GRISPE

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

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

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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 embossments (Fig. 1) or indentations (Fig.2) on the webs, or outwards stiffeners (Fig.3) on the edge.

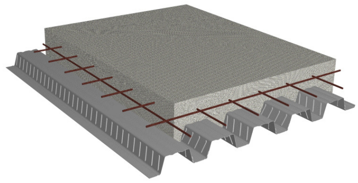


Fig. 1 - Indentations in a composite slab

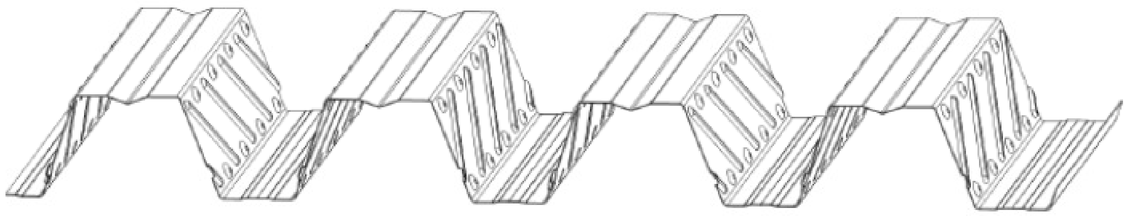


Fig. 2 - PCB 80 deck from BACACIER SAS, with embossments and indentations

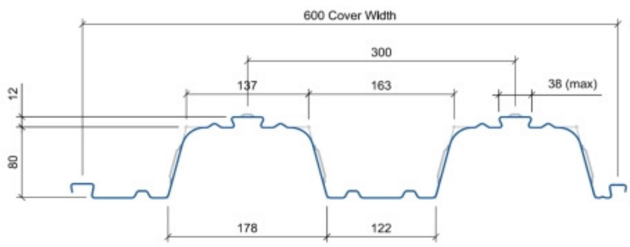


Fig. 3 - TR80 deck from SMD

At the composite stage the behavior of composite slabs with embossments has been determined by numerous studies [1] to [7], embossments increase for the composite steel-concrete slab shear connection, moment capacity, mid-span deflections and end slips.

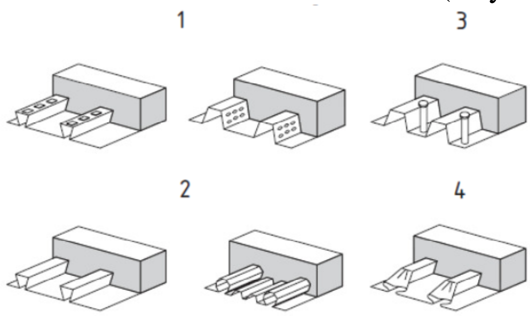
At the construction stage the sheeting used as shuttering has to support the fresh concrete weight and the construction loads, and in this case the effect of the embossments and indentations is not favorable. Unfortunately the European Standard EN 1993-1-3 dealing with design rules for cold-formed members and sheeting doesn't cover profiles with embossments, indentations or outwards stiffeners. Moreover the existing studies and researches on this type of profile don't allow to quantify precisely by calculation the effect of embossment and indentations on the steel deck resistance and stiffness and to analyse the bending resistance of sheeting with outwards stiffener in the upper flange. A study performed by P. Luure and M. Crisinel [8] shows an influence of about 10% on the resistance and on the stiffness. J. M. Davies [9] found in his finite element analysis a decrease of 8 to 10% of the bending strength for dimples in top flange, for dimples in the webs the decrease of bending strength was less important, about 3%. Unfortunately both studies don't take into account the effect of combined action of support reaction and negative moment whereas the interactive resistance M–F would be lower from the resistance of pure bending M_R or contact pure pressure F_R, as it could be shown for corrugated sheets by A. Biegus [10].

The aim of this document is to give a state of the art of the current European Standard EN and of the background information about steel decks with embossments, indentations and outwards stiffeners, and to emphasize the lack of data and knowledge.

2. EUROCODE

2.1. EN 1994-1-1

The profiled steel sheet with embossments and indentations are within the scope of the European standard EN 1994-1-1 for design of composite steel and concrete structures, as in the Part 9.1.2.1, embossments and indentations are defined as mechanical interlocks (Key 1 in Fig.4).



Key

1 mechanical interlock

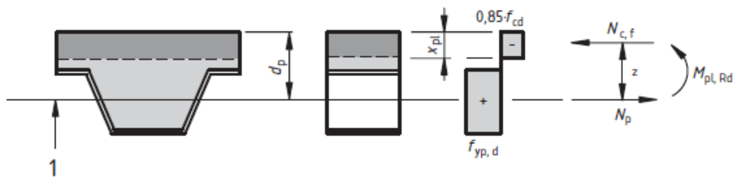
2 frictional interlock

3 end anchorage by through-deck welded studs

4 end anchorage by deformation of the ribs

Fig. 4 - Typical forms of interlock in composite slabs

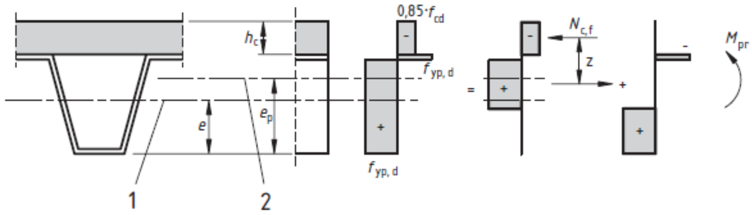
The methods of verifications of composite slabs for the ultimate states are determined in part 9.7. In case of flexure the standard specifies:
- in part 9.7.2 (3) that for the effective area of the steel sheeting, the width of embossments and indentations in the sheet should be neglected, unless it is shown by tests that a larger area is effective
- in part 9.7.2 (5) and 9.7.2 (6) the stress distribution to calculate the sagging bending resistance of a cross-section with a neutral axis above the sheeting (Fig.5) and with a neutral axis in the sheeting (Fig. 6).



Key

1 centroidal axis of the profiled steel sheeting

Fig. 5 - Stress distribution for sagging bending if the neutral axis is above the steel sheeting



Key

1 centroidal axis of the profiled steel sheeting

2 plastic neutral axis of the profiled steel sheeting

Fig. 6 - Stress distribution for sagging bending if the neutral axis is in the steel sheeting.

- in part9.7.2 (7) the stress distribution to calculate the hogging bending resistance of a cross-section if the contribution of the steel sheeting is neglected (Fig. 7).

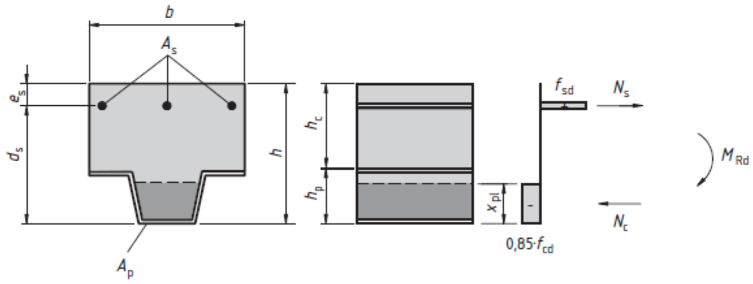


Fig. 7 - Stress distribution for hogging bending

The part 9.7.3 of this standard determines longitudinal shear for composite slabs without and anchorage and part 9.7.4 with end anchorage.

In several parts EN 1994-1-1 specifies that the steel sheeting alone, should be designed (part 9.4.1), verified for ultimate limit states (part 9.5. (1)) and for serviceability limit states (part 9.8), and determined (part 9.6. (1)) in accordance with EN 1993-1-3, but EN 1993-1-3 doesn't provide any information about design and verification of profiles with indentations, embossments or outwards stiffeners.

2.2. EN 1993-1-3

The European standard EN 1993-1-3 gives, for cold-formed members and sheeting, methods for design by calculation and for design assisted by testing. The design by calculation apply only within stated ranges of material properties and geometrical proportions for which sufficient experience and test evidence is available. These limitations do not apply to design assisted by testing. Examples of cross-sections for cold-formed members and sheets covered by EN 1993-1-3 are illustrated in figure 8 (part 1.5.1).

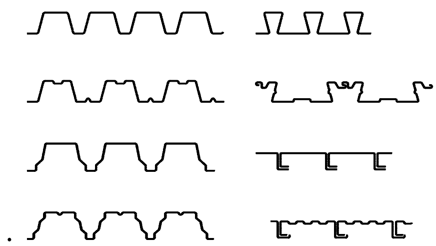
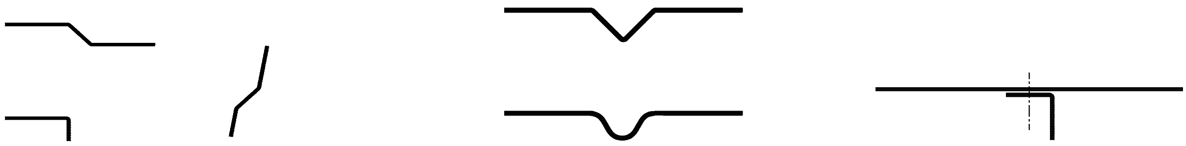


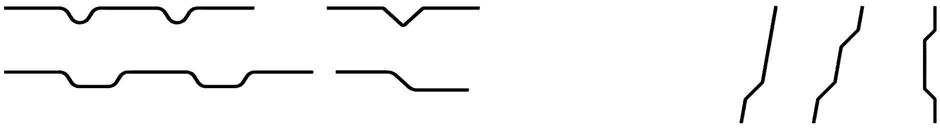
Fig. 8 - Examples of cold-formed members and profiled sheets

It is written in part 1.5.1. (5) that cross-sections of cold-formed members and sheets may either be unstiffened or incorporate longitudinal stiffeners in their webs or flanges, or in both. Unfortunately the form of stiffeners defined in part 1.5.2 don't include indentations, embossments, outwards stiffeners (Fig.9 and Fig. 10), in the flange only inwards stiffeners are defined.



Folds and bends — Folded groove and curved groove — Bolted angle stiffener

Fig. 9 - Typical forms of stiffeners for cold-formed members and sheeting



Intermediate flange stiffeners — Intermediate web stiffeners

Fig. 10 - Typical intermediate longitudinal stiffeners

To design a steel sheeting <u>two criteria of verification must be determined</u>, resistance at ultimate limit states and flexion stiffness at serviceability limit states. EN 1993-1-3 provides the methodology to determine those criteria for steel sheeting only with typical stiffeners.

First, effective section properties must be calculated. Buckling of plane elements and flexural buckling of a stiffener reduce resistance therefore an effective width of the element (Fig. 11) and a reduced thickness of the stiffener must be determined in accordance with part 5.5.

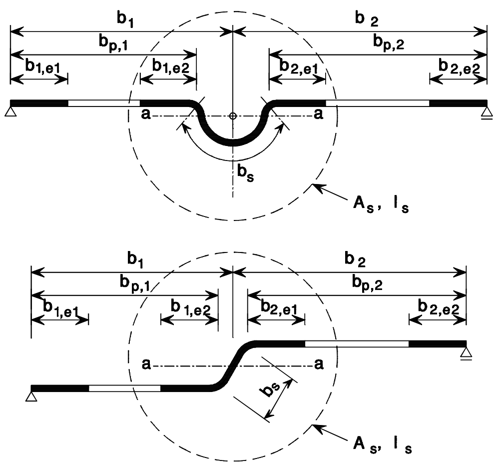


Figure 11 - Intermediate stiffeners

In the case of sheeting with intermediate stiffeners in the flanges and in the webs (Fig. 12), interaction between the flexural buckling of the flange stiffeners and the web stiffeners must be taken into account (part 5.5.3.4.4).

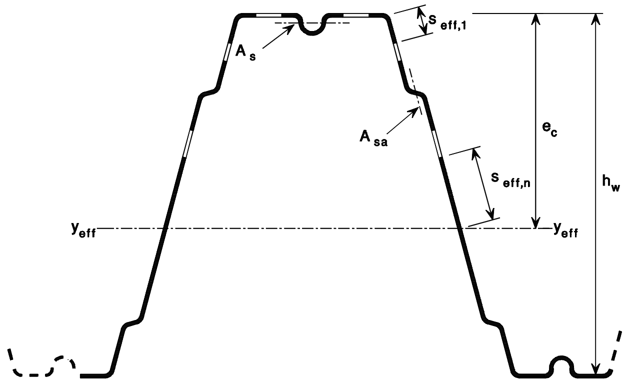


Figure 12 - Trapezoidal profiled sheeting with flange stiffeners and web stiffeners

Next, resistance of cross-sections at ultimate limit states must be calculated. Resistance to axial tension, to axial compression (Fig. 13), to bending moment (Fig. 14), to shear force, to torsional moment, local transverse forces (Fig. 15) and to combined forces and moments must be determined with the effective cross-section.

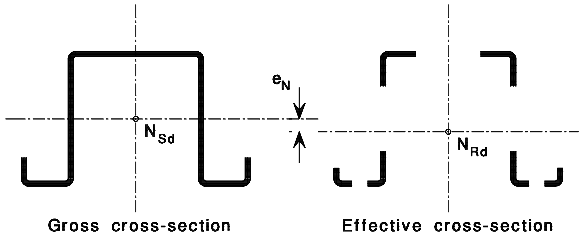


Figure - 13 Effective cross-section under compression

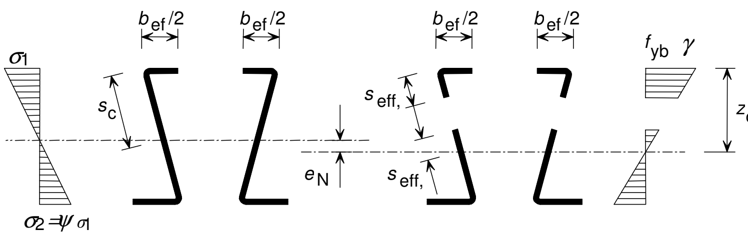


Figure 14 - Effective cross-section for resistance to bending moments

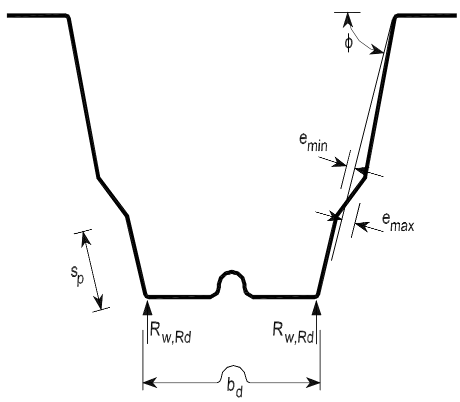


Figure 15 - Stiffened webs for local transverse forces

At least flexion stiffness at serviceability limit states must be calculated in accordance with part 7. All serviceability limit state calculations must use the properties of the effective cross-section obtained from Section 5.1, as in the expression of moment of area :

$$I_{\text{fic}} = I_{\text{gr}} - \frac{\sigma_{\text{gr}}}{\sigma}(I_{\text{gr}} - I(\sigma)_{\text{eff}}) \qquad \ldots (7.1)$$

where

I_{gr} is second moment of area of the gross cross-section;

σ_{gr} is maximum compressive bending stress in the serviceability limit state, based on the gross cross-section (positive in formula);

$I(\sigma)_{\text{eff}}$ is the second moment of area of the effective cross-section with allowance for local buckling calculated for a maximum stress $\sigma \geq \sigma_{\text{gr}}$, in which the maximum stress is the largest absolute value of stresses within the calculation length considered.

Therefore calculation of the deflection also takes into account the effective cross-section.

As we see above, the criteria of verification of a steel sheeting must take into account the effective cross-section which is impacted by the web and flange stiffeners, therefore the absence of indentations, embossments and outwards stiffeners in the standard EN 1993-1-3 is a real lack to correctly determine and verify the resistance of a steel sheeting for composite slabs by calculation approach. And this lack is even more disturbing and serious as several previous studies have shown that the effect of embossments unfavorable to certain criteria as bending resistance. In the next chapter we will focus on studies performed on sheeting with indentations, embossments and outwards stiffeners.

3. STATE OF THE ART

The review of the existing published and on-going works allowed to find few studies on steel sheeting with embossments and indentations and no study on sheeting with outwards stiffeners.

Two finite element analysis of the effect of embossment in the structural behavior of the steel deck profile strength and stiffness were reported.

The first one [11], made by O. T. BAIAO FILHO, presents the effect of the embossments in a profile element when subjected to axial load and to bending moment. A model (Fig. 16) of a trapezoidal deck profile having 0.316 in. thickness is considered. Its structural behavior, in axial tension and bending is approximately the same as the real deck's.

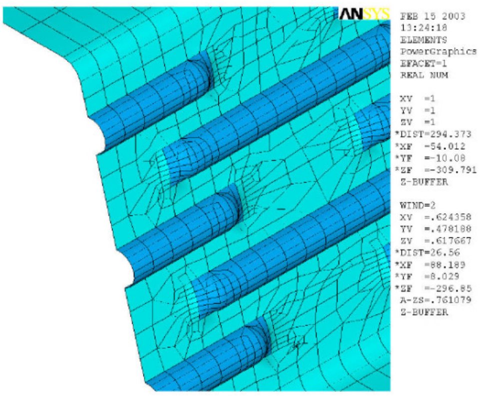


Figure 16 - Embossment model

A comparison between deck without and with embossments is presented for axial tension (Fig. 17) and for bending moment (Fig. 18)

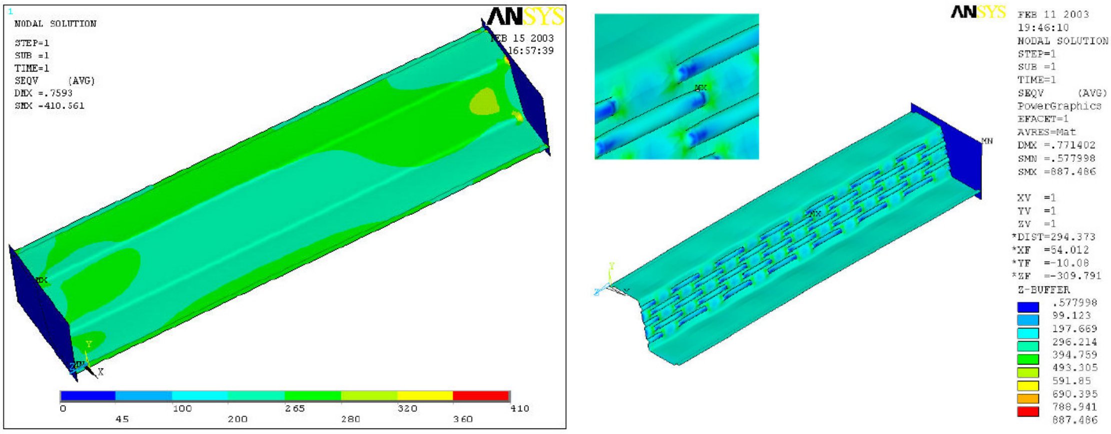


Figure 17 - Models without and with embossments subject to axial tension force - SEQV

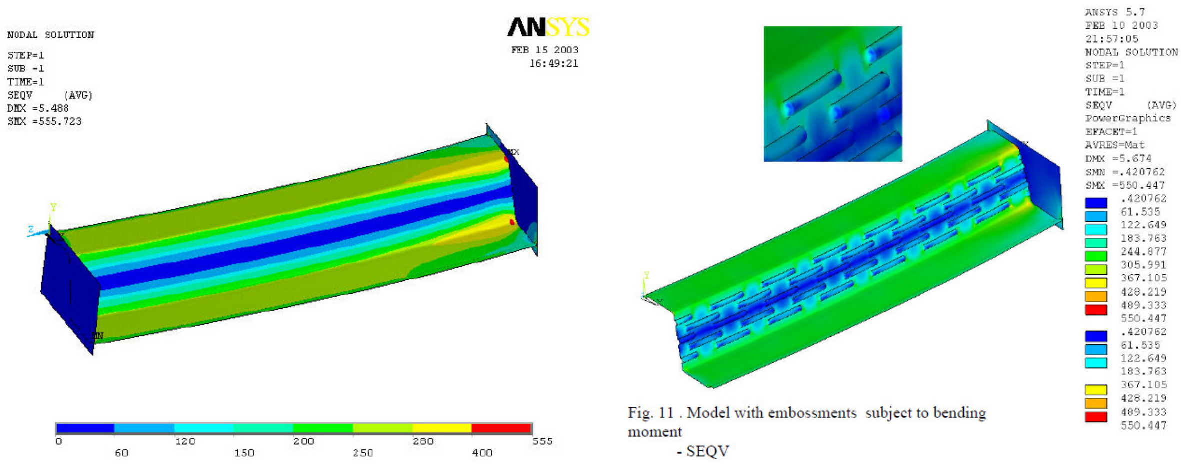


Figure 18 - Models without and with embossments subject to bending moment - SEQV

The author finds that the maximum perpendicular displacement to the model axis is 0.216 in. for the flat plate model and 0.223 in. for the model with embossments (difference of about 3.4%). He concludes that the presence of embossments have a very small effect in the structural behavior of the model, when subject to a bending moment, and that making embossments causes only a small loss in the steel deck profile stiffness, nevertheless he doesn't specify if it concerns moment of inertia, bending or shear resistance. These analyses are rather approximate and the validation must be done with the full-scale test results.

<u>The reviewer notes</u>:

- The small impact of the embossment is predictable, because of relatively small part of cross section impacted by the embossment.

- The effect of combined action of support reaction and negative moment was not studied in this paper

- No global conclusion can be drawn because only one type of profile and one type of embossments was analyzed

The second finite element analysis [12] made by E. S. Mistakidis, K.G. Dimitriadis, presents the contribution of the embossed areas of the steel sheeting to the total strength in pure tension and in pure bending. It is based on three-dimensional models of the steel sheeting (Fig. 19)

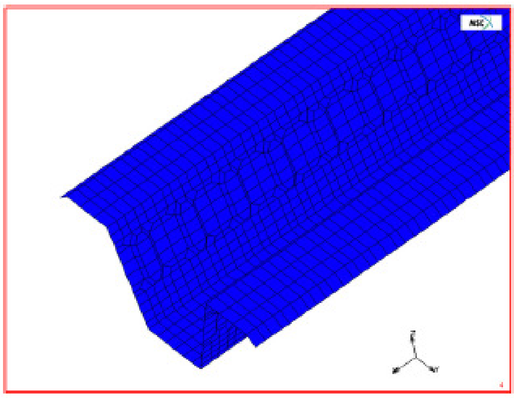


Figure 19 - Details of the F.E. discretization of the embossments

Two series of analyses were performed, with the steel profile subjected to pure tension and to pure bending. The studied trapezoidal profile was SYMDECK 73. A parametric analysis was performed in order to study the effect of the depth of the embossments or the indentations to the strength and the stiffness of the steel sheeting, four different depth were used (0.5, 1.0, 1.5, 2.5 mm). The MARC FE code was used.

In pure tension for the different depth of embossment a diagram was given of the percentage of the area of the full cross-section that is active for every value of the strain (Fig. 20). Based on these results the following formula is proposed of the axial strength of the steel profile with embossments in terms of an "effective thickness" of the region of the cross -section that corresponds to the positions of embossments:

$$N_{Rd} = A_{p,eff}\frac{f_{yp}}{\gamma_{ap}} = \left(A_{net} + A_{emb}\frac{t_{eff,N}}{t}\right)\frac{f_{yp}}{\gamma_{ap}}, \qquad (2)$$

where $A_{p,eff}$ is the effective cross-sectional area of the steel profile in tension, $A_{p,emb}$ the cross-sectional area of the steel profile that corresponds to the region of the embossments, $A_{p,net}$ the cross-sectional area of the steel profile excluding the region of the embossments, i.e. $A_{p,net} = A_{p,full} - A_{p,emb}$, where $A_{p,full}$ is the full cross-sectional area of the steel profile, f_{yp} the yield strength of the profile steel sheeting, and γ_{ap} the partial safety factor for the profile steel sheeting.

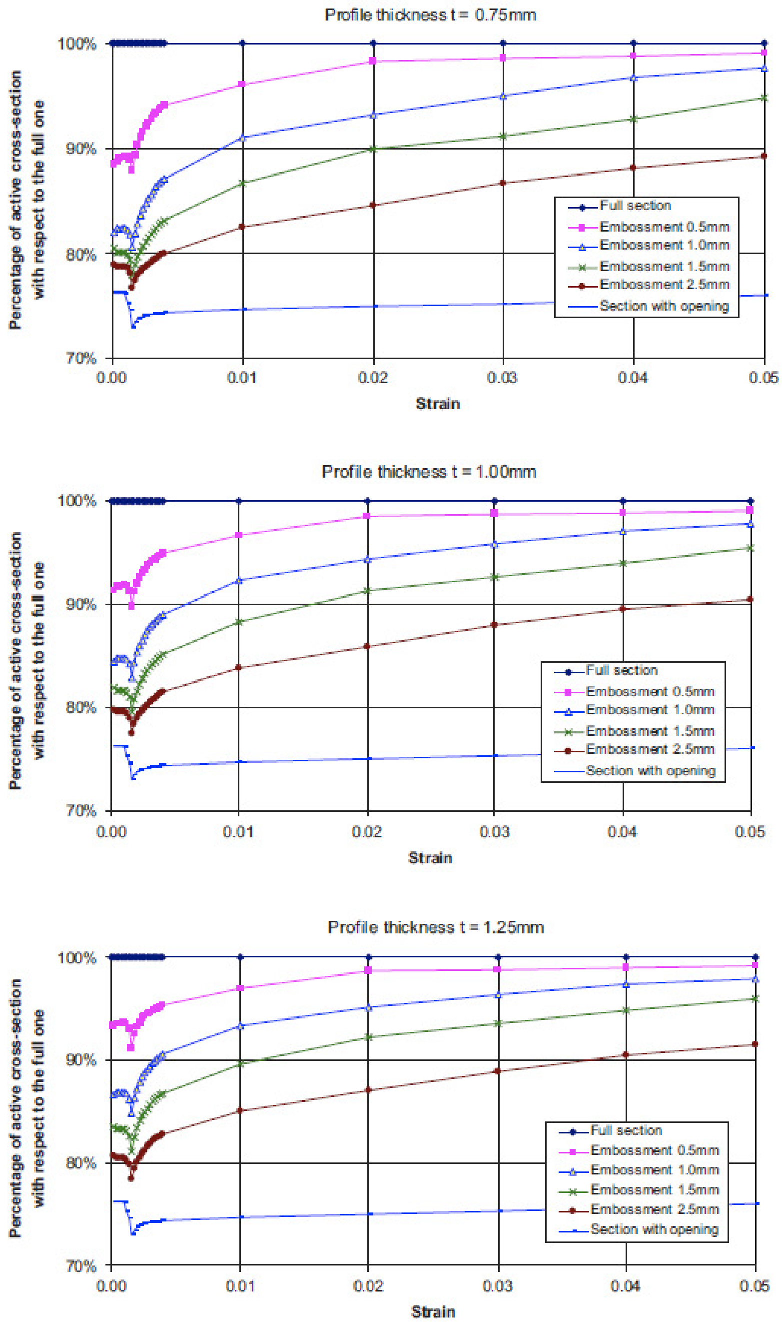


Figure 20 - Percentage of active cross-section (with respect to the full one) - strain diagram

In pure bending tension for the different depth of embossment a diagram was given of bending strength ratio (with respect to full section) for various embossment depths (Fig. 21).

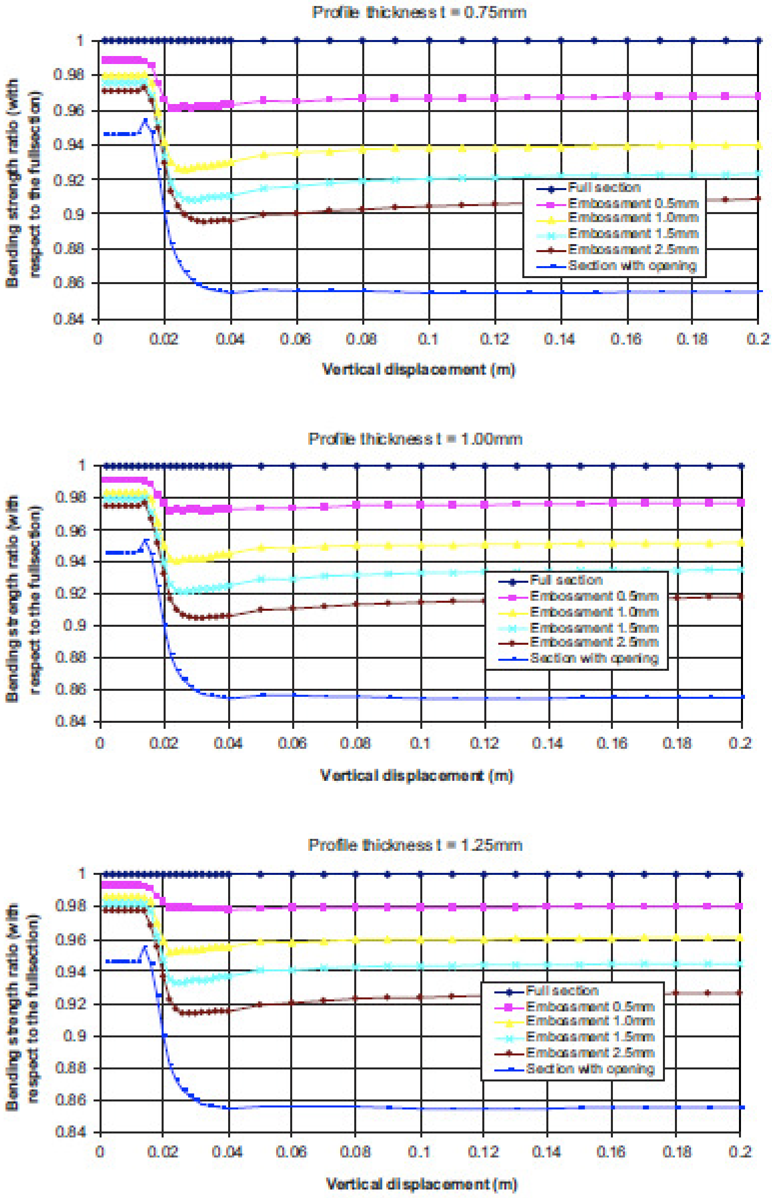


Figure 21 - Bending strength ratio (with respect to full section) for various embossment depths

The effective thickness was calculated as a function of the depth of the embossment, in the elastic range, on the left of Figure 22 and in the plastic range on the right of Figure 22.

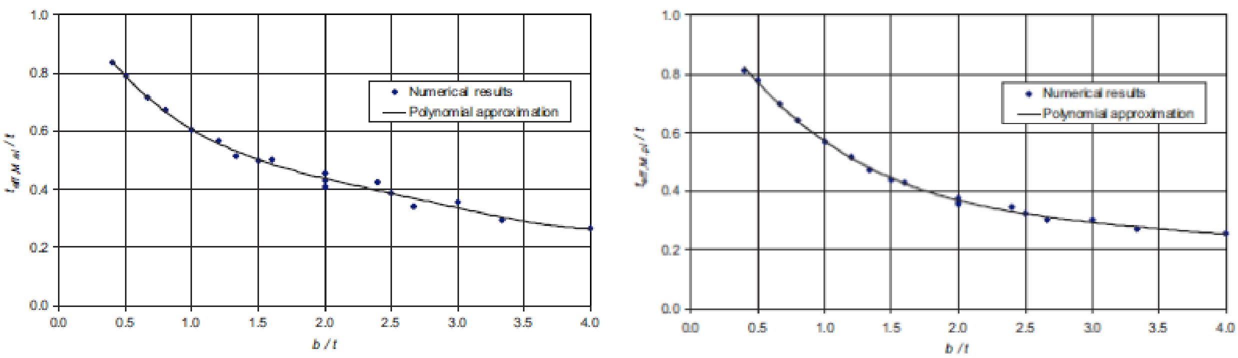


Figure 22 - Relationship between the ratios b/t and $t_{eff,M/t}$ in elastic and plastic ranges

The authors specify that the elastic bending resistances can be used together with the provisions of EN 1993-1-3 for the design of cold formed sections, while the plastic bending resistance is used for the design of composite slabs in bending.

According to the authors the following formula should be used:

- when the neutral axis lies within the sheeting

$$M_{p,Rd} = N_{cf}z + 1.25M_{pa}\left(1 - \frac{N_{cf}}{A_p f_{yp}/\gamma_{ap}}\right), \qquad (4)$$

where, z is the lever arm of the internal tension and compression forces of the cross-section, N_{cf} the design value of the compressive normal force in the concrete flange and M_{pa} the design value of the plastic resistance moment of the effective cross-section of the profile steel sheeting.

- and when the neutral axis lies within the sheeting the following formula should be used:

$$M_{p,Rd} = N_{cf}z + 1.25M_{pa,eff}\left(1 - \frac{N_{cf}}{A_{p,eff} f_{yp}/\gamma_{ap}}\right).$$

The reviewer notes

The above equation may be presented under the following form:

$$M_{pr} = N_{pa}\eta\frac{z}{2} * \mathrm{Min}[1.25(1-\eta),1)]$$

As it was demonstrated in [12] the above equation (4) adopted in the EN 1994-1-1 is not exact, because it is based on some arbitrary hypotheses and assumptions.

The more realistic formula, given by A. Palisson and L. Sokol in [13] is $M_{pr} = N_{pa} z_{pr} \dfrac{(1-\eta)(\chi+\eta)}{1+\chi}$

In this paper it was demonstrated that the contribution of the embossment seems significant the area of the embossments region can be considered as active. There was a strong relation between the area of the embossment region and the ratio between the depth of the embossment and the thickness of the profile, for both cases of tension and bending of the profile. Modified formulas are proposed for the calculation of the sagging bending resistance of composite slabs, taking into account the effective area of the embossments region and leading to an increase of the bending strength of the order of 15%.

The reviewer notes:
The effect of combined action of support reaction and negative moment was not studied in this paper.

The single testing study was performed by P. Luure and M. Crisinel [8] who conducted tests to determine the influence of web embossments/indentations on the resistance of two types of

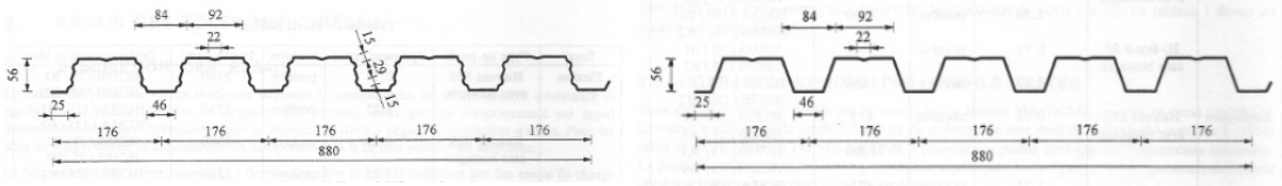


Figure 23 - HAIRCOL 55S with and without embossments

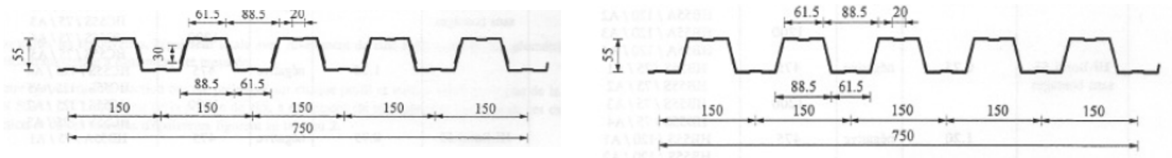


Figure 24- HI-BOND 55 with and without indentations

In total 16 bending and 32 bending - support reaction interaction tests were carried out. The same profiles with and without embossments/indentations were tested, with two different thicknesses of the sheets t=0.75mm and t=1.25mm. Tests were performed in accordance with Standard DIN 18807 [14], very close to EN 1993-1-3.

The aim of bending tests (Fig. 25) was to determine bending moment resistance and the flexion stiffness.

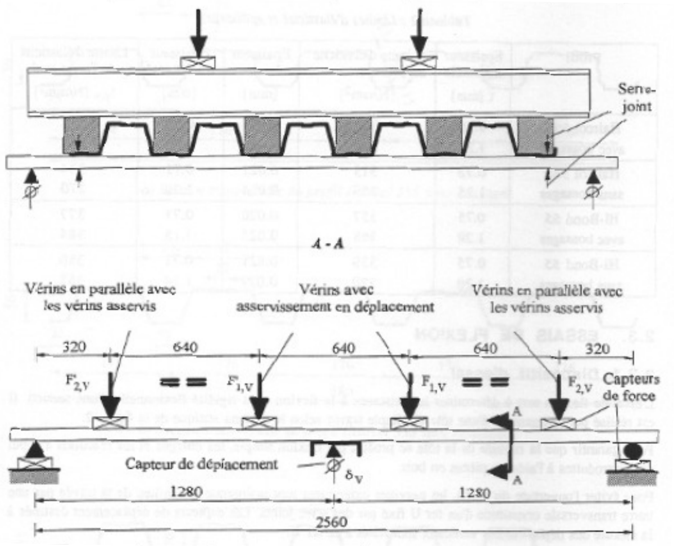


Figure 25- Bending test set-up

The bending moment was calculated with the following equation:

$M_v = \left[3\cdot\left(F_{1,v}+F'_{1,v}\right)+F_{2,v}+F'_{2,v}\right]\cdot\frac{L}{16}+M_0$ where:

$F_{i,v}$ are measured forces; L is test span (L = 2560 mm); M = sheet own weight +accessories weigth

The stiffness was calculated with the following equation:

$$EI_v = \frac{0.9141 \cdot (\Delta F_{1,v} + \Delta F'_{1,v}) + 0.3672 \cdot (\Delta F_{2,v} + \Delta F'_{2,v})}{48} \cdot \frac{L^3}{\Delta \delta_v}$$ where:

$\Delta F_{i,v}$ are force differences corresponding to moment difference; $\Delta\delta v$ are deflection differences; L is test span (L = 2560 mm) (Fig. 26)

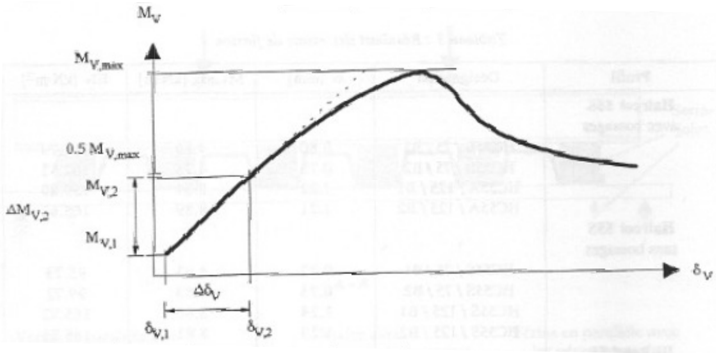


Figure 26 - Flexion stiffness determination

The aim of interaction tests (Fig. 27) was to simulate the behavior on the intermediate support.

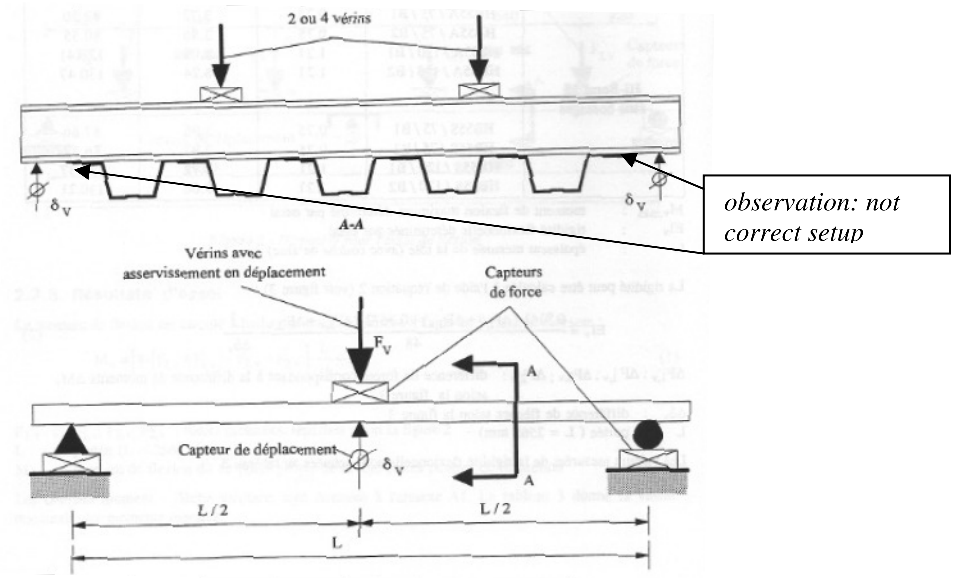


Figure 27- Interaction test set-up

The reaction and the bending moment are calculated with the following equations:

$$R_v = F_v + R_0$$

$$M_v = \frac{F_v \cdot L}{4} + M_0$$

where:

Fv is the measured force; R0 is the initial load due to sheet own weight +accessories weight; M0 is the initial moment due to sheet own weight +accessories weight; L is test span (L = 475 or 1200 mm).

The results of these tests showed that embossments decrease the bending resistance of the profiled sheeting of 10% On the contrary the tests showed that embossments increase the web crippling resistance of 10%. But to draw any global conclusions a test program even more complete should be carried out, with different types of profiles and embossments.

The reviewer notes:
- The effect of combined action of support reaction and negative moment was not studied in this paper
- The conclusion of this study does not permit to predict the impact of the embossment in function of its type and positioning

J. M. Davies [9] investigated the effect of dimples on the bending strength using the finite element method. Two decking profiles have been analysed: the Holorib profile with square dimples in the flanges and the Metecno profile with rectangular dimples in the webs (Fig. 28).

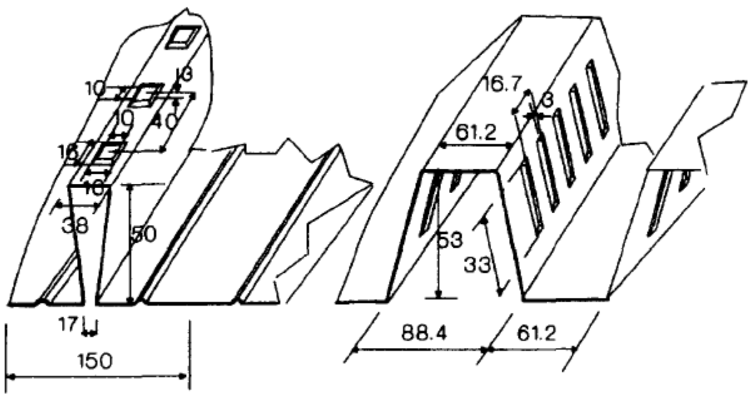


Fig. 28 - Holorib profile with square dimples in the flanges and the Metecno profile with rectangular dimples in the webs

The authors found that the dimples decrease the bending strength. In the case of the dimples in the webs the reduction was about 3%, in the case of the dimples in the flange the reduction was 8.21% for the Holorib 0.9/50 profile and 10.96% for the Holorib 1.2/50 profile. This decrease was approximately inversely proportional to $\lambda_p = b/t\sqrt{F_y/E})$. The author noted that if elastic buckling of flange dominates the strength of a steel deck, λ_p has a relatively large value, dimples in the compression flanges can increase the bending strength. The author intends, in further parametric studies, to investigate relationship between compression flange dimples, λ_p and bending strength.

The reviewer notes:
- The effect of combined action of support reaction and negative moment was not studied for decks with dimples
- The conclusion of this study is that the influence on bending strength depends on type and positioning of stiffeners, but the relationship was not established.

4. CONCLUSIONS

As we could see in this state of the art there is a real lack of data and knowledge about the effect of embossments, indentations and outwards stiffeners on the steel deck resistance and stiffness it means on the bending strength ($M_{c,Rd}$) on the shear ($V_{w,Rd}$) and on support strength ($R_{w,Rd}$). The European Standard EN 1993-1-3 dealing with design rules for cold-formed members and sheeting doesn't cover profiles with embossments, indentations or outwards stiffeners. The background information for the effect of such stiffeners is that embossments decrease of about 10% the

bending resistance of the profiled sheeting and that embossments increase of about 10% the web crippling resistance. But the test program which led to these tendencies was not important enough to establish global conclusions.
Therefore a series of tests should be performed in order to acquire data on resistance and stiffness of the steel decks with embossment and indentations or with outwards stiffener in the upper flange.

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