GRISPE

Guidelines and **R**ecommendations for **I**ntegrating **S**pecific **P**rofiled steel sheets in the **E**urocodes (**GRISPE**)

Working Package 1

WP1 Background guidance for EN 1993-1-3 to design of special shape sheeting (with outwards stiffeners in the flange)

30th June 2015

Deliverable D 1.6

Guidelines and Recommandations for Integrating Specific Profiled Steels sheets in the Eurocodes (GRISPE)

Project co-funded under the Research Fund for Coal and Steel
Grant agreement No RFCS-CT-2013-00018
Proposal No RFS-PR-12027

Author(s)
Palisson Anna, Sokol Palisson Consultants

Drafting history	
Final Version Revision 01	*14th February 2016*
Final Version Revision 02	*31st August 2016*

Dissemination Level		
PU	*Public*	
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)*	***x***

Verification and Approval
Coordinator David Izabel, SNPPA
WP1 Leader SOKOL PALISSON CONSULTANTS
Other Beneficiaries SNPPA, Bac Acier, IFL, Joris Ide, KIT

Deliverable	
D 1.6 WP1 Background guidance for EN 1993-1-3 (stiffeners)	***Due date : 30.06.2015*** ***Completion date: 30.06.2015***

1. INTRODUCTION

Due to its many construction advantages steel decking is frequently used in steel-framed construction for both roofs and floors for interior design, commercial and industrial refurbishments and for the building trade. In order to increase the shear connection between the steel and the concrete in the composite slabs, steel decks are reinforced with connectors such as outwards stiffeners on the upper flange (Fig. 1.1).

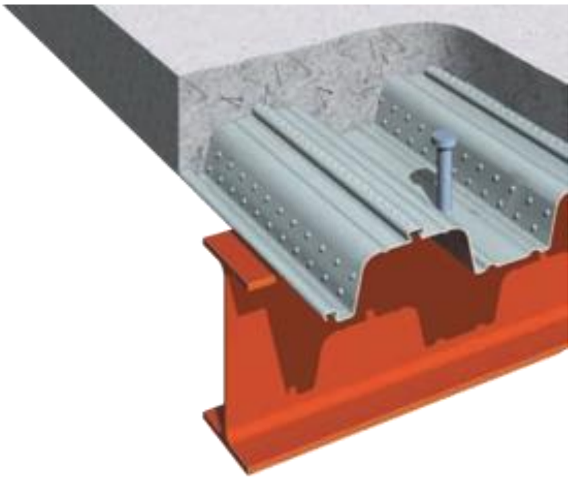

Fig. 1.1 – Outwards stiffeners in a composite slab (Comflor 80 Tatasteel)

As we could see in the state of the art [1] completed within GRISPE project, at the construction stage there is a real lack of data and knowledge about outwards stiffeners in the upper flange and about the effect of embossments on these stiffeners. The European Standard EN 1993-1-3 dealing with design rules for cold-formed members and sheeting doesn't cover profiles with outwards stiffeners. Therefore the one way to design sheeting with outwards stiffeners in the upper flange is to determine resistance values by testing, which takes a long time and is expensive.

The aim of this study is to develop a calculation method for steel decks:

- with outwards stiffeners in the upper flange, based on global testing on sheetings
- and with embossments on these stiffeners, based on global testing on sheetings and on local tensile testing with and without embossments

2. ACQUIRED DATA THROUGH GRISPE PROJECT

2.1. Steel sheeting test analysis

A program of 8 single span tests was performed on steel trapezoidal sheeting (Comflor® 80 profile from TataSteel) in order to determine the resistance and stiffness values of steel decks with outwards stiffeners in the upper flange [2], [3]. The Comflor® 80 profile was tested in positive flexion, with two different thicknesses 0,9 mm and 1,2 mm (Fig. 2.1.1.)

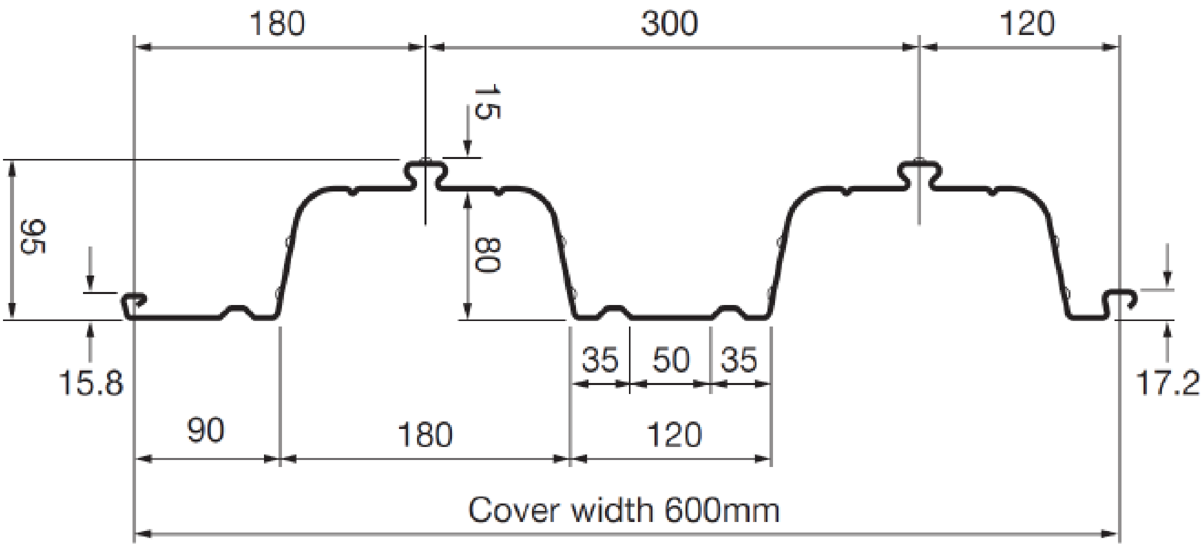

Fig. 2.1.1: Comflor® 80 profile from TataSteel

The profiles were tested according to EN 1993-1-3, Annex A, single span configuration (Fig. 2.1.2 and Fig. 2.1.3):

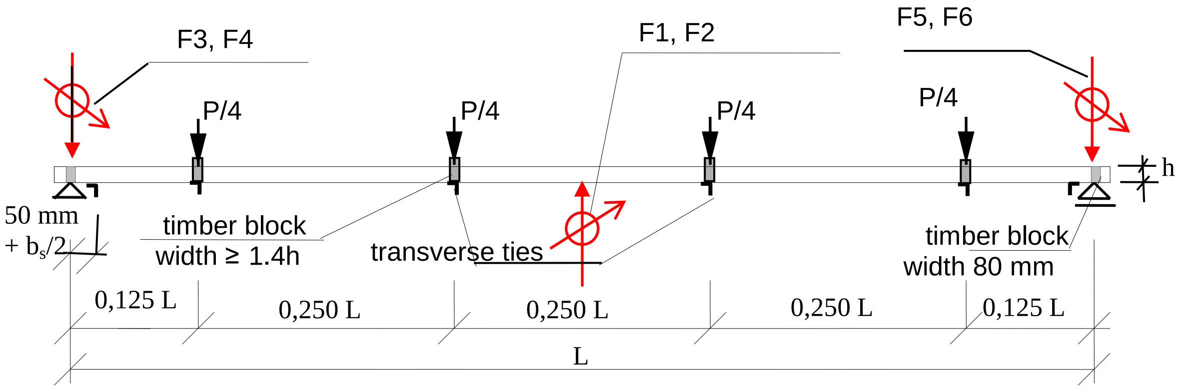

Fig. 2.1.2. – Test set-up for single span tests

Fig. 2.1.3 – Test set-up with Comflor® 80 0,9 mm

The failure mode occurred by buckling of the upper flange near the load applying traverse (Fig. 2.1.4)

Fig. 2.1.4 – Failure mode (Comflor® 80 0,9 mm)

The tested profile properties are:
t= 0,875 mm and f_{yb} = 470,5 N/mm^2
t= 1,164 mm and f_{yb} = 467,5 N/mm^2

The tests analysis and interpretation allowed us to determine the resistance moment and inertia moment for 1m width of profile (Table 2.1.1):

COMFLOR 80		COMFLOR 80	
t_{nom} mm	M_R kN*m/m	t_{nom} mm	I_{eff} mm4/m
0,90	13,50	0,90	1445269
1,20	21,73	1,20	1942531

Table 2.1.1 - Resistance moment and inertia moment

These resistance moments will be compared to resistance moments calculated according to EN 1993-1-3 determined for inwards stiffeners.

2.2. Coupon tensile test analysis [4] and [5]

54 tensile testing on coupons with and without embossments were performed with two different thicknesses in order to determine the influence of embossments on the yield stress.

a) plate coupons

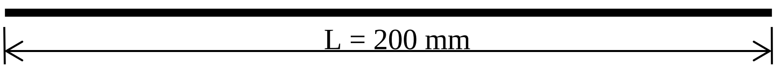

Fig. 2.2.1: Tensile plate coupon

b) coupons with embossment

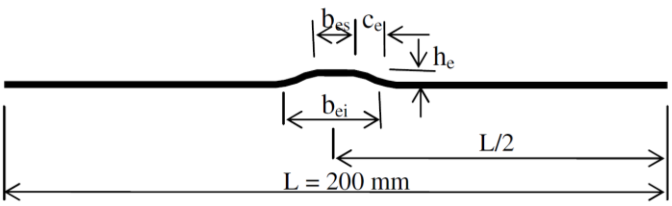

Fig. 2.2.2: Tensile coupon with embossment

Values of h_e: 0 mm; 1 mm; 2 mm; 3 mm; 4 mm

Values of b_e: 0 mm; 10 mm

Thickness: 0.75 mm; 1 mm

The stress decreases in accordance with the embossments. The more important the embossment is the more important the stress decrease is.

The relationship obtained between the stiffness of folded and flat samples is shown in the deliverable D1.5, paragraph 2.2.
In this document is also explained the determination of the ratio ρ value for the determination of the effective thickness $t_{eff} = \rho_p * t$ of the embossment, where $\rho_p = K_{pe}/K_p$ (Tables 2.2.2.5 et 2.2.2.6)

These relations between $\rho_p = K_{pe}/K_p$ and the actual height of the embossment "h_e" will be used to model the embossment on the outwards stiffener.

3. STUDY ON CALCULATION METHOD OF STEEL DECKS WITH OUTWARDS STIFFENERS

As a rule, in the calculation according to the EN 1993-1-3 it is assumed that the flange stiffeners are oriented inwardly of the section, i.e. downwards in the case of the upper flange (Fig. 3.1)

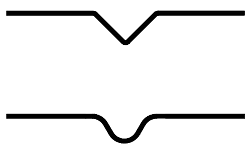

Fig. 3.1 - Typical forms of stiffeners in upper flange of cold-formed sections

In order to study the behaviour of the section with outwards stiffener in the upper flange, we choose the existing on the market Comflor® 80 profile shown in the Fig. 2.1.1.

The geometrical proportions *b/t*, *h/t*, *c/t* and *d/t* of this profile are inside the range of width to thickness given in Table 3.1.1 (Table 5.1 of EN 1993-1-3)

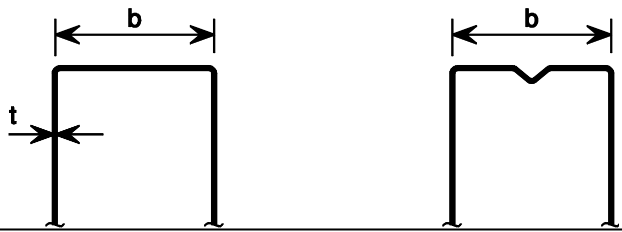	$b/t \leq 500$
	$45° \leq \phi \leq 90°$ $h/t \leq 500 \sin\phi$

Table 3.1.1 - Maximum width to thickness ratios

However, the internal radius r=25 mm is superior to limit value indicated in the EN 1993-1-3 for the theoretical calculation, which is equal to $0{,}04\ t\ E\ /\ f_y$ (16 mm for t=0,9 mm and 21 mm for t=1,2 mm). According to this:
- for t=0.9 mm: $r=0.064\ t\ E\ /\ f_y >\ 0{,}04\ t\ E\ /\ f_y = 16$ mm
- for t=0.9 mm: $r=0.048\ t\ E\ /\ f_y >\ 0{,}04\ t\ E\ /\ f_y = 16$ mm

Therefore, performing the theoretical calculation with the actual radius r=25 mm we verify in the same time if the limit given in the current version of the EN 1993-1-3 can be increased.

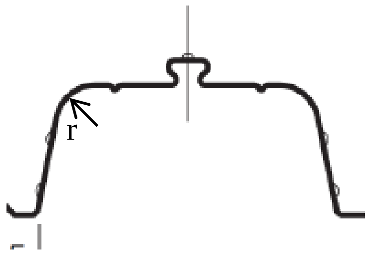

Fig. 3.2 – Internal radius r

Three options of theoretical calculation are performed to determine the resistance to positive bending moment. The results of this theoretical calculation are compared to the tests results.

The tested profile properties are:
t= 0,875 mm and f_{yb} = 470,5 N/mm^2
t= 1,164 mm and f_{yb} = 467,5 N/mm^2

3.1. First design

First design is based on 2 assumptions:

1) The upper part of the outwards stiffener is considered as a plate element without an embossment, i.e. the embossment is neglected (Fig. 3.1.1)

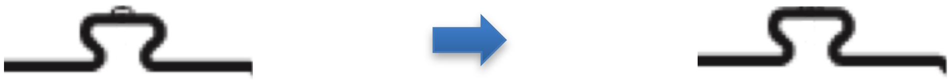

Fig. 3.1.1 – Upper part of the outwards stiffener considered as a plate element

2) The definition of the effective section modulus W_{eff} is based on an effective cross-section with a stress σ_1, and a distance z_c from neutral axis to the upper part of the outwards stiffener (Fig. 3.1.2).

With $\sigma_1 = \sigma_2 / \psi$ and $\psi = (h - z_c)/ z_c$

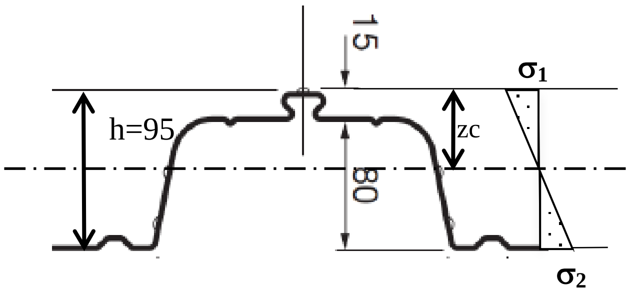

Fig. 3.1.2 – Stresses σ_1, σ_2 and distance z_c from neutral axis

The calculated resistance moments are much lower than resistance moments defined by testing (Table 3.1.1).

t_{nom}	M_R (kN*m/m)		
mm	Test	Calculation	
0,90	13,50	10,40	23,0%
1,20	21,73	15,66	27,9%

Table 3.1.1 – Resistance moments defined by testing and by first design calculation

The effective section modulus W_{eff} defined according to the first design seems to be much too low. The assumption of the effective section modulus W_{eff} based on an effective cross-section with a stress σ_1, and a distance z_c from neutral axis up to the upper part of the outwards stiffener (Fig. 3.1.2) is given up.

3.2. Second design

Second design is based on 2 assumptions:

1) The upper part of the outwards stiffener is considered as a plate element without embossment, i.e. the embossment is neglected as in the § 3.1 (Fig. 3.1.1)

2) The definition of the effective section modulus W_{eff} is based on an effective cross-section with a stress σ_1 in the upper flange and the upper part of the outwards stiffener and $\boldsymbol{\sigma_2}$ in the bottom flange (Fig. 3.2.1).

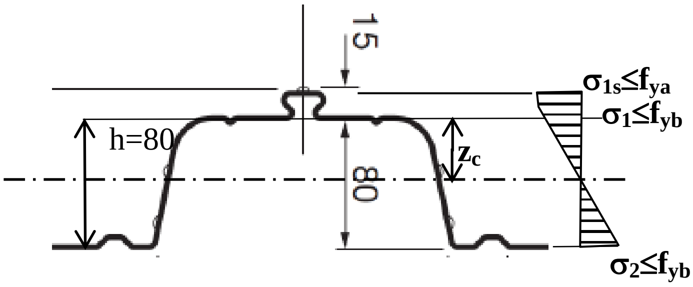

Fig. 3.2.1 – Stresses σ_1, σ_2 and distance z_c from neutral axis

Depending on the distance z_c the yield stress is reached in the upper or lower flange.
If the yield stress is reached in the lower flange then $\sigma_2 = f_{yb}$ and $\sigma_1 \leq f_{yb}$
If the yield stress is reached in the upper flange then $\sigma_1 = f_{yb}$ and $\sigma_2 \leq f_{yb}$
In each case the stress σ_{1s} is limited to the f_{ya} value defined according to the EN 1993-1-3 clause 3.2.2(3) , corresponding to the stiffener area A_s according to the EN 1993-1-3 clause 5.5.3.3(4), i.e. $\sigma_{1s} \leq f_{ya.}$

Based on these assumptions, the calculated resistance moment for t = 0,9 mm is overestimated comparing to resistance moment defined by testing (Table 3.2.1).

t_{nom}	M_R (kN*m/m)		
mm	Test	Calculation	
0,90	13,50	14,04	**-4,0%**
1,20	21,73	21,62	**0,5%**

Table 3.2.1 – Resistance moments defined by testing and by first design calculation

This means that neglecting the influence of the embossment leads to an unsafe result.

3.3. Third design

Third design is based on 2 assumptions:

1) <u>The embossments in the outwards stiffener and in the web are taken into account in the calculation:</u>

a) The upper part of the outwards stiffener is considered as a plate element with a reduced thickness instead of embossment $t_{red} = \rho * t$ (Fig. 3.3.1) (see the deliverable D1.5).

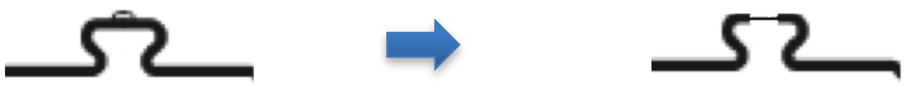

Fig. 3.3.1 – Upper part of the outwards stiffener with a reduced thickness replacing the embossment

b) The web embossments (Fig. 3.3.2) are considered as plate elements with a reduced thickness instead of embossment $t_{red} = \rho * t$ (see the deliverable D1.5). The calculation is performed in different sections of the web in order to determine the section which induces the most important reduction of the resistance moment.

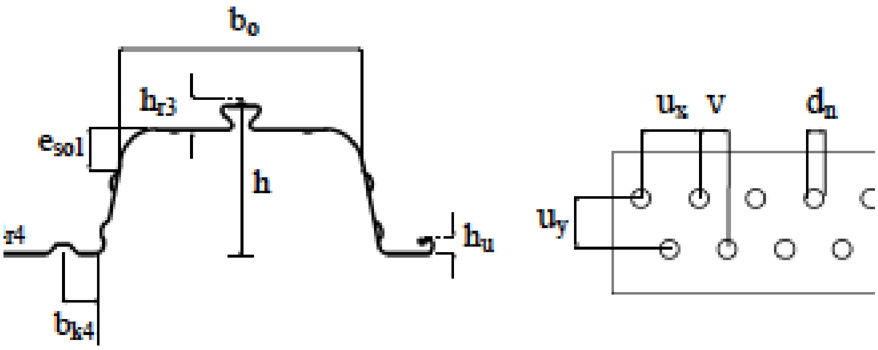

Fig 3.3.2 – Web embossments

Ratio ρ is defined according to D.15 § 2.2 ($\rho_p=K_{pe}/K_p$) for thickness t = 0,75 mm and t = 1 mm., considering two factors:

I. height of the embossment "h_e" (the height of the outwards stiffener embossment = the height of the web embossment)
II. thickness (t=0,9 mm and t= 1,2 mm being thicknesses of tested Comflor® 80 profile)

Ratio ρ for t=0,9mm is interpolated between the values for t=0,75mm and t=1mm, and ratio ρ for t=1,2mm is taken equal to t=1mm for safety reason, in order to avoid an extrapolation.

Therefore ratio ρ values defined in this way are presented in Table 3.3.1:

t (mm)	0,75	1	0,9	1,2
ratio ρ for COMFLOR 80 h_e	0,060	0,067	0,063	0,067

Table 3.3.1 - Ratio ρ values corresponding to the height of embossment "h_e" of COMFLOR 80 outwards stiffener and to the different thicknesses

2) The definition of the effective section modulus W_{eff} is based on an effective cross-section with a stress σ_1 in the upper flange and $\boldsymbol{\sigma_2}$ in the bottom flange (Fig. 3.2.1), as in the § 3.2.

In Table 3.3.2 are presented resistance moments calculated according to the third design but only with the outwards stiffener embossment modeled with a reduced thickness (assumption 1) a)). The calculated resistance moment for t = 0,9 mm is very close to resistance moment defined by testing therefore it is not safe.

t_{nom}	M_R (kN*m/m)		
mm	Test	Calculation	
0,90	13,50	13,45	**0,4%**
1,20	21,73	20,54	**5,5%**

Table 3.3.2 – Resistance moments defined by testing and by calculation with outwards stiffener embossment modeled with a reduced thickness

In Table 3.3.3 are presented resistance moments calculated according to the third design with both the outwards stiffener embossment and the web embossments modeled with a reduced thickness (assumption 1) a) and b)). The presented results are those for the section of the web which induces the lowest resistance moment.

t_{nom} mm	M_R (kN*m/m) Test	M_R (kN*m/m) Calculation	
0,90	13,50	13,13	**2,8%**
1,20	21,73	20,29	**6,6%**

Table 3.3.3 – Resistance moments defined by testing and by calculation with outwards stiffener embossment and web embossments modeled with a reduced thickness

We can conclude that the third design with the upper part of the outwards stiffener and the web embossments considered as a plate element with a reduced thickness instead of embossment $t_{red} = \rho * t$ and ratio ρ defined according to D.15 § 2.2 ($\rho_p = K_{pe}/K_p$) gives a resistance to bending moment close to the values by testing and on the safe side.

4. CONCLUSION

This study allowed us to develop a calculation method for steel decks:

- with outwards stiffeners in the upper flange, based on global testing on sheetings
- and with embossments on these stiffeners and on the web, based on global testing on sheetings and on local tensile testing with and without embossments

In this calculation method:

1) The embossments in the outwards stiffener and in the web are considered as a plate element with a reduced thickness instead of embossment $t_{red} = \rho * t$ and ratio ρ defined according to D.15 § 2.2 ($\rho_p = K_{pe}/K_p$)

2) The definition of the effective section modulus W_{eff} is based on an effective cross-section with a stress σ_1 in the upper flange and the upper part of the outwards stiffener and $\boldsymbol{\sigma_2}$ in the bottom flange

REFERENCES

[1] A. PALISSON (Sokol Palisson Consultants) "GRISPE D1.1, WP1 BACKGROUND DOCUMENT" 2013

[2] A. PALISSON (Sokol Palisson Consultants) "GRISPE D1.2, WP1 TEST PROGRAM DEFINITION" 2013

[3] C. FAUT (KIT) "GRISPE D1.3, “WP1 Test report of steel trapezoidal sheeting with and without embossments and outward stiffeners " 2014

[4] A. PALISSON (Sokol Palisson Consultants) "GRISPE D1.4, “WP1 TEST ANALYSIS AND INTERPRETATION" 2015

[5] A. PALISSON (Sokol Palisson Consultants) "GRISPE D1.5, “WP1 BACKGROUND GUIDANCE FOR EN 1993-1-3 (stiffeners & flanges)" 2015