GRISPE PLUS

VALORISATION OF KNOWLEDGE FOR SPECIFIC PROFILED STEEL SHEETS

WP N°: 3
WP Title: eLectures: Interactive electronic lectures
Deliverable N°: D3.1
Deliverable Title : Steel decks with outwards stiffeners
Deliverable Date: 31st of March 2018

The GRISPE PLUS project has received financial support from the European Community's Research Fund for Coal and Steel (RFCS) under grant agreement N° 754092"

Author(s)		
Sokol Palisson Consultants, Anna Palisson		
Drafting history		
DRAFT N° 1 –DATE:		
DRAFT N° 2- DATE:		
FINAL- DATE: 31st of March		
Dissemination Level		
PU	*Public-Open*	
PP	*Restricted to the Commission Services, the Coal and Steel Technical Groups and the European Committee for Standardisation (CEN)*	
RE	*Restricted to a group specified by the Beneficiaries*	
CO	*Confidential, only for Beneficiaries (including the Commission services)*	

D3.1 STEEL DECK WITH OUTWARDS STIFFENERS

RFCS funded – agreement N° 754092

Disclaimer notice

and

EU acknowledgement of support

Disclaimer notice

By making use of any information or content in this manual (Part 1 and Part 2) you agree to the following:

No warranties

All the information or content provided in this manual is provided "as is" and with no warranties. No express or implies warranties of any type, including for example implied warranties of merchantability or fitness for a particular purpose, are made with respect to the information or content, or any use of the information or content in this manual.

The authors make no representations or extend no warranties of any type as to the completeness, accuracy, reliability, suitability or timeliness of any information or content in this manual.

Disclaimer of liability

This manual is for informational purposes only. It is your responsibility to independently determine whether to perform, use or adopt any of the information or content in this manual.

The authors specifically disclaim liability for incidental or consequential damages and assume no responsibility or liability for any loss or damage suffered by any person as a result of the use or misuse of any of the information or content in this manual.

The authors will not be liable to you for any loss or damage including without limitation direct, indirect, special or consequential loss or damage, or any loss or damage whatsoever arising from loss of data or loss of business, production, revenue, income, profits, commercial opportunities, reputation or goodwill, arising out of, or in connection with, the use of the information or content in this manual.

The authors do not represent, warrant, undertake or guarantee that the use of the information or content in this manual will lead to any particular outcome or results.

Reasonableness

By using this manual, you agree that the exclusions and limitations of liability set out in this disclaimer are reasonable. If you do not think they are reasonable, you must not use this manual.

Severability

If any part of this disclaimer is declared unenforceable or invalid, the remainder will continue to be valid and enforceable.

"The information and views set out in this manual (Part 1 and Part 2) are those of the author(s) and do not necessarily reflect the official opinion of the European Union. Neither the European Union and bodies nor any person acting on their behalf may be held responsible for the use which may be made of the information or views contained therein"

EU acknowledgement of support

The GRISPE project has received financial support from the European Community's Research Fund for Coal and Steel (RFCS)under grant agreement No75 4092

PART 1: DESIGN MANUAL FOR STEEL DECKS WITH OUTWARDS STIFFENERS

SUMMARY

The purpose of this design manual is to present a new method of design by calculation for steel decking with outwards stiffeners, as developed in the European project GRISPE PLUS.

The manual is based on the Eurocode principles in general and more specifically on the EN 1993-1-3 and EN 1993-1-5 Eurocodes.

This new method of design by calculation for steel decking with outwards stiffeners, is based on tests carried out within the European GRISPE project (2013-2016).

The background of this method is described in Annex 1.

Chapter 1 details the type of profiles concerned, the state of the art, the main research results of GRISPE and the general design requirements and rules;

Chapter 2 outlines the preliminary considerations that must be taken into account during the predesign phases, including in particular the verification of the field of application of the new design method;

Chapter 3 states the technological requirements that have to be respected including support frame, profiles characteristics and assemblies;

Chapter 4 lists the materials properties of the profiles;

Chapter 5 specifies the determination of actions and combinations

Chapter 6 gives the basis of the design

Chapter 7 lists the specific design consideration not covered by the manual

Chapter 8 explains in detail the new design method (principles, field of application, and description of how to apply the new formulas).

Preface

This Design manual have been carried out with the support of RFCS funding n°**754092**

This new design method has been presented at the evolution group of EN 1993-1-3 in 2016-2017 and is being considered for inclusion into the Eurocodes.

This Design manual has been written by PALISSON Anna and has been discussed in a GRISPE PLUS working group composed by the following members:

Mickael BLANC	France
Silvia CAPRILI	Italy
David IZABEL	France
Markus KUHNENNE	Germany
Anna PALISSON	France
Valérie PRUDOR	France
Irene PUNCELLO	Italy
Dominik PYSCHNY	Germany
Thibaut RENAUX	France
Daniel SPAGNI	France

Corresponding members have included:

SOKOL	Léopold	France

Figures

The figures have been produced by the following companies

Figure 1.1.1 – TATA STEEL CONSTRUCTION

Figure 1.3.1 - Sokol Palisson Consultants

Figure 1.3.2 - Sokol Palisson Consultants

Figure 6.2.1 - Sokol Palisson Consultants

Figure 6.3.2.1 - Copy of EN 1993-1-3

Figure 8.1.1 - Sokol Palisson Consultants

Figure 8.1.2 - Sokol Palisson Consultants

Figure 8.1.3 - Copy of EN 1993-1-3

Figure 8.2.1 - Sokol Palisson Consultants

Figure 8.2.2 – Copy of EN 1993-1-3

Figure 8.2.3 – Copy of EN 1993-1-3

CONTENT

ANNEX 1

SCOPE OF THE PUBLICATION

The aim of this publication is to present the new design method for steel decks with outwards stiffeners that has been proposed for inclusion in Eurocode EN 1993-1-3.

This design manual deals with currently occurring situations.

For specific issues (e.g. opening) or for exceptional situations (seismic, fire, etc.) it is necessary to follow the relevant clauses of the Eurocodes and/or EN 1090-4.

NOTATIONS

The following symbols are used :

t : design thickness

t_{nom} : nominal thickness

t_{eff}: effective thickness

h_w : profile height

f_{yb} : yield strength

E : Young's modulus

t_{red} : reduced thickness

b_{pi} : widths of plane cross section parts

$b_{i,eff}$: effective width

A_g : area of the gross cross-section

A_{eff} : effective area

z_G : position of the neutral axis

σ_{xx} : stress

χ_d : reduction factor for the distortional buckling resistance

$M_{c,Rd}$: resistance moment

M_{span} : span resistance moment

e_c : distance from the compressed flange and the position of the neutral axis

s_n : width of the part of the web between the compressed flange and the position of the neutral axis

s_{eff} : effective cross section for the web

W_{eff} : effective section modulus

1. INTRODUCTION

1.1. Type of profiled steel sheets

This design manual deals with steel sheeting with outwards stiffeners.

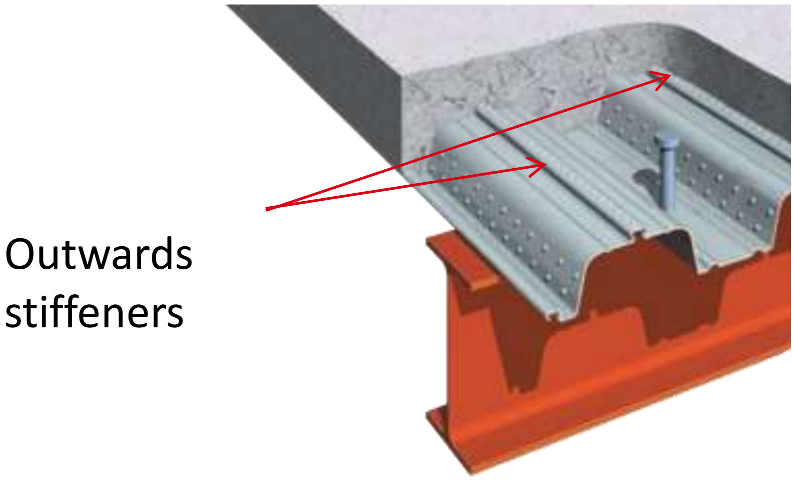


Figure 1.1.1 *– Steel sheeting with outwards stiffeners*

1.2. State of the art pre-GRISPE

Steel decking has become an integral structural element in composite slabs for both roofs and floors, with a variety of corrugations of varying depth. It is often the preferred material for interior design, commercial and industrial refurbishments and for the building trade in general because it is sturdy, lightweight and need limited maintenance.
In order to increase the shear connection between the steel and the concrete in the composite slabs, steel decks are equipped with outwards stiffeners in the upper flanges.
This type of sheeting has been optimized over the years and many new shapes have appeared on the markets.
At the construction stage where the sheeting used as shuttering has to support the fresh concrete weight and the construction loads, no existing study allows to calculate the moment resistance of steel sheets with this outwards stiffeners.
In EN 1994-1 for the design of the decking profile in composite stage, a link with EN 1993-1-3 is made.
EN 1993-1-3 deals in 1.5.1 (4) with the sheeting but in section 1.5.2 « Types of stffeners » the profiles with outwards stiffeners are not taken into account.
In summary within the current texts of the Eurocodes, the only option for manufacturers to design this family of products is to carry out expensive and time consuming tests.

1.3. Main results of GRISPE

In order to determine the moment resistance of steel decks with outwards stiffeners a programme of single span tests was performed according to EN 1993-1-3 Annex A on steel trapezoidal sheeting with outwards stiffeners (Figure 1.3.1; Figure 1.3.2),
Based on these test results and analysis, an innovative design model was developed and validated to determine the span moment resistance of a profile with outwards stiffeners.

Figure 1.3.1 *– Single span test*

Figure 1.3.2 *– Failure mode*

1.4. General design requirements and rules

(1) The design of steel sheeting with outwards stiffeners should be in accordance with the general rules given in EN 1993-1-1.

(2) Appropriate partial factors shall be adopted for ultimate limit states and serviceability limit states according to EN 1993-1-3.

2. PRELIMINARY CONSIDERATION – PRE-DESIGN

2.1. Field of application of the new design method

This manual gives design requirements for steel sheeting with outwards stiffeners. The execution of steel structures made of sheeting is covered in EN 1090.

This manual gives methods for design by calculation This method applies within stated ranges of material properties and geometrical proportions

This manual does not cover load arrangement for loads during execution and maintenance.

The calculation rules given in this manual are only valid if the tolerances of the cold formed members comply with EN 1993-1-3.

2.2. Technological dispositions of the profile sheet

2.2.1. Form of sections

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

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

(3) Cross-sections of sheets may either be unstiffened or incorporate longitudinal stiffeners in their webs.

2.2.2. Cross-section dimensions

The cross-section dimensions should satisfy the general requirements given in EN 1993-1-3, section 1.5.3.

(1) The thickness t is a steel design thickness (the steel core thickness extracted minus tolerance if needed as specified in clause 3.2.4 of EN 1993-1-3), if not otherwise stated.

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

(3)

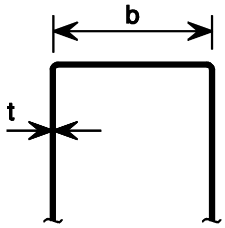
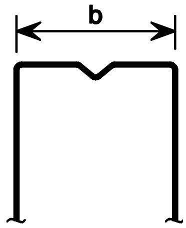
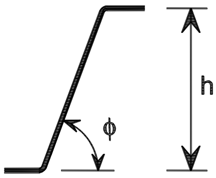
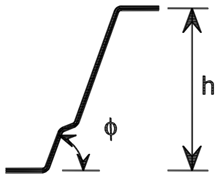
		$b/t \leq 500$
		$45° \leq \phi \leq 90°$ $h/t \leq 500 \sin\phi$

***Table 2.2.2.1** – Checking of geometrical proportions*

3. BASIC TECHNOLOGICAL REQUIREMENTS

Profiled sheet and CE marking

Steel decks are CE marked according to the standard EN 1090-1.

4. MATERIAL PROPERTIES

Steel sheet

The material properties should satisfy the requirements given in EN 1993-1-3, section 3.

The usual types of steel are the grades S320GD + ZA and S350GD + ZA

The thickness tolerances should satisfy the requirements given in EN 1993-1-3, section 3.2.4.

5. ACTION LOADS AND COMBINATIONS

The actions and combinations which should be taken into account must be determined according to EN 1991-1-6 Eurocode 1: Actions on the structures, Part 1-6 : General actions – Actions during execution, 2005, and their National Annexes.

6. BASIS OF THE DESIGN

6.1. Principles

This new design method is given to calculate resistance of sheeting with outwards stiffeners to bending moment

6.2. Field of application of the new design method

This new design method is for sheeting with outwards stiffeners (Figure (6.2.1).

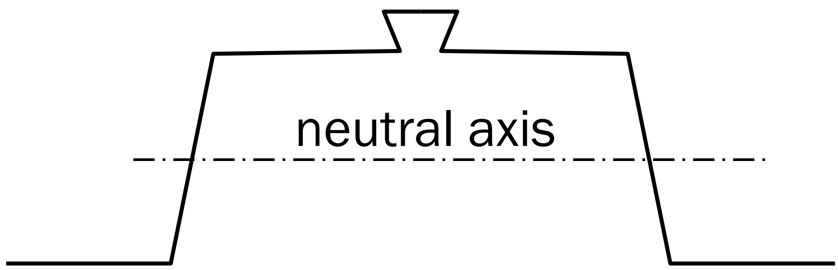


Figure 6.2.1 *– Sheeting with outwards stiffeners*

6.3. Design procedure

6.3.1. Effective section of sheeting with outwards stiffeners`

(1) The effective width of plane wall should be calculated according to 5.5.1(2) of EN 1993-1-3

(2) For intermediate stiffeners facing outwards of upper flange, the calculations should be performed by taking the stress in the stiffener as equal to the stress in the flange.

6.3.2. Resistance moment of sheeting with outwards stiffeners

The design moment resistance of a cross-section for bending about one principal axis $M_{c,Rd}$ is determined according to EN 1993-1-3 "6.1.4 Bending moment", as follows (see figure 6.3.2.1):

$$M_{c,Rd} = W_{eff} f_{yb} / \gamma_{M0}$$

The effective section modulus W_{eff} should be based on an effective cross-section that is subject only to bending moment about the relevant principal axis, with a maximum stress $\sigma_{max,Ed}$ equal to f_{yb} / γ_{M0}, allowing for the effects of local and distortional buckling as specified in Section 5.5. and in 7.1

7. SPECIFIC DESIGN CONSIDERATION

Situations not covered by the present Manual

Fire

Seismic

Environmental aspect

Thermal

Acoustic

Others

8. DESIGN EXAMPLE

8.1. Explanation of the "outwards stiffener" software calculation

This software allows to calculate span moment resistance for a profile with outwards stiffener in the upper flange and with two stiffeners in the lower flange.

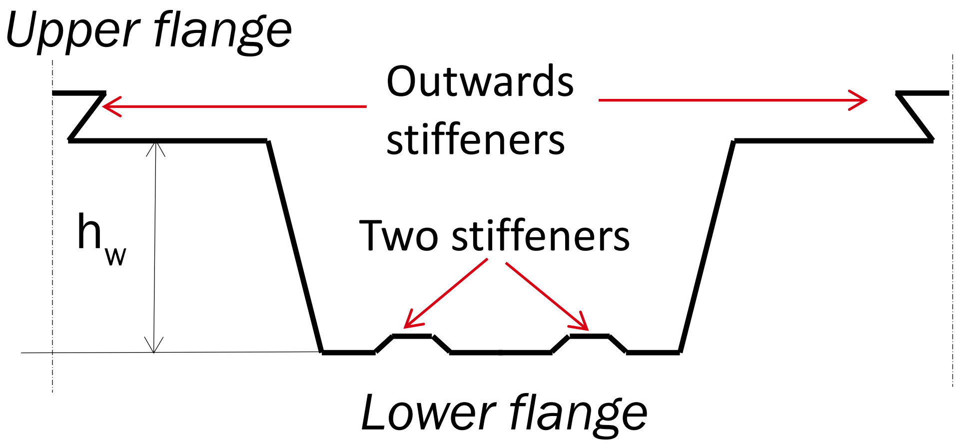


Figure 8.1.1 *- Steel sheeting with outwards stiffener in the upper flange and with two stiffeners in the lower flange*

1) DATA

All the red cells have to be filled with the profile dimensions (*Figure 8.1.2*): internal bend radius R1, $R2_{sup}$, $R2_{inf}$, angles θ_1 and θ_2 , design thickness t, nominal thickness t_{nom}, the pitch, web height h_w, depth of the superior stiffener d_s, depth of the inferior stiffener d_i, yield strength f_{yb}, Young's modulus E and γ_{M0}.

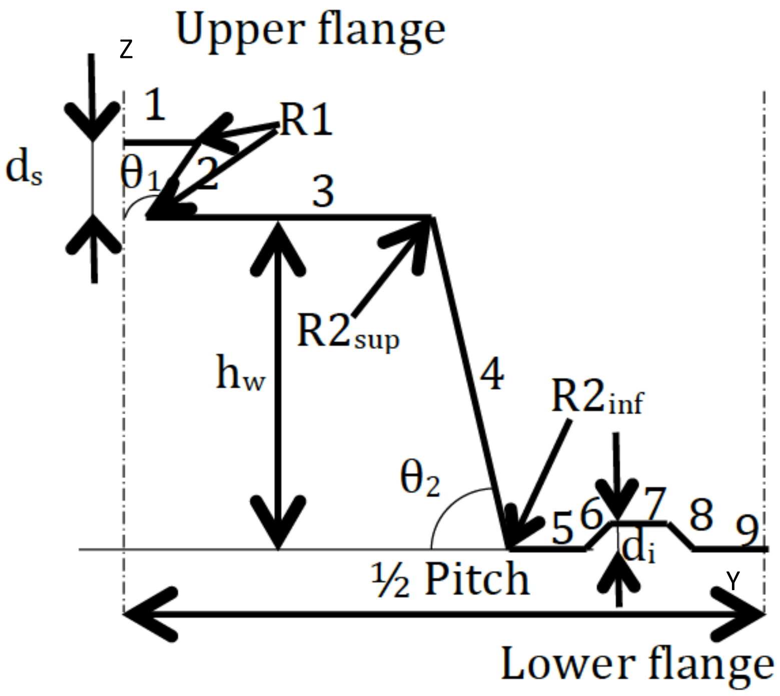


Figure 8.1.2 *- Element numbers*

R1 (mm)	θ_1 (rad)	$R2_{sup}$ (mm)	$R2_{inf}$ (mm)	θ_2 (rad)	t_{nom} (mm)	t (mm)

Pitch (mm)	h_w (mm)	d_s (mm)	d_i (mm)	f_{yb} (N/mm^2	E (N/mm^2)	γ_{M0}

Table 8.1.1 *- Excel cells to be filled with the profile dimensions*

Fill the red cells of the following table with dimensions (b_{pi}) of all elements of ½ pitch. The element numbers are given in the Figure 8.1.2. The length of the elements are measured from the midpoints « P » of the adjacent corner elements as indicated in Figure 8.1.3.

Element	b_{pi} (mm)
1	
2	
3	
4	
5	
6	
7	
8	
9	

Table 8.1.2 - *Excel cells to be filled with the elements dimensions*

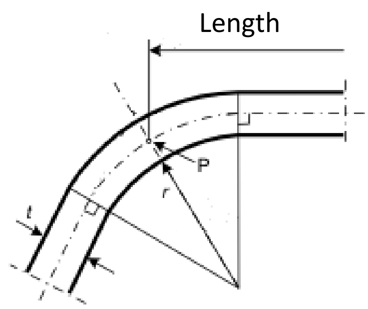


Figure 8.1.3 *- Length of the elements measured from the midpoints « P »*

2) CHECKING OF GEOMETRICAL PROPORTIONS

Fill the red cell with b value and the software automatically displays the checking of geometrical proportions

b=	75.00
b/t=	87.21
θ_2=	79.38
h/t=	93.02
500sin(θ2)=	491.44
r < $0{,}04\ t\ E\ /\ f_y$	15.37

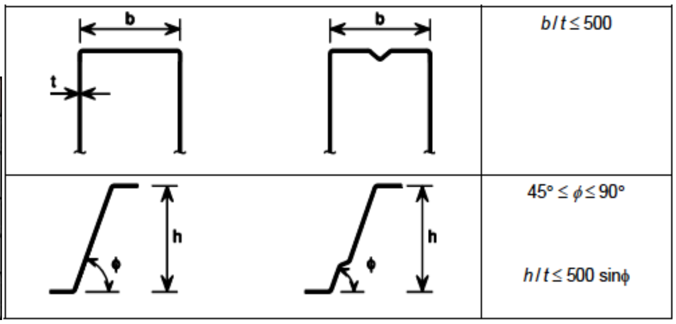


Table 8.1.3 *- Automatic checking of geometrical proportions*

3) RESULTS

The software automatically displays the results :

⇨ span moment resistance M_{span}= 13.3 kNm/m

8.2. Auto-control of the software - details of the calculation steps

The auto control is based on the calculation of span moment resistance value of a profile with nominal thickness=0,90 mm

1) DATA

Software and calculation:

R1 (mm)	θ_1 (rad)	$R2_{sup}$ (mm)	$R2_{inf}$ (mm)	θ_2 (rad)	t_{nom} (mm)	t (mm)
0.00	1.89	15.00	5.00	1.39	0.90	0.86

Pitch (mm)	h_w (mm)	d_s (mm)	d_i (mm)	f_{yb} (N/mm²)	E (N/mm²)	γ_{M0}
300.00	80.00	15.00	6.00	450.00	210000.00	1.00

Table 8.2.1 *- Excel cells filled with the profile dimensions*

Element	b_{pi} (mm)
1	12.00
2	15.81
3	68.00
4	77.57
5	15.00
6	8.49
7	8.00
8	8.49
9	25.00

Table 8.2.2 *- Excel cells filled with the elements dimensions*

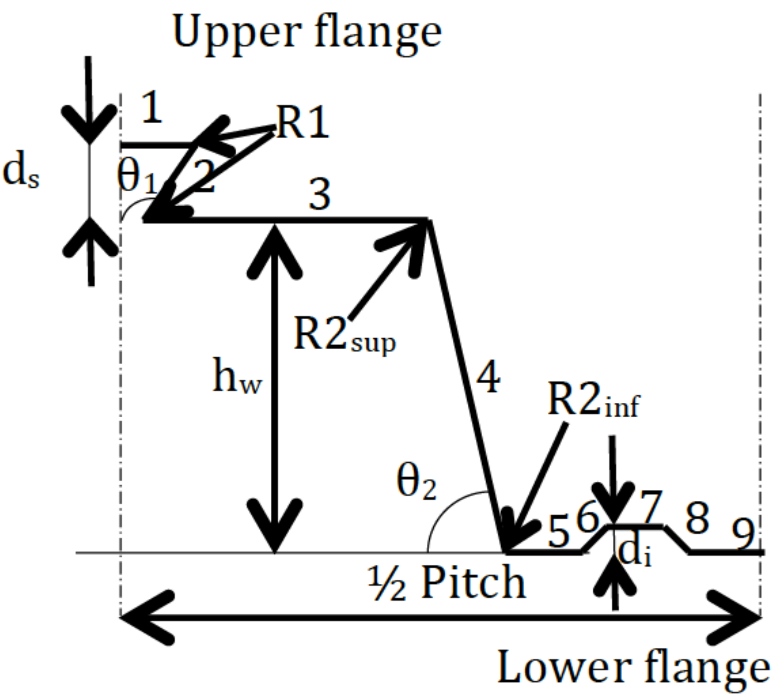


Figure 8.2.1 *- Elements numbers*

2) Checking of geometrical proportions

The software automatically displays the checking of geometrical proportions

b=	75.00
b/t=	87.21
θ_2=	79.38
h/t=	93.02
500sin(θ2)=	491.44
r < 0,04 $t E / f_y$	16.05

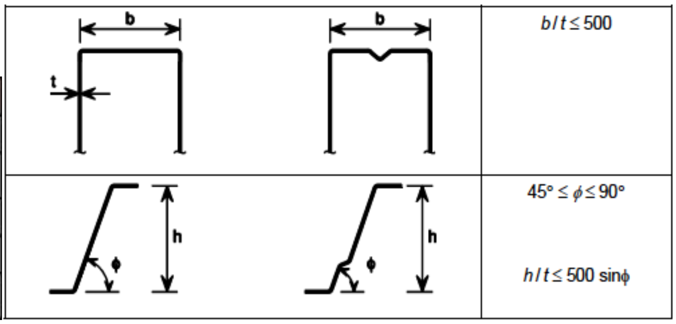


Table 8.2.3 *- Automatic checking of geometrical proportions*

3) RESULTS

Software:

⇨ span moment resistance M_{span}= 13.3 kNm/m

Calculation:

Calculation of A_g the area of the gross cross-section

A_g is the sum of the areas of each element (length x t)

A_g = 206.8 mm²

Position of the neutral axis: z_G = 46.6 mm

Calculation of A_{eff} the effective area:

1st Step

A_{eff} is the sum of the effective areas of each element

Upper flange effective area

The upper flange has 1 stiffenes therefore the effective cross-section of the flange is calculated according to EN 1993-1-3 § "5.5.3.4.2 Flanges with intermediate stiffeners".

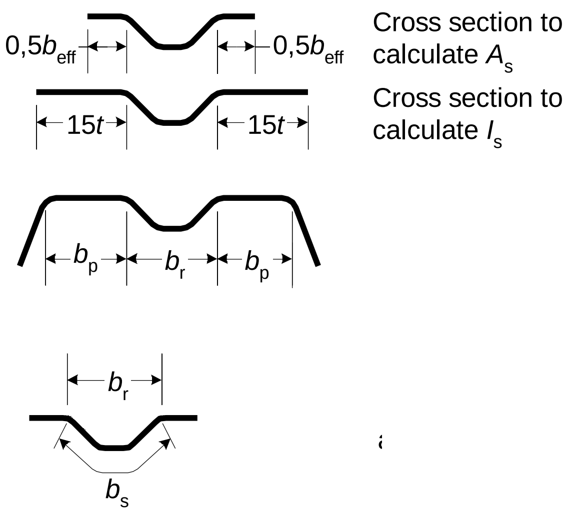


Figure 8.2.2 *- Flange with one stiffener*

stress in the upper flange is $\sigma_{com} = f_{yb} \times (h_w - z_G)/ z_G$ = 323 N / mm²

b_p = 68 mm, ρ =0.57 ➔ 0,5 b_{eff} = 19.39 mm

Stiffeners:

The cross section of the stiffener is calculated according to EN 1993-1-3 § "5.5.3.3 Plane elements with intermediate stiffeners »

critical buckling stress $\sigma_{cr,s}$ = 325 N/mm²

reduction factor for the distortional buckling resistance χ_d = 0,619

Web Effective area

The web effective area is calculated according to "5.5.3.4.3 Webs with up to two intermediate stiffeners" of EN 1993-1-3

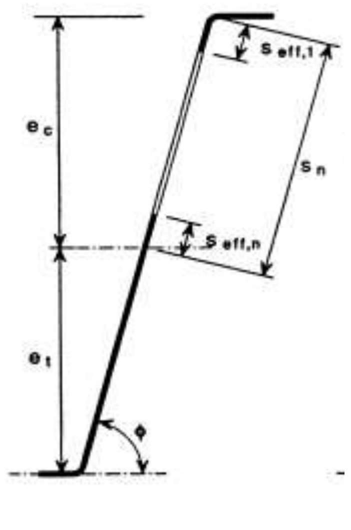


Figure 8.2.3 *- Web effective area*

$e_c = h_w - z_G$=33.4 mm ➔ s_n = 31.1 mm

$\sigma_{com} = f_{yb}$ x $(h_w - z_G)/ z_G$ = 323 N / mm² ➔ $s_{eff,0}$ = 20,84mm ➔ $s_{eff,1}$ = 20,84 mm ➔ $s_{eff,n}$ = 31,26 mm ➔ $s_{eff,1} + s_{eff,n} \geq s_n$ the entire web is effective

$s_{eff,1} = 0{,}4 s_n$

$s_{eff,n} = 0{,}6 s_n$

Lower flange effective area

Lower flange in this case is in tension ➔ the effective area = gross section area

Total effective area

A_{eff} = 176.2 mm²

Position of the neutral axis of the effective section: z_G = 40.57 mm

Iteration: Next Steps

In the next steps the new position of the neutral axis of the effective section is taken to calculate the new σ_{com} .

The upper flange effective area is calculated as in step 1 but taking the new σ_{com} calculated with new position of the neutral axis z_c

Web Effective area is calculated as in step 1 but taking the new σ_{com} calculated with new position of the neutral axis z_c

All the values of step 2, step 3 and step 4 are indicated in following table. The convergence is considered satisfactory at step 4, the iteration stops at step 4.

		2nd step	3rd step	4th step
Upper flange	σ_{com}	437	450	450
	ρ	0.469	0.460	0.460
	$0,5\ b_{1,eff}$	15.96	15.63	15.63
Upper flange :	$\sigma_{cr,s}$	350.22	352.81	352.81
	χ_d	0.65	0.65	0.65
	t_{red}	0.58	0.56	0.56
Web	e_c	39.4	39.4	39.4
	s_n	37.2	37.2	37.2
	$s_{eff,0}$	17.9	17.9	17.9
	$s_{eff,1}$	17.9	17.9	17.9
	$s_{eff,n}$	26.9	26.9	26.9
	$s_{eff,1} + s_{eff,n}$	44.8	44.8	44.8
		entire web is effective	entire web is effective	entire web is effective
	$s_{eff,1}$	0,4sn	0,4sn	0,4sn
	$s_{eff,n}$	0,6sn	0,6sn	0,6sn
Total effective	A_{eff}	163.4	162.3	162.3
Position of ne	z_c	37.2	36.9	36.9

Table 8.2.4 *– Step 2, Step 3 and Step 4 values*

Calculation of span moment resistance:

$$M_{c,Rd} = W_{eff}\, f_{yb} / \gamma_{M0}$$

For ½ pitch I_{eff} =191665 mm^4

For the profile I_{eff} = 1278 mm^3

v = max (36.9;43.1)=43.1 mm

W_{eff} = I_{eff} / v = 29.6 mm^3

M_{span} = 13.3 kNm/m

The result is similar to the software result

M_{span}= 13.3 kNm/m

Annex 1

Background of the new design method for steel decks with embossments

D1.1	GRISPE WP1 Background document	Anna PALISSON (Sokol Palisson Consultants)
D1.2	GRISPE WP1 Test programme definition	Anna PALISSON (Sokol Palisson Consultants)
D1.3	GRISPE Test report of steel trapezoidal sheeting with and without embossments and outward stiffeners	Christian FAUTH (KIT)
D1.4	GRISPE WP1 Test analysis and interpretation	Anna PALISSON (Sokol Palisson Consultants)
D1.6	GRISPE Background guidance for EN 1993-1-3 to design of special shape sheeting (with outwards stiffeners in the flange)	Anna PALISSON (Sokol Palisson Consultants)

PART 2: WORKED EXAMPLE FOR STEEL DECKS WITH OUTWARDS STIFFENERS

SUMMARY

The purpose of this worked example is to present a new method of design by calculation for steel decking with outwards stiffeners, as developed in the European project GRISPE PLUS.

The worked example on the Eurocode principles in general and more specifically on the EN 1993-1-3 and EN 1993-1-5 Eurocodes.

This new method of design by calculation for steel decking with outwards stiffeners, is based on tests carried out within the European GRISPE project (2013-2016).

The background of this method is described in Annex 1.

Chapter 1 details the data and the sheeting cross-section

Chapter 2 explains the calculation of the gross section

Chapter 3 explains the calculation of the effective section

Chapter 4 explains the calculation of the moment resistance

Preface

This Worked Example have been carried out with the support of RFCS funding n°**754092**

This new design method has been presented at the evolution group of EN 1993-1-3 in 2016-2017 and is being considered for inclusion into the Eurocodes.

This Worked Example has been written by Anna PALISSON and has been discussed in a GRISPE PLUS working group composed by the following members:

Mickael BLANC	France
Silvia CAPRILI	Italy
David IZABEL	France
Markus KUHNENNE	Germany
Anna PALISSON	France
Valérie PRUDOR	France
Irene PUNCELLO	Italy
Dominik PYSCHNY	Germany
Thibaut RENAUX	France
Daniel SPAGNI	France

Corresponding members have included:

SOKOL	Léopold	France

Figures

The figures have been produced by the following companies

Figure 1.1 - Sokol Palisson Consultants

Figure 1.1.1 - Sokol Palisson Consultants

Figure 2.1 - Copy of EN 1993-1-3

Figure 3.1.1 - Copy of EN 1993-1-3

Figure 3.1.2 - Copy of EN 1993-1-3

Figure 3.1.3 - Sokol Palisson Consultants

CONTENT

SCOPE OF THE PUBLICATION

The aim of this publication is to present an example of the application of the new design method for steel decks with outwards stiffeners, that has been proposed for inclusion in Eurocode EN 1993-1-3.

This Worked Example eals with currently occurring situations.

For specific issues (e.g. opening) or for exceptional situations (seismic, fire, etc.) it is necessary to follow the relevant clauses of the Eurocodes and/or EN 1090-4.

NOTATIONS

The following symbols are used :

t : design thickness

t_{nom} : nominal thickness

t_{eff}: effective thickness

h_w : profile height

f_{yb} : yield strength

E : Young's modulus

t_{red} : reduced thickness

b_{pi} : widths of plane cross section parts

$b_{i,eff}$: effective width

A_g : area of the gross cross-section

A_{eff} : effective area

z_G : position of the neutral axis

σ_{xx} : stress

χ_d : reduction factor for the distortional buckling resistance

$M_{c,Rd}$: resistance moment

M_{span} : span resistance moment

e_c : distance from the compressed flange and the position of the neutral axis

s_n : width of the part of the web between the compressed flange and the position of the neutral axis

s_{eff} : effective cross section for the web

W_{eff} : effective section modulus

1. INTRODUCTION

This example shows how to deal with steel sheeting with outwards stiffeners when determining the bending capacity of a sheeting with outwards stiffeners in the upper flange and two stiffeners in the lower flange.

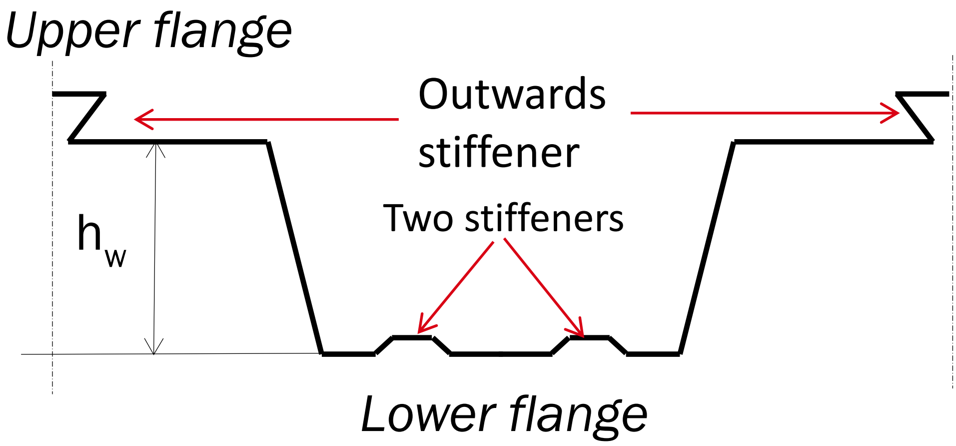


Figure 1.1 *- Steel sheeting with outwards stiffener in the upper flange and with two stiffeners in the lower flange*

1.1. Sheeting cross section

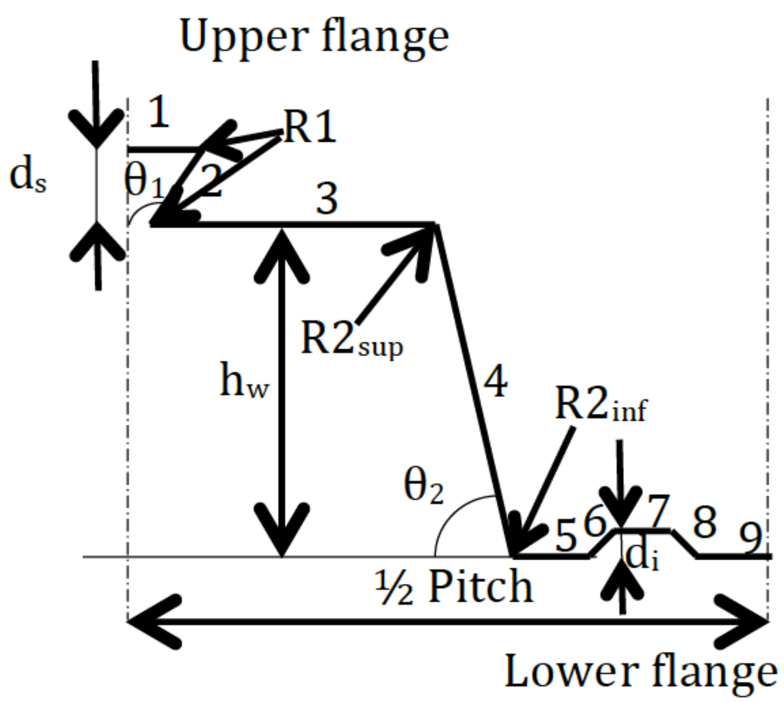


Figure 1.1.1 *- Elements numbers*

1.2. Sheeting values

The example is based on the calculation of span moment resistance value of a profile with the following data:

R1 (mm)	θ_1 (rad)	$R2_{sup}$ (mm)	$R2_{inf}$ (mm)	θ_2 (rad)	t_{nom} (mm)	t (mm)
0.00	1.89	15.00	5.00	1.39	0.90	0.86

Pitch (mm)	h_w (mm)	d_s (mm)	d_i (mm)	f_{yb} (N/mm²)	E (N/mm²)	γ_{M0}
300.00	80.00	15.00	6.00	450.00	210000.00	1.00

Table 1.2.1 *- Sheeting data*

Element	b_{pi} (mm)
1	12.00
2	15.81
3	68.00
4	77.57
5	15.00
6	8.49
7	8.00
8	8.49
9	25.00

Table 1.2.2 *- Elements dimensions*

<u>Checking of geometrical proportions</u>

b = 75; t = 0.86; h = 60; f_y = 450

	b=	75.00
	b/t=	87.21
	θ_2=	79.38
	h/t=	93.02
	500sin(θ2)=	491.44
r <	$0{,}04\ t\ E\ /\ f_y$	16.05

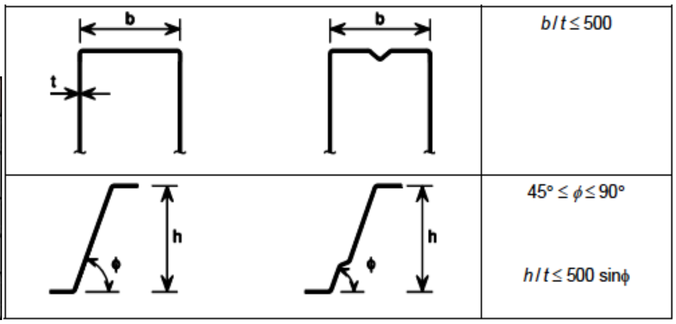
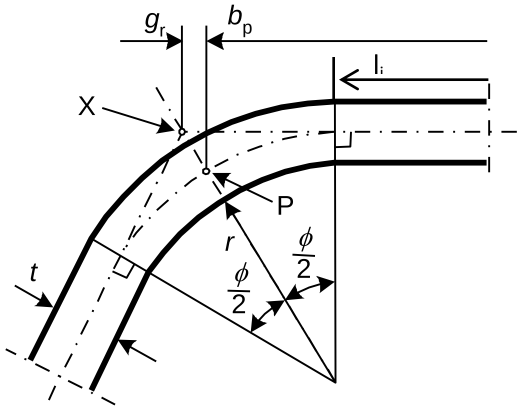


Table 1.2.3 *- Checking of geometrical proportions*

2. CALCULATION OF A_g THE AREA OF THE GROSS-SECTION

A_g is the sum of the areas of each element (length x t)

length = $l_i = b_p - r_m \times \sin\pi/4$



(a) midpoint of corner or bend

X is intersection of midlines

P is midpoint of corner

$r_m = r + t/2$

Figure 2.1 *- Notional widths of plane cross section parts b_p allowing for corner radii*

Element	l_i (mm)	A_i(mm²)	z(mm)	S_i(mm³)	z0(mm)
1	12.0	10.3	95.0	980.40	-48.41
Corner 1_{sup}	0.0	0.0	95.0	0.00	-48.41
2	15.8	13.6	87.5	1189.81	-40.91
Corner 1_{inf}	0.0	0.0	80.0	0.00	-33.41
3	58.4	50.2	80.0	4019.33	-33.41
Corner 2_{sup}	20.8	17.9	75.6	1351.88	-29.05
4	64.8	55.7	35.9	2001.69	10.67
Corner 2_{inf}	6.9	6.0	1.5	8.66	45.14
5	11.8	10.2	0.0	0.00	46.59
6	8.5	7.3	3.0	21.89	43.59
7	8.0	6.9	6.0	41.28	40.59
8	8.5	7.3	3.0	21.89	43.59
9	25.0	21.5	0.0	0.00	46.59
TOTAL		206.8		9636.8	46.6

Table 2.1 *- Elements dimensions*

A_g = 206.8 mm²

Position of the neutral axis: $z_G = S / A_g$ = 46,6 mm

3. CALCULATION OF THE EFFECTIVE AREA A_{eff} OF THE SECTION

A_{eff} is the sum of the effective areas of each element.

3.1. Step 1

Upper flange effective area

The upper flange has an outwards stiffener. The effective cross-section of the flange is calculated according to EN 1993-1-3 § "5.5.3.4.2 Flanges with intermediate stiffeners". **With stress in the outwards stiffener equal to stress in the upper flange.**

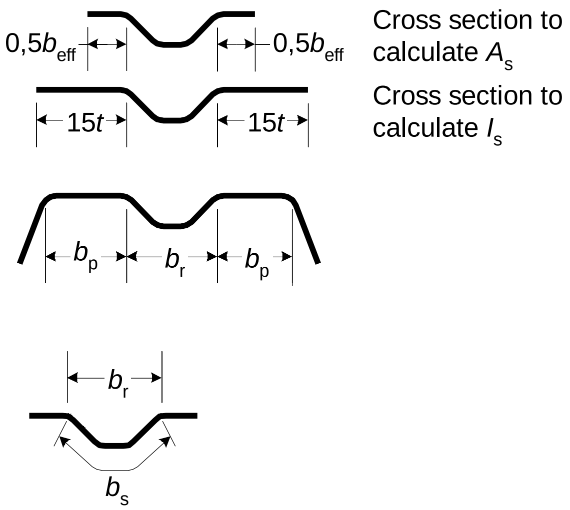


Figure 3.1.1 *- Flange with one stiffenes*

stress in the upper flange is $\sigma_{com} = f_{yb} \times (h_w - z_G)/ z_G$ = 323 N / mm²

b_p = 68 mm

$\lambda_p = b_p/t/(28.4\ \varepsilon k_\sigma^{1/2})$ with $\varepsilon=(235/ f_{yb})^{1/2}$

$\psi=\sigma_2/ \sigma_1= 1$ ➔ Coefficient $k_\sigma=4$

$\lambda_p=1.926$

$\lambda_{pred}= \lambda_p \times \sqrt{\frac{\sigma\ com}{fy/\gamma M0}}$ ➔ λ_{pred1}= 1.631

$\lambda_{pred} > 0.673$ ➔ $\rho = \frac{1-0{,}055(3+\psi)/\bar{\lambda}_{p,red}}{\bar{\lambda}_{p,red}} + 0{,}18\frac{(\bar{\lambda}_p-\bar{\lambda}_{p,red})}{(\bar{\lambda}_p-0{,}6)}$ ➔ ρ = 0.57

$b_{eff}= \rho * b_p$ = 38.8 ➔ 0,5 b_{eff} = 19.4 m

<u>Stiffener of the upper flange:</u>

The cross section of the stiffener is calculated according to EN 1993-1-3 § "5.5.3.3 Plane elements with intermediate stiffeners »

Calculation of critical buckling stress $\sigma_{cr,s}$

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

b_s = 55.6 mm, b_p = 68 mm

Calculation of A_s

Element	l_i (mm)	A_i(mm²)
plane part	19.39	16.68
Corner 1_{inf}	0.00	0.00
2	15.81	13.60
Corner 1_{sup}	0.00	0.00
1	24.00	20.64
Corner 1_{sup}	0.00	0.00
2	15.81	13.60
Corner 1_{inf}	0.00	0.00
plane part	19.39	16.68
TOTAL		81.2

Table 3.1.1 *- Elements lengths and areas*

A_s = 81.2 mm²

Calculation of I_s

Element	l_i (mm)	A_i(mm²)	z(mm)	S_i(mm³)	z0(mm)	h	I_i(mm⁴)
plane part	12.90	11.09	0.00	0.00	7.33	0.86	597.44
Corner 1_{inf}	0.00	0.00	0.00	0.00	7.33	0.00	0.00
2	15.81	13.60	7.50	101.98	-0.17	15.00	255.33
Corner 1_{sup}	0.00	0.00	15.00	0.00	-7.67	0.00	0.00
1	24.00	20.64	15.00	309.60	-15.33	1.72	1214.17
Corner 1_{sup}	0.00	0.00	15.00	0.00	-7.67	0.00	0.00
2	15.81	13.60	7.50	101.98	-0.17	15.00	255.33
Corner 1_{inf}	0.00	0.00	0.00	0.00	7.33	0.00	0.00
plane part	12.90	11.09	0.00	0.00	7.33	0.86	597.44
TOTAL		70.0		513.6	7.33		2919.7

Table 3.1.2 *- Elements lengths and moment areas*

I_s = 2919.7 mm^4

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

l_b = 869.3

s_w = 73.7

l_b / s_w = 11.8 ≥ 2 ➔ $k_w = k_{wo}$

$$k_{wo} = \sqrt{\frac{s_w + 2b_d}{s_w + 0{,}5b_d}}$$

$b_d = 2b_p + b_s$= 191.6 mm

k_{wo} = 1.64

critical buckling stress $\sigma_{cr,s}$ = 324.7 N/mm²

$$\bar{\lambda}_d = \sqrt{f_{yb}/\sigma_{cr,s}}$$

λ_d = 1.177

$$0{,}65 < \bar{\lambda}_d < 1{,}38 \rightarrow \chi_d = 1{,}47 - 0{,}723\bar{\lambda}_d$$

reduction factor for the distortional buckling resistance χ_d = 0,619

Reduced thickness $t_{red} = c_d t \frac{f_{yb}/g_{M0}}{s_{com,Ed}}$

Reduced thickness t_{red} = 0.74 mm

Web Effective area

The web effective area is calculated according to "5.5.3.4.3 Webs with up to two intermediate stiffeners" of EN 1993-1-3

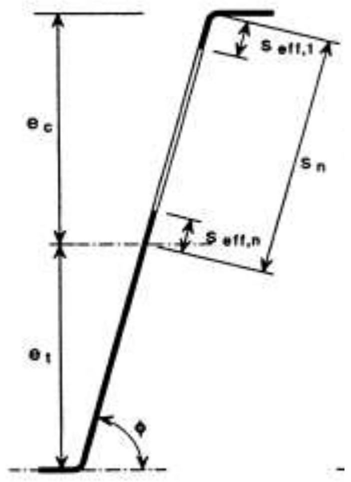


Figure 3.1.2 - *Web effective area*

$e_c = h_w - z_G$=33.4 mm ➔ s_n = 31.1 mm

$\sigma_{com} = f_{yb} \times (h_w - z_G)/ z_G$ = 323 N / mm²

effective section properties refined iteratively ➔

$$s_{\mathrm{eff},0} = 0{,}95t\sqrt{\frac{E}{\gamma_{\mathrm{M}0}\,\sigma_{\mathrm{com,Ed}}}}$$

➔ $s_{eff,0}$ = 20,84 mm

$s_{eff,1} = s_{eff,0}$ ➔ $s_{eff,1}$ = 20,84 mm

$s_{eff,n} = 1.5\ s_{eff,0}$ ➔ $s_{eff,n}$ = 31.26 mm ➔ $s_{eff,1} + s_{eff,n} \geq s_n$ the entire web is effective

$s_{eff,1} = 0{,}4 s_n$

$s_{eff,n} = 0{,}6 s_n$

<u>Lower flange effective area</u>

Lower flange in this case is in tension ➔ all width is effective

Total effective area

Calculation of A_{eff}

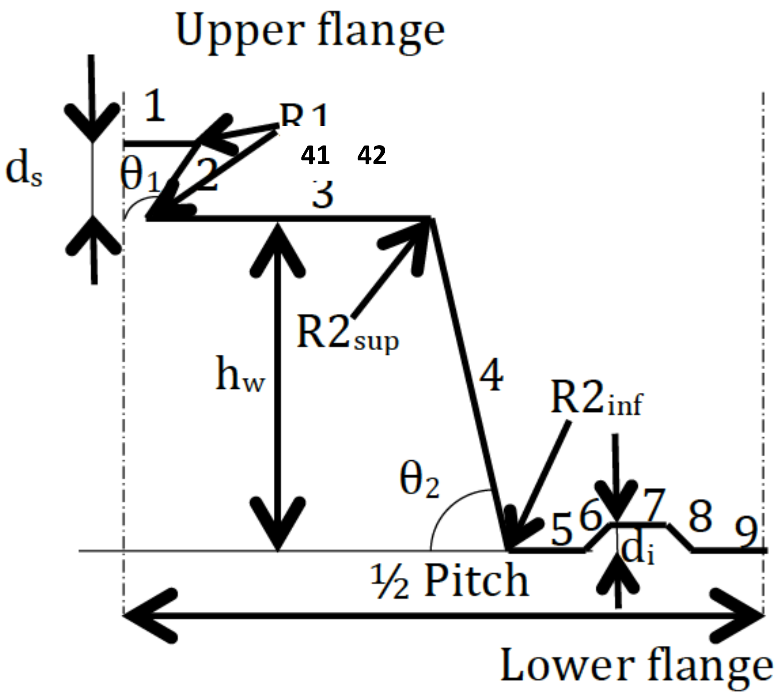


Figure 3.1.3 *- Elements numbers*

Element	l_i (mm)	t_{eff} (mm)	A_i(mm²)	z(mm)	S_i(mm³)	z0(mm)
1	12.0	0.7	8.9	95.0	846.1	-54.4
Corner 1_{sup}	0.0	0.7	0.0	95.0	0.0	-54.4
2	15.8	0.7	11.7	87.5	1026.8	-46.9
Corner 1_{inf}	0.0	0.7	0.0	80.0	0.0	-39.4
31	19.4	0.7	14.4	80.0	1151.5	-39.4
32	9.8	0.9	8.4	80.0	675.2	-39.4
Corner 2_{sup}	20.8	0.9	17.9	75.6	1351.9	-35.1
4	64.8	0.9	55.7	35.9	2001.7	4.6
Corner 2_{inf}	6.9	0.9	6.0	1.5	8.7	39.1
5	11.8	0.9	10.2	0.0	0.0	40.6
6	8.5	0.9	7.3	3.0	21.9	37.6
7	8.0	0.9	6.9	6.0	41.3	34.6
8	8.5	0.9	7.3	3.0	21.9	37.6
9	25.0	0.9	21.5	0.0	0.0	40.6
TOTAL			176.2		7147.0	40.6

Table 3.1.3 *- Elements lengths and areas*

A_{eff} = 176.2 mm²

Position of the neutral axis of the effective section: z_G = 40,6 mm

3.2. Iteration: Next Steps

In the next steps the new position of the neutral axis of the effective section is taken to calculate the new σ_{com} .

The upper flange effective area is calculated as in step 1 but taking the new σ_{com} calculated with new position of the neutral axis z_c

Web Effective area is calculated as in step 1 but taking the new σ_{com} calculated with new position of the neutral axis z_c

Lower flange effective area

Lower flange in this case is in tension ➔ Lower flange in this case is in tension ➔ all width is effective

All the values of steps 2, 3 and 4are indicated in following table. The convergence is considered satisfactory at step 4, the iteration stops at step 4.

		2nd step	3rd step	4th step
Upper flange	σ_{com}	437	450	450
	ρ	0.469	0.460	0.460
	0,5 $b_{1,eff}$	15.96	15.63	15.63
Upper flange :	$\sigma_{cr,s}$	350.22	352.81	352.81
	χ_d	0.65	0.65	0.65
	t_{red}	0.58	0.56	0.56
Web	e_c	39.4	39.4	39.4
	s_n	37.2	37.2	37.2
	$s_{eff,0}$	17.9	17.9	17.9
	$s_{eff,1}$	17.9	17.9	17.9
	$s_{eff,n}$	26.9	26.9	26.9
	$s_{eff,1} + s_{eff,n}$	44.8	44.8	44.8
		entire web is effective	entire web is effective	entire web is effective
	$s_{eff,1}$	0,4sn	0,4sn	0,4sn
	$s_{eff,n}$	0,6sn	0,6sn	0,6sn
Total effective	A_{eff}	163.4	162.3	162.3
Position of ne	z_c	37.2	36.9	36.9

Table 3.2.1 *– Steps 2, 3, 4 values*

4. CALCULATION OF SPAN MOMENT RESISTANCE

The span moment resistance is calculated with step 4 values

Element	l_i (mm)	t_{eff} (mm)	A_i(mm²)	z(mm)	S_i(mm³)	z0(mm)	h	I_i(mm⁴)
1	12.0	0.6	6.7	95.0	640.7	-58.1	0.9	22784.9
Corner 1_{sup}	0.0	0.6	0.0	95.0	0.0	-58.1	0.0	0.0
2	15.8	0.6	8.9	87.5	777.5	-50.6	15.0	22940.3
Corner 1_{inf}	0.0	0.6	0.0	80.0	0.0	-43.1	0.0	0.0
31	15.6	0.6	8.8	80.0	702.9	-43.1	0.9	16341.2
32	6.1	0.9	5.2	80.0	416.6	-43.1	0.9	9684.5
Corner 2_{sup}	20.8	0.9	17.9	75.6	1351.9	-38.8	0.0	27109.4
4	64.8	0.9	55.7	35.9	2001.7	1.0	63.7	18884.8
Corner 2_{inf}	6.9	0.9	6.0	1.5	8.7	35.4	0.0	7484.0
5	11.8	0.9	10.2	0.0	0.0	36.9	0.9	13807.1
6	8.5	0.9	7.3	3.0	21.9	33.9	8.5	8417.3
7	8.0	0.9	6.9	6.0	41.3	30.9	0.9	6558.7
8	8.5	0.9	7.3	3.0	21.9	33.9	8.5	8417.3
9	25.0	0.9	21.5	0.0	0.0	36.9	0.9	29235.5
TOTAL			162.3		5984.9	36.9		191664.9

Table 4.1 *– Step 4 values*

$$M_{c,Rd} = W_{eff}\, f_{yb} / \gamma_{M0}$$

For ½ pitch I_{eff} =191665 mm^4

For the profile I_{eff} = 1278 mm^3

v = max (36.9;43.1)=43.1 mm

W_{eff} = I_{eff} / v = 29.6 mm^3

M_{span} = 13.3 kNm/m

Annex 1

Background of the new design method for steel decks with outwards stiffeners

D1.1	GRISPE WP1 Background document	Anna PALISSON (Sokol Palisson Consultants)
D1.2	GRISPE WP1 Test programme definition	Anna PALISSON (Sokol Palisson Consultants)
D1.3	GRISPE Test report of steel trapezoidal sheeting with and without em-bossments and outward stiffeners	Christian FAUTH (KIT)
D1.4	GRISPE WP1 Test analysis and interpretation	Anna PALISSON (Sokol Palisson Consultants)
D1.6	GRISPE Background guidance for EN 1993-1-3 to design of special shape sheeting (with outwards stiffeners in the flange)	Anna PALISSON (Sokol Palisson Consultants)