GRISPE

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

Working Package 2

Background and draft annexes for EN 1993-1-3 for corrugated sheets

30 June 2016

Deliverable D 2.5

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

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

Author(s)		
Christian Fauth, KIT		
Rainer Holz, IFL		
Drafting history		
Final Version		*30 June 2016*
Dissemination Level		
PU	*Public*	
PP	*Restricted to the Commission Services, the Coal and Steel Technical Groups and the European Committee for Standardisation (CEN)*	
RE	*Restricted to a group specified by the Beneficiaries*	
CO	*Confidential, only for Beneficiaries (including the Commission services)*	***x***
Verification and Approval		
Coordinator David Izabel, SNPPA		
WP2 Leader Rainer Holz, IFLSSON CONSULTANTS		
Other Beneficiaries SNPPA, SPC, Bac Acier, Joris Ide, KIT		
Deliverable		
D 2.5 WP2 Background and draft annexes for EN 1993-1-3 for corrugated sheets	***Due date : 30.06.2016*** ***Completion date: 30.06.2016***	

1. Introduction

Corrugated steel sheets are the oldest cold formed steel sheets, they have a continuous curvature instead of the flat sections like trapezoidal profiles.

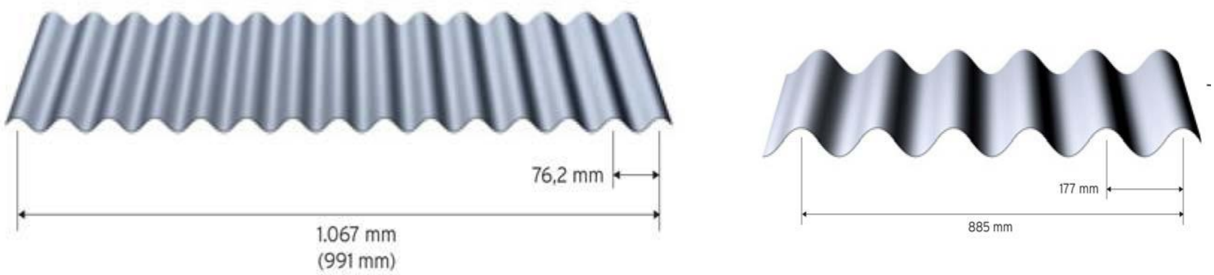

Fig.1: Cross section

The failure of these profiles in bending occurs normally through plastic deformation and not through local buckling because of the small slenderness of the d/r-ratio. The failure under local loads occurs through plastic deformation of the crests or the valleys of the profile.
The aim of the GRISPE project is to develop a design model to calculate the load-bearing capacity in bending and under local loads (end support resistance) and for the combination of bending and support reaction.
Therefore three types of tests were executed; single span tests for the positive bending moment (gravity loading) in span, internal support tests for load case gravity loading and uplifting loading with different spans for the moment-support interaction and end support tests for load case gravity loading for the local resistance of the profiles.
In the test report D 2.3 [3] the test range and the results are documented. The tests are evaluated and the ultimate bending moment, the end support resistance and the moment-support interaction were determined in D 2.4 [4].

2. Acquired data through GRISPE project

In the GRISPE project a large test program was performed to determine the load-bearing capacity of corrugated sheets. In the following table the performed tests are documented.

Type of test	Thickness [mm]	Support width [mm] / Fastening	Span [mm]		Number of tests	
			18/76	46/150	18/76	46/150
Single span test with gravity loading	0.63	-	1500	2000	3	6
	1.00	-	2000	3000	3	3
Internal support tests with gravity loading	0.63	10	400	600	2	2
			800	1000	2	2
		40	400	600	2	2
			800	1000	2	2
	1.00	10	400	600	2	2
			1000	1200	2	2
		40	400	600	2	2
			1000	1200	2	2
Internal support tests with uplift loading	0.63	valley	400	600	2	2
			800	1000	2	2
		crest	400	600	2	2
			800	1000	2	2
	1.00	valley	400	900	2	2
			1000	1400	2	2
		crest	400	900	2	2
			1000	1400	2	2
End support tests with gravity loading	0.63	-	1000	1050	4	3
	1.00	-	1000	1050	4	3
Shear test	0.63	-	1000	1000	1	1

Table 1: Tests performed

Two different profiles in two thicknesses (different d/r-ratio) were tested. They are shown in Figure 4 and 5.

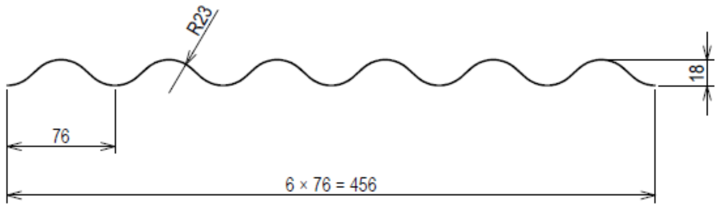

Fig. 2: Cross section of the profile 18/76

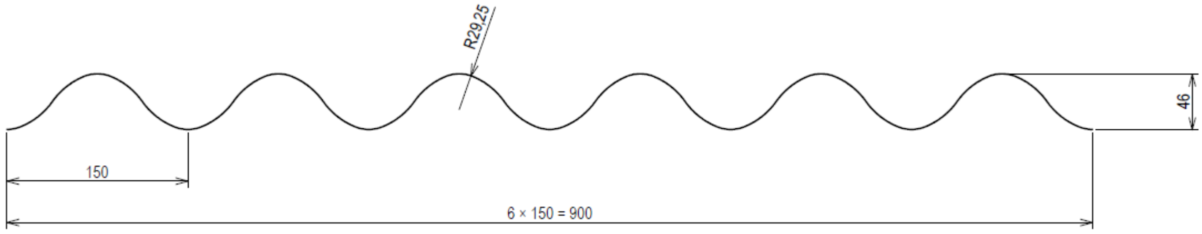

Fig. 3: Cross section of the profile

Detailed information of the test setups and the test results are documented in [3].
The test setup and main results of the interpretation and analysis of the test results are listed again in this document. They are as follows:

Single span tests:

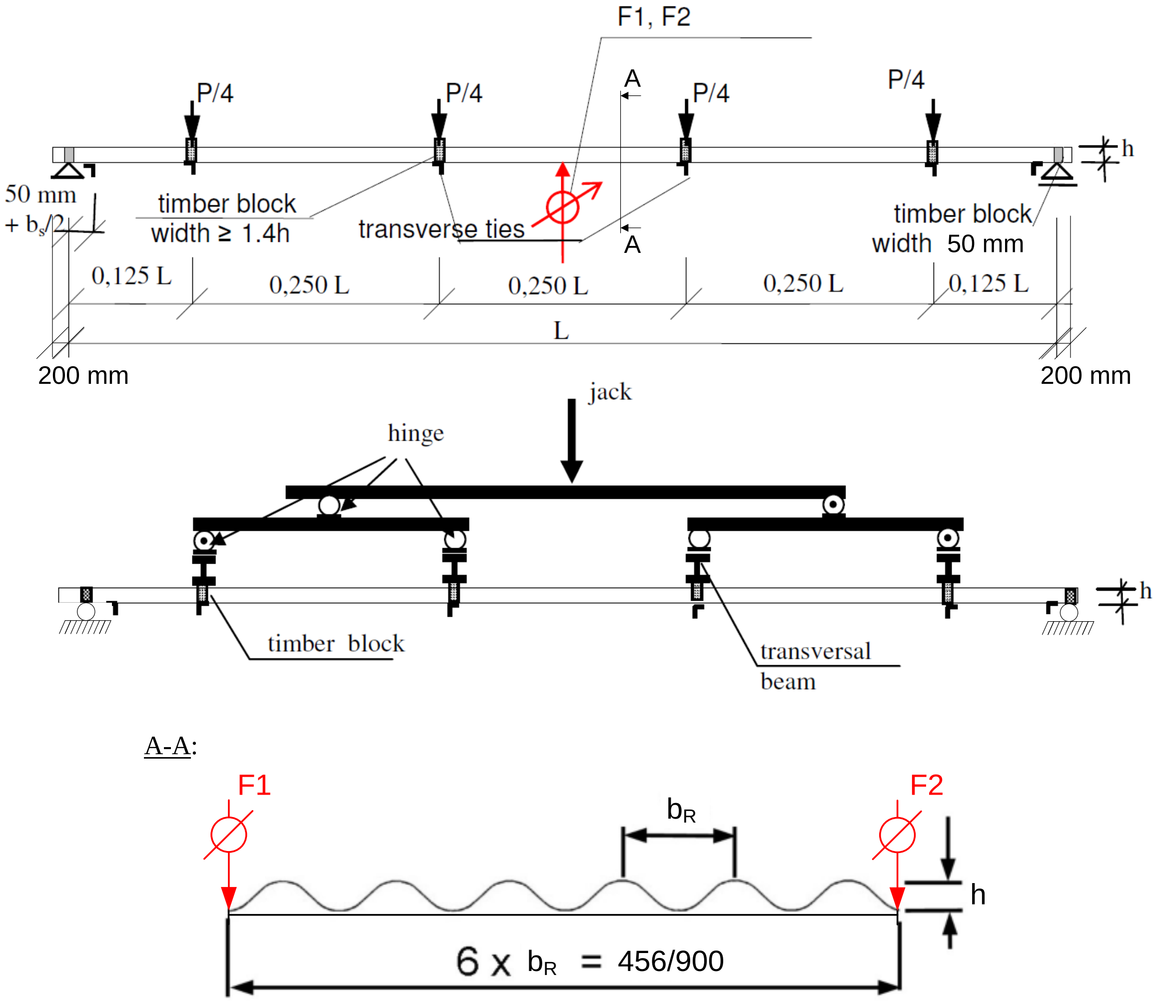

Fig. 4: Test setup single span tests

Fig. 5: Picture of the test setup single span tests

Profile	nominal thickness t mm	steel core thickness t_{cor} mm	yield strength f_{yb} N/mm²	span moment (test) $M_{c,Rk,F}$ kNm/m
Bacacier 18/76	0,63 1,00	0,523 0,943	333,7 402,0	1,09 2,08
Bacacier 46/150	0,63 1,00	0,520 0,933	364,3 409,0	2,41 5,47

Table 2: Test results (characteristic bending moment) of the single span tests

Internal support tests for gravity loading:

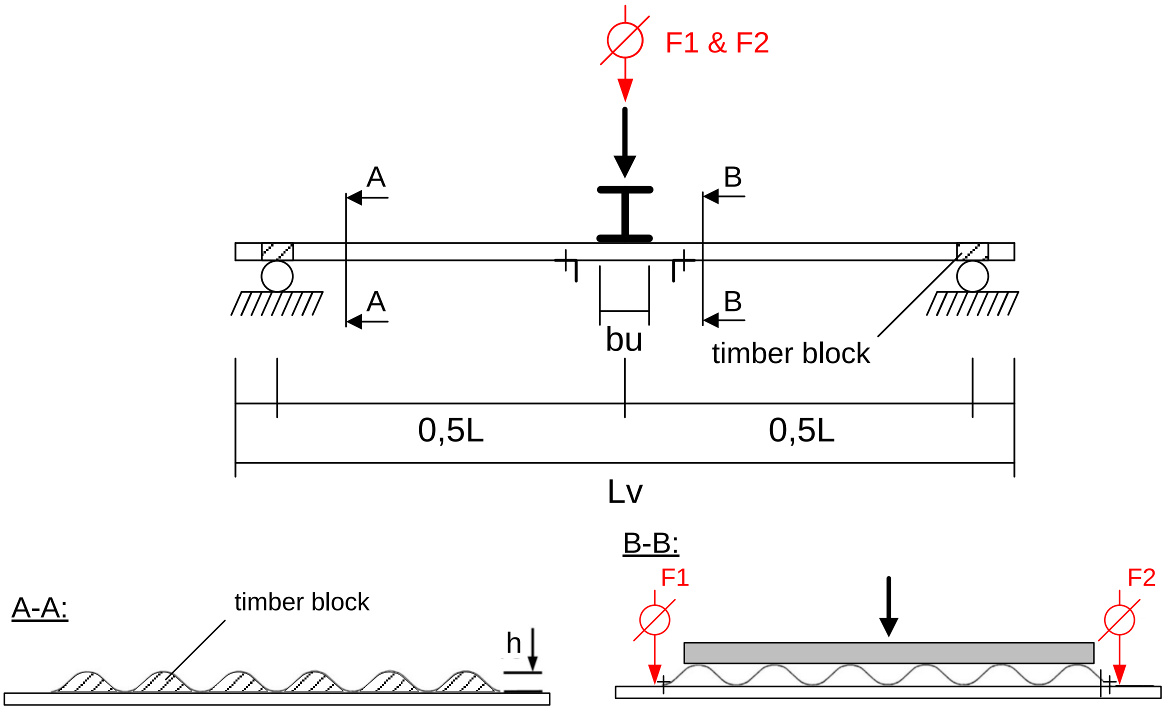

Fig. 6: Test setup internal support tests for gravity loading

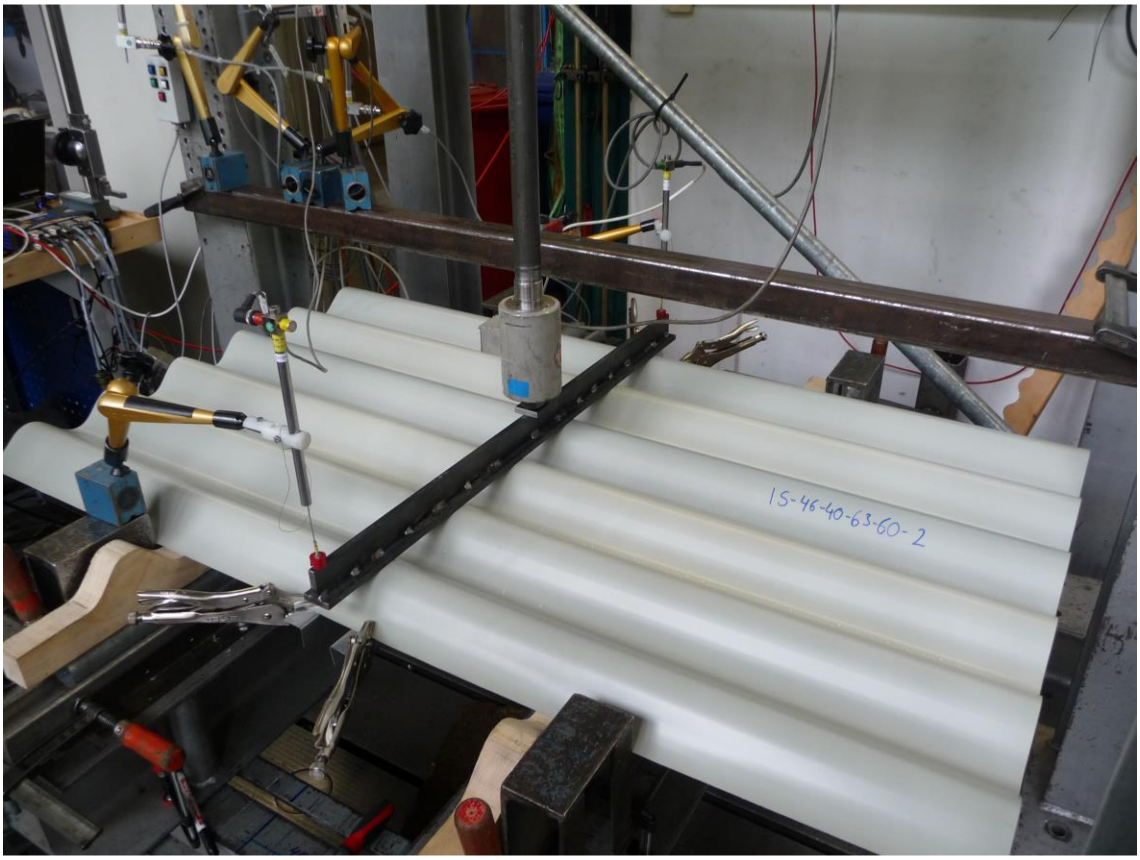

Fig. 7: Picture of the test setup internal support tests for gravity loading

Profile	nominal thickness t mm	support width $L_{a,B}$ mm	span moment $M_{c,Rk,F}$ kNm/m	maximum bending moment $M_{c,Rk,B}$ kNm/m	corresp. support reaction R_1 kN/m	corresp. bending moment M_2 kNm/m	max. support reaction $R_{w,Rk,B}$ kN/m	interaction parameter $M^0_{Rk,B}$ kNm/m	interaction parameter $R^0_{Rk,B}$ kN/m
Bacacier 18/76	0,63	10	1,09	0,88	4,40	0,77	7,81	1,02	32,00
		40		1,12	5,61	1,05	10,58	1,21	81,80
	1,00	10	2,08	2,27	9,06	2,01	20,15	2,49	104,44
		40		2,44	9,75	2,58	25,88	2,44	∞
Bacacier 46/150	0,63	10	2,41	1,20	4,79	0,98	6,55	1,81	14,26
		40		1,27	5,07	1,09	7,31	1,68	20,83
	1,00	10	5,47	3,74	12,43	3,02	20,12	4,92	52,04
		40		3,92	13,03	3,36	22,40	4,71	78,14

Table 3: Test results of the internal support tests for gravity loading

<u>Internal support tests for uplift loading:</u>

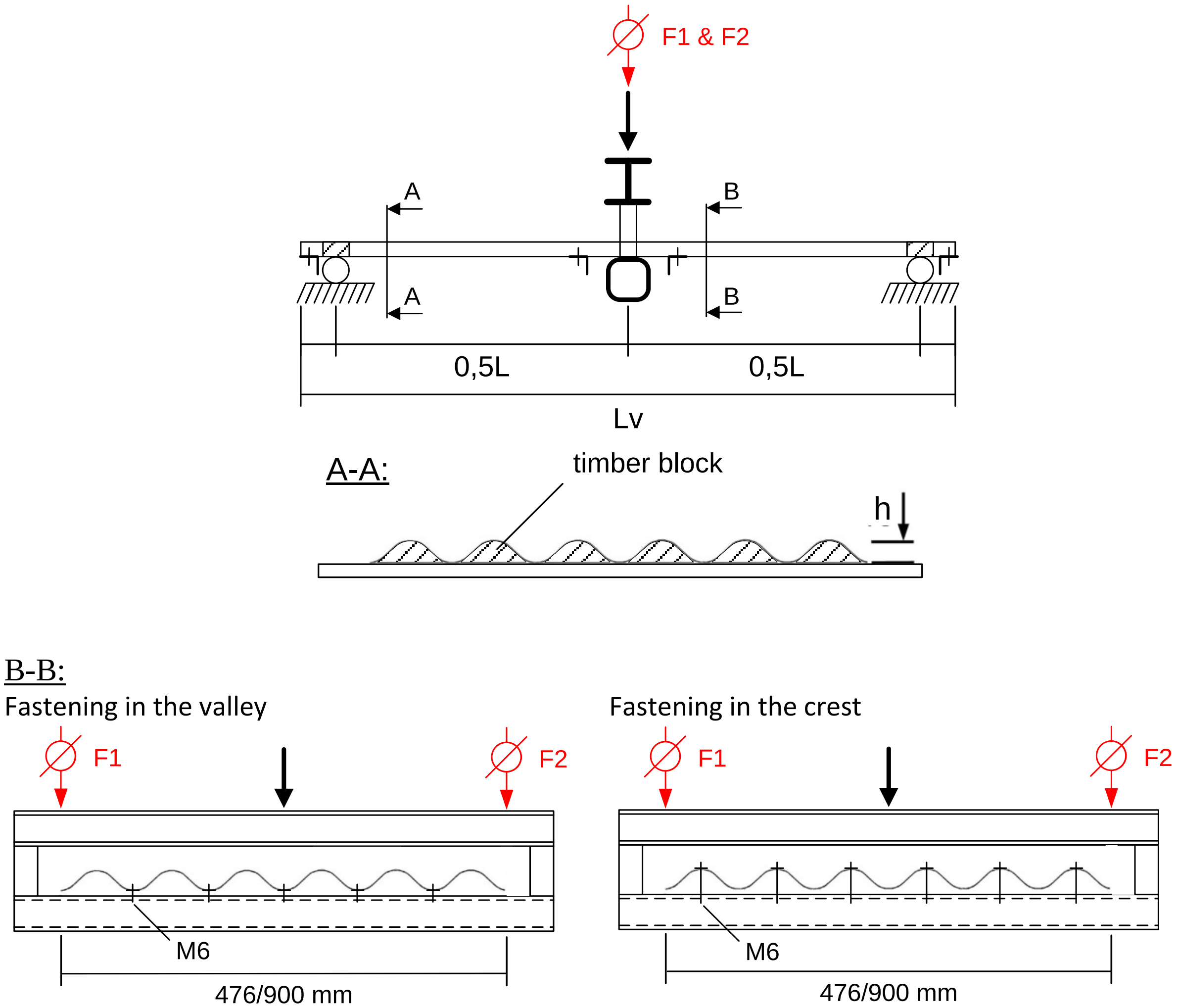

Fig. 8: Test setup internal support tests for uplift loading

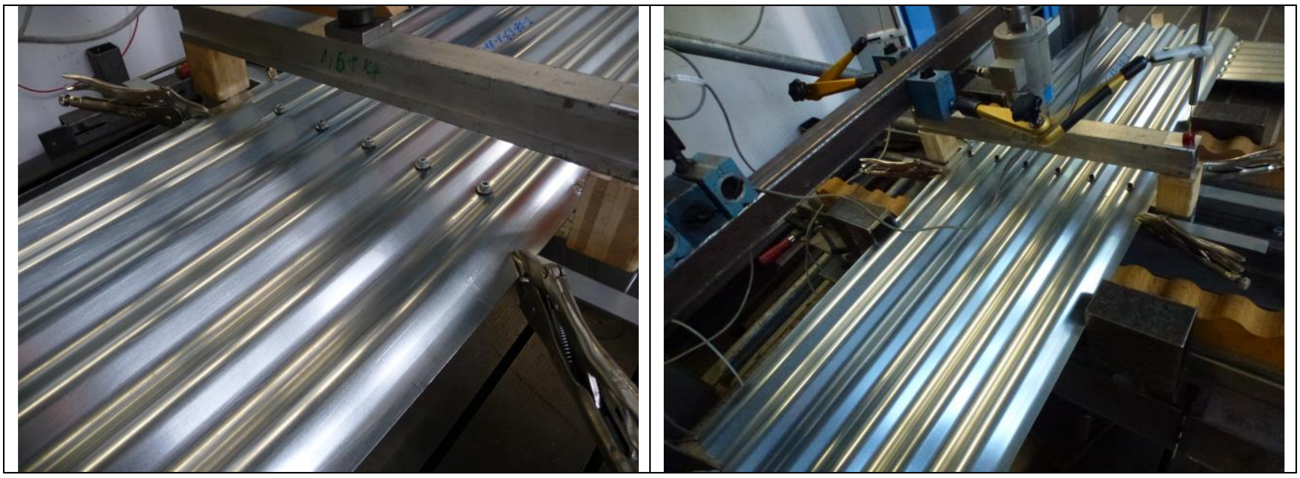

Fig. 9: Picture of the test setup internal support tests for uplift loading (fastening in the valley or crest)

Profile	nominal thickness t mm	fixing config-uration	span moment $M_{c,Rk,F}$ kNm/m	maximum bending moment $M_{c,Rk,B}$ kNm/m	corresp. support reaction R_1 kN/m	corresp. bending moment M_2 kNm/m	max. support reaction $R_{w,Rk,B}$ kN/m	interaction parameter $M^0_{Rk,B}$ kNm/m	interaction parameter $R^0_{Rk,B}$ kN/m
Bacacier 18/76	0,63	crest valley	1,09	0,85 1,06	4,23 5,31	0,74 1,13	7,52 11,41	0,98 1,06	31,22 ∞
	1,00	crest valley	2,08	2,13 2,26	8,50 9,02	1,87 2,33	18,83 23,40	2,34 2,26	94,17 ∞
Bacacier 46/150	0,63	crest valley	2,41	0,99 2,36	3,95 9,43	0,84 2,34	5,64 15,62	1,34 2,36	15,16 ∞
	1,00	crest valley	5,47	3,59 5,62	10,22 16,01	3,08 5,44	13,67 24,16	5,11 5,62	34,39 ∞

Table 4: Test results of the internal support tests for uplift loading

End support tests for gravity loading:

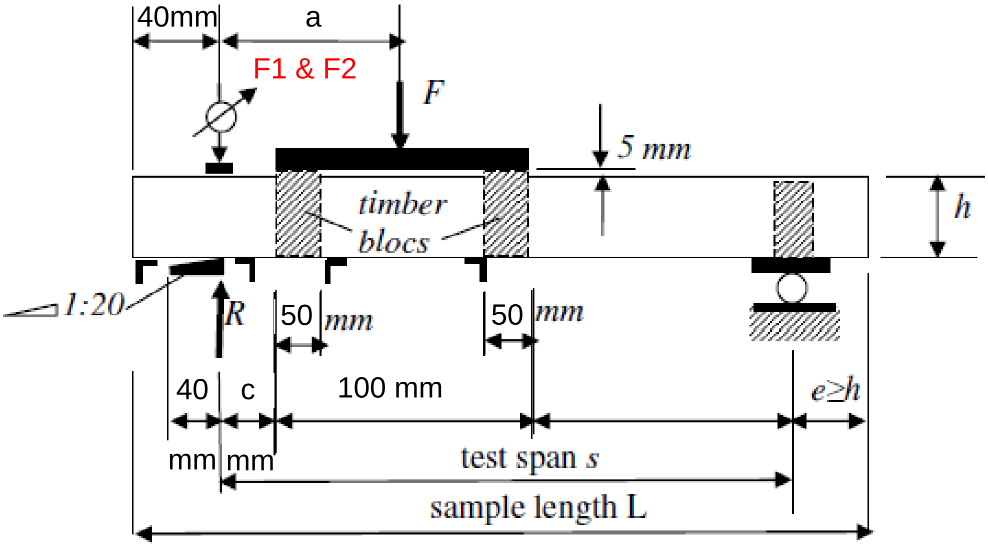

Fig. 10: Test setup end support tests for gravity loading

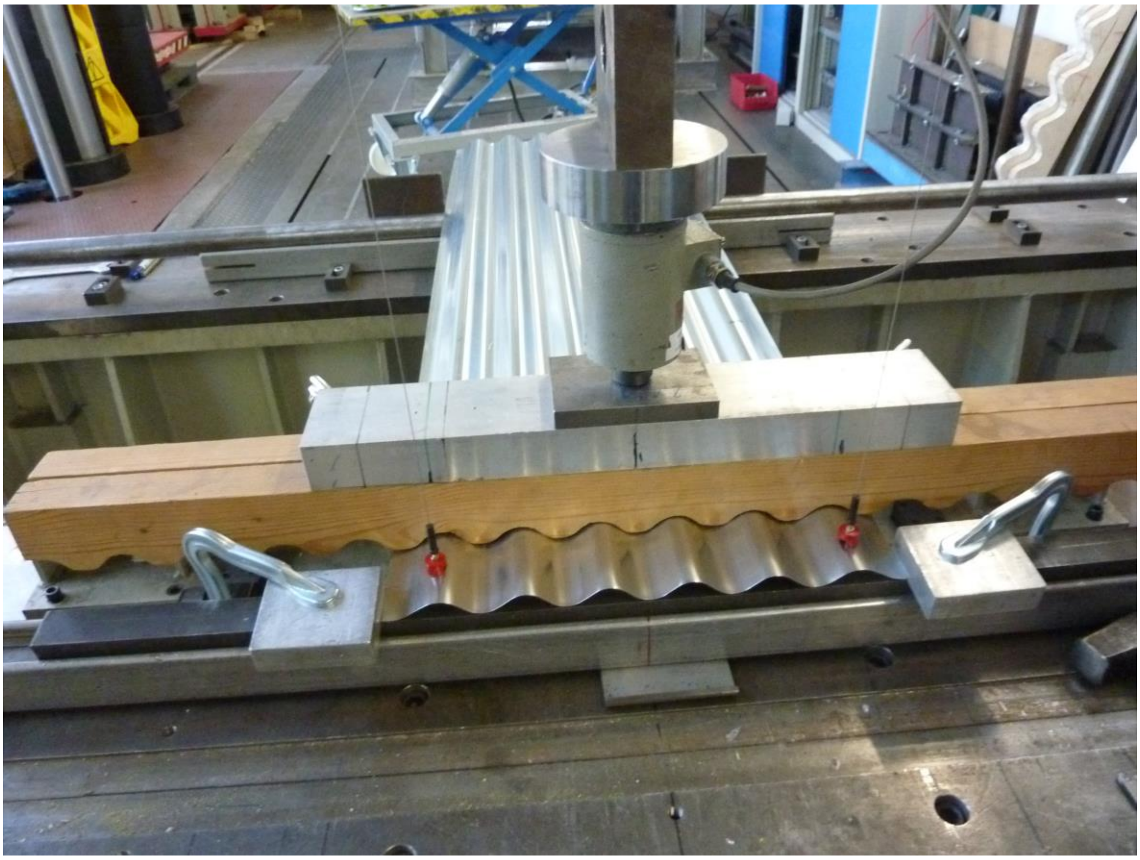

Fig. 11: Picture of the test setup end support tests for gravity loading

Profile	nominal thickness t mm	support width $L_{a,A}$ mm	overhang c mm	support reaction $R_{w,Rk,A}$ kN/m	shear resistance $V_{w,Rk}$ kN/m
Bacacier 18/76	0,63 1,00	0 0	40 40	18,13 40,09	18,77
Bacacier 46/150	0,63 1,00	0 0	40 40	13,26 39,20	16,78

Table 5: Test results of the end support tests for gravity loading

More detailed information of the analysis and interpretation of the test results are documented in [4].

3. Calculation method for corrugated sheets

In order to calculate the bending stiffness and the ultimate bending moment for corrugated profiles with sinusoidal cross section, two approaches are proposed.

Generally applicable design procedure with respect to local buckling in the compressed area (StBkN5)

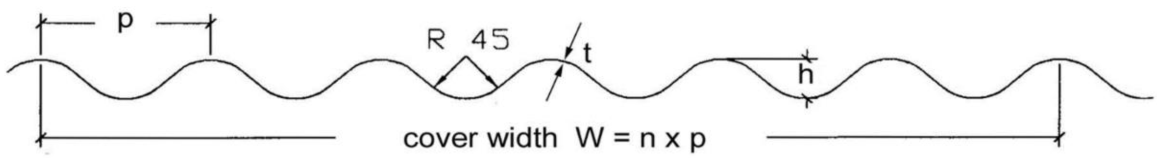

Fig. 12: Typical cross section, definition of parameters

- If $R / t \leq 0{,}04 * E / f_{yb}$: The cross section needs not to be checked for local buckling

  Characteristic bending moment: $M_{c,Rk} = Wy * f_{yb}$

- If $R / t > 0{,}04 * E / f_{yb}$: The characteristic bending moment should be calculated using the reduced compressive stress σ_c

  Characteristic bending moment: $M_{c,Rk} = Wy * \sigma_c$

  with:

  slenderness ratio: $\alpha = \sqrt{f_{yb}/\sigma_{elr}}$

  buckling stress: $\sigma_{elr} = 0{,}60 * \eta * E * t/R$

  coefficient η: $\eta = 0{,}19 + \frac{0{,}67}{\sqrt{1+R/(100*t)}}$

  for $\alpha \leq 0{,}30$ $\sigma_c = f_{yb}$

for $0,30 < \alpha \leq 1,10$ $\sigma_c = (1,126 - 0,419 * \alpha) * f_{yb}$
for $1,10 < \alpha$ $\sigma_c = (0,8/\alpha^2) * f_{yb}$

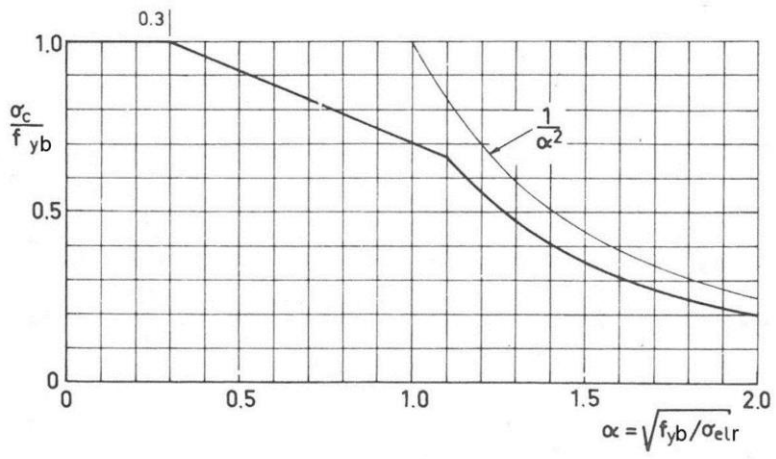

Fig. 13: ultimate compressive stress with respect to local buckling of the cylindrical part of the profile

The moment of inertia, which is used to calculate deformations in serviceability limit state, should be calculated using the same procedure as for bending moment, but with reduced stress f_{yb} / 1,5.

Simplified procedure for restricted application range (tanks formula)

If the conditions

- Profile installed as single span girder and
- Uniformly distributed loads and
- ratio $R / t \leq 0,1 * E / f_{yb}$ and
- steel core thickness $t_{cor} \geq 0,55$ mm and
- profile height 18 mm $\leq h \leq$ 46 mm and
- profile pitch 76 mm $\leq p \leq$ 150 mm

are met, the following simplified procedure may be adopted :

moment of inertia per unit width: $J_y = 0,13 * t * h^2$

section modulus per unit width: $W_y = 0,26 * t * h$

characteristic bending moment:: $M_{c,Rk} = W_y * f_{yb}$

Profile	Nominal thickness t	steel core t_{cor}	yield strength f_{yb}	Test: span moment $M_{c,Rk,F}$	calculation: tanks $M_{c,Rk,F}$	calculation: StBkN5 $M_{c,Rk,F}$	calculation: elastic Moment $M_{c,Rk,F}$	calculation: plastic Moment $M_{c,Rk,F}$
	mm	mm	N/mm²	kNm/m	kNm/m	kNm/m	kNm/m	kNm/m
Bacacier 18/76	0,63	0,523	333,7	1,09	0,817	0,875	0,912	1,151
	1,00	0,943	402,0	2,08	1,774	1,968	1,980	2,500
Bacacier 46/150	0,63	0,520	364,3	2,41	2,266	2,233	2,411	3,143
	1,00	0,933	409,0	5,47	4,564	4,725	4,857	6,332

Table 6: Comparison of the test values with the calculated values

Load bearing under line loads, load bearing capacity at supports under combined bending and shear solicitation

The internal support tests for uplift load with fixing in the valley don't show an interactive influence of the line load on the bending moment. Since the line load is introduced as a tension force on the cross section, the bending moment is not reduced compared to the bending moment capacity in span (see table 4). The interaction parameter $R^0_{R,kB}$ is ∞. The bending moment resistance at internal support is the same as in span.

Uplift load, fixing in valley: $M_{c,Rk,B} = M_{c,Rk,F}$

If the line load acts as compression force on the cross section – that is the case at internal supports under downward loading as well as under uplift loading with fixing in the crest -, the bending moment at internal supports is often considerably smaller than the bending moment in span (see table 3 and 4). For small ratios R/t – for instance profile 18/76, thickness 1,0 mm – there is no reduction compared to the bending moment capacity in span, for great ratios R/t – for instance profile 46/150 , thickness 0,63 mm – the bending moment at internal support drops to 40% of the bending moment capacity in span. Beside the R/t-ratio, the mode, how the line load is introduced into the cross section, plays a roll for the bending moment. The concerned parameters are the width of the support and the way, how the linear load is introduced: by a flat support or by punctual fixing screws. The test results were not sufficient to conclude a design rule for the bending moment – support reaction – interaction.

4. Conclusion

This document proposes two design approaches for the corrugated sheets in bending. One based on a Swedish approach and one on the tank approach defined already in the Eurocode. For this second approach, the tank formula is defined with a field of application calibrated on the tests done during GRISPE project.

5. References

[1] EN 1993-1.3: Eurocode 3 – Design of steel structures. Part 1.3: General rules – supplementary rules for cold-formed members and sheeting
[2] Deliverable D 2.1: Background Document. KIT, 30.11.2013
[3] Deliverable D 2.3: Test report. Corrugated sheets. KIT, 31.05.2015
[4] Deliverable D 2.4: Test analysis and interpretation. Corrugated sheets. IFL, 30.06.2016