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Evrokod 3: Projektiranje jeklenih konstrukcij - 1-5. del: Elementi ploļ evinaste konstrukcije

Eurocode 3 - Design of steel structures - Part 1-5: Plated structural elements

Eurocode 3 - Bemessung und Konstruktion von Stahlbauten - Teil 1-5: Plattenförmige Bauteile

Eurocode 3 - Calcul des structures en acier - Partie 1-5: Plaques planes

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ICS:

91.010.30	Tehniļ ni vidiki	Technical aspects
91.080.10	Kovinske konstrukcije	Metal structures

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Eurocode 3 - Design of steel structures - Part 1-5: Plated structural elements

Eurocode 3 - Calcul des structures en acier - Partie 1-5: Plaques planes

Eurocode 3 - Bemessung und konstruktion von Stahlbauten - Teil 1-5: Plattenbeulen

This European Standard was approved by CEN on 13 January 2006.

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Content

Foreword

This European Standard EN 1993-1-5,, Eurocode 3: Design of steel structures Part 1.5: Plated structural elements, has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », the Secretariat of which is held by BSI. CEN/TC250 is responsible for all Structural Eurocodes.

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of an identical text or by endorsement, at the latest by April 2007 and conflicting National Standards shall be withdrawn at latest by March 2010.

This Eurocode supersedes ENV 1993-1-5.

According to the CEN-CENELEC Internal Regulations, the National Standard 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.

National annex for EN 1993-1-5

This standard gives alternative procedures, values and recommendations with notes indicating where national choices may have to be made. The National Standard implementing EN 1993-1-5 should have a National Annex containing all Nationally Determined Parameters to be used for the design of steel structures to be constructed in the relevant country.

National choice is allowed in EN 1993-1-5 through:

- 2.2(5)
- 3.3(1)
- 4.3(6)
- 5.1(2)
- 6.4(2)
- 8(2)
- 9.1(1)
- 9.2.1(9)
- 10(1)
- 10(5)
- C.2(1)
- C.5(2)
- C.8(1)
- C.9(3)
- D.2.2(2)

1 Introduction

1.1 Scope

(1) EN 1993-1-5 gives design requirements of stiffened and unstiffened plates which are subject to in-plane forces.

(2) Effects due to shear lag, in-plane load introduction and plate buckling for I-section girders and box girders are covered. Also covered are plated structural components subject to in-plane loads as in tanks and silos. The effects of out-of-plane loading are outside the scope of this document.

NOTE 1: The rules in this part complement the rules for class 1, 2, 3 and 4 sections, see EN 1993-1-1.

NOTE 2: For the design of slender plates which are subject to repeated direct stress and/or shear and also fatigue due to out-of-plane bending of plate elements (breathing) see EN 1993-2 and EN 1993-6.

NOTE 3: For the effects of out-of-plane loading and for the combination of in-plane effects and out-of-plane loading effects see EN 1993-2 and EN 1993-1-7.

NOTE 4: Single plate elements may be considered as flat where the curvature radius r satisfies:

$$r \geq \frac{a^2}{t} \quad (1.1)$$

where a is the panel width

t is the plate thickness

1.2 Normative references

(1) 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.

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

1.3 Terms and definitions

For the purpose of this standard, the following terms and definitions apply:

1.3.1
elastic critical stress
stress in a component at which the component becomes unstable when using small deflection elastic theory of a perfect structure

1.3.2
membrane stress
stress at mid-plane of the plate

1.3.3
gross cross-section
the total cross-sectional area of a member but excluding discontinuous longitudinal stiffeners

1.3.4
effective cross-section and effective width
the gross cross-section or width reduced for the effects of plate buckling or shear lag or both; to distinguish between their effects the word "effective" is clarified as follows:
"effective^{p}" denotes effects of plate buckling

"effective^{s}" denotes effects of shear lag
"effective" denotes effects of plate buckling and shear lag

1.3.5
plated structure
a structure built up from nominally flat plates which are connected together; the plates may be stiffened or unstiffened

1.3.6
stiffener
a plate or section attached to a plate to resist buckling or to strengthen the plate; a stiffener is denoted:

- longitudinal if its direction is parallel to the member;
- transverse if its direction is perpendicular to the member.

1.3.7
stiffened plate
plate with transverse or longitudinal stiffeners or both

1.3.8
subpanel
unstiffened plate portion surrounded by flanges and/or stiffeners

1.3.9
hybrid girder
girder with flanges and web made of different steel grades; this standard assumes higher steel grade in flanges compared to webs

1.3.10
sign convention
unless otherwise stated compression is taken as positive

1.4 Symbols

(1) In addition to those given in EN 1990 and EN 1993-1-1, the following symbols are used:

$A_{s\ell}$ total area of all the longitudinal stiffeners of a stiffened plate;

A_{st} gross cross sectional area of one transverse stiffener;

A_{eff} effective cross sectional area;

$A_{c,eff}$ effective^{p} cross sectional area;

$A_{c,eff,loc}$ effective^{p} cross sectional area for local buckling;

a length of a stiffened or unstiffened plate;

b width of a stiffened or unstiffened plate;

b_w clear width between welds;

b_{eff} effective^{s} width for elastic shear lag;

F_{Ed} design transverse force;

h_w clear web depth between flanges;

L_{eff} effective length for resistance to transverse forces, see 6;

$M_{f.Rd}$ design plastic moment of resistance of a cross-section consisting of the flanges only;

$M_{pl.Rd}$ design plastic moment of resistance of the cross-section (irrespective of cross-section class);

M_{Ed} design bending moment;

N_{Ed} design axial force;

t thickness of the plate;

V_{Ed} design shear force including shear from torque;

W_{eff} effective elastic section modulus;

β effective^s width factor for elastic shear lag;

(2) Additional symbols are defined where they first occur.

2 Basis of design and modelling

2.1 General

(1)P The effects of shear lag and plate buckling shall be taken into account at the ultimate, serviceability or fatigue limit states.

NOTE: Partial factors γ_{M0} and γ_{M1} used in this part are defined for different applications in the National Annexes of EN 1993-1 to EN 1993-6.

2.2 Effective width models for global analysis

(1)P The effects of shear lag and of plate buckling on the stiffness of members and joints shall be taken into account in the global analysis.

(2) The effects of shear lag of flanges in global analysis may be taken into account by the use of an effective^s width. For simplicity this effective^s width may be assumed to be uniform over the length of the span.

(3) For each span of a member the effective^s width of flanges should be taken as the lesser of the full width and $L/8$ per side of the web, where L is the span or twice the distance from the support to the end of a cantilever.

(4) The effects of plate buckling in elastic global analysis may be taken into account by effective^p cross sectional areas of the elements in compression, see 4.3.

(5) For global analysis the effect of plate buckling on the stiffness may be ignored when the effective^p cross-sectional area of an element in compression is larger than ρ_{lim} times the gross cross-sectional area of the same element.

NOTE 1: The parameter ρ_{lim} may be given in the National Annex. The value ρ_{lim} = 0,5 is recommended.

NOTE 2: For determining the stiffness when (5) is not fulfilled, see Annex E.

2.3 Plate buckling effects on uniform members

(1) Effective^p width models for direct stresses, resistance models for shear buckling and buckling due to transverse loads as well as interactions between these models for determining the resistance of uniform members at the ultimate limit state may be used when the following conditions apply:

- panels are rectangular and flanges are parallel;
- the diameter of any unstiffened open hole or cut out does not exceed 0,05b, where b is the width of the panel.

NOTE: The rules may apply to non rectangular panels provided the angle α_{limit} (see Figure 2.1) is not greater than 10 degrees. If α_{limit} exceeds 10, panels may be assessed assuming it to be a rectangular panel based on the larger of b_1 and b_2 of the panel.

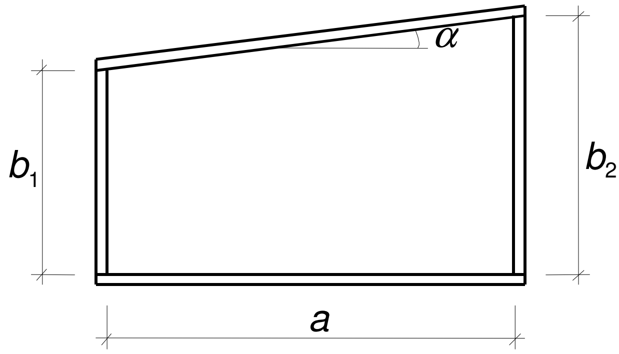


Figure 2.1: Definition of angle α

(2) For the calculation of stresses at the serviceability and fatigue limit state the effective^{s} area may be used if the condition in 3.1 is fulfilled. For ultimate limit states the effective area according to 3.3 should be used with β replaced by β_{ult}.

2.4 Reduced stress method

(1) As an alternative to the use of the effective^{p} width models for direct stresses given in sections 4 to 7, the cross sections may be assumed to be class 3 sections provided that the stresses in each panel do not exceed the limits specified in section 10.

NOTE: The reduced stress method is analogous to the effective^{p} width method (see 2.3) for single plated elements. However, in verifying the stress limitations no load shedding has been assumed between the plated elements of the cross section.

2.5 Non uniform members

(1) Non uniform members (e.g. haunched members, non rectangular panels) or members with regular or irregular large openings may be analysed using Finite Element (FE) methods.

NOTE 1: See Annex B for non uniform members.

NOTE 2: For FE-calculations see Annex C.

2.6 Members with corrugated webs

(1) For members with corrugated webs, the bending stiffness should be based on the flanges only and webs should be considered to transfer shear and transverse loads.

NOTE: For plate buckling resistance of flanges in compression and the shear resistance of webs see Annex D.

3 Shear lag in member design

3.1 General

(1) Shear lag in flanges may be neglected if $b_0 < L_e/50$ where b_0 is taken as the flange outstand or half the width of an internal element and L_e is the length between points of zero bending moment, see 3.2.1(2).

(2) Where the above limit for b_0 is exceeded the effects due to shear lag in flanges should be considered at serviceability and fatigue limit state verifications by the use of an effective[s] width according to 3.2.1 and a stress distribution according to 3.2.2. For the ultimate limit state verification an effective area according to 3.3 may be used.

(3) Stresses due to patch loading in the web applied at the flange level should be determined from 3.2.3.

3.2 Effective[s] width for elastic shear lag

3.2.1 Effective width

(1) The effective[s] width b_{eff} for shear lag under elastic conditions should be determined from:

$$b_{eff} = \beta\, b_0 \qquad (3.1)$$

where the effective[s] factor β is given in Table 3.1.

This effective width may be relevant for serviceability and fatigue limit states.

(2) Provided adjacent spans do not differ more than 50% and any cantilever span is not larger than half the adjacent span the effective lengths L_e may be determined from Figure 3.1. For all other cases L_e should be taken as the distance between adjacent points of zero bending moment.

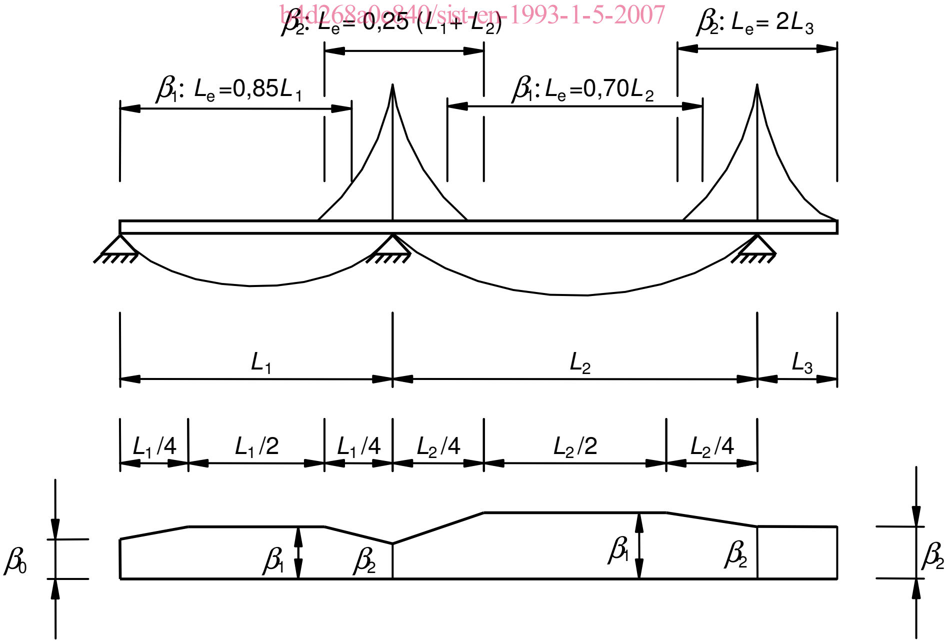
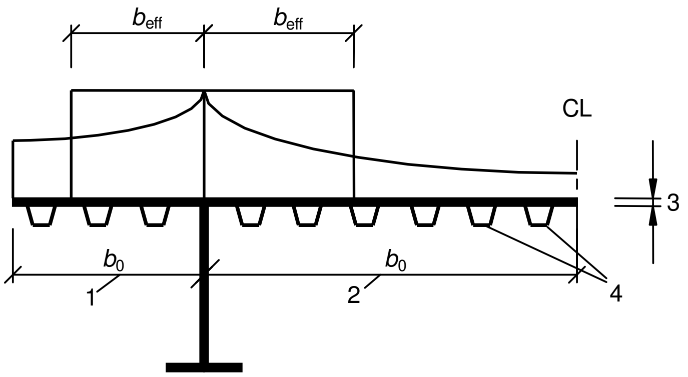


Figure 3.1: Effective length L_e for continuous beam and distribution of effective[s] width



1 for flange outstand
2 for internal flange
3 plate thickness t
4 stiffeners with $A_{s\ell} = \sum A_{s\ell i}$

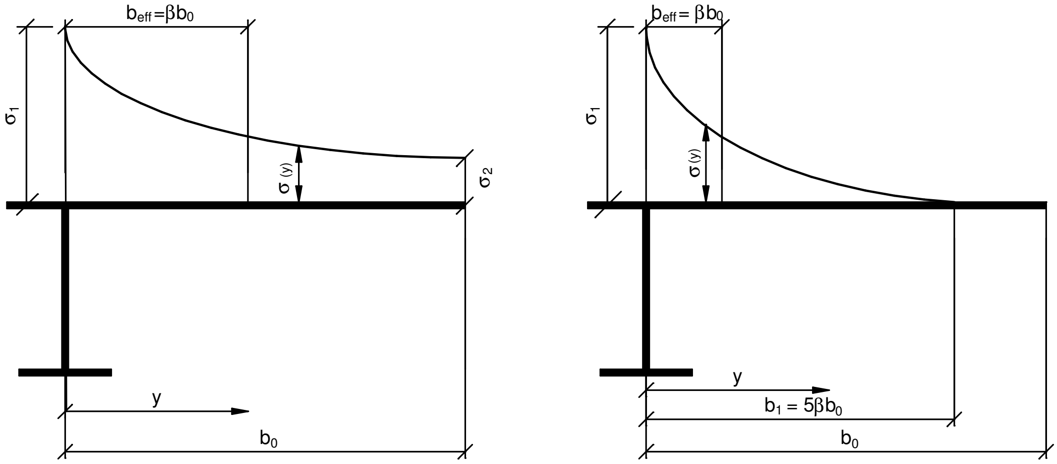
Figure 3.2: Notations for shear lag

Table 3.1: Effective[s] width factor β

κ	Verification	β – value
$\kappa \le 0{,}02$		$\beta = 1{,}0$
$0{,}02 < \kappa \le 0{,}70$	sagging bending	$\beta = \beta_1 = \dfrac{1}{1 + 6{,}4\,\kappa^2}$
	hogging bending	$\beta = \beta_2 = \dfrac{1}{1 + 6{,}0\left(\kappa - \dfrac{1}{2500\,\kappa}\right) + 1{,}6\,\kappa^2}$
$> 0{,}70$	sagging bending	$\beta = \beta_1 = \dfrac{1}{5{,}9\,\kappa}$
	hogging bending	$\beta = \beta_2 = \dfrac{1}{8{,}6\,\kappa}$
all κ	end support	$\beta_0 = (0{,}55 + 0{,}025 / \kappa)\,\beta_1$, but $\beta_0 < \beta_1$
all κ	Cantilever	$\beta = \beta_2$ at support and at the end
$\kappa = \alpha_0\, b_0 / L_e$ with $\alpha_0 = \sqrt{1 + \dfrac{A_{s\ell}}{b_0 t}}$ in which $A_{s\ell}$ is the area of all longitudinal stiffeners within the width b_0 and other symbols are as defined in Figure 3.1 and Figure 3.2.		

3.2.2 Stress distribution due to shear lag

(1) The distribution of longitudinal stresses across the flange plate due to shear lag should be obtained from Figure 3.3.



$\beta > 0{,}20:$

$\sigma_2 = 1{,}25\,(\beta - 0{,}20)\,\sigma_1$

$\sigma(y) = \sigma_2 + (\sigma_1 - \sigma_2)\,(1 - y/b_0)^4$

$\beta \le 0{,}20:$

$\sigma_2 = 0$

$\sigma(y) = \sigma_1 (1 - y/b_1)^4$

σ_1 is calculated with the effective width of the flange b_{eff}

Figure 3.3: Distribution of stresses due to shear lag

3.2.3 In-plane load effects

(1) The elastic stress distribution in a stiffened or unstiffened plate due to the local introduction of in-plane forces (patch loads), see Figure 3.4, should be determined from:

$$\sigma_{z,Ed} = \frac{F_{Ed}}{b_{eff}\left(t_w + a_{st,l}\right)} \tag{3.2}$$

with: $b_{eff} = s_e \sqrt{1 + \left(\frac{z}{s_e\, n}\right)^2}$

$$n = 0{,}636 \sqrt{1 + \frac{0{,}878\, a_{st,1}}{t_w}}$$

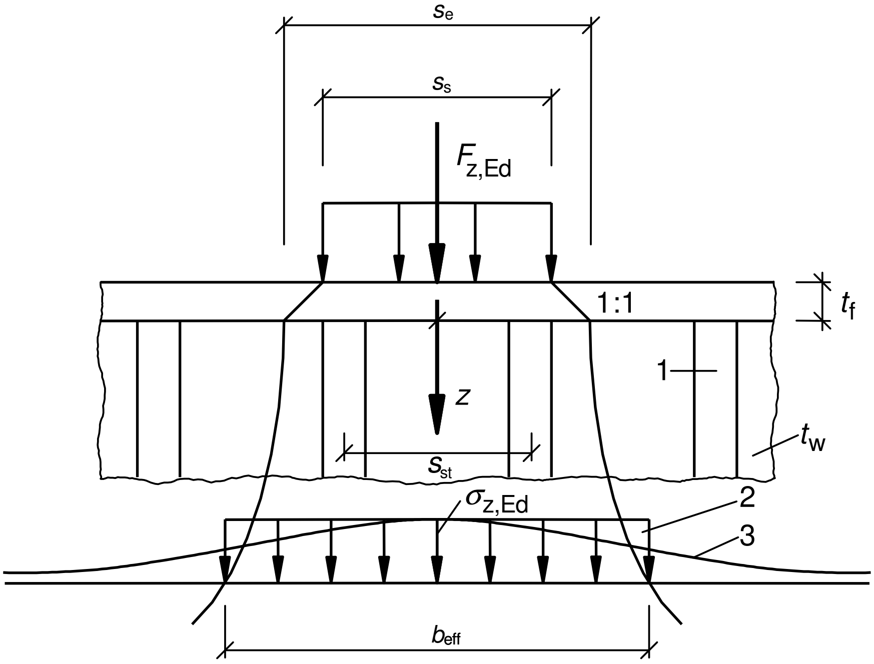
$$s_e = s_s + 2\, t_f$$

where $a_{\mathrm{st,1}}$ is the gross cross-sectional area of the stiffeners smeared over the length s_e. This may be taken, conservatively, as the area of the stiffeners divided by the spacing s_{st};

t_{w} is the web thickness;

z is the distance to flange.

NOTE: The equation (3.2) is valid when $s_{st}/s_e \le 0{,}5$; otherwise the contribution of stiffeners should be neglected.



1 stiffener
2 simplified stress distribution
3 actual stress distribution

Figure 3.4: In-plane load introduction

NOTE: The above stress distribution may also be used for the fatigue verification.

3.3 Shear lag at the ultimate limit state

(1) At the ultimate limit state shear lag effects may be determined as follows:

a) elastic shear lag effects as determined for serviceability and fatigue limit states,

b) combined effects of shear lag and of plate buckling,

c) elastic-plastic shear lag effects allowing for limited plastic strains.

NOTE 1: The National Annex may choose the method to be applied. Unless specified otherwise in EN 1993-2 to EN 1993-6, the method in NOTE 3 is recommended.

NOTE 2: The combined effects of plate buckling and shear lag may be taken into account by using A_{eff} as given by:

$$A_{eff} = A_{c,eff}\,\beta_{ult} \tag{3.3}$$

where $A_{c,eff}$ is the effective^p area of the compression flange due to plate buckling (see 4.4 and 4.5);

β_{ult} is the effective^s width factor for the effect of shear lag at the ultimate limit state, which may be taken as β determined from Table 3.1 with α_0 replaced by

$$\alpha_0^* = \sqrt{\frac{A_{c,eff}}{b_0\, t_f}} \tag{3.4}$$

t_f is the flange thickness.

NOTE 3: Elastic-plastic shear lag effects allowing for limited plastic strains may be taken into account using A_{eff} as follows:

$$A_{eff} = A_{c,eff}\,\beta^{\kappa} \geq A_{c,eff}\,\beta \tag{3.5}$$

where β and κ are taken from Table 3.1.

The expressions in NOTE 2 and NOTE 3 may also be applied for flanges in tension in which case $A_{c,eff}$ should be replaced by the gross area of the tension flange.

4 Plate buckling effects due to direct stresses at the ultimate limit state

4.1 General

(1) This section gives rules to account for plate buckling effects from direct stresses at the ultimate limit state when the following criteria are met:

a) The panels are rectangular and flanges are parallel or nearly parallel (see 2.3);

b) Stiffeners, if any, are provided in the longitudinal or transverse direction or both;

c) Open holes and cut outs are small (see 2.3);

d) Members are of uniform cross section;

e) No flange induced web buckling occurs.

NOTE 1: For compression flange buckling in the plane of the web see section 8.

NOTE 2: For stiffeners and detailing of plated members subject to plate buckling see section 9.

4.2 Resistance to direct stresses

(1) The resistance of plated members may be determined using the effective areas of plate elements in compression for class 4 sections using cross sectional data (A_{eff}, I_{eff}, W_{eff}) for cross sectional verifications and member verifications for column buckling and lateral torsional buckling according to EN 1993-1-1.

(2) Effective^{p} areas should be determined on the basis of the linear strain distributions with the attainment of yield strain in the mid plane of the compression plate.

4.3 Effective cross section

(1) In calculating longitudinal stresses, account should be taken of the combined effect of shear lag and plate buckling using the effective areas given in 3.3.

(2) The effective cross sectional properties of members should be based on the effective areas of the compression elements and on the effective^{s} area of the tension elements due to shear lag.

(3) The effective area A_{eff} should be determined assuming that the cross section is subject only to stresses due to uniform axial compression. For non-symmetrical cross sections the possible shift e_N of the centroid of the effective area A_{eff} relative to the centre of gravity of the gross cross-section, see Figure 4.1, gives an additional moment which should be taken into account in the cross section verification using 4.6.

(4) The effective section modulus W_{eff} should be determined assuming the cross section is subject only to bending stresses, see Figure 4.2. For biaxial bending effective section moduli should be determined about both main axes.

NOTE: As an alternative to 4.3(3) and (4) a single effective section may be determined from N_{Ed} and M_{Ed} acting simultaneously. The effects of e_N should be taken into account as in 4.3(3). This requires an iterative procedure.