GRISPE

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

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Test Program Definition

Working Package 2

Deliverable D 2.2

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

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Summary

1 Introduction

This document contains the definition and the descriptions of experimental research, which is carried out within the GRISPE project, working package 2 “Calculation methods for liner trays, corrugated sheeting, curved profiles and assembled profiles”. The aim of these tests is to develop or to improve the design rules for these members and sheeting.

The tests concern the following four families of cold formed steel elements:

- Corrugated sheets
  Tests are carried out to determine the bending moment capacity and the load bearing capacity at intermediate supports (combination of bending moment and support reaction). The test results are used to develop design rules for this type of profiles.

- Curved profiles
  The subjects are trapezoidal or sinusoidal sheets, which are curved by bending or rollforming during manufacturing. The influence of this manufacturing procedure on the load bearing capacity, in particular on the bending moment capacity, in comparison with the straight profile is investigated. Furthermore the bearing behavior under combined bending moment and axial compression, as it happens in curved sheets which work as an arch, is verified by some tests.

- Liner trays
  In order to improve and to broaden the design rules according EN 1993-1-3 for liner trays the effect of the stabilization of the liner trays by the outward cladding is studied. The tests comprise liner trays with directly fastened cladding – perpendicularly orientated – and with cladding in the parallel direction orientated, which is fixed to the liner trays using intermediate profiles (spacers). The second configuration includes also the composite effect of the outward cladding.

- Assembled profiles
  Assembled profiles in the GRISPE context are trapezoidal profiles which perform an overlapping joint at intermediate supports or which are doubled locally at intermediate supports. On the basis of tests, the increase of the bearing capacity compared to a single continuous profile without overlap or reinforcement is studied. The design model for the overlap joint according to DIN 18807 is verified by tests.

All tests are carried out according to the testing rules of EN 1993-1-3 or DIN 18807. Tests with simulation of uniformly distributed loads are executed in a vacuum chamber. The load is applied by air pressure instead of several line loads. This mode to apply the test load is in conformity with the mentioned standards.

2 Corrugated sheeting

Tested profiles:	sinusoidal profile Bacacier 18/76
	sinusoidal profile Bacacier 46/150
thickness of the test specimen	0,63 mm; 1,00 mm

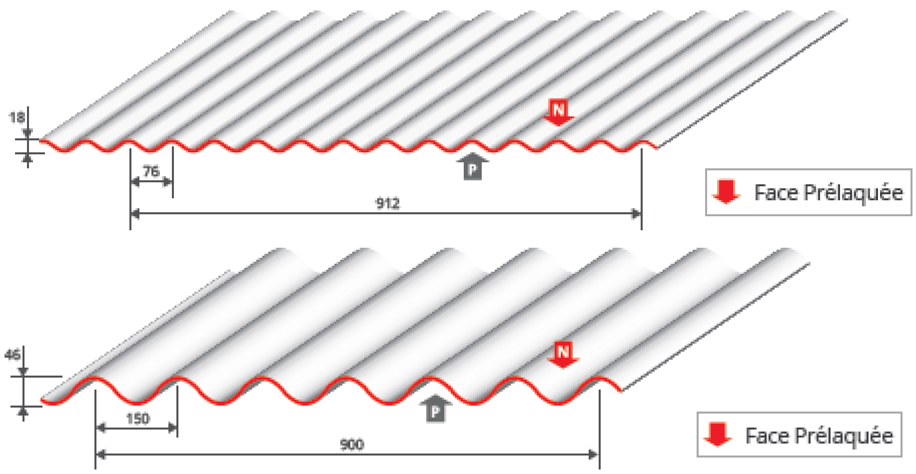

Fig. 1: Tested profiles Sinus 18/76 and Sinus 46/150

Aims of the experimental investigation

a) ultimate bending moment of the corrugated cross section

The ultimate bending moment and the effective moment of inertia are determined by load tests with single span sheets, which are loaded with uniformly distributed air pressure (see fig. 2). Therefore, the test specimen is installed in a vacuum chamber. In order to control and to verify the imposed load, the air pressure as well as the support reactions are measured.

Both profiles are different concerning the r/t-ratios of the sinusoidal waves. Furthermore, the sheet thickness is varied to cover a wide range of slenderness ratios r/t. The details of the test parameters are given in table 1.

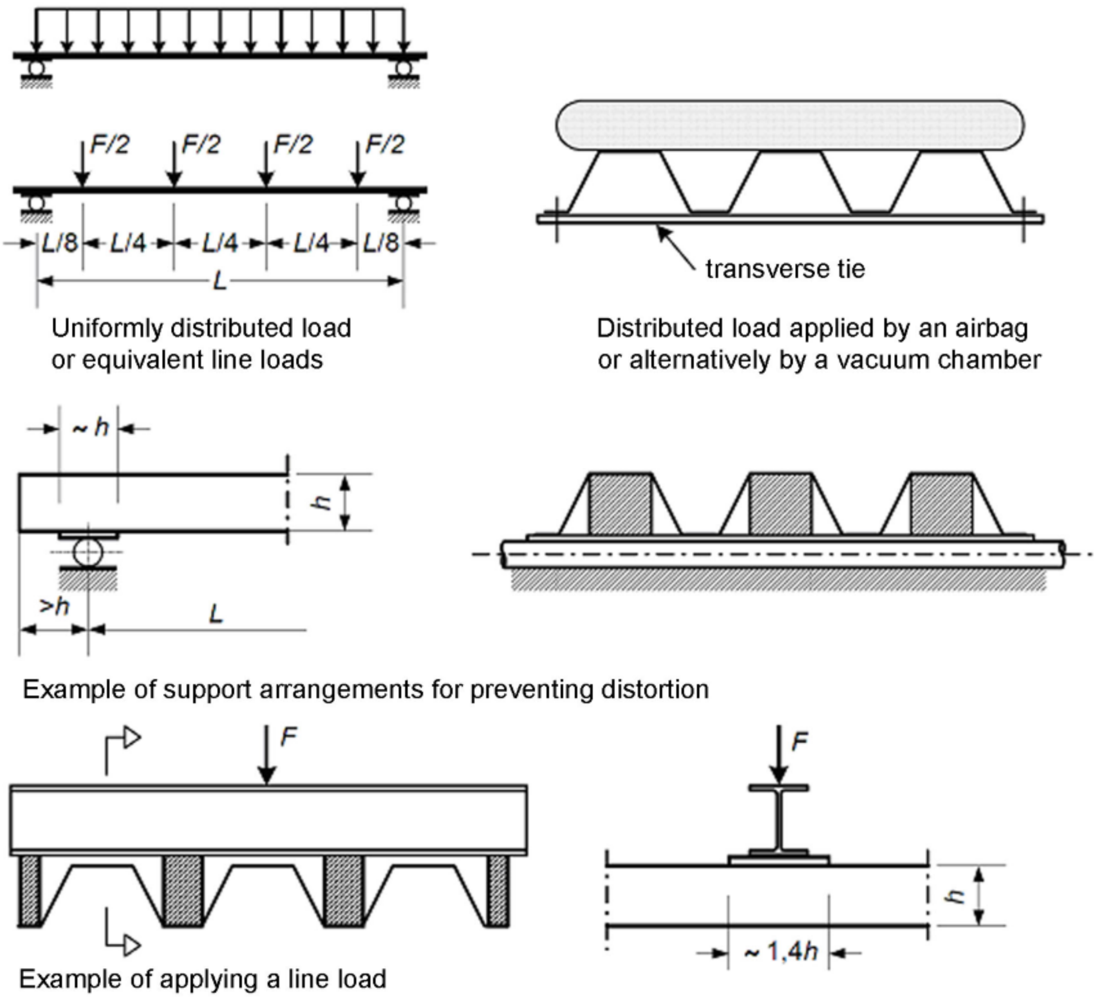

Fig. 2: Test principle of single span load tests in order to determine the bending moment capacity and the effective bending stiffness

b) load bearing capacity at intermediate supports

The load bearing capacity at intermediate supports under combined bending moment and support reaction is determined by 3-point bending tests on sheets placed as single span beam. The introduced line load represents the support reaction in reality.

Modeling the load case downward loading, the test load is introduced as a transverse compression force on top of the test specimen. The width of the support and the sheet thickness are varied to cover the real range of these parameters in practice. The span length influences the M-R-ratio at the support. For short span lengths, the support reaction is dominant, for greater span lengths the bending moment.

For the load case uplift loading, the type of fastening influences the load bearing capacity. The load is applied by a traverse, which is fixed to the specimen. When the sheets are fixed in the valley, the load is introduced as a tension force in the lower part of the profile. Fastening in the crest leads to a compression force on top of the profile. By varying the span length, the M-R-ratio at the support is changed.
The details of the test parameters are given in table 1.

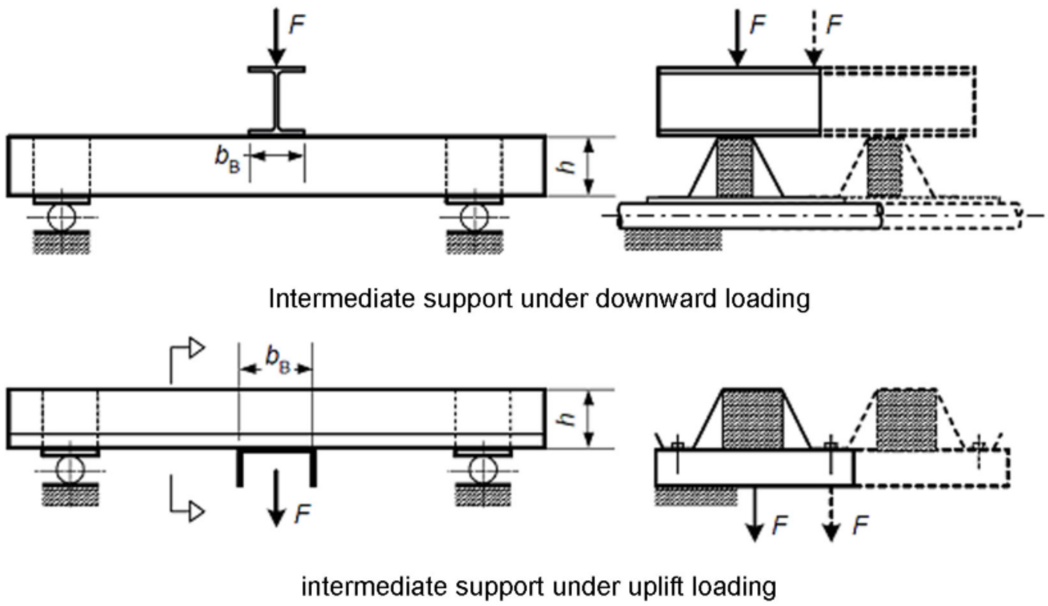

Fig. 3: Test principle of intermediate support test, downward loading and uplift loading

c) **load bearing capacity at end supports**
The load bearing capacity at end supports is determined by 3-point bending tests on sheets placed as single span beam. The test load is introduced as a line load near to the interesting end support.
The details of the test parameters are given in table 1.

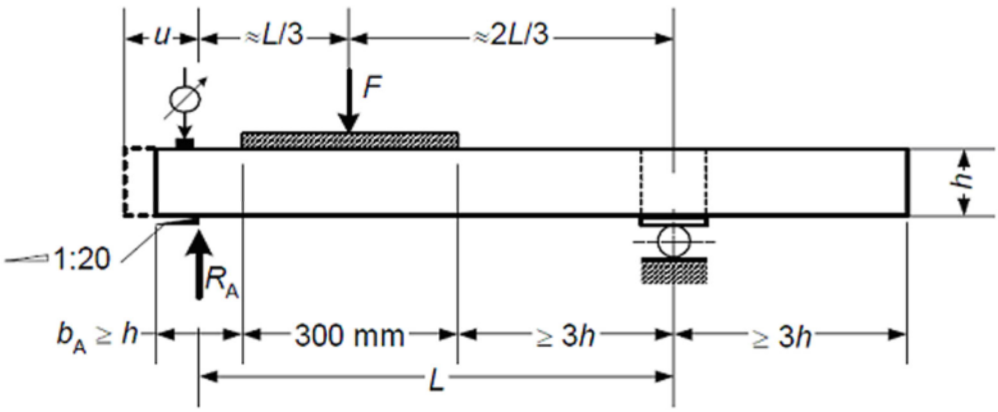

Fig. 4: Test setup of end support test, downward loading

Type of profile	Type of test	thickness [mm]	support width [mm] / Fastening	span [m]	number of identical tests	Total number of tests
Bacacier 18/76	vacuum chamber, single span	0,63	-	1,50	3	6
		1,00	-	2,00	3	
	3-point bending intermediate support downward load	0,63	10	0,40	2	16
				0,80	2	
			40	0,40	2	
				0,80	2	
		1,00	10	0,40	2	
				1,00	2	
			40	0,40	2	
				1,00	2	
	3-point bending intermediate support uplift load	0,63	valley	0,40	2	16
				0,80	2	
			crest	0,40	2	
				0,80	2	
		1,00	valley	0,40	2	
				1,00	2	
			crest	0,40	2	
				1,00	2	
	3-point bending end support downward load	0,63	0	1,00	3	6
		1,00		1,00	3	
	tensile tests	0,63			3	6
		1,00			3	
Bacacier 46/150	vacuum chamber, single span	0,63	-	2,00	3	6
		1,00	-	3,00	3	
	3-point bending intermediate support downward load	0,63	10	0,60	2	16
				1,00	2	
			40	0,60	2	
				1,00	2	
		1,00	10	0,60	2	
				1,20	2	
			40	0,60	2	
				1,20	2	
	3-point bending intermediate support uplift load	0,63	valley	0,60	2	16
				1,00	2	
			crest	0,60	2	
				1,00	2	
		1,00	valley	0,60	2	
				1,20	2	
			crest	0,60	2	
				1,20	2	
	3-point bending end support downward load	0,63	0	1,00	3	6
		1,00		1,00	3	
	tensile tests	0,63			3	6
		1,00			3	
	Total number test with profiles					**88**
	Total number tensile tests					**12**

Table 1: List of tests for corrugated sheets

3 Curved profiles

Tested profiles:	trapezoidal profile without stiffeners Bacacier 35/207 trapezoidal profile with stiffeners Bacacier 45/333 sinusoidal profile Bacacier 46/150
thickness of the test specimen	0,63 mm; 1,00 mm

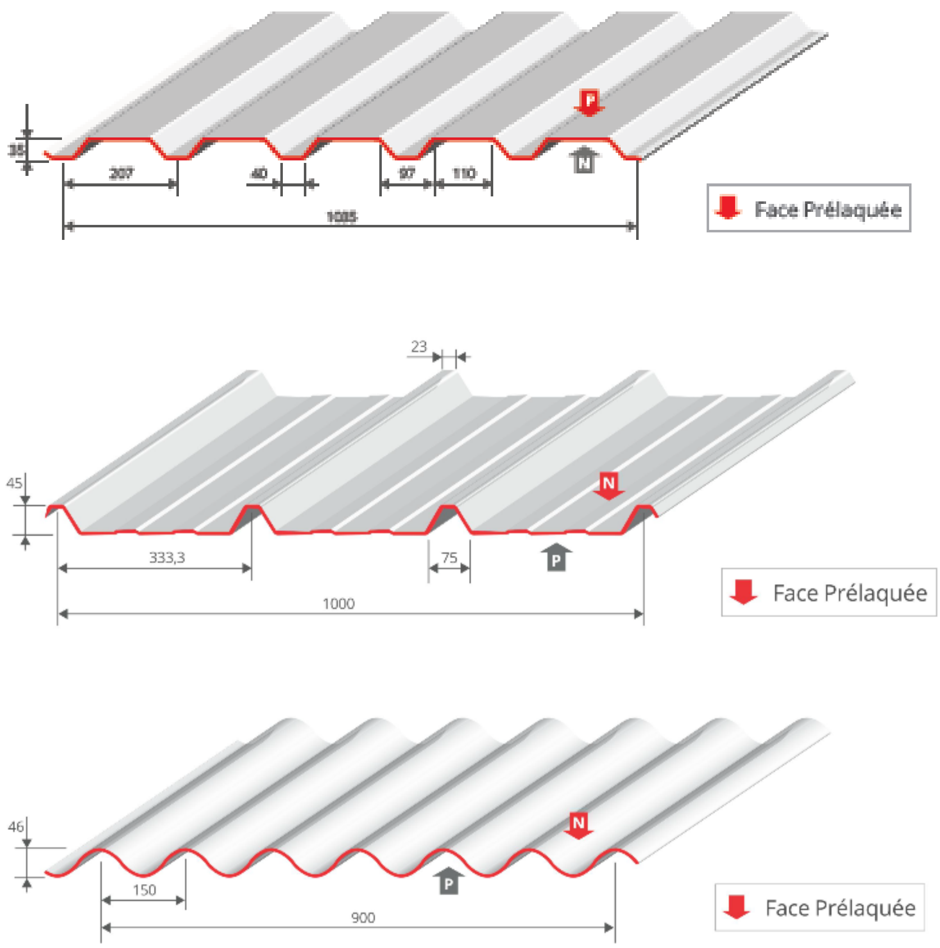

Fig. 5: Tested profiles Bacacier 35/207, 45/333 and Sinus 46/150

Aim of the experimental investigation

The study focuses on profiles, which were curved during manufacturing by bending/roll-forming. By this process, internal stresses are created in the cross section of the profile which may influence the ultimate bending moment and the ultimate axial compression force of the profile. The ultimate bending moment and the effective moment of inertia are determined by load tests with curved single span sheets, which are loaded with two or four vertical line loads to simulate uniformly distributed load. The test specimens are placed on supports which are movable in horizontal direction. Therefore, no axial forces can appear in the apex of the curved specimen where the bending moment becomes a maximum. The test setup is in principle the same as for straight profiles (see fig. 2). The radius of curvature is varying to see the influence on the internal stresses and on the bending moment capacity of the profile.

Some more tests are performed with curved profiles, which are placed on horizontally fixed supports. The profiles work as an arch, the profile is stressed by bending moments and axial compression forces. These tests are executed in order to verify the design formula for combined bending moment/axial compression given in EN 1993-1-3. Because this formula is valid for trapezoidal sheets, these tests are not done with the sinusoidal profile. By varying the span of the specimen different slopes are performed and consequently different ratios bending moment/axial compression.

The details of the test parameters are given in table 2

Type of profile	Type of test	thickness [mm]	radius of curvature [m]	span [m]	number of identical tests	total number of tests
Bacacier 35/207	6- or 4-point bending, depending of the radius	0,63	4	3,00	2	12
			10	3,00	2	
			20	3,00	2	
		1,00	4	4,00	2	
			10	4,00	2	
			20	4,00	2	
	4-point bending with horizontal support	0,63	10	3,00	2	4
				8,00	2	
	tensile tests	0,63			3	6
		1,00			3	
Bacacier 45/333	6- or 4-point bending, depending of the radius	0,63	4	3,00	2	12
			10	3,00	2	
			20	3,00	2	
		1,00	4	4,00	2	
			10	4,00	2	
			20	4,00	2	
	4-point bending with horizontal support	0,63	10	3,00	2	4
				8,00	2	
	tensile tests	0,63			3	6
		1,00			3	
Bacacier 18/76	6- or 4-point bending, depending of the radius	0,63	4	3,00	2	12
			10	3,00	2	
			20	3,00	2	
		1,00	4	4,00	2	
			10	4,00	2	
			20	4,00	2	
	tensile tests	0,63			3	6
		1,00			3	
	Total number test with profiles					**44**
	Total number tensile tests					**18**

Table 2: List of tests for curved profiles

4 Liner trays

Tested profiles: Joris Ide 110/600
Joris Ide 160/600
thickness of the test specimen 0,75 mm; 1,00 mm

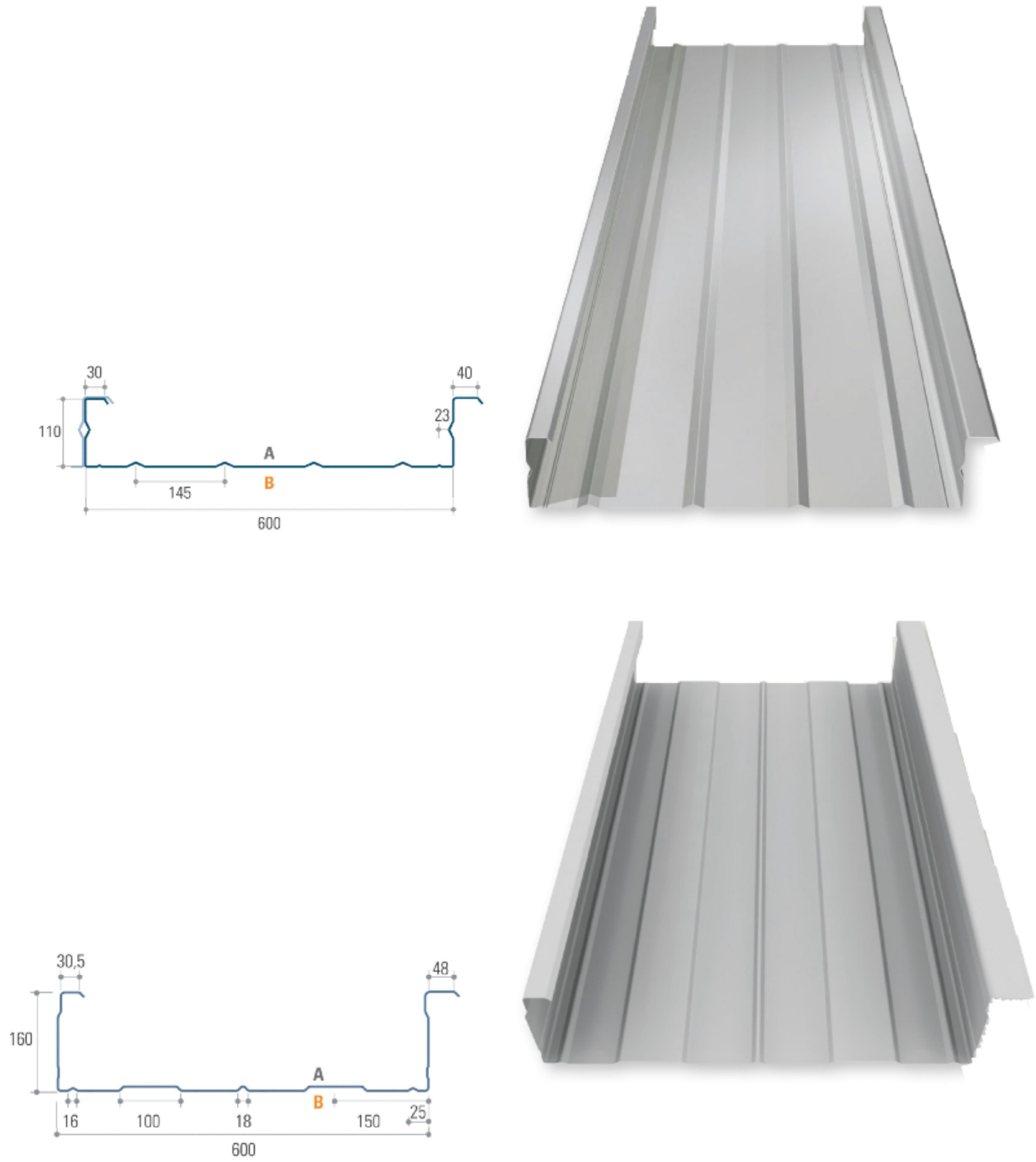

Fig. 5: Tested liner trays Joris Ide 110/600 and 160/600

Aim of the experimental investigation

Based on tests, the design procedure according EN 1993-1-3 for liner trays shall be improved and extended. Especially the lateral stabilization of the small flanges, which is taken into account by the coefficient β_b, depending of the distance of the fastenings of the outward cladding s_1, is considered. Therefore, single span tests for downward loading and intermediate support tests for uplift loading are carried out with different distances s_1. In both test configurations, the liner trays are charged by positive bending moments, and the small flanges of the liner trays are compressed and therefore affected by lateral buckling. By varying the distance s_1 and by choosing two different liner trays with different widths of the small flanges, a wide range of buckling slenderness values of the small flanges is covered. Test setup for single span tests see fig. 2, test setup for intermediate support tests see fig. 3.

Additional tests are carried out for wall constructions, where the outward cladding is orientated in the same sense like the liner trays and placed on perpendicular spacers with Z- or Omega-cross section. In that case, the center-center distance of the spacers is the fastening's distance s_1. By the composite effect of this type of wall construction – the outward cladding works as a tension- or compression-flange of the overall cross section – the load bearing behavior is expected to be more favorable, especially for double- or multi-span systems. The contribution of the outward cladding depends of the stiffness of the spacer profiles; different dimensions of the spacers are investigated. The test specimen is installed in a vacuum chamber. In order to control and to verify the imposed load, the air pressure as well as the support reactions are measured.

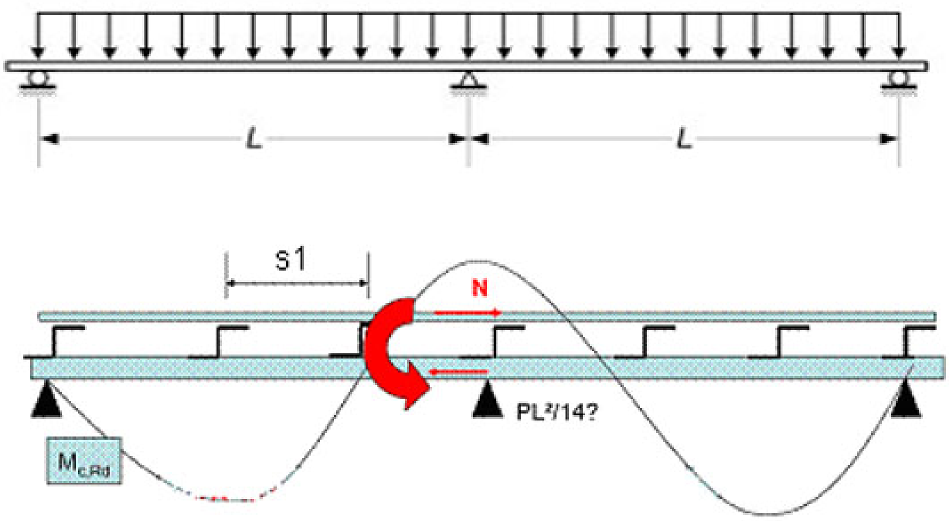

Fig. 6: Test principle double span load tests

The details of the test parameters are presented in table 3.

Type of profile	Type of test	thickness [mm]	cladding	distance s_1 [mm]	span [m]	number of identical tests	total number of tests
JI 110/600	vacuum chamber, single span	0,75	35/207-0,63 perpendicular	621	6,00	2	32
				1242	6,00	2	
				1863	6,00	2	
		1,00		621	6,00	2	
				1242	6,00	2	
				1863	6,00	2	
	vacuum chamber, double span	0,75	35/207-0,63 parallel Z-spacers 50 mm	1863	4,00	2	
			omega spacers 50 mm	1863	4,00	2	
			Z-spacers 200 mm	1863	4,00	2	
			omega spacers 200 mm	1863	4,00	2	
	3-point bending intermediate support uplift load	0,75	35/207-0,63 perpendicular	621	2,00	2	
				1242	2,00	2	
				1863	2,00	2	
		1,00		621	2,00	2	
				1242	2,00	2	
				1863	2,00	2	
	tensile tests	0,75				3	6
		1,00				3	
JI 160/600	vacuum chamber, single span	0,75	35/207-0,63 perpendicular	621	6,00	2	24
				1242	6,00	2	
				1863	6,00	2	
		1,00		621	6,00	2	
				1242	6,00	2	
				1863	6,00	2	
	3-point bending intermediate support uplift load	0,75	35/207-0,63 perpendicular	621	2,00	2	
				1242	2,00	2	
				1863	2,00	2	
		1,00		621	2,00	2	
				1242	2,00	2	
				1863	2,00	2	
	tensile tests	0,75				3	6
		1,00				3	
	Total number test with profiles						**56**
	Total number tensile tests						**12**

Table 3: List of tests for liner trays

5 Assembled Profiles

Tested profiles:	Joris Ide 135/310 Joris Ide 158/250
thickness of the test specimen	0,75 mm; 1,00 mm

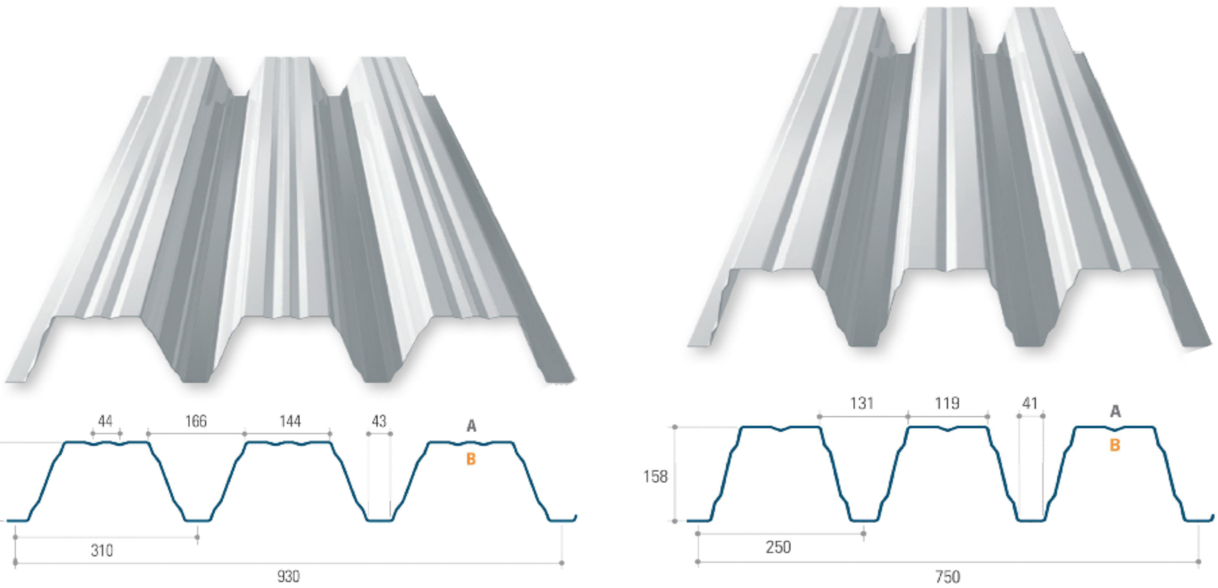

Fig. 5: Tested trapezoidal profiles Joris Ide 135/310 and 158/250

The profile 135/310 consists of relatively wide ribs with not so steep webs; assembling this type of trapezoidal sheeting the overlapping ends fit well. The profile 158/250 consists of high, narrow ribs with steep webs; assembling this type of profile leads to a small gap between the sheets. Among the usual roofing profiles, these two types cover the full range regarding the slope of the webs and therefore the quality how good the ends of the sheets fit together.

For trapezoidal roofing profiles which are used with span lengths of several meters, it can be useful or necessary to execute transverse joints with overlap. Three types of joints are considered:

Overlap joint according to DIN 18807
This joint consists of an overlap at one side of the support. This joint is a suitable solution to avoid single span systems, which are very unfavorable due to their big deflections, or double span systems, which are unfavorable due to their moment distribution and to the unequal loading of the substructure like frames or girders – and this can be achieved with reasonable sheet lengths regarding the handling during erection. So, single or double span sheets can be assembled to continuous systems over 3 spans at least. The purpose of this joint is a continuous assembling of the sheets without increase of the bending moment resistance of the overlapping sheets compared to a single continuous sheet.

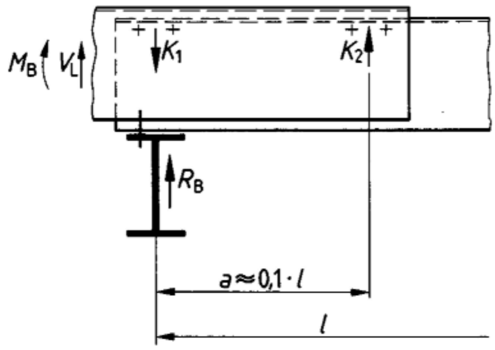

Fig. 8: Overlap joint according to DIN 18807

Overlap joint
This joint consists of overlaps at both sides of the support. Beside the continuity at the sheet's ends, this type of joint increases the load bearing capacity of the system compared to a single continuous sheet.

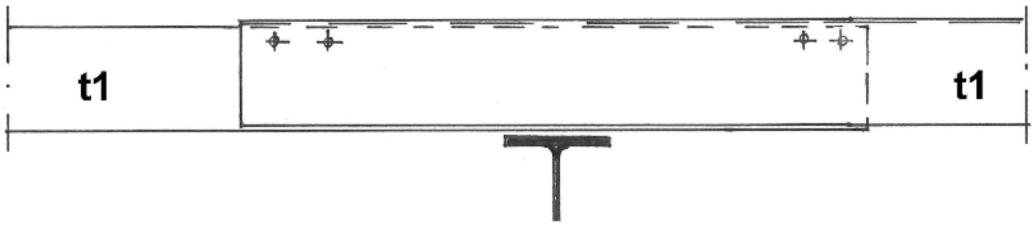

Fig. 9: Overlap joint

Continuous sheet with local reinforcement
This mode of profile's assembling is a possibility to create locally higher load bearing capacity. This solution can be useful in cases if exceptionally higher load bearing capacity is required for instance caused by snow accumulations or unequal spans.

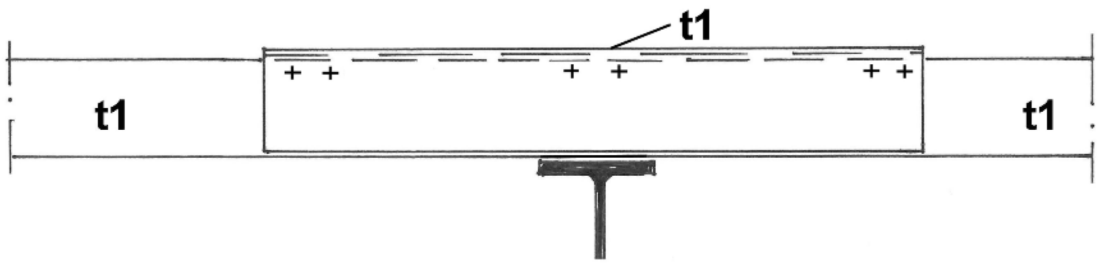

Fig. 9: Continuous profile with local reinforcement

Aim of the experimental investigation

In order to study the load bearing behavior at intermediate supports, namely the bending moment resistance and the resistance against local forces, intermediate support tests for downward loading are carried out. The test principle is shown in fig. 3.

Tests with single sheets constitute the basis for the comparison with the different types of joints. The tests with overlaps according to DIN 18807 are executed to verify the design rules specified in DIN 18807 which concern the fasteners. The resistance of the profile is taken as equal to the resistance of a single continuous sheet. Tests with both side overlaps and with continuous profiles with reinforcement will give the basis for new design rules which take into account the enhanced load bearing capacity in comparison with a single continuous profile.

Variation of the span length controls the M-R-ratio at the support: for short span lengths, .the support reaction is dominant for the failure of the profile, great span lengths lead to a bending moment dominated failure. Furthermore, the sheet thickness and the width of the support are varied. The details of the test parameters are presented in table 4.

Type of profile	Type of test	Type of assembling	thickness [mm]	support width [mm]	span [m]	number of identical tests	total number of tests
JI 135/310	3-point bending intermediate support downward load	Continuous profile	0,75	60	0,80	2	64
					2,40	2	
				160	0,80	2	
					2,40	2	
			1,00	60	0,80	2	
					2,80	2	
				160	0,80	2	
					2,80	2	
		Joint according DIN 18807	0,75	60	0,80	2	
					2,40	2	
				160	0,80	2	
					2,40	2	
			1,00	60	0,80	2	
					2,80	2	
				160	0,80	2	
					2,80	2	
		Overlap	0,75	60	0,80	2	
					2,40	2	
				160	0,80	2	
					2,40	2	
			1,00	60	0,80	2	
					2,80	2	
				160	0,80	2	
					2,80	2	
		Continuous profile with reeinforcement	0,75	60	0,80	2	
					2,40	2	
				160	0,80	2	
					2,40	2	
			1,00	60	0,80	2	
					2,80	2	
				160	0,80	2	
					2,80	2	
	tensile tests		0,75			3	6
			1,00			3	

Table 4: List of tests for assembled profiles

Type of profile	Type of test	Type of assembling	thickness [mm]	support width [mm]	span [m]	number of identical tests	total number of tests
JI 158/250	3-point bending intermediate support downward load	Continuous profile	0,75	60	0,80	2	64
					2,80	2	
				160	0,80	2	
					2,80	2	
			1,00	60	0,80	2	
					3,20	2	
				160	0,80	2	
					3,20	2	
		Joint according DIN 18807	0,75	60	0,80	2	
					2,80	2	
				160	0,80	2	
					2,80	2	
			1,00	60	0,80	2	
					3,20	2	
				160	0,80	2	
					3,20	2	
		Overlap	0,75	60	0,80	2	
					2,80	2	
				160	0,80	2	
					2,80	2	
			1,00	60	0,80	2	
					3,20	2	
				160	0,80	2	
					3,20	2	
		Continuous profile with reeinforcement	0,75	60	0,80	2	
					2,80	2	
				160	0,80	2	
					2,80	2	
			1,00	60	0,80	2	
					3,20	2	
				160	0,80	2	
					3,20	2	
	tensile tests		0,75			3	6
			1,00			3	
	Total number test with profiles						**128**
	Total number tensile tests						**12**

Table 4 (continued): List of tests for assembled profiles

6 Tensile tests

As far as possible the test specimens should be produced from the same coil in order to minimize the spread of the material's characteristics of the specimens. From each family of test specimens coming form the same coil, 3 samples are taken. By tensile tests, the material properties core thickness, yield strength, tensile strength and elongation at fracture are determined for each family.