GRISPE

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

Test report

Corrugated Sheets

Main Part

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Guidelines and Recommendations for Integrating Specific Profiled Steels sheets in the Euro-codes (GRISPE)

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Content

1 Preliminary remarks

Versuchsanstalt für Stahl, Holz und Steine of the Karlsruhe Institute of Technology (KIT) investigated the load-bearing capacity of corrugated steel sheets for the research project "Guidelines and Recommendations for Integrating Specific Profiled Steels sheets in the Eurocodes (GRISPE)" co-funded under the Research Fund for Coal and Steel. The corrugated steel sheets were produced by Bacacier (France). The test program was specified in the deliverable D2.2 "Test program definition".

2 Object of testing

The tested corrugated sheets from Bacacier consist of steel sheeting according to EN 10346:2009, which are formed to profiles with the following section heights and overall widths by roll-forming:

Type of profile	Steel grade according to EN 10346:2009	Height [mm]	Width [mm]	Thickness [mm]
Bacacier 18/76	S320GD	18	456	0.63 and 1.00
Bacacier 46/150	S320GD	46	900	0.63 and 1.00

Table 1: Section heights and overall widths of the different tested profiles

The nominal cross-section geometry of the tested profiles is given in annex A.1 to A.2.

3 Scope of testing

The test performances for determination of the resistance values for bending, shear and web crippling were done according to EN 1993-1-3:2010. The tests performed are listed in table 2 as follows. In addition, tensile tests according to EN 6892-1:2009 on specimens taken from the sheeting were performed to determine of the material properties. Furthermore the profile geometry was measured.

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 2: Tests performed with Bacacier 18/76 and Bacacier 46/150

4 Test performance and results

4.1 General remarks

The test specimens were delivered April 13th and April 23th 2015. The tests were performed using calibrated testing machines of the Versuchsanstalt für Stahl, Holz und Steine of the Karlsruhe Institute of Technology (KIT). The specimens are all described by the following system:

Single Span positive bending test (SSP):

System:	SSP – XX – XXX – XX
First block (two char.):	Profile height [mm]
	18 = Bacacier 18/76
	46 = Bacacier 46/150
Second block (three char.):	Sheet thickness
	063 = 0.63 mm
	100 = 1.00 mm
Third block (one char.):	Test number (running)

Internal support test (IS):

System:	IS – XX – XX – XXX – XXX – X
First block:	Profile height [mm]
(two char.)	18 = Bacacier 18/76
	46 = Bacacier 46/150
Second block:	Support width [mm] / Fastening position
(one or two char.)	10 = 10 mm
	40 = 40 mm
	V = valley
	C = crest
Third block:	Sheet thickness
(two or three char.):	63 = 0.63 mm
	100 = 1.00 mm
Fourth block:	Span length [cm]
(two or three char.)	
Fifth block (one char.):	Test Number (running)

End support test / Shear test (ES-Q / S):

System:	ES – Q – XX – XXX – XXX – XX
First block (two char.):	Profile height [mm]
	18 = Bacacier 18/76
	46 = Bacacier 46/150
Second block (three char.):	Sheet thickness
	063 = 0.63 mm
	100 = 1.00 mm
Third block:	Span length [cm]
(two or three char.)	
Fourth block (one char.):	Test number (running)

4.2 Single span tests

For the determination of the characteristic values of the mid-span moment resistance, single span tests for load case "gravity loading" (positive bending) were performed with uniformly distributed load simulated by four line loads. The tests performed are shown in table 2. The overhang of each profile was 200 mm. The load was introduced into the valleys of the sheets via transverse steel sections and timber blocks. The profiles were prevented from spreading by transverse ties. At the end supports timber blocks were used to avoid local deformation. The deflections were measured continuously in mid-span by two trip wire displacement sensors, the deflections were measured under the bottom flanges, see figure B.1 in annex B. The structure of the specimens and the static systems are given in annex B. The load was applied deflection-controlled with a speed of 30 mm/min. The load was measured continuously using a load cell with a maximum capacity of 50 kN. The displacement and the load measured were visualized as load-deflection curve.

In all single span tests a non-linear load-deflection behaviour appeared until the failure load was reached. Failure occurred in the tests with the profile 18/76 with thickness t_N = 1.00 mm by plastic deformation. In all other tests failure occurred by buckling of the crest of the sheets in the middle of the span near the load applying traverse. The results of the single span tests are listed in the following tables 3 and 4. The load F_{max} indicates the failure load including preload, but without self-weight of the test specimens. Annex B shows the experimental set-up, photos from the tests and the load deflection-curve.

Test	Span [mm]	Length of specimen [mm]	Nominal thickness [mm]	Measured t_N incl. zinc coating [mm]	Preload [kN]	F_{max} [kN]
SSP-18-063-1	1500	1900	0.63	0.57	0.25	2.75
SSP-18-063-2				0.59		2.69
SSP-18-063-3				0.57		2.82
SSP-18-100-1	2000	2400	1.00	0.96	0.26	3.87
SSP-18-100-2				0.98		3.91
SSP-18-100-3				0.96		3.89

Table 3: Results of single span tests (Bacacier 18/76)

Test	Span [mm]	Length of specimen [mm]	Nominal thick-ness [mm]	Measured t_N incl. zinc coating [mm]	Preload [kN]	F_{max} [kN]
SSP-46-063-1	2000	2400	0.63	0.58	0.22	9.51
SSP-46-063-2				0.57		9.03
SSP-46-063-3				0.57		8.70
SSP-46-063-4				0.57		8.48
SSP-46-063-5				0.57		9.17
SSP-46-063-6				0.57		9.03
SSP-46-100-1	3000	3400	1.00	0.99	0.51	13.57
SSP-46-100-2				0.96		13.40
SSP-46-100-3				0.97		13.54

Table 4: Results of single span tests (Bacacier 46/150)

4.3 Internal support tests

Instead of extensive investigations of the intermediate support area of continuous beams, internal support tests for load case "gravity loading" and "uplift loading" were performed. The tests performed are shown in table 2. Loading was applied in mid-span via a transverse steel plate with a width of b_u = 10 mm or b_u = 40 mm ("gravity loading") or via bolts M6 and washers diameter d = 16 mm in each valley or crest of the sheets ("uplift loading"). The profiles were prevented from spreading by transverse ties. At the supports the profiles were pivoted on timber blocks. The deflections were measured continuously in mid-span by two trip wire displacement sensors. The deflections were measured continuously at the load applying transverse steel plate. The structure of the specimens and the static systems are given in annex C ("gravity loading") and annex D ("uplift loading").

The load was applied deflection-controlled with a speed of 3 mm/min to 6 mm/min, the speed was increased to 10 mm/min after the maximum load was reached. The load was measured continuously using a calibrated load cell. In all internal support tests (an approximately linear elastic load-bearing behaviour appeared until failure load was reached. Failure occurred by deformation of the crest (buckling). The results of the internal support tests are listed in the following four tables. The length of all specimens was l_v = 1500 mm. The load F_{max} indicates the failure load including preload, but without self-weight of the test specimens. Annex C shows the test setup, photos of the tests and the load deflection-curves for load case "gravity loading". Annex D shows the test setup, photos of the tests and the load deflection-curves for load case "uplift loading".

Test	Span [mm]	Support width [mm]	Nominal thick-ness [mm]	Measured t_N incl. zinc coating [mm]	Preload [kN]	F_{max} [kN]
IS-18-10-63-40-1	400	10	0.63	0.56	0.03	3.57
IS-18-10-63-40-2				0.57		3.58
IS-18-10-63-80-1	800			0.56		2.01
IS-18-10-63-80-2				0.59		2.02
IS-18-40-63-40-1	400	40		0.59		4.89
IS-18-40-63-40-2				0.58		4.88
IS-18-40-63-80-1	800			0.58		2.57
IS-18-40-63-80-2				0.57		2.61
IS-18-10-100-40-1	400	10	1.00	1.00		9.32
IS-18-10-100-40-2				1.00		9.14
IS-18-10-100-100-1	1000			0.98		4.17
IS-18-10-100-100-2				0.98		4.13
IS-18-40-100-40-1	400	40		0.98		11.87
IS-18-40-100-40-2				0.99		12.02
IS-18-40-100-100-1	1000			1.00		4.51
IS-18-40-100-100-2				0.98		4.49

Table 5: Results of internal support tests for load case “gravity loading”

Test	Span [mm]	Support width [mm]	Nominal thick-ness [mm]	Measured t_N incl. zinc coating [mm]	Preload [kN]	F_{max} [kN]
IS-46-10-63-60-1	600	10	0.63	0.60	0.06	5.95
IS-46-10-63-60-2				0.60		5.93
IS-46-10-63-100-1	1000			0.59		4.32
IS-46-10-63-100-2				0.58		4.36
IS-46-40-63-60-1	600	40		0.61		6.90
IS-46-40-63-60-2				0.61		7.20
IS-46-40-63-100-1	1000			0.59		4.71
IS-46-40-63-100-2				0.59		5.07
IS-46-10-100-60-1	600	10	1.00	1.00		18.08
IS-46-10-100-60-2				0.97		18.42
IS-46-10-100-120-1	1200			0.98		11.29
IS-46-10-100-120-2				0.98		11.26
IS-46-40-100-60-1	600	40		1.00		21.74
IS-46-40-100-60-2				1.01		21.46
IS-46-40-100-120-1	1200			0.96		12.53
IS-46-40-100-120-2				0.97		12.60

Table 6: Results of internal support tests for load case “gravity loading”

Test	Span [mm]	Fastening	Nominal thick-ness [mm]	Measured t_N incl. zinc coating [mm]	Preload [kN]	F_{max} [kN]
IS-18-V-63-40-1	400	valley	0.63	0.60	0.03	5.41
IS-18-V-63-40-2				0.60		5.28
IS-18-V-63-80-1	800			0.61		2.52
IS-18-V-63-80-2				0.60		2.46
IS-18-C-63-40-1	400	crest		0.57		3.48
IS-18-C-63-40-2				0.59		3.49
IS-18-C-63-80-1	800			0.58		1.98
IS-18-C-63-80-2				0.57		1.94
IS-18-V-100-40-1	400	valley	1.00	0.98		10.87
IS-18-V-100-40-2				0.97		11.06
IS-18-V-100-100-1	1000			0.97		4.24
IS-18-V-100-100-2				0.97		4.21
IS-18-C-100-40-1	400	crest		0.95		8.90
IS-18-C-100-40-2				0.96		8.55
IS-18-C-100-100-1	1000			0.96		3.95
IS-18-C-100-100-2				0.98		3.93

Table 7: Results of internal support tests for load case “uplift loading”

Test	Span [mm]	Fastening	Nominal thick-ness [mm]	Measured t_N incl. zinc coating [mm]	Preload [kN]	F_{max} [kN]
IS-46-V-63-60-1	600	valley	0.63	0.60	0.24	14.17
IS-46-V-63-60-2				0.60		14.55
IS-46-V-63-100-1	1000			0.58		8.66
IS-46-V-63-100-2				0.59		8.67
IS-46-C-63-60-1	600	crest		0.61		5.18
IS-46-C-63-60-2				0.61		5.43
IS-46-C-63-100-1	1000			0.58		3.66
IS-46-C-63-100-2				0.57		3.76
IS-46-V-100-90-1	900	valley	1.00	0.97		21.96
IS-46-V-100-90-2				-		22.45
IS-46-V-100-140-1	1400			0.97		14.84
IS-46-V-100-140-2				0.95		14.58
IS-46-C-100-90-1	900	crest		0.96		12.71
IS-46-C-100-90-2				0.97		12.99
IS-46-C-100-140-1	1400			0.96		9.92
IS-46-C-100-140-2				0.96		9.29

Table 8: Results of internal support tests for load case “uplift loading”

4.4 End support tests and shear tests

For the determination of the characteristic values of the end support resistance, end support tests and shear tests for load case “gravity loading” were performed. The tests performed are shown in table 2. The load was applied via a transverse steel plate with a width of b = 300 mm (ES-Q-63-100-1) or b = 100 mm (all other ES-tests) and timber blocks attached to the valley of the sheets.

The profiles were prevented from spreading by transverse ties. At the tested end support a cutting edge (gradient of 1:20) is located (end support test) or a timber block without a cutting edge (shear test). At the opposite end support timber blocks were used to avoid web crippling. The deflections were measured continuously at the transverse steel plate and at the end support with the cutting edge by two trip wire displacement sensors. At the end support the deflections were measured at the crest of the profile, see figure D.1 in annex E (end support test). The structure of the specimens and the static systems are given in annex E (end support test) and annex F (shear test). The load was applied deflection-controlled with

a speed of 3 mm/min. The load was measured continuously using a calibrated load cell. Failure occurred by deformation of the webs (web-crippling) at the end supports followed by buckling of the sheets below the load applying plate. In ES-Q-18-63-100-1 and the both shear tests failure occurred only by bending below the load applying plate.
The results of the end support and shear tests are listed in table 9. The length of all specimens was l_v = 1500 mm. The load F_{max} indicates the failure load including preload, but without self-weight of the test specimens. Annex E (end support tests) and annex F (shear tests) show the test setup, photos from the tests and the load deflection-curves.

Test	Span [mm]	Nominal thickness [mm]	a [mm]	c [mm]	Measured t_N incl. zinc coating [mm]	Preload [kN]	F_{max} [kN]
ES-Q-18-63-100-1	1000	0.63	300	150	0.56	0.52	3.29
ES-Q-18-63-100-2			100	50	0.56	0.09	10.07
ES-Q-18-63-100-3					0.56		9.81
ES-Q-18-63-100-4					0.57		9.63
ES-Q-18-100-100-1	1000	1.00	100	50	0.97	0.09	-
ES-Q-18-100-100-2					0.97		23.06
ES-Q-18-100-100-3					0.97		22.05
ES-Q-18-100-100-4					0.97		20.14
ES-Q-46-63-105-1	1050	0.63	150	100	0.57	0.10	14.36
ES-Q-46-63-105-2					0.58		14.65
ES-Q-46-63-105-3					0.58		15.71
ES-Q-46-100-105-1	1050	1.00	150	100	0.98	0.10	44.83
ES-Q-46-100-105-2					0.97		43.40
ES-Q-46-100-105-3					0.97		43.97
S-18-63-100-1	1000	0.63	80	30	0.56	0.06	9.96
S-46-63-100-1	1000		115	70	0.58	0.06	18.27

Table 9: Results of end support and shear tests

4.5 Measurement of the profile geometry

The dimensions of the different profiles (Bacacier 18/76 and Bacacier 46/150) for both nominal thicknesses t_N = 0.63 mm and t_N = 1.00 mm were determined. The results are documented in annex G.

4.6 Material properties

For the determination of the material properties, 3 specimens per sheet and per thickness were worked out, from additional delivered flat sheets from the same coil than the corrugated sheets, for tensile tests according to EN 6892-1:2009 with the specimen shape 2 according to EN 6892-1:2009 table B.1. The determination of the yield strength $R_{p0.2}$ and the tensile strength R_m was based upon the measured sheet thickness exclusive of zinc coating. The results of the tensile tests are given in table 10.

Profile	Nominal thickness t_N [mm]	Core thickness t_K [mm]	Yield strength $R_{p0,2}$ [N/mm²]	Tensile strength R_m [N/mm²]	Elongation at fracture $A_{L=80mm}$ [%]
Bacacier 18/76	0.63	0.50	339	469	24.6
		0.55	340	462	25.3
		0.52	322	450	24.8
	1.00	0.93	404	458	20.9
		0.96	412	457	21.7
		0.94	390	453	22.0
Bacacier 46/150	0.63	0.51	361	409	28.5
		0.53	362	410	28.9
		0.52	370	409	27.4
	1.00	0.92	413	462	21.2
		0.95	422	465	21.7
		0.93	392	457	21.8

Table 10: Results of tensile tests

5 Summary

For the research project “Guidelines and Recommendations for Integrating Specific Profiled Steels sheets in the Eurocodes (GRISPE)” co-funded under the Research Fund for Coal and Steel the “Versuchsanstalt für Stahl, Holz und Steine” of the Karlsruhe Institute of Technology (KIT) made experimental investigations according to EN 1993-1-3:2010 on the load-bearing capacity of corrugated steel sheets. Also tensile tests according to EN 6892.1:2009 and profile geometry measurements were accomplished.

In chapter 2 the corrugated sheets are described with regard to application, geometry and material. Chapter 3 reflects the scope of testing. The description of the test set-up, the test performance and the documentation of the test results are given in chapter 4.