GRISPE PLUS

VALORISATION OF KNOWLEDGE
FOR SPECIFIC PROFILED STEEL SHEETS

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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.

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FIGURES

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Figure 1.9	KIT
Figure 5.1	BACACIER
Figure 5.2	BACACIER
Figure 5.3	BACACIER
Figure 5.4	BACACIER
Figure 5.5	BACACIER
Figure 7.1	BACACIER
Figure 7.2	BACACIER
Figure 7.3	BACACIER
Figure 7.4	BACACIER
Figure 7.5	BACACIER
Figure 7.6	BACACIER

CONTENT

Scope of the publication ... 7
Notations ... 7
1. Introduction ... 8
  1.1. Type of profiled steel sheets concerned ... 8
  1.2. State of the art ... 8
  1.3. Main results of GRISPE ... 9
  1.4. General design requirements and rules ... 11
2. Preliminay considerations ... 12
  2.1. Field of application of the new design method ... 12
  2.2. Technological dispositions ... 12
3. Basic technological requirements ... 12
4. Material properties ... 12
5. Basis of the design ... 13
  5.1. Principles ... 13
  5.2. Field of application of the new design method ... 13
  5.3. Design procedure ... 13
    5.3.1. Moment resistance with the wide flange in compression ... 13
    5.3.2. Moment resistance with the wide flange in tension ... 14
    5.3.3. Resistance to end support reaction ... 16
    5.3.4. Resistance to dislocation of the joint ... 16
6. Specific design consideration ... 16
7. Design example ... 17
  7.1. Description of the building and loading assumption ... 17
  7.2. Hypothesis ... 17
    7.2.1. Disposition ... 17
    7.2.2. Geometry of the profile ... 18
    7.2.3. Material properties ... 18
  7.3. Calculation of the profile resistances ... 18
    7.3.1. Validity of the geometry of the profile ... 18
    7.3.2. Resistance to dislocation of the joint ... 18
    7.3.3. Moment resistance under pressure load ... 19
    7.3.4. Moment resistance under suction load ... 21
    7.3.5. Resistance to end support reaction ... 23
  7.4. Check in ULS ... 24
    7.4.1. Loads and internal forces ... 24
    7.4.2. Verifications ... 24
  7.5. Check in SLS ... 25
    7.5.1. Loads and deflection ... 25
    7.5.2. Verifications ... 25

7.6. Software verification 25
Table of figures 26
Bibliography 27
Annex: amendment project submitted to CEN 28

SCOPE OF THE PUBLICATION

The aim of this publication is to present the new design method for interlocking planks in accordance with [1] that has been proposed for inclusion in [2].

This design manual deals with currently occurring situations.

For exceptional situations (seismic, fire, etc.) it is necessary to follow the relevant clauses of the Eurocodes and/or [1].

NOTATIONS

The following symbols are used :

b_u: useful width of the wide flange of the plank

h: overall depth of the plank

b_f: width of the fixed flange of the joint of the plank

c_f: width of the free flange of the joint of the plank (undefined for chevron joint)

φ: angle of the joint relative the flanges

L: span of the plank

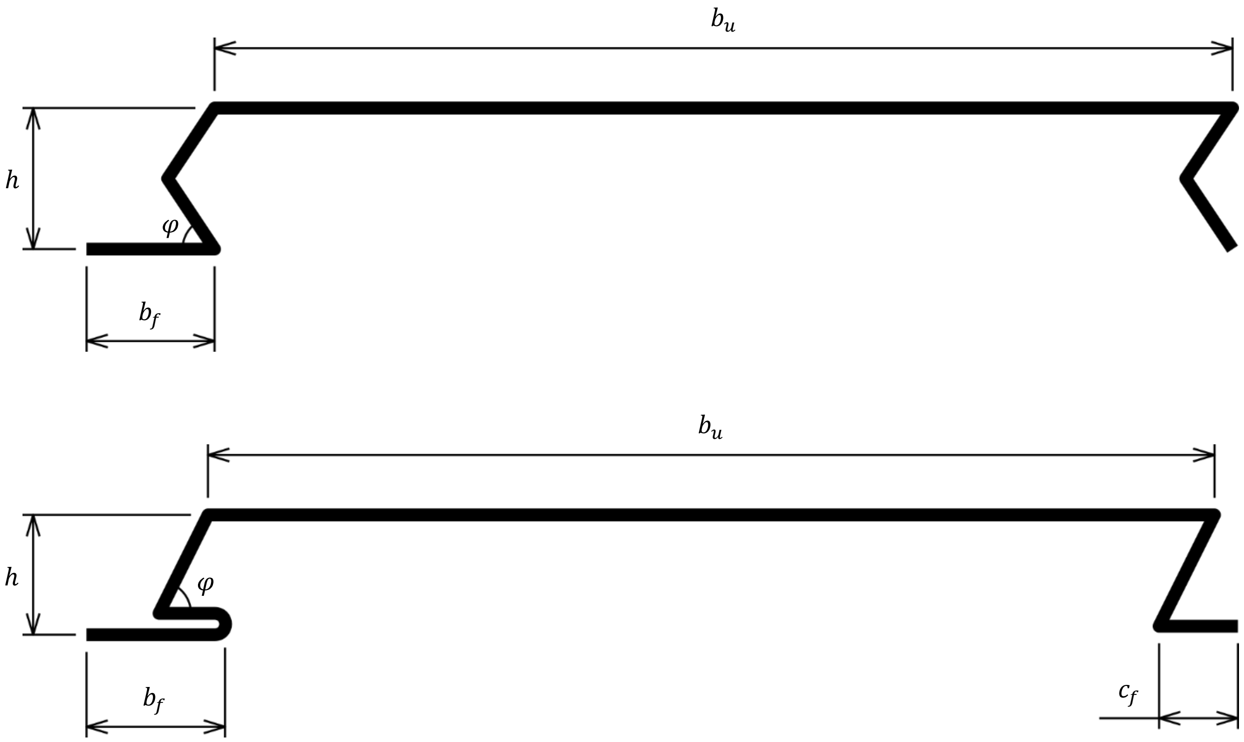


Figure 0.1 Geometrical definition of a plank profile

1. INTRODUCTION

1.1. Type of profiled steel sheets concerned

This design manual deals with interlocking planks used for cladding. The method presented below is valid for the two main shape of joint for such profiles : chevron joint (Figure 1.1) and clip joint (Figure 1.2).

Figure 1.1 Chevron joint interlocking plank

Figure 1.2 Clip joint interlocking plank

1.2. State of the art

In the story of steel building envelope, interlocking planks were developed for esthetical application. Indeed, the search for both hidden fixings and wide flat surfaces took over mechanical considerations. To this end, many shapes of joint, as shown in Figure 1.3, were developed by manufacturers.

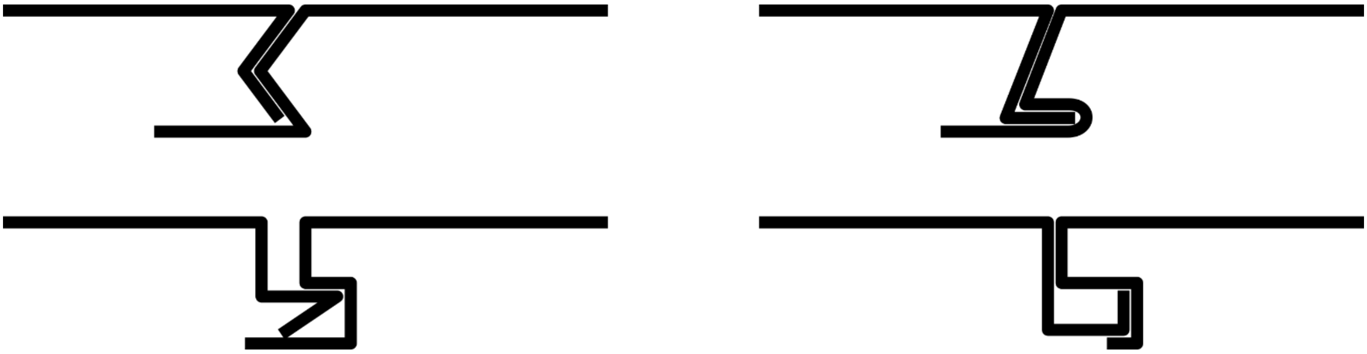


Figure 1.3 Different shapes of joint (not exhaustive)

Considering esthetical aspect, the two previous points (hidden fixings and wide flat surface) represent a certain advantage and a good reply to architects' concern. This make these products preconisation profiles that are becoming common as they are more and more prescribed.

Concerning the evaluation of the performances of interlocking planks under wind loads, various answers are provided by each country. When some authorize only design by testing, others allow both design by calculation and testing. Although design procedures are different, no harmonized solution was included in Eurocodes.

Interlocking planks are not explicitly a part of the current scope of the Eurocode. But, as liner trays, they can be characterized as a "large channel-type sections with two narrow flanges, two webs and one wide flange". Therefore, we can assume that formulas given for the calculation of the resistances of liner trays should give interesting results when used on interlocking planks.

Even if these results represent a good estimation of the behaviour of the profiles we are currently dealing with, a typical failure mode has to be taken into account. Actually, the fact that one edge of the joint is free to move, due to the hidden fixings solutions, a specific behaviour is observed during tests under suction loads. As the load applied on the profile is increasing, the free edge is slowly going out of the joint resulting in a dislocation of this last (see Figure 1.4), while the aspect of the wide flange is still decent.

Figure 1.4 Gradual dislocation of the joint during suction loads tests

1.3. Main results of GRISPE

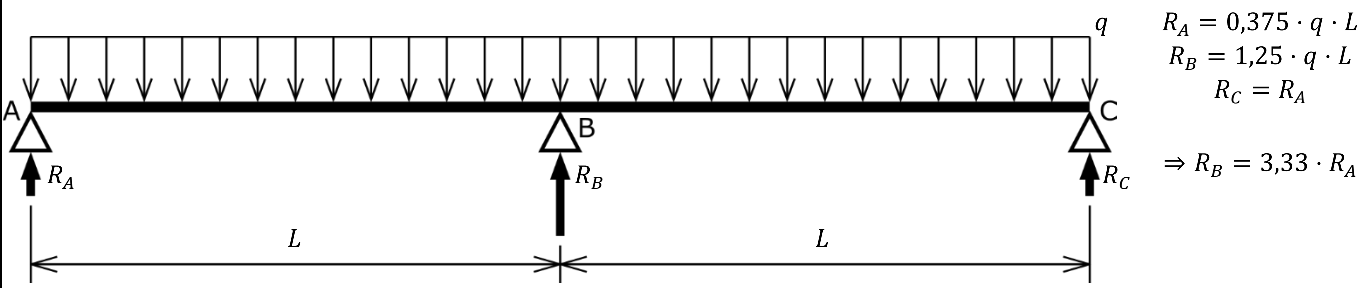
A full Eurocode campaign (see [3] and [4]) was carried out on the two profiles presented in Figure 1.1, comprising:

- Single span bending tests in vacuum chamber (see Figure 1.5)
  - Under pressure loads
  - Under suction loads
- Double span bending tests in vacuum chamber
  - Under pressure loads
  - Under suction loads
- End support test

Those tests were realized on two different nominal thicknesses: 0.75 and 1 mm.

Figure 1.5 Test sample positioned on the vacuum chamber (pressure loads set-up)

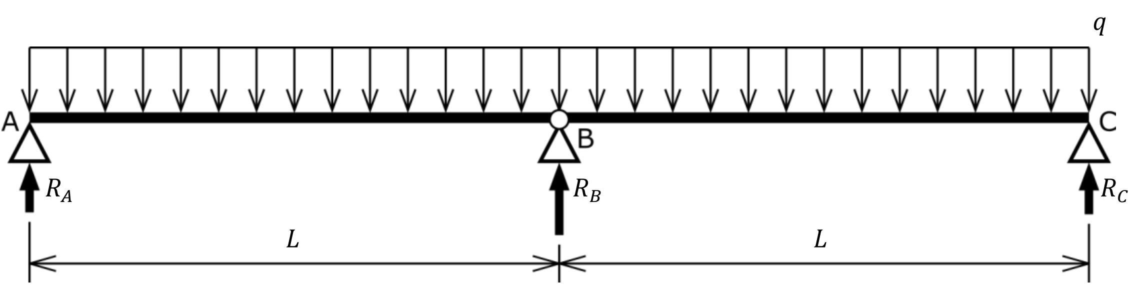
One of the most significant result is the fact that, during double span tests under both suction and pressure loads, plank profiles are showing no resistance on intermediate support and is behaving like a hinge. In fact, analysing supports reactions measures, we found that central support reaction is equal to the value we will expect with two isostatic beams and not the one awaited for a single continuous beam (see Figure 1.6 and Figure 1.7). This observation is confirmed by the characteristic moment resistance (M_{Rk}) of the profiles in mid-span that are consistent whether the test is performed in single or double span.



$R_A = 0{,}375 \cdot q \cdot L$
$R_B = 1{,}25 \cdot q \cdot L$
$R_C = R_A$

$\Rightarrow R_B = 3{,}33 \cdot R_A$

Figure 1.6 Expected behaviour for double span tests



$R_A = 0{,}50 \cdot q \cdot L$
$R_B = 1{,}00 \cdot q \cdot L$
$R_C = R_A$

$\Rightarrow R_B = 2{,}00 \cdot R_A$

Figure 1.7 Observed behaviour for double span tests

The other major learning we found out during bending tests under suction loads is that, unlike when load is applied by means of timber blocks, dislocation of the joint is not the exclusive failure mode observed on the vacuum chamber. Some of the samples failed by dislocation of the joint but most of them failed by local buckling of the joint in mid-span, as on Figure 1.8. Vacuum chamber is the most realistic way to apply loads representing wind ones that plank profiles have to face on actual buildings, therefore current resistance values given for interlocking planks, when tests are executed using timber blocks, may be too penalizing.

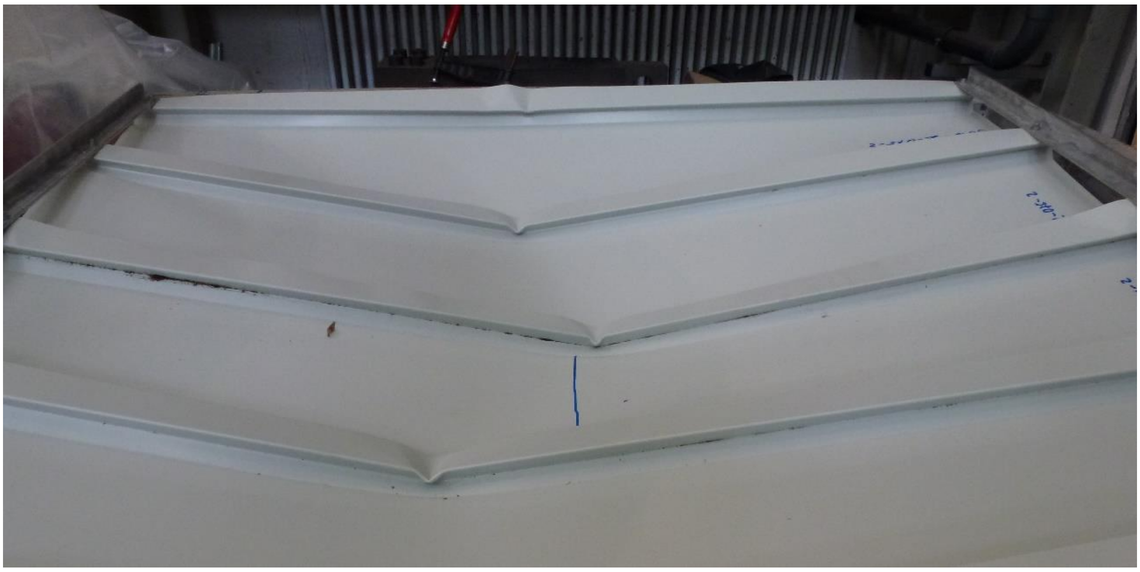


Figure 1.8 Failure by local buckling of the joint for single span bending test under suction loads

Perhaps this point should be the main subject of a full study to get a better understanding of such a phenomena. A typical failure occurring by dislocation of the joint is for double span bending test under suction loads can be seen on Figure 1.9 below.

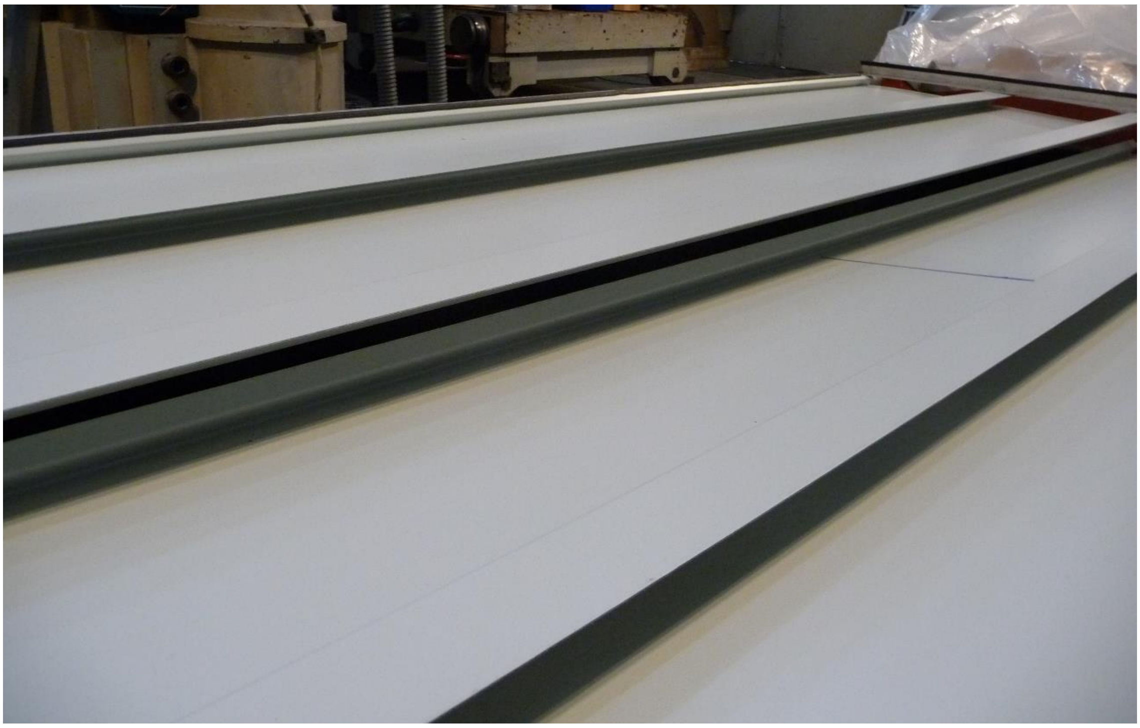


Figure 1.9 Failure by dislocation of the joint for double span bending test under suction loads

1.4. General design requirements and rules

The following design method only offers a way for the calculation of the design resistance R_d according to [5] and its amendment [6]. Design values of the effects of actions have to be evaluated in conformity to every relevant part of [7] or [8] and it amendment [9].

The succeeding procedure respects general rules given in [10] and its amendment [11] and the basis of design defined in part 2 of [2].

An amendment project was proposed to CEN for validation and inclusion in the Eurocode. This amendment project is given in Annex.

2. PRELIMINAY CONSIDERATIONS

2.1. Field of application of the new design method

This manual presents a new design method for interlocking planks compliant to [1].

2.2. Technological dispositions

The minimal dimensions of the supports are:

- Steel support:
    - Minimal width: 40 mm
    - Minimal thickness: 1.5 mm
- Wood support:
    - Minimal width: 60 mm
    - Minimal height: 80 mm
- Concrete support: not allowed directly. To correct the unevenness of the facing, a metal or wooden secondary frame have to be installed.

The characteristics of the screws are:

- For steel support:
    - Minimal diameter: 5.5 mm
    - Minimal length: such as the screw thread passes through the support
- For wood support:
    - Minimal diameter: 6.3 mm
    - Minimal length: such as the anchorage length is 50mm at least

The fixing density is: 1 screw per support per plank.

3. BASIC TECHNOLOGICAL REQUIREMENTS

Interlocking planks are CE marked according to the standard [1].

4. MATERIAL PROPERTIES

The material properties, if not further specified, used in calculation have to satisfy requirements defined within section 3 of [2].

5. BASIS OF THE DESIGN

5.1. Principles

This method is based on liner trays design calculation method already included in [2]. This method is complemented by an additional criterion taking into account the possible dislocation of the joint.

The new design method can be used to determine:

- Resistance to bending moment with the wide flange in compression
- Resistance to bending moment with the wide flange in tension
- Resistance to end support reactions
- Resistance to dislocation of the joint

5.2. Field of application of the new design method

The following design procedure may be used to evaluate the resistance of plank profiles provided that the geometrical properties are within the range given below:

$$\begin{array}{rcccl} 0.75\,mm & \leq & t_{nom} & \leq & 1.00\,mm \\ & & b_f & \leq & 40\,mm \\ 25\,mm & \leq & h & \leq & 30\,mm \\ & & b_u & \leq & 300\,mm \\ & & \varphi & \leq & 60° \\ 11\,mm & \leq & c_f & & \end{array}$$

For the notations, see **Figure 0.1**.

The design resistance values obtained are only relevant when compared to uniform load actions, mainly wind action loads.

5.3. Design procedure

5.3.1. Moment resistance with the wide flange in compression

According to [12] and its amendment [13], the effective part of the wide flange (internal evenly compressed element) is:

$$b_{u,eff} = \rho_u \cdot b_u$$

Based on this effective width of the wide flange $b_{u,eff}$ and the fully effective webs and narrow flanges, we determine the centroid of the section (see Figure 5.1).

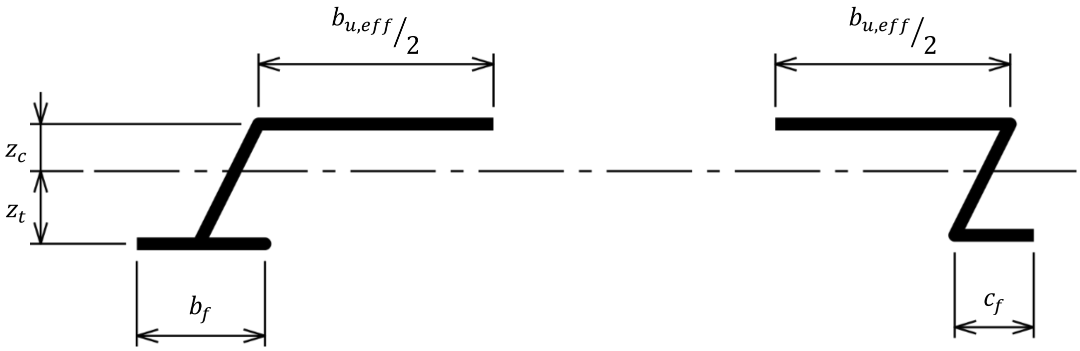


Figure 5.1 Centroid of the cross section considering effective wide flange

The effective compressed height of the web (see Figure 5.2), conforming to [12] and its amendment [13], is:

$$h_{eff} = \rho_w \cdot z_c$$

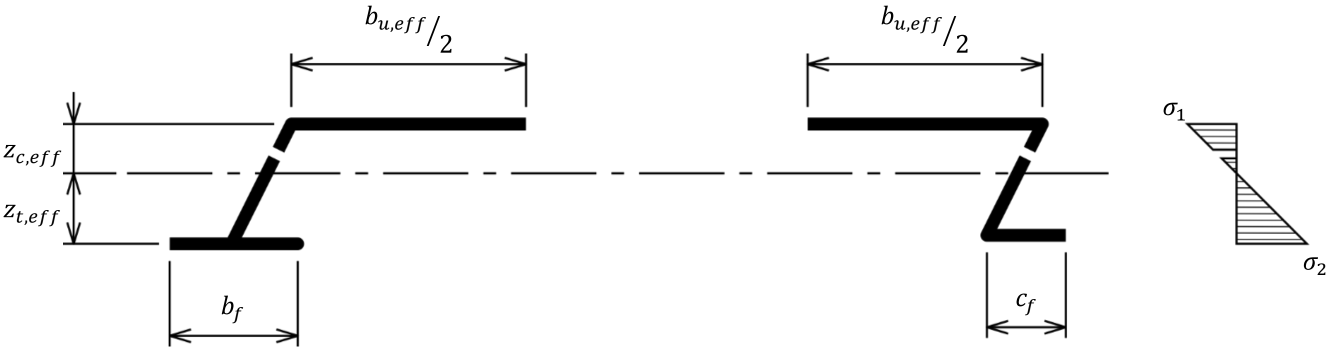


Figure 5.2 Centroid of the effective cross section and stress distribution

The moment resistance is thus determined, considering effective web and wide flange, using the formula (10.19) of [2]:

$$M_{c,Rd} = W_{eff} \cdot \frac{0.8 \cdot f_{yb}}{\gamma_{M0}}$$

With:

$$W_{eff} = \frac{I_{y,eff}}{\max(z_{c,eff}; z_{t,eff})}$$

Note

An amendment has been proposed to remove the 0.8 factor in a further version of the Eurocode. Once this amendment will be published, the 0.8 factor may also be removed from the above $M_{c,Rd}$ formula.

5.3.2. Moment resistance with the wide flange in tension

According to § 10.2.2.2(1) of [2], the centroid of the gross section is determined. The effective width of the wide flange is calculated taking into account the centroid of the gross section (see Figure 5.3) e_0:

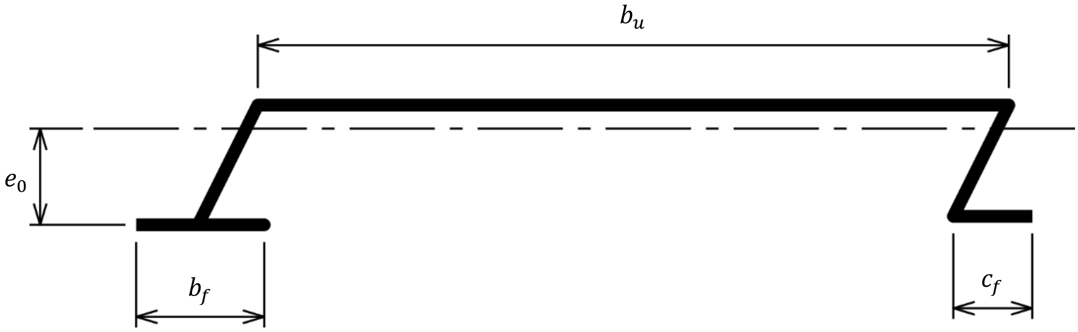


Figure 5.3 Centroid of the gross cross section

Therefore, the effective width of the wide flange is calculated using the following formula:

$$b_{u,eff} = \frac{53.3 \cdot 10^{10} \cdot {e_0}^2 \cdot t^4}{h \cdot L \cdot {b_u}^3}$$

The effective widths of the narrow flanges are evaluated according to [12] and its amendment [13], as outstanding evenly compressed elements:

$$\begin{cases} b_{f,eff} = \rho_b \cdot b_f \\ c_{f,eff} = \rho_c \cdot c_f \end{cases}$$

Based on this effective widths of the flanges $b_{u,eff}$, $b_{f,eff}$, $c_{f,eff}$ and the fully effective webs, we determine the centroid of the section (see Figure 5.4)

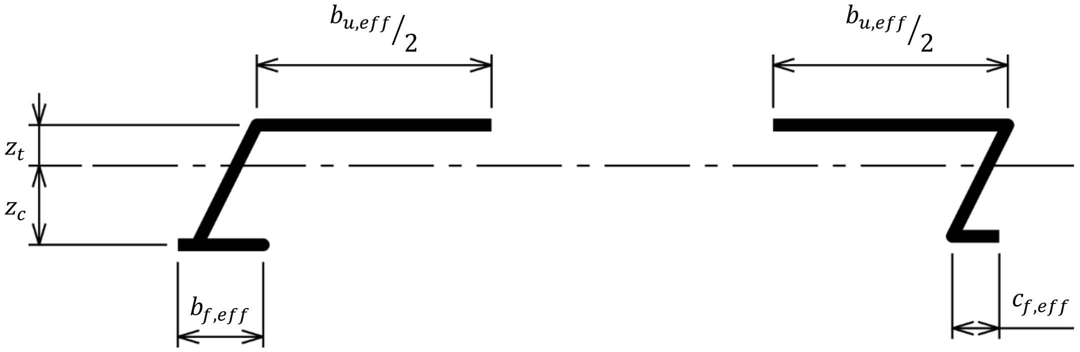


Figure 5.4 Centroid of the cross section considering effective flanges

As before, effective compressed part of the web (see Figure 5.5), conforming to [12] and its amendment [13], is:

$$h_{eff} = \rho_w \cdot z_c$$

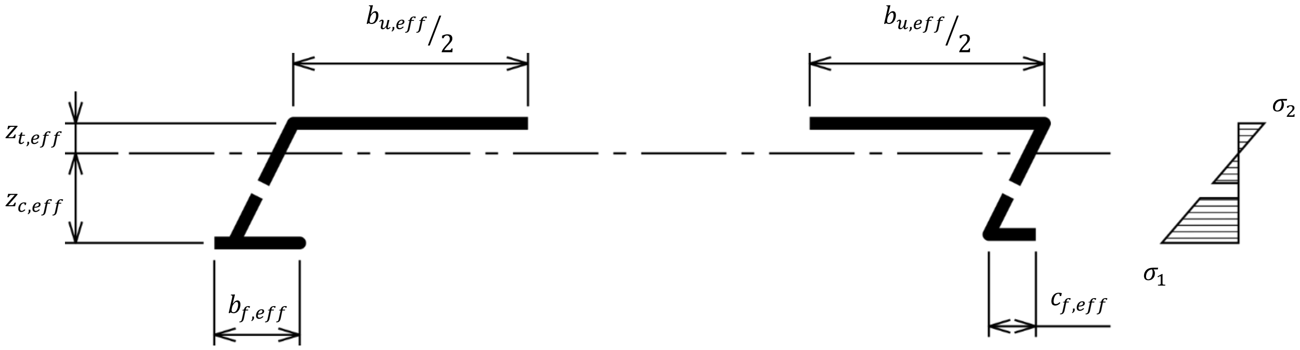


Figure 5.5 Centroid of the effective cross section and stress distribution

As previously, the moment resistance is thus determined, considering effective web and flanges, using the formula (10.19) of [2]:

$$M_{b,Rd} = W_{eff} \cdot \frac{0.8 \cdot f_{yb}}{\gamma_{M0}}$$

With:

$$W_{eff} = \frac{I_{y,eff}}{\max(z_{c,eff}; z_{t,eff})}$$

Note

An amendment has been proposed to remove the 0.8 factor in a further version of the Eurocode. Once this amendment will be published, the 0.8 factor may also be removed from the above $M_{c,Rd}$ formula.

5.3.3. Resistance to end support reaction

According to §6.1.7.3(2) of [2], the end support resistance of one web is determined by:

$$R_{w,Rd} = \frac{\alpha \cdot t^2 \cdot \sqrt{f_{yb} \cdot E} \cdot \left(1 - 0.1 \cdot \sqrt{\frac{r}{t}}\right) \cdot \left(0.5 + \sqrt{0.02 \cdot \frac{l_a}{t}}\right) \cdot \left[2.4 + \left(\frac{\varphi}{90}\right)^2\right]}{\gamma_{M1}}$$

With:

- $\alpha = 0.115$ (new value proposed in the amendment)
- $l_a = 10\,mm$

For the notations, see Figure 0.1.

5.3.4. Resistance to dislocation of the joint

To evaluate the plank resistance to dislocation of the joint should be determined from:

$$q_{Rd} = 2 \cdot \frac{E \cdot 1000 \cdot t^3 \cdot \delta_{lim}}{12 \cdot (1 - \nu^2) \cdot \sqrt{\left(\frac{2 \cdot b_f{}^3}{3}\right)^2 + \left[b_f \cdot \left(\frac{b_u \cdot h}{3} + \frac{h^2}{2}\right)\right]^2}} \cdot \frac{1000}{b_u}$$

With :

$$\delta_{lim} = \begin{cases} c_f & \text{for clip joints} \\ \dfrac{h}{2 \cdot \tan\varphi} & \text{for chevron joints} \end{cases}$$

For the notations, see **Figure 0.1**.

6. SPECIFIC DESIGN CONSIDERATION

The subsequent issues are not covered by the present manual:

- Fire design
- Seismic design
- Environmental aspects
- Thermal aspects
- Acoustic aspects
- Every other subject not clearly identified higher or lower.

7. DESIGN EXAMPLE

7.1. Description of the building and loading assumption

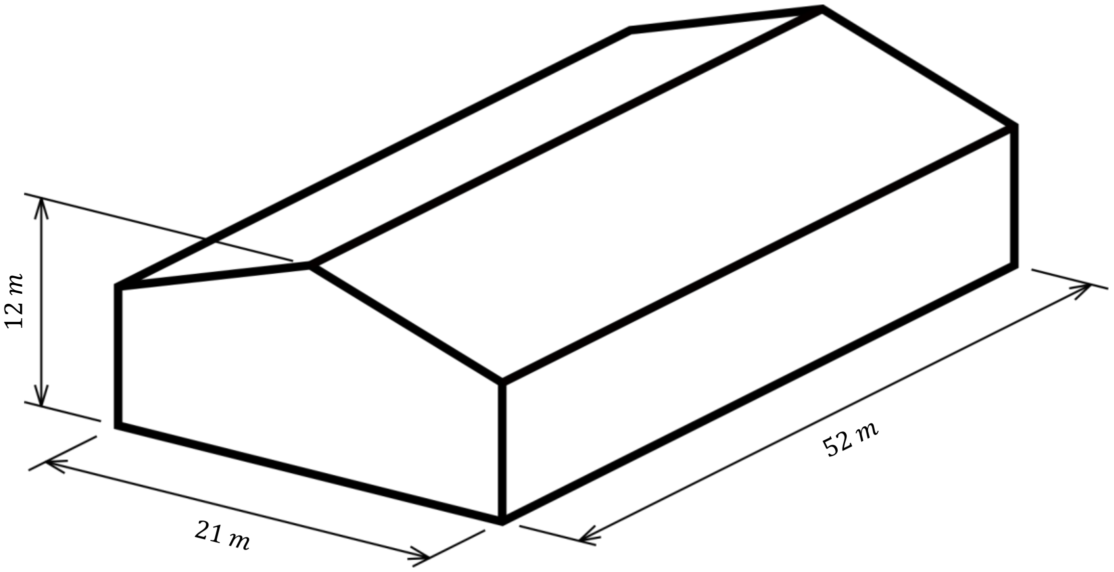


Figure 7.1 Dimensions of the building

Only wind load action are taken into account thereafter.

Design values for action (W):
Peak velocity pressure:
$q_p = 456\ N/m^2$
Pressure coefficients:
External pressure $c_{pe} = +0.7$
External suction $c_{pe} = -1.2$
Internal pressure $c_{pi} = \pm 0.3$

Combinations
Ultimate Limit State (ULS):
$1.5 \times W$
Service Limit State (SLS):
W

Deflection criteria in SLS used: $L/200$

7.2. Hypothesis

7.2.1. Disposition

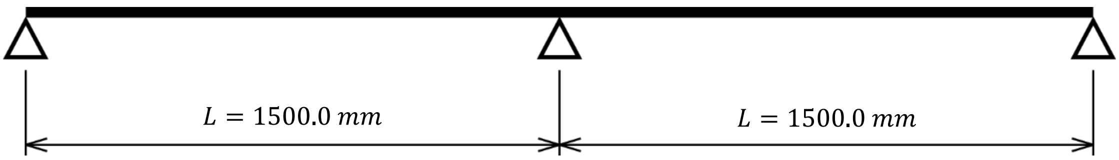


Figure 7.2 Static scheme of the planks disposition

7.2.2. Geometry of the profile

The profile designed thereafter is the following:

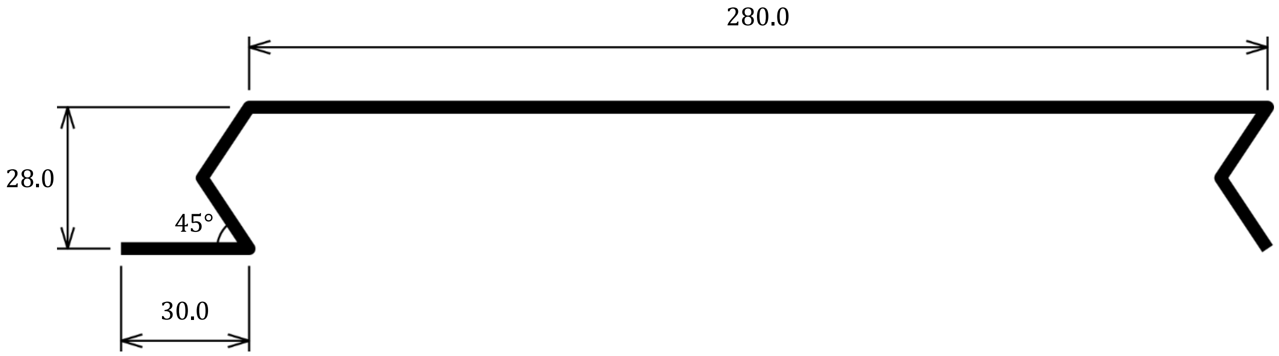


Figure 7.3 Geometry of the profile designed

Notation:

$b_u = 280.0\ mm$
$h = 28.0\ mm$
$b_f = 30.0\ mm$
$\varphi = 45°$

7.2.3. Material properties

General:

$E = 210000\ N/mm^2$
$\nu = 0{,}3$

Steel used:

Grade of steel: S320
$f_{yb} = 320\ N/mm^2$
$t_{nom} = 0{,}75\ mm$
$t = 0.71\ mm$

7.3. Calculation of the profile resistances

7.3.1. Validity of the geometry of the profile

$0.75\ mm \leq t_{nom} = 0.75\ mm < 1.00\ mm$
$b_f = 30.0\ mm < 40\ mm$
$25\ mm < h = 28.0\ mm < 30\ mm$
$b_u = 280.0\ mm < 300\ mm$
$\varphi = 45° < 60°$

The geometry of the profile is within the range of validity of the design procedure.

7.3.2. Resistance to dislocation of the joint

$$\delta_{lim} = \frac{28.0}{2 \cdot \tan 45} = 14.0\ mm$$

$$q_{Rd} = 2 \cdot \frac{210000 \times 1000 \times 0.71^3 \times 14.0}{12 \cdot (1 - 0.3^2) \cdot \sqrt{\left(\frac{2 \times 30.0^3}{3}\right)^2 + \left[30.0 \cdot \left(\frac{280.0 \times 28.0}{3} + \frac{28.0^2}{2}\right)\right]^2}} \cdot \frac{1000}{280.0}$$
$$= 7486\ {}^{N}\!/_{m^2}$$

7.3.3. Moment resistance under pressure load

Under pressure loads, the wide flange is working in compression.

Step 1: Effective width of the wide flange (evenly compressed)

According to Table 4.1 of [12] and its amendment [13]: $k_\sigma = 4.0$

$$\varepsilon = \sqrt{\frac{235}{320}} = 0.857$$

$$\bar{\lambda}_{p,u} = \frac{280.0/0.71}{28.4 \times 0.857 \times \sqrt{4.0}} = 8.102 > 0.5 + \sqrt{0.085 - 0.055 \times 1} = 0.673$$

$$\rho_u = \frac{8.102 - 0.055 \cdot (3+1)}{8.102^2} = 0.120$$

$$\frac{b_{u,eff}}{2} = \frac{0.120 \times 280.0}{2} = 16.8\,mm$$

Step 2: Calculation of z_c and z_t

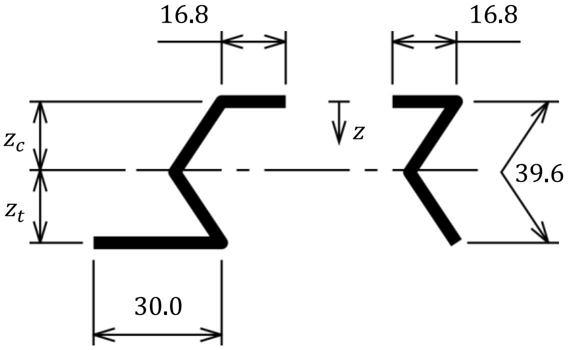


Figure 7.4 Calculation of z_c (wide flange in compression)

	l mm	z mm	$l \cdot z$ mm^2
Left edge (fixed)	16.8	0.0	0.00
	39.6	14.0	554.40
	30.0	28.0	840.00
Right edge (free)	16.8	0.0	0.00
	39.6	14.0	554.40
Σ	**142.8**	**–**	**1948.80**

$$z_c = \frac{1948.80}{142.8} = 13.6\,mm$$

$$z_t = 28.0 - 13.6 = 14.4\,mm$$

Step 3: Effectiveness of the web

$$\psi = \frac{\sigma_2}{\sigma_1} = -\frac{14.4}{13.6} = -1.059$$

$$k_\sigma = 5.98 \cdot (1 + 1.059)^2 = 25.35$$

$$\bar{\lambda}_w = \frac{28.0 / 0.71}{28.4 \times 0.857 \times \sqrt{25.35}} = 0.322 < 0.673$$

$$\rho_w = 1.0$$

The web is fully effective

Step 4: Calculation of $M_{b,Rd,c}$

	l mm	z mm	$l \cdot z$ mm^2	$l \cdot z^2$ mm^3	I_{part}/t mm^3
Left edge (fixed)	16.8	0.0	0.00	0.000	0.706
	39.6	14.0	554.40	7761.600	2587.200
	30.0	28.0	840.00	23520.000	1.260
Right edge (free)	16.8	0.0	0.00	0.000	0.706
	39.6	14.0	554.40	7761.600	2587.200
Σ	**142.8**	**–**	**1948.80**	**39043.200**	**5174.400**

$$z_{c,eff} = \frac{1948.80}{142.8} = 13.6\,mm$$

$$z_{t,eff} = 28.0 - 13.6 = 14.4\,mm$$

$$I_{y,eff} = (39043.200 + 5174.400 - 142.8 \times 13.6^2) \cdot 0.71 \times \frac{1000.0}{280.0} = 45149\,{mm^4}/{m}$$

$$W_{eff} = \frac{45149}{\max(13.6; 14.4)} = 3135\,{mm^3}/{m}$$

$$M_{c,Rd} = (3135 \cdot 10^{-3}) \times \frac{0.8 \times 320}{1.0} = 802\,{N \cdot m}/{m}$$

7.3.4. Moment resistance under suction load

Under suction loads, the wide flange is working in tension.

Step 1: Centroid of the gross cross section

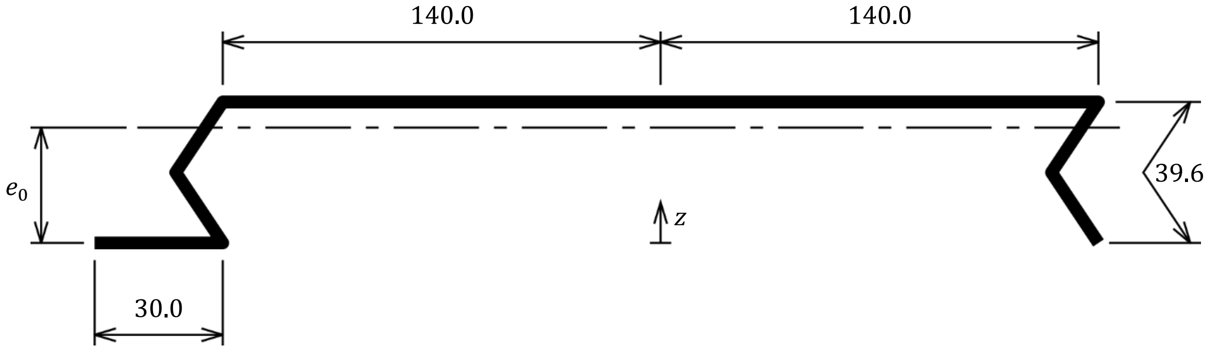


Figure 7.5 Calculation of e_0 (wide flange in tension)

	l mm	z mm	$l \cdot z$ mm^2
Left edge (fixed)	30.0	0.0	0.00
	39.6	14.0	554.40
	140.0	28.0	3920.00
Right edge (free)	39.6	14.0	554.40
	140.0	28.0	3920.00
Σ	$\mathbf{389.2}$	**–**	$\mathbf{8948.80}$

$$e_0 = \frac{8948.80}{389.2} = 23.0\,mm$$

Step 2: Effective width of the wide flange

$$\frac{b_{u,eff}}{2} = \frac{53.3 \times 10^{10} \times 23.0^2 \times 0.71^4}{2 \times 28.0 \times 1500 \times 280.0^3} = 38.9\,mm$$

Step 3: Effective width of the narrow flange (evenly compressed)

According to Table 4.2 of [12] and its amendment [13]: $k_\sigma = 0.43$

$$\bar{\lambda}_{p,b} = \frac{30.0/0.71}{28.4 \times 0.857 \times \sqrt{0.43}} = 2.647 > 0.748$$

$$\rho_b = \frac{2.647 - 0.188}{2.647^2} = 0.351$$

$$b_{f,eff} = 0.351 \times 30.0 = 10.5\,mm$$

Step 4: Calculation of z_c and z_t

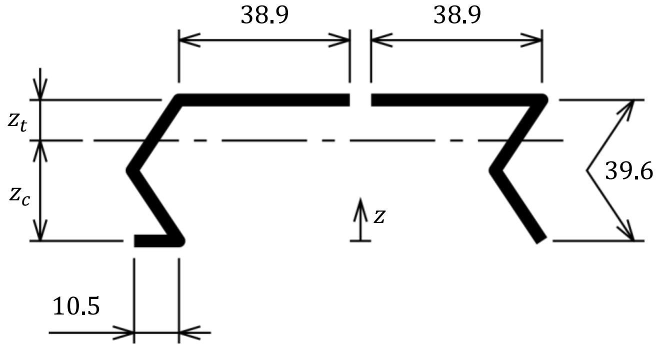


Figure 7.6 Calculation of z_c (wide flange in tension)

	l mm	z mm	$l \cdot z$ mm^2
Left edge (fixed)	10.5	0.0	0.00
	39.6	14.0	554.40
	38.9	28.0	1089.20
Right edge (free)	39.6	14.0	554.40
	38.9	28.0	1089.20
$\boldsymbol{\Sigma}$	**167.5**	**–**	**3287.20**

$$z_c = \frac{3287.20}{167.5} = 19.6\,mm$$

$$z_t = 28.0 - 19.6 = 8.4\,mm$$

Step 5: Effectiveness of the web

$$\psi = \frac{\sigma_2}{\sigma_1} = -\frac{8.4}{19.6} = -0.429$$

$$k_\sigma = 7.81 - 6.29 \times (-0.429) + 9.78 \times (-0.429)^2 = 12.31$$

$$\bar{\lambda}_w = \frac{28.0/0.71}{28.4 \times 0.857 \times \sqrt{12.31}} = 0.462 < 0.673$$

$$\rho_w = 1.0$$

The web is fully effective

Step 6: Calculation of $M_{b,Rd,c}$

	$\boldsymbol{l}$ $\boldsymbol{mm}$	$\boldsymbol{z}$ $\boldsymbol{mm}$	$\boldsymbol{l \cdot z}$ $\boldsymbol{mm^2}$	$\boldsymbol{l \cdot z^2}$ $\boldsymbol{mm^3}$	$\boldsymbol{I_{part}/t}$ $\boldsymbol{mm^3}$
Left edge (fixed)	10.5	0.0	0.00	0.000	–
	39.6	14.0	554.40	7761.600	2587.200
	38.9	28.0	1089.20	30497.600	–
Right edge (free)	39.6	14.0	554.40	7761.600	–
	38.9	28.0	1089.20	30497.600	2587.200
$\boldsymbol{\Sigma}$	$\boldsymbol{167.5}$	–	$\boldsymbol{3287.20}$	$\boldsymbol{76518.400}$	$\boldsymbol{5174.400}$

$$z_{c,eff} = \frac{3287.20}{167.5} = 19.6\,mm$$

$$z_{t,eff} = 28.0 - 19.6 = 8.4\,mm$$

$$I_{y,eff} = (76518.400 + 5174.400 - 167.5 \times 19.6^2) \cdot 0.71 \times \frac{1000.0}{280.0} = 43985\,{}^{mm^4}\!/_{m}$$

$$W_{eff} = \frac{43985}{\max(19.6; 84)} = 2244\,{}^{mm^3}\!/_{m}$$

$$M_{b,Rd} = (2244 \cdot 10^{-3}) \times \frac{0.8 \times 320}{1.0} = 574\,{}^{N \cdot m}\!/_{m}$$

7.3.5. Resistance to end support reaction

Each plank has two webs, therefore we have:

$$R_{w,Rd} = 2 \cdot \frac{0.115 \cdot 0.71^2 \cdot \sqrt{320 \cdot 210000} \cdot \left(1 - 0.1 \cdot \sqrt{\frac{2.0}{0.71}}\right) \cdot \left(0.5 + \sqrt{0.02 \cdot \frac{10.0}{0.71}}\right) \cdot \left[2.4 + \left(\frac{45}{90}\right)^2\right]}{1.0} \cdot \frac{1000.0}{280.0}$$

$$= 7716\,{}^{N}\!/_{m}$$

7.4. Check in ULS

7.4.1. Loads and internal forces

Under pressure:

Wind load:

$$w_{p,ult} = 1.5 \cdot [0.7 - (-0.3)] \cdot 456 = 684\ N/m^2$$

Maximum span moment:

$$M_{Ed,p} = \frac{684 \times 1.500^2}{8} = 192\ N \cdot m$$

Reaction at end support:

$$R_{Ed,p} = \frac{(1.5 \times 456) \cdot 1.500}{2} = 513\ N$$

Under suction:

Wind load:

$$w_{s,ult} = 1.5 \cdot [-1.2 - 0.3] \cdot 456 = -1026\ N/m^2$$

Maximum span moment:

$$M_{Ed,s} = \frac{1026 \times 1.500^2}{8} = 289\ N \cdot m$$

The interaction criteria is not verified because it is admitted the intermediate support behave like a hinge (cf. Figure 1.7).

7.4.2. Verifications

Under pressure:

Maximum span moment:

$$\frac{M_{c,Rd}}{M_{Ed,p}} = \frac{802}{289} = 2.78 > 1.0$$

Reaction at end support:

$$\frac{R_{w,Rd}}{R_{Ed,p}} = \frac{7716}{513} = 15.04 > 1.0$$

Under suction:

Wind load:

$$\frac{q_{Rd}}{w_{s,ult}} = \frac{7486}{1026} = 7.30 > 1.0$$

Maximum span moment:

$$\frac{M_{b,Rd}}{M_{Ed,s}} = \frac{574}{289} = 1.99 > 1.0$$

The fastener resistance may have to be check according to §8 of [2].

The interaction criteria is not verified because it is admitted the intermediate support behave like a hinge (cf. Figure 1.7).

7.5. Check in SLS

7.5.1. Loads and deflection

Under pressure:

Wind load:

$$w_{p,ser} = [0.7 - (-0.3)] \cdot 456 = 456\ N/m^2$$

Maximum deflection:

$$\delta_p = \frac{456 \times 1.500^4}{192 \times 210000 \times 45149 \cdot 10^{-6}} = 1.3 \cdot 10^{-3}\ m$$

Under suction:

Wind load:

$$w_{s,ser} = (-1.2 - 0.3) \cdot 456 = -684\ N/m^2$$

Maximum deflection:

$$\delta_s = \frac{684 \times 1.500^4}{192 \times 210000 \times 43985 \cdot 10^{-6}} = 2.0 \cdot 10^{-3}\ m$$

7.5.2. Verifications

Under pressure:

Maximum deflection:

$$\delta_p = 1.3 \cdot 10^{-3}\ m < \frac{1.500}{200} = 7.5 \cdot 10^{-3}\ m$$

Under suction:

Wind load:

$$\frac{q_{Rd}}{w_{s,ult}} = \frac{7486}{684} = 10.94 > 1.0$$

Maximum deflection:

$$\delta_s = 2.0 \cdot 10^{-3}\ m < \frac{1.500}{200} = 7.5 \cdot 10^{-3}\ m$$

7.6. Software verification

An Excel software is available on GRISPE plus website (www.grispeplus.eu). The following table gives a comparison of the values calculated above and the values given by the software.

Value	**Manual calculation**	**Software calculation**
q_{Rd} N/m^2	7486	7486
$M_{c,Rd}$ $N \cdot m/m$	802	797
$M_{b,Rd}$ $N \cdot m/m$	574	567
$R_{w,Rd}$ N/m	7716	7716

The differences we notice above are the results of rounding errors of the intermediate values.

TABLE OF FIGURES

Figure 0.1 Geometrical definition of a plank profile 7

Figure 1.1 Chevron joint interlocking plank 8

Figure 1.2 Clip joint interlocking plank 8

Figure 1.3 Different shapes of joint (not exhaustive) 8

Figure 1.4 Gradual dislocation of the joint during suction loads tests 9

Figure 1.5 Test sample positioned on the vacuum chamber (pressure loads set-up) 9

Figure 1.6 Expected behaviour for double span tests 10

Figure 1.7 Observed behaviour for double span tests 10

Figure 1.8 Failure by local buckling of the joint for single span bending test under suction loads .. 10

Figure 1.9 Failure by dislocation of the joint for double span bending test under suction loads 11

Figure 5.1 Centroid of the cross section considering effective wide flange 13

Figure 5.2 Centroid of the effective cross section and stress distribution 14

Figure 5.3 Centroid of the gross cross section 14

Figure 5.4 Centroid of the cross section considering effective flanges 15

Figure 5.5 Centroid of the effective cross section and stress distribution 15

Figure 7.1 Dimensions of the building 17

Figure 7.2 Static scheme of the planks disposition 17

Figure 7.3 Geometry of the profile designed 18

Figure 7.4 Calculation of z_c (wide flange in compression) 19

Figure 7.5 Calculation of e_0 (wide flange in tension) 21

Figure 7.6 Calculation of z_c (wide flange in tension) 22

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[3] C. FAUTH, GRISPE – WP4: Calculation method for cladding systems – D 4.3 Test report, 2016.

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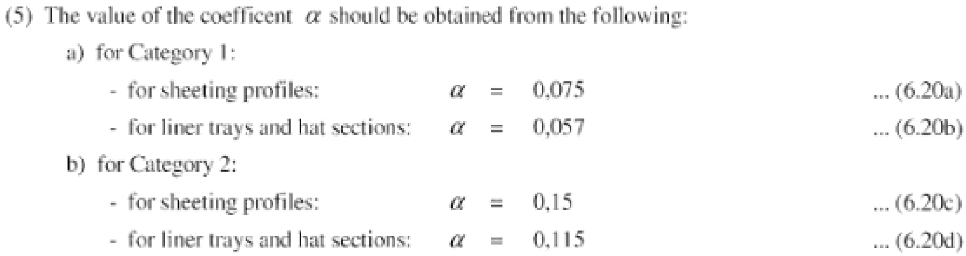
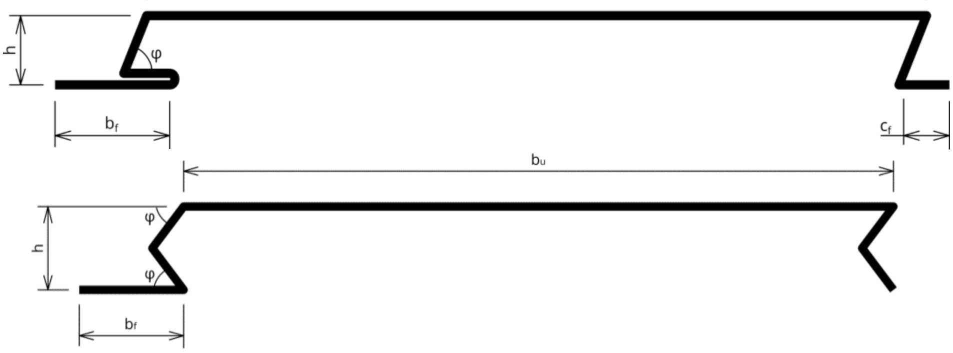
[10] CEN, EN 1993-1-1:2005 – Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings, Brussels, 2005.

[11] CEN, EN 1993-1-1:2005/A1:2014 – Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings – Amendment A1, Brussels, 2014.

[12] CEN, EN 1993-1-5:2006 – Eurocode 3: Design of steel structures – Part 1-5: General rules - Plated structural elements, Brussels, 2006.

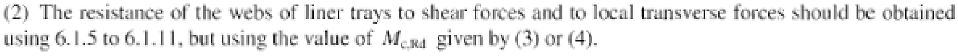
[13] CEN, EN 1993-1-5:2006/A1:2017 – Eurocode 3: Design of steel structures – Part 1-5: General rules - Plated structural elements – Amendment A1.

ANNEX: AMENDMENT PROJECT SUBMITTED TO CEN

AM–1-3–2013–60	
Subject	Plank profiles
Clause No. / Subclause No. / Annex	Clauses 6.1.7.3 (5), Section 10.2
Reason for amendment	The plank profiles are often used but the information is not provided in the EN 1993-1-3 as to the design rules for this type of profiles.
Proposed change	The current clause 6.1.7.3 (5) states:  (5) The value of the coefficent α should be obtained from the following: a) for Category 1: - for sheeting profiles: $\alpha = 0{,}075$ ... (6.20a) - for liner trays and hat sections: $\alpha = 0{,}057$ ... (6.20b) b) for Category 2: - for sheeting profiles: $\alpha = 0{,}15$ ... (6.20c) - for liner trays and hat sections: $\alpha = 0{,}115$ ... (6.20d) Replace the current clause with: (5) The value of the coefficient α should be obtained from the following: a) for Category 1 : – for sheeting profiles: $\alpha = 0{,}075$ ... (6.20a) – for liner trays and hat sections: $\alpha = 0{,}057$ ... (6.20b) – for plank profiles: $\alpha = 0{,}115$ ... (6.20c) b) for Category 2: – for sheeting profiles: $\alpha = 0{,}15$ ... (6.20d) – for liner trays and hat sections: $\alpha = 0{,}115$ ... (6.20e) – for plank profiles: $\alpha = 0{,}115$ ... (6.20f) The current title of the section 10.2 is : **10.2 Liner trays restrained by sheeting** Replace the current title with : **10.2 Liner trays restrained by sheeting and plank profiles** Add the following sentence and figure to the clause 10.2.1 (1): Plank profiles should be large channel type section with two webs and a flat wide flange. The joint between planks can be a clip one or chevron shaped as shown in figure 10.10.  Figure 10.10: Typical geometry for plank profiles

Renumber the remaining figures

The current clause 10.2.1 (2) states:



(2) The resistance of the webs of liner trays to shear forces and to local transverse forces should be obtained using 6.1.5 to 6.1.11, but using the value of $M_{c,Rd}$ given by (3) or (4).

Replace the clause 10.2.1 (2) with:

(2) The resistance of the webs of liner trays and plank profiles to shear forces and to local transverse forces should be obtained using 6.1.5 to 6.1.11, but using the value of $M_{c,Rd}$ given by (3) or (4).

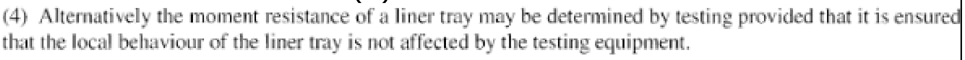
Add in the current clause 10.2.1 (3):

The moment resistance $M_{c,Rd}$ of a plank profile may be obtained using 10.2.2 provided that the geometrical properties are within the range given in table 10.7

Table 10.7: Range of validity for plank profiles

0,75 mm ≤	t_{nom}	≤ 1 mm
	b_f	≤ 40 mm
25 mm ≤	h	≤ 30 mm
	b_u	≤ 300mm
	φ	≤ 60°
11 mm ≤	c_f	

The current clause 10.2.1 (4) states:



(4) Alternatively the moment resistance of a liner tray may be determined by testing provided that it is ensured that the local behaviour of the liner tray is not affected by the testing equipment.

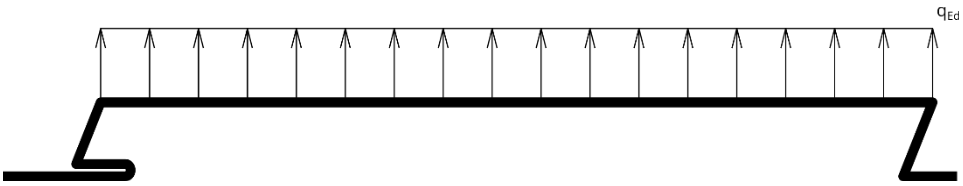
Change the clause 10.2.1 (4) with:

(2) Alternatively the moment resistance of a liner tray or plank profile may be determined by testing provided that it is ensured that the local behaviour of the liner tray or plank profile is not affected by the testing equipment.

Add the following new section :

10.2.3 Non dislocation of the joint for plank profiles

(1) Dislocation of the joints is a particular failure mode for plank profiles when solicited in suction



(2) To prevent the dislocation of the joint of plank profile, it must be verified :

$$q_{Ed}\ (\mathrm{kN/m^2}) \leq q_{Rd}\ (\mathrm{kN/m^2})$$

(3) The load resistance regarding joint dislocation of a plank profile is :

$$q_{Rd} = \frac{0{,}8 \cdot 2 \cdot E \cdot 1000 \cdot t^3 \cdot \delta_{\mathrm{lim}}}{b_u \cdot \left(12 \cdot (1-\nu^2) \cdot \sqrt{\left(\frac{2 \cdot {b_f}^3}{3}\right)^2 + \left[b_f \cdot \left(\frac{b_u \cdot h}{3} + \frac{h^2}{2}\right)\right]^2}\right)}$$

Where:

- For clip joint:

$$\delta_{\mathrm{lim}} = c_f$$

- For chevron shaped joint:

$$\delta_{\mathrm{lim}} = \frac{h}{2 \cdot \tan\varphi}$$

Background information	D4.5 – Background guidance for EN 1993-1-3 Proposal from M. Blanc, T. Renaux, and D. Izabel