The European Union

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EN 1999-1-4 (2007) (English): Eurocode 9: Design of aluminium structures - Part 1-4: Cold-formed structural sheeting [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1999-1-4:2007/A1

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English Version

Eurocode 9: Design of aluminium structures - Part 1-4: Cold-formed structural sheeting

Eurocode 9 - Calcul des structures en aluminium - Partie 1-4: Tôles de structure formées à froid

Eurocode 9: Bemessung und Konstruktion von Aluminiumtragwerken - Teil 1-4: Kaltgeformte Profiltafeln

This amendment A1 modifies the European Standard EN 1999-1-4:2007; it was approved by CEN on 8 April 2011.

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.

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Ref. No. EN 1999-1-4:2007/A1:2011: E

Contents

Page

Foreword

This European Standard (EN 1999-1-4:2007) has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », 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of an identical text or by endorsement, at the latest by August 2007, and conflicting national standards shall be withdrawn at the latest by March 2010.

This European Standard supersedes ENV 1999-1-1:1998, ENV 1999-1-2:1998 and ENV 1999-2:1998.

CEN/TC 250 is responsible for all Structural Eurocodes.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard:

Austria, Bulgaria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italia, Latvia, Lithuania, Luxemburg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom

Background of the Eurocode programme

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonisation of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonised technical rules for the design of construction works, which, in a first stage, would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

For fifteen years, the Commission, with the help of a Steering Committee with Representatives of Member States, conducted the development of the Eurocodes programme, which led to the first generation of European codes in the 1980s.

In 1989, the Commission and the Member States of the EU and EFTA decided, on the basis of an agreement[1] between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to the CEN through a series of Mandates, in order to provide them with a future status of European Standard (EN). This links de facto the Eurocodes with the provisions of all the Council's Directives and/or Commission's Decisions dealing with European standards (e.g. the Council Directive 89/106/EEC on construction products - CPD - and Council Directives 93/37/EEC, 92/50/EEC and 89/440/EEC on public works and services and equivalent EFTA Directives initiated in pursuit of setting up the internal market).

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

EN 1990	Eurocode 0:	Basis of Structural Design
EN 1991	Eurocode 1:	Actions on structures
EN 1992	Eurocode 2:	Design of concrete structures
EN 1993	Eurocode 3:	Design of steel structures
EN 1994	Eurocode 4:	Design of composite steel and concrete structures
EN 1995	Eurocode 5:	Design of timber structures
EN 1996	Eurocode 6:	Design of masonry structures
EN 1997	Eurocode 7:	Geotechnical design
EN 1998	Eurocode 8:	Design of structures for earthquake resistance
EN 1999	Eurocode 9:	Design of aluminium structures

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[1] Agreement between the Commission of the European Communities and the European Committee for Standardisation (CEN) concerning the work on EUROCODES for the design of building and civil engineering works (BC/CEN/03/89).

Eurocode standards recognise the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State.

Status and field of application of Eurocodes

The Member States of the EU and EFTA recognise that Eurocodes serve as reference documents for the following purposes:

- as a means to prove compliance of building and civil engineering works with the essential requirements of Council Directive 89/106/EEC, particularly Essential Requirement No.1 – Mechanical resistance and stability, and Essential Requirement No 2 – Safety in case of fire
- as a basis for specifying contracts for the execution of construction works and related engineering services
- as a framework for drawing up harmonised technical specifications for construction products (En's and ETA's)

The Eurocodes, as far as they concern the construction works themselves, have a direct relationship with the Interpretative Documents[2] referred to in Article 12 of the CPD, although they are of a different nature from harmonised product standards[3]. Therefore, technical aspects arising from the Eurocodes work need to be adequately considered by CEN Technical Committees and/or EOTA Working Groups working on product standards with a view to achieving full compatibility of these technical specifications with the Eurocodes.

The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and an innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

National standards implementing Eurocodes

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National annex [informative].

The National Annex (informative) may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, i.e. :

- values for partial factors and/or classes where alternatives are given in the Eurocode;
- values to be used where a symbol only is given in the Eurocode;
- geographical and climatic data specific to the Member State, e.g. snow map;
- the procedure to be used where alternative procedures are given in the Eurocode;
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

Links between Eurocodes and harmonised technical specifications (EN's and ETA's) for products

There is a need for consistency between the harmonised technical specifications for construction products and the technical rules for works[4]. Furthermore, all the information accompanying the CE Marking of the

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[2] According to Art. 3.3 of the CPD, the essential requirements (ERs) shall be given concrete form in interpretative documents for the creation of the necessary links between the essential requirements and the mandates for harmonised ENs and ETAGs/ETAs.

[3] According to Art. 12 of the CPD the interpretative documents shall :
a) give concrete form to the essential requirements by harmonising the terminology and the technical bases and indicating classes or levels for each requiremen where necessary ;
b) indicate methods of correlating these classes or levels of requirement with the technical specifications, e.g. methods of calculation and of proof, technical rule for project design, etc. ;
c) serve as a reference for the establishment of harmonised standards and guidelines for European technical approvals.
The Eurocodes, *de facto*, play a similar role in the field of the ER 1 and a part of ER 2.

[4] see Art.3.3 and Art.12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID 1.

construction products which refer to Eurocodes shall clearly mention which Nationally Determined Parameters have been taken into account.

Foreword to amendment A1

This document (EN 1999-1-4:2007/A1:2011) has been prepared by Technical Committee CEN/TC 250 "Structural Eurocodes", the secretariat of which is held by BSI.

This Amendment to the European Standard EN 1999-1-4:2007 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2012, and conflicting national standards shall be withdrawn at the latest by August 2012.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

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, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

National Annex for EN 1999-1-4

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 1999-1-4 should have a National Annex containing all Nationally Determined Parameters to be used for the design of aluminium structures to be constructed in the relevant country.

National choice is allowed in EN 1999-1-4 through clauses:

- 2(3)
- 2(4)
- 2(5)
- 3.1(3)
- 7.3(3)
- A.1(1)
- A.3.4(3)

1 General

1.1 Scope

1.1.1 Scope of EN 1999

(1)P EN 1999 applies to the design of buildings and civil engineering and structural works in aluminium. It complies with the principles and requirements for the safety and serviceability of structures, the basis of their design and verification that are given in EN 1990 – Basis of structural design.

(2) EN 1999 is only concerned with requirements for resistance, serviceability, durability and fire resistance of aluminium structures. Other requirements, e.g. concerning thermal or sound insulation, are not considered.

(3) EN 1999 is intended to be used in conjunction with:

- EN 1990 "Basis of structural design"
- EN 1991 "Actions on structures"
- European Standards construction products relevant for aluminium structures
- EN 1090-1: Execution of steel structures and aluminium structures – Part 1: Requirements for conformity assessment of structural components[5]
- EN 1090-3: Execution of steel structures and aluminium structures – Part 3: Technical requirements for aluminium structures[5]

(4) EN 1999 is subdivided in five parts:

EN 1999-1-1	Design of Aluminium Structures: General structural rules.
EN 1999-1-2	Design of Aluminium Structures: Structural fire design.
EN 1999-1-3	Design of Aluminium Structures: Structures susceptible to fatigue.
EN 1999-1-4	Design of Aluminium Structures: Cold-formed structural sheeting.
EN 1999-1-5	Design of Aluminium Structures: Shell structures.

1.1.2 Scope of EN 1999-1-4

(1)P EN 1999-1-4 gives design requirements for cold-formed trapezoidal aluminium sheeting. It applies to cold-formed aluminium products made from hot rolled or cold rolled sheet or strip that have been cold-formed by such processes as cold-rolled forming or press-breaking. The execution of aluminium structures made of cold-formed sheeting is covered in EN 1090-3.

NOTE The rules in this part complement the rules in other parts of EN 1999-1.

(2) Methods are also given for stressed-skin design using aluminium sheeting as a structural diaphragm.

(3) This part does not apply to cold-formed aluminium profiles like C-, Z- etc profiles nor cold-formed and welded circular or rectangular hollow sections.

(4) EN 1999-1-4 gives methods for design by calculation and for design assisted by testing. The methods for the design by calculation apply only within stated ranges of material properties and geometrical properties for which sufficient experience and test evidence is available. These limitations do not apply to design by testing.

(5) EN 1999-1-4 does not cover load arrangement for loads during execution and maintenance.

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[5] To be published

1.2 Normative references

(1) The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

1.2.1 General references

EN 1090-1:	Execution of steel structures and aluminium structures – Part 1: Requirements for conformity assessment of structural components[6]
EN 1090-3:	Execution of steel structures and aluminium structures – Part 3: Technical requirements for aluminium structures[6]

1.2.2 References on structural design

EN 1990	Eurocode 0 - Basis of structural design
EN 1991	Eurocode 1 – Action on structures – All parts
EN 1995-1-1	Eurocode 5: Design of timber structures - Part 1-1 General rules and rules for buildings
EN 1999-1-1	Eurocode 9: Design of aluminium structures - Part 1-1 General structural rules

1.2.3 Materials and materials testing

[AC1⟩ EN 485-2:2008 ⟨AC1]	Aluminium and aluminium alloys - Sheet, strip and plate - Part 2: Mechanical properties
[AC1⟩ EN 508-2 ⟨AC1]	Roofing products from metal sheet - Specification for self-supporting products of steel, aluminium or stainless steel sheet - Part 2: Aluminium
[AC1⟩ EN 1396:2007 ⟨AC1]	Aluminium and aluminium alloys - Coil coated sheet and strip for general applications - Specifications
EN 10002-1	Metallic materials - Tensile testing - Part 1: Method of test at ambient temperature

[AC1⟩ *Text deleted* ⟨AC1]

1.2.4 References on fasteners

EN ISO 1479	Hexagon head tapping screws
EN ISO 1481	Slotted pan head tapping screws
EN ISO 15480	Hexagon washer head drilling screws with tapping screw thread
EN ISO 15481	Cross recessed pan head drilling screws with tapping screw thread
EN ISO 15973	Closed end blind rivets with break pull mandrel and protruding head
EN ISO 15974	Closed end blind rivets with break pull mandrel and countersunk head
EN ISO 15977	Open end blind rivets with break pull mandrel and protruding head
EN ISO 15978	Open end blind rivets with break pull mandrel and countersunk head
EN ISO 15981	Open end blind rivets with break pull mandrel and protruding head
EN ISO 15982	Open end blind rivets with break pull mandrel and countersunk head
ISO 7049:1994	Cross recessed pan head tapping screws

1.2.5 Other references

EN ISO 12944-2	Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 2: Classification of environments

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[6] To be published

1.3 Terms and definitions

Supplementary to EN 1999-1-1, for the purposes of EN 1999-1-4, the following definitions apply:

1.3.1

base material

the flat sheet aluminium material out of which profiled sheets are made by cold forming

1.3.2

proof strength of base material

the 0,2 % proof strength f_0 of the base material

1.3.3

diaphragm action

structural behaviour involving in-plane shear in the sheeting

1.3.4

partial restraint

restriction to some extent of the lateral or rotational displacement of a cross-section part, that increases its buckling resistance

1.3.5

restraint

full restriction of the lateral displacement or rotational movement of a plane cross-section part, that increases its buckling resistance

1.3.6

slenderness parameter

a normalised, material related slenderness ratio

1.3.7

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

1.3.8

support

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

1.3.9

effective thickness

a design value of the thickness to allow for local buckling of plane cross section part.

1.3.10

reduced effective thickness

a design value of the thickness to allow for distortional buckling of stiffeners in a second step of the calculation procedure for plane cross section parts, where local buckling is allowed for in the first step .

1.4 Symbols

(1) In addition to those given in EN 1999-1-1, the following main symbols are used:

Section 1 to 6

C	rotational spring stiffness;
k	linear spring stiffness;
θ	rotation;
b_p	notional flat width of plane cross-section part;
h_w	web height, measured between system lines of flanges;
s_w	slant height of web, measured between midpoints of corners;
χ_d	reduction factor for distortional buckling (flexural buckling of stiffeners);
φ	is the angle between two plane elements;
ϕ	is the slope of the web relative to the flanges.

Section 8 Joints with mechanical fasteners

d_w	diameter of the washer or the head of the fastener;
$f_{u,min}$	minor ultimate tensile strength of both connected parts;
$f_{u,sup}$	ultimate tensile strength of the supporting component into which a screw is fixed;
f_y	yield strength of supporting component of steel;
t_{min}	thickness of the thinner connected part or sheet;
t_{sup}	thickness of the supporting member in which the screw is fixed;

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

1.5 Geometry and conventions for dimensions

1.5.1 Form of sections

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

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

(3) Typical forms of cross-sections for cold formed profiled sheets are shown in Figure 1.1.

(4) Cross-sections of cold formed sheets can 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 sheets are shown in Figure 1.2;

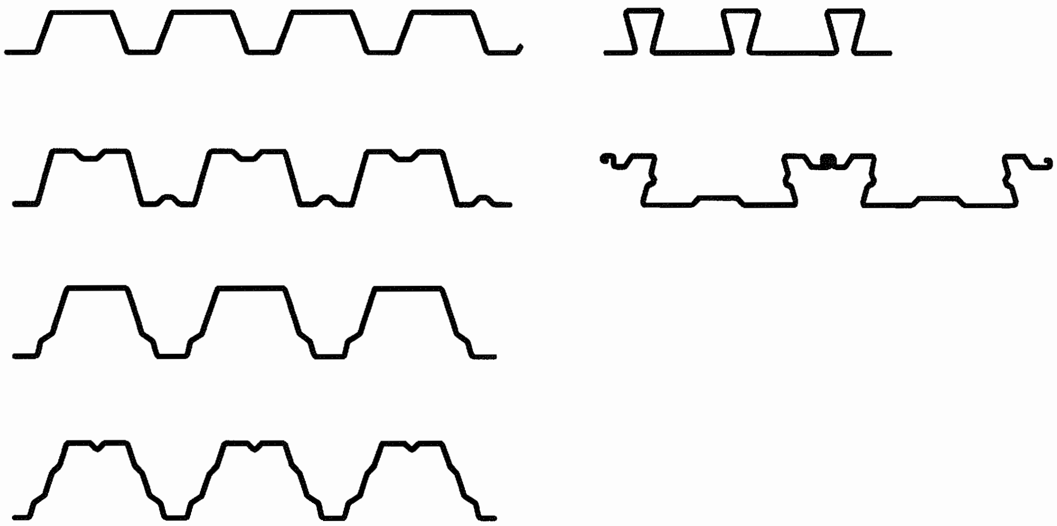


Figure 1.1 - Examples of cold-formed sheeting

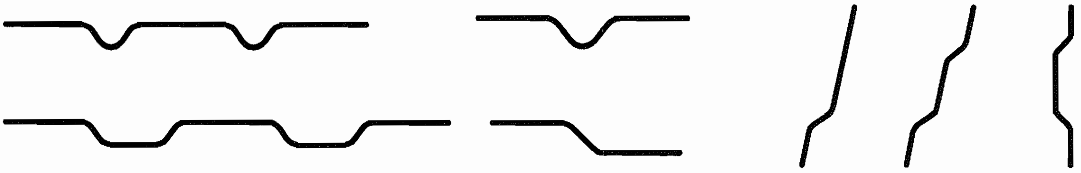


Figure 1.2 - Typical intermediate longitudinal stiffeners

1.5.3 Cross-section dimensions

(1) Overall dimensions of cold-formed sheeting, including overall width b, overall height h, internal bend radius r and other external dimensions denoted by symbols without subscripts, are measured to the outer contour of the section, unless stated otherwise, see Figure 5.1.

(2) Unless stated otherwise, the other cross-sectional dimensions of cold-formed sheeting, denoted by symbols with subscripts, such as b_p, 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 webs of cold-formed profiled sheets, the slant height s is measured parallel to the slope.

(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 an aluminium design thickness if not otherwise stated. See 3.2.2.

1.5.4 Convention for member axis

(1) For profiled sheets the following axis convention is used in EN 1999-1-4:

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

2 Basis of design

(1)P The design of cold-formed sheeting shall be in accordance with the general rules given in EN 1990 and EN 1999-1-1.

(2)P Appropriate partial factors shall be adopted for ultimate limit states and serviceability limit states.

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

- resistance of cross-sections and members to instability:	γ_{M1}
- resistance of cross-sections in tension to fracture:	γ_{M2}
- resistance of joints:	γ_{M3}

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

$\gamma_{M1} = 1{,}10$

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

$\gamma_{M3} = 1{,}25$

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

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

$\gamma_{M,ser} = 1{,}0$.

(5) For the design of structures made of cold-formed sheeting a distinction should be made between "**Structural Classes**" dependent on its function in the structure defined as follows:

Structural Class I:	Construction where cold-formed sheeting is designed to contribute to the overall strength and stability of the structure, see 6.3.3;
Structural Class II:	Construction where cold-formed sheeting is designed to contribute to the strength and stability of individual structural components;
Structural Class III:	Construction where cold-formed sheeting is used as a component that only transfers loads to the structure.

NOTE 1 National Annex may give rules for the use of Structural Classes and the connection to Consequence Classes in EN 1990.

NOTE 2 For Structural Class I and II the requirement for execution should be given in the execution specification, see EN 1090-3

3 Materials

3.1 General

(1) The methods for design by calculation given in EN 1999-1-4 may be used for the structural alloys in the tempers listed in table 3.1.

(2) For design by calculation given in EN 1999-1-4 the 0,2 proof strength f_o should be at least $f_o = 165$ N/mm^2.

(3) Aluminium sheet and strip used for cold-formed profile sheeting should be suitable for the specific cross section depending on cold forming and cold forming process.

NOTE For other aluminium materials and products see National Annex.

3.2 Structural aluminium alloys

3.2.1 Material properties

(1) The characteristic values of 0,2 proof strength f_o and tensile strength f_u have been obtained by adopting the values for minimum $R_{p0,2}$ and R_m direct from the relevant product standards.

(2) It may be assumed that the properties in compression are the same as those in tension.

(3) If partially plastic moment resistance is utilised, the ratio of the characteristic ultimate tensile strength f_u to the characteristic 0,2 proof strength f_o should be not less than 1,2.

(4) The material constants (modulus of elasticity etc) should be taken as given in EN 1999-1-1.

Table 3.1 - Characteristic values of 0,2% proof strength f_o, ultimate tensile strength, f_u, elongation A_{50}, for sheet and strip for tempers with f_o > 165 N/mm^2 and thickness between 0,5 and 6 mm

Designation numerical EN AW-	Designation chemical EN AW-	Durability rating 5)	Temper 1), 2), 3)	Thickness up to mm	f_u R_m N/mm^2	f_o $R_{p0,2}$ 1) N/mm^2	A_{50} % 4)
3003	AlMn1Cu	A	H18	3,0	190	170	2
			H48	3,0	180	165	2
3004	AlMn1Mg1	A	H14 | H24/H34	6 | 3	220	180 | 170	2-3 | 4
			H16 | H26/H36	4 | 3	240	200 | 190	1-2 | 3
			H18 | H28/H38	3 | 1,5	260	230 | 220	1-2 | 3
			H44	3	210	180	4
			H46	3	230	200	3
			H48	3	260	220	3
3005	AlMn1Mg0,5	A	H16	4	195	175	2
			H18 | H28	3	220	200 | 190	2 | 2-3
			H48	3	210	180	2
3103	AlMn1	A	H18	3	185	165	2
3105	AlMn0,5Mg0,5	A	H18 | H28	3 | 1,5	195	180 | 170	1 | 2
			H48	3	195	170	2
5005	AlMg1(B)	A	H18	3	185	165	2
5052	AlMg2,5	A	H14	6	230	180	3-4
			H16 | H26/H36	6	250	210 | 180	3 | 4-6
			H18 | H28/H38	3	270	240 | 210	2 | 3-4
			H46	3	250	180	4-5
			H48	3	270	210	3-4
5251	[AC1⟩ AlMg2Mn0,3 ⟨AC1]	A	H14	6	210	170	2-4
			H16 | H26/H36	4	230	200 | 170	2-3 | 4-7
			H18 | H28/H38	3	255	230 | 200	2 | 3
			H46	3	210	165	4-5
			H48	3	250	215	3
[A1⟩ 6025-7072 alclad$^{6)}$	AlMg2,5SiMnCu-AlZn1 alclad$^{6)}$	A	H34	5	210	165	2-3
			H36	5	220	185	2-4 ⟨A1]

1) The values for temper H1x, H2x, H3x according to [AC1⟩ EN 485-2:2008 ⟨AC1]

2) The values for temper H4x (coil coated sheet and strip) according to [AC1⟩ EN 1396:2007 ⟨AC1]

3) If two (three) tempers are specified in one line, tempers separated by "|" have different technological values, but separated by "/" have same values. (The tempers show differences only for f_o and A_{50}.)

4) A_{50} may be depending on the thickness of material in the listed range, therefore sometimes also a A_{50}-range is given.

5) Durability rating, see EN 1999-1-1

[A1⟩ 6) EN AW-6025-7072 alclad (EN AW-AlMg2,5SiMnCu-AlZn1 alclad) is a composite material with core material EN AW-6025 and a cladding on both sides with EN AW-7072. For reasons of durability the cladding should have a thickness of at least 4% of the overall thickness of the material on each side. If the thickness of the cladding exceeds 5% this fact should be considered in the structural calculations, i.e. only the core thickness of the composite sheet should be taken in account. For these reasons the minimum cladding thickness of 4% and the minimum core thickness should be specified in the execution specification in order that the constructor can procure the corresponding constituent products with inspection certificate 3.1. ⟨A1]

3.2.2 Thickness and geometrical tolerances

(1) The provisions for design by calculation given in this EN 1999-1-4 may be used for alloy within the following ranges of nominal thickness t_{nom} of the sheeting exclusive of organic coatings:

$$t_{\mathrm{nom}} \geq 0{,}5 \text{ mm}$$

(2) The nominal thickness t_{nom} should be used as design thickness t if a negative deviation is less than 5 %. Otherwise

$$t = t_{\mathrm{nom}}(100 - dev)/95 \tag{3.1}$$

where dev is the negative deviation in %.

(3) Tolerances for roofing products are given in EN 508-2.

3.3 Mechanical fasteners

(1) The following types of mechanical fasteners may be used:

- self-tapping screws as thread-forming self-tapping screws or self-drilling self-tapping screws according to standards listed in 8.3;
- blind rivets according to standards listed in 8.2.

(2) The characteristic shear resistance $F_{\mathrm{v,Rk}}$ and the characteristic tension resistance $F_{\mathrm{t,Rk}}$ of the mechanical fasteners should be calculated according to 8.2 and 8.3.

(3) For details concerning suitable self-tapping screws, and self-drilling screws and blind rivets, reference should be made to EN 1090-3.

(4) Characteristic shear resistance and characteristic tension resistance of mechanical fasteners not covered in this European Standard may be taken from ETA certifications.

4 Durability

(1) For basic requirements, see Section 4 of EN 1999-1-1

(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 For corrosion resistance of fasteners for the environmental corrosivity categories following EN ISO 12944-2, see Annex B.

(3) The environmental conditions prevailing from the time of manufacture, including those during transport and storage on site, should be taken into account.

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 cross-section parts should be measured from the midpoints of the adjacent corner cross-section parts, as indicated in Figure 5.1.

(2) In cross-sections with rounded corners, the calculation of section properties should be based upon the actual 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 section properties may be neglected if the internal radius $r \leq 10t$ and $r \leq 0{,}15b_p$ and the cross-section may be assumed to consist of plane cross-section parts with sharp corners.

(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, using the following approximations:

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

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

with:

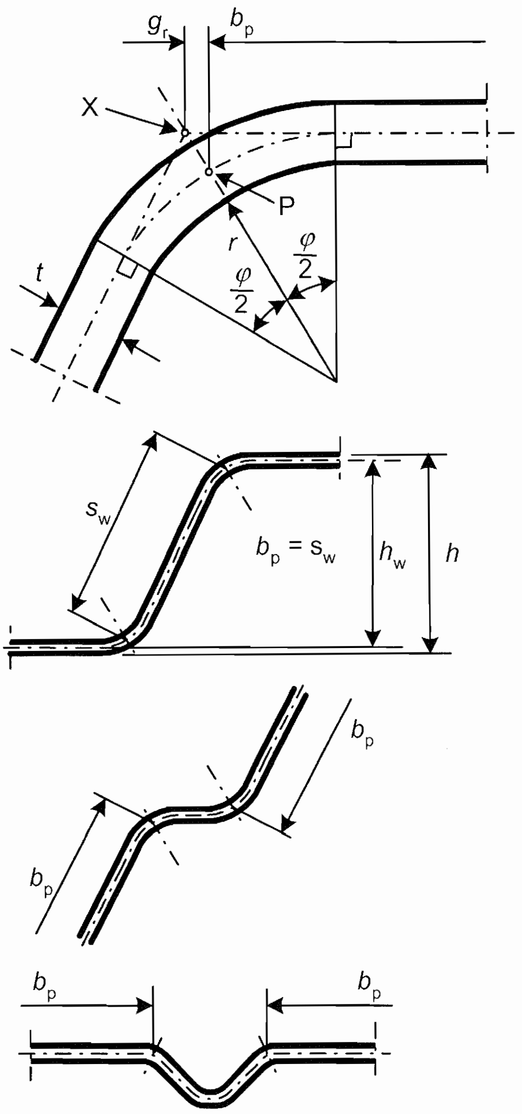
$$\delta = 0{,}43 \cdot \sum_{j=1}^{n}(r_j \varphi_j / 90) \bigg/ \sum_{i=1}^{m} b_{p,i} \tag{5.1c}$$

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 cross-section part 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;
φ	is the angle between two plane elements;
m	is the number of plane cross-section parts;
n	is the number of curved cross-section parts without consideration of the curvature of stiffeners in webs and flanges;
r_j	is the internal radius of curved cross-section part.

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

(6) Where the internal radius $r \geq 0{,}04tE / f_o$, then the resistance of the cross-section should be determined by tests.



(a) midpoint of corner or bend

X is intersection of midlines
P is midpoint of corner

$r_m = r + t/2$

$g_r = r_m\left(\tan(\frac{\varphi}{2}) - \sin(\frac{\varphi}{2})\right)$

(b) notional flat width b_p for a web
(b_p = slant height s_w)

(c) notional flat width b_p of plane parts adjacent to web stiffener

(d) notional flat width b_p of flat parts adjacent to flange stiffener

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

5.2 Geometrical proportions

(1) The provisions for design by calculation given in EN 1999-1-4 should not be applied to cross-sections outside the range of width-to-thickness ratios b/t and s_w/t given in (2).

(2) The maximum width-to-thickness ratios are:

- for compressed flanges $b/t \leq 300$
- for webs $s_w/t \leq 0{,}5E/f_o$

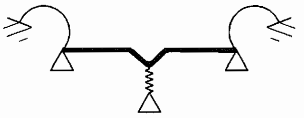
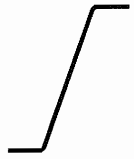
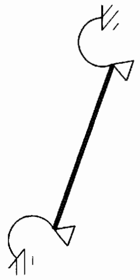
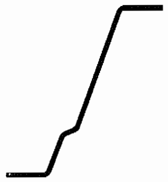
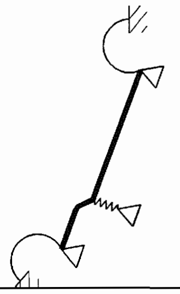
NOTE These limits b/t and s_w/t given in (2) may be assumed to represent the field for which sufficient experience and verification by testing is available. Cross-sections with larger width-to-thickness ratios may also be used, provided that their resistance at ultimate limit states and their behaviour at serviceability limit states are verified by testing and/or by calculations, where the results are confirmed by an appropriate number of tests.

5.3 Structural modelling for analysis

(1) The parts of a cross-section may be modelled for analysis as indicated in Table 5.1

(2) The mutual influence of multiple stiffeners should be taken into account.

Table 5.1 - Modelling of parts of a cross-section

Type of cross-section part	Model	Type of cross-section part	Model
			
			

5.4 Flange curling

(1) The effect on the load bearing resistance of curling (i.e. inward curvature towards the neutral plane) of a very wide flange in a profile subject to flexure, or of an initially curved profile subject 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 load bearing resistance, for instance due to decrease in length of the lever arm for part of the wide flange, and to the possible effect of bending should be taken into account.

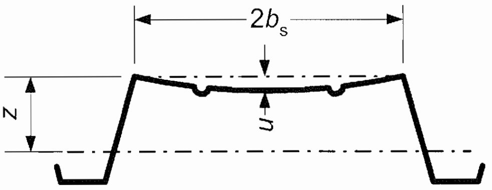


Figure 5.2 - Flange curling

(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 transverse stiffeners in flanges.

- For a profile, which is straight prior to application of loading, see Figure 5.2:

$$u = \frac{2\sigma_a^2 b_s^4}{E^2 t^2 z} \tag{5.1e}$$

- For an initially curved profile

$$u = \frac{2\sigma_a b_s^4}{E t^2 r} \tag{5.1f}$$

where:

u is bending of the flange towards the neutral axis (curling), see Figure 5.2;

b_s is half the distance between the webs;

z is distance of flange under consideration from neutral axis;

r is radius of curvature of initially curved profile;

σ_a is mean stress in the flange calculated with the gross area. If the stress is calculated for 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.

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 sheeting.

(2) Local buckling effects may be considered by using effective cross-sectional properties, calculated on the basis of the effective thickness, see EN 1999-1-1.

(3) In determining resistance to local buckling, the 0,2 proof strength f_o should be used.

(4) For effective cross-section properties for serviceability verifications, see 7.1(3)

(5) The distortional buckling of cross-section parts with intermediate stiffeners is considered in 5.5.3.

5.5.2 Plane cross-section parts without stiffeners

(1) The effective thickness t_{eff} of compression cross-section parts should be obtained as $t_{\mathrm{eff}} = \rho \cdot t$, where ρ is a reduction factor allowing for local buckling.

(2) The notional flat width b_p of a plane cross-section part should be determined as specified in 5.1. In the case of plane cross-section parts in a sloping web, the appropriate slant height should be used.

(3) The reduction factor ρ to determine t_{eff} should be based on the largest compressive stress $\sigma_{\mathrm{com,Ed}}$ in the relevant cross-section part (calculated on the basis of the effective cross-section), when the resistance of the cross-section is reached.

(4) If $\sigma_{\mathrm{com,Ed}} = f_0 / \gamma_{\mathrm{M1}}$ the reduction factor ρ should be obtained from the following:

- if $\bar{\lambda}_p \leq \bar{\lambda}_{\mathrm{lim}}$: $\rho = 1{,}0$ (5.2a)
- if $\bar{\lambda}_p > \bar{\lambda}_{\mathrm{lim}}$: $\rho = \alpha\left(1 - 0{,}22/\bar{\lambda}_p\right) / \bar{\lambda}_p$ (5.2b)

in which the plate slenderness $\bar{\lambda}_p$ is given by:

$$\bar{\lambda}_p = \sqrt{\frac{f_o}{\sigma_{\mathrm{cr}}}} \equiv \frac{b_p}{t} \cdot \sqrt{\frac{12\left(1 - \nu^2\right) f_o}{\pi^2 E k_\sigma}} \cong 1{,}052 \frac{b_p}{t} \sqrt{\frac{f_o}{E k_\sigma}} \tag{5.3}$$

k_σ is the relevant buckling factor from Table 5.3. The parameters $\bar{\lambda}_{\mathrm{lim}}$ and α may be taken from Table 5.2.

Table 5.2 - Parameters λ_{lim} and α

$\bar{\lambda}_{\mathrm{lim}}$	α
0,517	0,90

(5) If $\sigma_{\mathrm{com,Ed}} < f_o / \gamma_{\mathrm{M1}}$ the reduction factor ρ may be determined as follows:

Use expressions (5.2a) and (5.2b) but replace the plate slenderness $\bar{\lambda}_p$ by the reduced plate slenderness $\bar{\lambda}_{p,\mathrm{red}}$ given by:

$$\bar{\lambda}_{p,red} = \bar{\lambda}_p \sqrt{\frac{\sigma_{com,Ed}}{f_o/\gamma_{M1}}} \tag{5.4}$$

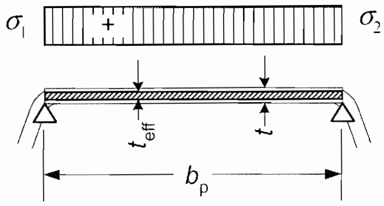
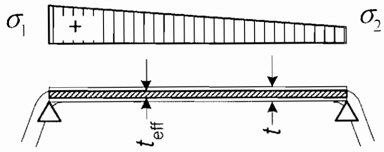
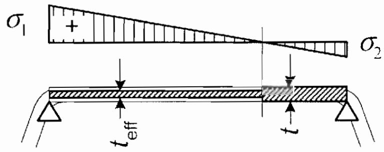
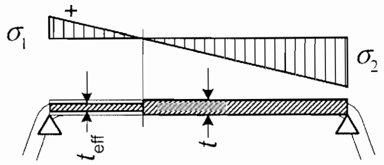
(6) For calculation of effective stiffness at serviceability limit states, see 7.1(3)

(7) In determining the effective thickness of a flange cross-section part subject to stress gradient, the stress ratio ψ used in Table 5.3 may be based on the properties of the gross cross-section.

(8) In determining the effective thickness of a web cross-section part the stress ratio ψ used in Table 5.3 may be obtained using the effective area of the compression flange but the gross area of the web.

(9) Optionally the effective section properties may be refined by repeating (6) and (7) iteratively, but using the effective cross-section already found in place of the gross cross-section. The minimum steps in the iteration dealing with stress gradient are two.

Table 5.3 - Buckling coefficient k_σ for cross-section parts in compression

Cross-section part (+ = compression)	$\psi = \sigma_2 / \sigma_1$	Buckling factor k_σ
	$\psi = +1$	$k_\sigma = 4{,}0$
	$+1 > \psi \geq 0$	$k_\sigma = \frac{8{,}2}{1{,}05 + \psi}$
	$0 > \psi \geq -1$	$k_\sigma = 7{,}81 - 6{,}26\psi + 9{,}78\psi^2$
	$-1 > \psi \geq -3$	$k_\sigma = 5{,}98(1 - \psi)^2$

5.5.3 Plane cross-section parts with intermediate stiffeners

5.5.3.1 General

(1) The design of compression cross-section parts with 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 cross-section parts.

(2) The spring stiffness of a stiffener should be determined by applying a unit load per unit length u as illustrated in Figure 5.3. The spring stiffness k per unit length may be determined from:

$$k = u/\delta \tag{5.5}$$

where δ is the deflection of a transverse plate strip due to the unit load u acting at the centroid (b_1) of the effective part of the stiffener.

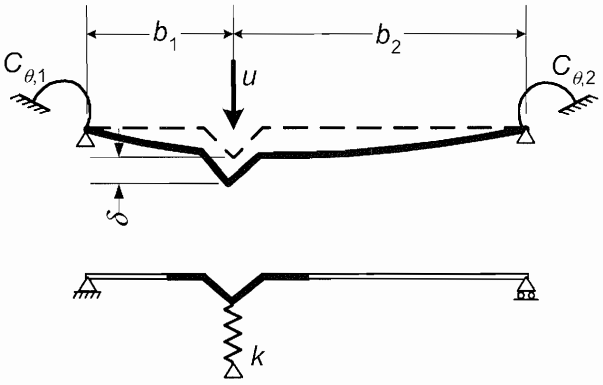


Figure 5.3 - Model for determination of spring stiffness

(3) In determining the values of the rotational spring stiffness $C_{\theta,1}$ 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 cross-section part, or on any other parts of the cross-section that is subject to compression.

(4) 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:

$$\delta = \frac{u b_1^2 b_2^2}{3(b_1 + b_2)} \frac{12(1-\nu^2)}{E t^3} \tag{5.6}$$

(5) The reduction factor χ_d for the distortional buckling resistance of a stiffener (flexural buckling of an intermediate stiffener) should be obtained from Table 5.4 for the slenderness parameter given in (5.7)

$$\overline{\lambda}_s = \sqrt{f_o / \sigma_{cr,s}} \tag{5.7}$$

where: $\sigma_{cr,s}$ is the elastic critical stress for the stiffener from 5.5.3.3 or 5.5.4.2.

Table 5.4 - Reduction factor χ_d for distortional buckling of stiffeners

$\overline{\lambda}_s$	χ_d
$\overline{\lambda}_s \le 0{,}25$	1,00
$0{,}25 < \overline{\lambda}_s < 1{,}04$	$1{,}155 - 0{,}62\overline{\lambda}_s$
$1{,}04 \le \overline{\lambda}_s$	$0{,}53 / \overline{\lambda}_s$

5.5.3.2 Condition for use of the design procedure

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

(2) The stiffeners should be equally shaped and not more than two in number. For more stiffeners not more than two should be taken into account.

(3) If the criteria in (1) and (2) are met the effectiveness of the stiffener may be determined from the design procedure given in 5.5.3.3.

5.5.3.3 Design procedure

(1) The cross-section of an intermediate stiffener should be taken as comprising the stiffener itself plus the adjacent effective portions of the adjacent plane cross-section parts $b_{p,1}$ and $b_{p,2}$ shown in Figure 5.4.

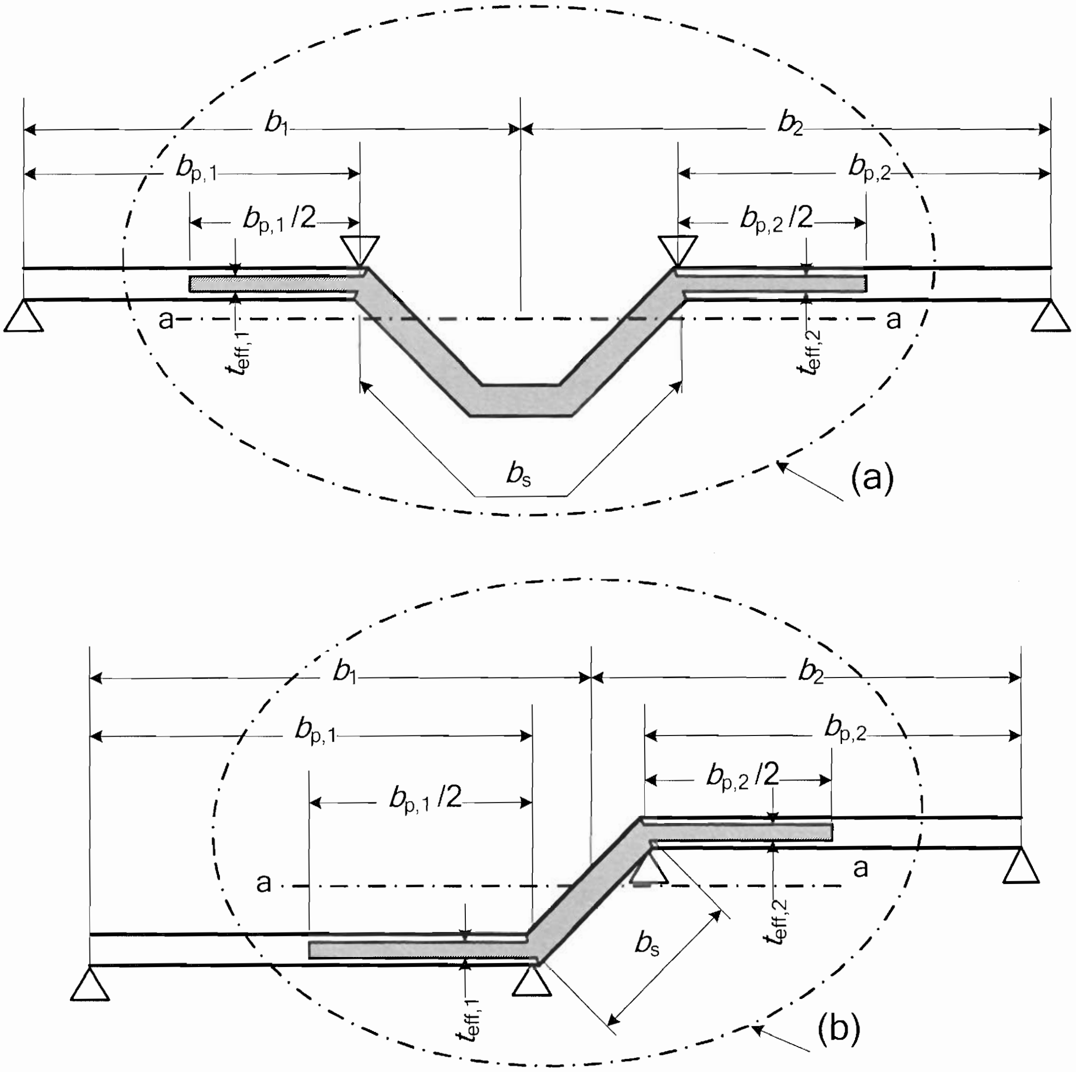


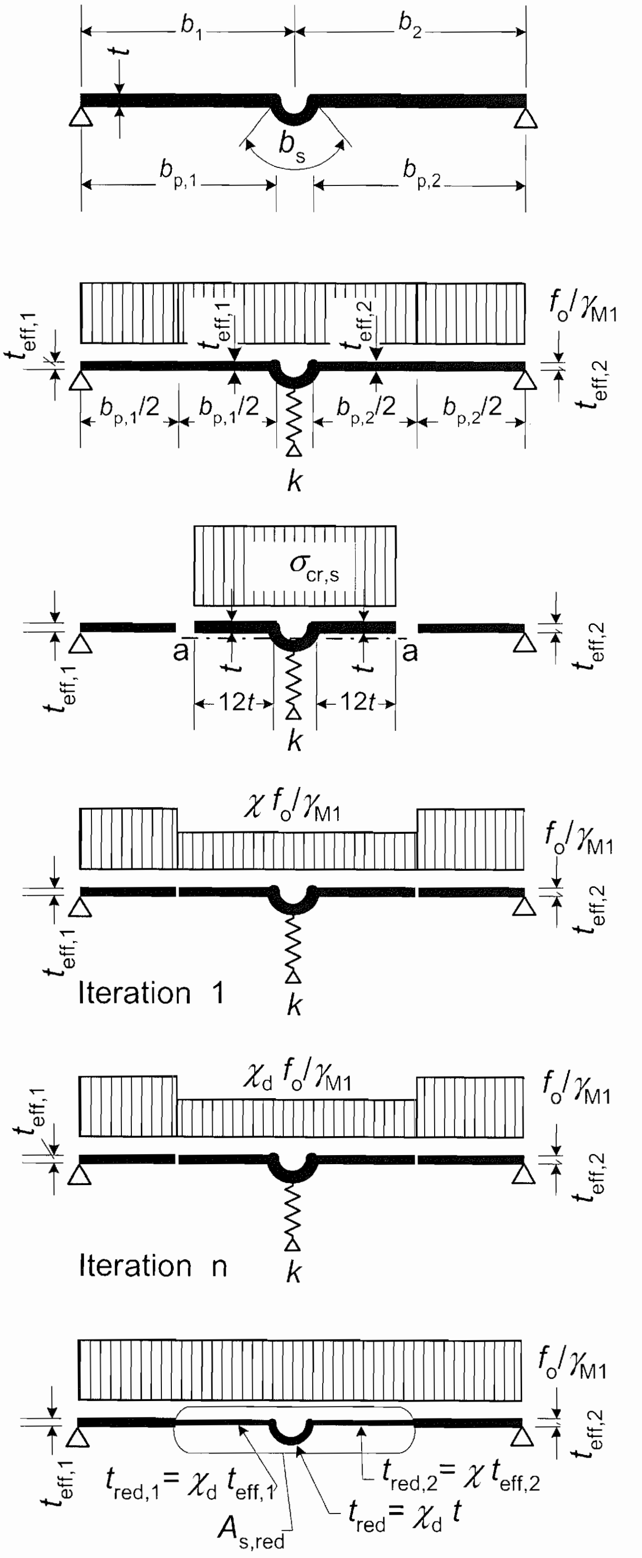
Figure 5.4 – Initial effective cross-section area A_s for intermediate stiffeners in (a) flange and (b) web

(2) The procedure, which is illustrated in Figure 5.5, should be carried out in steps as follows:

- **Step 1**: Obtain an initial effective cross-section for the stiffener to calculate the cross-section area A_s using effective thickness determined by assuming that the stiffener is longitudinally supported and that $\sigma_{com,Ed} = f_o/\gamma_{M1}$, see (3) and (4);

- **Step 2**: Use another effective cross-section of the stiffener to calculate the effective second moment of inertia in order to determine the reduction factor for distortional buckling, allowing for the effects of the continuous spring restraint, see (5) and (6);

- **Step 3**: Optionally iterate to refine the value of the reduction factor for buckling of the stiffener, see (7) and (8).



a) Gross cross-section and boundary conditions

b) **Step 1**: Effective cross-section for $k = \infty$ based on $\sigma_{com,Ed} = f_o / \gamma_{M1}$

c) **Step 2**: Elastic critical stress $\sigma_{cr,s}$ for effective cross-section based on effective width $12t$ and spring stiffness k

d) Reduced strength $\chi_d f_o / \gamma_{M1}$ for effective area of stiffener A_s, with reduction factor χ_d based on $\sigma_{cr,s}$

e) **Step 3**: Optionally repeat step 1 by calculating the effective thickness with a reduced compressive stress $\sigma_{com,Ed,i} = \chi_d f_o / \gamma_{M1}$ 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 $A_{s,red}$ with reduced thickness t_{red} corresponding to $\chi_{d,n}t$ for stiffener and reduced effective thickness $\chi_{d,n}t_{eff}$ for adjacent flat parts.

Figure 5.5 – Model for calculation of compression resistance of a flange with intermediate stiffener

(3) Initial values of the effective thickness $t_{eff,1}$ and $t_{eff,2}$ shown in Figure 5.4 should be determined from 5.5.2 by assuming that the plane cross-section parts $b_{p,1}$ and $b_{p,2}$ are doubly supported, see Table 5.1.

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

$$A_s = t_{eff,1}\, b_{p,1} / 2 + t\, b_s + t_{eff,2}\, b_{p,2} / 2 \qquad (5.8)$$

in which the stiffener width b_s is as shown in Figure 5.4.

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

$$\sigma_{cr,s} = \frac{2\sqrt{kEI_s}}{A_s} \tag{5.9}$$

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, using the thickness t and notional effective width $12t$ of adjacent plane cross-section parts about the centroidal axis a - a of its effective cross-section, see Figure 5.6(a).

(6) The reduction factor χ_d for the distortional buckling resistance of an intermediate stiffener should be obtained from the value of $\sigma_{cr,s}$ using the method given in 5.5.3.1(5).

(7) If $\chi_d < 1$ it may optionally be refined iteratively, starting the iteration with modified values of ρ obtained using 5.5.2(4) with $\sigma_{com,Ed}$ equal to $\chi_d f_o / \gamma_{M1}$, so that:

$$\lambda_{p,red} = \lambda_p \sqrt{\chi_d} \tag{5.10}$$

(8) If iteration is carried out, it should be continued until the current value of χ_d is approximately equal to, but not more than, the previous value.

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

$$A_{s,red} = \chi_d A_s \frac{f_o / \gamma_{M1}}{\sigma_{com,Ed}} \quad \text{but} \quad A_{s,red} \leq A_s \tag{5.11}$$

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

(10) In determining effective section properties, the reduced effective area $A_{s,red}$ should be represented by using a reduced thickness $t_{red} = \chi_d t_{eff}$ for all the cross-section parts included in A_s

5.5.4 Trapezoidal sheeting profiles with intermediate stiffeners

5.5.4.1 General

(1) This sub-clause should be used in association with 5.5.3.3 for flanges with intermediate flange stiffeners and for webs with intermediate stiffeners.

(2) Interaction between distortional buckling of intermediate flange stiffeners and intermediate web stiffeners should also be taken into account using the method given in 5.5.4.4.

5.5.4.2 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 $A_{s,red}$ of up to two intermediate stiffeners and two strips of width $0{,}5b_p$ and thickness t_{eff} adjacent to the edges supported by webs, see Figure 5.5f).

(2) For one central flange stiffener, the elastic critical buckling stress $\sigma_{\mathrm{cr,s}}$ should be obtained from:

$$\sigma_{\mathrm{cr,s}} = \frac{4{,}2\kappa_{\mathrm{w}} E}{A_{\mathrm{s}}} \sqrt{\frac{I_{\mathrm{s}} t^3}{4 b_{\mathrm{p}}^2 \left(2 b_{\mathrm{p}} + 3 b_{\mathrm{s}}\right)}} \tag{5.12}$$

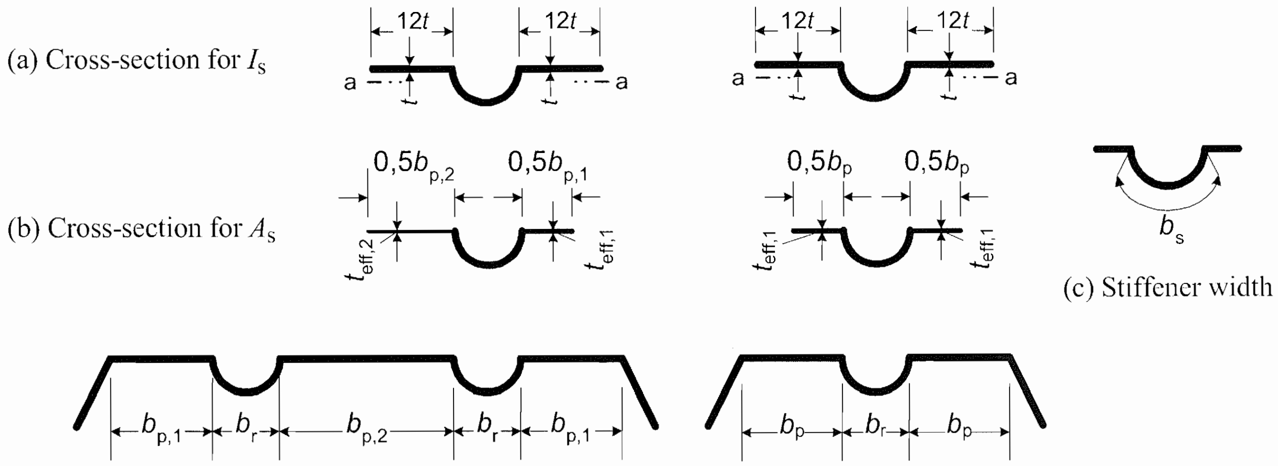
where:

b_{p} is the notional flat width of plane cross-section part shown in Figure 5.6;

b_{s} is the stiffener width, measured around the perimeter of the stiffener, see Figure 5.6(c);

κ_{w} is a coefficient that allows for partial rotational restraint of the stiffened flange by the webs, see (5) and (6);

and A_{s} and I_{s} are as defined in 5.5.3.3 and Figure 5.6.



(a) Cross-section for I_{s}

(b) Cross-section for A_{s}

(c) Stiffener width

Figure 5.6 – Effective cross section for calculation of I_{s} and A_{s} for compression flange with two or one stiffener

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

$$\sigma_{\mathrm{cr,s}} = \frac{4{,}2\kappa_{\mathrm{w}} E}{A_{\mathrm{s}}} \sqrt{\frac{I_{\mathrm{s}} t^3}{8 b_1^2 \left(3 b_{\mathrm{e}} - 4 b_1\right)}} \tag{5.13}$$

with:

$b_{\mathrm{e}} = 2b_{\mathrm{p,1}} + b_{\mathrm{p,2}} + 2b_{\mathrm{s}}$

$b_1 = b_{\mathrm{p,1}} + 0{,}5 b_{\mathrm{r}}$

where:

$b_{\mathrm{p,1}}$ is the notional flat width of an outer plane cross-section part, as shown in Figure 5.6;

$b_{\mathrm{p,2}}$ is the notional flat width of the central plane cross-section part, as shown in Figure 5.6;

b_{s} is the stiffener width, measured around the perimeter of the stiffener, see Figure 5.6(c).

(4) If there are three stiffeners, the one in the middle should be assumed to be ineffective.

(5) The value of κ_{w} may be calculated from the compression flange buckling wavelength l_{b} as follows:

- if $l_{\mathrm{b}}/s_{\mathrm{w}} \geq 2$: $\kappa_{\mathrm{w}} = \kappa_{\mathrm{wo}}$ (5.14a)
- if $l_{\mathrm{b}}/s_{\mathrm{w}} < 2$: $\kappa_{\mathrm{w}} = \kappa_{\mathrm{wo}} - (\kappa_{\mathrm{wo}} - 1)\left[2l_{\mathrm{b}}/s_{\mathrm{w}} - (l_{\mathrm{b}}/s_{\mathrm{w}})^2\right]$ (5.14b)

where:

s_{w} is the slant height of the web, see Figure 5.7(a).

l_b half wavelength for elastic buckling of stiffener, see (7).

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

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

- for a compression flange with one intermediate stiffener:

$$l_b = 3{,}07\sqrt[4]{I_s b_p{}^2 (2b_p + 3b_s)/t^3} \qquad (5.15)$$

$$\kappa_{wo} = \sqrt{\frac{s_w + 2b_d}{s_w + 0{,}5b_d}} \qquad (5.16)$$

with:

$b_d = 2b_p + b_s$

- for a compression flange with two or three intermediate stiffeners:

$$l_b = 3{,}65\sqrt[4]{I_s b_l{}^2 (3b_e - 4b_l)/t^3} \qquad (5.17)$$

$$\kappa_{wo} = \sqrt{\frac{(2b_e + s_w)(3b_e - 4b_l)}{b_l(4b_e - 6b_l) + s_w(3b_e - 4b_l)}} \qquad (5.18)$$

(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:

$$A_{s,red} = \chi_d A_s \frac{f_o / \gamma_{M1}}{\sigma_{com,Ed}} \quad \text{but} \quad A_{s,red} \le A_s \qquad (5.19)$$

(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(5).

(10) If the webs are also stiffened, the reduction factor χ_d should be obtained using the method given in 5.5.3.1(5), but with the modified elastic critical stress $\sigma_{cr,mod}$ given in 5.5.4.4.

(11) In determining effective section properties, the reduced effective area $A_{s,red}$ should be represented by using a reduced thickness $t_{red} = \chi_d\, t_{eff}$ for all the cross-section parts included in A_s.

5.5.4.3 Webs with up to two intermediate stiffeners under stress gradient

(1) The effective cross-section of the compressed zone of a web 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 profile cross-section, see Figure 5.7. Webs under uniform compression stress should be treated analogously to stiffened flanges.

(2) The effective cross-section of a web as shown in Figure 5.7 should be taken to include:

a) a strip of width $s_a/2$ and effective thickness $t_{eff,a}$ adjacent to the compression flange;

b) the reduced effective area $A_{s,red}$ of each web stiffener up to a maximum of two;

c) a strip of width $2s_n/3$ adjacent to the effective centroidal axis;

d) the part of the web in tension.

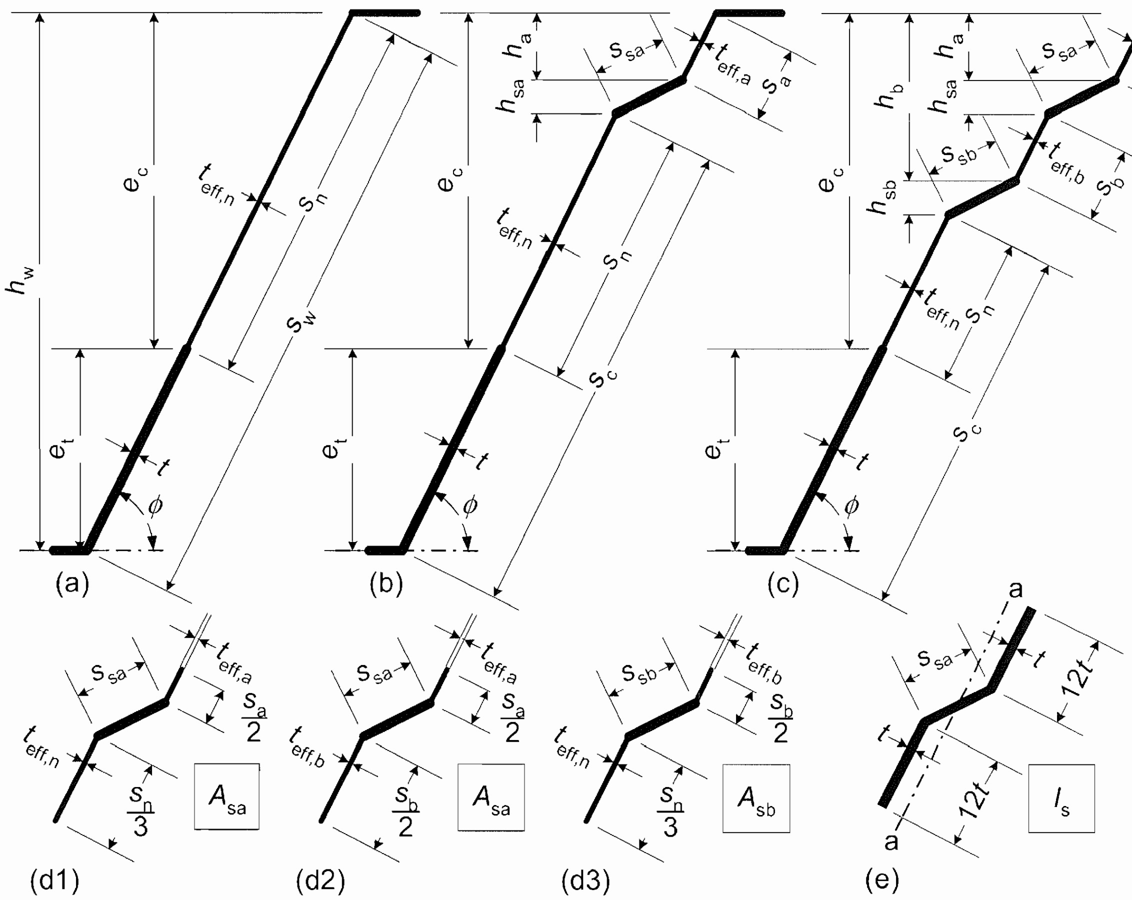


Figure 5.7 - Effective cross-sections of webs of cold-formed profiled sheets

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

- for a single stiffener:

$$A_{sa} = (t_{eff,a}\frac{s_a}{2} + t s_{sa} + t_{eff,n}\frac{s_n}{3}), \qquad \text{Figure 5.7(d1)} \qquad (5.20a)$$

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

$$A_{sa} = (t_{eff,a}\frac{s_a}{2} + t s_{sa} + t_{eff,b}\frac{s_b}{2}), \qquad \text{Figure 5.7(d2)} \qquad (5.20b)$$

- for a second stiffener

$$A_{sb} = (t_{eff,b}\frac{s_b}{2} + t s_{sb} + t_{eff,n}\frac{s_n}{3}), \qquad \text{Figure 5.7(d3)} \qquad (5.21)$$

in which the dimensions s_a, s_{sa}, s_b, s_{sb}, and s_n are as shown in Figure 5.7 and $t_{eff,a}$, $t_{eff,b}$ and $t_{eff,n}$ are given in (5).

(4) Initially the location of the effective centroidal axis should be based on the effective area of the flanges but with the gross area of the webs.

(5) If the slenderness $\overline{\lambda}_p$ of the part of the web which is in compression is larger than $\overline{\lambda}_{lim}$ (see 5.5.2(4)), the effective thickness $t_{teff,a}$, $t_{teff,b}$ and $t_{teff,n}$ should be determined as follows:

$$t_{eff} = \rho t \qquad (5.22)$$

where ρ is calculated using expression (5.2) with slenderness $\overline{\lambda}_p$ and stress relation factor ψ according to Table 5.5, where e_c and e_t are the distances from the effective centroidal axis to the system line of the compression and tension flange, see Figure 5.7, and the dimensions h_a, h_b, h_{sa}, h_{sb}, s_n and ϕ are as shown in Figure 5.7.

(6) To calculate the initial effective area A_{sa} and A_{sb} of web stiffeners, s_a and s_b are divided into two equal parts $s_a/2$ and $s_b/2$. The web part s_n over the centroidal axis is divided into one part $s_n/3$ adjacent to the stiffener, Figure 5.7 (d1) and (d3), and one part $2s_n/3$ adjacent to the centroidal axis.

AC1⟩ **Table 5.5 - Slenderness $\overline{\lambda}_p$ and stress relation factor ψ for a web with stiffeners**

Web part location	Web part	Slenderness $\overline{\lambda}_p$	Stress relation factor ψ
No stiffeners, Figure 5.7 (a)			
Between compression flange and centroidal axis	s_n	$\overline{\lambda}_p = 1{,}052\frac{s_n}{t}\sqrt{\frac{f_o}{E\,k_\sigma}}$	$\psi = -\frac{e_t}{e_c}$
One stiffener, Figure 5.7 (b)			
Adjacent to compression flange	s_a	$\overline{\lambda}_p = 1{,}052\frac{s_a}{t}\sqrt{\frac{f_o}{E\,k_\sigma}}$	$\psi = \frac{e_c - h_a}{e_c}$
Adjacent to centroidal axis	s_n	$\overline{\lambda}_p = 1{,}052\frac{s_c}{t}\sqrt{\frac{f_o}{E\,k_\sigma}\cdot\frac{(e_c - h_a - h_{sa})}{e_c}}$	$\psi = -\frac{e_t}{s_n \cdot \sin\phi}$
Two stiffeners, Figure 5.7 (c)			
Adjacent to compression flange	s_a	$\overline{\lambda}_p = 1{,}052\frac{s_a}{t}\sqrt{\frac{f_o}{E\,k_\sigma}}$	$\psi = \frac{e_c - h_a}{e_c}$
Between stiffeners	s_b	$\overline{\lambda}_p = 1{,}052\frac{s_b}{t}\sqrt{\frac{f_o}{E\,k_\sigma}\cdot\frac{(e_c - h_a - h_{sa})}{e_c}}$	$\psi = \frac{e_c - h_b}{e_c - h_a - h_{sa}}$
Adjacent to centroidal axis	s_n	$\overline{\lambda}_p = 1{,}052\frac{s_c}{t}\sqrt{\frac{f_o}{E\,k_\sigma}\cdot\frac{(e_c - h_b - h_{sb})}{e_c}}$	$\psi = -\frac{e_t}{s_n \cdot \sin\phi}$

⟨AC1

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

$$\sigma_{cr,sa} = \frac{1{,}05\,\kappa_f E\sqrt{I_{sa}t^3 s_1}}{A_{sa}s_2(s_1 - s_2)} \tag{5.23}$$

in which s_1 and s_2 are given by the following:

- for a single stiffener:

$$s_1 = 0{,}9(s_a + s_{sa} + s_c)\,, \qquad s_2 = s_1 - s_a - 0{,}5\,s_{sa} \tag{5.24}$$

- for the stiffener closer to the compression flange, in webs with two stiffeners where the other stiffener is in tension or close to the centroidal axis:

$$s_1 = s_a + s_{sa} + s_b + 0{,}5(s_{sb} + s_c)\,, \qquad s_2 = s_1 - s_a - 0{,}5\,s_{sa} \tag{5.25}$$

where:

κ_f is a coefficient that allows for partial rotation restraint of the stiffened web by the flanges;

I_{sa} is the second moment of area of a stiffener cross-section comprising the fold, width s_{sa}, and two adjacent strips, each of width $12t$, about its own centroidal axis parallel to the plane web cross-section parts, see Figure 5.7(e). In calculating I_{sa} the possible difference in slope between the plane cross-section parts on either side of the stiffener may be neglected.

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

(9) For a single stiffener in compression, or for the stiffener closer to the compression flange in a web with two stiffeners, the reduced effective area $A_{\mathrm{sa,red}}$ (Step 2 in Figure 5.5) should be determined from:

$$A_{\mathrm{sa,red}} = \frac{\chi_{\mathrm{d}} A_{\mathrm{sa}}}{1 - \dfrac{h_{\mathrm{a}} + 0{,}5\, h_{\mathrm{sa}}}{e_{\mathrm{c}}}} \quad \text{but} \quad A_{\mathrm{sa,red}} \le A_{\mathrm{sa}} \tag{5.26}$$

(10) If the flanges are also stiffened, the reduction factor χ_{d} should be obtained using the method given in 5.5.3.1(5), but with the modified elastic critical stress $\sigma_{\mathrm{cr,mod}}$ given in 5.5.4.4.

(11) For a single stiffener in tension, the reduced effective area $A_{\mathrm{sa,red}}$ should be taken as equal to A_{sa}.

(12) For webs with two stiffeners, the reduced effective area $A_{\mathrm{sb,red}}$ for the second stiffener, close to the neutral axis, should be taken as equal to A_{sb}

(13) In determining effective section properties, the reduced effective area $A_{\mathrm{sa,red}}$ should be represented by using a reduced thickness $t_{\mathrm{red}} = \chi_{\mathrm{d}}\, t_{\mathrm{eff}}$ for all the cross-section parts included in A_{sa}.

(14) If $\chi_{\mathrm{d}} < 1$ it may optionally be refined iteratively, see 5.5.3(7).

(15) For the effective section properties at serviceability limit states, see 7.1.

5.5.4.4 Sheeting with flange stiffeners and web stiffeners

(1) In the case of sheeting with intermediate stiffeners in the flanges and in the webs, see Figure 5.8, interaction between the distortional buckling of the flange stiffeners and the web stiffeners should be allowed for by using a modified elastic critical stress $\sigma_{\mathrm{cr,mod}}$ for both types of stiffeners, obtained from:

$$\sigma_{\mathrm{cr,mod}} = \frac{\sigma_{\mathrm{cr,s}}}{\sqrt[4]{1 + \left[\beta_{\mathrm{s}} \dfrac{\sigma_{\mathrm{cr,s}}}{\sigma_{\mathrm{cr,sa}}}\right]^4}} \tag{5.27}$$

where:

$\sigma_{\mathrm{cr,s}}$ is the elastic critical stress for an intermediate flange stiffener, see 5.5.4.2(2) for a flange with a single stiffener or 5.5.4.2(3) for a flange with two stiffeners;

$\sigma_{\mathrm{cr,sa}}$ is the elastic critical stress for a single web stiffener, or the stiffener closer to the compression flange in webs with two stiffeners, see 5.5.4.3(7).

$\beta_{\mathrm{s}} = 1 - (h_{\mathrm{a}} + 0{,}5 h_{\mathrm{sa}}) / e_{\mathrm{c}}$ for a profile in bending

$\beta_{\mathrm{s}} = 1$ for a profile in axial compression

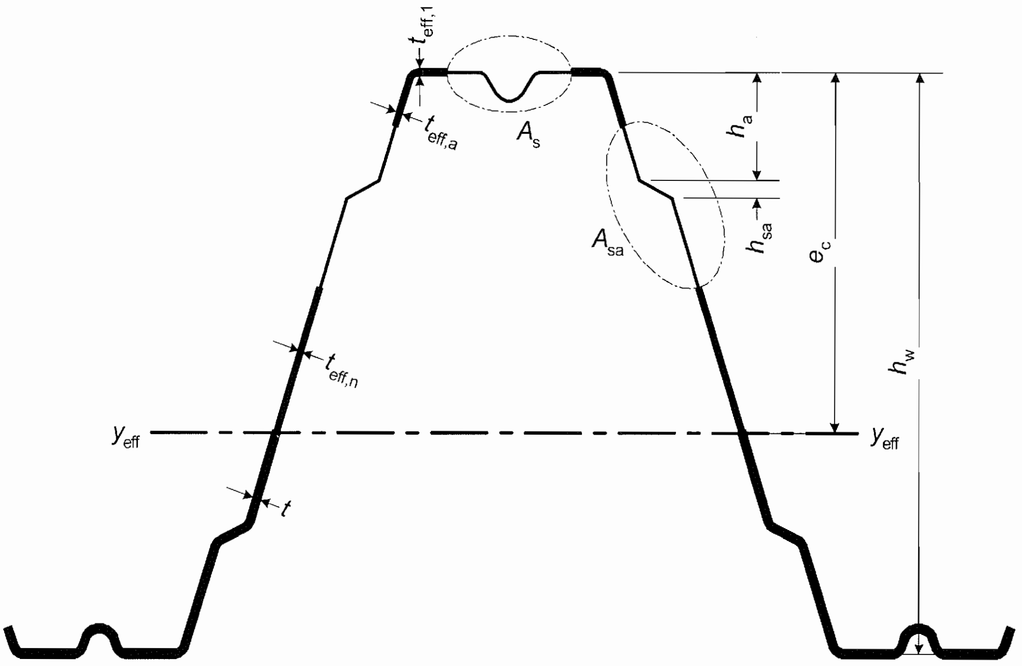


Figure 5.8 – Effective cross section of cold-formed profiled sheeting with flange stiffeners and web stiffeners

6 Ultimate limit states

6.1 Resistance of cross-sections

6.1.1 General

(1) The rules in this section apply to the design by calculation.

(2) Design assisted by testing may be used instead of design by calculation for any resistance, see Section 9 and Annex A.

NOTE Design assisted by testing is particularly likely to be beneficial for cross sections with relatively high b_p/t ratios, e.g. in relation to inelastic behaviour, web crippling or shear lag.

(3) For design by calculation, the effects of local buckling and distortional buckling should be taken into account by using effective section properties determined as specified in 5.5.

(4) The buckling resistance of sheeting members in compression should be verified as specified in 6.2.

6.1.2 Axial tension

(1) The design resistance of a cross-section for uniform tension $N_{t,Rd}$ should be determined from:

$$N_{t,Rd} = \frac{f_o A_g}{\gamma_{M1}} \quad \text{but} \quad N_{t,Rd} \leq F_{net,Rd} \tag{6.1}$$

where:

A_g is the gross area of the cross-section;

$F_{net,Rd}$ is the net-section resistance for the appropriate type of mechanical fastener.

6.1.3 Axial compression

(1) The design resistance of a cross-section for compression $N_{c,Rd}$ should be determined from:

- if the effective area A_{eff} is less than the gross area A_g (section with reduction due to local and/or distortional buckling)

$$N_{c,Rd} = A_{eff} f_o / \gamma_{M1} \tag{6.2}$$

- if the effective area A_{eff} is equal to the gross area A_g (section with no reduction due to local or distortional buckling)

$$N_{c,Rd} = A_g f_o / \gamma_{M1} \tag{6.3}$$

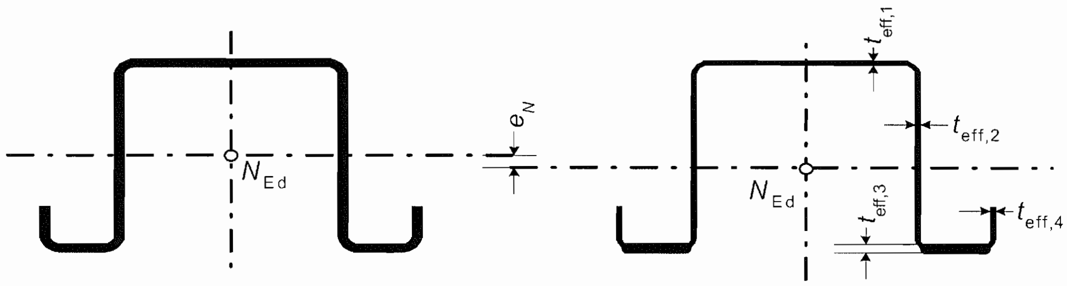
where:

A_{eff} is the effective area of the cross-section, obtained from 5.5.2 by assuming a uniform compressive stress equal to f_o / γ_{M1}.

(2) The internal normal force in a member should be taken as acting at the centroid of its gross cross-section. This is a conservative assumption, but can be used without further analysis. Further analysis may give a more realistic situation of the internal forces for instance in case of uniformly building-up of normal force in the compression cross-section part.

(3) The design compression resistance of a cross-section for uniform compression should be assumed to act at the centroid of its effective cross-section. If this does not coincide with the centroid of its gross cross-section, the shift e_N of the centroidal axes (see Figure 6.1) should be taken into account, using the method given in

6.1.9. If the shift of the neutral axis gives a favourable result, then that shift should be neglected only if the shift has been calculated at yield strength and not with the actual compressive stresses.



(a) Gross cross-section (b) Effective cross-section

Figure 6.1 – Illustration of shift of neutral axis in cross-section under compression

6.1.4 Bending moment

6.1.4.1 Elastic and elastic-plastic resistance with yielding at the compressed flange

(1) The design moment resistance of a cross-section for bending $M_{c,Rd}$ should be determined as follows:

- if the effective section modulus W_{eff} is less than the gross elastic section modulus W_{el} :

$$M_{c,Rd} = W_{eff} f_o / \gamma_{M1} \tag{6.4}$$

- if the effective section modulus W_{eff} is equal to the gross elastic section modulus W_{el} :

$$M_{c,Rd} = f_o \left(W_{el} + (W_{pl} - W_{el}) 4(1 - \lambda / \lambda_{el})\right) / \gamma_{M1} \text{ but not more than } W_{pl} f_o / \gamma_{M1} \tag{6.5}$$

where:

λ is the slenderness of the cross-section part which correspond to the largest value of λ / λ_{el} ;

For double supported plane cross-section parts $\lambda = \overline{\lambda}_p$ and $\lambda_{el} = \overline{\lambda}_{lim}$ where $\overline{\lambda}_{lim}$ is found in Table 5.2;

For stiffened cross-section parts $\lambda = \overline{\lambda}_s$ and $\lambda_{el} = 0{,}25$, see 5.5.3.1.

NOTE The resulting bending moment resistance as a function of the slenderness of the most slender cross-section part is illustrated in Figure 6.2.

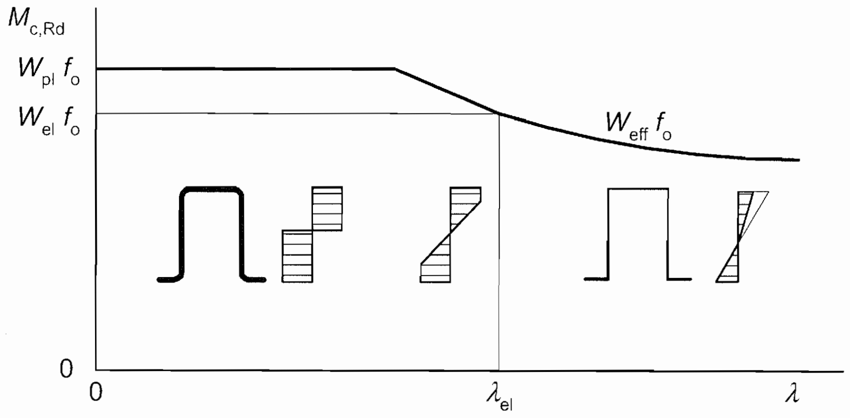


Figure 6.2 - Bending moment resistance as a function of the slenderness

(2) Expression (6.5) is applicable provided that the slope ϕ of the web relative to the flanges (see Figure 6.5) is less than 60°.

(3) If (2) is not fulfilled the following expression should be used:

$$M_{c,Rd} = W_{el} f_o / \gamma_{M1} \tag{6.6}$$

(4) The effective section modulus W_{eff} should be based on an effective cross-section that is subject only to bending moment, with a maximum stress $\sigma_{max,Ed}$ equal to f_o / γ_{M1}, allowing for the effects of local and distortional buckling as specified in 5.5. Where shear lag is relevant (see EN 1999-1-1), allowance should also be made for its effects.

(5) The stress ratio $\psi = \sigma_2 / \sigma_1$ used to determine the effective portions of the web may be obtained by using the effective area of the compression flange but the gross area of the web, see Figure 6.3.

(6) If yielding occurs first at the compression edge of the cross-section, unless the conditions given in 6.1.4.2 are met the value of W_{eff} should be based on a linear distribution of stress across the cross-section.

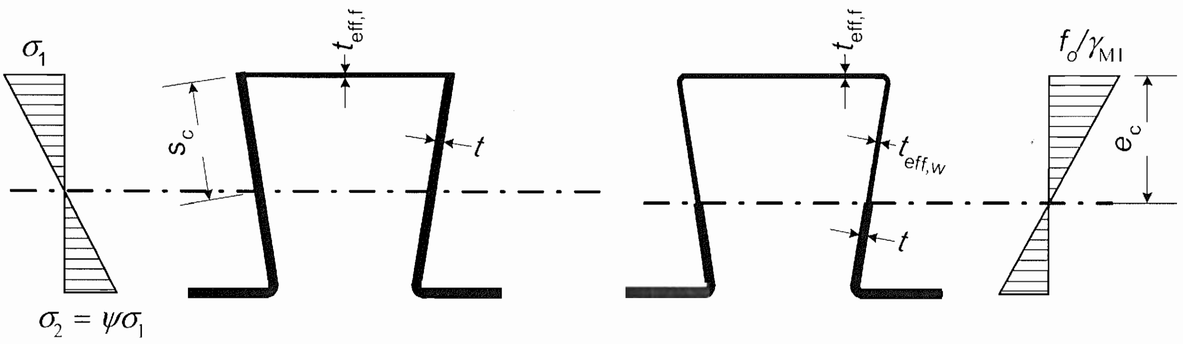


Figure 6.3 - Effective cross-section for resistance to bending moments

(7) If redistribution of bending moments is assumed in the global analysis the provisions given in 7.2 should be satisfied. If the residual moment at the intermediate support is not assumed to be zero, the acting residual moment should be determined by test.

6.1.4.2 Elastic and elastic-plastic resistance with yielding at the tension flange only

(1) Provided that yielding occurs first at the tension edge, plastic reserves in the tension zone may be utilised without any strain limitation until the maximum compressive stress $\sigma_{com,Ed}$ reaches f_o/γ_{M1}. In this clause only the bending case is considered. For axial load and bending 6.1.8 or 6.1.9 should be applied.

(2) In this case, the effective partially plastic section modulus $W_{pp,eff}$ should be based on a stress distribution that is bilinear in the tension zone but linear in the compression zone.

(3) In the absence of a more detailed analysis, the effective thickness t_{eff} of the webs may be obtained using 5.5.2 by basing e_c on the bilinear stress distribution (see Figure 6.4), by assuming $\psi = -1$.

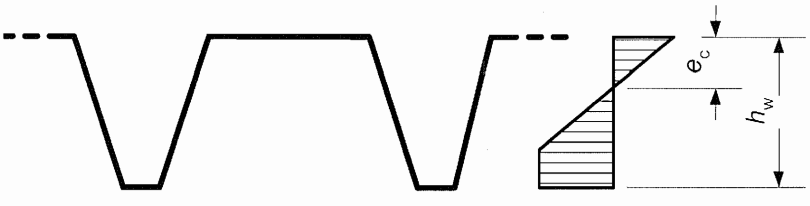


Figure 6.4 - Measure e_c for determination of effective thickness

(4) If redistribution of bending moments is assumed in the global analysis the provisions given in 7.2 should be satisfied. If the residual moment at the intermediate support is not assumed to be zero, the acting residual moment should be determined by test.

6.1.4.3 Effects of shear lag

(1) The effects of shear lag should be taken into account according to EN 1999-1-1.

(2) Shear lag effects may be ignored for flanges with $b/t \le 300$.

6.1.5 Shear force

(1) The shear resistance $V_{\mathrm{b,Rd}}$ should be determined from:

$$V_{\mathrm{b,Rd}} = (h_{\mathrm{w}} / \sin \phi)\, t f_{\mathrm{bv}} / \gamma_{\mathrm{M1}} \tag{6.7}$$

where:

f_{bv} is the shear strength considering buckling according to Table 6.1;

h_{w} is the web height between the midlines of the flanges, see Figure 6.5;

ϕ is the slope of the web relative to the flanges.

Table 6.1 - Shear buckling strength f_{bv} in relation to web slenderness parameter $\overline{\lambda}_{\mathrm{w}}$

Web slenderness parameter	Web without stiffening at the support	Web with stiffening at the support [1)]
$\overline{\lambda}_{\mathrm{w}} \ge 0{,}83$	$0{,}58 f_{\mathrm{o}}$	$0{,}58 f_{\mathrm{o}}$
$0{,}83 < \overline{\lambda}_{\mathrm{w}} \le 1{,}40$	$0{,}48 f_{\mathrm{o}} / \overline{\lambda}_{\mathrm{w}}$	$0{,}48 f_{\mathrm{o}} / \overline{\lambda}_{\mathrm{w}}$
$\overline{\lambda}_{\mathrm{w}} \ge 1{,}40$	$0{,}67 f_{\mathrm{o}} / \overline{\lambda}_{\mathrm{w}}^{2}$	$0{,}48 f_{\mathrm{o}} / \overline{\lambda}_{\mathrm{w}}$
1) Stiffening at the support, such as cleats, arranged to prevent distortion of the web and designed to resist the support reaction.		

(2) The web slenderness parameter $\overline{\lambda}_{\mathrm{w}}$ should be obtained from the following:

- for webs without longitudinal stiffeners:

$$\overline{\lambda}_{\mathrm{w}} = 0{,}346 \frac{s_{\mathrm{w}}}{t} \sqrt{\frac{f_{\mathrm{o}}}{E}} \tag{6.8a}$$

- for webs with longitudinal stiffeners, see Figure 6.5:

$$\overline{\lambda}_{\mathrm{w}} = 0{,}346 \frac{s_{\mathrm{d}}}{t} \sqrt{\frac{5{,}34\, f_{\mathrm{o}}}{k_{\tau}\, E}} \quad \text{but} \quad \overline{\lambda}_{\mathrm{w}} \ge 0{,}346 \frac{s_{\mathrm{p}}}{t} \sqrt{\frac{f_{\mathrm{o}}}{E}} \tag{6.8b}$$

with:

$$k_{\tau} = 5{,}34 + \frac{2{,}10}{t} \sqrt[3]{\frac{\sum I_{\mathrm{s}}}{s_{\mathrm{d}}}} \tag{6.9}$$

where:

I_{s} is the second moment of area of the individual longitudinal stiffener, about the axis a - a as indicated in Figure 6.5;

s_{d} is the total developed slant height of the web, as indicated in Figure 6.5;

s_{p} is the slant height of the largest plane part in the web, see Figure 6.5;

s_{w} is the slant height of the web, as shown in Figure 6.5, between the midpoints of the corners, see Figure 6.5.

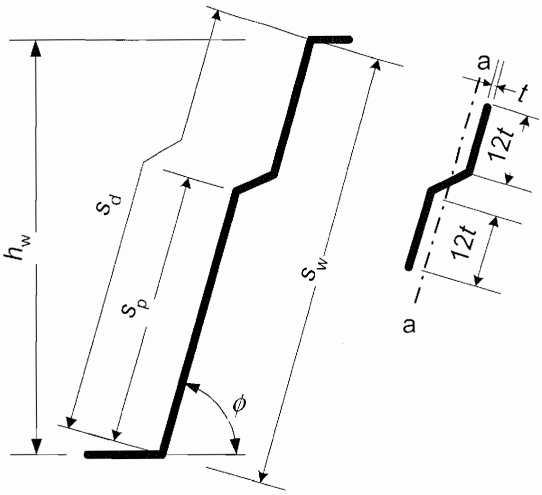


Figure 6.5 – Geometry of a longitudinally stiffened web and effective cross section of stiffener

6.1.6 Torsion

(1) Torsion stiffness and resistance is negligible in profiled sheeting.

6.1.7 Local transverse forces

6.1.7.1 General

(1) To avoid crushing, crippling or buckling in a web subject to a support reaction or other local transverse force applied through the flange, the transverse force F_{Ed} should satisfy:

$$F_{Ed} \leq R_{w,Rd} \tag{6.10}$$

where $R_{w,Rd}$ is the local transverse resistance of the web.

(2) The local transverse resistance of a web $R_{w,Rd}$ should be obtained as follows:

a) for unstiffened webs: from 6.1.7.2
b) for stiffened webs: from 6.1.7.3

(3) Where the local load or support reaction is applied through a cleat that is arranged to prevent distortion of the web and is designed to resist the local transverse force, the local resistance of the web to the transverse force need not be considered.

6.1.7.2 Cross-sections with unstiffened webs

(1) The local transverse resistance of an unstiffened web, see Figure 6.6, should be determined as specified in (2), provided that both of the following conditions are satisfied:

- the clear distance c from the actual bearing point for the support reaction or local load to a free end, see Figure 6.7, is at least 40 mm;
- the cross-section satisfies the following criteria:

$$r/t \leq 10 \tag{6.11a}$$

$$h_w/t \leq 200 \sin\phi \tag{6.11b}$$

$$45 \leq \phi \leq 90° \tag{6.11c}$$

where:

h_w is the web height between the midlines of the flanges;
r is the internal radius of the corners;
ϕ is the slope of the web relative to the flanges [degrees].

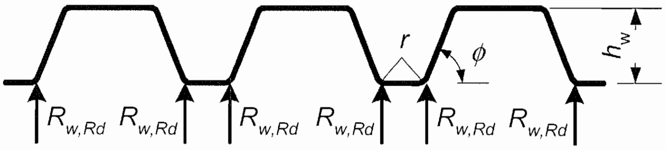


Figure 6.6 - Examples of cross-section with two or more webs

(2) Where both conditions specified in (1) are satisfied, the local transverse resistance $R_{\mathrm{w,Rd}}$ per web of the sheeting profile should be determined from:

$$R_{\mathrm{w,Rd}} = \alpha t^2 \sqrt{f_{\mathrm{o}} E}\left(1 - 0{,}1\sqrt{r/t}\right)\left(0{,}5 + \sqrt{0{,}02 l_{\mathrm{a}}/t}\right)\left(2{,}4 + (\phi/90)^2\right)/\gamma_{\mathrm{M1}} \qquad (6.12)$$

where:

l_a is the effective bearing length for the relevant category, see (4);
α is the coefficient for the relevant category, see (3);
s_w is the slant length of the web ($= h_w / \sin\phi$);
r is the inner bending radius ($r < 10\ t$).

(3) The value of the coefficient α should be obtained from Figure 6.7.

(4) The values of l_a should be obtained from (5). The maximum design value for l_a is 200 mm. When the support is a cold-formed section with one web or round tube, for s_s should be taken a value of 10 mm. The relevant category (1 or 2) should be based on the clear distance e between the local load and the nearest support, or the clear distance c from the support reaction or local load to a free end, see Figure 6.7.

(5) The value of the effective bearing length l_a for sheeting profiles should be obtained from the following:

a) for Category 1:

$$l_a = s_s \text{ but } l_a \leq 40 \text{ mm} \qquad (6.13a)$$

b) for Category 2:

if $\beta_V \leq 0{,}2$: $l_a = s_s$ (6.13b)
if $\beta_V \geq 0{,}3$: $l_a = 10$ mm (6.13c)
if $0{,}2 < \beta_V < 0{,}3$: interpolate linearly between the values of l_a for 0,2 and 0,3 with:

$$\beta_v = \frac{|V_{\mathrm{Ed,1}}| - |V_{\mathrm{Ed,2}}|}{|V_{\mathrm{Ed,1}}| + |V_{\mathrm{Ed,2}}|} \qquad (6.14)$$

in which $|V_{\mathrm{Ed,1}}|$ and $|V_{\mathrm{Ed,2}}|$ are the absolute values of the transverse shear force on each side of the local load or support reaction, and $|V_{\mathrm{Ed,1}}| \geq |V_{\mathrm{Ed,2}}|$ and s_s is the actual length of stiff bearing.

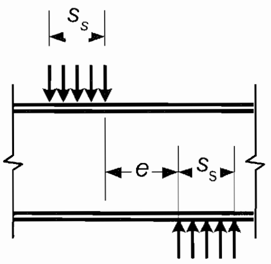
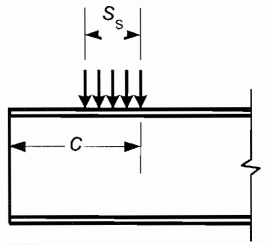
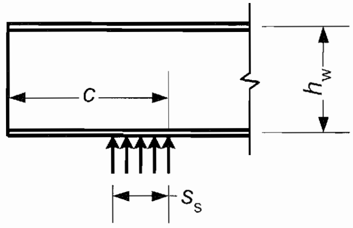
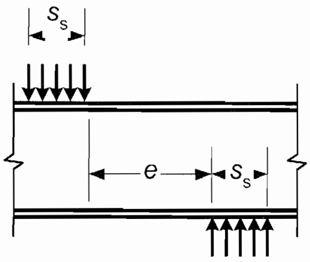
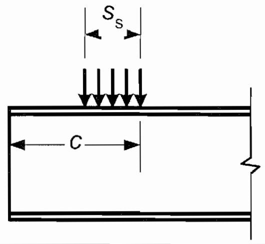
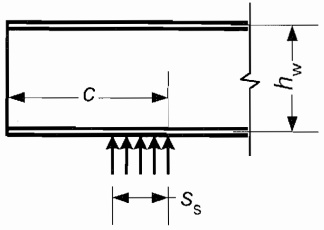
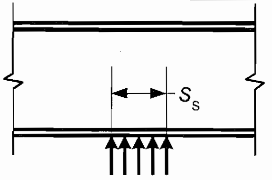
	Category 1: $\alpha = 0,075$ - local load applied with $e \leq 1,5\ h_w / t$ clear from nearest support;
	Category 1: $\alpha = 0,075$ - local load applied with $c \leq 1,5\ h_w / t$ clear from a free end;
	Category 1: $\alpha = 0,075$ - reaction at end support with $c \leq 1,5\ h_w / t$ clear from a free end;
	Category 2; $\alpha = 0,15$ - local load applied with $e > 1,5\ h_w / t$ clear from nearest support;
	Category 2; $\alpha = 0,15$ - local load applied with $c > 1,5\ h_w / t$ clear from a free end;
	Category 2; $\alpha = 0,15$ - reaction at end support with $c > 1,5\ h_w / t$ clear from a free end;
	Category 2; $\alpha = 0,15$ - reaction at internal support;

Figure 6.7 - Local loads and support-categories for cross-sections with two or more webs

6.1.7.3 Stiffened webs

(1) The local transverse resistance of a stiffened web may be determined as specified in (2) for cross-sections with longitudinal web stiffeners folded in such a way that the two folds in the web are on opposite sides of the system line of the web joining the points of intersection of the midline of the web with the midlines of the flanges, see Figure 6.8, that satisfy the condition:

$$2 < e_{\mathrm{max}}/t < 12 \tag{6.15}$$

where:

e_{max} is the larger eccentricity of the folds relative to the system line of the web.

(2) For cross-sections with stiffened webs satisfying the conditions specified in (1), the local transverse resistance of a stiffened web may be determined by multiplying the corresponding value for a similar unstiffened web, obtained from 6.1.7.2, by the factor $\kappa_{\mathrm{a,s}}$ given by:

$$\kappa_{\mathrm{a,s}} = 1{,}45 - 0{,}05\, e_{\mathrm{max}}/t \quad \text{but} \quad \kappa_{\mathrm{a,s}} \leq 0{,}95 + 35\,000\, t^2\, e_{\mathrm{min}}/(b_{\mathrm{d}}^2\, s_{\mathrm{p}}) \tag{6.16}$$

where:

b_{d} is the developed width of the loaded flange, see Figure 6.8;
e_{min} is the smaller eccentricity of the folds relative to the system line of the web, see Figure 6.8;
s_{p} is the slant height of the plane web cross-section part nearest to the loaded flange, see Figure 6.8.

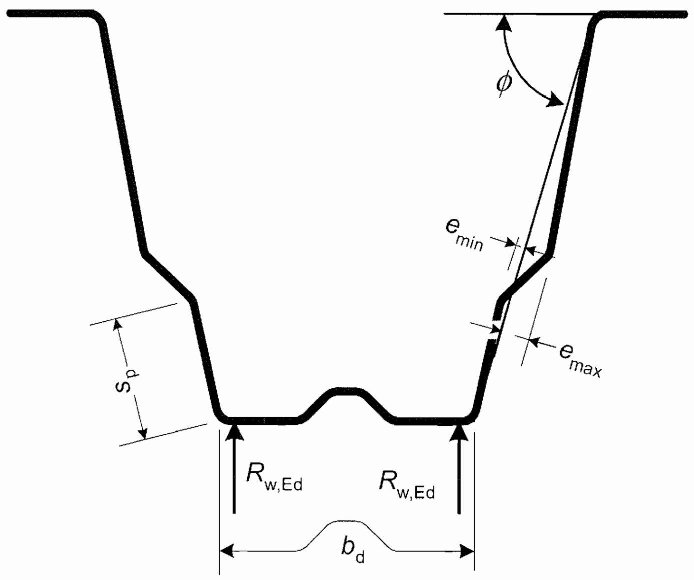


Figure 6.8 - Support loads and geometry of stiffened webs

6.1.8 Combined tension and bending

(1) Cross-sections subject to combined axial tension N_{Ed} and bending moment $M_{\mathrm{y,Ed}}$ should satisfy the criterion:

$$\frac{N_{\mathrm{Ed}}}{N_{\mathrm{t,Rd}}} + \frac{M_{\mathrm{y,Ed}}}{M_{\mathrm{cy,Rd,ten}}} \leq 1 \tag{6.17a}$$

where:

$N_{t,Rd}$ is the design resistance of a cross-section for uniform tension (6.1.2);

$M_{cy,Rd,ten}$ is the design moment resistance of a cross-section for maximum tensile stress if subject only to moment about the y - y axes (6.1.4).

(2) If $M_{cy,Rd,com} \leq M_{cy,Rd,ten}$, where $M_{cy,Rd,com}$ is the moment resistance for the maximum compressive stress in a cross-section that is subject to moment only, the following criterion should also be satisfied:

$$\frac{M_{y,Ed}}{M_{cy,Rd,com}} - \frac{N_{Ed}}{N_{t,Rd}} \leq 1 \tag{6.17b}$$

6.1.9 Combined compression and bending

(1) Cross-sections subject to combined axial compression N_{Ed} and bending moment $M_{y,Ed}$ should satisfy the criterion:

$$\frac{N_{Ed}}{N_{c,Rd}} + \frac{M_{y,Ed} + \Delta M_{y,Ed}}{M_{cy,Rd,com}} \leq 1 \tag{6.18}$$

in which $N_{c,Rd}$ is as defined in 6.1.3 and $M_{cy,Rd,com}$ is as defined in 6.1.8.

(2) The additional moment $\Delta M_{y,Ed}$ due to shift of the centroidal axis should be taken as:

$$\Delta M_{y,Ed} = N_{Ed}\, e_N \tag{6.18b}$$

in which e_N is the shift of the y - y centroidal axes due to axial forces, see 6.1.3 (3).

(3) If $M_{cy,Rd,ten} \leq M_{cy,Rd,com}$ the following criterion should also be satisfied:

$$\frac{M_{y,Ed} + \Delta M_{y,Ed}}{M_{cy,Rd,ten}} - \frac{N_{Ed}}{N_{c,Rd}} \leq 1 \tag{6.19}$$

in which $M_{cy,Rd,ten}$ is as defined in 6.1.8.

6.1.10 Combined shear force, axial force and bending moment

(1) Provided that $V_{Ed}/V_{w,Rd}$ (see below) does not exceed 0,5, the design resistance to bending moment and axial force need not be reduced to allow for the shear force. If $V_{Ed}/V_{w,Rd}$ is more than 0,5 the combined effects of an axial force N_{Ed}, a bending moment M_{Ed} and a shear force V_{Ed} should satisfy:

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \left(1 - \frac{M_{f,Rd}}{M_{pl,Rd}}\right)\left(\frac{2V_{Ed}}{V_{w,Rd}} - 1\right)^2 \leq 1 \tag{6.20}$$

where:

N_{Rd} is the design resistance of the cross-section for tension or compression given in 6.1.2 or 6.1.3;

$M_{y,Rd}$ is the design moment resistance of the cross-section given in 6.1.4;

$V_{w,Rd}$ is the design shear resistance of the web given in 6.1.5. For members with more than one web $V_{w,Rd}$ is the sum of the resistances of the webs;

$M_{f,Rd}$ is the design plastic moment resistance of the cross-section consisting of the effective area of the flanges only;

$M_{pl,Rd}$ is the design plastic moment resistance of the cross-section consisting of the effective area of the flanges and the fully effective web irrespective of its section class.

6.1.11 Combined bending moment and local load or support reaction

(1) Cross-sections subject to the combined action of a bending moment M_{Ed} and a transverse force due to a local load or support reaction F_{Ed} should satisfy the following:

$$\frac{M_{Ed}}{M_{c,Rd}} \leq 1 \tag{6.21a}$$

$$\frac{F_{Ed}}{R_{w,Rd}} \leq 1 \tag{6.21b}$$

$$0{,}94 \cdot \left[\frac{M_{Ed}}{M_{c,Rd}}\right]^2 + \left[\frac{F_{Ed}}{R_{w,Rd}}\right]^2 \leq 1 \tag{6.22}$$

where:

$M_{c,Rd}$ is the moment resistance of the cross-section given in 6.1.4.1;

$R_{w,Rd}$ is the appropriate value of the sum of the local transverse resistances of the individual webs from 6.1.7.

(2) In expression (6.22) the bending moment M_{Ed} may be calculated at the edge of the support.

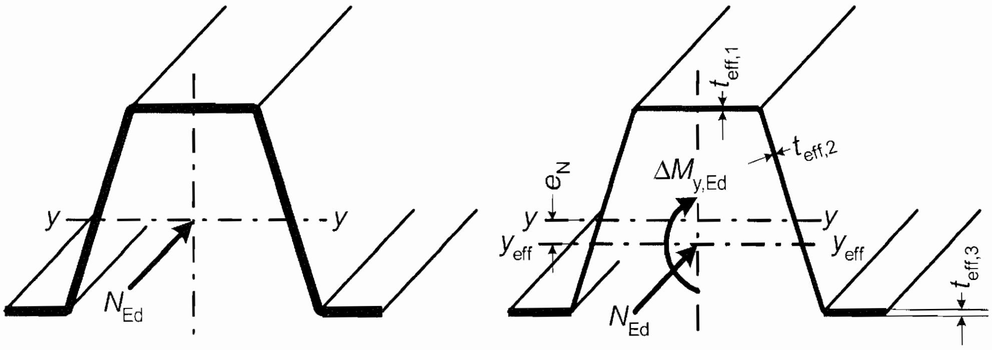
6.2 Buckling resistance

6.2.1 General

(1) The effects of local and distortional buckling should be taken into account. Methods as specified in 5.5 may be used.

(2) The internal axial force in a sheeting should be taken as acting at the centroid of its gross cross-section.

(3) The resistance of sheeting to axial compression should be assumed to act at the centroid of its effective cross-section. If this does not coincide with the centroid of its gross cross-section, moments corresponding to the shift of the centroidal axes (see Figure 6.9) should be taken into account, using the method given in 6.2.3.



(a) Gross cross-section, (b) effective cross-section

Figure 6.9 – Illustration of shift of centroidal axis of effective cross-section

6.2.2 Axial compression

6.2.2.1 Design flexural buckling resistance

(1) The design buckling resistance for axial compression $N_{\mathrm{b,Rd}}$ should be obtained from:

$$N_{\mathrm{b,Rd}} = \chi A_{\mathrm{eff}} f_{\mathrm{o}} / \gamma_{\mathrm{M1}} \tag{6.23}$$

where:

A_{eff} is the effective area of the cross-section, obtained from Section 5 by assuming a uniform compressive stress $\sigma_{\mathrm{com,Ed}}$ equal to $f_{\mathrm{o}}/\gamma_{\mathrm{M1}}$;

χ is the appropriate value of the reduction factor for buckling resistance.

(2) The reduction factor χ for buckling resistance should be determined from:

$$\chi = \frac{1}{\phi + (\phi^2 - \bar{\lambda}^2)^{0,5}} \quad \text{but} \quad \chi \leq 1,0 \tag{6.24a}$$

with:

$$\phi = 0,5\left(1 + \alpha(\bar{\lambda} - \bar{\lambda}_0) + \bar{\lambda}^2\right) \tag{6.24b}$$

where:

α is an imperfection factor;

$\bar{\lambda}_0$ is the limit of the horizontal plateau;

λ is the slenderness parameter for the relevant buckling mode.

(3) The imperfection factor for sheeting is $\alpha = 0,13$ and the limit of the horizontal plateau is $\bar{\lambda}_0 = 0,2$.

(4) The slenderness parameter for flexural buckling should be determined from the following:

$$\bar{\lambda} = \frac{l}{i\pi}\sqrt{\frac{f_{\mathrm{o}}}{\mathrm{E}}} \tag{6.25}$$

where:

l is the buckling length for flexural buckling about the y – y axes (l_{y});

i is the radius of gyration about the corresponding axes (i_{y}), based on the properties of the gross cross-section.

6.2.3 Bending and axial compression

(1) All members subject to combined bending and axial compression should satisfy the criterion:

$$\frac{N_{\mathrm{Ed}}}{\chi_y f_{\mathrm{o}} \omega_{\mathrm{x}} A_{\mathrm{eff}} / \gamma_{\mathrm{M1}}} + \frac{M_{\mathrm{y,Ed}} + \Delta M_{\mathrm{y,Ed}}}{f_{\mathrm{o}} W_{\mathrm{eff,y,com}} / \gamma_{\mathrm{M1}}} \leq 1 \tag{6.26}$$

where:

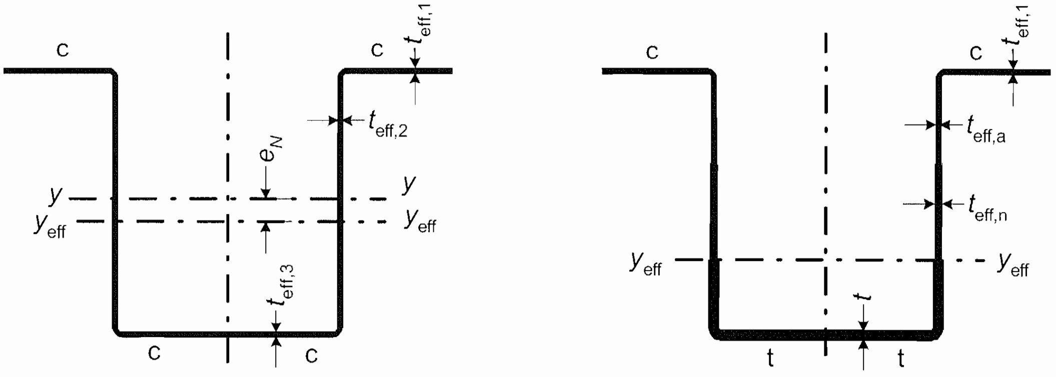
A_{eff} is the effective area of an effective cross-section that is subject only to axial compression; see Figure 6.10(a);

$W_{\mathrm{eff,y,com}}$ is the effective section modulus for the maximum compressive stress in an effective cross-section that is subject only to moment about the y - y axis, see Figure 6.10 (b);

$\Delta M_{y,Ed}$ is the additional moment due to possible shift of the centroidal axis in the y direction, see 6.1.9(2);

χ_y is the reduction factor from 6.2.2 for buckling about the y - y axis;

ω_x is an interaction expression , see (2).



(a) Axial compression (b) moment about y – y axis.

Figure 6.10 – Models for calculation of effective section properties

(2) For sheeting subjected to combined axial force and unequal end moments and/or transverse loads, different sections along the span should be checked. The actual bending moment in the studied section is used in the interaction expression and

$$\omega_x = \frac{1}{\chi_y + (1-\chi_y)\sin(\pi x_s / l_c)} \qquad (6.27)$$

where:

x_s is the distance from the studied section to a hinged support or a point of contra-flexure of the deflection curve for elastic buckling of an axial force only, see Figure 5.9 of EN1999-1-1.

$l_c = KL$ is the buckling length, see Table 5.7 of EN1999-1-1.

NOTE For simplification $\omega_x = 1$ may be used.

6.3 Stressed skin design

6.3.1 General

(1) The interaction between structural members and sheeting panels that are designed to act together as parts of a combined structural system, may be allowed for as described in this chapter 6.3

(2) Diaphragms may be formed from profiled sheeting of aluminium used as roof or wall cladding.

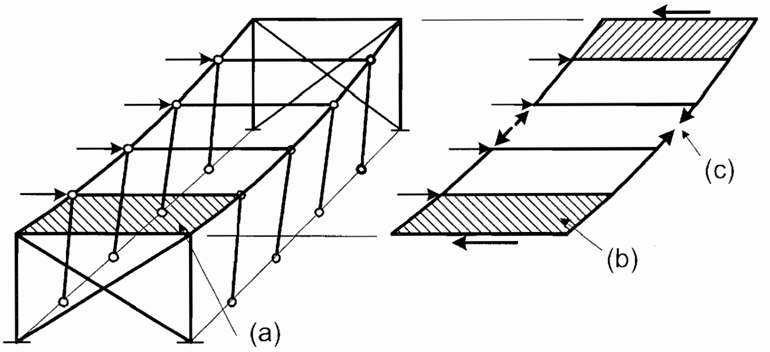
NOTE Information on the verification of such diaphragms can be obtained from:
ECCS Publication No. 88 (1995): *European recommendations for the application of metal sheeting acting as a diaphragm.*

6.3.2 Diaphragm action

(1) In stressed skin design, advantage may be taken of the contribution that diaphragms of sheeting used as roofing, flooring or wall cladding make to the overall stiffness and strength of the structural frame, by means of their stiffness and strength in shear.

(2) Roofs and floors may be treated as deep plate girders extending throughout the length of a building, resisting transverse in-plane loads and transmitting them to end gables, or to intermediate stiffened frames. The panel of sheeting may be treated as a web that resists in-plane transverse loads in shear, with the edge members acting as flanges that resist axial tension and compression forces, see Figures 6.11 and 6.12.

(3) Similarly, rectangular wall panels may be treated as bracing systems that act as shear diaphragms to resist in-plane forces.



(a) Sheeting
(b) Shear field in sheeting
(c) Flange forces in edge members

Figure 6.11 - Stressed skin action in a flat-roof building

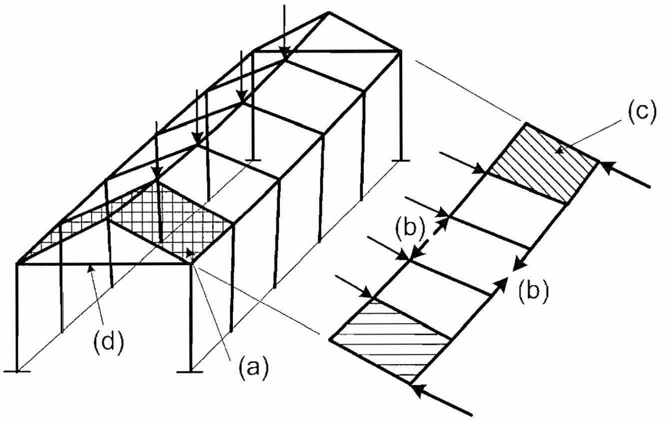
6.3.3 Necessary conditions

(1) Methods of stressed skin design that utilize sheeting as an integral part of a structure, may be used only under the following conditions:

- the use made of the sheeting, in addition to its primary purpose, is limited to the formation of shear diaphragms to resist structural displacement in the plane of that sheeting;
- the diaphragms have longitudinal edge members to carry flange forces arising from diaphragm action;
- the diaphragm forces in the plane of a roof or floor are transmitted to the foundations by means of braced frames, further stressed-skin diaphragms, or other methods of sway resistance;
- suitable structural joints are used to transmit diaphragm forces to the main framework and to join the edge members acting as flanges;
- the sheeting is treated as a structural component that cannot be removed without proper consideration;
- the execution specification, including the calculations and drawings, draws attention to the fact that the building is designed to utilize stressed skin action;
- it is recommended to install warning signs to inform that the walls are utilized as structural skin components and any removal needs precaution to maintain stability.

(2) Stressed skin design should be used predominantly in low-rise buildings, or in the floors and facades of high-rise buildings.

(3) Stressed skin diaphragms should be used predominantly to resist wind loads, snow loads and other loads that are applied through the sheeting itself. They may also be used to resist small transient loads, such as surge from light overhead cranes or hoists on runway beams, but may not be used to resist permanent external loads, such as those from plant.



(a) Sheeting
(b) Flange forces in edge members
(c) Shear field in sheeting
(d) Gable tie required to resist forces in roof sheeting

Figure 6.12 - Stressed skin action in a pitched roof building

6.3.4 Profiled aluminium sheet diaphragms

(1) In a profiled aluminium sheet diaphragm, see Figure 6.13, both ends of the sheets should be attached to the supporting members by means of self-tapping screws, self-drilling screws, welding, bolts or other fasteners of a type that will not work loose in service, pull out, or fail in shear before causing tearing of the sheeting. All such fasteners should be fixed directly through the sheeting into the supporting member, for example through the troughs of profiled sheets, unless special measures are taken to ensure that the joints effectively transmit the forces assumed in the design.

(2) The seams between adjacent sheets should be fastened by rivets, self-drilling screws, welds, or other fasteners of a type that will not work loose in service, pull out, or fail in shear before causing tearing of the sheeting. The spacing of such fasteners should not exceed 500 mm.

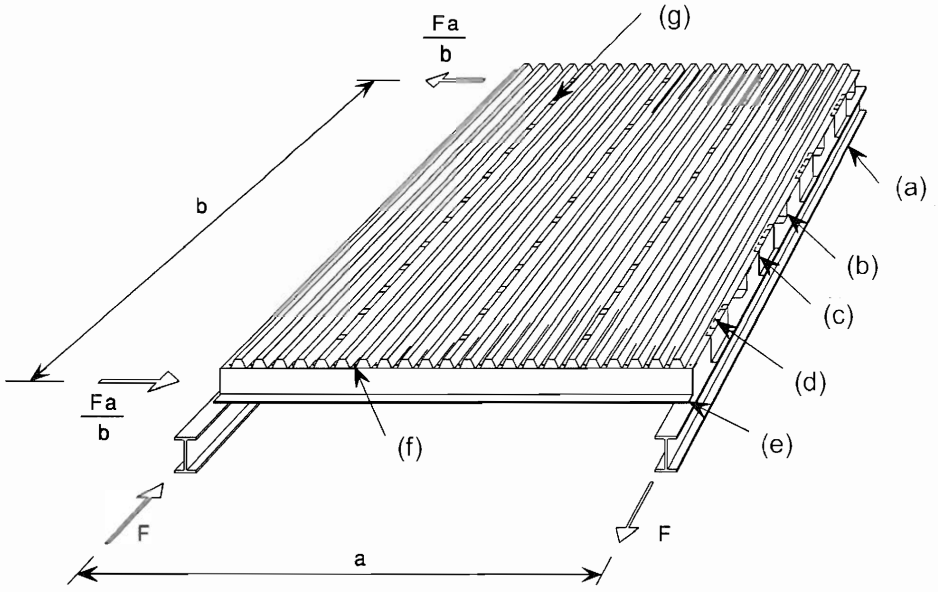
(3) The distances from all fasteners to the edges and ends of the sheets should be adequate to prevent premature tearing of the sheets.

(4) Small randomly arranged openings, up to 3% of the relevant area, may be introduced without special calculation, provided that the total number of fasteners is not reduced. Openings up to 15% of the relevant area may be introduced if justified by detailed calculations. Areas that contain larger openings should be split into smaller areas, each with full diaphragm action.

(5) All sheeting that also forms part of a stressed-skin diaphragm should first be designed for its primary purpose in bending. To ensure that any deterioration of the sheeting would be apparent in bending before the resistance to stressed skin action is affected, it should then be verified that the shear stress due to diaphragm action does not exceed $0{,}25 f_o / \gamma_{M1}$

(6) The shear resistance of a stressed-skin diaphragm should be based on the least tearing strength of the seam fasteners or the sheet-to-member fasteners parallel to the corrugations or, for diaphragms fastened only to longitudinal edge members, the end sheet-to-member fasteners. The calculated shear resistance for any other type of failure should exceed this minimum value by at least the following:

- for failure of the sheet-to-purlin fasteners under combined shear and wind uplift, by at least 40%;
- for any other type of failure, by at least 25%.



(a) Rafter

(b) Purlin

(c) Shear connector

(d) Sheet-to-shear connector fastener

(e) Purlin

(f) Sheet-to-purlin fastener

(g) Seam fastener

Figure 6.13 - Arrangement of an individual panel

6.4 Perforated sheeting with the holes arranged in the shape of equilateral triangles

(1) Perforated sheeting may be designed by calculation, provided that the rules for non-perforated sheeting are modified by introducing the effective thicknesses given below.

NOTE These calculation rules tend to give conservative values. More economical solutions might be obtained from design assisted by testing.

(2) Provided that $0,2 \leq d/a \leq 0,9$ gross section properties may be calculated using 6.1.2 to 6.1.5, but replacing t by $t_{\mathrm{a,eff}}$ obtained from:

$$t_{\mathrm{a,eff}} = 1{,}18t\left(1 - d/(0{,}9a)\right) \tag{6.28}$$

where:

d is the diameter of the perforations;

a is the spacing between the centres of the perforations.

(3) Provided that $0,2 \leq d/a \leq 0,9$ effective section properties may be calculated using 5.5, but replacing t by $t_{\mathrm{b,eff}}$ obtained from:

$$t_{\mathrm{b,eff}} = t\sqrt[3]{1{,}18\left(1 - d/a\right)} \tag{6.29}$$

(4) Provided that $0,2 \leq d/a \leq 0,8$ the resistance of a single unstiffened web to local transverse forces may be calculated using 6.1.7, but replacing t by $t_{\mathrm{c,eff}}$ obtained from:

$$t_{\mathrm{c,eff}} = t\left[1 - (d/a)^2 s_{\mathrm{per}} / s_{\mathrm{w}}\right]^{3/2} \tag{6.30}$$

where:

s_{per} is the slant height of the perforated portion of the web, centric in the web height;

s_{w} is the total slant height of the web.

7 Serviceability limit states

7.1 General

(1) The rules for serviceability limit states given in EN 1999-1-1 should also be applied to cold-formed sheeting.

(2) The properties of the effective cross-section for serviceability limit states obtained from (3) should be used in all serviceability limit state calculations for cold-formed sheeting.

(3) The second moment of area may be calculated by interpolation of gross cross-section and effective cross-section using the expression:

$$I_{\mathrm{eff,ser}} = I_{\mathrm{gr}} - \sigma_{\mathrm{gr}} (I_{\mathrm{gr}} - I_{\mathrm{eff}}) / f_{\mathrm{o}} \tag{7.1}$$

where:

I_{gr}	is the second moment of area of gross section;
I_{eff}	is the second moment of area of the effective cross-section in the ultimate limit state, with allowance for local buckling;
σ_{gr}	is the maximum compressive bending stress in the serviceability limit state, based on the gross cross-section (positive in the formula).

(4) The effective second moment of area $I_{\mathrm{eff,ser}}$ may be taken as variable along the span. Alternatively a uniform value may be used, based on the maximum span moment due to serviceability loading.

7.2 Plastic deformation

(1) In case of plastic global analysis, the combination of support moment and support reaction at an internal support should not exceed 0,9 times the combined design resistance determined using $\gamma_{\mathrm{M,ser}}$ and $I_{\mathrm{eff,ser}}$ according to 7.1(3).

(2) The combined design resistance may be determined from expression (6.22) in 6.1.11, but using the effective cross-section for serviceability limit states and $\gamma_{\mathrm{M,ser}}$.

7.3 Deflections

(1) The deflections may be calculated assuming elastic behaviour.

(2) The influence of slip in the joints (for example in the case of continuous sheeting with overlaps) should be considered in the calculation of deflections, forces and moments.

NOTE For commonly used fasteners according to 8.2 and 8.3 the slip may be ignored.

(3) With reference to EN 1990 – Annex A1.4 limits for deflections should be specified for each project and agreed with the client.

NOTE The National Annex may specify the limits.

8 Joints with mechanical fasteners

8.1 General

(1) Joints with mechanical fasteners should be compact in shape. The positions of the fasteners should be arranged to provide sufficient room for satisfactory assembly and maintenance.

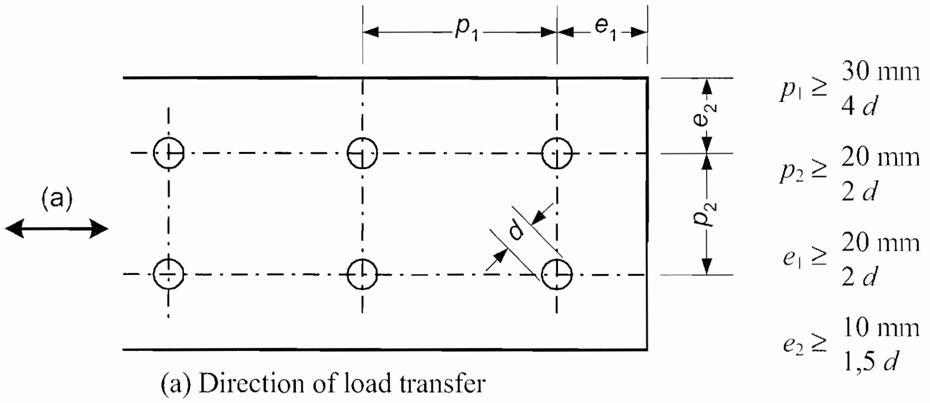
(2) The shear forces on individual mechanical fasteners in a joints may be assumed to be equal, provided that:

- the fasteners have sufficient ductility;
- shear of the fastener is not the critical failure mode.

(3) For design by calculation, the resistance of mechanical fasteners subject to predominantly static loads should be determined from 8.2 for blind rivets and 8.3 for self-tapping screws and self-drilling screws.

(4) The meanings of the symbols, used in the above named clauses are found in EN 1999-1-1 with additions in 1.4 of EN 1999-1-4.

(5) The partial factor for calculating the design resistances of mechanical fasteners should be taken as γ_{M3} according to 2(3).



(a) Direction of load transfer

Figure 8.1 - End distance, edge distance and spacing for fasteners

(6) The pull-through resistances given in 8.2.3.1 for blind rivets or in 8.3.3.1 for self-tapping screws and self-drilling screws are depending on the location of the fasteners and should be reduced if the fasteners are not located centrally in the troughs of the sheeting. If attachment is at a quarter point, the design resistance should be reduced to $0{,}9F_{p,Rd}$ and if there are fasteners at both quarter points, the resistance should be taken as $0{,}7F_{p,Rd}$ per fastener, see Table 8.3.

(7) For a fastener loaded in combined shear and tension, provided that $F_{p,Rd}$, $F_{o,Rd}$, $F_{b,Rd}$ and $F_{n,Rd}$ are determined by calculation on the basis of 8.2 for blind rivets or 8.3 for self-tapping screws and self-drilling screws, the resistance of the fastener to combined shear and tension may be verified using:

$$\frac{F_{t,Ed}}{\min(F_{p,Rd}, F_{o,Rd})} + \frac{F_{v,Ed}}{\min(F_{b,Rd}, F_{n,Rd})} \leq 1 \qquad (8.1)$$

(8) The gross section distortion may be neglected if the design resistance is obtained from 8.2.3 and 8.3.3 provided that the fastening is through a flange not more than 150 mm wide.

(9) The diameter of holes for screws should be in accordance with the manufacturer's guidelines. These guidelines should be based on following criteria:

- the applied torque should be just higher than the threading torque;
- the applied torque should be lower than the thread stripping torque or head-shearing torque;
- the threading torque should be smaller than 2/3 of the head-shearing torque.

(10) The design rules for blind rivets are valid only if the diameter of the hole is not more than 0,1 mm larger than the diameter if the rivet.

8.2 Blind rivets

8.2.1 General

(1) The resistance of blind rivets loaded in shear is the minor value of the bearing resistance $F_{b,Rd}$, the net-section resistance $F_{net,Rd}$ of the sheeting and the shear resistance of the fastener $F_{v,Rd}$.

(2) The shank of the blind rivet should be of EN AW- 5019.

(3) Blind rivets according to EN ISO 15973, EN ISO 15974, EN ISO 15977, EN ISO 15978, EN ISO 15981 or EN ISO 15982 should be used

8.2.2 Design resistances of riveted joints loaded in shear

8.2.2.1 Bearing resistance

$$F_{b,Rd} = 2{,}5 f_{u,min} \sqrt{t^3 d} \, / \gamma_{M3} \quad \text{for } t_{sup} / t = 1{,}0, \quad \text{but} \quad F_{b,Rd} \leq 1{,}5 f_{u,min}\, t\, d / \gamma_{M3} \qquad (8.2a)$$

$$F_{b,Rd} = 1{,}5 f_{u,min}\, t\, d / \gamma_{M3} \quad \text{for } t_{sup} / t \geq 2{,}5 \qquad (8.2b)$$

For thicknesses $1{,}0 < t_{sup} / t < 2{,}5$ the bearing resistance $F_{b,Rd}$ may be obtained by linear interpolation.

8.2.2.2 Net section resistance

$$F_{net,Rd} = A_{net} f_u / \gamma_{M3} \qquad (8.3)$$

8.2.2.3 Shear resistance

$$F_{v,Rd} = 38\, d^2 / \gamma_{M3} \quad \text{[N]} \quad \text{with } d \text{ in mm} \qquad (8.4)$$

Conditions for bearing and shear resistance:

- $f_{u,min} > 260$ N/mm^2 should not be taken into account
- $2{,}6 \text{ mm} \leq d \leq 6{,}4$ mm

8.2.3 Design resistances for riveted joints loaded in tension

8.2.3.1 Pull-through resistance

$$F_{p,Rd} = 2{,}35\, \alpha_E\, t\, f_o / \gamma_{M3} \quad \text{[N] with } t \text{ in mm and } f_o \text{ in N/mm}^2\text{ ; } \alpha_E \text{ according to Table 8.3} \qquad (8.5)$$

Conditions:

- $t \leq 1{,}5$ mm; $d_w \geq 9{,}5$ mm;
- $f_o > 220$ N/mm^2 should not be taken into account

8.2.3.2 Pull-out resistance

- Supporting member of steel: $F_{o,Rd} = 0{,}47\, t_{sup}\, d\, f_y / \gamma_{M3}$ (8.6)

- Supporting member of aluminium: $F_{o,Rd} = 0{,}20\, t_{sup}\, d\, f_o / \gamma_{M3}$ (8.7)

Conditions:

- $t_{sup} > 6$ mm, $f_y > 350$ N/mm^2, $f_o > 220$ N/mm^2 should not be taken into account (everyone to be fulfilled)
- the drilling holes have to be performed according to the recommendations of the manufacturer

8.2.3.3 Tension resistance

$F_{t,Rd} = 47\, d^2 / \gamma_{M3}$ [N], where d to be taken in mm. (8.8)

8.3 Self-tapping / self-drilling screws

8.3.1 General

(1) The resistance of screws loaded in shear is the minor value of the bearing resistance $F_{b,Rd}$, the net-section resistance $F_{net,Rd}$ of the sheeting and the shear resistance of the fastener $F_{v,Rd}$.

(2) The limits for diameters of screws given in the following clauses should be valid, unless other limits can be obtained and verified by adequate tests.

(3) The limits for strength values of supporting materials should be valid, unless other limits can be obtained and verified by adequate tests.

(4) Self-tapping screws according to EN ISO 1479, EN ISO 1481 or ISO 7049 should be used.

(5) Self-drilling screws according to EN ISO 15480 or EN ISO 15481 should be used.

8.3.2 Design resistance of screwed joints loaded in shear

8.3.2.1 Bearing resistance

(1) Bearing resistance if supporting members are of steel or aluminium is given by:

$$F_{b,Rd} = 2{,}5 f_{u,min} \sqrt{t^3 d} / \gamma_{M3} \quad \text{for } t_{sup}/t = 1{,}0, \quad \text{but} \quad F_{b,Rd} \le 1{,}5 f_{u,min}\, t\, d / \gamma_{M3} \tag{8.9a}$$

$$F_{b,Rd} = 1{,}5 f_{u,min}\, t\, d / \gamma_{M3} \quad \text{for } t_{sup}/t \ge 2{,}5 \tag{8.9b}$$

For thicknesses $1{,}0 < t_{sup}/t < 2{,}5$ the bearing resistance $F_{b,Rd}$ may be obtained by linear interpolation.

Conditions:

- self- tapping and self- drilling screws should be of steel or stainless steel with diameter $d \ge 5{,}5$ mm,
- $f_{u,min} > 260$ N/mm^2 should not be taken into account;
- for $t > t_{sup}$ take $t = t_{sup}$;
- the drilling holes have to be performed according to the recommendations of the manufacturer.

(2) Bearing resistance of aluminium sheeting if supporting members are of timber is given by:

$$F_{b,Rd} \le 1{,}5\, t\, d\, f_{u,min} / \gamma_{M3} \quad [\text{N}] \tag{8.10}$$

(3) For resistance of supporting member of timber, see EN 1995-1-1, Section 8, steel-to-timber connection.

Conditions:

- self-tapping and self- drilling screws of steel or stainless steel with 5,5 mm $\le d \le$ 8 mm;
- edge distances and spacing in the member of timber, see EN 1995-1-1, Section 8.

8.3.2.2 Net section resistance

$$F_{\mathrm{net,Rd}} = A_{\mathrm{net}} f_{\mathrm{u}} / \gamma_{\mathrm{M3}} \tag{8.11}$$

8.3.2.3 Shear resistance

Design shear resistance of screws of steel or stainless steel is given by:

$$F_{\mathrm{v,\,Rd}} = 380\, A_{\mathrm{s}} / \gamma_{\mathrm{M3}} \quad [\mathrm{N}],\ \text{with } A_{\mathrm{s}} \text{ in mm}^2 \tag{8.12}$$

8.3.3 Design resistance of screwed joints loaded in tension

8.3.3.1 Pull-through resistance

(1) The pull-through resistance of screwed joints loaded in tension is given by:

$$F_{\mathrm{p,Rd}} = 6{,}1\ \alpha_{\mathrm{L}}\ \alpha_{\mathrm{E}}\ \alpha_{\mathrm{M}}\ t f_{\mathrm{u}} \sqrt{d_{\mathrm{w}}/22}\ / \gamma_{\mathrm{M3}} \quad [\mathrm{N}] \tag{8.13}$$

with: t and d_{w} in mm and f_{u} in N/ mm^2 and

- α_{L} correction factor with respect to tension in bending (Table 8.1);
- α_{M} correction factor with respect to the type of washer (Table 8.2);
- α_{E} correction factor with respect to the location of fasteners (Table 8.3).

Conditions:

- $t \leq 1{,}5$ mm;
- $d_{\mathrm{w}} \geq 14$ mm and thickness of the washer ≥ 1 mm;
- width of the adjacent flange of the sheet cross-section part ≤ 200 mm;
- $d_{\mathrm{w}} > 30$ mm and $f_{\mathrm{u}} > 260$ N/mm should not be taken into account;
- at a depth of the sheeting smaller than 25 mm, the pull-through- resistance should be reduced by 30 %.

Table 8.1 - Correction factor α_{L}, to take account of tensile bending stresses at support fastenings

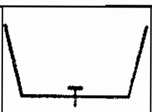
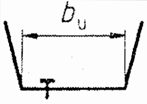
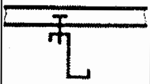
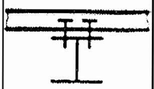
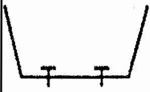
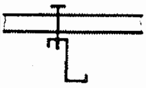
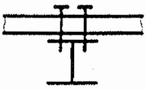
Ultimate strength [N/mm^2]	α_{L}		
	Span $L < 1{,}5$ m	Span $1{,}5 \leq L \leq 4{,}5$ m	Span $L > 4{,}5$ m
< 215	1	1	1
≥ 215	1	$1{,}25 - L/6$	0,5

NOTE At end supports without bending stresses and at connections at the upper flange always $\alpha_{\mathrm{L}} = 1$

Table 8.2 - Correction factor α_{M} to take account of the material of the washer

Material of the washer	α_{M}
Carbon steel, stainless steel	1,0
Aluminium	0,8

Table 8.3 - Correction factor α_E to take account of the location of the fasteners

For the flange in contact with the support						without contact	
Joint							
α_E	1,0	$b_u \le 150$:0,9 $b_u > 150$:0,7	0,7	0,9	0,7 0,7	1,0	0,9

NOTE The combination of correction factors is not necessary. The smallest value applies.

8.3.3.2 Pull-out resistance

(1) The pull-out resistance for self- tapping screws and self-drilling screws of steel or stainless steel, where supporting members are of steel or aluminium, is given by:

$$F_{o,Rd} = 0{,}95 f_{u,sup} \sqrt{t_{sup}^3 \cdot d} \,/\gamma_{M3} \tag{8.14}$$

Conditions:

- self-tapping screws and self-drilling screws of steel- or stainless steel;
- diameter of the screws 6,25 mm $\le d \le$ 6,5 mm;
- $t_{sup} > 6$ mm and $f_{u,sup} > 250$ N/ mm^2 for aluminium <u>or</u>
- $t_{sup} > 5$ mm and $f_{u,sup} > 400$ N/ mm^2 for steel should not be taken into account;
- the diameter of the drilling hole should be in accordance with the recommendations of the manufacturer.

(2) For supporting members of timber, see EN 1995-1-1, Section 8.

8.3.3.3 Tension resistance

(1) The design tension resistance of screws of steel or stainless steel is given by:

$$F_{t,Rd} = 560\, A_s \,/\gamma_{M3} \quad [\text{N}] \quad \text{with } A_s \text{ in mm}^2 \tag{8.15}$$

9 Design assisted by testing

(1) This Section 9 may be used to apply the principles for design assisted by testing given in EN 1990 with the additional specific requirements of cold-formed sheeting.

(2) Testing of profile sheeting should apply the principles given in Annex A.

(3) Tensile testing of aluminium alloys should be carried out in accordance with EN 10002-1. Testing of other aluminium properties should be carried out in accordance with the relevant European Standards.

(4) Testing of fasteners and connections should be carried out in accordance with the relevant European Standard or International Standard.

NOTE Pending availability of an appropriate European or International Standard, information on testing procedures for fasteners can be obtained from:

ECCS Publication No. 21 (1983): *European recommendations for steel construction: the design and testing of connections in steel sheeting and sections*;

ECCS Publication No. 42 (1983): *European recommendations for steel construction: mechanical fasteners for use in steel sheeting and sections*.

Annex A [normative] – Testing procedures

A.1 General

(1) This Annex A gives appropriate standardized testing and evaluation procedures for a number of tests that are commonly required in practice, as a basis for harmonization of future testing.

NOTE 1 In the field of cold-formed sheeting, many standard products are commonly used for which design by calculation might not lead to economical solutions, so it is frequently desirable to use design assisted by testing.

NOTE 2 AC1⟩ The National Annex may give further information on testing and on the evaluation of test results ⟨AC1

NOTE 3 The National Annex may give conversion factors for existing test results to be equivalent to the outcome of standardised tests according to this annex.

(2) This annex covers:

- tests on profiled sheets, see A.2;
- valuation of test results to determine design values, see A.3.

A.2 Tests on profiled sheets

A.2.1 General

(1) Loading may be applied through air bags or in a vacuum chamber or by metal or timber cross beams arranged to simulate uniformly distributed loading.

(2) To prevent spreading of corrugations, transverse ties or other appropriate test accessories such as timber blocks may be applied to the test specimen. Some examples are given in Figure A.1.

(3) Test specimens for sheet profiles should normally comprise at least two complete corrugations, but a test specimen may comprise just one complete corrugation, provided that the stiffness of the corrugations is sufficient. Free longitudinal edges should be in the tension zone during test procedure.

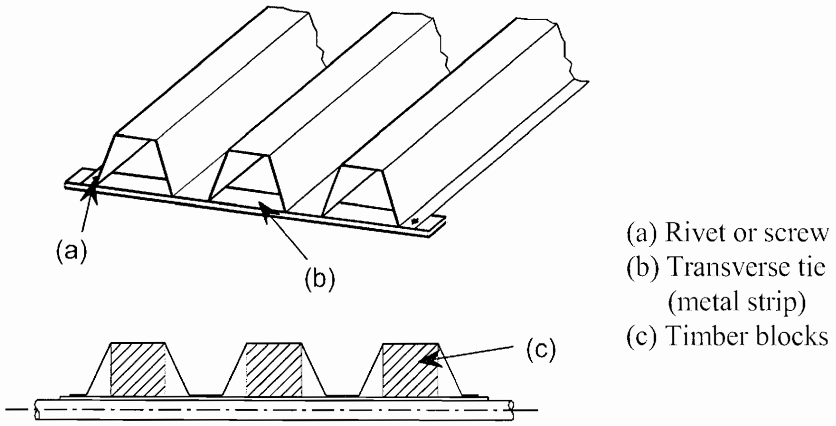


Figure A.1 - Examples of appropriate test accessories

(4) For uplift tests, the test set-up should realistically simulate the behaviour of the sheeting under practical conditions. The type of joints between the sheet and the supports should be the same as in the joints to be used in practice.

(5) To give the results a wide range of applicability, hinged and roller supports should preferably be used, to avoid any influence of torsional or longitudinal restraint at the supports on the test results.

(6) It should be ensured that the direction of the loading remains perpendicular to the initial plane of the sheet throughout the test procedure.

(7) To eliminate the deformations of the supports, the deflections at both ends of the test specimen should also be measured.

(8) The test result should be taken as the maximum value of the loading applied to the specimen either coincident with failure or immediately prior to failure as appropriate.

A.2.2 Single span test

(1) A test set-up equivalent to that shown in Figure A.2 may be used to determine the midspan moment resistance (in the absence of shear force) and the effective flexural stiffness.

(2) The span should be chosen such that the test results represent the moment resistance of the sheet.

(3) The moment resistance should be determined from the test result.

(4) The flexural stiffness should be determined from a plot of the load-deflection behaviour.

A.2.3 Double span test

(1) The test set-up shown in Figure A.3 may be used to determine the resistance of a sheet that is continuous over two or more spans to combinations of moment and shear at internal supports, and its resistance to combined moment and support reaction for a given support width.

(2) The loading should preferably be uniformly distributed (applied using an air bag or a vacuum chamber, for example).

(3) Alternatively any number of line loads (transverse to the span) may be used, arranged to produce internal moments and forces that are appropriate to represent the effects of uniformly distributed loading. Some examples of suitable arrangements are shown in Figure A.4.

A.2.4 Internal support test

(1) As an alternative to A.2.3, the test set-up shown in Figure A.5 may be used to determine the resistance of a sheet that is continuous over two or more spans to combinations of moment and shear at internal supports, and its resistance to combined moment and support reaction for a given support width.

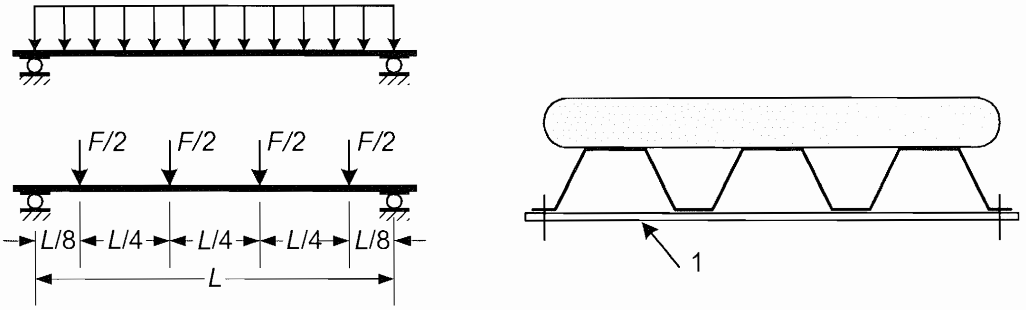
(2) The test span s used to represent the portion of the sheet between the points of contraflexure each side of the internal support, in a sheet continuous over two equal spans L may be obtained from:

$$s = 0{,}4L \tag{A.1}$$

(3) If plastic redistribution of the support moment is expected, the test span s should be reduced to represent the appropriate ratio of support moment to shear force.

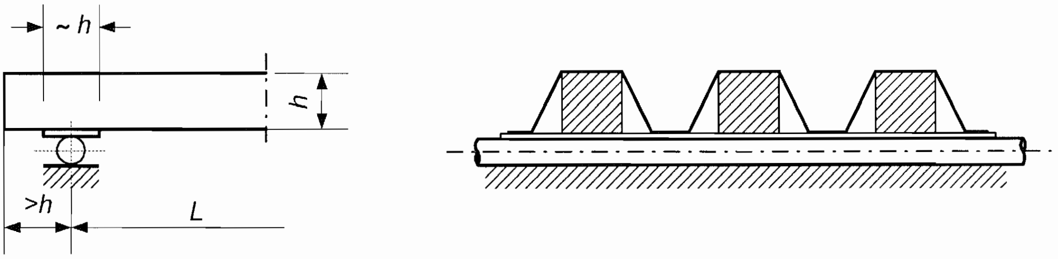
(4) The width b_B of the beam used to apply the test load should be selected to represent the actual support width to be used in practice.

(5) Each test result may be used to represent the resistance to combined bending moment and support reaction (or shear force) for a given span and a given support width. To obtain information about the interaction of bending moment and support reaction, tests should be carried out for several different spans.

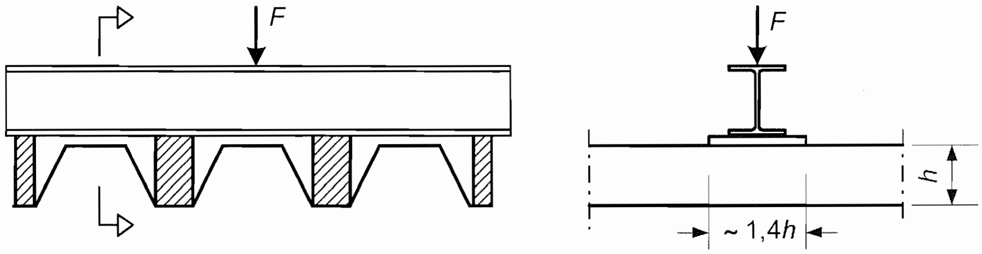


a) Uniformly distributed loading and an example of alternative equivalent line loads

b) Distributed loading applied by an airbag (alternatively by a vacuum test rig)
1 = transverse tie



c) Example of support arrangements for preventing distortion



d) Example of method of applying a line load

Figure A.2 - Test set-up for single span tests

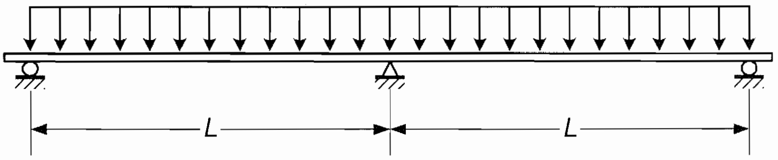


Figure A.3 - Test setup for double span tests

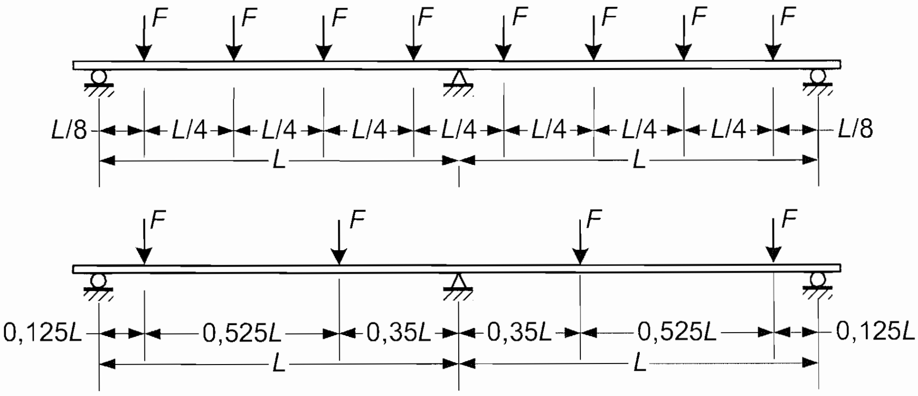
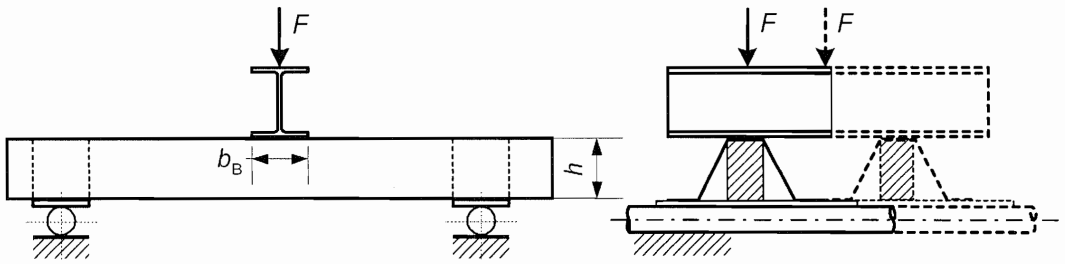
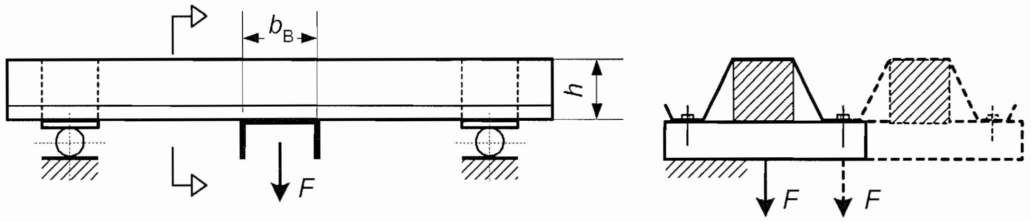


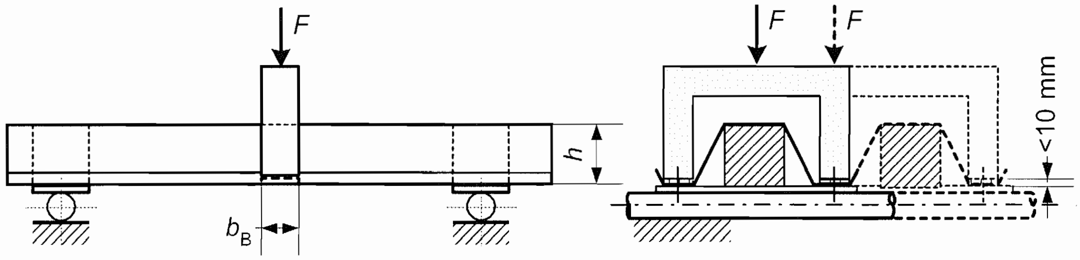
Figure A.4 - Examples of suitable arrangements of alternative line loads



a) Internal support under gravity loading

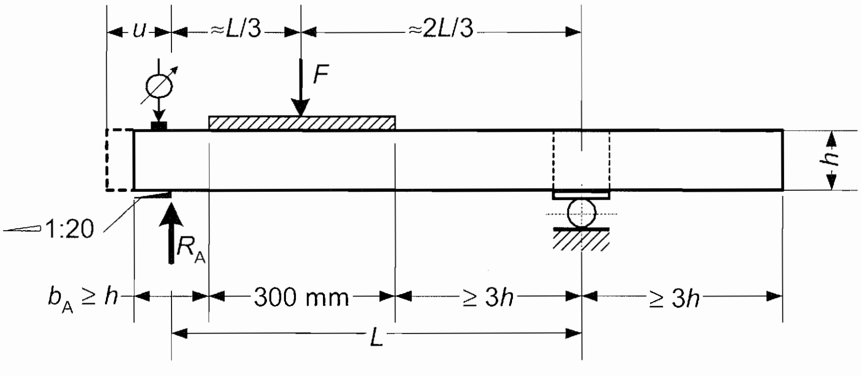


b) Internal support under uplift loading



c) Internal support with loading applied to tension flange

Figure A.5 - Test set-up for internal support test



Key:

b_A = support length

u = length from internal edge of end support to end of sheet

Figure A.6 - Test set-up for end support tests

A.2.5 End support test

(1) The test set-up shown in Figure A.6 may be used to determine the resistance of a sheet at an end support.

(2) Separate tests should be carried out to determine the shear resistance of the sheet for different lengths u from the contact point at the inner edge of the end support, to the actual end of the sheet, see Figure A.6.

A.3 Evaluation of test results

A.3.1 General

(1) A specimen under test should be regarded as having failed if the applied test loads reach their maximum values, or if the gross deformations exceed specified limits.

(2) In the testing of joints, or of components in which the examination of large deformations is necessary for accurate assessment (for example, in evaluating the moment-rotation characteristics of sleeves), no limit need be placed on the gross deformation during the test.

(4) An appropriate margin of safety should be available between a ductile failure mode and possible brittle failure modes. As brittle failure modes do not usually appear in large-scale tests, additional detail tests should be carried out where necessary.

NOTE This is often the case for joints.

A.3.2 Adjustment of test results

(1) Test results should be appropriately adjusted to allow for variations between the actual measured properties of the test specimens and their nominal values.

(2) The actual measured 0,2 % proof strength $f_{0,2,\mathrm{obs}}$ should not deviate by more than ± 25% from the nominal 0,2 % proof strength $f_{0,2}$.

(3) The actual measured material thickness t_{obs} should not exceed the design thickness t based on the nominal material thickness t_{nom} by more than 12%.

(4) Adjustments should be made in respect of the actual measured values of the material thickness t_{obs} and the 0,2 % proof strength $f_{0,2,\mathrm{obs}}$ for all tests, except where the design expression that uses the test results also uses the actual measured value of the thickness or 0,2 % proof strength of the material, as appropriate.

(5) The adjusted value $R_{\mathrm{adj},i}$ of the test result for test i should be determined from the actual measured test result $R_{\mathrm{obs},i}$ using:

$$R_{\mathrm{adj},i} = R_{\mathrm{obs},i} / \mu_{\mathrm{R}} \tag{A.2}$$

in which μ_{R} is the resistance adjustment coefficient given by:

$$\mu_{\mathrm{R}} = \left(\frac{f_{0,2,\mathrm{obs}}}{f_{0,2}}\right)^{\alpha} \left(\frac{t_{\mathrm{obs}}}{t}\right)^{\beta} \tag{A.3}$$

(6) The exponent α for use in expression (A.2) should be obtained as follows:

- if $f_{0,2,\mathrm{obs}} \leq f_{0,2}$: $\alpha = 0$
- if $f_{0,2,\mathrm{obs}} > f_{0,2}$ $\alpha = 1$
- for profiled sheets in which compression parts have such large b_{p}/t ratios that local buckling is clearly the failure mode: $\alpha = 0,5$

(7) The exponent β for use in expression (A.2) should be obtained as follows:

- if $t_{\mathrm{obs}} \leq t$: $\beta = 1$
- if $t_{\mathrm{obs}} > t$: $\beta = 2$

A.3.3 Characteristic values

A.3.3.1 General

(1) Characteristic values may be determined statistically, provided that there are at least 4 test results.

NOTE A larger number is generally preferable, particularly if the scatter is relatively wide.

(2) The characteristic minimum value should be determined using the following provisions. If the characteristic maximum value or the characteristic mean value is required, it should be determined by using appropriate adaptations of the provisions given for the characteristic minimum value.

3) The characteristic value of a resistance R_k determined on the basis of at least 4 tests may be obtained from:

$$R_k = R_m - k\,s \tag{A.4}$$

where:

s is the standard deviation;

k is the appropriate coefficient from Table A.1;

R_m is the mean value of the adjusted test results R_{adj}.

(4) The standard deviation s may be determined using:

$$s = \sqrt{\frac{\sum_{i=1}^{n} R_{adj,i}^2 - \sum_{i=1}^{n} R_m^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} R_{adj,i}^2 - n \cdot R_m^2}{n-1}} \tag{A5}$$

where:

$R_{adj,i}$ is the adjusted test result for test i;

n is the number of tests.

Table A.1 - Values of the coefficient *k*

n	4	5	6	8	10	20	30	∞
k	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

A.3.3.2 Characteristic values for families of tests

(1) A series of tests carried out on a number of otherwise similar sheets, in which one or more parameters is varied, may be treated as a single family of tests, provided that they all have the same failure mode. The parameters that are varied may include cross-sectional dimensions, spans, thicknesses and material strengths.

(2) The characteristic resistances of the members of a family may be determined on the basis of a suitable design expression that relates the test results to all the relevant parameters. This design expression may either be based on the appropriate equations of structural mechanics, or determined on an empirical basis.

(3) The design expression should be modified to predict the mean measured resistance as accurately as practicable, by adjusting the coefficients to optimise the correlation.

NOTE Information on this process is given in Annex D of EN 1990.

(4) In order to calculate the standard deviation s, each test result should first be normalized by dividing it by the corresponding value predicted by the design expression. If the design expression has been modified as specified in (3), the mean value of the normalized test results will be unity. The number of tests n should be taken as equal to the total number of tests in the family.

(5) For a family of at least four tests, the characteristic resistance R_k should then be obtained from expression (A.3) by taking R_m as equal to the value predicted by the design expression, and using the value of k from Table A.1 corresponding to a value of n equal to the total number of tests in the family.

A.3.4 Design values

(1) The design value of a resistance R_d should be derived from the corresponding characteristic value R_k determined by testing, using:

$$R_d = R_k / (\gamma_M \gamma_{sys}) \tag{A.6}$$

where:

γ_M is the partial factor for resistance;

γ_{sys} is a partial factor for differences in behaviour under test conditions and service conditions.

(2) For a family of at least four tests, the value of γ_M may be determined using statistical methods.

NOTE Information on an appropriate method is given in Annex D of EN 1990.

(3) Alternatively γ_M may be taken as equal to the appropriate value of γ_M for design by calculation given in Section 2.

NOTE The National Annex may give values for γ_M and γ_{sys}. A recommended value for γ_{sys} is 1,0 in case of sheeting.

(4) For other types of tests in which possible instability phenomena, or modes of behaviour, of structures or structural components might not be covered sufficiently by the tests, the value of γ_{sys} should be assessed taking into account the actual testing conditions, in order to achieve the necessary reliability.

A.3.5 Serviceability

(1) The provisions given in Section 7 should be satisfied.

Annex B [informative] – Durability of fasteners

(1) For mechanical joints in cold-formed sheeting Table B.1 may be applied

Table B.1 - Fastener material with regard to corrosion environment (and sheeting material only for information). Only risk of corrosion is considered. Environmental corrosivity categories according to EN ISO 12944-2

Corro-sivity category	Sheet material	Material of fastener					
		Alumi-nium	Electro galvanized steel. Coat thickness ≥ 7μm	Hot-dip zinc coated steel [b]. Coat thick-ness ≥45μm	Stainless steel, case hardened. 1.4006 [d, e]	Stainless steel, 1.4301 [d] 1.4436 [d]	Monel [a]
C1	A, B, C	X	X	X	X	X	X
	D, E, S	X	X	X	X	X	X
C2	A	X	-	X	X	X	X
	C, D, E	X	-	X	X	X	X
	S	X	-	X	X	X	X
C3	A	X	-	X	-	X	X
	C, E	X	-	X	(X)[c]	(X)[c]	-
	D	X	-	X	-	(X)[c]	X
	S	-	-	X	X	X	X
C4	A	X	-	(X)[c]	-	(X)[c]	-
	D	-	-	X	-	(X)[c]	-
	E	X	-	X	-	(X)[c]	-
	S	-	-	X	-	X	X
C5-I	A	X	-	-	-	(X)[c]	-
	D[f]	-	-	X	-	(X)[c]	-
	S	-	-	-	-	X	-
C5-M	A	X	-	-	-	(X)[c]	-
	D[f]	-	-	X	-	(X)[c]	-
	S	-	-	-	-	X	-

NOTE Fastener of steel without coating may be used in corrosivity category C1.

A = aluminium irrespective of surface finish
B = un-coated steel sheet
C = hot-dip zinc coated (Z275) or aluzinc coated (AZ150) steel sheet
D = hot-dip zinc coated + coating of paint or plastic
E = aluzinc coated (AZ185) steel sheet
S = stainless steel
X = type of material recommended from corrosion standpoint
(X) = type of material recommended from corrosion standpoint under the specified condition only

- = type of material not recommended from corrosion standpoint
a refers to rivets only
b refers to screws and nuts only
c insulation washer of material resistant to aging between sheeting and fastener
d stainless steel EN 10 088
e risk of discoloration
f always check with sheet supplier

(2) The environmental corrosivity categories following EN ISO 12944-2 are presented in Table B.2.

Table B.2 - Atmospheric-corrosivity categories according to EN ISO 12944-2 and example of typical environment

Corrosivity category	Corrosivity level	Example of typical environments in temperature climate (informative)	
		Exterior	Interior
C1	very low	-	Heated buildings with clean atmospheres, e.g. offices, shops, schools, hotels.
C2	low	Atmospheres with low level of pollution. Mostly rural areas.	Unheated buildings where condensation may occur, e.g. depots, sport halls.
C3	medium	Urban and industrial atmospheres, moderate sulphur dioxide pollution. Coastal areas with low salinity.	Production rooms with high humidity and some air pollution, e.g. food-processing, plants, laundries, breweries and dairies.
C4	high	Industrial areas and coastal areas with moderate salinity.	Chemical plants, swimming pools, coastal ship- and boatyards.
C5-I	very high (industrial)	Industrial areas with high humidity and aggressive atmospheres.	Buildings and areas with almost permanent condensation and with high pollution.
C5-M	very high (marine)	Coastal and offshore areas with high salinity.	Buildings and areas with almost permanent condensation and with high pollution

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