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 liner trays

31st October 2015

Deliverable D 2.5

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

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D 2.5 WP2 Background and draft annexes for EN 1993-1-3 for liner trays	***Due date : 31.10.2015*** ***Completion date: 31.12.2015***

1. Introduction

Façades with liner trays are mostly cladded with trapezoidal sheeting on the outer side. In general, the outer cladding works as a diaphragm and stabilizes the small flanges of the liner trays against lateral displacements. The stabilizing effect depends on the distance s_1 between the fixings of the outer cladding.

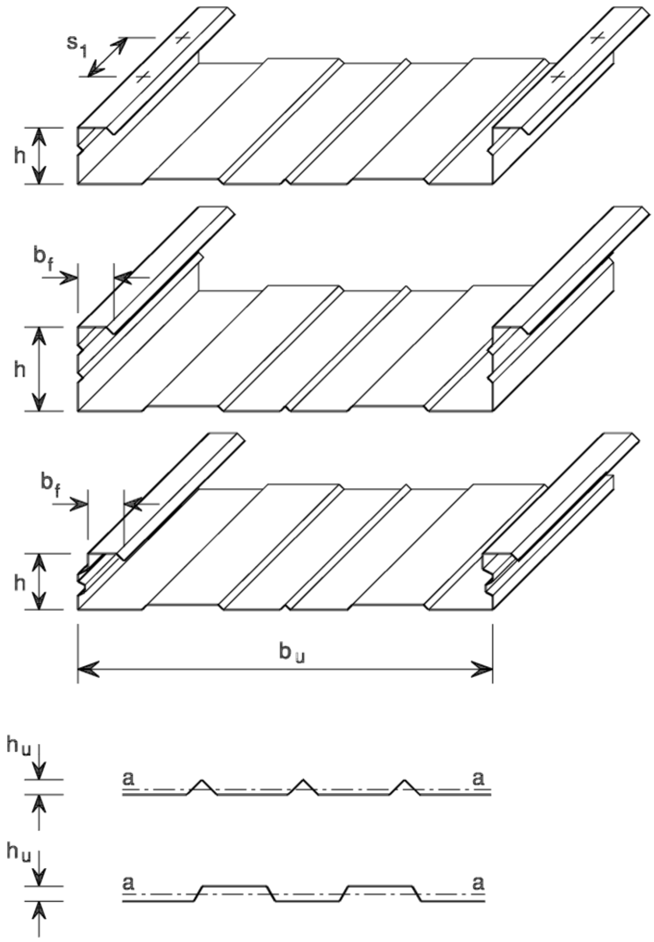


Fig.1: Typically design of liner trays [1]

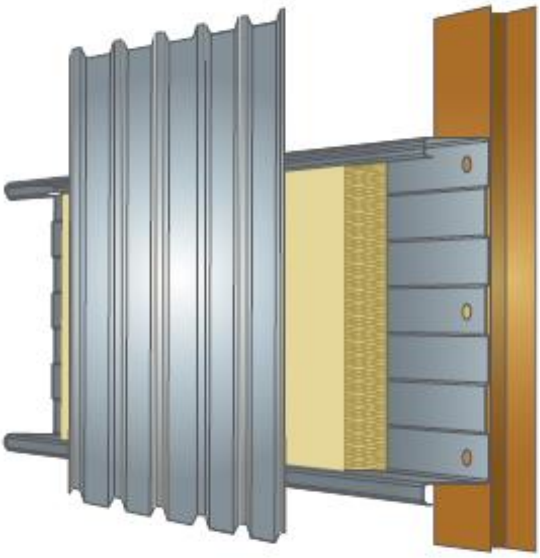


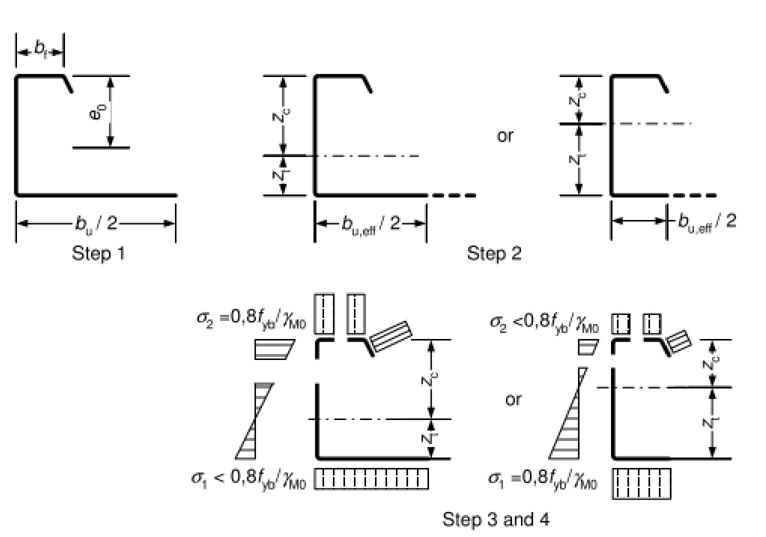
Fig. 2: Typically two layer build-up wall cladding system with liner trays

The positive bending moment is the load bearing value, which is influenced by the fixing distance s_1. Under positive bending moment, the small flanges of the liner trays are compressed; the bearing capacity is reached, when the small flanges fail by lateral buckling. The fixing distance s_1 controls the buckling length of the small flanges and therefore the ultimate bending moment of the liner trays.

As we could see in the state of the art [2] European Standard EN 1993-1-3 [1] deals with a design models for bending which is valid in the following range

0,75 mm	$\leq$	t_{nom}	$\leq$	1,5 mm
30 mm	$\leq$	b_f	$\leq$	60 mm
60 mm	$\leq$	h	$\leq$	200 mm
300 mm	$\leq$	b_u	$\leq$	600 mm
		I_a / b_u	$\leq$	10 mm^4/mm
		s_1	$\leq$	1000 mm

Fig. 3: Range of validity of design model in EN 1993-1-3



$$M_{b,Rd} = 0{,}8\ \beta_b\ W_{eff,com} f_{yb} / \gamma_{M0}$$

with:

$$W_{eff,com} = I_{y,eff} / z_c$$

$$W_{eff,t} = I_{y,eff} / z_t$$

in which the correlation factor β_b is given

- if $s_1 \leq 300$ mm:

$$\beta_b = 1{,}0$$

- if $300 \text{ mm} \leq s_1 \leq 1000$ mm:

$$\beta_b = 1{,}15 - s_1 / 2000$$

Figure 10.11: Determination of moment resistance — wide flange in tension

Fig. 4: Design model in EN 1993-1-3 for small flange in compression (wide flange in tension)

Inside this range the load bearing capacity can be calculated (under consideration of flange curling according to [3]). Outside this range the only possibility it to determine the load-bearing capacity by testing according to annex A in [1].

The aim of the GRISPE project is to develop a design model for distance values $s_1 > 1000$ mm and to research the influence of the fixing distance s_1 on the bending moment capacity of liner trays as well as to improve the coefficient β_b and to extend the application range.

Because the actual design rule to take into account the effect of the fixing distance s1 is rather conservative, and furthermore limited to a maximum fixing distance s1 = 1000 mm. Both aspects will be improved.

Therefore two types of tests were executed; both tests lead to positive bending moments in the liner trays. Single span tests with positive loading simulating the situation in the span of the liner trays under wind pressure and 3-point-bending-tests, which represent the area at intermediate supports under wind suction load, were executed. By varying the distance s_1 the influence on the load bearing capacity of the liner trays was studied.

In the test report D 2.3 [4] the test range and the results are documented. The tests are evaluated and the ultimate bending moments of the liner trays depending of the fixing distance s_1 were determined in D 2.4 [5].

2. Acquired data through GRISPE project

In the GRISPE project a large test program was performed to determine the influence of the distance s_1 on the load bearing capacity of liner trays in bending.

Type of test	Profile	Nominal thickness [mm]	Span [mm]	Distance s_1 [mm]	Distance profile	Number of tests
Single span test, positive bending	JI D_110-600SR	0.75 and 1.00	6000	621	-	4
				1242	-	5
				1863	-	4
				-	-	4*)
	JI D_160-600SR	0.75 and 1.00		621	-	4
				1242	-	5
				1863	-	4
				-	-	4*)
Internal support, load case uplift loading	JI D_110-600SR	0.75 and 1.00	2000	621	-	4
				1242	-	4
				1863	-	4
				-	-	2*)
	JI D_160-600SR	0.75 and 1.00		621	-	4
				1242	-	4
				1863	-	4
				-	-	2*)
Double span test, positive bending	JI D_110-600SR	0.75	2 x 4000	1863	Z-profile h=50mm	2
					Z-profile h=200mm	2
					Omega-profile h=50mm	2
					Omega-profile h=200mm	2
					Z-profile h=50mm	1*)

*) without trapezoidal sheet

Table 1: Tests performed

Two different liner trays in two thicknesses were tested. They are shown in Figure 4 and 5.

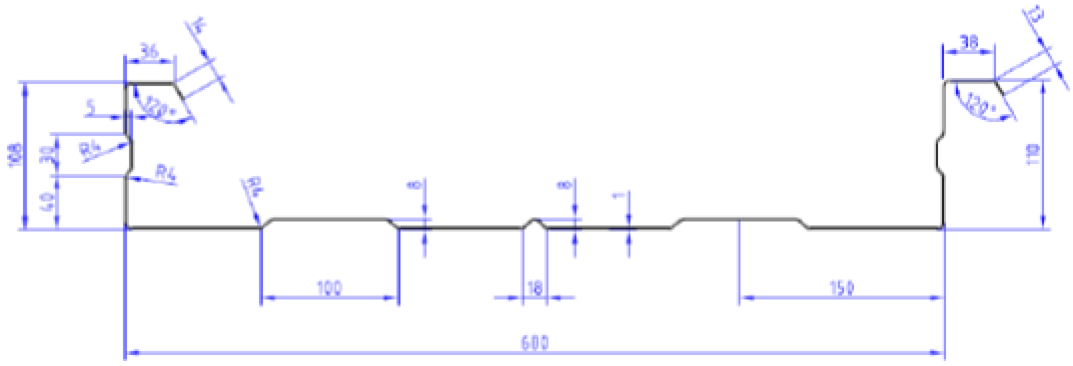


Fig. 5: Cross section of the liner tray JID 110/600

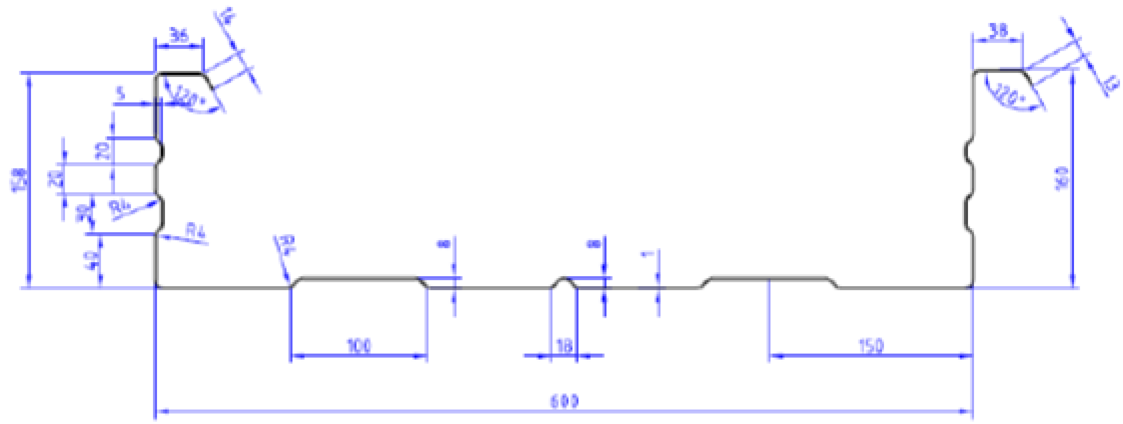


Fig. 6: Cross section of the liner tray JID 110/600

As outer cladding trapezoidal sheets JID 35/207, sheet thickness 0,63 mm, were used.

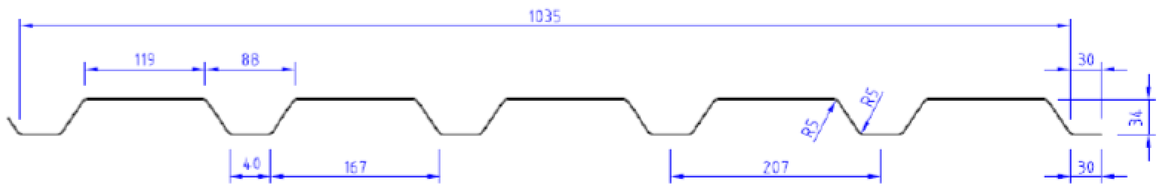


Fig. 7: Cross section of the trapezoidal sheeting JID 35/207

Detailed information of the test setups and the test results are documented in [4].
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:

<u>Single span tests:</u>

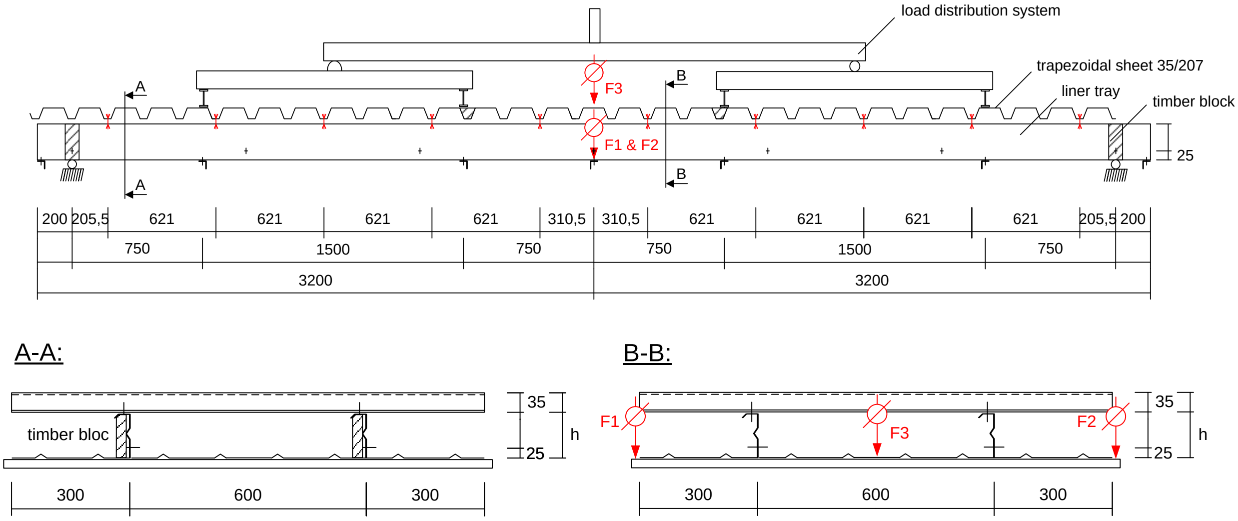


Fig. 8: Test setup single span tests

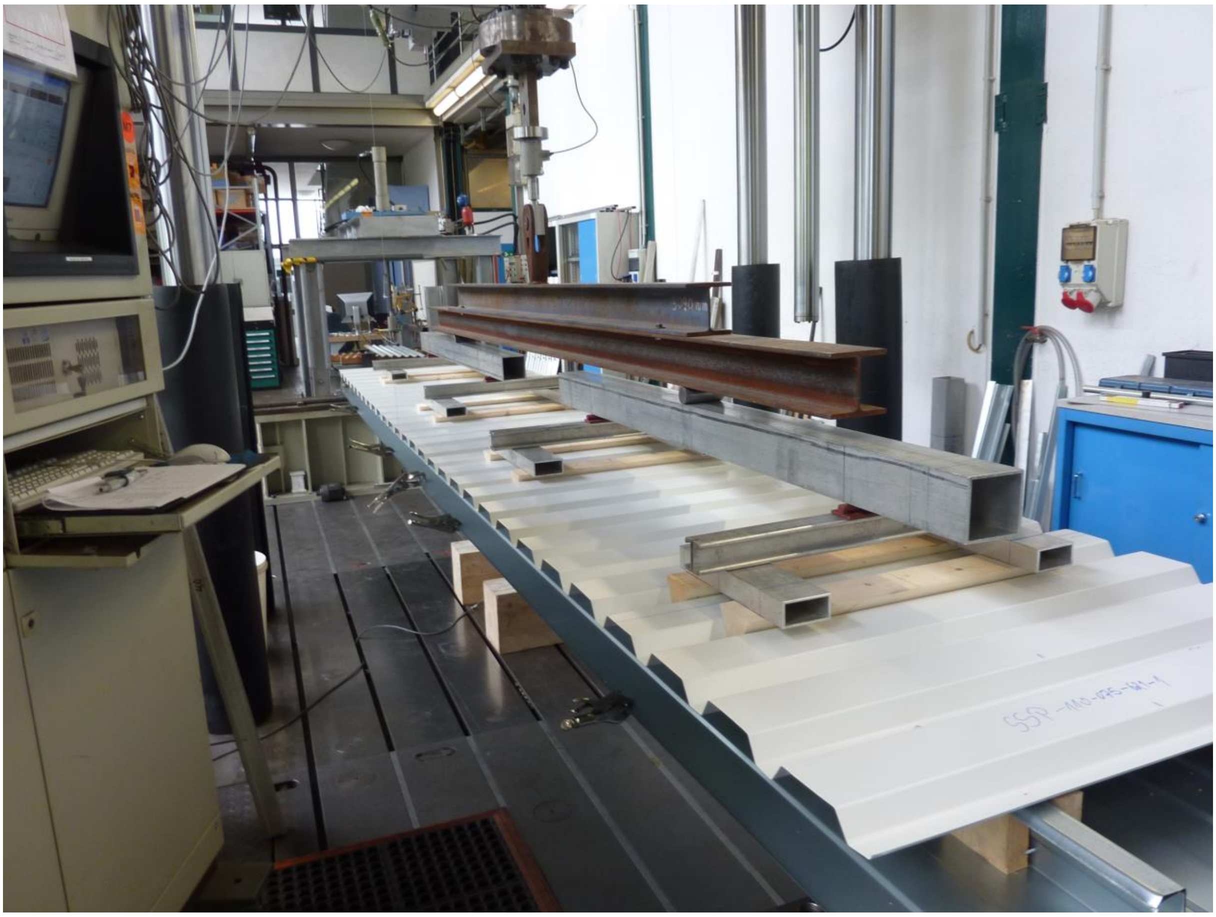


Fig. 9: Picture of the test setup single span tests

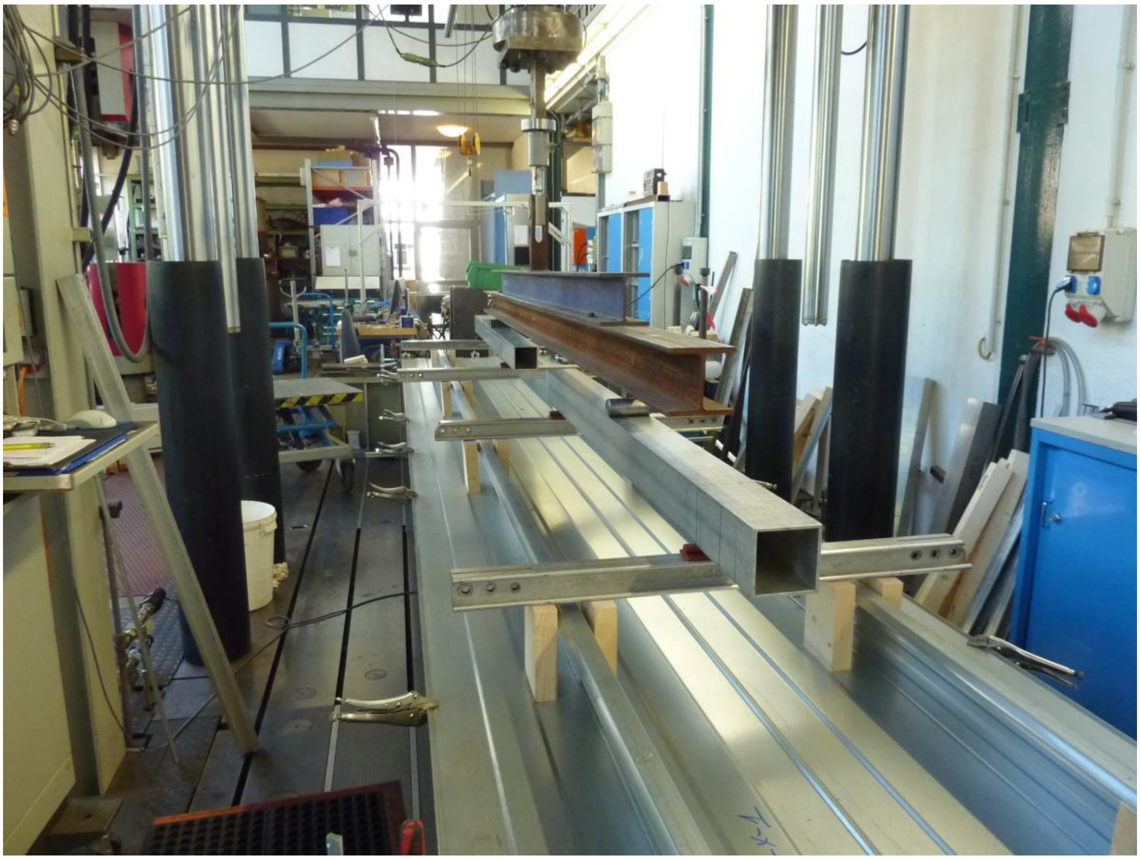


Fig. 10: Picture of the test setup single span tests without outer cladding

s_1 mm	ultimate span moment $M_{c,Rk,F}$ (kNm/m)			
	JID 110-0.75	JID 110-1.00	JID 160-0.75	JID 160-1.00
621	3.50	6.54	5.35	9.92
1242	3.19	6.05	3.87	7.93
1863	2.98	5.71	3.56	6.61
6000[1)]	2.69	5.59	2.94	6.34

1) Tests without outer cladding

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

In order to determine the lower limit of the bending moment capacity of the liner trays, tests with pure liner trays without any outer cladding were performed. In that case, no stabilizing effect of the outer cladding exists. The compressed small flanges of the liner trays are only stabilized against lateral buckling by the lateral bending stiffness of the webs of the liner trays and not by any restraining outer cladding. The buckling length of the small flanges is round about the span length.

The following figure 10 shows the results related to the characteristic bending moment for a fixing distance s_1 = 621 mm.

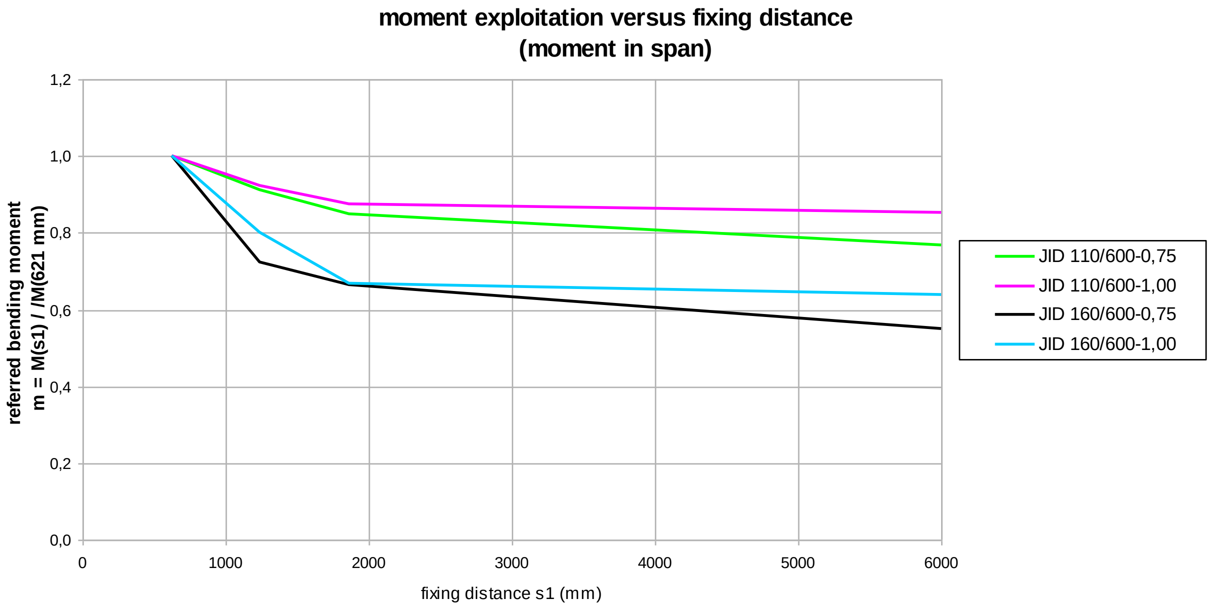


Fig. 11: Graphic view of the test results: related characteristic bending moment depending of the fixing distance s_1

The effect of the fixing distance s_1 on the bending moment is very similar for different sheet thicknesses; but the height of the liner tray plays a more important roll. For higher liner trays the drop of the bending moment with increasing fixing distance is greater.

<u>Internal support tests:</u>

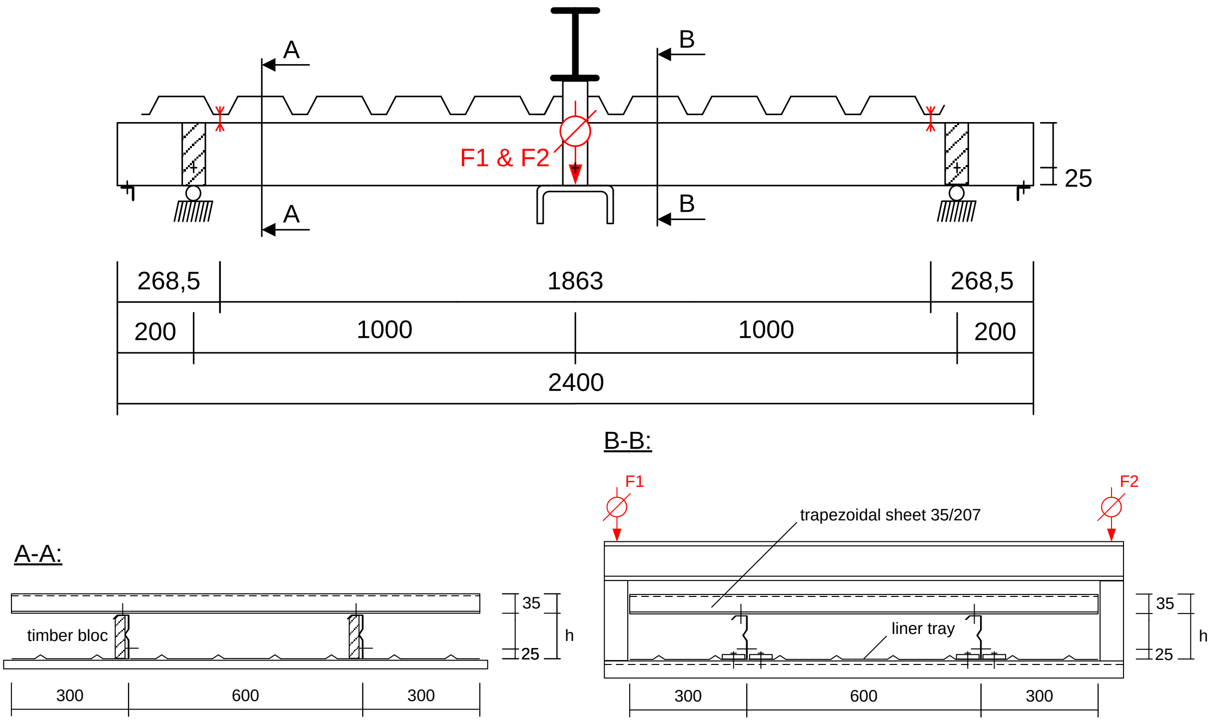


Fig. 12: Test setup internal support tests

Fig. 13: Picture of the test setup internal support tests

s_1	ultimate span moment $M_{c,Rk,F}$ (kNm/m)			
Mm	JID 110-0.75	JID 110-1.00	JID 160-0.75	JID 160-1.00
621	4.09	6.88	5.83	9.63
1242	2.96	5.47	3.98	7.40
1863	2.97	5.65	3.86	7.44
2000[1)]	2.79	5.17	3.04	6.85

1) Tests without outer cladding

Table 3: Test results (characteristic bending moment at support) of the internal support tests

The following figure 13 shows the results related to the characteristic bending moment for a fixing distance s_1 = 621 mm.

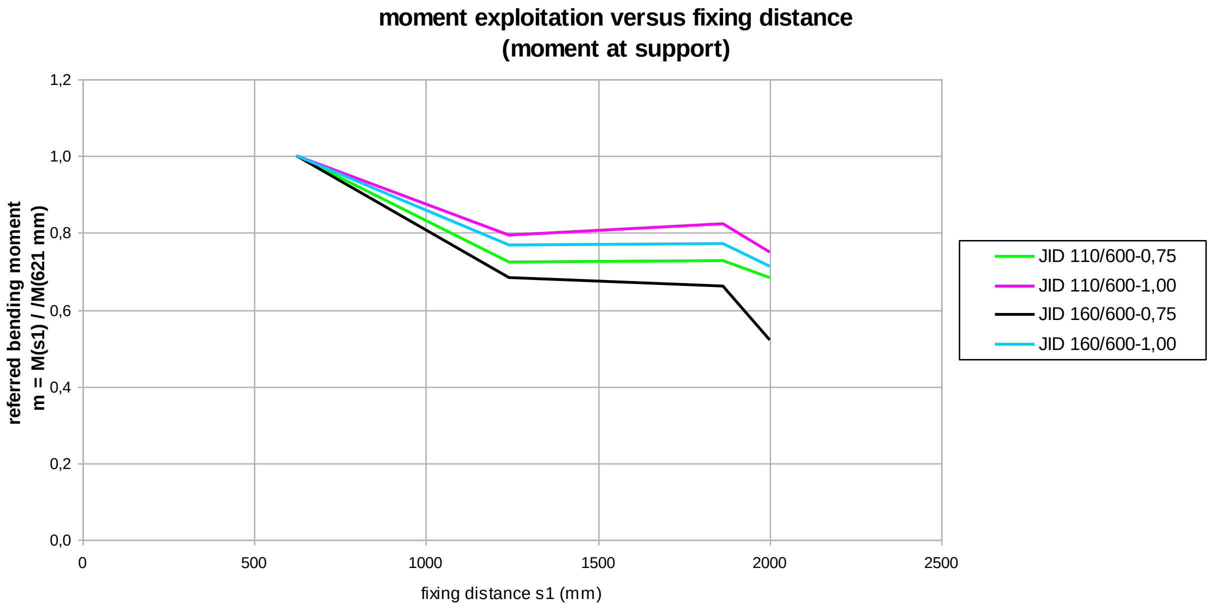


Fig. 14: Graphic view of the test results: characteristic bending moment at support depending of the fixing distance s_1

The effect of the fixing distance s_1 on the bending moment is very similar for different sheet thicknesses; but the height of the liner tray plays a not so important role as in the single span tests. More detailed information of the analysis and interpretation of the test results are documented in [5].

<u>Double span tests:</u>

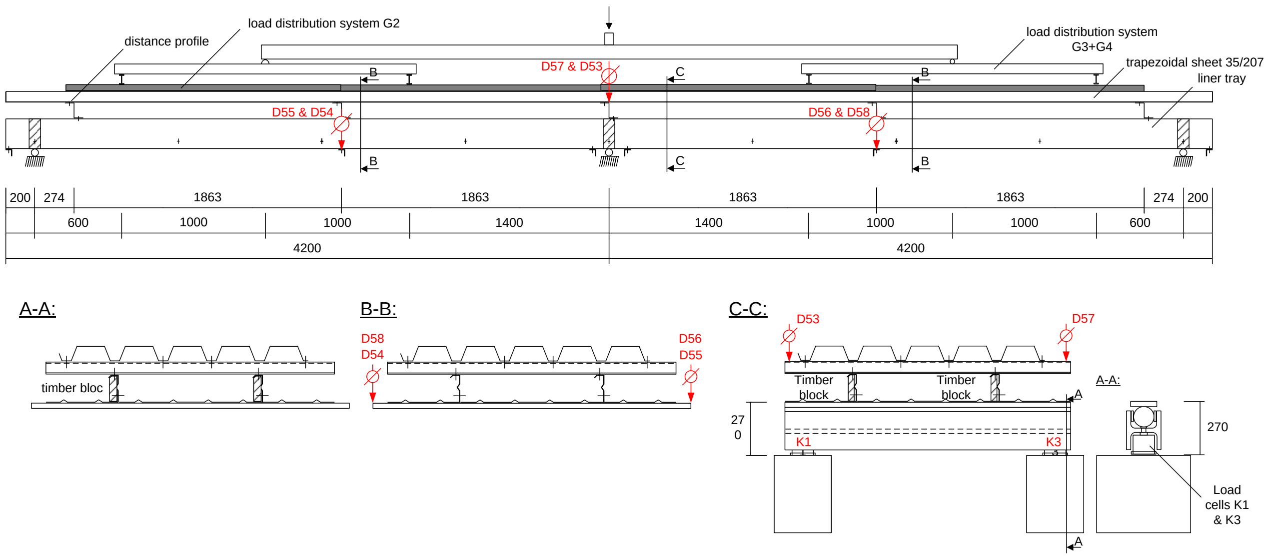


Fig. 15: test setup of double span test

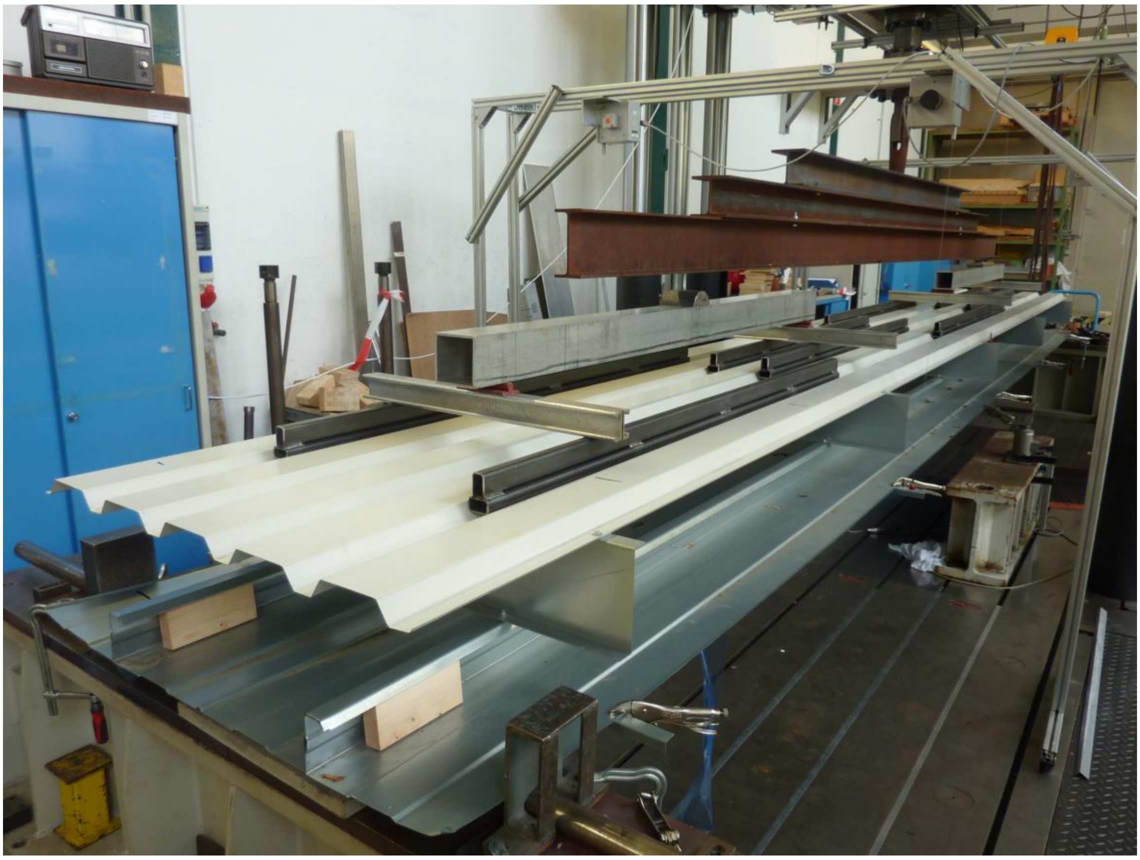


Fig. 16: Picture of the test setup double span test

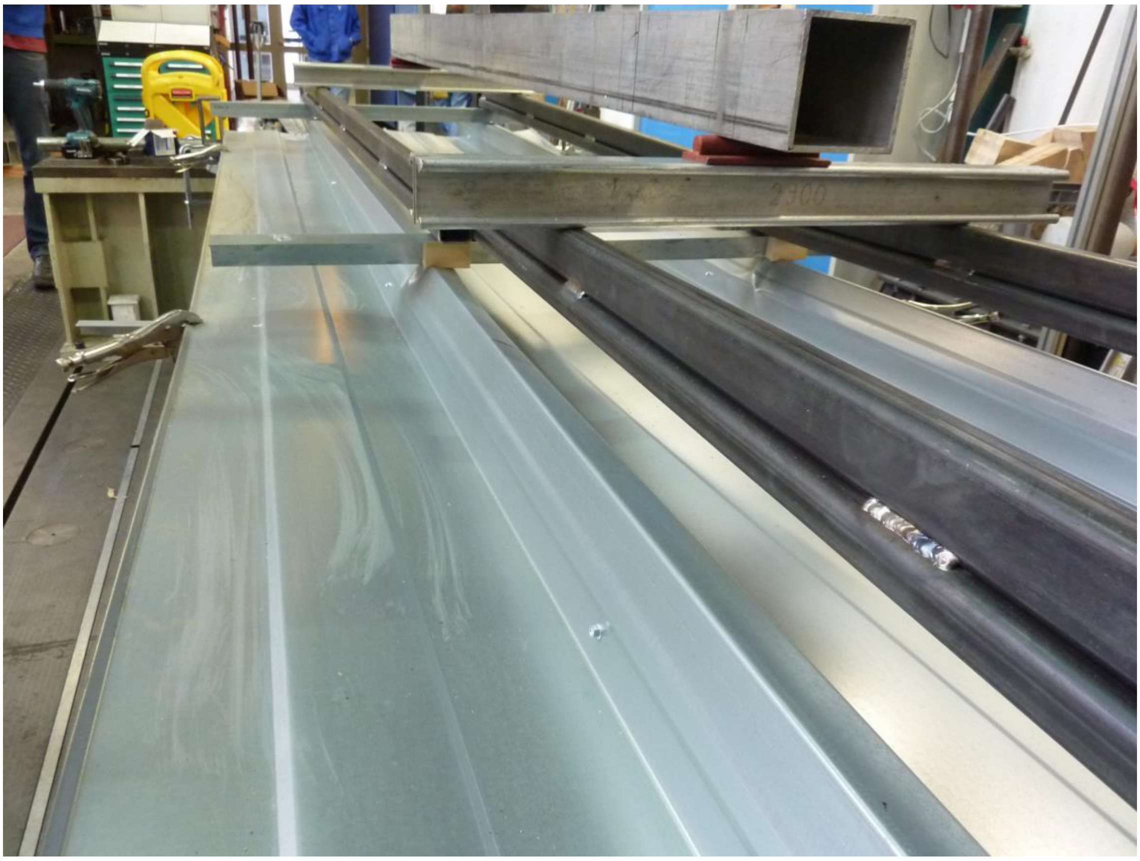


Fig. 17: Picture of the test setup double span test without outer cladding

The test results of the double span tests are documented in table 4.

s_1	Ultimate load (kN)				
	Z50	Z200	Omega 50	Omega 200	Z50 without outer cladding
1863	21.63	21.71	26.68	25.73	16.57

Table 4: Test results of the double span tests

3. Calculation method for s_1 > 1000 mm

The ultimate positive bending moment of the liner trays (wide flange in tension) is generally determined by the ultimate compression forces of the small flanges. The compressed flanges are stabilized against lateral buckling by the connections between liner tray and outer cladding; the fixing distance s_1 determines the buckling length of the compressed flange and therefore the ultimate compression forces of the small flanges and in consequence also the ultimate bending moment. The ultimate bending moment is approximately proportional to the compression resistance of the small flanges.

The reduction coefficient β_b to respect the fixing distance s_1 corresponds approximately to the reduction of the compression resistance of the small flanges.

Ultimate bending moment $M_{c,Rk,2} = M_{c,Rk,1} * \frac{N_{R,k,2}}{N_{R,k,1}} = M_{c,Rk,1} * \beta_b$

with:

$M_{c,Rk,1}$ (already known) ultimate positive bending moment of the liner trays for a fixing distance $s_{1,1}$

Design by calculation: The bending moment $M_{c,Rk,1}$ is the calculated ultimate bending moment for the fixing distance $s_{1,1}$ = 300 mm according to Clause 10.2.2.2 (β_b = 1,0)

Design by testing: The bending moment $M_{c,Rk,1}$, which is determined by testing, is related to the distance $s_{1,1}$, which was chosen for the tests. This fixing distance $s_{1,1}$ is mentioned in the technical documents of the liner tray (often: s_1 = 621 mm = 3 ribs of the cladding profile 35/307)

$M_{c,Rk,2}$ (unknown) ultimate positive bending moment of the liner trays for a fixing distance $s_{1,2}$

The bending moment $M_{c,Rk,2}$ is the recalculated ultimate bending moment for the interesting fixing distance $s_{1,2}$ .The interesting fixing distance $s_{1,2}$ corresponds to the foreseen fixing distance in a specific application.

The fixing distance $s_{1,2}$ should not exceed max s_1 = 2000 mm

$\beta_b = \frac{N_{R,k,2}}{N_{R,k,1}}$ reduction coefficient for fixing distances $s_1 \geq s_{1,1}$

$N_{R,k,1}$ characteristic compression force of the small flanges of the liner trays, calculated with the buckling length $l = s_{1,1}$

$N_{R,k,2}$ characteristic compression force of the small flanges of the liner trays, calculated with the buckling length $l = s_{1,2}$

The calculation of the characteristic compression force of the small flanges of the liner trays should respect the following principles:

- **Step 1:** Gross cross section of flanges

  The gross cross section of the compressed flange consists of the small flange, the edge stiffener and 1/5 of the web. Separate calculations should be executed for the small flanges on both sides of the liner tray, because the cross sections of both flanges are different.

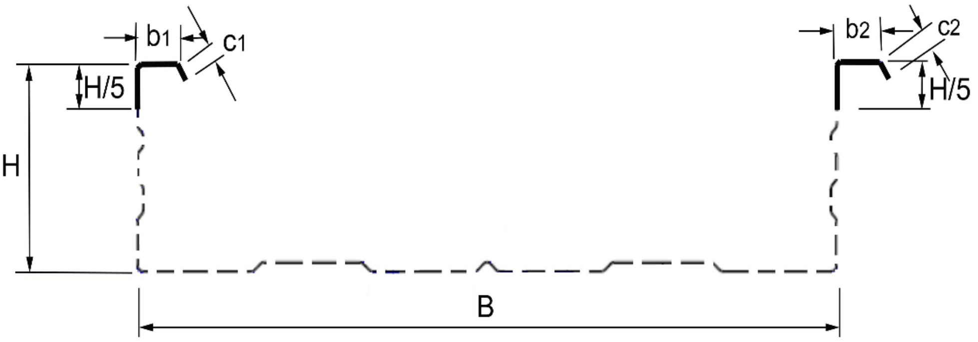


Fig 18: Liner tray, definition of the gross cross sections of the compressed flanges

- **Step 2:** Effective cross section of flanges

  The effective cross section should consider local buckling of flange (b_{ef1}, b_{ef2}) and the stiffener (c_{ef}) as well as buckling of the stiffener (t_{red}). The calculation is done for a chosen stress $\boldsymbol{\sigma}_{com}$ for both flanges of the liner tray.

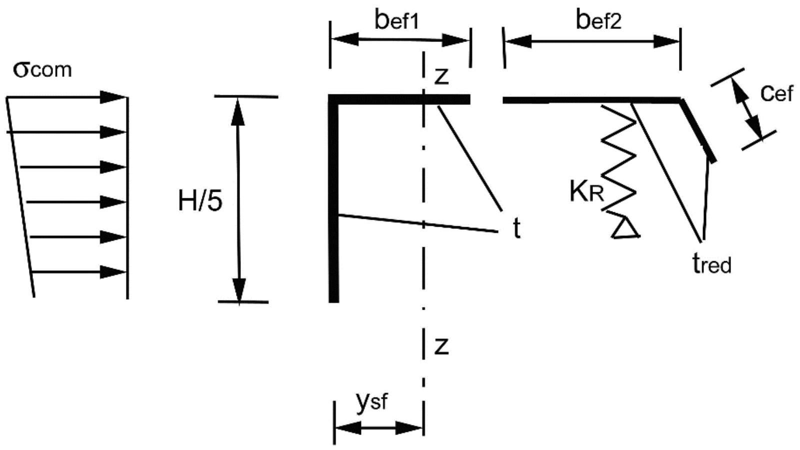


Fig 19: effective cross section of the compressed flange for a chosen stress σ_{com}.

Cross section values

- y_{sf} position of the neutral axis for lateral bending
- A_{fz} effective area of the compressed flange
- J_{fz} effective moment of inertia for bending about z-z-axis

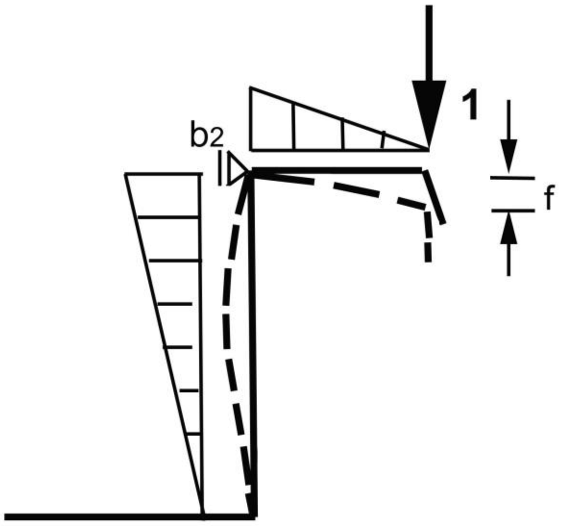


Fig 20: spring stiffness of the edge stiffener (shown for flange 2, analogue for flange 1)

spring stiffness $K_R = \dfrac{E * t^3}{12 * \left(1 - \mu^2\right)} * \dfrac{3}{b_2 * \left(b_2^{\,2} + b_2 * H\right)}$

- **Step 3:** Ultimate compression force of the small flange with respect to lateral buckling

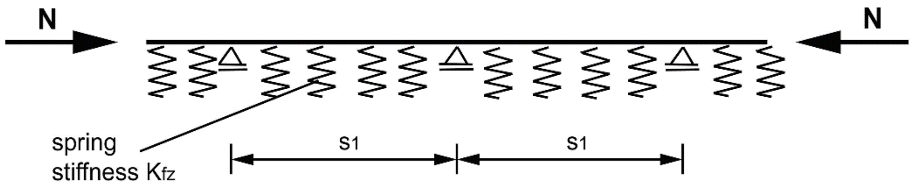


Fig 21: static system of the compressed small flange of the liner tray

When considering lateral buckling of the compressed flange, the elastic foundation of the compressed flange in the lateral direction may be taken into account:

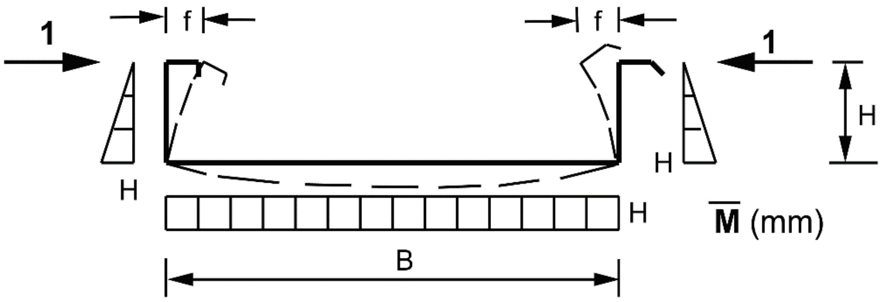


Fig 22: Moment distribution to calculate the spring stiffness K_{fz}

spring stiffness $$K_{fz} = \frac{E * t^3}{12 * \left(1 - \mu^2\right)} * \frac{6}{\left(2 * H^3 + 3 * B * H^2\right)}$$

critical axial force $$N_{cr} = \frac{n^2 * \pi^2 * E * J_{fz}}{s_1^2} + \frac{K_{fz} * s_1^2}{n^2 * \pi^2}$$

Normally, the axial force is a minimum for n = 1 (n = number of buckling waves between neighbored fixings).

The ultimate axial compression force N_{Rk} is calculated according to EN 1993-1-1 clause 6.3.1.1. Hereby, buckling curve a_0 may be used.

ultimate axial force $N_{Rk} = \mathbf{X}(a_0) * N_{pl}$

$= \mathbf{X}(a_0) * A_{fz} * f_{yb}$

ultimate compressive stress $\boldsymbol{\sigma}_k = \mathbf{X}(a_0) * f_{yb}$

If $\boldsymbol{\sigma}_k$ is different from the initially chosen stress $\boldsymbol{\sigma}_{com}$, the calculation should be repeated from step 2 using $\boldsymbol{\sigma}_{com} = \boldsymbol{\sigma}_k$ until the stress $\boldsymbol{\sigma}_{com}$, which is the basis for the effective cross section, and the buckling stress of the compressed flange $\boldsymbol{\sigma}_k$ have converged.

Analogue calculations should be executed for both flanges of the liner tray.

- **Step 4:** Reduction coefficient β_b

  The calculation according step 2 and step 3 is done for both flanges and for both fixing distances $s_{1,1}$ and $s_{1,2}$. The reduction coefficient for the fixing distance $s_{1,2}$ is

  $$\beta_b \text{ (distance } s_{1,2}) = [N_{Rk} \text{ (fl 1, } s_{1,2}) + N_{Rk} \text{ (fl 2, } s_{1,2})] / [N_{Rk} \text{ (fl 1, } s_{1,1}) + N_{Rk} \text{ (fl 2, } s_{1,1})]$$

In the following figures 23 to 26 the results calculated with the presented calculation method, the test results and the calculated values β_b according to EN 1993-1-3 are compared.

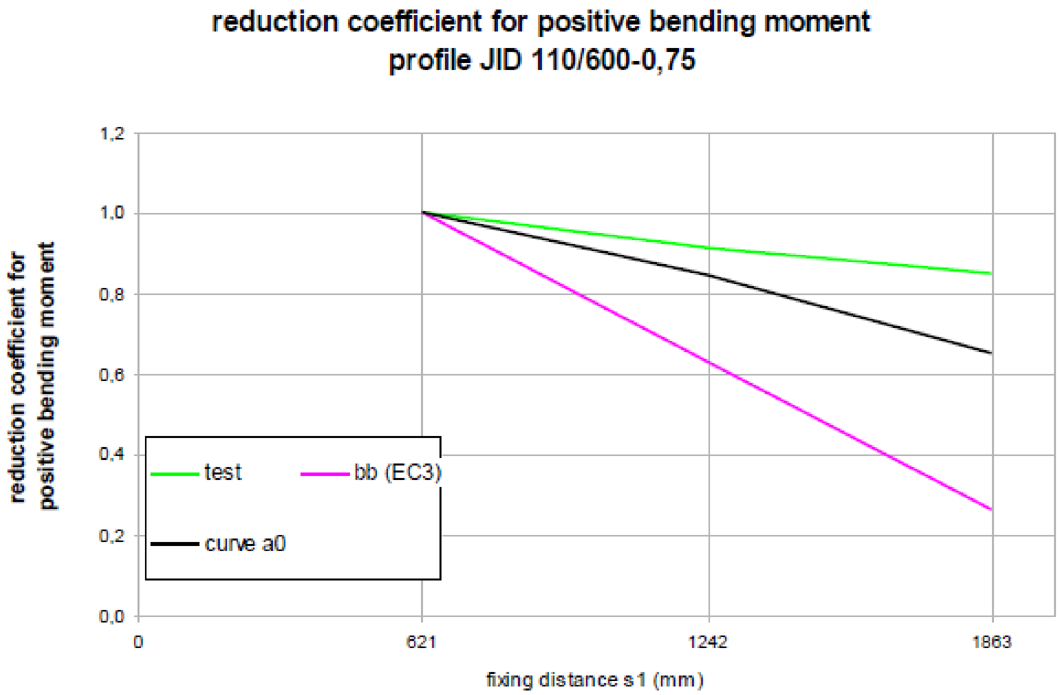


Fig. 23: Comparison of calculated reduction coefficients with test results (JID 110/600-0.75)

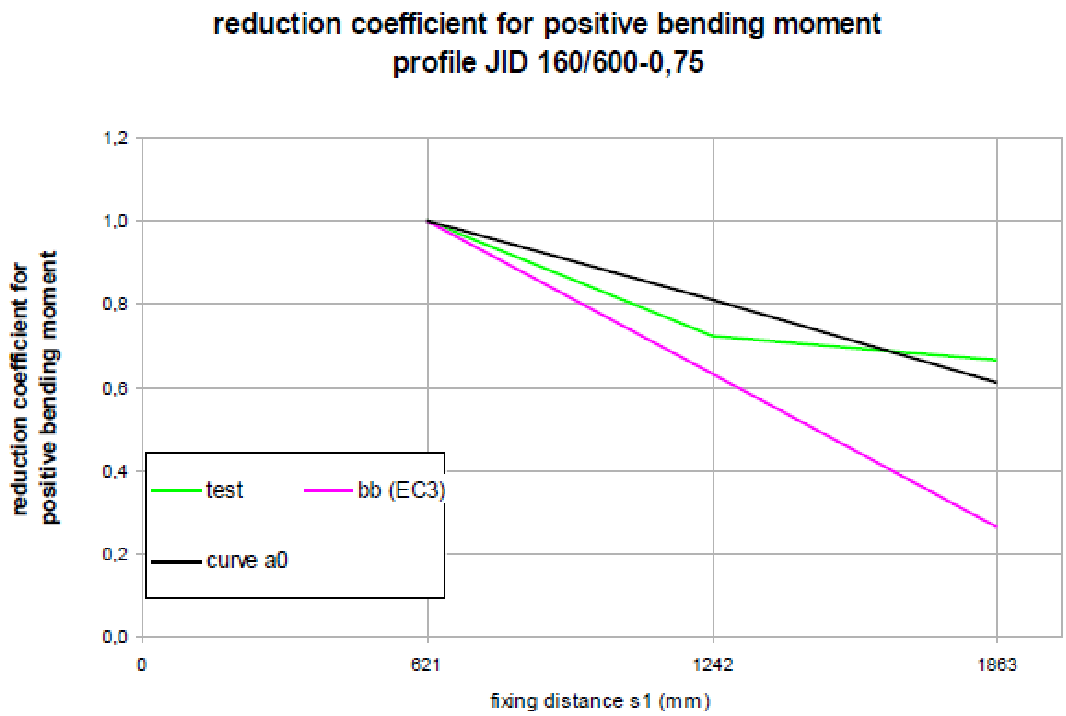


Fig. 24: Comparison of calculated reduction coefficients with test results (JID 160/600-0.75)

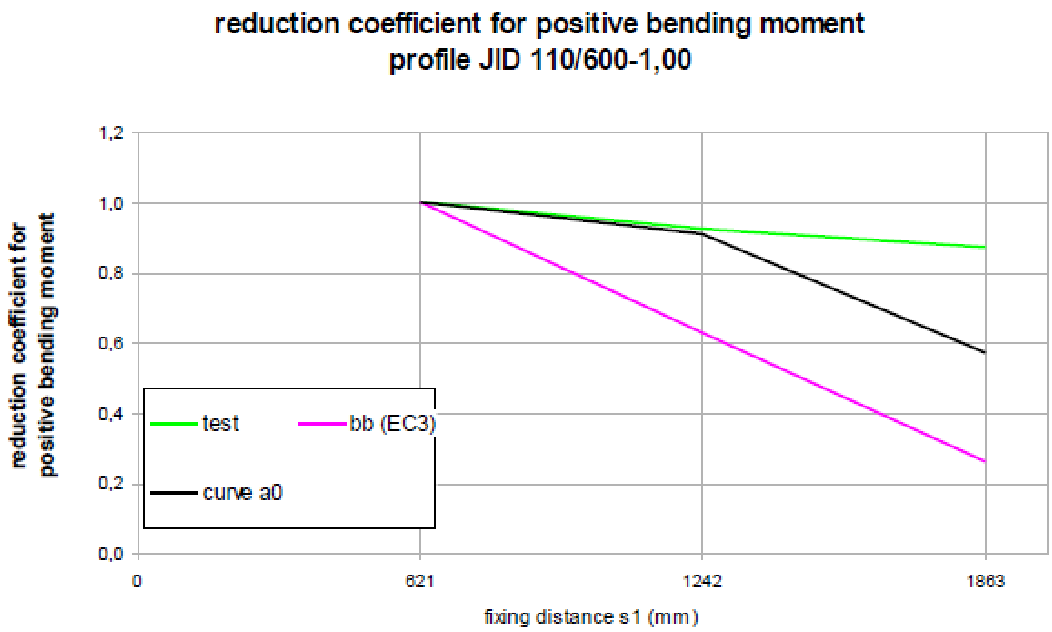


Fig. 25: Comparison of calculated reduction coefficients with test results (JID 110/600-1.00)

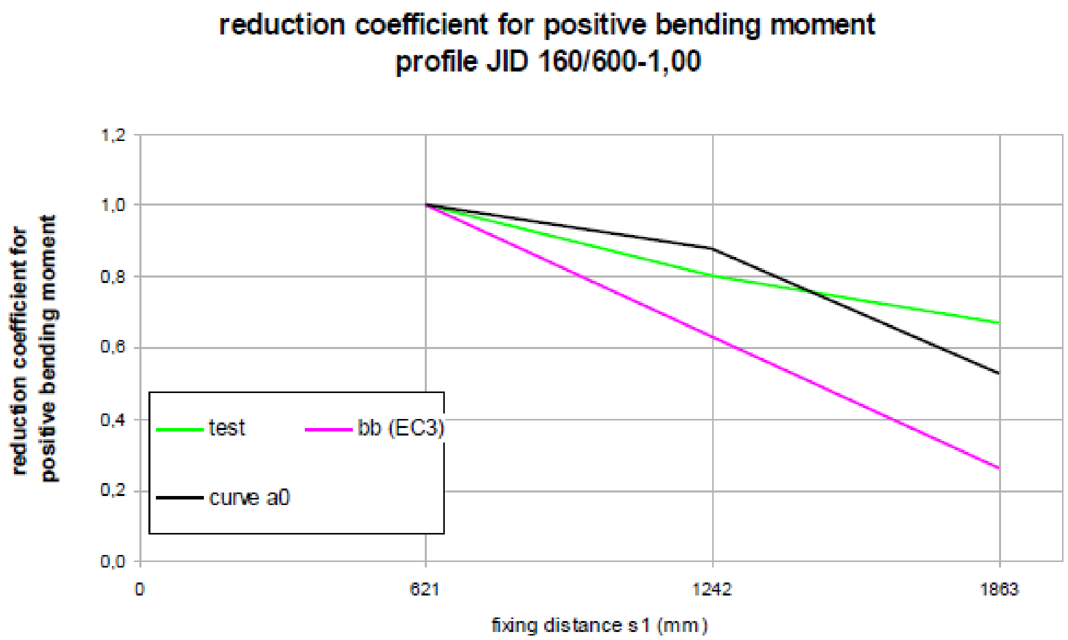


Fig. 26: Comparison of calculated reduction coefficients with test results (JID 160/600-1.00)

4. Conclusion

The calculation method improves the coefficient β_b (influence s_1) and extends the application range of this coefficient. This calculation model can be transferred to the EC without further adjustments.

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] Baehre R., Buca J. (1986). Die wirksame Breite des Zuggurtes von biegebeanspruchten Kassetten, Stahlbau 55 (9), 1986

[4] Deliverable D 2.3: Test report. Liner trays. KIT, 31.05.2015

[5] Deliverable D 2.4: Test analysis and interpretation. Liner trays. IFL, 31.10.2015