

Eurocode 3 — Design of steel structures —

Part 1-3: General rules — Supplementary rules for cold-formed members and sheeting

ICS 91.010.30; 91.080.10

National foreword

This British Standard is the UK implementation of EN 1993-1-3:2006, incorporating corrigendum November 2009. It supersedes DD ENV 1993-1-3:2001 which is withdrawn. It partially supersedes BS 5950-5:1998, BS 5950-6:1995 and BS 5950-9:1994.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by CEN corrigendum November 2009 is indicated in the text by AC1 AC1.

The UK participation in its preparation was entrusted by Technical Committee B/525, Building and civil engineering structures, to Subcommittee B/525/31, Structural use of steel.

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

The structural Eurocodes are divided into packages by grouping Eurocodes for each of the main materials: concrete, steel, composite concrete and steel, timber, masonry and aluminium; this is to enable a common date of withdrawal (DOW) for all the relevant parts that are needed for a particular design. The conflicting national standards will be withdrawn at the end of the coexistence period, after all the EN Eurocodes of a package are available. Following publication of the EN, there is a period allowed for national calibration during which the National Annex is issued, followed by a coexistence period of a maximum three years. During the coexistence period Member States are encouraged to adapt their national provisions. Conflicting national standards will be withdrawn by March 2010 at the latest. Where a normative part of this EN allows for a choice to be made at national level, the range and possible choice will be given in the normative text, and a note will qualify it as a Nationally Determined Parameter (NDP). NDPs can be a specific value for a factor, a specific level or class, a particular method or a particular application rule if several are proposed in the EN. To enable EN 1993-1-3 to be used in the UK, the NDPs will be published in a National Annex, which will be made available by BSI in due course after public consultation has taken place.

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

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

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English Version

**Eurocode 3 - Design of steel structures - Part 1-3: General rules
- Supplementary rules for cold-formed members and sheeting**

Eurocode 3 - Calcul des structures en acier - Partie 1-3:
Règles générales - Règles supplémentaires pour les
profilés et plaques à parois minces formés à froid

Eurocode 3 - Bemessung und Konstruktion von
Stahlbauten - Teil 1-3: Allgemeine Regeln - Ergänzende
Regeln für kaltgeformte dünnwandige Bauteile und Bleche

This European Standard was approved by CEN on 16 January 2006.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard 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 Central Secretariat has the same status as the official versions.

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Foreword

This European Standard EN 1993-1-3, Eurocode 3: Design of steel structures: Part 1-3 General rules – Supplementary rules for cold formed members and sheeting, 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 1993-1-3.

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 1993-1-3

This standard gives alternative procedures, values and recommendations for classes with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1993-1-3 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 1993-1-3 through clauses:

- 2(3)P
- 2(5)
- 3.1(3) Note 1 and Note 2
- 3.2.4(1)
- 5.3(4)
- 8.3(5)
- 8.3(13), Table 8.1
- 8.3(13), Table 8.2
- 8.3(13), Table 8.3
- 8.3(13), Table 8.4
- 8.4(5)
- 8.5.1(4)
- 9(2)
- 10.1.1(1)
- 10.1.4.2(1)
- A.1(1), NOTE 2
- A.1(1), NOTE 3
- A.6.4(4)
- E(1)

1 Introduction

1.1 Scope

AC1 (1) EN 1993-1-3 gives design requirements for cold-formed members and sheeting. It applies to cold-formed steel products made from coated or uncoated hot or cold rolled sheet or strip, that have been cold-formed by such processes as cold-rolled forming or press-braking. It may also be used for the design of profiled steel sheeting for composite steel and concrete slabs at the construction stage, see EN 1994. The execution of steel structures made of cold-formed members and sheeting is covered in EN 1090. **AC1**

NOTE: The rules in this part complement the rules in other parts of EN 1993-1.

- (2) Methods are also given for stressed-skin design using steel sheeting as a structural diaphragm.
- (3) This part does not apply to cold-formed circular and rectangular structural hollow sections supplied to EN 10219, for which reference should be made to EN 1993-1-1 and EN 1993-1-8.
- (4) EN 1993-1-3 gives methods for design by calculation and for design assisted by testing. The methods for design by calculation apply only within stated ranges of material properties and geometrical proportions for which sufficient experience and test evidence is available. These limitations do not apply to design assisted by testing.
- (5) EN 1993-1-3 does not cover load arrangement for testing for loads during execution and maintenance.
- (6) The calculation rules given in this standard are only valid if the tolerances of the cold formed members comply with EN 1090-2

1.2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this European Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

However, parties to agreements based on this European Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

EN 1993	<i>Eurocode 3 – Design of steel structures</i>
Part 1-1 to part 1-12	
EN 10002	<i>Metallic materials - Tensile testing:</i>
Part 1:	<i>Method of test (at ambient temperature);</i>
EN 10025-1	<i>Hot-rolled products of structural steels - Part 1: General delivery conditions;</i>
EN 10025-2	<i>Hot-rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steels;</i>
EN 10025-3	<i>Hot-rolled products of structural steels - Part 3: Technical delivery conditions for normalized / normalized rolled weldable fine grain structural steels;</i>
EN 10025-4	<i>Hot-rolled products of structural steels - Part 4: Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels;</i>
EN 10025-5	<i>Hot-rolled products of structural steels - Part 5: Technical delivery conditions for structural steels with improved atmospheric corrosion resistance;</i>
EN 10143	<i>Continuously hot-dip metal coated steel sheet and strip - Tolerances on dimensions and shape;</i>
EN 10149	<i>Hot rolled flat products made of high yield strength steels for cold-forming:</i>
Part 2:	<i>Delivery conditions for normalized/normalized rolled steels;</i>
Part 3:	<i>Delivery conditions for thermomechanical rolled steels;</i>
EN 10204	<i>Metallic products. Types of inspection documents (includes amendment A 1:1995);</i>
EN 10268	<i>Cold-rolled flat products made of high yield strength micro-alloyed steels for cold forming - General delivery conditions;</i>

- EN 10292 *Continuously hot-dip coated strip and sheet of steels with higher yield strength for cold forming - Technical delivery conditions;*
- EN 10326 *Continuously hot-dip coated strip and sheet of structural steels - Technical delivery conditions;*
- EN 10327 *Continuously hot-dip coated strip and sheet of low carbon steels for cold forming - Technical delivery conditions;*
- EN-ISO 12944-2 *Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Part 2: Classification of environments (ISO 12944-2:1998);*
- EN 1090-2 *Execution of steel structures and aluminium structures
Part 2: Technical requirements for steel structures;*
- EN 1994 *Eurocode 4: Design of composite steel and concrete structures;*
- EN ISO 1478 *Tapping screws thread;*
- EN ISO 1479 *Hexagon head tapping screws;*
- EN ISO 2702 *Heat-treated steel tapping screws - Mechanical properties;*
- EN ISO 7049 *Cross recessed pan head tapping screws;*
- EN ISO 10684 *Fasteners – hot deep galvanized coatings*
- ISO 4997 *Cold reduced steel sheet of structural quality;*
- EN 508-1 *Roofing products from metal sheet - Specification for self-supporting products of steel, aluminium or stainless steel sheet - Part 1: Steel;*
- FEM 10.2.02 *Federation Europeenne de la manutention, Secion X, Equipment et procedes de stockage, FEM 10.2.02, The design of static steel pallet racking, Racking design code, April 2001 Version 1.02.*

1.3 Terms and definitions

Supplementary to EN 1993-1-1, for the purposes of this Part 1-3 of EN 1993, the following terms and definitions apply:

1.3.1

basic material

The flat sheet steel material out of which cold-formed sections and profiled sheets are made by cold-forming.

1.3.2

basic yield strength

The tensile yield strength of the basic material.

1.3.3

diaphragm action

Structural behaviour involving in-plane shear in the sheeting.

1.3.4

liner tray

Profiled sheet with large lipped edge stiffeners, suitable for interlocking with adjacent liner trays to form a plane of ribbed sheeting that is capable of supporting a parallel plane of profiled sheeting spanning perpendicular to the span of the liner trays.

1.3.5

partial restraint

Restriction of the lateral or rotational movement, or the torsional or warping deformation, of a member or element, that increases its buckling resistance in a similar way to a spring support, but to a lesser extent than a rigid support.

1.3.6

relative slenderness

A normalized non-dimensional slenderness ratio.

1.3.7

restraint

Restriction of the lateral or rotational movement, or the torsional or warping deformation, of a member or element, that increases its buckling resistance to the same extent as a rigid support.

1.3.8

stressed-skin design

A design method that allows for the contribution made by diaphragm action in the sheeting to the stiffness and strength of a structure.

1.3.9

support

A location at which a member is able to transfer forces or moments to a foundation, or to another member or other structural component.

1.3.10

nominal thickness

A target average thickness inclusive zinc and other metallic coating layers when present rolled and defined by the steel supplier (t_{nom} not including organic coatings).

1.3.11

steel core thickness

A nominal thickness minus zinc and other metallic coating layers (t_{cor}).

1.3.12

design thickness

the steel core thickness used in design by calculation according to 1.5.3(6) and 3.2.4.

1.4 Symbols

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

f_y	yield strength
f_{ya}	average yield strength
f_{yb}	basic yield strength
t	design core thickness of steel material before cold forming, exclusive of metal and organic coating
t_{nom}	nominal sheet thickness after cold forming inclusive of zinc and other metallic coating not including organic coating
t_{cor}	the nominal thickness minus zinc and other metallic coating
K	spring stiffness for displacement
C	spring stiffness for rotation

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

(3) A symbol may have several meanings in this part.

1.5 Terminology and conventions for dimensions

1.5.1 Form of sections

(1) Cold-formed members and profiled sheets have within the permitted tolerances a constant nominal thickness over their entire length and may have either a uniform cross section or a tapering cross section along their length.

(2) The cross-sections of cold-formed members and profiled sheets essentially comprise a number of plane elements joined by curved elements.

(3) Typical forms of sections for cold-formed members are shown in figure 1.1.

NOTE: The calculation methods of this Part 1-3 of EN 1993 does not cover all the cases shown in figures 1.1-1.2.

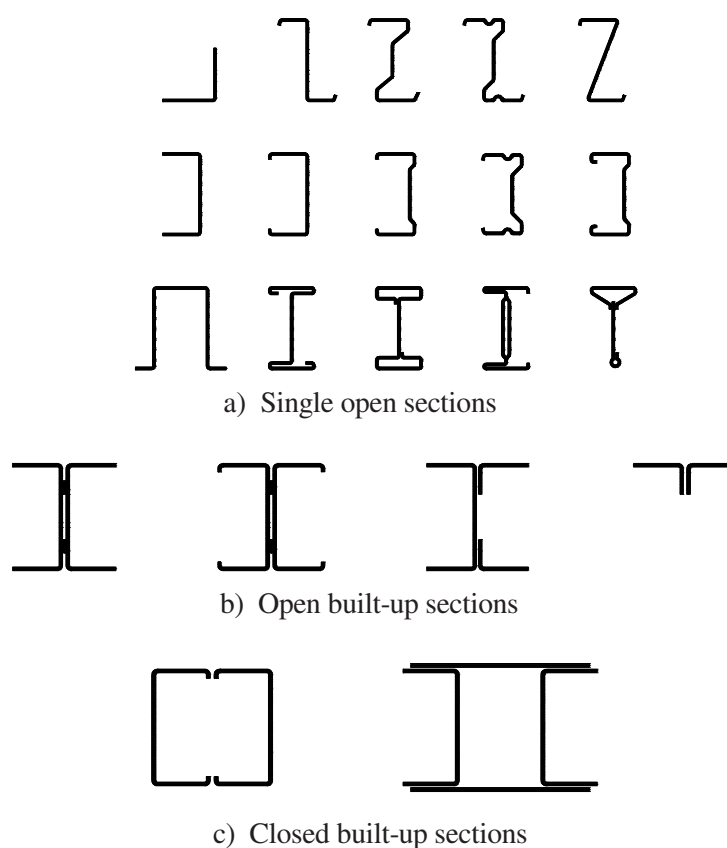
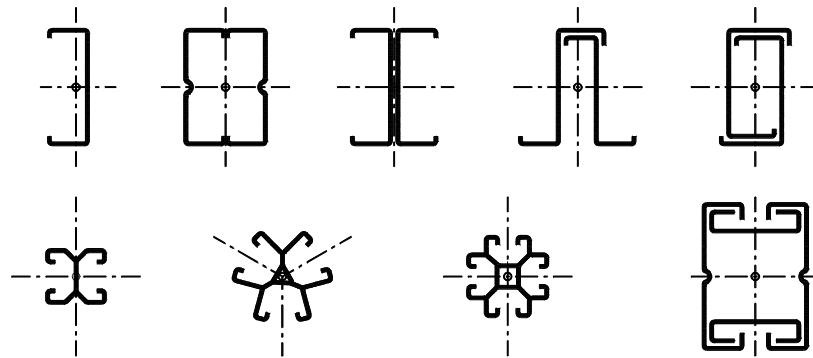


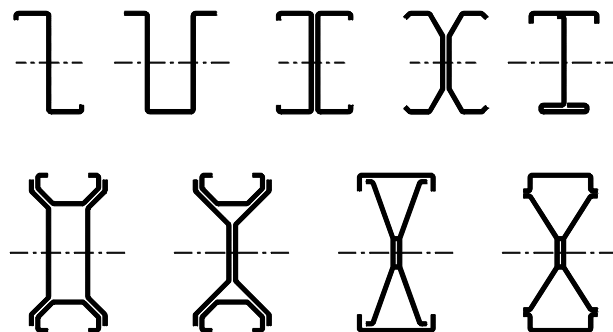
Figure 1.1: Typical forms of sections for cold-formed members

(4) Examples of cross-sections for cold-formed members and sheets are illustrated in figure 1.2.

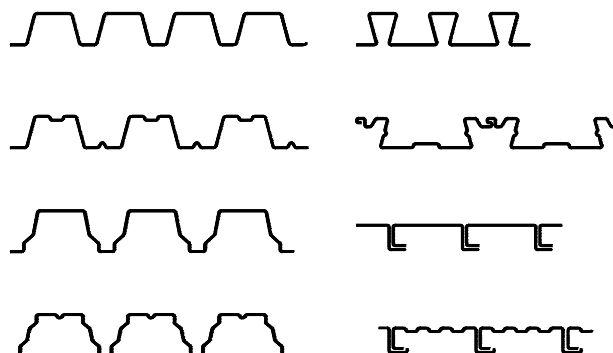
NOTE: All rules in this Part 1-3 of EN 1993 relate to the main axis properties, which are defined by the main axes $y - y$ and $z - z$ for symmetrical sections and $u - u$ and $v - v$ for unsymmetrical sections as e.g. angles and Zed-sections. In some cases the bending axis is imposed by connected structural elements whether the cross-section is symmetric or not.



a) Compression members and tension members



b) Beams and other members subject to bending



c) Profiled sheets and liner trays

Figure 1.2: Examples of cold-formed members and profiled sheets

(5) Cross-sections of cold-formed members and sheets may either be unstiffened or incorporate longitudinal stiffeners in their webs or flanges, or in both.

1.5.2 Form of stiffeners

(1) Typical forms of stiffeners for cold-formed members and sheets are shown in figure 1.3.

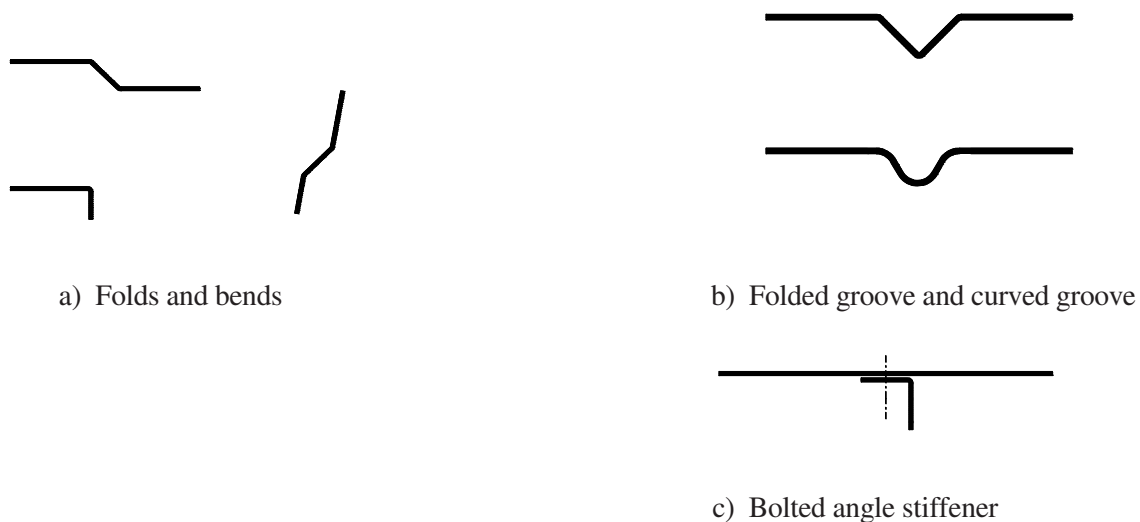


Figure 1.3: Typical forms of stiffeners for cold-formed members and sheeting

- (2) Longitudinal flange stiffeners may be either edge stiffeners or intermediate stiffeners.
(3) Typical edge stiffeners are shown in figure 1.4.



Figure 1.4: Typical edge stiffeners

- (4) Typical intermediate longitudinal stiffeners are illustrated in figure 1.5.

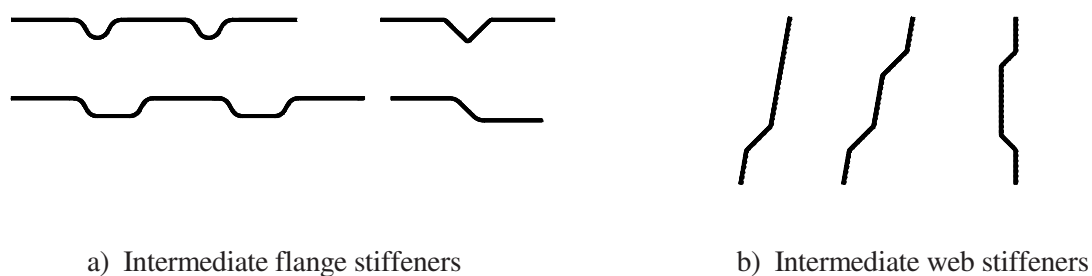


Figure 1.5: Typical intermediate longitudinal stiffeners

1.5.3 Cross-section dimensions

- (1) Overall dimensions of cold-formed members and sheeting, including overall width b , overall height h , internal bend radius r and other external dimensions denoted by symbols without subscripts, such as a , c or d , are measured to the face of the material, unless stated otherwise, as illustrated in figure 1.6.

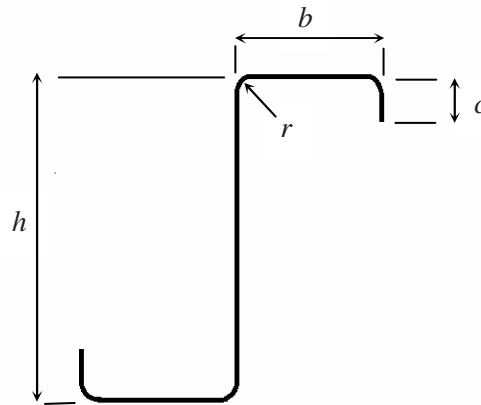


Figure 1.6: Dimensions of typical cross-section

- (2) Unless stated otherwise, the other cross-sectional dimensions of cold-formed members and sheeting, denoted by symbols with subscripts, such as b_d , h_w or s_w , are measured either to the midline of the material or the midpoint of the corner.
- (3) In the case of sloping elements, such as webs of trapezoidal profiled sheets, the slant height s is measured parallel to the slope. The slope is straight line between intersection points of flanges and web.
- (4) The developed height of a web is measured along its midline, including any web stiffeners.
- (5) The developed width of a flange is measured along its midline, including any intermediate stiffeners.
- (6) The thickness t is a steel design thickness (the steel core thickness extracted minus tolerance if needed as specified in clause 3.2.4), if not otherwise stated.

1.5.4 Convention for member axes

- (1) In general the conventions for members is as used in Part 1-1 of EN 1993, see Figure 1.7.

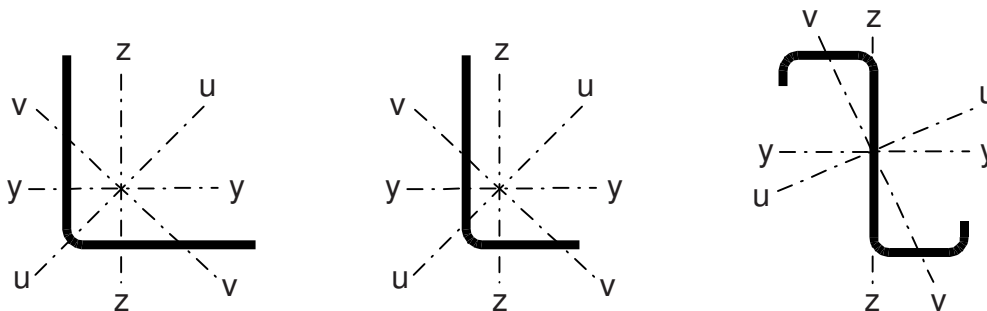


Figure 1.7: Axis convention

- (2) For profiled sheets and liner trays the following axis convention is used:

- $y - y$ axis parallel to the plane of sheeting;
- $z - z$ axis perpendicular to the plane of sheeting.

2 Basis of design

- (1) The design of cold formed members and sheeting should be in accordance with the general rules given in EN 1990 and EN 1993-1-1. For a general approach with FE-methods (or others) see EN 1993-1-5, Annex C.
- (2)P Appropriate partial factors shall be adopted for ultimate limit states and serviceability limit states.

(3)P For verifications by calculation at ultimate limit states the partial factor γ_M shall be taken as follows:

- resistance of cross-sections to excessive yielding including local and distortional buckling: γ_{M0}
- resistance of members and sheeting where failure is caused by global buckling: γ_{M1}
- resistance of net sections at fastener holes: γ_{M2}

NOTE: Numerical values for γ_{M_i} may be defined in the National Annex. The following numerical values are recommended for the use in buildings:

$$\gamma_{M0} = 1,00;$$

$$\gamma_{M1} = 1,00;$$

$$\gamma_{M2} = 1,25.$$

(4) For values of γ_M for resistance of connections, see Section 8.

(5) For verifications at serviceability limit states the partial factor $\gamma_{M,ser}$ should be used.

NOTE: Numerical value for $\gamma_{M,ser}$ may be defined in the National Annex. The following numerical value is recommended for the use in buildings:

$$\gamma_{M,ser} = 1,00 .$$

(6) For the design of structures made of cold formed members and sheeting a distinction should be made between “structural classes” associated with failure consequences according to EN 1990 – Annex B defined as follows:

Structural Class I: Construction where cold-formed members and sheeting are designed to contribute to the overall strength and stability of a structure;

Structural Class II: Construction where cold-formed members and sheeting are designed to contribute to the strength and stability of individual structural elements;

Structural Class III: Construction where cold-formed sheeting is used as an element that only transfers loads to the structure.

NOTE 1: During different construction stages different structural classes may be considered.

NOTE 2: For requirements for execution of sheeting see EN 1090.

3 Materials

3.1 General

(1) All steels used for cold-formed members and profiled sheets should be suitable for cold-forming and welding, if needed. Steels used for members and sheets to be galvanized should also be suitable for galvanizing.

(2) The nominal values of material properties given in this Section should be adopted as characteristic values in design calculations.

(3) This part of EN 1993 covers the design of cold formed members and profiles sheets fabricated from steel material conforming to the steel grades listed in table 3.1a.

Table 3.1a: Nominal values of basic yield strength f_{yb} and ultimate tensile strength f_u

Type of steel	Standard	Grade	f_{yb} N/mm ²	f_u N/mm ²
Hot rolled products of non-alloy structural steels. Part 2: Technical delivery conditions for non alloy structural steels	EN 10025: Part 2	S 235 S 275 S 355	235 275 355	360 430 510
Hot-rolled products of structural steels. Part 3: Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels	EN 10025: Part 3	S 275 N S 355 N S 420 N S 460 N S 275 NL S 355 NL S 420 NL S 460 NL	275 355 420 460 275 355 420 460	370 470 520 550 370 470 520 550
Hot-rolled products of structural steels. Part 4: Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels	EN 10025: Part 4	S 275 M S 355 M S 420 M S 460 M S 275 ML S 355 ML S 420 ML S 460 ML	275 355 420 460 275 355 420 460	360 450 500 530 360 450 500 530

NOTE 1: For steel strip less than 3 mm thick conforming to EN 10025, if the width of the original strip is greater than or equal to 600 mm, the characteristic values may be given in the National Annex. Values equal to 0,9 times those given in Table 3.1a are recommended.

NOTE 2: For other steel materials and products see the National Annex. Examples for steel grades that may conform to the requirements of this standard are given in Table 3.1b.

Table 3.1b: Nominal values of basic yield strength f_{yb} and ultimate tensile strength f_u

Type of steel	Standard	Grade	f_{yb} N/mm ²	f_u N/mm ²
Cold reduced steel sheet of structural quality	ISO 4997	CR 220	220	300
		CR 250	250	330
		CR 320	320	400
Continuous hot dip zinc coated carbon steel sheet of structural quality	EN 10326	S220GD+Z	220	300
		S250GD+Z	250	330
		S280GD+Z	280	360
		S320GD+Z	320	390
		S350GD+Z	350	420
Hot-rolled flat products made of high yield strength steels for cold forming. Part 2: Delivery conditions for thermomechanically rolled steels	EN 10149: Part 2	S 315 MC	315	390
		S 355 MC	355	430
		S 420 MC	420	480
		S 460 MC	460	520
		S 500 MC	500	550
		S 550 MC	550	600
		S 600 MC	600	650
		S 650 MC	650	700
		S 700 MC	700	750
	EN 10149: Part 3	S 260 NC	260	370
		S 315 NC	315	430
		S 355 NC	355	470
		S 420 NC	420	530
Cold-rolled flat products made of high yield strength micro-alloyed steels for cold forming	EN 10268	H240LA	240	340
		H280LA	280	370
		H320LA	320	400
		H360LA	360	430
		H400LA	400	460
Continuously hot-dip coated strip and sheet of steels with higher yield strength for cold forming	EN 10292	H260LAD	240 2)	340 2)
		H300LAD	280 2)	370 2)
		H340LAD	320 2)	400 2)
		H380LAD	360 2)	430 2)
		H420LAD	400 2)	460 2)
Continuously hot-dipped zinc-aluminium (ZA) coated steel strip and sheet	EN 10326	S220GD+ZA	220	300
		S250GD+ZA	250	330
		S280GD+ZA	280	360
		S320GD+ZA	320	390
		S350GD+ZA	350	420
Continuously hot-dipped aluminium-zinc (AZ) coated steel strip and sheet	EN 10326	S220GD+AZ	220	300
		S250GD+AZ	250	330
		S280GD+AZ	280	360
		S320GD+AZ	320	390
		S350GD+AZ	350	420
Continuously hot-dipped zinc coated strip and sheet of mild steel for cold forming	EN 10327	DX51D+Z	140 1)	270 1)
		DX52D+Z	140 1)	270 1)
		DX53D+Z	140 1)	270 1)

1) Minimum values of the yield strength and ultimate tensile strength are not given in the standard. For all steel grades a minimum value of 140 N/mm² for yield strength and 270 N/mm² for ultimate tensile strength may be assumed.

2) The yield strength values given in the names of the materials correspond to transversal tension. The values for longitudinal tension are given in the table.

3.2 Structural steel

3.2.1 Material properties of base material

- (1) The nominal values of yield strength f_{yb} or $\overline{AC1}$ ultimate tensile strength $\overline{AC1}$ f_u should be obtained
- either by adopting the values $f_y = R_{eh}$ or $R_{p0.2}$ and $f_u = R_m$ direct from product standards, or
 - by using the values given in Table 3.1a and b
 - by appropriate tests.
- (2) Where the characteristic values are determined from tests, such tests should be carried out in accordance with EN 10002-1. The number of test coupons should be at least 5 and should be taken from a lot in following way:
- Coils:
 - For a lot from one production (one pot of melted steel) at least one coupon per coil of 30% of the number of coils;
 - For a lot from different productions at least one coupon per coil;
 - Strips: At least one coupon per 2000 kg from one production.
- The coupons should be taken at random from the concerned lot of steel and the orientation should be in the length of the structural element. The characteristic values should be determined on basis of a statistical evaluation in accordance with EN 1990 Annex D.
- It may be assumed that the properties of steel in compression are the same as those in tension.
 - The ductility requirements should comply with 3.2.2 of EN 1993-1-1.
 - The design values for material coefficients should be taken as given in 3.2.6 of EN 1993-1-1
 - The material properties for elevated temperatures are given in EN 1993-1-2.

3.2.2 Material properties of cold formed sections and sheeting

- (1) Where the yield strength is specified using the symbol f_y the average yield strength f_{ya} may be used if (4) to (8) apply. In other cases the basic yield strength f_{yb} should be used. Where the yield strength is specified using the symbol f_{yb} the basic yield strength f_{yb} should be used.
- (2) The average yield strength f_{ya} of a cross-section due to cold working may be determined from the results of full size tests.
- (3) Alternatively the increased average yield strength f_{ya} may be determined by calculation using:

$$f_{ya} = f_{yb} + (f_u - f_{yb}) \frac{knt^2}{A_g} \quad \text{but} \quad f_{ya} \leq \frac{(f_u + f_{yb})}{2} \quad \dots (3.1)$$

where:

- A_g is the gross cross-sectional area;
- k is a numerical coefficient that depends on the type of forming as follows:
- $k = 7$ for roll forming;
 - $k = 5$ for other methods of forming;
- n is the number of 90° bends in the cross-section with an internal radius $r \leq 5t$ (fractions of 90° bends should be counted as fractions of n);
- t is the design core thickness of the steel material before cold-forming, exclusive of metal and organic coatings, see 3.2.4.

- (4) The increased yield strength due to cold forming may be taken into account as follows:

- in axially loaded members in which the effective cross-sectional area A_{eff} equals the gross area A_g ;
 - in determining A_{eff} the yield strength f_y should be taken as f_{yb} .
- (5) The average yield strength f_{ya} may be utilised in determining:
- the cross-section resistance of an axially loaded tension member;
 - the cross-section resistance and the buckling resistance of an axially loaded compression member with a fully effective cross-section;
 - the moment resistance of a cross-section with fully effective flanges.
- (6) To determine the moment resistance of a cross-section with fully effective flanges, the cross-section may be subdivided into m nominal plane elements, such as flanges. Expression (3.1) may then be used to obtain values of increased yield strength $f_{y,i}$ separately for each nominal plane element i , provided that:

$$\frac{\sum_{i=1}^m A_{g,i} f_{y,i}}{\sum_{i=1}^m A_{g,i}} \leq f_{ya} \quad \dots (3.2)$$

where:

$A_{g,i}$ is the gross cross-sectional area of nominal plane element i ,

and when calculating the increased yield strength $f_{y,i}$ using the expression (3.1) the bends on the edge of the nominal plane elements should be counted with the half their angle for each area $A_{g,i}$.

(7) The increase in yield strength due to cold forming should not be utilised for members that are subjected to heat treatment after forming at more than 580°C for more than one hour.

NOTE: For further information see EN 1090, Part 2.

(8) Special attention should be paid to the fact that some heat treatments (especially annealing) might induce a reduced yield strength lower than the basic yield strength f_{yb} .

NOTE: For welding in cold formed areas see also EN 1993-1-8.

3.2.3 Fracture toughness

(1) See EN 1993-1-1 and EN 1993-1-10.

3.2.4 Thickness and thickness tolerances

(1) The provisions for design by calculation given in this Part 1-3 of EN 1993 may be used for steel within given ranges of core thickness t_{cor} .

NOTE: The ranges of core thickness t_{cor} for sheeting and members may be given in the National Annex. The following values are recommended:

- for sheeting and members: $0,45 \text{ mm} \leq t_{\text{cor}} \leq 15 \text{ mm}$
- for connections: $0,45 \text{ mm} \leq t_{\text{cor}} \leq 4 \text{ mm}$, see 8.1(2)

(2) Thicker or thinner material may also be used, provided that the load bearing resistance is determined by design assisted by testing.

(3) The steel core thickness t_{cor} should be used as design thickness, where

$$t = t_{\text{cor}} \quad \text{if } tol \leq 5\% \quad \dots (3.3a)$$

$$\boxed{\text{AC1}} \ t = t_{\text{cor}} \frac{100 - tol}{95} \quad \text{if } tol > 5\% \ \boxed{\text{AC1}} \quad \dots (3.3b)$$

$$\text{with } t_{\text{cor}} = t_{\text{nom}} - t_{\text{metallic coatings}} \quad \dots (3.3c)$$

where tol is the minus tolerance in %.

NOTE: For the usual Z 275 zinc coating, $t_{\text{zinc}} = 0,04$ mm.

(4) For continuously hot-dip metal coated members and sheeting supplied with negative tolerances less or equal to the "special tolerances (S)" given in EN 10143, the design thickness according to (3.3a) may be used. If the negative tolerance is beyond "special tolerance (S)" given in EN 10143 then the design thickness according to (3.3b) may be used.

(5) t_{nom} is the nominal sheet thickness after cold forming. It may be taken as the value to t_{nom} of the original sheet, if the calculative cross-sectional areas before and after cold forming do not differ more than 2%; otherwise the notional dimensions should be changed.

3.3 Connecting devices

3.3.1 Bolt assemblies

(1) Bolts, nuts and washers should conform to the requirements given in EN 1993-1-8.

3.3.2 Other types of mechanical fastener

(1) Other types of mechanical fasteners as:

- self-tapping screws as thread forming self-tapping screws, thread cutting self-tapping screws or self-drilling self-tapping screws,
- cartridge-fired pins,
- blind rivets

may be used where they comply with the relevant European Product Specification.

(2) The characteristic shear resistance $F_{v,Rk}$ and the characteristic minimum tension resistance $F_{t,Rk}$ of the mechanical fasteners may be taken from the EN Product Standard or ETAG or ETA.

3.3.3 Welding consumables

(1) Welding consumables should conform to the requirements given in EN 1993-1-8.

4 Durability

(1) For basic requirements see section 4 of EN 1993-1-1.

NOTE: $\boxed{\text{AC1}}$ EN 1090-2, 9.3.1 $\boxed{\text{AC1}}$ lists the factors affecting execution that need to be specified during design.

(2) Special attention should be given to cases in which different materials are intended to act compositely, if these materials are such that electrochemical phenomena might produce conditions leading to corrosion.

NOTE 1: For corrosion resistance of fasteners for the environmental class following EN-ISO 12944-2 see Annex B.

NOTE 2: For roofing products see EN 508-1.

NOTE 3: For other products see Part 1-1 of EN 1993.

NOTE 4: For hot dip galvanized fasteners see EN ISO 10684.

5 Structural analysis

5.1 Influence of rounded corners

- (1) In cross-sections with rounded corners, the notional flat widths b_p of the plane elements should be measured from the midpoints of the adjacent corner elements as indicated in figure 5.1.
- (2) In cross-sections with rounded corners, the calculation of section properties should be based upon the nominal geometry of the cross-section.
- (3) Unless more appropriate methods are used to determine the section properties the following approximate procedure may be used. The influence of rounded corners on cross-section resistance may be neglected if the internal radius $r \leq 5 t$ and $r \leq 0,10 b_p$ and the cross-section may be assumed to consist of plane elements with sharp corners (according to figure 5.2, note b_p for all flat plane elements, inclusive plane elements in tension). For cross-section stiffness properties the influence of rounded corners should always be taken into account.

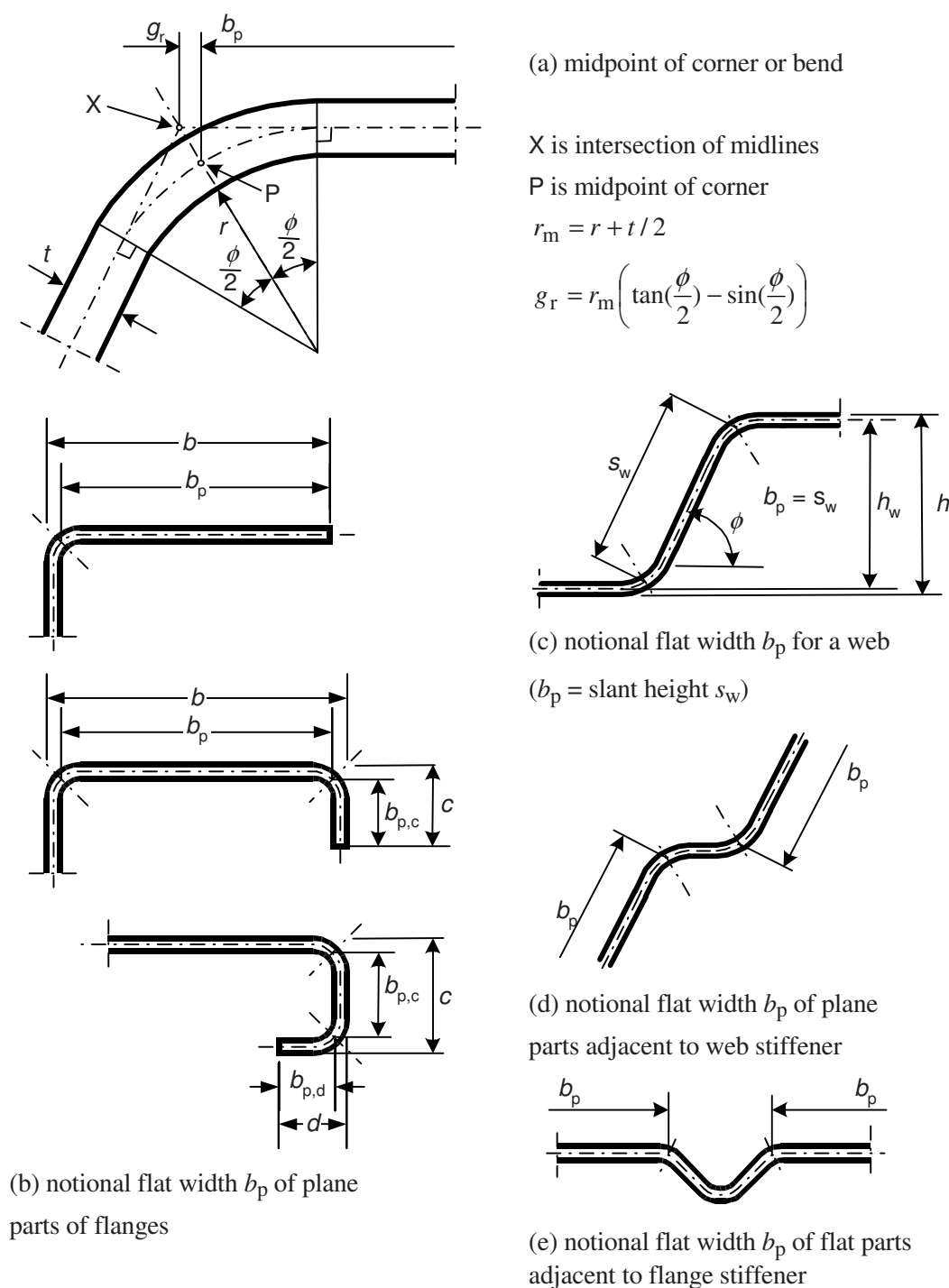


Figure 5.1: Notional widths of plane cross section parts b_p allowing for corner radii

(4) The influence of rounded corners on section properties may be taken into account by reducing the properties calculated for an otherwise similar cross-section with sharp corners, see figure 5.2, using the following approximations:

$$A_g \approx A_{g,sh} (1 - \delta) \quad \dots (5.1a)$$

$$I_g \approx I_{g,sh} (1 - 2\delta) \quad \dots (5.1b)$$

$$I_w \approx I_{w,sh} (1 - 4\delta) \quad \dots (5.1c)$$

with:

$$\delta = 0,43 \frac{\sum_{j=1}^n r_j \frac{\phi_j}{90^\circ}}{\sum_{i=1}^m b_{p,i}} \quad \dots (5.1d)$$

where:

- A_g is the area of the gross cross-section;
- $A_{g,sh}$ is the value of A_g for a cross-section with sharp corners;
- $b_{p,i}$ is the notional flat width of plane element i for a cross-section with sharp corners;
- I_g is the second moment of area of the gross cross-section;
- $I_{g,sh}$ is the value of I_g for a cross-section with sharp corners;
- I_w is the warping constant of the gross cross-section;
- $I_{w,sh}$ is the value of I_w for a cross-section with sharp corners;
- ϕ is the angle between two plane elements;
- m is the number of plane elements;
- n is the number of curved elements;
- r_j is the internal radius of curved element j .

(5) The reductions given by expression (5.1) may also be applied in calculating the effective section properties A_{eff} , $I_{y,eff}$, $I_{z,eff}$ and $I_{w,eff}$, provided that the notional flat widths of the plane elements are measured to the points of intersection of their midlines.

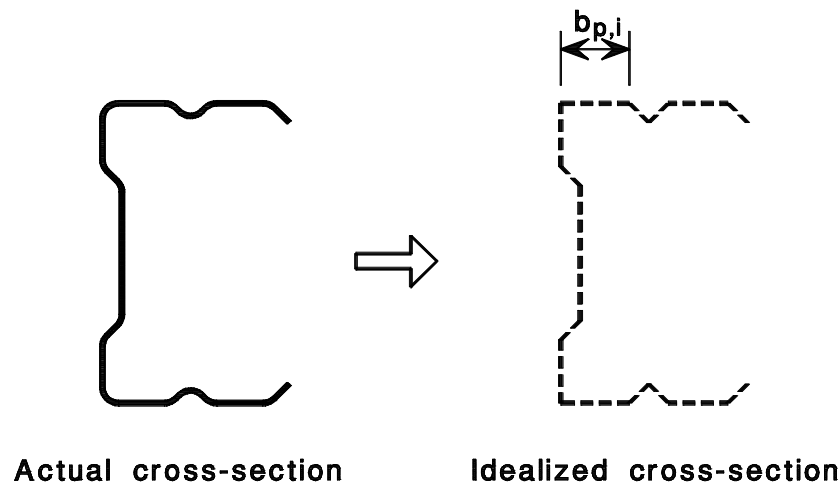


Figure 5.2: Approximate allowance for rounded corners

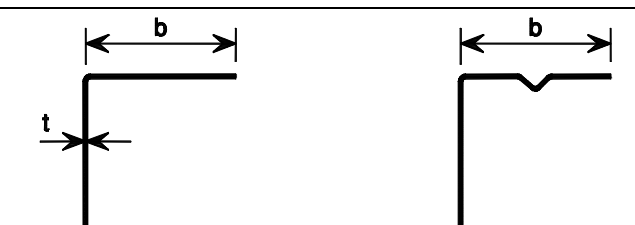
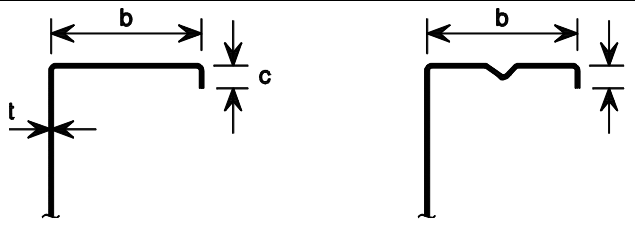
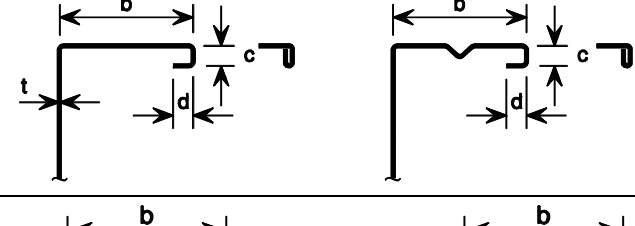
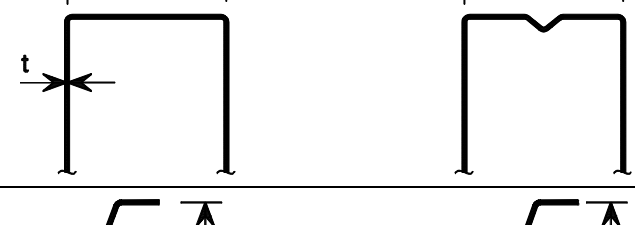
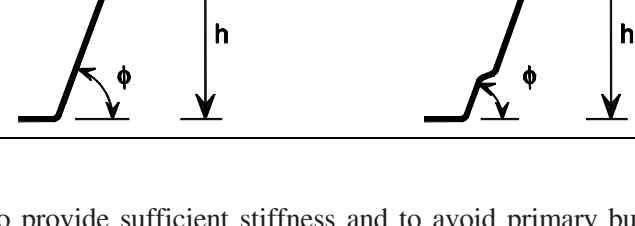
(6) Where the internal radius $r > 0,04 t E / f_y$ then the resistance of the cross-section should be determined by tests.

5.2 Geometrical proportions

(1) The provisions for design by calculation given in this Part 1-3 of EN 1993 should not be applied to cross-sections outside the range of width-to-thickness ratios b/t , h/t , c/t and d/t given in Table 5.1.

NOTE: These limits b/t , h/t , c/t and d/t given in table 5.1 may be assumed to represent the field for which sufficient experience and verification by testing is already available. Cross-sections with larger width-to-thickness ratios may also be used, provided that their resistance at ultimate limit states and their behaviour at serviceability limit states are verified by testing and/or by calculations, where the results are confirmed by an appropriate number of tests.

Table 5.1: Maximum width-to-thickness ratios

Element of cross-section	Maximum value
	$b/t \leq 50$
	$b/t \leq 60$ $c/t \leq 50$
	$b/t \leq 90$ $c/t \leq 60$ $d/t \leq 50$
	$b/t \leq 500$
	$45^\circ \leq \phi \leq 90^\circ$ $h/t \leq 500 \sin \phi$

(2) In order to provide sufficient stiffness and to avoid primary buckling of the stiffener itself, the sizes of stiffeners should be within the following ranges:

$$0,2 \leq c/b \leq 0,6 \quad \dots (5.2a)$$

$$0,1 \leq d/b \leq 0,3 \quad \dots (5.2b)$$

in which the dimensions b , c and d are as indicated in table 5.1. If $c/b < 0,2$ or $d/b < 0,1$ the lip should be ignored ($c = 0$ or $d = 0$).

NOTE 1: Where effective cross-section properties are determined by testing and by calculations, these limits do not apply.

NOTE 2: The lip measure c is perpendicular to the flange if the lip is not perpendicular to the flange.

NOTE 3: For FE-methods see Annex C of EN 1993-1-5.

5.3 Structural modelling for analysis

- (1) Unless more appropriate models are used according to EN 1993-1-5 the elements of a cross-section may be modelled for analysis as indicated in table 5.2.
- (2) The mutual influence of multiple stiffeners should be taken into account.
- (3) Imperfections related to flexural buckling and torsional flexural buckling should be taken from table 5.1 of EN 1993-1-1

NOTE: See also clause 5.3.4 of EN 1993-1-1.

- (4) For imperfections related to lateral torsional buckling an initial bow imperfections e_0 of the weak axis of the profile may be assumed without taking account at the same time an initial twist

NOTE: The magnitude of the imperfection may be taken from the National Annex. The values $e_0/L = 1/600$ for elastic analysis and $e_0/L = 1/500$ for plastic analysis are recommended for sections assigned to LTB buckling curve a taken from EN 1993-1-1, section 6.3.2.2.

Table 5.2: Modelling of elements of a cross-section

Type of element	Model	Type of element	Model

5.4 Flange curling

- (1) The effect on the loadbearing resistance of curling (i.e. inward curvature towards the neutral plane) of a very wide flange in a profile subjected to flexure, or of a flange in an arched profile subjected to flexure in which the concave side is in compression, should be taken into account unless such curling is less than 5% of the depth of the profile cross-section. If curling is larger, then the reduction in loadbearing resistance, for instance due to a decrease in the length of the lever arm for parts of the wide flanges, and to the possible effect of the bending of the webs should be taken into account.

NOTE: For liner trays this effect has been taken into account in 10.2.2.2.

(2) Calculation of the curling may be carried out as follows. The formulae apply to both compression and tensile flanges, both with and without stiffeners, but without closely spaced transversal stiffeners at flanges. For a profile which is straight prior to application of loading (see figure 5.3).

$$u = 2 \frac{\sigma_a^2 b_s^4}{E^2 t^2 z} \quad \dots (5.3a)$$

For an arched beam:

$$u = 2 \frac{\sigma_a b_s^4}{E t^2 r} \quad \dots (5.3b)$$

where:

- u is bending of the flange towards the neutral axis (curling), see figure 5.3;
- b_s is one half the distance between webs in box and hat sections, or the width of the portion of flange projecting from the web, see figure 5.3;
- t is flange thickness;
- z is distance of flange under consideration from neutral axis;
- r is radius of curvature of arched beam;
- σ_a is mean stress in the flanges calculated with gross area. If the stress has been calculated over the effective cross-section, the mean stress is obtained by multiplying the stress for the effective cross-section by the ratio of the effective flange area to the gross flange area.

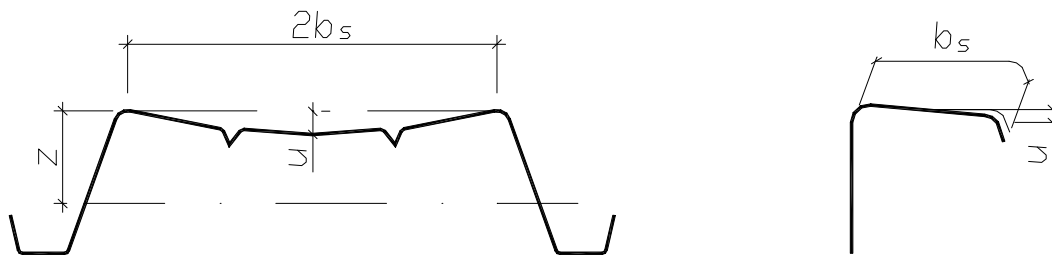


Figure 5.3: Flange curling

5.5 Local and distortional buckling

5.5.1 General

- (1) The effects of local and distortional buckling should be taken into account in determining the resistance and stiffness of cold-formed members and sheeting.
- (2) Local buckling effects may be accounted for by using effective cross-sectional properties, calculated on the basis of the effective widths, see EN 1993-1-5.
- (3) In determining resistance to local buckling, the yield strength f_y should be taken as f_{yb} when calculating effective widths of compressed elements in EN 1993-1-5.

NOTE: For resistance see 6.1.3(1).

- (4) For serviceability verifications, the effective width of a compression element should be based on the compressive stress $\sigma_{com,Ed,ser}$ in the element under the serviceability limit state loading.
- (5) The distortional buckling for elements with edge or intermediate stiffeners as indicated in figure 5.4(d) are considered in Section 5.5.3.

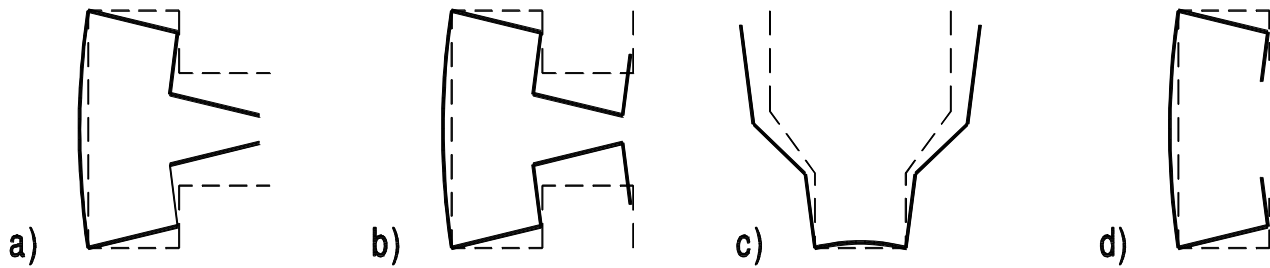


Figure 5.4: Examples of distortional buckling modes

(6) The effects of distortional buckling should be allowed for in cases such as those indicated in figures 5.4(a), (b) and (c). In these cases the effects of distortional buckling should be determined performing linear (see 5.5.1(7)) or non-linear buckling analysis (see EN 1993-1-5) using numerical methods or column stub tests.

(7) Unless the simplified procedure in 5.5.3 is used and where the elastic buckling stress is obtained from linear buckling analysis the following procedure may be applied:

- 1) For the wavelength up to the nominal member length, calculate the elastic buckling stress and identify the corresponding buckling modes, see figure 5.5a.
- 2) Calculate the effective width(s) according to 5.5.2 for locally buckled cross-section parts based on the minimum local buckling stress, see figure 5.5b.
- 3) Calculate the reduced thickness (see 5.5.3.1(7)) of edge and intermediate stiffeners or other cross-section parts undergoing distortional buckling based on the minimum distortional buckling stress, see figure 5.5b.
- 4) Calculate overall buckling resistance according to 6.2 (flexural, torsional or lateral-torsional buckling depending on buckling mode) for nominal member length and based on the effective cross-section from 2) and 3).

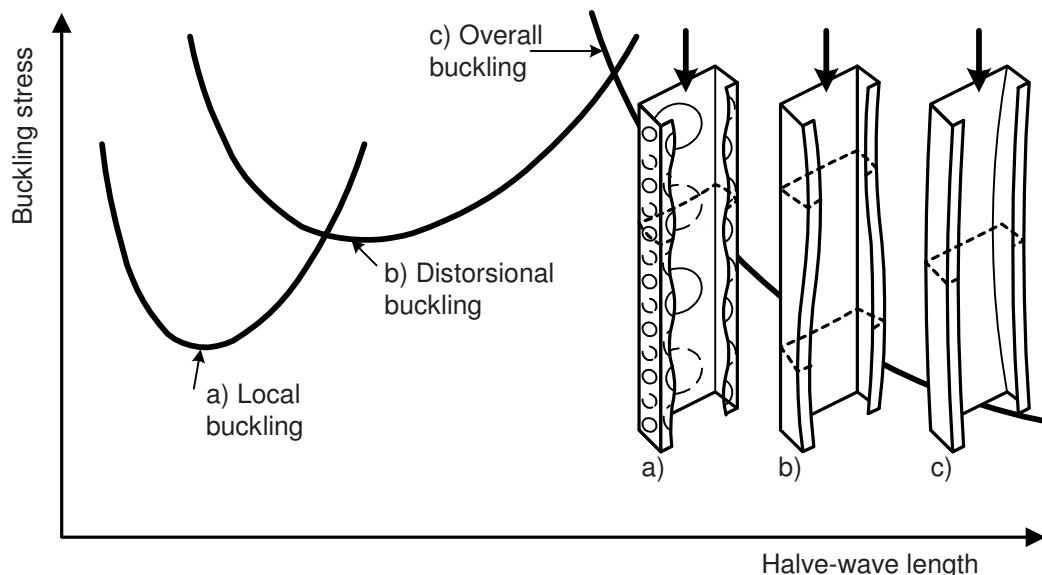


Figure 5.5a: Examples of elastic critical stress for various buckling modes as function of *half-wave length* and examples of buckling modes.

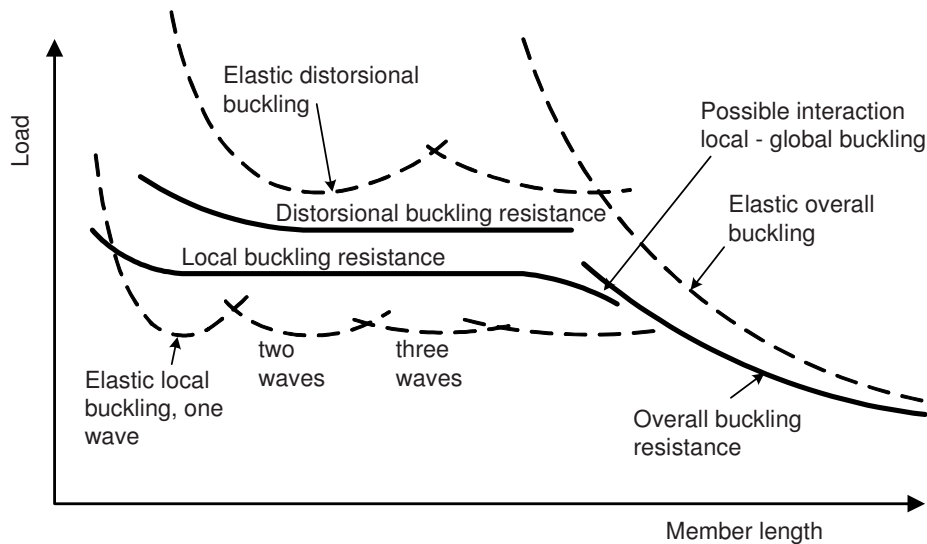


Figure 5.5 b: Examples of elastic buckling load and buckling resistance as a function of member length

5.5.2 Plane elements without stiffeners

- (1) The effective widths of unstiffened elements should be obtained from EN 1993-1-5 using the notional flat width b_p for $\bar{b}$ by determining the reduction factors for plate buckling based on the plate slenderness $\bar{\lambda}_p$.
- (2) The notional flat width b_p of a plane element should be determined as specified in figure 5.1 of section 5.1.4. In the case of plane elements in a sloping webs, the appropriate slant height should be used.

NOTE: For outstands an alternative method for calculating effective widths is given in Annex D.

- (3) In applying the method in EN 1993-1-5 the following procedure may be used:
 - The stress ratio ψ , $\langle \overline{\sigma}_1 \rangle$ from tables 4.1 and 4.2 of EN 1993-1-5 $\langle \overline{\sigma}_1 \rangle$ used to determine the effective width of flanges of a section subject to stress gradient, may be based on gross section properties.
 - The stress ratio ψ , $\langle \overline{\sigma}_1 \rangle$ from tables 4.1 and 4.2 of EN 1993-1-5 $\langle \overline{\sigma}_1 \rangle$ used to determine the effective width of web, may be obtained using the effective area of compression flange and the gross area of the web.
 - The effective section properties may be refined by using the stress ratio ψ based on the effective cross-section already found in place of the gross cross-section. The minimum steps in the iteration dealing with the stress gradient are two.
 - The simplified method given in 5.5.3.4 may be used in the case of webs of trapezoidal sheeting under stress gradient.

5.5.3 Plane elements with edge or intermediate stiffeners

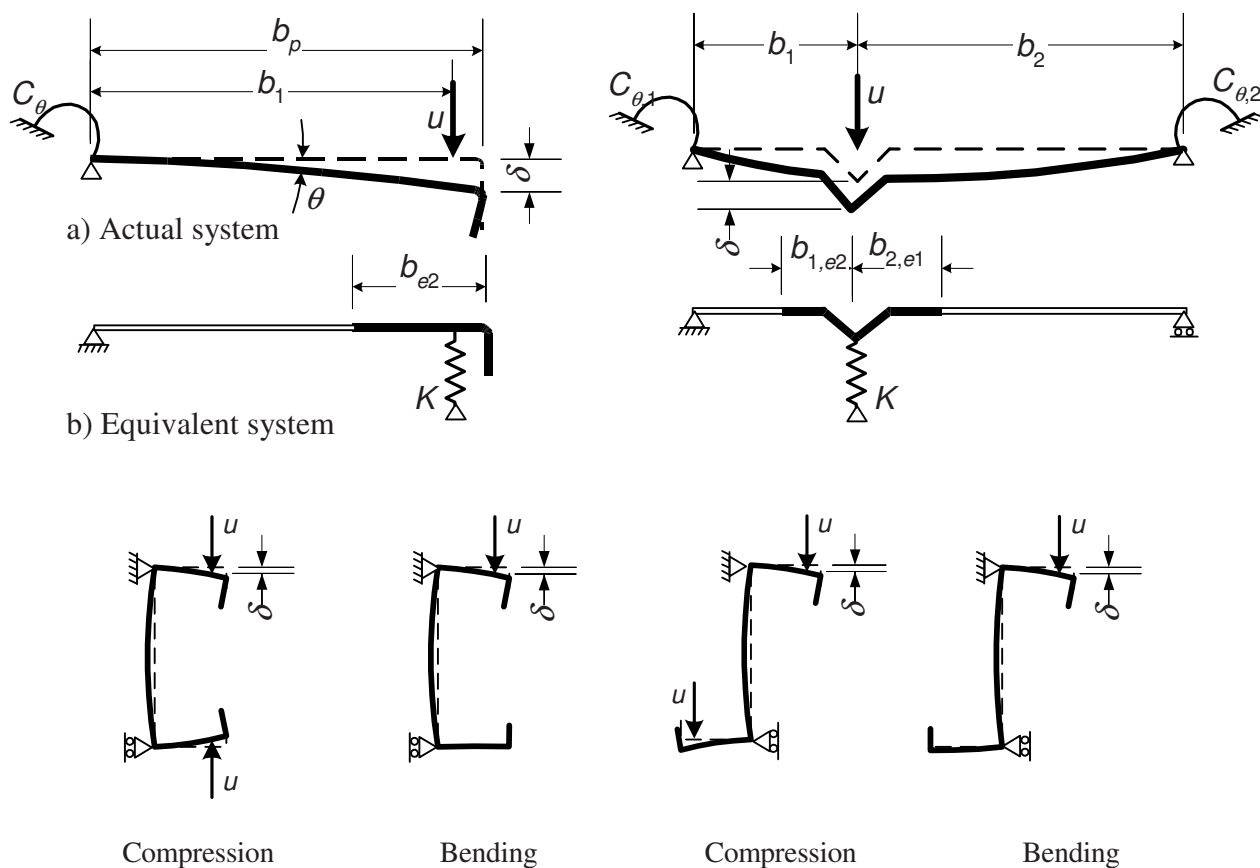
5.5.3.1 General

- (1) The design of compression elements with edge or intermediate stiffeners should be based on the assumption that the stiffener behaves as a compression member with continuous partial restraint, with a spring stiffness that depends on the boundary conditions and the flexural stiffness of the adjacent plane elements.
- (2) The spring stiffness of a stiffener should be determined by applying an unit load per unit length u as illustrated in figure 5.6. The spring stiffness K per unit length may be determined from:

$$K = u / \delta \quad \dots (5.9)$$

where:

δ is the deflection of the stiffener due to the unit load u acting in the centroid (b_1) of the effective part of the cross-section.



c) Calculation of δ for C and Z sections

Figure 5.6: Determination of spring stiffness

(3) In determining the values of the rotational spring stiffnesses C_θ , $C_{\theta,1}$ and $C_{\theta,2}$ from the geometry of the cross-section, account should be taken of the possible effects of other stiffeners that exist on the same element, or on any other element of the cross-section that is subject to compression.

(4) For an edge stiffener, the deflection δ should be obtained from:

$$\delta = \theta b_p + \frac{u b_p^3}{3} \cdot \frac{12(1-\nu^2)}{Et^3} \quad \dots (5.10a)$$

with:

$$\theta = u b_p / C_\theta$$

(5) In the case of the edge stiffeners of lipped C-sections and lipped Z-sections, C_θ should be determined with the unit loads u applied as shown in figure 5.6(c). This results in the following expression for the spring stiffness K_1 for the flange 1:

$$K_1 = \frac{Et^3}{4(1-\nu^2)} \cdot \frac{1}{b_1^2 h_w + b_1^3 + 0,5 b_1 b_2 h_w k_f} \quad \dots (5.10b)$$

where:

b_1 is the distance from the web-to-flange junction to the gravity center of the effective area of the edge stiffener (including effective part b_{e2} of the flange) of flange 1, see figure 5.6(a);

b_2 is the distance from the web-to-flange junction to the gravity center of the effective area of the edge stiffener (including effective part of the flange) of flange 2;

h_w is the web depth;

$k_f = 0$ if flange 2 is in tension (e.g. for beam in bending about the y-y axis);

$k_f = \frac{A_{s2}}{A_{s1}}$ if flange 2 is also in compression (e.g. for a beam in axial compression);

$k_f = 1$ for a symmetric section in compression.

A_{s1} and A_{s2} is the effective area of the edge stiffener (including effective part b_{e2} of the flange, see figure 5.6(b)) of flange 1 and flange 2 respectively.

(6) For an intermediate stiffener, as a conservative alternative the values of the rotational spring stiffnesses $C_{\theta 1}$ and $C_{\theta 2}$ may be taken as equal to zero, and the deflection δ may be obtained from:

$$\delta = \frac{ub_1^2 b_2^2}{3(b_1 + b_2)} \cdot \frac{12(1-\nu^2)}{Et^3} \quad \dots (5.11)$$

(7) The reduction factor χ_d for the distortional buckling resistance (flexural buckling of a stiffener) should be obtained from the relative slenderness $\bar{\lambda}_d$ from:

$$\chi_d = 1,0 \quad \text{if } \bar{\lambda}_d \leq 0,65 \quad \dots (5.12a)$$

$$\chi_d = 1,47 - 0,723\bar{\lambda}_d \quad \text{if } 0,65 < \bar{\lambda}_d < 1,38 \quad \dots (5.12b)$$

$$\chi_d = \frac{0,66}{\bar{\lambda}_d} \quad \text{if } \bar{\lambda}_d \geq 1,38 \quad \dots (5.12c)$$

where:

$$\bar{\lambda}_d = \sqrt{f_{yb}/\sigma_{cr,s}} \quad \dots (5.12d)$$

where:

$\sigma_{cr,s}$ is the elastic critical stress for the stiffener(s) from 5.5.3.2, 5.5.3.3 or 5.5.3.4.

(8) Alternatively, the elastic critical buckling stress $\sigma_{cr,s}$ may be obtained from elastic first order buckling analysis using numerical methods (see 5.5.1(7)).

(9) In the case of a plane element with an edge and intermediate stiffener(s) in the absence of a more accurate method the effect of the intermediate stiffener(s) may be neglected.

(5) Initial values of the effective widths c_{eff} and d_{eff} shown in figure 5.7 should be obtained as follows:

a) for a single edge fold stiffener:

$$c_{\text{eff}} = \rho b_{p,c} \quad \dots (5.13a)$$

with ρ obtained from 5.5.2, except using a value of the buckling factor k_{σ} given by the following:

- if $b_{p,c}/b_p \leq 0,35$:

$$k_{\sigma} = 0,5 \quad \dots (5.13b)$$

- if $0,35 < b_{p,c}/b_p \leq 0,6$:

$$k_{\sigma} = 0,5 + 0,83 \sqrt[3]{(b_{p,c}/b_p - 0,35)^2} \quad \dots (5.13c)$$

b) for a double edge fold stiffener:

$$c_{\text{eff}} = \rho b_{p,c} \quad \dots (5.13d)$$

with ρ obtained from 5.5.2 with a buckling factor k_{σ} for a doubly supported element from table 4.1 in EN 1993-1-5

$$d_{\text{eff}} = \rho b_{p,d} \quad \dots (5.13e)$$

with ρ obtained from 5.5.2 with a buckling factor k_{σ} for an outstand element from table 4.2 in EN 1993-1-5.

(6) The effective cross-sectional area of the edge stiffener A_s should be obtained from:

$$A_s = t(b_{e2} + c_{\text{eff}}) \quad \text{or} \quad \dots (5.14a)$$

$$A_s = t(b_{e2} + c_{e1} + c_{e2} + d_{\text{eff}}) \quad \dots (5.14b)$$

respectively.

NOTE: The rounded corners should be taken into account if needed, see 5.1.

(7) The elastic critical buckling stress $\sigma_{\text{cr,s}}$ for an edge stiffener should be obtained from:

$$\sigma_{\text{cr,s}} = \frac{2 \sqrt{K E I_s}}{A_s} \quad \dots (5.15)$$

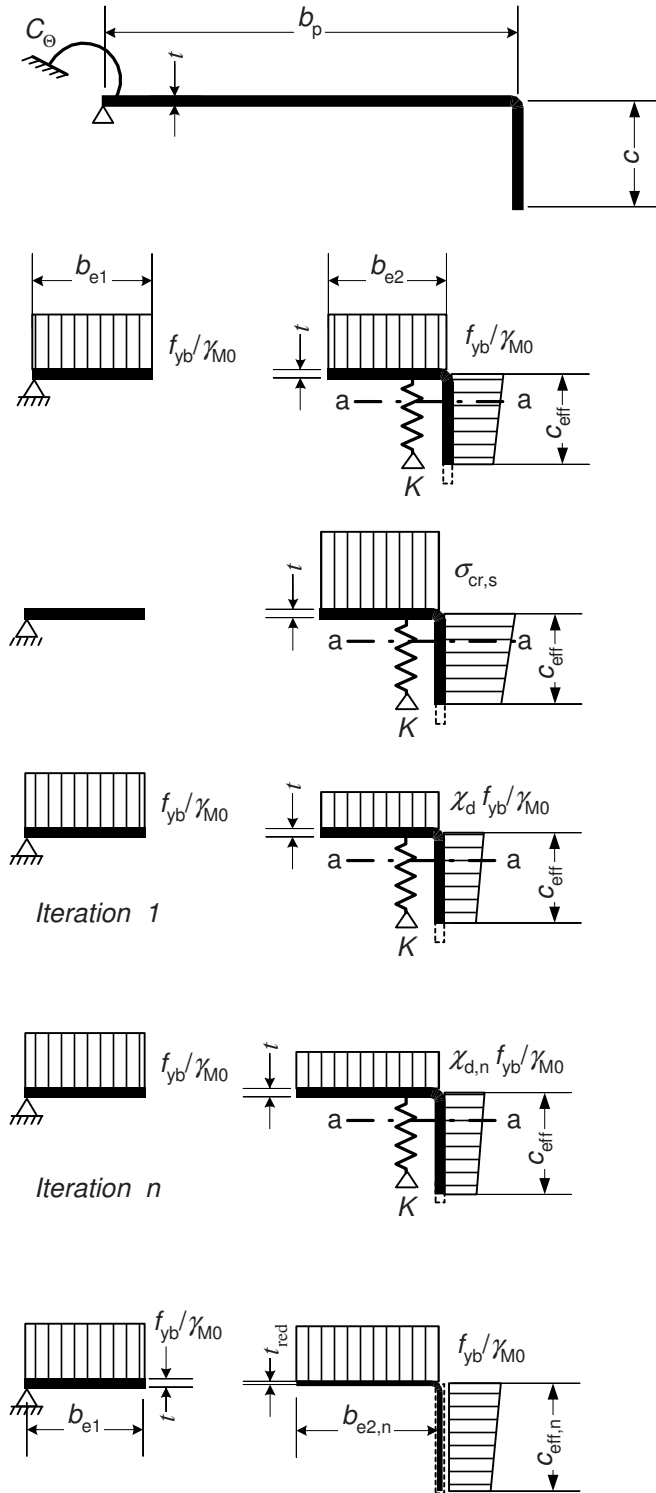
where:

K is the spring stiffness per unit length, see 5.5.3.1(2).

I_s is the effective second moment of area of the stiffener, taken as that of its effective area A_s about the centroidal axis $a - a$ of its effective cross-section, see figure 5.7.

(8) Alternatively, the elastic critical buckling stress $\sigma_{\text{cr,s}}$ may be obtained from elastic first order buckling analyses using numerical methods, see 5.5.1(7).

(9) The reduction factor χ_d for the distortional buckling (flexural buckling of a stiffener) resistance of an edge stiffener should be obtained from the value of $\sigma_{\text{cr,s}}$ using the method given in 5.5.3.1(7).



a) Gross cross-section and boundary conditions

b) **Step 1:** Effective cross-section for $K = \infty$
based on $\sigma_{\text{com,Ed}} = f_{yb} / \gamma_{M0}$

c) **Step 2:** Elastic critical stress $\sigma_{\text{cr,s}}$ for
effective area of stiffener A_s from step 1

d) Reduced strength $\chi_d f_{yb} / \gamma_{M0}$ for effective
area of stiffener A_s , with reduction factor χ_d
based on $\sigma_{\text{cr,s}}$

e) **Step 3:** Optionally repeat step 1 by
calculating the effective width with a reduced
compressive stress $\sigma_{\text{com,Ed,i}} = \chi_d f_{yb} / \gamma_{M0}$ with χ_d
from previous iteration, continuing until $\chi_{d,n} \approx \chi_{d,(n-1)}$
but $\chi_{d,n} \leq \chi_{d,(n-1)}$.

f) Adopt an effective cross-section with b_{e2} , c_{eff}
and reduced thickness t_{red} corresponding to $\chi_{d,n}$

Figure 5.8: Compression resistance of a flange with an edge stiffener

(10) If $\chi_d < 1$ it may be refined iteratively, starting the iteration with modified values of ρ obtained using $\overline{\text{AC1}} 5.5.2(1) \overline{\text{AC1}}$ with $\sigma_{\text{com,Ed,i}}$ equal to $\chi_d f_{yb} / \gamma_{M0}$, so that:

$$\bar{\lambda}_{p,\text{red}} = \bar{\lambda}_p \sqrt{\chi_d} \quad \dots (5.16)$$

(11) The reduced effective area of the stiffener $A_{s,red}$ allowing for flexural buckling should be taken as:

$$A_{s,red} = \chi_d A_s \frac{f_{yb}/\gamma_{M0}}{\sigma_{com,Ed}} \quad \text{but } A_{s,red} \leq A_s \quad \dots (5.17)$$

where

$\sigma_{com,Ed}$ is compressive stress at the centreline of the stiffener calculated on the basis of the effective cross-section.

(12) In determining effective section properties, the reduced effective area $A_{s,red}$ should be represented by using a reduced thickness $t_{red} = t A_{s,red}/A_s$ for all the elements included in A_s .

5.5.3.3 Plane elements with intermediate stiffeners

(1) The following procedure is applicable to one or two equal intermediate stiffeners formed by grooves or bends provided that all plane elements are calculated according to 5.5.2.

(2) The cross-section of an intermediate stiffener should be taken as comprising the stiffener itself plus the adjacent effective portions of the adjacent plane elements $b_{p,1}$ and $b_{p,2}$ shown in figure 5.9.

(3) The procedure, which is illustrated in figure 5.10, should be carried out in steps as follows:

- **Step 1:** Obtain an initial effective cross-section for the stiffener using effective widths determined by assuming that the stiffener gives full restraint and that $\sigma_{com,Ed} = f_{yb}/\gamma_{M0}$, see (4) and (5);
- **Step 2:** Use the initial effective cross-section of the stiffener to determine the reduction factor for distortional buckling (flexural buckling of an intermediate stiffener), allowing for the effects of the continuous spring restraint, see (6), (7) and (8);
- **Step 3:** Optionally iterate to refine the value of the reduction factor for buckling of the stiffener, see (9) and (10).

(4) Initial values of the effective widths $b_{1,e2}$ and $b_{2,e1}$ shown in figure 5.9 should be determined from 5.5.2 by assuming that the plane elements $b_{p,1}$ and $b_{p,2}$ are doubly supported, see table 4.1 in EN 1993-1-5.

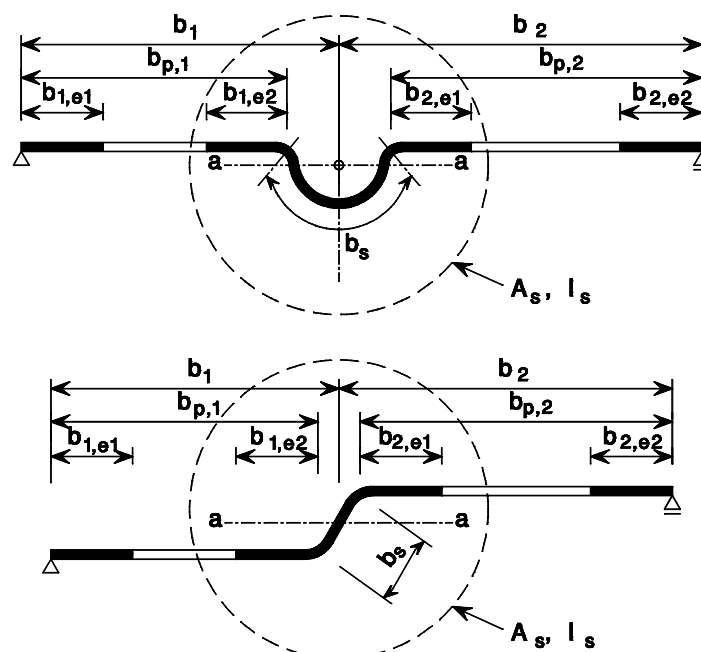


Figure 5.9: Intermediate stiffeners

(5) The effective cross-sectional area of an intermediate stiffener A_s should be obtained from:

$$A_s = t(b_{1,e2} + b_{2,e1} + b_s) \quad \dots (5.18)$$

in which the stiffener width b_s is as shown in figure 5.9.

NOTE: The rounded corners should be taken into account if needed, see 5.1.

(6) The critical buckling stress $\sigma_{cr,s}$ for an intermediate stiffener should be obtained from:

$$\sigma_{cr,s} = \frac{2\sqrt{KEI_s}}{A_s} \quad \dots (5.19)$$

where:

K is the spring stiffness per unit length, see 5.5.3.1(2).

I_s is the effective second moment of area of the stiffener, taken as that of its effective area A_s about the centroidal axis $a - a$ of its effective cross-section, see figure 5.9.

(7) Alternatively, the elastic critical buckling stress $\sigma_{cr,s}$ may be obtained from elastic first order buckling analyses using numerical methods, see 5.5.1(7).

(8) The reduction factor χ_d for the distortional buckling resistance (flexural buckling of an intermediate stiffener) should be obtained from the value of $\sigma_{cr,s}$ using the method given in 5.5.3.1(7).

(9) If $\chi_d < 1$ it may optionally be refined iteratively, starting the iteration with modified values of ρ obtained using $\overline{\lambda}_{AC1}$ 5.5.2(1) $\overline{\lambda}_{AC1}$ with $\sigma_{com,Ed,i}$ equal to $\chi_d f_{yb} / \gamma_{M0}$, so that:

$$\overline{\lambda}_{p,red} = \overline{\lambda}_p \sqrt{\chi_d} \quad \dots (5.20)$$

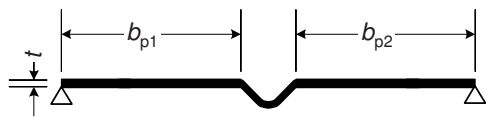
(10) The reduced effective area of the stiffener $A_{s,red}$ allowing for distortional buckling (flexural buckling of a stiffener) should be taken as:

$$A_{s,red} = \chi_d A_s \frac{f_{yb} / \gamma_{M0}}{\sigma_{com,Ed}} \quad \text{but } A_{s,red} \leq A_s \quad \dots (5.21)$$

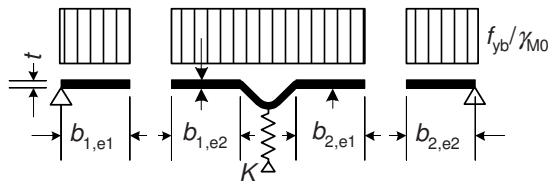
where

$\sigma_{com,Ed}$ is compressive stress at the centreline of the stiffener calculated on the basis of the effective cross-section.

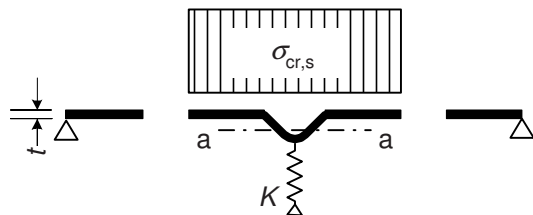
(11) In determining effective section properties, the reduced effective area $A_{s,red}$ should be represented by using a reduced thickness $t_{red} = t A_{s,red} / A_s$ for all the elements included in A_s .



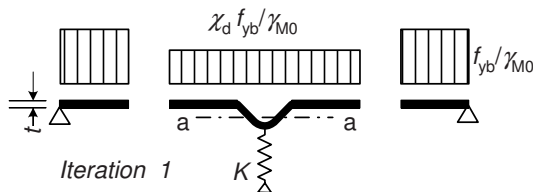
a) Gross cross-section and boundary conditions



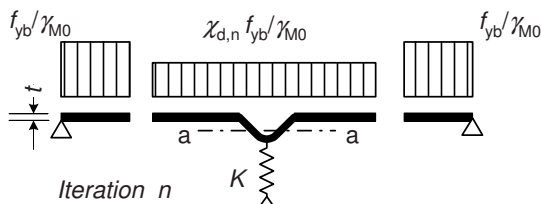
b) **Step 1:** Effective cross-section for $K = \infty$ based on $\sigma_{\text{com,Ed}} = f_{yb} / \gamma_{M0}$



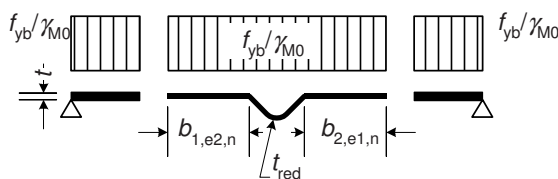
c) **Step 2:** Elastic critical stress $\sigma_{\text{cr,s}}$ for effective area of stiffener A_s from step 1



d) Reduced strength $\chi_d f_{yb} / \gamma_{M0}$ for effective area of stiffener A_s , with reduction factor χ_d based on $\sigma_{\text{cr,s}}$



e) **Step 3:** Optionally repeat step 1 by calculating the effective width with a reduced compressive stress $\sigma_{\text{com,Ed,i}} = \chi_d f_{yb} / \gamma_{M0}$ with χ_d from previous iteration, continuing until $\chi_{d,n} \approx \chi_{d,(n-1)}$ but $\chi_{d,n} \leq \chi_{d,(n-1)}$.



f) Adopt an effective cross-section with $b_{1,e2}$, $b_{2,e1}$ and reduced thickness t_{red} corresponding to $\chi_{d,n}$

Figure 5.10: Compression resistance of a flange with an intermediate stiffener

5.5.3.4 Trapezoidal sheeting profiles with intermediate stiffeners

5.5.3.4.1 General

- (1) This sub-clause 5.5.3.4 should be used for trapezoidal profiled sheets, in association with 5.5.3.3 for flanges with intermediate flange stiffeners and 5.5.3.3 for webs with intermediate stiffeners.
- (2) Interaction between the buckling of intermediate flange stiffeners and intermediate web stiffeners should also be taken into account using the method given in 5.5.3.4.4.

5.5.3.4.2 Flanges with intermediate stiffeners

- (1) If it is subject to uniform compression, the effective cross-section of a flange with intermediate stiffeners should be assumed to consist of the reduced effective areas $A_{s,red}$ including two strips of width $0,5b_{eff}$ (or $15t$, see figure 5.11) adjacent to the stiffener.
- (2) For one central flange stiffener, the elastic critical buckling stress $\sigma_{cr,s}$ should be obtained from:

$$\sigma_{cr,s} = \frac{4,2 k_w E}{A_s} \sqrt{\frac{I_s t^3}{4 b_p^2 (2 b_p + 3 b_s)}} \quad \dots (5.22)$$

where:

- b_p is the notional flat width of plane element shown in figure 5.11;
- b_s is the stiffener width, measured around the perimeter of the stiffener, see figure 5.11;
- A_s, I_s are the cross-section area and the second moment of area of the stiffener cross-section according to figure 5.11;
- k_w is a coefficient that allows for partial rotational restraint of the stiffened flange by the webs or other adjacent elements, see (5) and (6). For the calculation of the effective cross-section in axial compression the value $k_w = 1,0$.

The equation 5.22 may be used for wide grooves provided that flat part of the stiffener is reduced due to local buckling and b_p in the equation 5.22 is replaced by the larger of b_p and $0,25(3b_p+b_r)$, see figure 5.11. Similar method is valid for flange with two or more wide grooves.

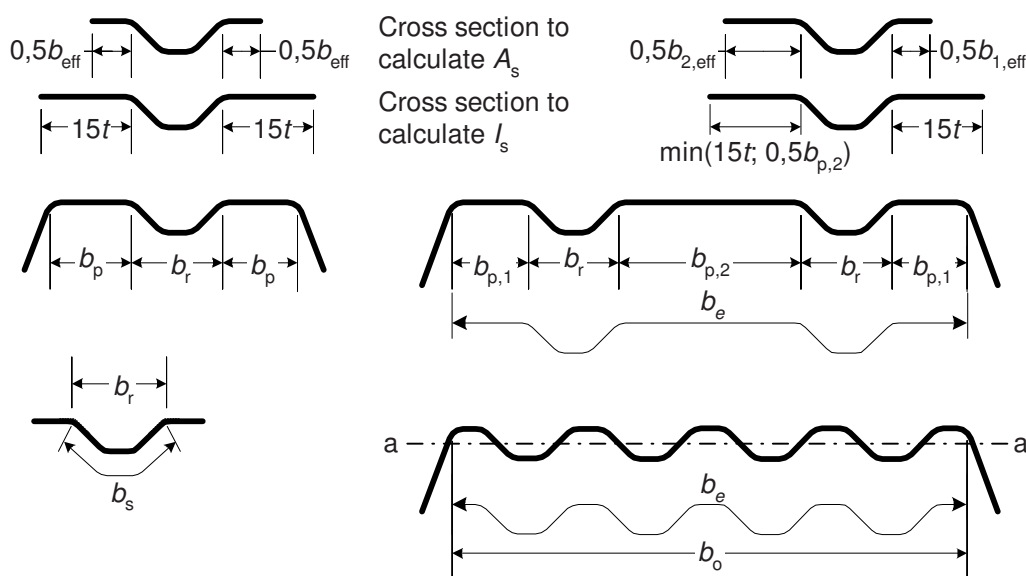


Figure 5.11: Compression flange with one, two or multiple stiffeners

(3) For two symmetrically placed flange stiffeners, the elastic critical buckling stress $\sigma_{cr,s}$ should be obtained from:

$$\sigma_{cr,s} = \frac{4,2 k_w E}{A_s} \sqrt{\frac{I_s t^3}{8 b_1^2 (3 b_e - 4 b_1)}} \quad \dots (5.23a)$$

with:

$$b_e = 2b_{p,1} + b_{p,2} + 2b_s$$

$$b_1 = b_{p,1} + 0,5 b_r$$

where:

$b_{p,1}$ is the notional flat width of an outer plane element, as shown in figure 5.11;

$b_{p,2}$ is the notional flat width of the central plane element, as shown in figure 5.11;

b_r is the overall width of a stiffener, see figure 5.11;

A_s, I_s are the cross-section area and the second moment of area of the stiffener cross-section according to figure 5.11.

(4) For a multiple stiffened flange (three or more equal stiffeners) the effective area of the *entire flange* is

$$A_{eff} = \rho b_e t \quad \dots (5.23b)$$

where ρ is the reduction factor according to EN 1993-1-5, Annex E for the slenderness $\bar{\lambda}_p$ based on the elastic buckling stress

$$\sigma_{cr,s} = 1,8E \sqrt{\frac{I_s t}{b_o^2 b_e^3}} + 3,6 \frac{Et^2}{b_o^2} \quad \dots (5.23c)$$

where:

I_s is the sum of the second moment of area of the stiffeners about the centroidal axis a-a, neglecting the thickness terms $bt^3/12$;

b_o is the width of the flange as shown in figure 5.11;

b_e is the developed width of the flange as shown in figure 5.11.

(5) The value of k_w may be calculated from the compression flange buckling wavelength l_b as follows:

- if $l_b/s_w \geq 2$:

$$k_w = k_{w0} \quad \dots (5.24a)$$

- if $l_b/s_w < 2$:

$$k_w = k_{w0} - (k_{w0} - 1) \left[\frac{2l_b}{s_w} - \left(\frac{l_b}{s_w} \right)^2 \right] \quad \dots (5.24b)$$

where:

s_w is the slant height of the web, see figure 5.1(c).

(6) Alternatively, the rotational restraint coefficient k_w may conservatively be taken as equal to 1,0 corresponding to a pin-jointed condition.

(7) The values of l_b and k_{wo} may be determined from the following:

- for a compression flange with one intermediate stiffener:

$$l_b = 3,07 \sqrt[4]{\frac{I_s b_p^2 (2 b_p + 3 b_s)}{t^3}} \quad \dots (5.25)$$

$$k_{wo} = \sqrt{\frac{s_w + 2 b_d}{s_w + 0,5 b_d}} \quad \dots (5.26)$$

with:

$$b_d = 2b_p + b_s$$

- for a compression flange with two intermediate stiffeners:

$$l_b = 3,65 \sqrt[4]{I_s b_l^2 (3 b_e - 4 b_l) / t^3} \quad \dots (5.27)$$

$$k_{wo} = \sqrt{\frac{(2 b_e + s_w) (3 b_e - 4 b_l)}{b_l (4 b_e - 6 b_l) + s_w (3 b_e - 4 b_l)}} \quad \dots (5.28)$$

(8) The reduced effective area of the stiffener $A_{s,red}$ allowing for distortional buckling (flexural buckling of an intermediate stiffener) should be taken as:

$$A_{s,red} = \chi_d A_s \frac{f_{yb} / \gamma_{M0}}{\sigma_{com,ser}} \quad \text{but } A_{s,red} \leq A_s \quad \dots (5.29)$$

(9) If the webs are unstiffened, the reduction factor χ_d should be obtained directly from $\sigma_{cr,s}$ using the method given in 5.5.3.1(7).

(10) If the webs are also stiffened, the reduction factor χ_d should be obtained using the method given in 5.5.3.1(7), but with the modified elastic critical stress $\sigma_{cr,mod}$ given in 5.5.3.4.4.

(11) In determining effective section properties, the reduced effective area $A_{s,red}$ should be represented by using a reduced thickness $t_{red} = t A_{s,red} / A_s$ for all the elements included in A_s .

(12) The effective section properties of the stiffeners at serviceability limit states should be based on the design thickness t .

5.5.3.4.3 Webs with up to two intermediate stiffeners

(1) The effective cross-section of the compression zone of a web (or other element of a cross-section that is subject to stress gradient) should be assumed to consist of the reduced effective areas $A_{s,red}$ of up to two intermediate stiffeners, a strip adjacent to the compression flange and a strip adjacent to the centroidal axis of the effective cross-section, see figure 5.12.

(2) The effective cross-section of a web as shown in figure 5.12 should be taken to include:

- a strip of width $s_{eff,1}$ adjacent to the compression flange;
- the reduced effective area $A_{s,red}$ of each web stiffener, up to a maximum of two;
- a strip of width $s_{eff,n}$ adjacent to the effective centroidal axis;
- the part of the web in tension.

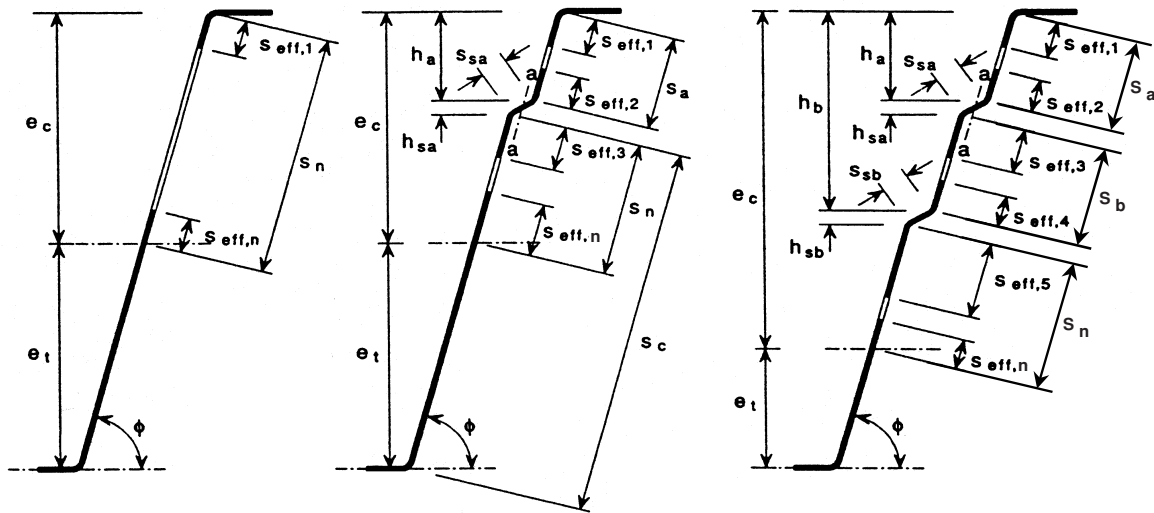


Figure 5.12: Effective cross-sections of webs of trapezoidal profiled sheets

(3) The effective areas of the stiffeners should be obtained from the following:

- for a single stiffener, or for the stiffener closer to the compression flange:

$$A_{sa} = t(s_{eff,2} + s_{eff,3} + s_{sa}) \quad \dots (5.30)$$

- for a second stiffener:

$$A_{sb} = t(s_{eff,4} + s_{eff,5} + s_{sb}) \quad \dots (5.31)$$

in which the dimensions $s_{eff,1}$ to $s_{eff,n}$ and s_{sa} and s_{sb} are as shown in figure 5.12.

(4) Initially the location of the effective centroidal axis should be based on the effective cross-sections of the flanges but the gross cross-sections of the webs. In this case the basic effective width $s_{eff,0}$ should be obtained from:

$$s_{eff,0} = 0,76 t \sqrt{E / (\gamma_{M0} \sigma_{com,Ed})} \quad \dots (5.32)$$

where:

$\sigma_{com,Ed}$ is the stress in the compression flange when the cross-section resistance is reached.

(5) If the web is not fully effective, the dimensions $s_{eff,1}$ to $s_{eff,n}$ should be determined as follows:

$$s_{eff,1} = s_{eff,0} \quad \dots (5.33a)$$

$$s_{eff,2} = (1 + 0,5h_a/e_c) s_{eff,0} \quad \dots (5.33b)$$

$$s_{eff,3} = [1 + 0,5(h_a + h_{sa})/e_c] s_{eff,0} \quad \dots (5.33c)$$

$$s_{eff,4} = (1 + 0,5h_b/e_c) s_{eff,0} \quad \dots (5.33d)$$

$$s_{eff,5} = [1 + 0,5(h_b + h_{sb})/e_c] s_{eff,0} \quad \dots (5.33e)$$

$$s_{eff,n} = 1,5s_{eff,0} \quad \dots (5.33f)$$

where:

e_c is the distance from the effective centroidal axis to the system line of the compression flange, see figure 5.12;

and the dimensions h_a , h_b , h_{sa} and h_{sb} are as shown in figure 5.12.

(6) The dimensions $s_{\text{eff},1}$ to $s_{\text{eff},n}$ should initially be determined from (5) and then revised if the relevant plane element is fully effective, using the following:

- in an unstiffened web, if $s_{\text{eff},1} + s_{\text{eff},n} \geq s_n$ the entire web is effective, so revise as follows:

$$s_{\text{eff},1} = 0,4s_n \quad \dots (5.34a)$$

$$s_{\text{eff},n} = 0,6s_n \quad \dots (5.34b)$$

- in stiffened web, if $s_{\text{eff},1} + s_{\text{eff},2} \geq s_a$ the whole of s_a is effective, so revise as follows:

$$s_{\text{eff},1} = \frac{s_a}{2 + 0,5h_a/e_c} \quad \dots (5.35a)$$

$$s_{\text{eff},2} = s_a \frac{(1 + 0,5h_a/e_c)}{2 + 0,5h_a/e_c} \quad \dots (5.35b)$$

- in a web with one stiffener, if $s_{\text{eff},3} + s_{\text{eff},n} \geq s_n$ the whole of s_n is effective, so revise as follows:

$$s_{\text{eff},3} = s_n \frac{[1 + 0,5(h_a + h_{sa})/e_c]}{2,5 + 0,5(h_a + h_{sa})/e_c} \quad \dots (5.36a)$$

$$s_{\text{eff},n} = \frac{1,5s_n}{2,5 + 0,5(h_a + h_{sa})/e_c} \quad \dots (5.36b)$$

- in a web with two stiffeners:

- if $s_{\text{eff},3} + s_{\text{eff},4} \geq s_b$ the whole of s_b is effective, so revise as follows:

$$s_{\text{eff},3} = s_b \frac{1 + 0,5(h_a + h_{sa})/e_c}{2 + 0,5(h_a + h_{sa} + h_b)/e_c} \quad \dots (5.37a)$$

$$s_{\text{eff},4} = s_b \frac{1 + 0,5h_b/e_c}{2 + 0,5(h_a + h_{sa} + h_b)/e_c} \quad \dots (5.37b)$$

- if $s_{\text{eff},5} + s_{\text{eff},n} \geq s_n$ the whole of s_n is effective, so revise as follows:

$$s_{\text{eff},5} = s_n \frac{1 + 0,5(h_b + h_{sb})/e_c}{2,5 + 0,5(h_b + h_{sb})/e_c} \quad \dots (5.38a)$$

$$s_{\text{eff},n} = \frac{1,5s_n}{2,5 + 0,5(h_b + h_{sb})/e_c} \quad \dots (5.38b)$$

(7) For a single stiffener, or for the stiffener closer to the compression flange in webs with two stiffeners, the elastic critical buckling stress $\sigma_{cr,sa}$ should be determined using:

$$\sigma_{cr,sa} = \frac{1,05 k_f E \sqrt{I_s t^3 s_1}}{A_{sa} s_2 (s_1 - s_2)} \quad \dots (5.39a)$$

in which s_1 is given by the following:

- for a single stiffener:

$$s_1 = 0,9(s_a + s_{sa} + s_c) \quad \dots (5.39b)$$

- for the stiffener closer to the compression flange, in webs with two stiffeners:

$$s_1 = s_a + s_{sa} + s_b + 0,5(s_{sb} + s_c) \quad \dots (5.39c)$$

with:

$$s_2 = s_1 - s_a - 0,5s_{sa} \quad \dots (5.39d)$$

where:

k_f is a coefficient that allows for partial rotational restraint of the stiffened web by the flanges;

I_s is the second moment of area of a stiffener cross-section comprising the fold width s_{sa} and two adjacent strips, each of width $s_{eff,1}$, about its own centroidal axis parallel to the plane web elements, see figure 5.13. In calculating I_s the possible difference in slope between the plane web elements on either side of the stiffener may be neglected;

s_c as defined in Figure 5.12.

(8) In the absence of a more detailed investigation, the rotational restraint coefficient k_f may conservatively be taken as equal to 1,0 corresponding to a pin-jointed condition.

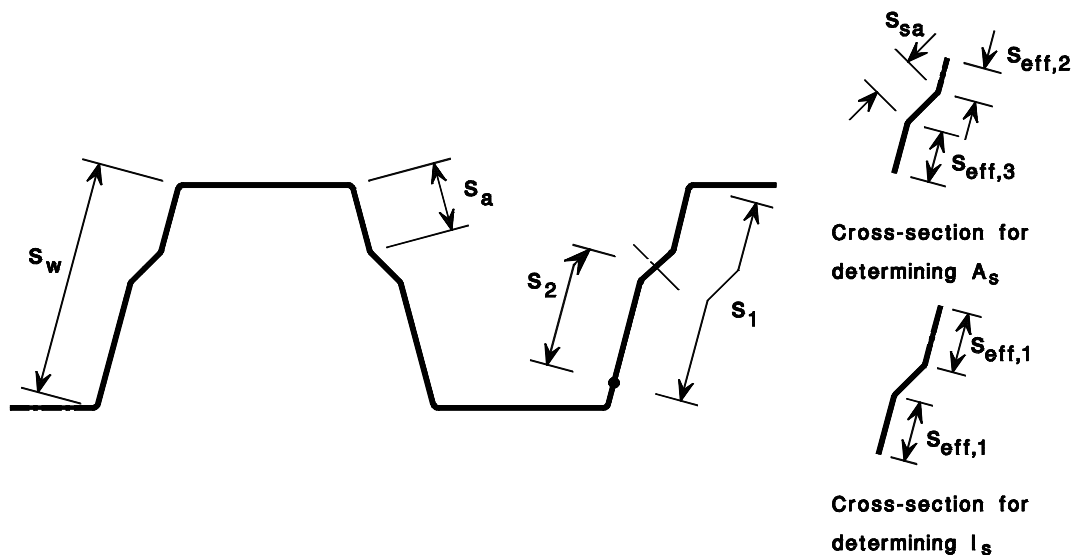


Figure 5.13: Web stiffeners for trapezoidal profiled sheeting

(9) For a single stiffener in compression, or for the stiffener closer to the compression flange in webs with two stiffeners, the reduced effective area $A_{sa,red}$ should be determined from:

$$A_{sa,red} = \frac{\chi_d A_{sa}}{1 - (h_a + 0,5h_{sa})/e_c} \quad \text{but } A_{sa,red} \leq A_{sa} \quad \dots (5.40)$$