Continuity of profiled steel sheets assembled on intermediate supports

Justification by calculations according to Eurocodes

Article

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SUMMARY

This article is part of the GRISPE PLUS project (valorisation), carried out following the GRISPE project (research). Both have been the subject of European RFCS subsidies and deal with 9 families of metal casing products. This article is devoted to one of the 9 product families, namely ribbed steel sheet (TAN) assemblies for flat roofing applications.

After a presentation of the context describing several engineering problems, an inventory of the solutions currently available within the normative corpus is drawn up.

The main results of the GRISPE project are presented along with the conditions for using a sizing method. This sizing method involves TANs assembled on a support in various configurations: single overlap, double overlap and continuous profile with local reinforcement on a support. These technologies induce a consequent contribution of additional resistance allowing, for example, to consider two isostatic profiles assembled as one and the same profile in continuity (case of single and double overlaps).

Calculation examples are presented in the last part to illustrate the application of this sizing method.

1 | CONTEXTUAL INTRODUCTION

The design, in accordance with the recommendations given by the Eurocodes, of profiled steel sheets covered by the product standard [1] and used for the realization of flat or low-slope roofs with insulation and waterproofing allows to deal with common cases. These cases correspond to a profiled steel sheet laid and fixed on several supports which has to resist, in particular, the application of uniformly distributed loads. The design of a roof grid made up of multi-bays with several profiled steel sheets is then divided into a succession of calculations, each of which consists of analysing the resistance of each profiled steel sheet and the continuity effect potentially induced by the overlapping of two successive profiled steel sheets on a support is thus not taken into account. The best strength configuration for profiled steel sheets, generally in hyperstatic installation on 3 supports, will therefore be preferred.

Roof and dome outlets, in increasing numbers respectively for smoke extraction and for natural lighting, inherent to the regulatory evolution in terms of fire safety and thermal perfromance, create discontinuities for the profile of applied loads which can be amplified by the combined effect of snow and wind. This situation is also typical on the edge of the roof in the presence of an acroterion. Moreover it can occur that, for diverse and varied reasons, these roof outlets or domes are added during the course of the construction site and therefore after the initial design of the structural grid and profiled steel sheets.

The engineer who carried out his calculation on the basis of a hyperstatic installation of a profiled steel sheet on 2 bays can thus be led frequently to modify the design. This is the case when the profiled steel sheet has to withstand an additional load in one of the two bays because it is located close to an acroterion or dome. This is also the case when this profiled steel sheet, initially designed on 2 bays, is in isostatic installation because a roof outlet is installed on the second bay. It is therefore not uncommon for the initial choice of profiled steel sheets to be questioned and that its strength has to be improved by increasing its thickness.

The standard [2] does not address the design of the continuity of a profiled steel sheet on support for in-situ configuration in the case of profiles transported in two different parts and then assembled on support in order to recreate a continuity of the profile by overlapping or in the case of solving a problem of excessive deflection between supports.

In order to provide the engineer with solutions to avoid an increase in thickness, the GRISPE and GRISPE PLUS projects were conducted. They make it possible to propose technological arrangements for assemblies of profiled steel sheets that lead to the optimisation of mechanical resistance. Design guides have been drafted and amendments have been proposed for consideration as part of the revision of Eurocode 3 Part 1-3 [2].

Figure 1 below shows the different practical solutions investigated.

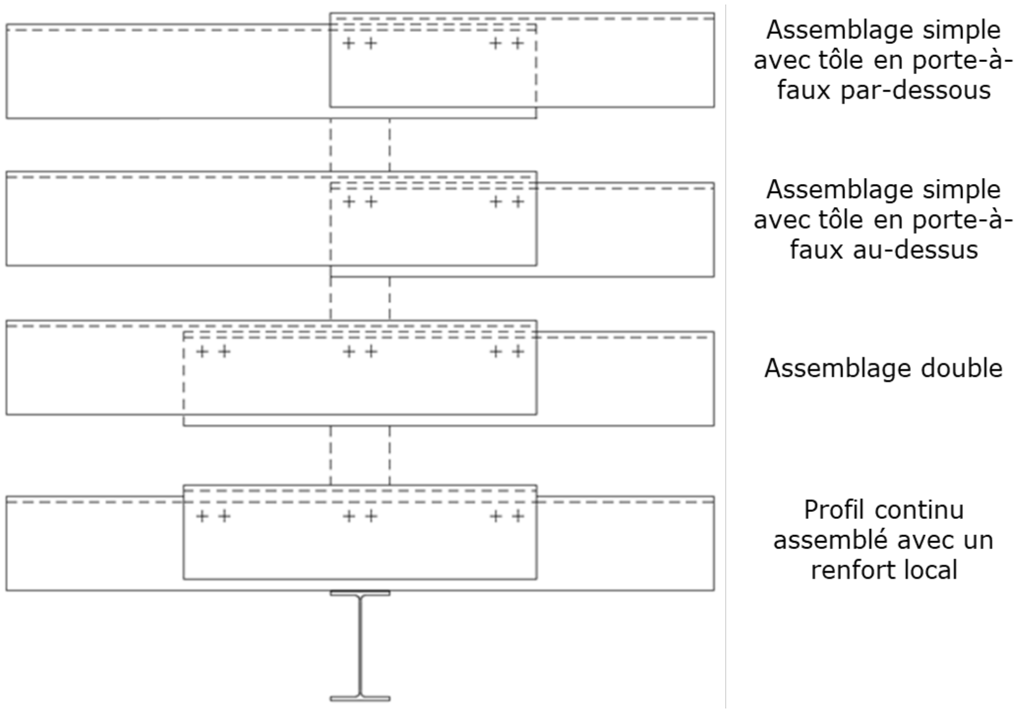

Figure 1 – Assemblies of profiled steel sheets on intermediate support

L'objectif principal du projet GRISPE PLUS est la promotion, la diffusion, la valorisation et l'utilisation pratique des conclusions et des résultats obtenus sur plusieurs familles de profils en acier étudiées dans le cadre du projet n°RFSR-CT-2013-0018 « Guidelines and Recommendations for Integrating Specific Profiled steel sheets in the Eurocodes » (GRISPE), financé partiellement par le RFCS. Le projet GRISPE PLUS a, quant à lui, reçu également un soutien financier du Fonds de Recherche du charbon et de l'acier (RFCS) de la Communauté Européenne au titre de la convention de subvention n°754092. Le projet GRISPE PLUS a été coordonné par l'Enveloppe métallique du bâtiment (EMB).

2 | NOTATIONS

j	Inclination of the rib web [3] [4] (degrees)
$\sum F_{V,Rd}$	Sum of the design shear resistances of the fasteners forming the connections in the webs [6] (kN)
a	Overlapping length [3] [4] (m)
a_{min}	Minimum overlapping length (m)
b	Range of width [2] (mm)
b_r	Pitch or rib spacing [3] [4] (m)
b_u	Width of the central support of the intermediate support test [5] [6] (mm)
d	Diameter of the holes [3] [4] (mm
h	Height of profiled sheet steel [2] (mm)
l ou L	Span, distance between supports [3] (m)
$l_{a,B}$	Width of the intermediate support [6] (mm)
p	Spacing of the fastners of the assembly [3] [4] (mm)
t	Design steel thickness [2] (mm)
F_{Ed}	Line force induced by the seam connection [6] (kN/m)
$F_{V,Rd}$	Design shear strength of a fastener [6] (kN)
K	Larger value of the two forces passing through connections 1 and 2 [3] [4] (kN)
K_i	Effort passing through connection i [3] [4] (kN)
K_1	Effort through connection 1 at the support [3] [4] (kN)
K_2	Effort through connection 2 at the connection end [3] [4] (kN
K_{Ed}	Maximum effective force through the connection [6] (kN)
L_v	Overall length of the test specimen [5] [6] (m)
$M_{I,Ed}$	Applied bending moment at the end of the overlap to the left of the support [6] (m. kN/m)
$M_{II,Ed}$	Applied bending moment at the end of the overlap to the right of the support [6] (m. kN/m)
M_B	Bending moment on supports [3] [4] (m.kN/m)
$M_{B,Ed}$	Applied bending moment at the intermediate support [6] (m. kN/m)
$M_{B,Rd}$	Design moment resistance at support [2] [6] (m. kN/m)
M_{Ed}	Applied moment on support [2] (m.kN/m)
$R_{B,Ed}$	Intermediate support reaction [6] (kN/m)

$R_{w,Rd,B}$	Design resistance to intermediate support reaction [6] (kN/m)
$R_{w,Rd,B,la=160}$	Design resistance to the reaction of a 160 mm wide intermediate support [6] (kN/m)
V_{Ed}	Applied shear force [2] (kN/m)
V_L	Vertical shear at support [3] [4] (kN/m)
$V_{L,Ed}$	Maximum applied shear force [6] (kN/m)
V_R	Shear force passing through the connection end [4] (kN/m)
$V_{w,Rd}$	Design shear resistance [2] [6] (kN/m)

3 I STATE OF THE ART OF STANDARDS

Standards [3] and [4] provide a solution for the overlapping of profiles which is only allowed for supports. In the overlapping area, the resistance thus obtained is that of a continuous profile.

The two simple assembly configurations are shown in Figures 2 and 3 below:

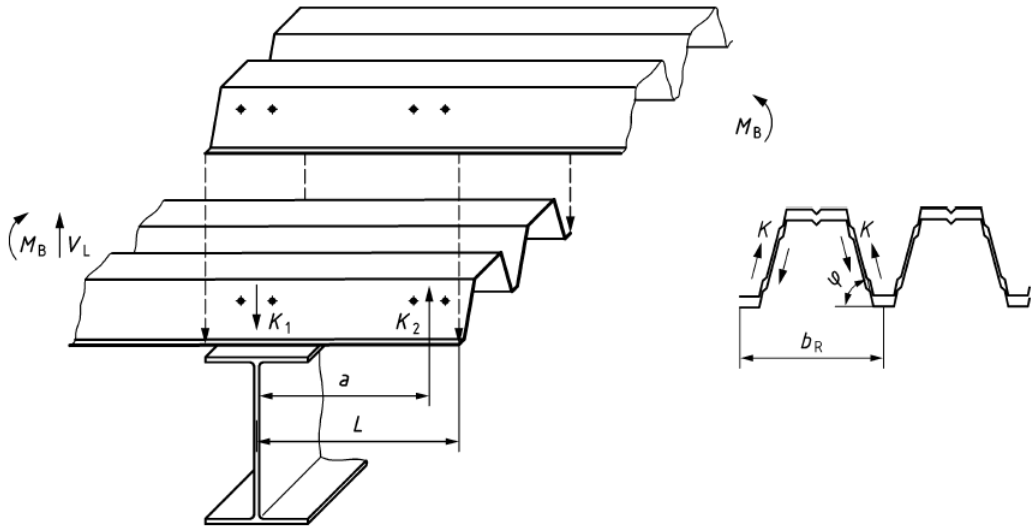

Figure 2 – Overlapped profiles in accordance with standard [4] and with the end of the profile cantilevered below

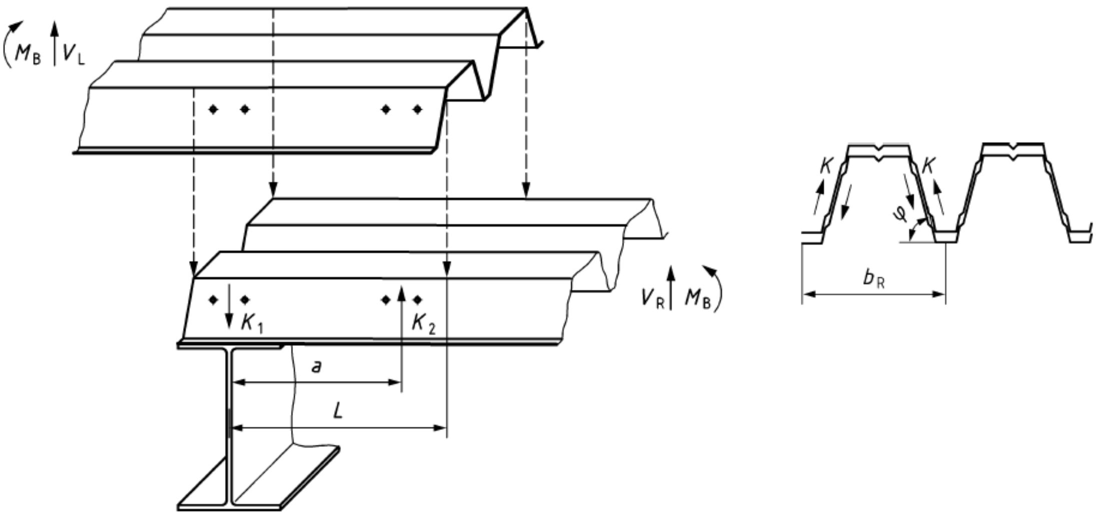

Figure 3 - Overlapped profiles in accordance with standard [4] with the end of the profile cantilevered above.

In both cases of assembly, 2 connections are made per rib web: connection 1 is located at the right of the support and connection 2 close to the end of the cantilever.

A maximum of 2 fasteners can be installed horizontally and vertically for each connection (maximum 4 fasteners). The required fastener edge and hole spacings, see figure 4 below, shall meet the following conditions:

- Hole spacing in the direction of the force: ≥ 3d and ≥ 20 mm;
- Horizontal edge spacing: ≥ 30 mm;
- Hole spacing p: ≥ 4d and ≥ 40 mm and ≤ 10d.

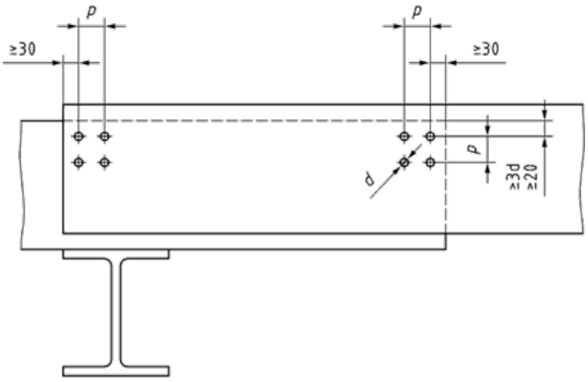

Figure 4 - Fastener layout according to standard [4] for efficient assembly.

In order for the assembly between profiled steel sheets to be fully efficient, the shear resistance of all the fasteners at each assembly, 4 fasteners in the case of Figure 4, must be greater than the force passing through it. The standard [3] requires the assemblies to be checked by considering the bigger value of the two forces K1 and K2 passing respectively through assemblies 1 and 2 of Figures 2 and 3

$$K_{Ed} = maxK_i = \frac{|M_{B,Ed}|}{2 * a * \sin\varphi} * b_R \qquad \text{(Figure 2)} \qquad (1)$$

Or :

$$K_{Ed} = maxK_i = \frac{\left|\frac{M_{B,Ed}}{a} + V_{L,Ed}\right|}{2 * \sin\varphi} * b_R \qquad \text{(Figure 3)} \qquad (2)$$

4 | MAIN RESULTS OF THE GRISPE PROJECT

To confirm the procedure described in the standard [3], a series of intermediate support tests, the principle of which is shown in Figure 6, were carried out on assemblies with single overlap. Additional tests, again according to figure 6, were carried out on assemblies with double overlap and on continuous profiles receiving local reinforcement at a support.
Two types of profiles (135/310 and 158/250), representative of the whole range with regard to the inclination of the ribs, were selected and supplied in 2 manufacturing thicknesses for the tests as shown in figure 5 below:

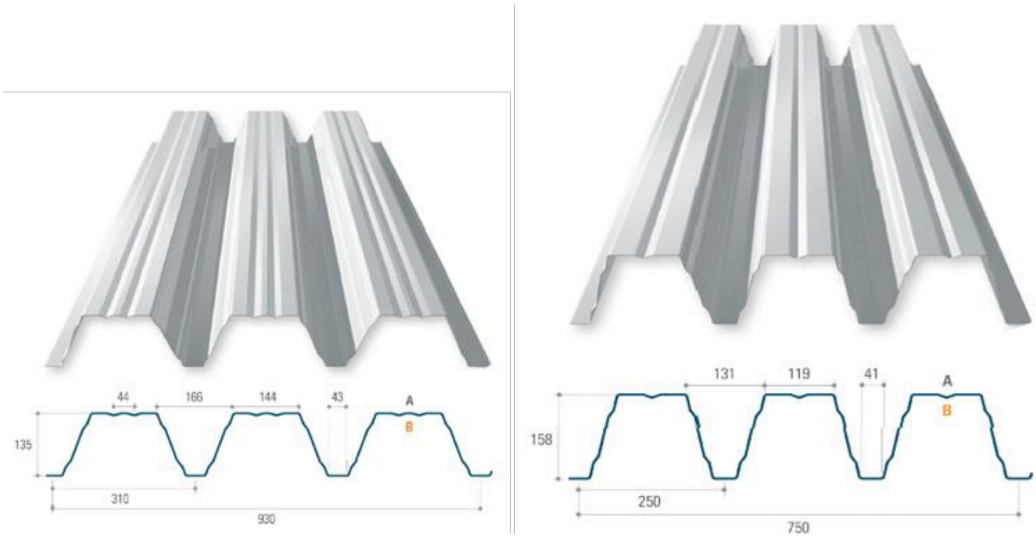

Figure 5 - Trapezoidal profiles tested.

In total, the campaign represents 128 tests in accordance with [2] to investigate the strength of several assembly configurations (Figures 6 and 7). Each configuration corresponds to a type of assembly (Figure 6), a type of profile (Figure 5), a profile thickness, an intermediate support width bu (Figure 6, 2 widths studied in the scope of GRISPE project) and a test span (2 in total). Each configuration is tested twice.

All these tests were accompanied by tensile tests on standard coupons. The tests carried out on the assemblies conforming to [3] were used to verify the design rules prescribed by the same standard [3], in particular concerning the fasteners. Tests carried out on simple unassembled continuous profiled steel sheets were used as reference cases.

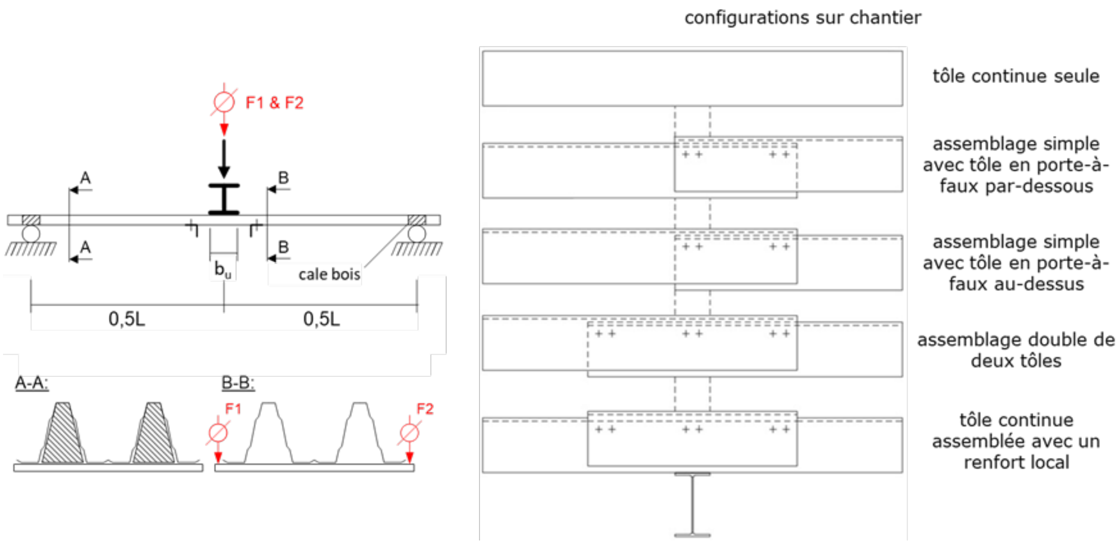

Figure 6 - Schematic principle of the intermediate support test

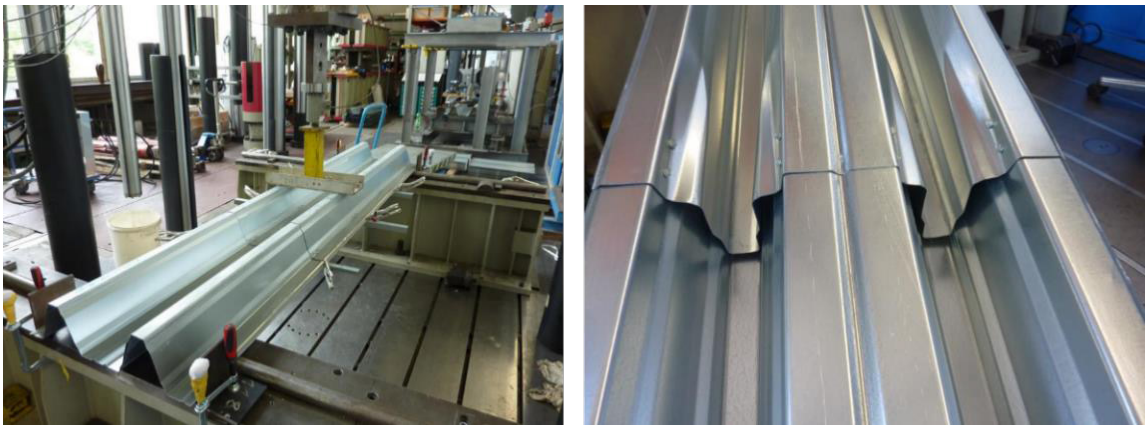

Figure 7 - Example of connection failure in an intermediate bearing test

The analysis and interpretation of the tests that were performed on the different assemblies were the subject of documents [5] and [6], and their comparison was based on interaction diagrams between the moment resistance (M) and the reaction resistance (R). These diagrams are drawn up in accordance with A.5.2.3 of Standard [2] and consist in plotting, for each tested span, the moment value (M) together with corresponding reaction value (R). The final result is a graph comprising as many points as there are tested spans. Figure A.8 of the standard [2] presents the case of tests with 3 spans, noting that GRISPE project was based on tests with 2 spans per studied configuration, the graph is presented in the form of Figure 8.

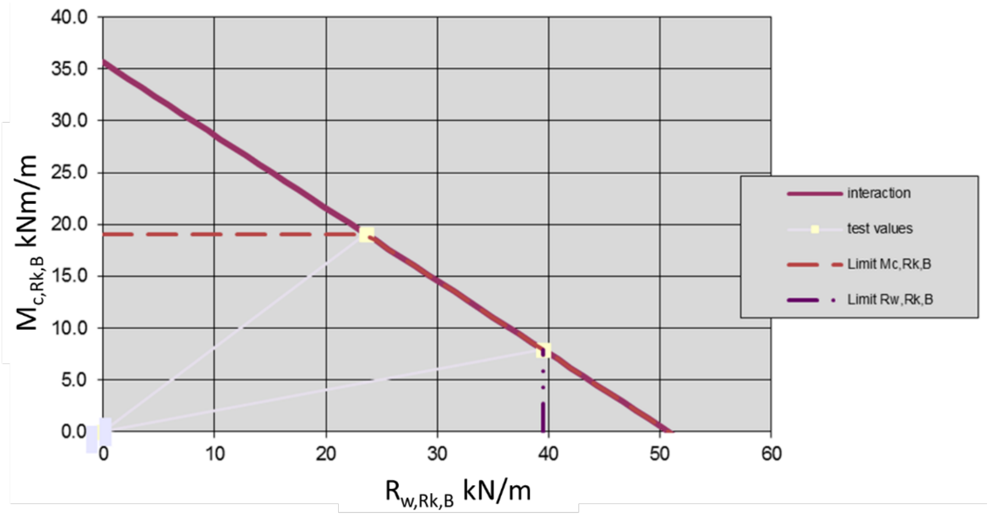

Figure 8 - Example of an interaction diagram obtained from 2 intermediate support tests.

The line of interaction, which passes through the two points associated with tested spans, makes it possible to determine the moment resistance on support and the reaction for any intermediate span. The maximum values of moment resistance and reaction resistance at support are illustrated by the horizontal segment« Limit $M_{c,Rk,B}$ » and the vertical segment« Limit $R_{w,Rk,B}$ » (Figure 8) which represent the maximum values of moment and resistance, respectively, obtained for a test couple.

Calculation methods have been provided in the framework of GRISPE project [6] for all types of assemblies, including a step of decomposition of the bending moment into two forces of equal intensity but of opposite direction; these forces being transmitted to the assemblies by the fasteners fixed in the webs and working in shear.

Indeed, the observations made during the test campaign revealed that the phenomenon governing profiled steel sheet assembly was a collapse due to shear.

Two other conclusions were drawn from GRISPE project:

- In the case of overlapping assembly on both sides of the support and the continuous profile with local reinforcement, the combination of the resistances of the two profiles does not correspond exactly to the algebraic addition of the whole but represents at most 1.8 x $M_{B,Rd}$ with $M_{B,Rd}$ the bending resistance of a profile;

- A specific failure mode may appear at the end of the assembly (see figure 7) when the overlapping length of the profiles is too short (a<L/10). It should therefore be ensured that half of the ultimate reaction resistance of the profile in an upside-down position ("negative" direction as opposed to the usual position of the profile in which it is laid), on an intermediate support with maximum permissible width, in general $l_{a,B}$ = 160 mm, is not less than the linear acting force passing at the end of the assembly (seam connection): 0,5 $R_{w,Rd,B} \geq F_{Ed}$.

5 | FOREWORD TO THE DESIGN METHOD

The design method described in the remainder of this paper provides only a means of determining the design resistances $M_{B'Rd}$ et $R_{w,Rd,B}$ of a profile assembly covered by Standard [1], in accordance with Standard [7], its amendment [8] and corrigendum [9]. Calculation values of the effects of actions shall be evaluated in accordance with each relevant part of Standard [10] and its corrigendum [11]; Standard [12], its corrigendum [13] and amendment [14]; Standard [15], its corrigendum [16] and amendment [17]. This method complies with the general rules provided in standard [18], its corrigendum [19] and amendment [20], and the design basis defined in part 2 of standard [2] and its corrigendum [21].

It should be noted that the national standards of some countries may be used in condition to follow the general design principles defined in [7].

This method is established in a field of minimum technological provisions, see paragraph 6, and does not deal with loading conditions from installation and maintenance. It is valid only if the tolerances of the cold-formed products comply with standard [2] and standard [21].

The following areas are not covered by the design method:

- the justification in case of fire, for which reference should be made to national regulations in accordance with [22] and [23];
- the justification for the seismic hazard for which reference should be made to national regulations in accordance with [24];
- the environmental aspects for which reference should be made to national regulations;
- the thermal performance for which reference should be made to national regulations in accordance with [25];
- and acoustics, for which reference should be made to national regulations.

As well as any other subject not clearly identified below.

The actions and their combinations shall be taken into account and determined in accordance with the standards :

- [8] and [9] for basis and combinations of actions,
- [10] and [11] for self-weights, uniform, central and other imposed actions,
- [12] to [14] for snow actions,
- [15] to [17] for wind actions.

6 | MINIMUM TECHNOLOGY PROVISIONS

The profiled steel sheets shall be placed on 3 or more supports with a minimum supporting width (support) of 60 mm, made of steel or wood. Direct contact of the profiled steel sheets with concrete is not allowed and any concrete support shall have a metal insert properly anchored in the concrete.

The profiled steel sheets shall have a constant nominal thickness, over their entire length, within allowed tolerances, and shall have a uniform cross-section along their length. The cross-sections of profiled steel sheets essentially comprise a number of flat elements assembled by rounding radii and their sizes meet the general requirements mentioned in Standard [2], section 1.5.3.

The provisions for design by calculation given here cannot be applied to a cross-section of which geometrical proportions are outside the width/thickness ratios b/t and h/t given in Figure 9 below, taken from Table 5.1 of the Standard [2].

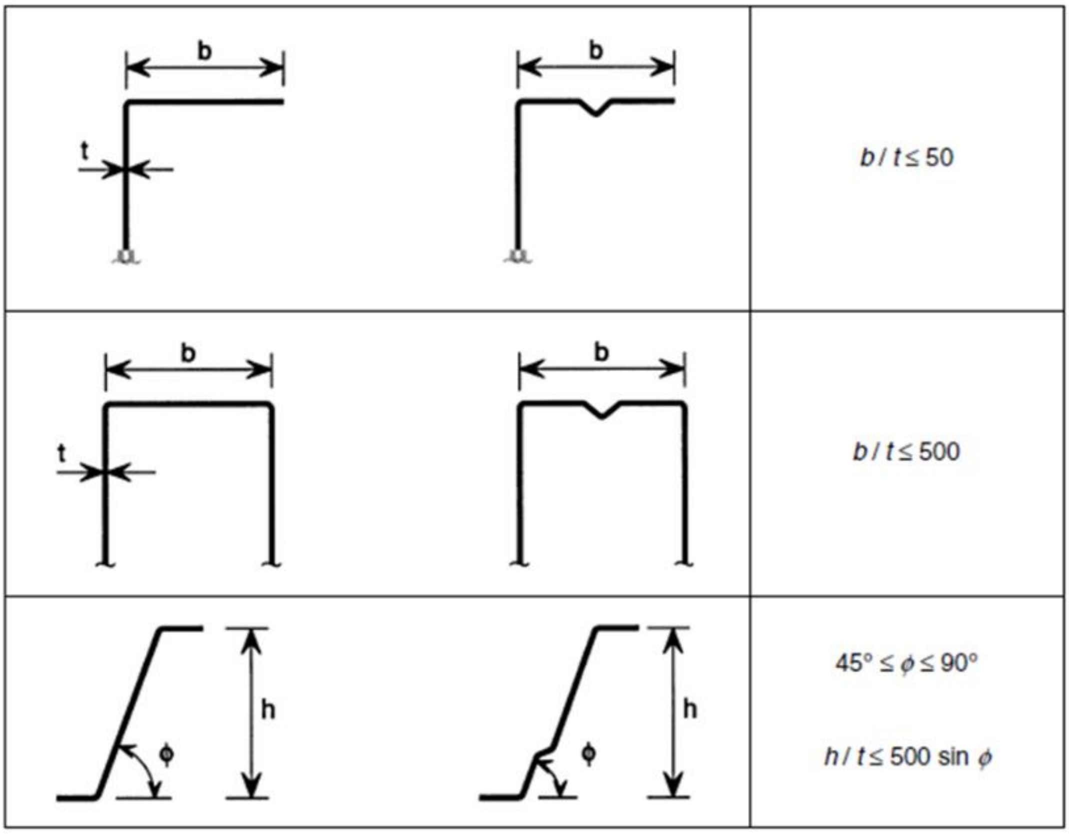

Figure 9 - Panel of geometric proportions.

The thickness t is the design steel thickness (thickness of black steel minus the tolerance, if necessary, as specified in clause 3.2.4 of Standard [2]), unless otherwise specified. The minimum nominal thickness is 0.75 mm.

The profiled steel sheets must not be perforated. Its cross-section is a profile of important height with stiffeners in the upper side (top) and in the web, see figure 10.

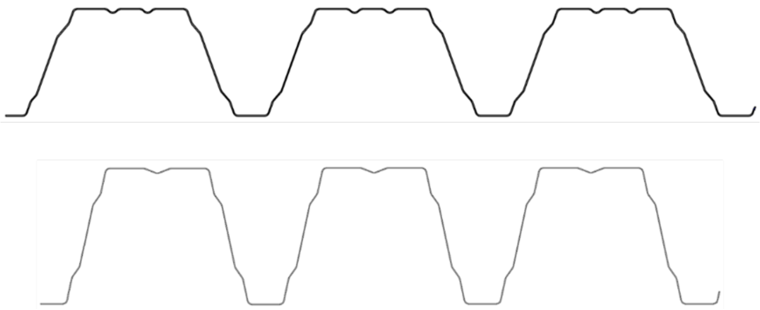

Figure 10 - Typical geometries of profiled steel sheets

The number and spacing of the fasteners are as described in paragraph 2 (see figure 4).

The recommended overlapping length "a" is L/10, where L is the distance between supports, with a minimum value a_{min} of 0.50 m.

Successive spans for which continuity is recreated by assembled profiled steel sheets may be equal or unequal.

The applied loads are distributed ones and the frame of the structure supporting the profiled steel sheets is made up of equal spans.

7 | BASIC TECHNOLOGICAL REQUIREMENTS AND MATERIAL REQUIREMENTS

The supports are in accordance with references [18] to [20] for steel or [26] to [29] for wood. Profiled steel sheets are CE-marked in accordance with standard [1] and their material properties shall meet the requirements of standard [2], section 3, with a minimum steel grade of S320 GD + Z. The material properties of the fasteners shall meet the requirements of Standard [2], Section 8. The partial factors of standard [2], section 2 shall be applied.

8 | BASIS OF DESIGN

This new calculation method is provided to:

- Determine the resistance of 4 types of assembly under combined bending moment and support reaction;
- check the assembly between two profiled steel sheets.

It is dedicated to assembled profiled steel sheets by overlapping just over intermediate supports according to one of the 4 solutions illustrated in Figure 1 [6].

The profiled steel sheets shall have the same design thickness and be assembled as shown in Figure 4.

A maximum of 4 fasteners, arranged in a square in each web, can be used at each joint to assemble the profiled steel sheets. Their implementation follows the requirements of standard [4] provided in paragraph 3.

9 | DESIGN PROCEDURE OF ASSEMBLIES

9.1 | PROFILED STEEL SHEETS ASSEMBLED WITH SIMPLE OVERLAPPING AND CANTILEVERED END OF PROFILE ON TOP

The procedure for designing profiled steel sheets assembled with single overlapping and cantilevered end of profile on top (see Figure 2) consists of 3 steps [6].

Step 1 – Verification of the strength of the assembly

The Verification of the resistance of the assembly in the support axis is conducted with the design resistance values ($M_{B,Rd}$ and $R_{w,Rd,B}$) of the continuous profile, in the same design thickness, taking into account the influence of support reaction (M-R-interaction) for downward loading or M-V interaction for uplift loading [6].

$M_{B,Rd}$ and $R_{w,Rd,B}$ can be determined by calculation in accordance with paragraphs 6.1.4 and 6.1.7 of Standard [2] and the M-R interaction according to paragraph 6.1.11 of the same Standard.

Thus, for downward loading, the verification should be down with:

$$\frac{M_{B,Ed}}{M_{B,Rd}} \leq 1{,}0\ ; \qquad (3)$$

$$\frac{R_{B,Ed}}{R_{w,Rd,B}} \leq 1{,}0\ ; \qquad (4)$$

$$\frac{M_{B,Ed}}{M_{B,Rd}} + \frac{R_{B,Ed}}{R_{w,Rd,B}} \leq 1{,}25. \qquad (5)$$

And for uplift loading:

$$\frac{M_{B,Ed}}{M_{B,Rd}} \leq 1,0\;; \tag{6}$$

$$\frac{V_{L,Ed}}{V_{w,Rd}} \leq 1,0\;; \tag{7}$$

$$\frac{M_{B,Ed}}{M_{B,Rd}} + \frac{V_{L,Ed}}{V_{w,Rd}} \leq 1,25. \tag{8}$$

Step 2 – Verification of web crippling

In the case of downward loading, the web crippling at the end of the cantilever shall be verified with:

$$F_{Ed} < F_{Rd} \tag{9a}$$

Where:

$$F_{Ed} = M_{B,Ed}/a \tag{9b}$$

And:

$$F_{Rd} = 0,5 \cdot R_{w,Rd,B} \tag{9c}$$

With: $R_{w,Rd,B}$ the ultimate support reaction at intermediate supports in the opposite profile position (in general negative position) for the maximum support width, in general, $l_{a,B}$ = 160 mm, given in kN.m/m; and $M_{B,Ed,}$ the applied bending moment at the intermediate support [6] (m. kN/m).

Taking account of the normal profile position defined in Figure 10, the opposite profile position is the position for which the biggest flange (top flange in Figure 10) is in contact with the support.

In the case of uplift loading, the web crippling is taken into account in Formulas 7 and 8.

Step 3 – Verification of the connection K_{Ed}

The verification, carried out in one web, can be done with:

$$\frac{K_{Ed}}{\sum F_{V,Rd}} \leq 1,0 \tag{10}$$

And:

$$K_{Ed} = \max K_i = \frac{\left|\left(M_{B,Ed}/a\right) + V_{L,Ed}\right|}{(2 \cdot \sin\varphi)} \cdot b_R \tag{11}$$

With: $\sum F_{V,Rd}$ the shear strength of all screws at each connection (4 screws in the case of Figure 4).

9.2 | Profiled steel sheets assembled with simple overlapping and cantilevered end of profile underneat

The procedure for designing profiled steel sheets assembled with simple overlapping and cantilevered end of profile underneath (see Figure 3) also consists of 3 steps [6].

Step 1 – Verification of the strength of the assembl

The verification of the strength of the assembly in the support axis is carried out on the basis of the design strength values ($M_{B,Rd}$ et $R_{w,Rd,B}$) of a continuous profile of the same design thickness, taking into account the influence of the support reaction (M-R interaction) in the case of downward loading and the M-V interaction in the case of uplift loading [6].

$M_{B,Rd}$ and $R_{w,Rd,B}$ can be determined by calculation in accordance with paragraphs 6.1.4 and 6.1.7 of Standard [2] and the M-R interaction according to paragraph 6.1.11 of the same Standard.

Thus, for downward loading, following verifications shall be conducted:

$$\frac{M_{B,Ed}}{M_{B,Rd}} \leq 1{,}0\ ; \tag{12}$$

$$\frac{R_{B,Ed}}{R_{w,Rd,B}} \leq 1{,}0\ ; \tag{13}$$

$$\frac{M_{B,Ed}}{M_{B,Rd}} + \frac{R_{B,Ed}}{R_{w,Rd,B}} \leq 1{,}25. \tag{14}$$

And for uplift loading:

$$\frac{M_{B,Ed}}{M_{B,Rd}} \leq 1{,}0\ ; \tag{15}$$

$$\frac{V_{L,Ed}}{V_{w,Rd}} \leq 1{,}0\ ; \tag{16}$$

$$\frac{M_{B,Ed}}{M_{B,Rd}} + \frac{V_{L,Ed}}{V_{w,Rd}} \leq 1{,}25. \tag{17}$$

Step 2 – Verification of web crippling

The verification of web crippling is taken into account in formulas 13 and 14 for downward loading and formulas 16 and 17 for uplift loading.

Step 3 – Verification of the shear connection K_{Ed}

The verification, carried out in one web, can be done with :

$$\frac{K_{Ed}}{\sum F_{V,Rd}} \leq 1{,}0 \tag{18}$$

And:

$$K_{Ed} = \max K_i = \frac{|M_{B,Ed}|}{(2 \cdot \mathrm{a} \cdot \sin\varphi)} \cdot b_R \tag{19}$$

With: $\sum F_{V,Rd}$ the shear strength of all screws at each connection (4 screws in the case of Figure 4).

9.3 | Profiled steel sheets assembled with double overlapping

The procedure for designing profiled steel sheets assembled with double overlapping consists of 5 steps [6].

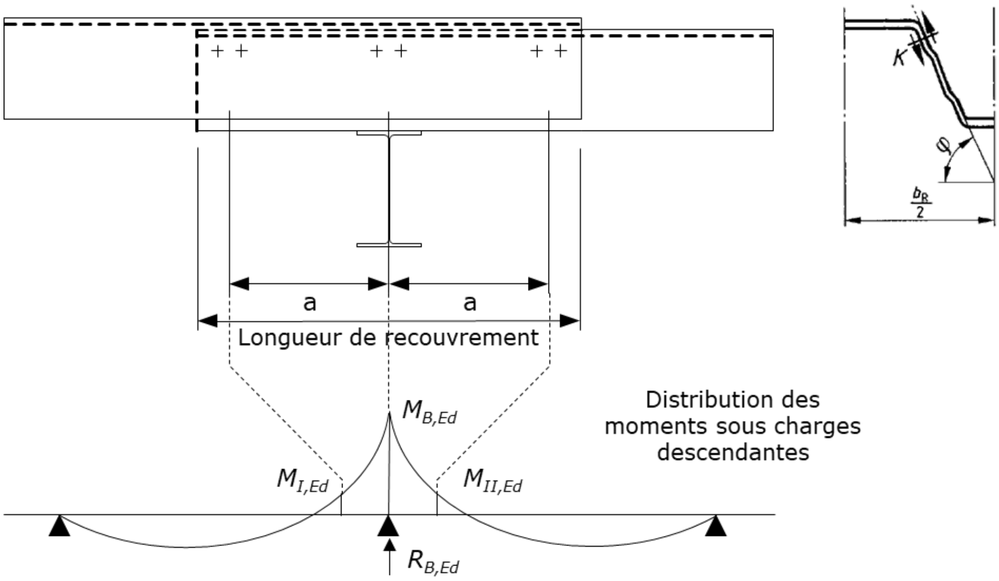

Figure 11 - Double recovery.

Step 1 – Preliminary considerationе

Bending moment distribution under design loads, as for continuous profiled steel sheets shall be determined in order to evaluate $M_{B,Ed}$, $M_{I,Ed}$, $M_{II,Ed}$ and $R_{Ed,B}$.

Step 2 – Verification of the strength of the assembly in support axis

The verification of the connection strength in support axis is carried out with 90% of the design strength values ($M_{B,Rd}$ and $R_{w,Rd,B}$) of each profile, in the same design thickness, as follows [6]:

$$M_{B,Ed} \leq 0{,}9 \cdot \sum M_{B,Rd} \; ; \tag{20}$$

$$R_{B,Ed} \leq 0{,}9 \cdot \sum R_{w,Rd,B} \, . \tag{21}$$

The M-R interaction according to paragraph 6.1.11. of standard [2] and the M-V interaction according to GRISPE project [6] should also be considered.

Thus, for downward loadings in addition to relations 20 and 21 above:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} \leq 1{,}25. \tag{22}$$

And for uplift loading:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} \leq 1{,}0 \; ; \tag{23}$$

$$\frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} \leq 1{,}0 \; ; \tag{24}$$

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} \leq 1{,}25. \tag{25}$$

Step 3 – Verification of the strength of the assembly at the ends of the overlap

This verification, of continuous profiles, is carried out with the bending moments $M_{I,Ed}$ or $M_{II,Ed}$ and the corresponding line loads induced by the connections K_i:

$$F_{Ed} = \frac{M_{B,Ed}}{2 \cdot a} \tag{26}$$

Line load F_{Ed} is determined for all load cases (downward and uplift)

In the case of downward loading, F_{Ed} acts as a tensile force in the webs of continuous profiles and the verification is conducted as follows

$$\frac{M_{I,Ed}}{M_{B,Rd}} \leq 1{,}0 \; ; \tag{27}$$

$$\frac{M_{II,Ed}}{M_{B,Rd}} \leq 1{,}0 \; ; \tag{28}$$

$$\frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}0 \; ; \tag{29}$$

and M-V interaction according to project GRISPE [6] at the ends of the overlap with:

$$\frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}25 \; ; \tag{30}$$

$$\frac{M_{II,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}25. \tag{31}$$

In the case of uplift loading, F_{Ed} acts as a compressive force in the webs of the continuous profiles and the verification is conducted as follows:

$$\frac{M_{I,Ed}}{M_{B,Rd}} \leq 1{,}0 \; ; \tag{32}$$

$$\frac{M_{II,Ed}}{M_{B,Rd}} \leq 1{,}0\,; \qquad (33)$$

$$\frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}0\,; \qquad (34)$$

and M-R interaction according to paragraph 6.1.11 of Standard [2] at the ends of the overlap with:

$$\frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}25\,; \qquad (35)$$

$$\frac{M_{II,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}25. \qquad (36)$$

For all of these load cases (verifications), the resistance values are those of profiles in the opposite position (negative) at intermediate supports.

Step 4 – Verification of web crippling

For downward loading, the web crippling at the ends of the cantilevers should be verified with:

$$F_{Ed} < F_{Rd} \qquad (37a)$$

Where:

$$F_{Ed} = M_{B,Ed}/a \qquad (37b)$$

And:

$$F_{Rd} = 0{,}5 \cdot R_{w,Rd,B} \qquad (37c)$$

With: $R_{w,Rd,B}$ the ultimate support reaction at intermediate supports in the opposite profile position (in general negative position) for the maximum support width, in general $l_{a,B}$ = 160 mm, expressed in kN.m/m; and $M_{B,Ed,}$ the applied bending moment at the intermediate support [6] (m. kN/m).

In the case of uplift loading, the web crippling is taken into account in Formulas (24) and (25).

Step 5 Verification of the connectionn K_{Ed}

The verification, carried out in one web, can be done with:

$$\frac{K_{Ed}}{\sum F_{V,Rd}} \leq 1{,}0 \qquad (38)$$

And:

$$K_{Ed} = \max K_i = \frac{|M_{B,Ed}|}{(4 \cdot \mathrm{a} \cdot \sin\varphi)} \cdot b_R \qquad (39)$$

With: $\sum F_{V,Rd}$ the shear strength of all screws at each connection (4 screws in the case of Figure 4).

The verification of the resistance shall be carried out for all load cases (downward and uplift).

9.4 | Continuous profile with local reinforcement

The procedure for dimensioning continuous profiled steel sheets with local reinforcement at intermediate support also consists of 5 steps [6].

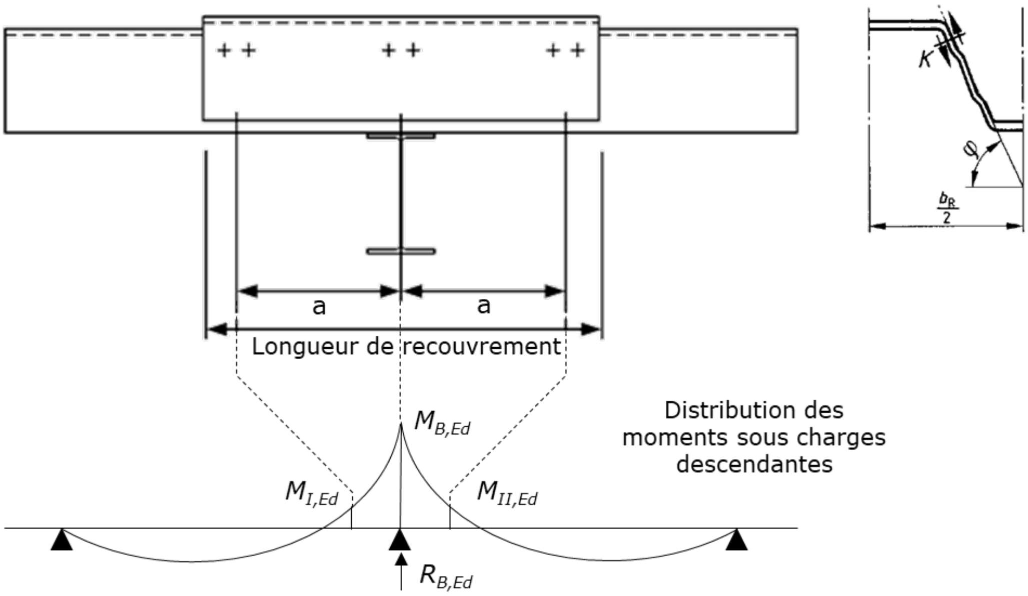

Figure 12 - Continuous profile with local reinforcement

Step 1 – Preliminary consideration

Bending moment distribution under design loads, as for continuous profiled steel sheets shall be determined in order to evaluate $M_{B,Ed}$, $M_{I,Ed}$, $M_{II,Ed}$ and $R_{Ed,B}$.

Step 2 – Verification of the strength of the assembly in support axis

The verification of the strength of the assembly in support axis is carried out with 90% of the design strength values ($M_{B,Rd}$ and $R_{w,Rd,B}$) of each profile, in the same design thickness, as follows [6]:

$$M_{B,Ed} \leq 0{,}9 \cdot \sum M_{B,Rd}\,; \tag{40}$$

$$R_{B,Ed} \leq 0{,}9 \cdot \sum R_{w,Rd,B}\,; \tag{41}$$

The M-R interaction according to paragraph 6.1.11. of standard [2] and the M-V interaction according to GRISPE project [6] should also be considered.

Thus, for downward loading, in addition to relations 40 and 41 above:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} \leq 1{,}25. \tag{42}$$

And for uplift loading:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} \leq 1{,}0\,; \tag{43}$$

$$\frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} \leq 1{,}0\,; \tag{44}$$

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} \leq 1{,}25. \tag{45}$$

Step 3 – Verification of the strength of the assembly at the ends of the overlap

This verification, of continuous profile, is carried out with the bending moments $M_{I,Ed}$ or $M_{II,Ed}$ and the corresponding line loads induced by the connections K_i:

$$F_{Ed} = \frac{M_{B,Ed}}{2 \cdot a} \tag{46}$$

Line load F_{Ed} is determined for all load cases (downward and uplift).

In the case of downward loading, F_{Ed} acts as a tensile force in the webs of continuous profiles and the verification is conducted as follows:

$$\frac{M_{I,Ed}}{M_{B,Rd}} \leq 1{,}0\,; \qquad (47)$$

$$\frac{M_{II,Ed}}{M_{B,Rd}} \leq 1{,}0; \qquad (48)$$

$$\frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}0; \qquad (49)$$

and M-V interaction according to GRISPE project [6] at the ends of the overlap with:

$$\frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}25\,; \qquad (50)$$

$$\frac{M_{II,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}25. \qquad (51)$$

In the case of uplift loading, F_{Ed} acts as a compressive stress in the webs of the continuous profiles and the verification is then conducted as follows:

$$\frac{M_{I,Ed}}{M_{B,Rd}} \leq 1{,}0\,; \qquad (52)$$

$$\frac{M_{II,Ed}}{M_{B,Rd}} \leq 1{,}0; \qquad (53)$$

$$\frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}0; \qquad (54)$$

and M-R interaction according to paragraph 6.1.11 of Standard [2] at the ends of the overlap with:

$$\frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}25\,; \qquad (55)$$

$$\frac{M_{II,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}25. \qquad (56)$$

For all of these load cases (verifications), the resistance values are those of profiles in the opposite position (negative) at intermediate supports.

Step 4 – Verification of web crippling

For downward loading, the web crippling at the ends of the cantilevers shall be checked by with:

$$F_{Ed} < F_{Rd} \qquad (57a)$$

Where:

$$F_{Ed} = M_{B,Ed}/a \qquad (57b)$$

And:

$$F_{Rd} = 0{,}5 \cdot R_{w,Rd,B} \qquad (57c)$$

With: $R_{w,Rd,B}$ the ultimate support reaction at intermediate supports in the opposite profile position (in general negative position) for the maximum support width, in general $l_{a,B}$ = 160 mm, expressed in kN.m/m; and $M_{B,Ed}$, the applied bending moment at the intermediate support [6] (m. kN/m).

In the case of uplift loading, the web crippling is taken into account in Formulas (44) and (45).

Step 5 – Verification of the connectionn K_{Ed}

The verification, carried out in one web, can be done with:

$$\frac{K_{Ed}}{\sum F_{V,Rd}} \leq 1{,}0 \qquad (58)$$

And:

$$K_{Ed} = \max K_i = \frac{|M_{B,Ed}|}{(4 \cdot \mathrm{a} \cdot \sin \varphi)} \cdot b_R \tag{59}$$

With: $\sum F_{V,Rd}$ the shear strength of all screws at each connection (4 screws in the case of Figure 4).

The verification of the connection shall be carried out for all load cases (downward and uplift).

10 | DESIGN EXAMPLES

10.1 | General

The two examples in this paper are taken from the design guides available at www.grispeplus.eu. The main steps are presented here and these guides should be consulted for details of the calculations.

These examples deal with insulated roofing processes of two buildings for which the steel supporting structure is made of IPE 330 hot rolled purlins (160 mm flange width) with a spacing of 5m45; and the verification of the assemblies located in zones H and I with reference to paragraph 7.2.3 of [15].

Both roofs consist of profiles steel sheets, mineral wool insulation and waterproofing. The total self-weight of the insulation and waterproofing g1 is 0.25 kN/m² in the case of Building 1 and 1.00 kN/m² in the case of Building 2 (presence of a heavy waterproofing complex).

The two 16 m high buildings are located in an industrial area near Ostend (Belgium) and both have an 80 cm high acroterion on the entire periphery of their roof.

The basic value of the reference wind speed $v_{b,0}$ is 26 m.s^{-1} and the terrain category is a category 0. The direction coefficient c_{dir} and the season coefficient c_{season} are considered to be 1, the same as the orography coefficient $c_0(z)$ and the turbulence factor k_l. For the air density r, the recommended value of [15] is applied, i.e. = 1.25 kg/m³.

Both buildings are located on a windswept site with a C_e of 0.8 according to [12] and a roof form factor for the snow load μ_i of 0.8.

Profiled steel sheet has a trapezoidal section 137-310-930 as follows:

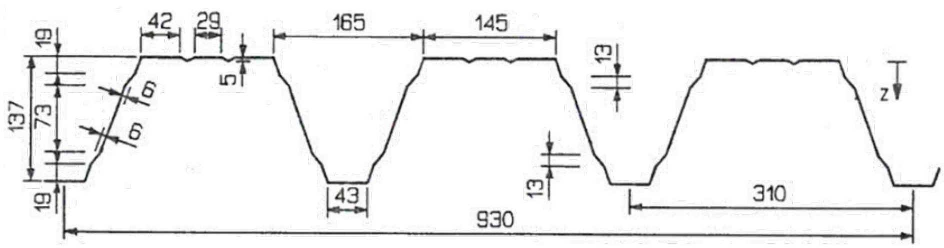

Figure 13 - profile 137-310-930 in positive position (normal position).

The pitch of the profile br is 310 mm. The web angle $\varphi = 66°$. The profile is made of steel grade S320 GD + Z 275 with a nominal thickness of 0.75 mm. Its self-weight g_0 is 0.097 kN/m².

The design resistance values of this profile are determined by calculation in accordance with [2], [21] and [31] to [33] and considering a partial factor γ_{m1} of 1.10:

- Design bending strength on support for the normal profile position under downward loading:
  $M_{B,Rd} = 8{,}17/1{,}1 = 7{,}42$ [kNm/m] ;
- Design bending strength on support and at the ends of the overlap for the opposite profile position under downward loading
  $M_{B,Rd} = 9{,}66/1{,}1 = 8{,}78$ [kNm/m] ;

- Design bending strength on support for the normal profile position under uplift loading:
  $M_{B,Rd} = 9{,}66/1{,}1 = 8{,}78$ [kNm/m] ;
- Design bending strength on support for the opposite profile position under uplift loading:
  $M_{B,Rd} = 8{,}30/1{,}1 = 7{,}54$ [kNm/m] ;
- Design resistance to the intermediate support reaction, for the normal profile position (160 mm support width):
  $R_{w,Rd,B} = 22{,}82/1{,}1 = 20{,}74$ [kN/m] ;
- Design resistance to the intermediate support reaction, for the opposite profile position (160 mm support width) :
  $R_{w,Rd,B,la=160} = 22{,}89/1{,}1 = 20{,}80$ [kN/m] ;
- Design shear strength:
  $V_{w,Rd} = 28{,}49/1{,}1 = 25{,}9$ [kN/m].

The fasteners comply with section 8 of [2] and are 6.3 mm diameter screws for which the design shear strength is in the scope of an ETA. The design shear strength of each screw, considering double steel thicknesses of 0.75mm, is $F_{V,Rd} = 0{,}875$ kN and consequently:

$\sum F_{V,Rd} = 3{,}50$ kN.

Each group of 4 screws is 30 mm away from the end of the overlap and from the top of the profiles and the distance between screw is 30 mm.

The roof of Building 1 is made of profiled steel sheets assembled by simple overlapping with cantilever alternately above and underneath. The overlap length (a) is 0.80 m. The roof of building 2 is divided into 2 zones: one made with profiled steel sheets assembled with double overlapping and the other with continuous profiled steel sheets with local reinforcement. The length of the overlaps is the same as above: a = 0.80 m.

These design examples do not deal with loads of high altitude. In the service phase, loads are inherent to the effects of wind and dead weight.

10.2 | Loading assumptions

The snow load is neglected in front of the other actions due to the characteristic value of snow on the ground at sea level of 0.2 kN/m² according to [12] and a combination factor Y_0 of 0.5 according to the Belgian National Annex of the standard [12].

In application of [15] to [17], the wind loads W_{50} are W_{50}^+ = 0.69 kN/m² under pressure and W_{50}- = - 1.24 kN/m² under depression.

In the case of Building 1, the most severe combination for the pressure effect in the sense of [8] [9] and the Belgian National Annex of [8] gives Q^+ = 1.50 kN/m². For depression, the most severe combination gives Q^-= -1.51 kN/m².

In the case of Building 2, the most severe combination for the pressure effect results in Q^+ = 2.51 kN/m². For depression, the most severe combination results in Q^-= -0.76 kN/m².

10.3 | Verification of assemblies of Building 1 – Example 1

10.3.1 | Loading conditions

It is considered a configuration of 2 equal bays of 5m45, with an uniformly distributed load.

For the wind pressure effect, the application of the combination of actions induces a moment applied on intermediate support:

$M_{B,Ed} = 5{,}57$ kNm/m ;

An intermediate support reaction of:

$R_{B,Ed} = 10{,}22$ kN/m

And a maximum shear force of:

$V_{L,Ed} = 5{,}11$ kN/m.

Under depression, the application of the combination of actions induces a moment applied on intermediate support:

$M_{B,Ed} = 5{,}61$ kNm/m ;

an intermediate support reaction of:

$R_{B,Ed} = 10{,}29$ kN/m

And a maximum shear force of:

$V_{L,Ed} = 5{,}14$ kN/m.

10.3.2 | Profiled steel sheets assembled with single overlapping and cantilevered end of profile on top

The 3 steps of the design procedure are detailed as follows

Step 1 – Verification of the strength of the assembly

For downward loading:

For the moment on intermediate support:

$$\frac{M_{B,Ed}}{M_{B,Rd}} = \frac{5{,}57}{7{,}42} = 0.751 < 1{,}0 \,;$$

For resistance on support:

$$\frac{R_{B,Ed}}{R_{w,Rd,B}} = \frac{10{,}22}{20{,}74} = 0.493 < 1{,}0 \,;$$

And for moment-support reaction interaction:

$$\frac{M_{B,Ed}}{M_{B,Rd}} + \frac{R_{B,Ed}}{R_{w,Rd,B}} = 1{,}244 < 1{,}25.$$

With uplift loading:

For the moment on intermediate support:

$$\frac{M_{B,Ed}}{M_{B,Rd}} = \frac{5{,}61}{8{,}78} = 0.638 < 1{,}0 \,;$$

For shear resistance:

$$\frac{V_{L,Ed}}{V_{w,Rd}} = \frac{5{,}14}{25{,}90} = 0.199 < 1{,}0 \,;$$

And for moment-vertical shear interaction:

$$\frac{M_{B,Ed}}{M_{B,Rd}} + \frac{V_{L,Ed}}{V_{w,Rd}} = 0{,}837 < 1{,}25.$$

Step 2 - Verification of web crippling

For uplift loading, verification of the web crippling is not required and for downward loading:

$$\frac{M_{B,Ed}}{(a \cdot 0{,}5 \cdot R_{w,Rd,B,la=160})} = \frac{5{,}57}{(0{,}8 \cdot 0{,}5 \cdot 20{,}80)} = 0{,}670 < 1{,}0.$$

Step 3 – Verification of the connection K_{Ed} :

$$K_{Ed} = \frac{|(5{,}57/0{,}8) + 5{,}11|}{(2 \cdot \sin(66°))} \cdot 0{,}31 = 2{,}05 \text{ kN and}$$

$$\frac{K_{Ed}}{\sum F_{V,Rd}} = \frac{2{,}05}{3{,}50} = 0{,}585 < 1{,}0$$

Note that 3 screws are enough to ensure the connection:

$$\frac{2{,}05}{(3 \cdot 0{,}875)} = 0{,}78 < 1$$

10.3.3 | Profiled steel sheets assembled with single overlapping and cantilevered end of profile underneath

The 3 steps of the design procedure are detailed as follows.

Step 1 – Verification of the strength of the assembly

For downward loading:

For the moment on intermediate support:

$$\frac{M_{B,Ed}}{M_{B,Rd}} = \frac{5{,}57}{7{,}42} = 0.751 \; < 1{,}0\;;$$

For resistance on support:

$$\frac{R_{B,Ed}}{R_{w,Rd,B}} = \frac{10{,}22}{20{,}74} = 0.493 < 1{,}0\;;$$

And for moment-support reaction interaction:

$$\frac{M_{B,Ed}}{M_{B,Rd}} + \frac{R_{B,Ed}}{R_{w,Rd,B}} = 1{,}244 \; < 1{,}25.$$

For uplift loading:

For the moment on intermediate support:

$$\frac{M_{B,Ed}}{M_{B,Rd}} = \frac{5{,}61}{8{,}78} = 0.638 < 1{,}0\;;$$

For the shear resistance:

And for moment-vertical shear interaction:

$$\frac{M_{B,Ed}}{M_{B,Rd}} + \frac{V_{L,Ed}}{V_{w,Rd}} = 0{,}837 \; < 1{,}25.$$

Step 2 – Verification of web cripplinge

For all load cases, no verification of the web crippling is required (see section 8.2).

Step 3 – Verification of the connection K_{Ed}:

$$K_{Ed} = \frac{|5{,}57|}{(2 \cdot 0{,}8 \cdot \sin(66°))} \cdot 0{,}31 = 1{,}18 \text{ kN et}$$

$$\frac{K_{Ed}}{\sum F_{V,Rd}} = \frac{1{,}18}{3{,}50} = 0.338 < 1{,}0$$

Once again, a smaller number of screws is enough to ensure the connection. With 2 screws:

$$\frac{1{,}18}{(2 \cdot 0{,}875)} = 0{,}67 < 1$$

10.4 | Verification of the assemblies of Building 2 – Example

10.4.1 | Loading conditions

It is considered a configuration of 2 equal bays of 5m45 with an uniformly distributed load.

For the wind pressure effect, the application of the combination of actions induces a moment applied on intermediate support:

$M_{B,Ed} = 9{,}33$ kNm/m ;

an intermediate supportg reaction of:

$R_{B,Ed} = 17{,}12$ kN/m ;

a maximum shear force of:

$V_{L,Ed} = 8{,}56$ kN/m

And a moment applied at the ends of the overlap of 3.29 kNm/m ($M_{I,Ed} = M_{II,Ed}$).

Under depression, the application of the combination of actions induces a moment applied on intermediate support:

$M_{B,Ed} = 2{,}82$ kNm/m ;

an intermediate supporting reaction of:

$R_{B,Ed} = 5{,}18$ kN/m ;

a maximum shear force of

$V_{L,Ed} = 2{,}59$ kN/m

and a moment applied at the ends of overlap of 0.99 kNm/m ($M_{I,Ed} = M_{II,Ed}$).

10.4.2 | Profiled steel sheets assembled with double overlapping

The 5 steps of the design procedure are detailed as follows.

Step 1 – Preliminary consideration

See paragraph 9.3 and 10.4.1

Step 2 – Verification of the strength of the assembly in support axis

For downward loading:

For the moment on intermediate support:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} = \frac{9{,}33}{0{,}9 \cdot 2 \cdot 7{,}42} = 0{,}699 < 1{,}0 ;$$

For resistance on support:

$$\frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} = \frac{17{,}12}{0{,}9 \cdot 2 \cdot 20{,}74} = 0{,}459 < 1{,}0 ;$$

And for moment-support reaction interaction:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} = 1{,}158 < 1{,}25.$$

For uplift loading:

For the moment on intermediate support:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} = \frac{2{,}82}{0{,}9 \cdot 2 \cdot 8{,}78} = 0{,}178 < 1{,}0 ;$$

For the shear resistance:

$$\frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} = \frac{2{,}59}{0{,}9 \cdot 2 \cdot 25{,}90} = 0{,}056 < 1{,}0;$$

And for the moment-vertical shear interaction:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} = 0{,}234 < 1{,}25.$$

Step 3 – Verification of the strength of the assembly at the ends of the overlap:

For downward loading, the line force is:

$$F_{Ed} = \frac{M_{B,Ed}}{2 \cdot a} = \frac{9{,}33}{2 \cdot 0{,}8} = 5{,}83 \text{ kN/m},$$

and the verification is conducted as follows:

$$\frac{M_{I,Ed}}{M_{B,Rd}} = \frac{M_{II,Ed}}{M_{B,Rd}} = \frac{3{,}29}{7{,}54} = 0{,}436 < 1{,}0\,;$$

$$\frac{F_{Ed}}{V_{w,Rd}} = \frac{5{,}83}{25{,}90} = 0{,}225 < 1{,}0$$

and $\frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} = 0{,}599 < 1{,}25.$

For uplift loading, the line force is:

$$F_{Ed} = \frac{M_{B,Ed}}{2 \cdot a} = \frac{2{,}82}{2 \cdot 0{,}8} = 1{,}76 \quad \text{kN/m}$$

And the verification is conducted as follows:

$$\frac{M_{I,Ed}}{M_{B,Rd}} = \frac{M_{II,Ed}}{M_{B,Rd}} = \frac{0{,}99}{8{,}78} = 0{,}113 < 1{,}0\,;$$

$$\frac{F_{Ed}}{R_{w,Rd,B}} = \frac{1{,}76}{20{,}80} = 0{,}085 < 1{,}0$$

and $\frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} = 0{,}198 < 1{,}25.$

Step 4 – Verification of web crippling:

In the case of uplift loading, the verification of web crippling is not required and for downward loading:

$$\frac{M_{B,Ed}}{(2 \cdot a \cdot 0{,}5 \cdot R_{w,Rd,B,la=160})} = \frac{9{,}33}{(2 \cdot 0{,}8 \cdot 0{,}5 \cdot 20{,}80)} = 0{,}561 < 1{,}0$$

Step 5 – Verification of the connection K_{Ed} :

For downward loading:

$$K_{Ed} = \frac{9{,}33}{(4 \cdot 0{,}8 \cdot \sin(66))} \cdot 0{,}31 = 0{,}99 \text{ kN}$$

and $\frac{K_{Ed}}{\sum F_{V,Rd}} = \frac{0{,}99}{3{,}50} = 0{,}283 < 1{,}0$

For uplift loading:

$$K_{Ed} = \frac{2{,}82}{(4 \cdot 0{,}8 \cdot \sin(66))} \cdot 0{,}31 = 0{,}30 \text{ kN}$$

and $\frac{K_{Ed}}{\sum F_{V.Rd}} = \frac{0{,}30}{3{,}50} = 0{,}085 < 1{,}0$

At this stage of the calculation, 2 screws are enough to ensure the connection:

$0{,}99/(2 \cdot 0{,}875) = 0{,}566 < 1\,;$

And if the overlap length is increased to 0.95 m then only 1 screw is sufficient to ensure the connection since K_{Ed} is reduced to 0.83. Thus, the overconsumption of 2x0.15 m of profiled steel sheets is counterbalanced by a 50% saving on the number of screws to be implemented (and the time involved).

10.4.3 | Continuous profile with local reinforcement

The 5 steps of the sizing procedure are detailed as follows.

Step 1 - Precondition:

see paragraph 9.4 and 10.4.1

Step 2 - Checking the strength of the assembly in support axis:

For downward loading:

For the moment on intermediate support:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} = \frac{9{,}33}{0{,}9 \cdot 2 \cdot 7{,}42} = 0{,}699 < 1{,}0\,;$$

for resistance on support:

$$\frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} = \frac{17{,}12}{0{,}9 \cdot 2 \cdot 20{,}74} = 0{,}459 < 1{,}0\,;$$

And for moment-support reaction interaction:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} = 1{,}158 < 1{,}25.$$

For uplift loading:

For the moment on intermediate support:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} = \frac{2{,}82}{0{,}9 \cdot 2 \cdot 8{,}78} = 0{,}178 < 1{,}0\,;$$

For the shear resistance:

$$\frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} = \frac{2{,}59}{0{,}9 \cdot 2 \cdot 25{,}90} = 0{,}056 < 1{,}0\,;$$

And for the moment-vertical shear interaction:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} = 0{,}234 < 1{,}25.$$

Step 3 – Verification of the strength of the assembly at the ends of the overlap:

For downward loading, the line force is:

$$F_{Ed} = \frac{M_{B,Ed}}{2 \cdot a} = \frac{9{,}33}{2 \cdot 0{,}8} = 5{,}83 \text{ kN}$$

and the verification is conducted as follows:

$$\frac{M_{I,Ed}}{M_{B,Rd}} = \frac{M_{II,Ed}}{M_{B,Rd}} = \frac{3{,}29}{7{,}54} = 0{,}436 < 1{,}0\,;$$

$$\frac{F_{Ed}}{V_{w,Rd}} = \frac{5{,}83}{25{,}90} = 0{,}225 < 1{,}0\,;$$

and $\frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} = 0{,}661 < 1{,}25.$

For uplift loading, the line force is:

$$F_{Ed} = \frac{M_{B,Ed}}{2 \cdot a} = \frac{2{,}82}{2 \cdot 0{,}8} = 1{,}76 \text{ kN/m}$$

And the verification is conducted as follows:

$$\frac{M_{I,Ed}}{M_{B,Rd}} = \frac{M_{II,Ed}}{M_{B,Ed}} = \frac{0{,}99}{8{,}78} = 0{,}113 < 1\,;$$

$$\frac{F_{Ed}}{R_{w,Rd,B}} = \frac{1{,}76}{20{,}80} = 0{,}085 < 1{,}0\,;$$

and $\frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} = 0{,}198 < 1{,}25$.

Step 4 – Verification of web crippling:

In the case of uplift loading, the verification of web crippling is not necessary and for downward loading:

$$\frac{M_{B,Ed}}{(2 \cdot a \cdot 0{,}5 \cdot R_{w,Rd,B,la=160})} = 0{,}561 < 1{,}0$$

Step 5 – Verification of the connection K_{Ed} :

For downward loading:

$$K_{Ed} = \frac{9{,}33}{(4 \cdot 0{,}8 \cdot \sin(66))} \cdot 0{,}31 = 0{,}99 \text{ kN}$$

and $\frac{K_{Ed}}{\sum F_{V,Rd}} = 0{,}283 < 1{,}0$.

For uplift loading:

$$K_{Ed} = \frac{2{,}82}{(4 \cdot 0{,}8 \cdot \sin(66))} \cdot 0{,}31 = 0{,}30 \text{ kN}$$

and $\frac{K_{Ed}}{\sum F_{V,Rd}} = 0{,}085 < 1{,}0$.

Note that for downward loading, 2 screws can ensure the connection and that only one screw is required for uplift loading.

10.5 | Calculation software tool

A dedicated Excel program is available on the GRISPE project website (www.grispeplus.eu).

11 | CONCLUSION AND PERSPECTIVE

The methods presented in detail in this paper allow the design of construction solutions of profiled steel sheets, so far not referenced in Eurocodes, which aim at recreating or reinforcing the continuity of a profiled steel sheet by means of a support assembly. The proposed types of assemblies have a single profiled steel sheet overlap on one side of the support, or a double overlap on both sides of the support.

The assembly of two statically determinate profiled steel sheets with simple overlapping leads to the recreation of continuity on support. The double overlapping of statically determinate profiled steel sheets and continuous profiled steel sheet with local reinforcement provide an additional benefit on the continuity behaviour which then leads to a resistance corresponding to 80% of the algebraic sum of the resistances of the assembled products. In addition to the respect of the verifications to be carried out and the installation of the fastening devices, the attention of the engineer in charge of the design of these connections has to also focus on the lengths of overlaps that inhibit the collapse due to the shearing force at the end of the assembly.

The interaction between bending moment on support and support reaction can lead to the collapse by web crippling. In general, this failure mode is characteristic of a support reaction in the form of a compressive force in the webs.

Concerning the verifications on the interaction between bending moment and shear force, the verification procedure of this paper could have been based on clause 6.1.10 of [2], which suggests a relation $V_{Ed}/V_{Rd} \leq 0{,}5$ which, if satisfied, exempt from applying equation 6.27 of [2]. However, if this relationship is not satisfied, the application of equation 6.27 becomes difficult because the values of the plastic moment resistance are not known. A safe solution is then to simplify equation 6.27 by reducing it to: $M_{Ed}/M_{B,Rd} + (2 \cdot V_{Ed}/V_{w,Rd} - 1)^2 \leq 1$.

It should be noted that the characteristic values for bending, shear and support reaction of profiled steel sheets can be determined by means of tests in accordance with [2], established by third parties and included in the manufacturer's technical data sheets.

In some countries, such as Germany, experimental characterization allows for the establishment of an M-R interaction formula that may be linear or parabolic depending on the test results and thus may differ from the equation provided in clause 6.1.11 of [2]. This procedure then forms part of a global approach to characterize a profiled steel sheet, including the application of clause 6.1.10 mentioned above, and which is thus the subject of declared, verified and usable characteristic values for the design of the profiled steel sheets on the basis of the interaction formulae and recommendations mentioned on the technical data sheet.

The design method of the continuity with overlapping of profiled steel sheets provided in this paper is of great interest for roofing applications. However, in France, apart from collaborative steel formworks and cladding products covered by the RAGE [30] rules, the profiled steel sheets dedicated to roofs are not yet the subject of technical recommendations for obtaining "Eurocode" characteristic values, either experimentally or by calculation. Such type of documents would make it possible to complete the set of tools and solutions for any engineer in charge of the design of steel roofs and facing practical problems inherent to the building site in the case where, in accordance with the market request, Eurocodes apply for both of action and resistance parts.

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