B;

alternatively the combined stress range (see 16.4.7) may be applied when the external loads contain portions from thermal expansions of attached piping; in this case the checks of 16.4.5 and 16.4.6 may be applied for the pressure and the mechanical portions of the external loads only but the check of 16.4.7 shall be done for the ranges of the pressure and the combined mechanical and thermal loads;

g) check the nozzle longitudinal stresses (see 16.4.8);

h) if stresses or load ratios are excessive, increase the shell or nozzle thickness, or reduce the loads, and return to step 1.

Step f) shall be made only at the nozzle edge.

16.4.5 Maximum allowable individual loads

16.4.5.1 To determine the maximum allowable values of pressure, axial load and bending moment, which may be independently applied to a nozzle the following procedure shall be applied.

16.4.5.2 Determine the reinforcement rate factor:

$$\kappa = \min\left(\frac{2 f_b \cdot e_b}{f \cdot e_c}\sqrt{\frac{e_b}{d}}\ ;\ 1{,}0\right) \quad (16.4\text{-}4)$$

For the calculation of the allowable loads at the edge of the reinforcing plate or for a nozzle on a shell without an opening, the reinforcement factor κ is equal to 1.

NOTE A shell without opening is used for trunnion loading.

16.4.5.3 Determine λ_S:

$$\lambda_S = \frac{d}{\sqrt{R \cdot e_c}} \quad (16.4\text{-}5)$$

16.4.5.4 Calculate permissible pressure P_{max} from the general formula for reinforcement of isolated openings in Clause 9. It is reproduced here from 9.5.2 for convenience and the notation is in 9.3.

$$P_{max} = \frac{(Af_s + Af_w) \cdot f_s + Af_b \cdot f_{ob} + Af_p \cdot f_{op}}{\left(Ap_s + Ap_b + 0{,}5\ Ap_\phi\right) + 0{,}5\ (Af_s + Af_w + Af_b + Af_p)} \quad (16.4\text{-}6)$$

NOTE For application of this formula to different load cases, see 3.16, NOTE 1.

16.4.5.5 Determine the allowable axial nozzle load $F_{Z,max}$ either from Figure 16.4-1 or by calculation:

$$F_{Z,max} = f \cdot e_c^2 \left(1{,}82 + 2{,}4 \cdot \sqrt{1 + \kappa} \cdot \lambda_S + 0{,}91 \cdot \kappa \cdot \lambda_S^2\right) \quad (16.4\text{-}7)$$

Non-dimensional upper and lower bounds are given in Figure 16.4-1.

16.4.5.6 Either read the allowable bending moment $M_{B,max}$ from Figure 16.4-2 or calculate it using:

$$M_{B,max} = f \cdot e_c^2 \cdot \frac{d}{4}\left(4{,}9 + 2{,}0 \cdot \sqrt{1 + \kappa} \cdot \lambda_S + 0{,}91 \cdot \kappa \cdot \lambda_S^2\right) \quad (16.4\text{-}8)$$

Non-dimensional upper and lower bounds are given in Figure 16.4-2.

16.4.5.7 Shear stresses

$$\tau_F = \frac{2 F_S}{\pi \cdot d \cdot e_c} \quad (16.4\text{-}8a)$$

$$\tau_Z = \frac{2 M_Z}{\pi \cdot d^2 \cdot e_c} \quad (16.4\text{-}8b)$$

$$\tau = \left|\tau_F\right| + \left|\tau_Z\right| \quad (16.4\text{-}8c)$$

16.4.6 Combination of external loads and internal pressure

16.4.6.1 To determine the effects of the combination of pressure, axial load and bending moment acting simultaneously, the following procedure shall be applied.

If the axial force and the bending moment include portions from the thermal expansions of attached piping, the applied loads need not include the thermal expansion effects. In this case the stress ranges check Subclause 16.4.7 shall be applied taking into account the total loads including the thermal portions (see 16.4.4 step f), second paragraph).

16.4.6.2 Calculate the individual load ratios as follows:

$$\Phi_P = \frac{P}{P_{max}} \qquad (16.4\text{-}9)$$

$$\Phi_Z = \frac{F_Z}{F_{Z,max}} \qquad (16.4\text{-}10)$$

$$\Phi_B = \frac{M_B}{M_{B,max}} \qquad (16.4\text{-}11)$$

$$\Phi_T = \frac{2\tau}{f} \qquad (16.4\text{-}11a)$$

16.4.6.3 Check that each individual load ratio is limited as follows:

$$\left|\Phi_P\right| \le 1{,}0 \qquad (16.4\text{-}12)$$

$$\left|\Phi_Z\right| \le 1{,}0 \qquad (16.4\text{-}13)$$

$$\left|\Phi_B\right| \le 1{,}0 \qquad (16.4\text{-}14)$$

$$\left|\Phi_T\right| \le 1{,}0 \qquad (16.4\text{-}14a)$$

16.4.6.4 Check that the interaction of all the loads meets the following:

$$\sqrt{\left[\max\left(\left|\Phi_P + \Phi_Z\right|;\left|\Phi_Z\right|;\left|\Phi_P - 0{,}2\cdot\Phi_Z\right|\right) + \Phi_B\right]^2 + \left|\Phi_T\right|^2} \le 1{,}0 \qquad (16.4\text{-}15)$$

The above formula is based on a linear interaction of pressure and axial load with the bending moment and yields a conservative result. In specific cases design by analysis, as given in Clause 5, may show that a circular interaction is less conservative.

16.4.7 Stress ranges and their combination

16.4.7.1 From the minimum and maximum values of the pressure and local loads, determine the following load ranges:

$$\Delta P = \max\,(P\,;0) - \min\,(P\,;0) \qquad (16.4\text{-}16)$$

$$\Delta F_Z = \max\,(F_Z\,;0) - \min\,(F_Z\,;0) \qquad (16.4\text{-}17)$$

$$\Delta M_B = \max\,(M_B\,;0) - \min\,(M_B\,;0) \qquad (16.4\text{-}18)$$

$\Delta F_S = \max (F_S ; 0) - \min (F_S; 0)$ (16.6-18a)

$\Delta M_Z = \max (M_Z ; 0) - \min (M_Z ; 0)$ (16.4-18b)

16.4.7.2 At the nozzle edge only, calculate the equivalent shell thickness e_{eq} . This is equal to e_c unless a reinforcing plate of width $L < \sqrt{R\,(e_a + e_2)}$ is used, in which case e_{eq} is given by:

$$e_{eq} = e_a + \min\left(\frac{e_2 \cdot L}{\sqrt{R\left(e_a + e_2\right)}} ; e_2\right) \cdot \min\left(\frac{f_2}{f} ; 1\right) \quad (16.4\text{-}19)$$

16.4.7.3 Determine the following stresses:

Due to the pressure range:

$$\Delta\sigma_P = scf_P \left(\frac{\Delta P \cdot R}{2\, e_{eq}}\right) \quad (16.4\text{-}20)$$

Due to the range of the axial load:

$$\Delta\sigma_{FZ} = scf_Z \left(\frac{\Delta F_Z}{\pi \cdot d \cdot e_{eq}}\right) \sqrt{\frac{R}{e_{eq}}} \quad (16.4\text{-}21)$$

Due to the moment range:

$$\Delta\sigma_{MB} = scf_M \left(\frac{4\,\Delta M_B}{\pi \cdot d^2 \cdot e_{eq}}\right) \sqrt{\frac{R}{e_{eq}}} \quad (16.4\text{-}22)$$

where

scf_P, scf_Z and scf_M are taken from Figures 16.4–3 to 16.4–8.

NOTE The *scf* factors in Figures 16.4–3 to 16.4–8 are from BS 5500:1997, G2.5 (see L.2 - ref [6]).

Range of shear stresses

$$\Delta\tau_F = \frac{2\,\Delta F_S}{\pi \cdot d \cdot e_c} \quad (16.4\text{-}22a)$$

$$\Delta\tau_Z = \frac{2\,\Delta M_Z}{\pi \cdot d^2 \cdot e_c} \quad (16.4\text{-}22b)$$

$$\Delta\tau = \Delta\tau_F + \Delta\tau_Z \quad (16.4\text{-}22c)$$

16.4.7.4 The equivalent stress range shall be restricted as follows:

$$\sqrt{\Delta\sigma_P^2 + \left(\Delta\sigma_{FZ} + \Delta\sigma_{MB}\right)^2 + 4 \cdot \Delta\tau^2} \le 3 f \quad (16.4\text{-}23)$$