GRISPE

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

Working Package 2

Assembled Profiles

Test analysis and interpretation

30 june 2016

Deliverable D 2.4

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

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1 Introduction

In general, trapezoidal sheets used for roofing are installed as 2- or multi-span girders in order to minimize the deflections and therefore to achieve bigger span lengths. In single span systems, the suitable span lengths would be rather small with respect to deflection conditions. On the other hand, trapezoidal profiles with profile heights up to 200 mm allow span lengths of more than 6 meters, which lead to enormous sheet lengths if the profile would be installed as 3-span-girder for instance. So big sheet lengths are not suitable considering transport and handling on site.

Beside of continuous sheets at intermediate supports, the sheets are often cut to good handling lengths of 1 or 2 spans and overlapped with the sheet on the next span. For different overlap configurations, the load bearing behavior of the profiles is studied by tests, which are evaluated in this paper. The aim of the tests is to determine the bending moment capacity and the capacity for local forces like the support reaction of the overlapped area as well as the interactive influence.

On the basis of the test results, a design procedure is developed which leads to a safe design and which is simple to execute.

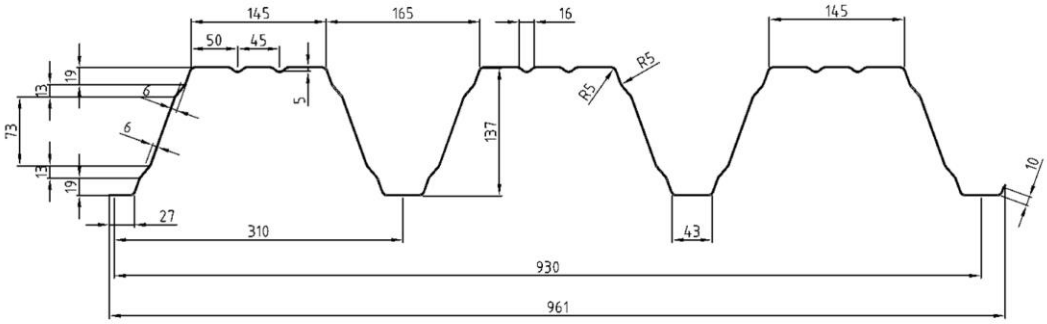
The following parameters are varied in order to cover a wide range of application:

- Type of overlap/assembly
- High profiles with steep and not so steep webs
- Sheet thickness 0,75 mm and 1,00 mm
- Support width 60 mm and 160 mm
- Test span in order to vary the ratio between bending moment and support reaction (moment-support reaction-interaction)

2 Description of the considered profiles and test parameters

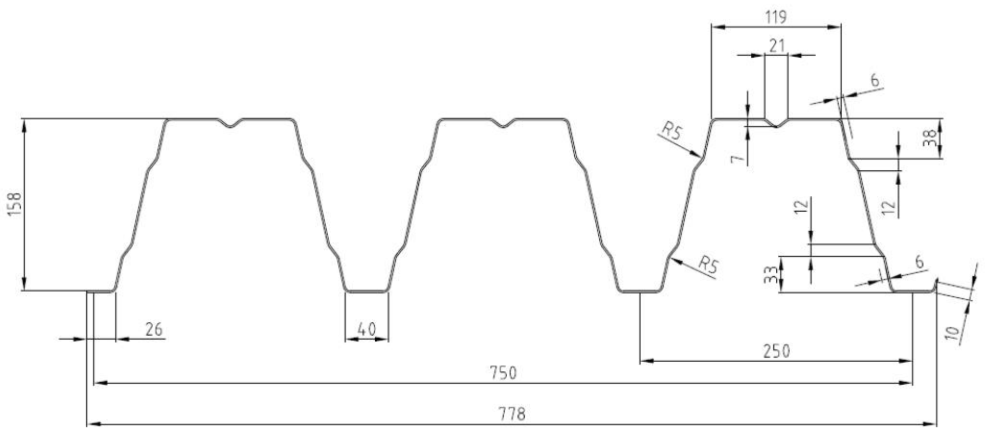
2.1 Cross sections

Two different profiles were tested: JID 137.310.930 and JID 158.250.750.



slope of webs: 66,0°
nominal sheet thickness: 0,75 mm; 1,00 mm

Fig. 1: Cross section trapezoidal profile JID 137.310.930



slope of webs: 73,9°
nominal sheet thickness: 0,75 mm; 1,00 mm

Fig. 2: Cross section trapezoidal profile JID 158.250.750

The geometry of the used profiles was measured at 3 different specimens per batch. The results are given in [1]. The measured values are sufficiently close to the nominal values. The used specimen and the test results can be considered as representative for the nominal cross sections.

2.2 Material

The tested profiles were produced from coils steel grade S320 GD according to EN 10346. The specimens were produced and delivered in 2 batches. From different test specimen material samples were taken and tensile tests executed. The results are given in table 1.

profile/batch JI D	material	nominal values t_N (mm) f_{yb} (N/mm²) f_u (N/mm²)	test no.	measured values			
				$t_{cor,obs}$ mm	$f_{yb,obs}$ N/mm²	$f_{u,obs}$ N/mm²	$A_{L=80}$ %
137-310-930 delivery 1	steel S320 GD	0,75 320 390	1 2 3	0,702 0,707 0,704	349 348 349	406 406 406	27,0 27,0 26,7
			mean values	0,704	348,7	406,0	26,9
137-310-930 delivery 2	steel S320 GD	0,75 320 390	1 2 3	0,700 0,700 0,700	338 340 346	412 411 410	29,0 27,7 27,9
			mean values	0,700	341,3	411,0	28,2
137-310-930 delivery 1	steel S320 GD	1,00 320 390	1 2 3	0,954 0,956 0,958	328 327 327	394 391 392	28,4 27,6 27,4
			mean values	0,956	327,3	392,3	27,8
137-310-930 delivery 2	steel S320 GD	1,00 320	1 2	0,950 0,960	322 334	391 390	28,8 28,9
			mean values	0,955	328,0	390,5	28,9
158-250-750 delivery 1	steel S320 GD	0,75 320 390	1 2 3	0,702 0,703 0,701	344 347 347	412 410 411	26,6 27,1 26,9
			mean values	0,702	346,0	411,0	26,9
158-250-750 delivery 2	steel S320 GD	0,75 320 390	1 2 3	0,700 0,700 0,700	348 348 341	411 411 412	28,6 27,9 27,4
			mean values	0,700	345,7	411,3	28,0
158-250-750 delivery 1	steel S320 GD	1,00 320 390	1 2 3	0,963 0,962 0,962	355 356 355	383 382 384	29,6 30,3 30,3
			mean values	0,962	355,3	383,0	30,1
158-250-750 delivery 2	steel S320 GD	1,00 320	1 2	0,950 0,960	331 323	389 390	30,8 29,5
			mean values	0,955	327,0	389,5	30,2

Table 1: Observed material properties and reference values

The scattering of the individual values among the samples of the same batch is very small; the mean values of the batch can be considered as representative for all test specimen of the same batch.

2.3 Tested assemblies

In the GRISPE project three configurations of assemblies were investigated.

a) DIN-joint: overlap on one side (designation "DIN")

The purpose of the DIN-joint is to create continuity between the adjacent spans and to provide the same resistance of the sheeting as at "normal" intermediate supports with continuous sheets without joint. Using this joint, sheets with a length of one or two spans can be composed to multi-span girders with the length of 3 or more spans. So, unfavorable static systems with one span (deflection of single-span girder is twice or more the deflection of multi-span girders) or with two spans (unfavorable load concentration on the substructure in the center, extreme bending moments at intermediate support) can be avoided. In general, the thickness of the overlapping sheets is the same. Therefore all tests were executed with specimens with the same thickness of the assembled sheets.

The DIN-joint can be installed in two versions:
- Overlapping sheet on top: This configuration is unfavorable considering the internal forces in the sheets and in the connections. But this configuration is easier to install, because the span-wards end of the overlap is visible from top, which makes easier to place the screws. In practice, this configuration is mostly chosen.
- Overlapping sheet underneath: Although this configuration is favorable considering the internal forces and the forces in the connections, this configurations is less executed in practice due to disadvantages regarding montage work.

All tests were done with the configuration "overlapping sheet on top".

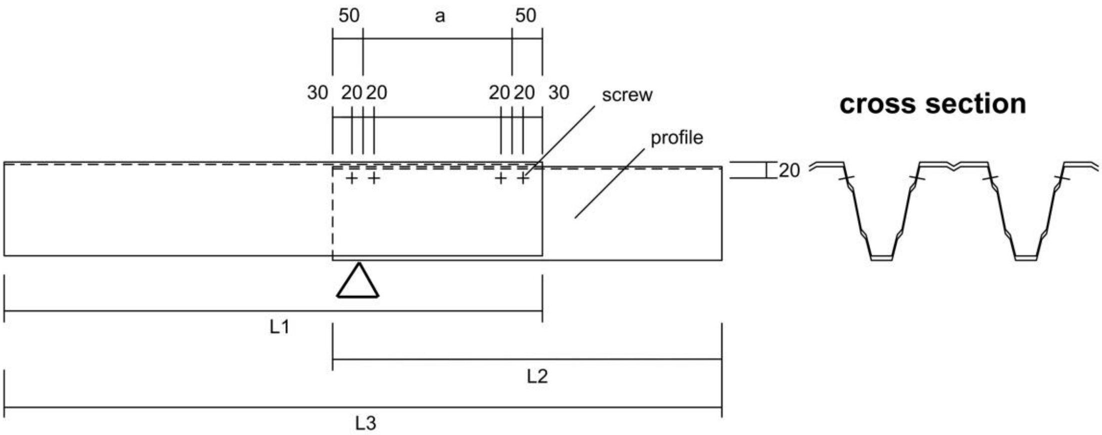


Fig. 3: assembly DIN-joint with overlap on one side of the support

b) Overlap on both sides (designation "OL")

The purpose of the joint with overlap on both sides is to create continuity between the adjacent spans and to enhance the resistance of the sheeting compared to continuous sheets without joint. On the one hand, the deflections are reduced (similar to DIN-joint), and on the other hand, a higher bearing resistance is provided at the supports, where the internal forces under distributed load become a maximum.

The tests were limited to configurations with the same thickness of both sheets.

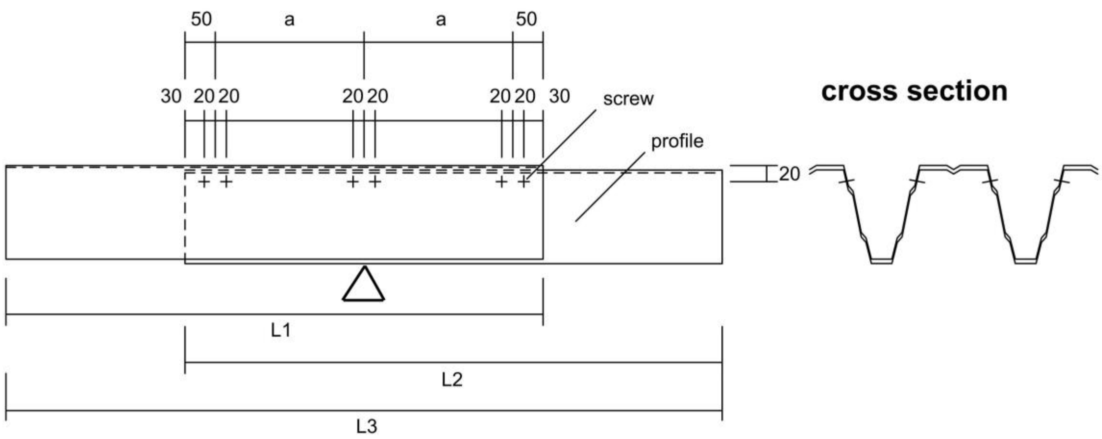


Fig. 4: assembly overlap with overlap on both sides of the support

c) Continuous sheet with local reinforcement (designation "CR")

The purpose of this assembly configuration is similar to the joint OL: to create continuity - provided by the continuous sheet underneath – and to enhance the bearing capacity at the supports, where the internal forces are extreme.

The tests were limited to configurations with the same thickness of both sheets.

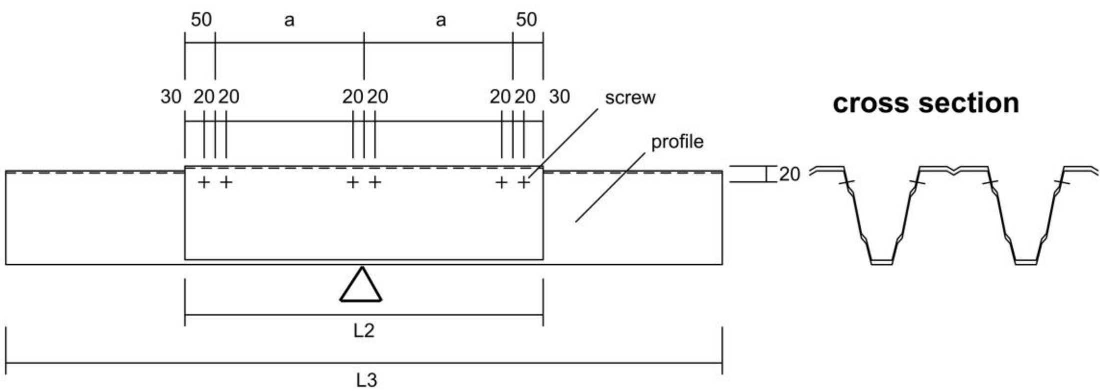


Fig. 5: assembly with continuous sheet underneath and a second sheet above

2.4 Overview of the test parameters

The following tables contains an overview of the test specimens and their main parameters. In general, 2 tests with identical parameters were executed. In three cases, additional test with an increased overlap length "a" were done. The reason for these additional tests was, that at the tests with the regular overlap length "a" (50 cm or 70 cm) failure occurred by web crippling at the end of the overlap and the test load didn't come up to the full bending moment capacity of the profiles. At the tests with increased overlap length "a", the failure mode was buckling in mid-span caused by bending moment.

profile / thickness	type of assembly	support width $l_{a,B}$ (mm)	length of overlap a (m)	test span (m)
137.310.930 - 0,75	C	60	n.e.	0,80
				2,40
		160		0,80
				2,40
137.310.930 - 1,00	C	60		0,80
				2,80
		160		0,80
				2,80
137.310.930 - 0,75	DIN	60	0,50	0,80
				2,40
		160		0,80
				2,40
		160	0,70	2,40
137.310.930 - 1,00	DIN	60	0,50	0,80
				2,80
		160		0,80
				2,80
137.310.930 - 0,75	OL	60	0,50	0,80
				1,30
				2,40
		160		0,80
				2,40
		160	0,70	2,40
137.310.930 - 1,00	OL	60	0,50	0,80
				2,80
		160		0,80
				2,80
		160	0,70	2,80
137.310.930 - 0,75	CR	60	0,50	0,80
				2,40
		160		0,80
				2,40
137.310.930 - 1,00	CR	60	0,50	0,80
				2,80
		160		0,80
				2,80

Table 2: Test parameters profile JID 137.310.930

Profile/ thickness	type assembly	support width $l_{a,B}$ (mm)	length of overlap a (m)	test span (m)
158.250.750 - 0,75	C	60	n.e.	0,80
				2,80
		160		0,80
				2,80
158.250.750 - 1,00	C	60		0,80
				3,20
		160		0,80
				3,20
158.250.750 - 0,75	DIN	60	0,60	0,80
				2,80
		160		0,80
				2,80
		160	0,80	2,80
158.250.750 - 1,00	DIN	60	0,60	0,80
				3,20
		160		0,80
				3,20
158.250.750 - 0,75	OL	60	0,60	0,80
				2,80
		160		0,80
				2,80
		160	0,80	2,80
158.250.750 - 1,00	OL	60	0,60	0,80
				3,20
		160		0,80
				3,20
		160	0,80	3,20
158.250.750 - 0,75	CR	60	0,60	0,80
				2,80
		160		0,80
				2,80
158.250.750 - 1,00	CR	60	0,60	0,80
				3,20
		160		0,80
				3,20

Table 3: Test parameters profile JID 158.250.750

3 Principles of test evaluation

3.1 Adjustment of test results

The aim of the project is to develop a design model for the assembled profiles. In general, the design values of the profiled sheeting are known and mentioned in an approval or in the CE-label. These values are valid for the single, not-assembled profile. It is the target to define a design procedure for the assemblies which is related to the characteristic values of the single profile.

Beside of the additional tests with an enhanced overlap length, all test specimens of the same profile/thickness are produced from the same coil. Considering the small scattering of the core thickness and the yield strength, the mean values of the tensile tests are representative for the complete family. The test results of all tests with the same profile/thickness are related to the same core thickness and the same yield stress, and no adjustment is necessary to make the results comparable and to exclude an eventual influence of different yield strength values and/or core thicknesses.

Only, when test specimens from delivery 2 are compared with test specimens of delivery 1, the test results have to be adjusted. In that case, the results of the tests with sheets coming from delivery 2 are adjusted to the mean values of core thickness and yield strength of the sheets of delivery 1. The results are adjusted following the rules of EN 1993-1-3. By this adjustment, the influence of the varying material properties is more or less equalized, and the interesting behaviour is not overlaid by variations of the thickness and yield strength.

$$R_{adj}=\frac{R_{obs}}{\mu_R}$$

R_{obs} observed test result with test specimen of delivery 2

R_{adj} adjusted test result to the mean values of delivery 1

$$\mu_R = \left(\frac{f_{yb,obs}}{f_{yb}}\right)^{\alpha}\left(\frac{t_{obs,cor}}{t_{cor}}\right)^{\beta}$$

$\alpha = 0{,}5$

$\beta = 1$ if $t_{cor} \geq t_{cor,obs}$

$\beta = 2$ if $t_{cor} < t_{cor,obs}$

t_{cor} reference value of the steel core thickness of delivery 1 (see table 1)

$t_{cor,obs}$ mean value of the steel core thickness of delivery 2 (see table 1)

f_{yb} reference value of the yield strength of delivery 1 (see table 1)

$f_{yb,obs}$ mean value of the yield strength of delivery 2 (see table 1)

Since the material properties of delivery 1 and delivery 2 are very similar, the correction coefficient μ_R is very close to 1,0.

3.2 Characteristic values

The characteristic values of the searched bearing properties are determined by a statistical evaluation of the test results.

A test family in this context includes all tests with the same assembly configuration and with the same profile. Tests with different span lengths, with different support widths and with different thicknesses are put in the same family. Mostly, a test family includes 16 tests (2 span lengths x 2 support widths x 2 thicknesses x 2 identical tests).

Each test family consists of several subsets; a subset is a small series of tests with identical conditions (same profile type, same nominal sheet thickness, same test setup etc.). Normally, a subset consists of 2 or 3 identical tests.

The test results of a subset are referred to its specific mean value R_m; the statistical evaluation is done with these normalized values.

The characteristic value is

$$R_k = R_m \cdot (1 - k \cdot s)$$

R_m mean value of the subset

s standard deviation

k coefficient depending of the number of tests according to table 4

n	3	4	5	6	8	10	20	30	∞
k	-	2,63	2,33	2,18	2,00	1,92	1,76	1,73	1,64

Table 4: fractile coefficients k according to EN 1993-1.3 table A.2

4 Test evaluation, characteristic load bearing values

4.1 Self-weight of the test specimens

The self-weight of the test specimens is taken from the type approval (see annex page 39 to 46).

profile	thickness t (mm)	self-weight (kN/m²)
JID 137.310.930	0,75	0,097
	1,00	0,129
JID 158.250.750	0,75	0,120
	1,00	0,160

Table 5: self-weight of the tested profiles

4.2 Test setup of the intermediate support tests, internal forces

Instead of extensive investigations with multi-span beams to study the behaviour at intermediate supports, intermediate support tests for load case “gravity loading” were performed. A short profile, which represents the part with negative bending moments at internal supports, is placed in the upside-down position as a single-span beam. The supports in the test represent the places with bending moment M = 0 in a multi-span beam under uniformly distributed. The load, which is applied in mid-span via a transverse steel plate with a width of b_u = 60 mm or b_u = 160 mm, represents the intermediate support of a multi-span beam. The plate width b_u corresponds to the support width $l_{a,B}$ in the real construction. In all intermediate support tests an approximately linear elastic load-bearing behaviour appeared until failure load was reached. Failure occurred through a combination of deformations of the web (web-crippling) and buckling of the compressed flanges of the profile. In the tests with short span, the local compression of the profile and web-crippling dominated the failure mode, in the tests with long span buckling of the upper flange became more important.

Fig. 6 shows the test setup. The test specimens are cut in a way that the lateral free edges are located in the tension zone of the cross section. Fig. 7 shows the 4 types of assemblies which were tested. The profiles are shown in the inverse position, how they are placed during the test. Type C is the continuous profile, which gives the reference values.

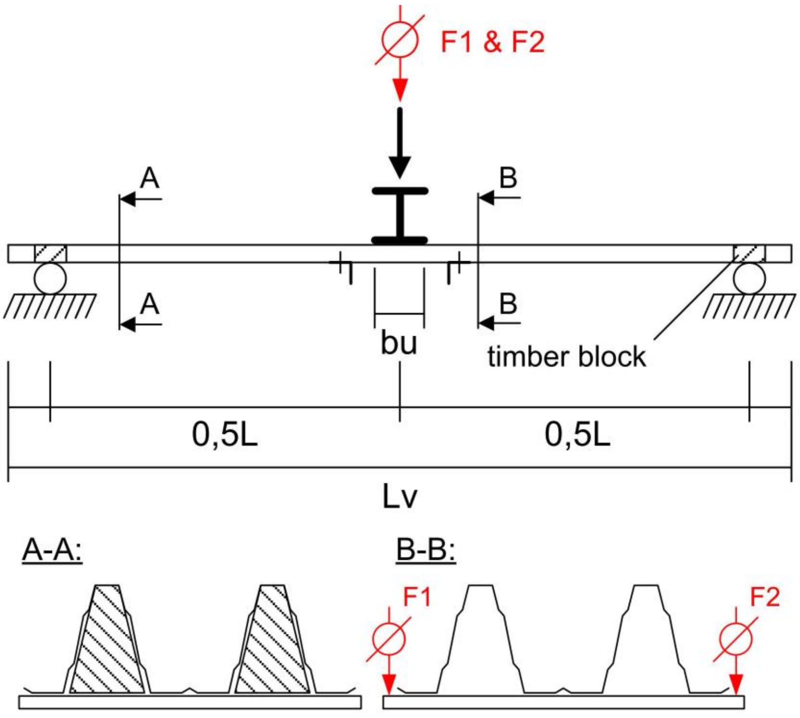


Fig. 6: Test setup intermediate support tests

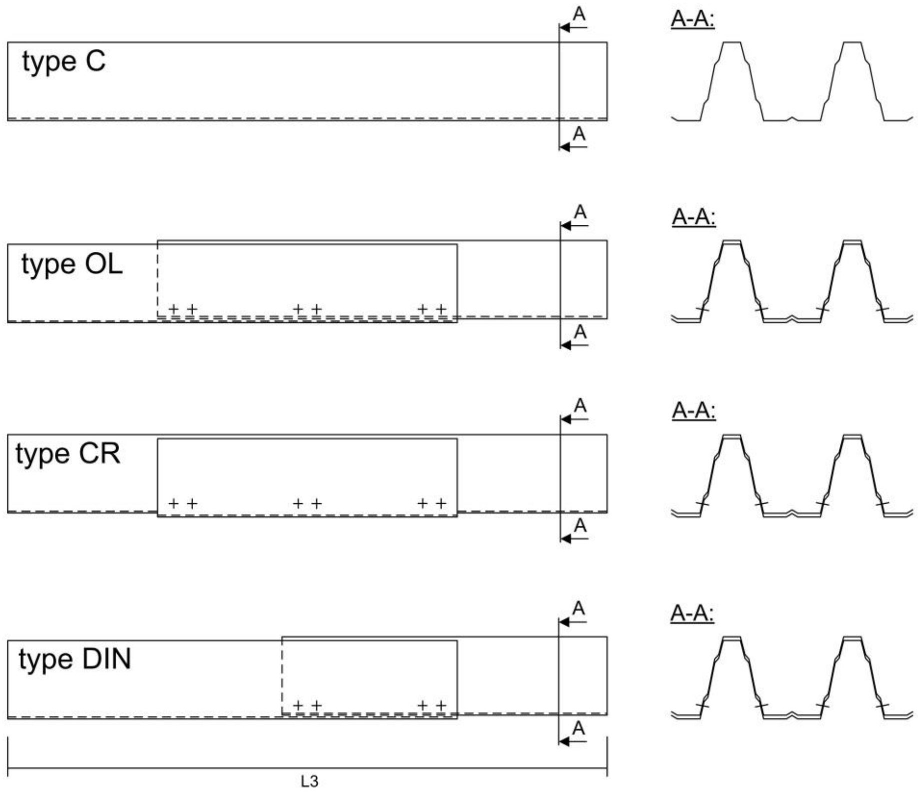


Fig. 7: Configuration of assemblies

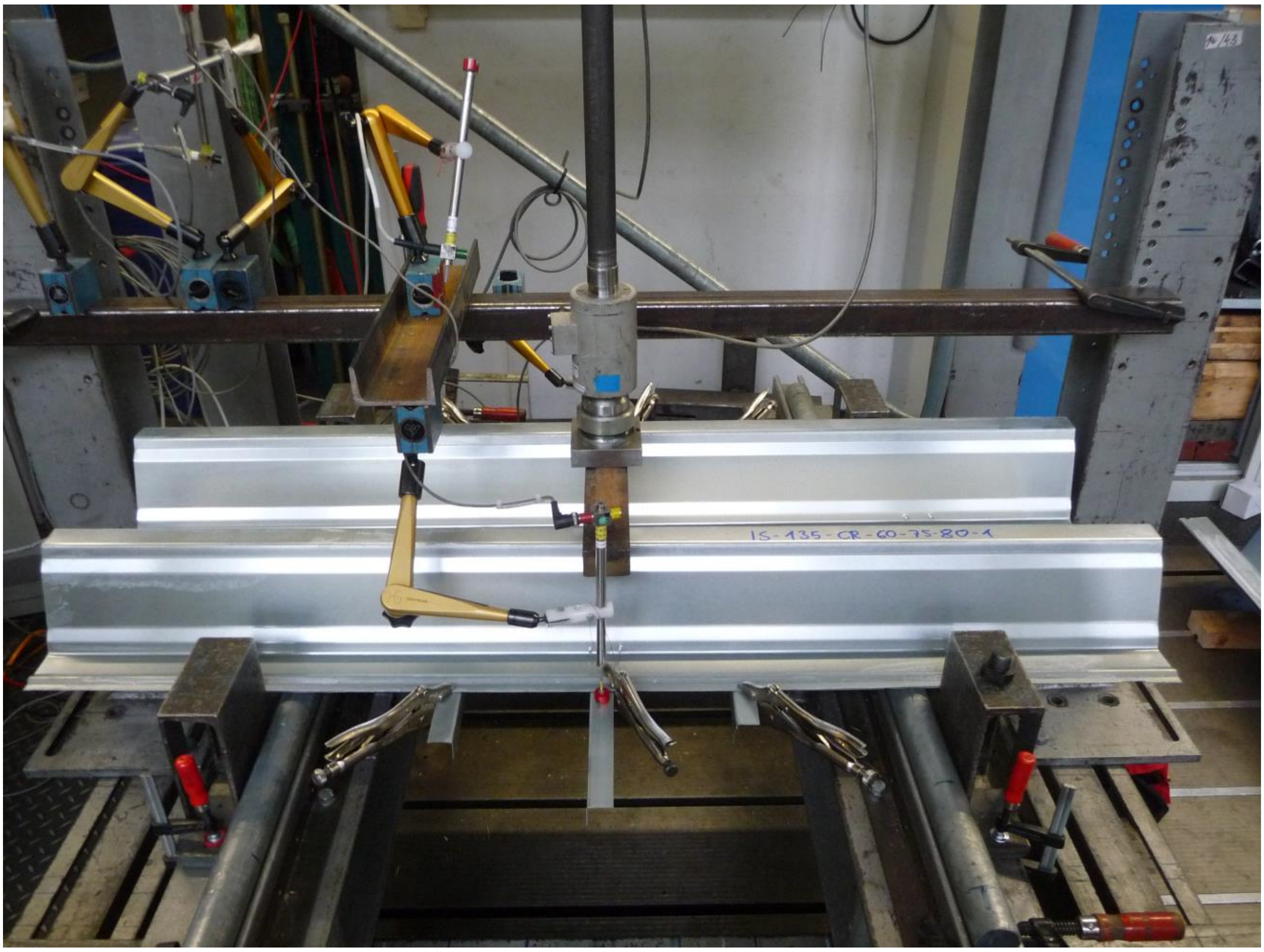


Fig. 8: Intermediate support test, real test setup

The final results of tests are:

- Support reaction:

$$R_{w,Rk,B} = F_{u,k} / b_V$$

- Bending moment at support

$$M_{c,Rk,B} = R_{w,Rk,B} * L/4 + g * L_V * [2 L – L_V] / 8$$

$R_{w,Rk,B}$	characteristic support reaction at intermediate support (kN/m)
$M_{c,Rk,B}$	characteristic bending moment at intermediate support (kNm/m)
$F_{u,k}$	characteristic load in kN (including preload)
b_V	width of the test specimen (here: b_V = 0,620 or 0,500 m)
L_V	length of the test specimen (here: L_V = 1,50 up to 3,60 m)
L	span length (here: L = 0,80 m up to 3,20 m)
g	self-weight of the test specimen according to table 5

For each subset, a combination of support reaction $R_{w,Rk,B}$ and bending moment $M_{c,Rk,B}$ is obtained which leads to failure of the profile or assembly. Each pair M and R represents 1 point of the interaction relation M-R. Varying the span creates different ratios M/R and different combinations of bending moment $M_{c,Rk,B}$ / support reaction $R_{w,Rk,B}$ which lead to failure of the profile or assembly. The interaction is limited by the test values $M_{c,Rk,B}$ determined by the tests with the maximum span length and $R_{w,Rk,B}$ determined by the tests with the minimum span length. Between these limits, the interaction is defined by linear interpolation. The values $M^0_{Rk,B}$ and $R^0_{Rk,B}$, which represent the intersection points between the interaction curve and the M-axis or the R-axis are necessary to describe the interaction curve. There is no mechanic background for these values and they don't represent a load bearing property of the profile or assembly. Fig. 9 shows an example of the M-R-interaction for a chosen set of parameters (profile, thickness, type of assembly, support width). In that way, all tests were evaluated and the M-R-interaction graphs established. The details and all results are shown in the annex page 1 to 38

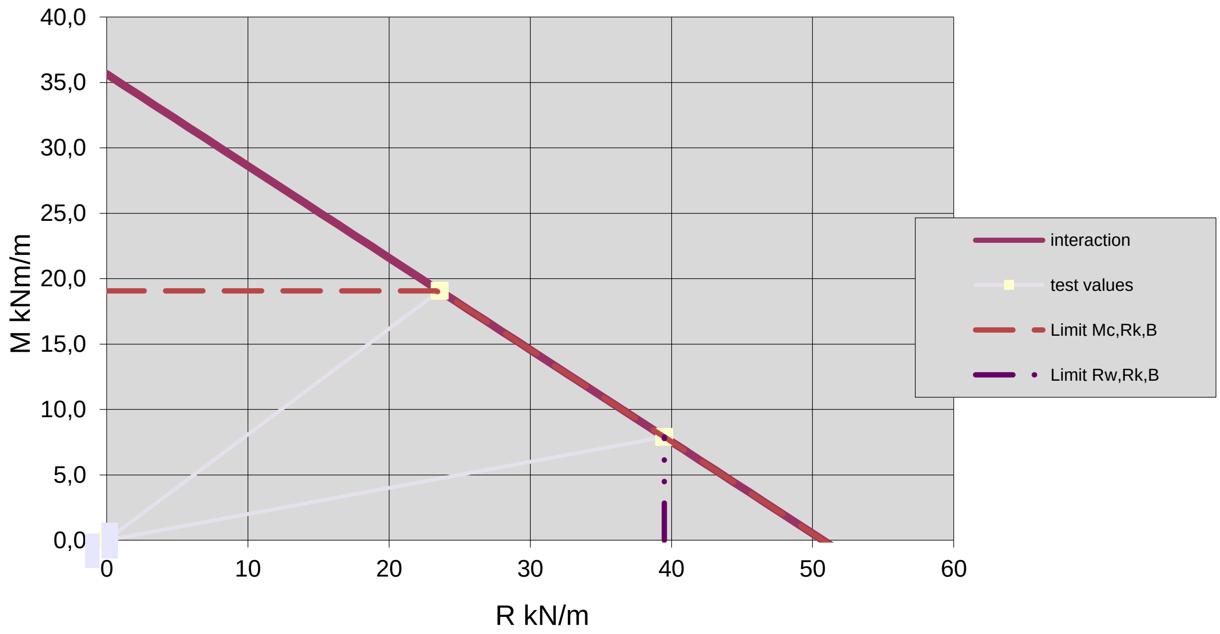


Fig. 9: Example of a M-R-interaction relation at intermediate supports

5 Comparison of the load bearing capacity of the different assembly configurations

In order to visualize and to compare the load bearing capacity of the different assembly configurations, the M-R-interaction graphs are presented in common diagrams. In one diagram, the M-R-graphs of the same profile, with the same thickness and with the same support width, but different assembly are presented.

The results obtained with continuous profiles are considered as reference (red interaction graph). The DIN-joint, which is assumed to create continuity, but without increase of the bearing capacity, is shown in the same scale. The assemblies “overlap at both sides” (OL) and “continuous with reinforcement” (CR) with doubled cross section are expected to have more or less the double bearing capacity; these graphs are scaled to 50%. If – in the ideal case – the bearing capacity of the assembly OL were exactly twice the bearing capacity of the continuous profile (reference), both graphs were identical. By this presentation mode, it is better visible if the assemblies with doubled cross section result in double bearing capacity or how much is missing.

a) Profile 137.310-0,75 mm, support width 60 mm

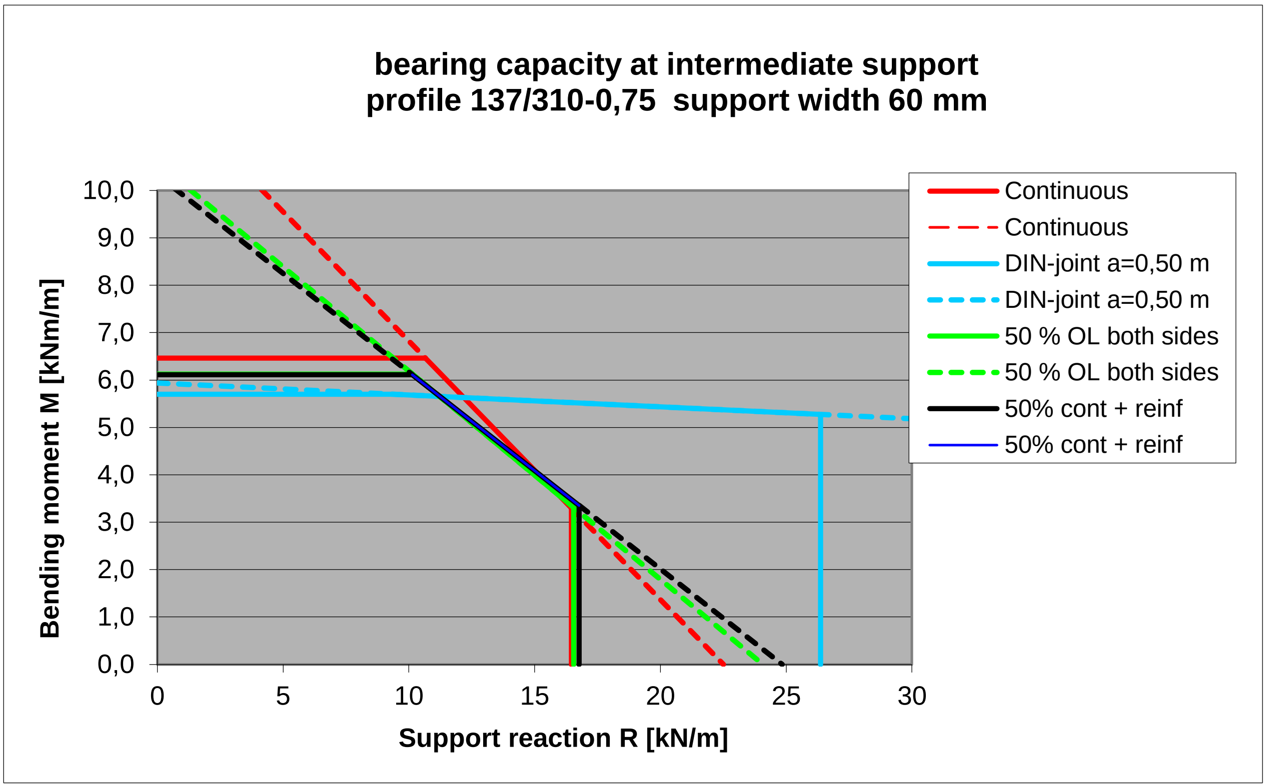


Fig. 10: M-R-interaction for profile JID 137.310-0,75 mm, support width 60 mm

Profile	137.310	thickness	0,75 mm	support width	60 mm
Type of assembly -	bending moment $M_{c,Rk,B}$ kNm/m	relative bending moment %	shear force at end of overlap F kN/m	0.5 R_{wRkB} kN/m	ratio F/(0,5 R_{wRkB}) -
Continuous	6,463	100,0	-	11,45	-
DIN a = 0,5 m	5,703	88,2	11,41	11,45	1,00
DIN a = 0,7 m	-	-	-	-	-
OL a = 0,5 m	12,247	189,5	12,25	11,45	1,07
OL a = 0,7 m	-	-	-	-	-
CR a = 0,5 m	12,230	189,2	12,23	11,45	1,07

Table 6: Comparison of the tested assemblies; profile JID 137.310-0,75 mm, support width 60 mm

The bearing capacity of the DIN-joint is mostly greater than the bearing capacity of the continuous profile, because the web crippling is much enhanced due to the doubled sheets in the support axis. But the maximum moment remains ca. 10% below the bending moment capacity or the continuous profile. The reason is, that failure occurs at the end of the overlap by web crippling; the full bending moment capacity of the section cannot be exploited.

The bearing capacity of the assemblies OL and CR is nearly twice the capacity of the continuous profile. Regarding the maximum support reaction, the resistance is exactly doubled – the red line (C) is identical to the green line (OL) and the black line (CR). Regarding the maximum bending moment, there is a small gap of 10%.

b) Profile 137.310-0,75 mm, support width 160 mm

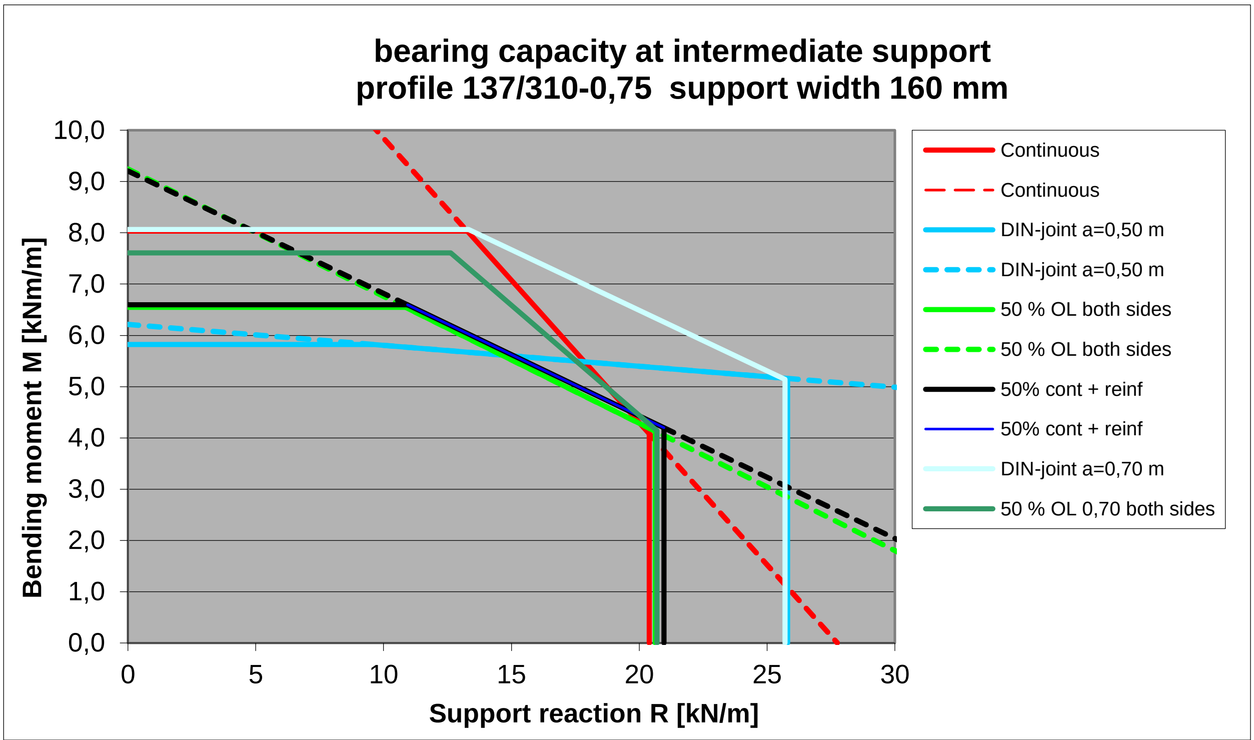


Fig. 11: M-R-interaction for profile JID 137.310-0,75 mm, support width 160 mm

Profile	137.310	thickness	0,75 mm	support width	160 mm
Type of assembly -	bending moment $M_{c,Rk,B}$ kNm/m	relative bending moment %	shear force at end of overlap F kN/m	0.5 R_{wRkB} kN/m	ratio F/(0,5 R_{wRkB}) -
Continuous	8,031	100,0	-	11,45	-
DIN a = 0,5 m	5,823	72,5	11,65	11,45	1,02
DIN a = 0,7 m	8,068	100,5	11,53	11,45	1,01
OL a = 0,5 m	13,100	163,1	13,10	11,45	1,14
OL a = 0,7 m	15,219	189,5	10,87	11,45	0,95
CR a = 0,5 m	13,188	164,2	13,19	11,45	1,15

Table 7: Comparison of the tested assemblies; profile JID 137.310-0,75 mm, support width 160 mm

With the increased support width 160 mm, the maximum bending moment of the continuous profile is considerably greater than for 60 mm (6,46 ➔ 8,03 kNm/m, gain ca. 25 %). But the maximum bending moment of the DIN-joint is the same as for 60 mm support width; the bending moment of the DIN assembly with an overlap length 0,5 m cannot be increased due to prior failure by web crippling at the end of the overlap. With an greater overlap length 0,70 m, the bending moment is the same as for the continuous profile.

The same behaviour can be stated for the assembly OL: bending moment with short overlap is about 160 % of the continuous profile, with increased overlap about 190 %.

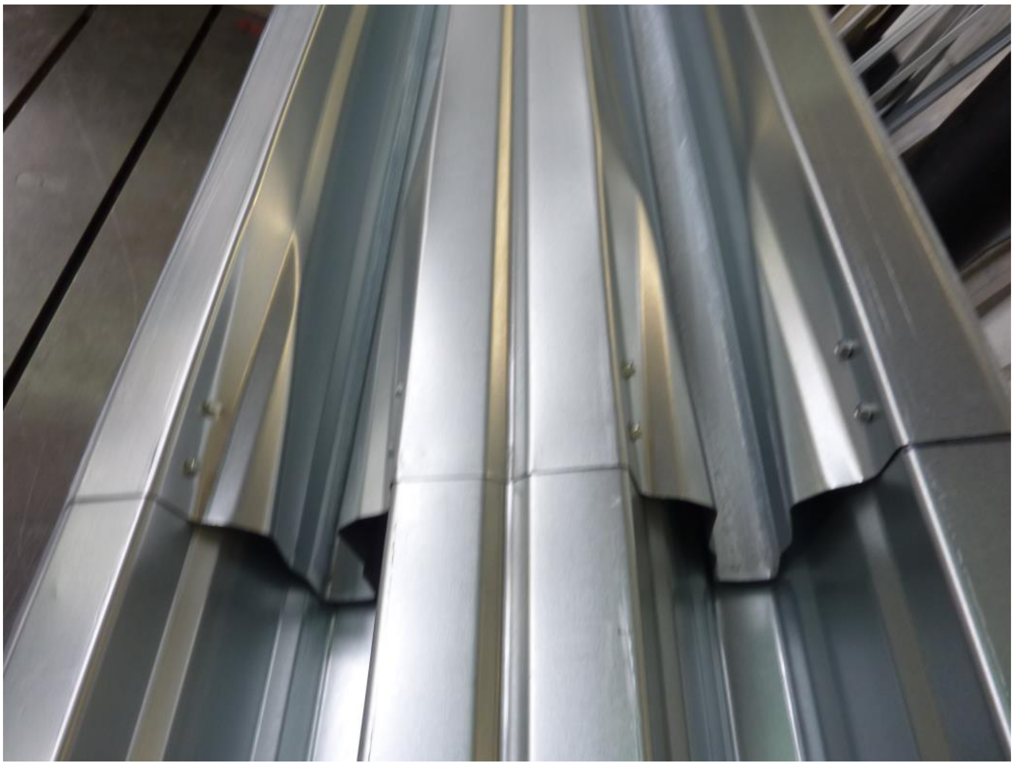


Fig. 12: Failure by web crippling at the end of overlap; no local buckling due to bending moment in the support axis

To avoid prior failure by web crippling, the overlap should be sufficiently long. The overlap should be chosen so long, that the shear force at the end of the overlap doesn't exceed the web crippling capacity of the profile. The shear force at the end of the overlap depends directly from the overlap length:

DIN-joint:	$F = M_{c,Rk,B} / a$
Overlap OL:	$F = M_{c,Rk,B} / (2 * a)$
Continuous profile with local reinforcement CR:	$F = M_{c,Rk,B} / (2 * a)$

The shear forces F in failure state are given in the tables above.

Since the design model should be simple and furthermore based on certified characteristic values of the profile, it is recommended to take 50% of the ultimate support reaction in the opposite profile's position at intermediate supports under downward loading. This characteristic value represents at the best the web crippling resistance at the end of overlap. The stresses created by F at the end of overlap and the stresses created by the support reaction $R_{w,Rk,B}$ are similar: The shear force is acting as compression force on the webs and introduced on the side of the broad flange of the profile.

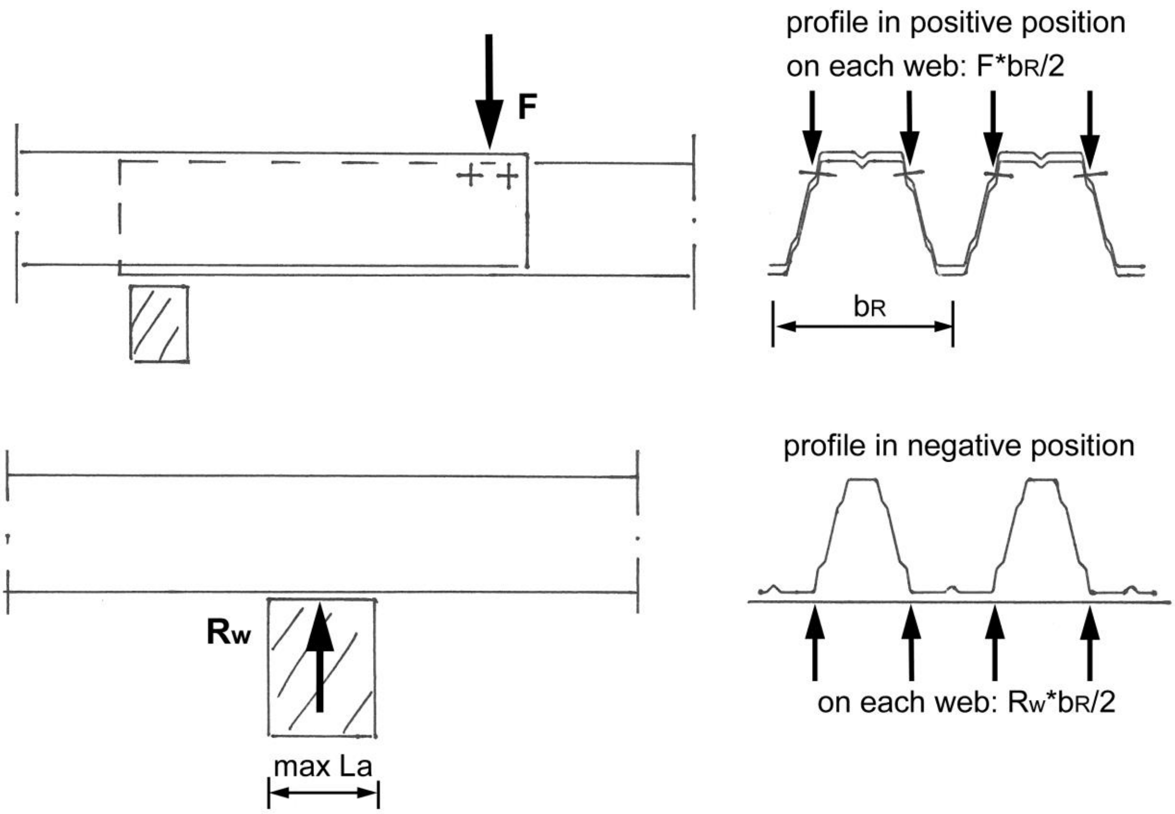


Fig. 13: Comparison web crippling at the end of overlap and at support

The R_w-value at intermediate supports with the greatest support width meets best the shear forces F found in the tests. But only the half of this resistance value should be taken, because the profile is only at one side of the load axis, which is not the case at intermediate supports. The support reactions at end supports, even for the greatest support width, are too small compared with the test results and would lead to an uneconomic design. Also the support reactions at intermediate supports with small support width are too small and uneconomic. The reason is, that – regarding web crippling - load introduction by the screws some mm below the flange is more favourable than load introduction by contact in the rounded corners flange-web.

The proposition to take the ultimate support reaction in the opposite position to design the overlap's length is a safe and simple approach. Developing a more precise formula which takes into account the place of load introduction and the slightly modified web crippling behaviour would on the one hand need a mass of additional tests and in the other hand unnecessarily complicate the design of the assemblies.

The resistance values 0,5 * $R_{w,Rk,B}$ are also presented in the tables above. The shear force F in test is mostly a little bit greater than the chosen bearing resistance; so, the limitation of F to the recommended resistance value is on the safe side.

For the underlying overlap, no web crippling is possible in the load case downward loading, because the shear force F is introduced into the cross section via the lower flange and acts as a tension force on the webs.

c) Profile 137.310-1,00 mm, support width 60 mm

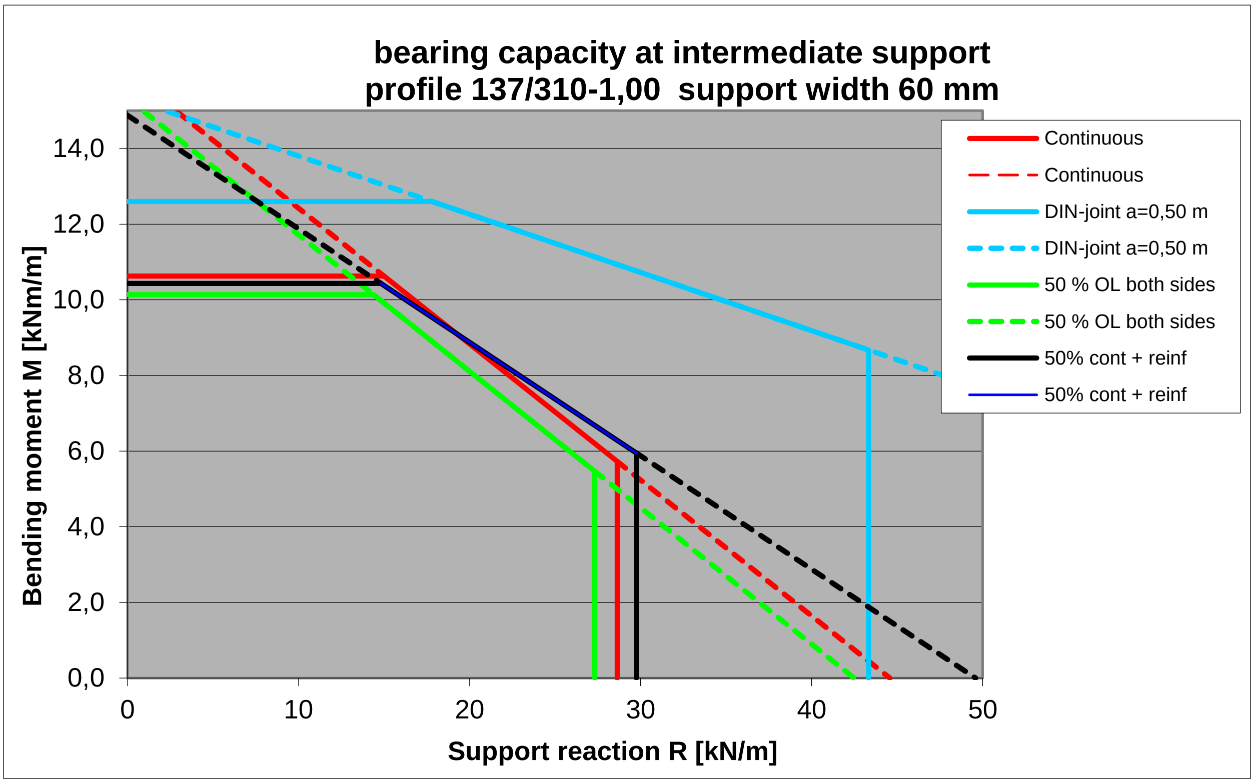


Fig. 14: M-R-interaction for profile JID 137.310-1,00 mm, support width 60 mm

Profile	137.310	thickness	1,00 mm	support width	60 mm
Type of assembly -	bending moment $M_{c,Rk,B}$ kNm/m	relative bending moment %	shear force at end of overlap F kN/m	0.5 R_{wRkB} kN/m	ratio F/(0,5 R_{wRkB}) -
Continuous	10,625	100,0	-	20,47	-
DIN a = 0,5 m	12,599	118,6	25,20	20,47	1,23
DIN a = 0,7 m	-	-	-	-	-
OL a = 0,5 m	20,270	190,8	20,27	20,47	0,99
OL a = 0,7 m	-	-	-	-	-
CR a = 0,5 m	20,866	196,4	20,87	20,47	1,02

Table 8: Comparison of the tested assemblies; profile JID 137.310-1,00 mm, support width 60 mm

The DIN-joint is at least on the same level as the reference profile, even with the short overlap 0,50 m. The assemblies OL and CR with doubled cross section have nearly the doubled resistance of the reference profile. Therefore, no additional tests with enhanced overlap length were done.

d) Profile 137.310-1,00 mm, support width 160 mm

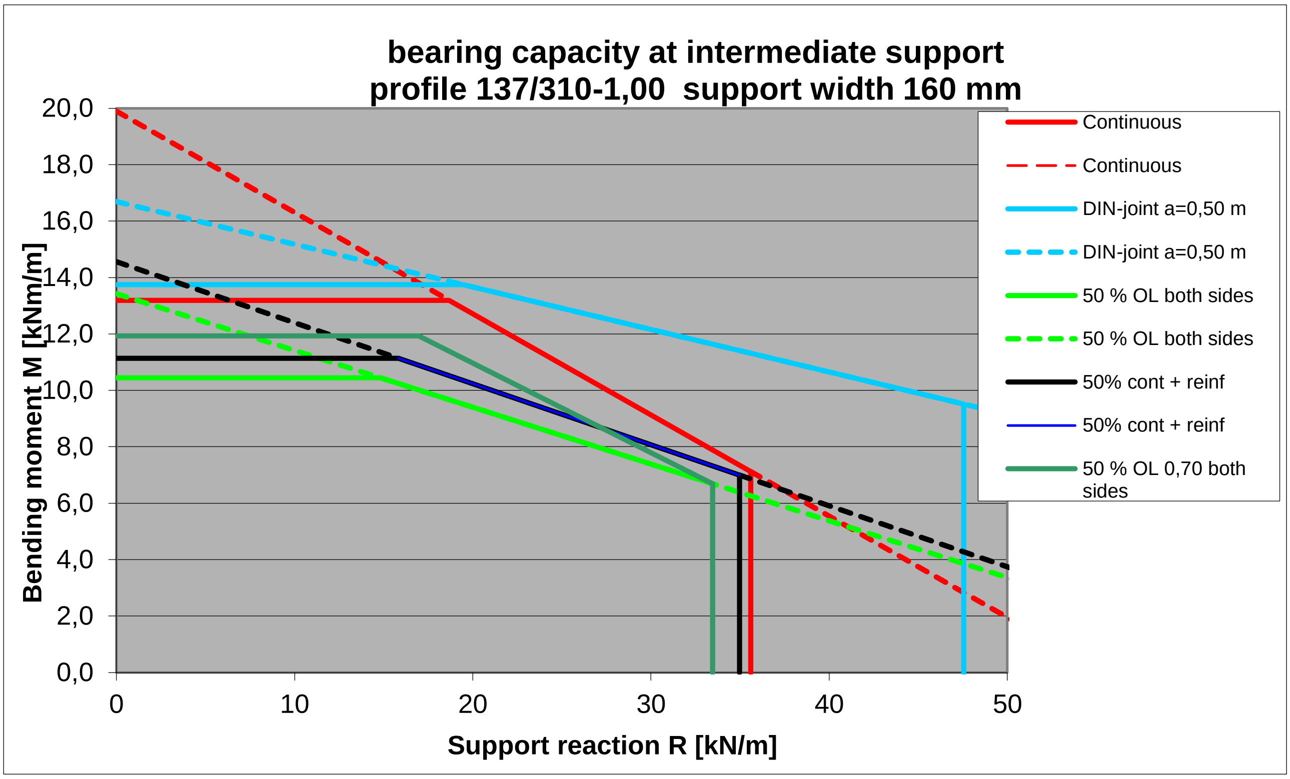


Fig. 15: M-R-interaction for profile JID 137.310-1,00 mm, support width 160 mm

Profile	137.310	thickness	1,00 mm	support width	160 mm
Type of assembly -	bending moment $M_{c,Rk,B}$ kNm/m	relative bending moment %	shear force at end of overlap F kN/m	0.5 R_{wRkB} kN/m	ratio F/(0,5 R_{wRkB}) -
Continuous	13,194	100,0	-	20,47	-
DIN a = 0,5 m	13,751	104,2	27,50	20,47	1,34
DIN a = 0,7 m	-	-	-	-	-
OL a = 0,5 m	20,884	158,3	20,88	20,47	1,02
OL a = 0,7 m	23,864	180,9	17,05	20,47	0,83
CR a = 0,5 m	22,274	168,8	22,27	20,47	1,09

Table 9: Comparison of the tested assemblies; profile JID 137.310-1,00 mm, support width 160 mm

With the short overlap 0,50 m, the assemblies OL and CR achieve only 160% or 170% of the reference profile. With enhanced overlap length, the bending resistance increases up to 180%.

e) Profile 158.250-0,75 mm, support width 60 mm

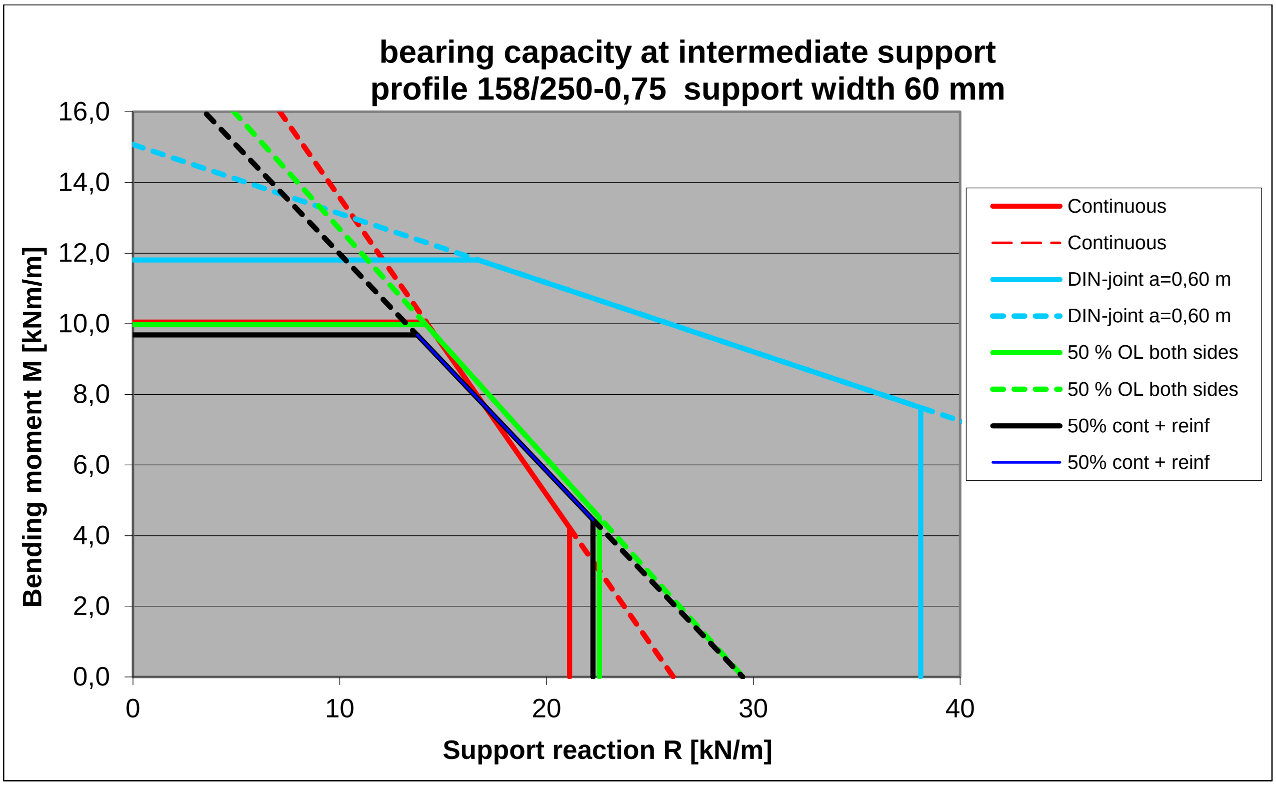


Fig. 16: M-R-interaction for profile JID 158.250-0,75 mm, support width 60 mm

Profile	158.250	thickness	0,75 mm	support width	60 mm
Type of assembly -	bending moment $M_{c,Rk,B}$ kNm/m	relative bending moment %	shear force at end of overlap F kN/m	0.5 R_{wRkB} kN/m	ratio F/(0,5 R_{wRkB}) -
Continuous	10,048	100,0	-	14,90	-
DIN a = 0,6 m	11,808	117,5	19,68	14,90	1,32
DIN a = 0,8 m	-	-	-	-	-
OL a = 0,6 m	19,947	198,5	16,62	14,90	1,12
OL a = 0,8 m	-	-	-	-	-
CR a = 0,6 m	19,358	192,6	16,13	14,90	1,08

Table 10: Comparison of the tested assemblies; profile JID 158.250-0,75 mm, support width 60 mm

The DIN-joint is at least on the same level as the reference profile, even with the short overlap 0,60 m. The assemblies OL and CR with doubled cross section have nearly the doubled resistance of the reference profile. Therefore, no additional tests with enhanced overlap length were done.

f) Profile 158.250-0,75 mm, support width 160 mm

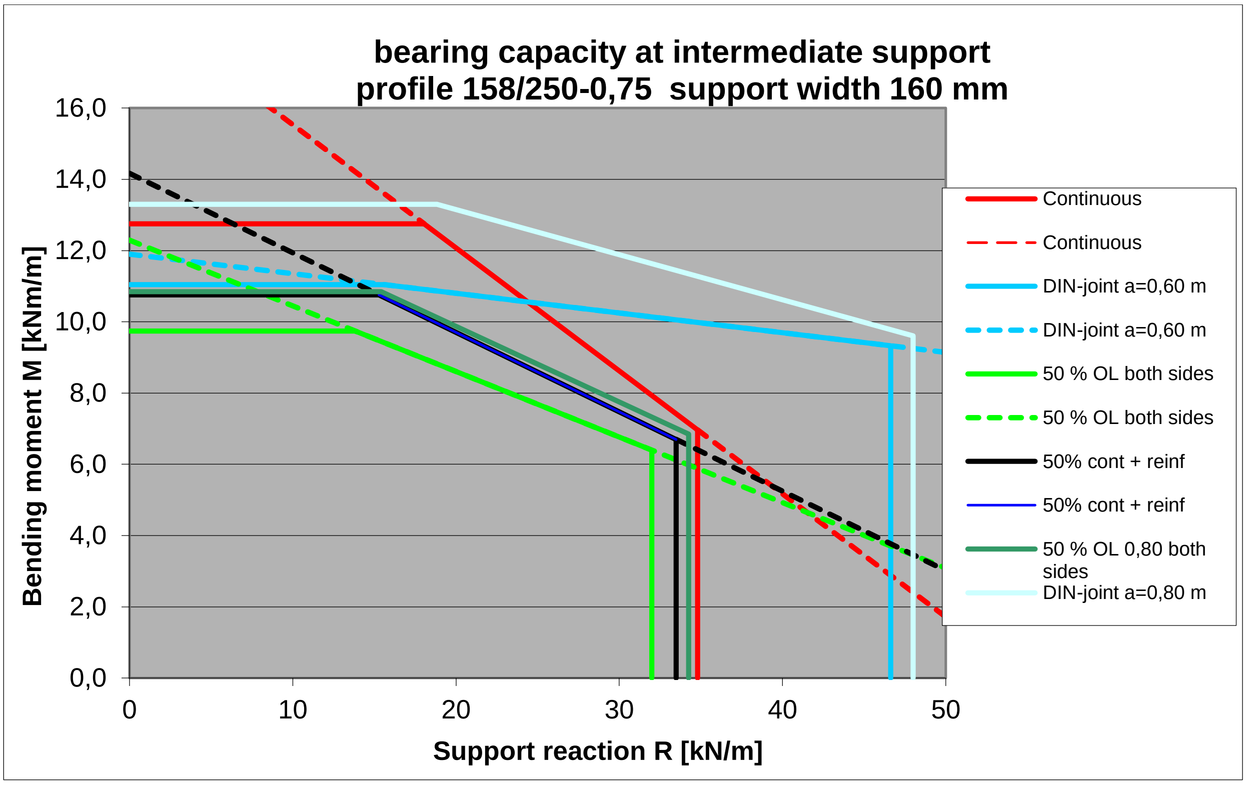


Fig. 17: M-R-interaction for profile JID 158.250-0,75 mm, support width 160 mm

Profile	158.250	thickness	0,75 mm	support width	160 mm
Type of assembly -	bending moment $M_{c,Rk,B}$ kNm/m	relative bending moment %	shear force at end of overlap F kN/m	0.5 R_{wRkB} kN/m	ratio F/(0,5 R_{wRkB}) -
Continuous	12,753	100,0	-	14,90	-
DIN a = 0,6 m	11,040	86,6	18,40	14,90	1,24
DIN a = 0,8 m	13,296	104,3	16,62	14,90	1,12
OL a = 0,6 m	19,490	152,8	16,24	14,90	1,09
OL a = 0,8 m	21,701	170,2	13,56	14,90	0,91
CR a = 0,6 m	21,518	168,7	17,93	14,90	1,20

Table 11: Comparison of the tested assemblies; profile JID 158.250-0,75 mm, support width 160 mm

The DIN-joint with enhanced overlap length 0,80 m has a bending resistance, which is greater than the continuous profile; the short overlap 0,60 m were not sufficient. Also for OL and CR assembly, the overlap length had to be increased to reach a bending resistance on the level 170% of the reference profile.

g) Profile 158.250-1,00 mm, support width 60 mm

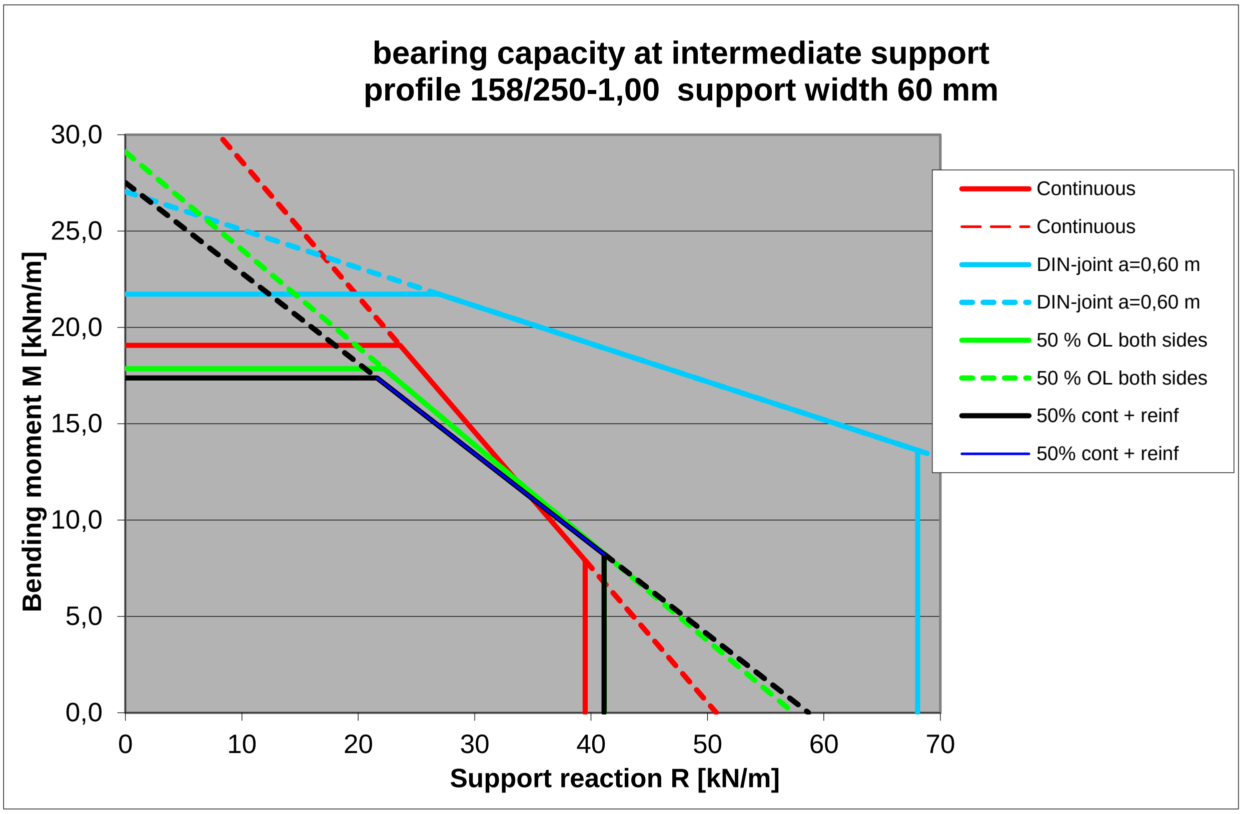


Fig. 18: M-R-interaction for profile JID 158.250-1,00 mm, support width 60 mm

Profile	158.250	thickness	1,00 mm	support width	60 mm
Type of assembly -	bending moment $M_{c,Rk,B}$ kNm/m	relative bending moment %	shear force at end of overlap F kN/m	0.5 R_{wRkB} kN/m	ratio F/(0,5 R_{wRkB}) -
Continuous	19,072	100,0	-	26,70	-
DIN a = 0,6 m	21,736	114,0	36,23	26,70	1,36
DIN a = 0,8 m	-	-	-	-	-
OL a = 0,6 m	35,702	187,2	29,75	26,70	1,11
OL a = 0,8 m	-	-	-	-	-
CR a = 0,6 m	34,767	182,3	28,97	26,70	1,09

Table 12: Comparison of the tested assemblies; profile JID 158.250-1,00 mm, support width 60 mm

The DIN-joint is at least on the same level as the reference profile, even with the short overlap 0,60 m. The assemblies OL and CR with doubled cross section have nearly the doubled resistance of the reference profile. Therefore, no additional tests with enhanced overlap length were done.

h) Profile 158.250-1,00 mm, support width 160 mm

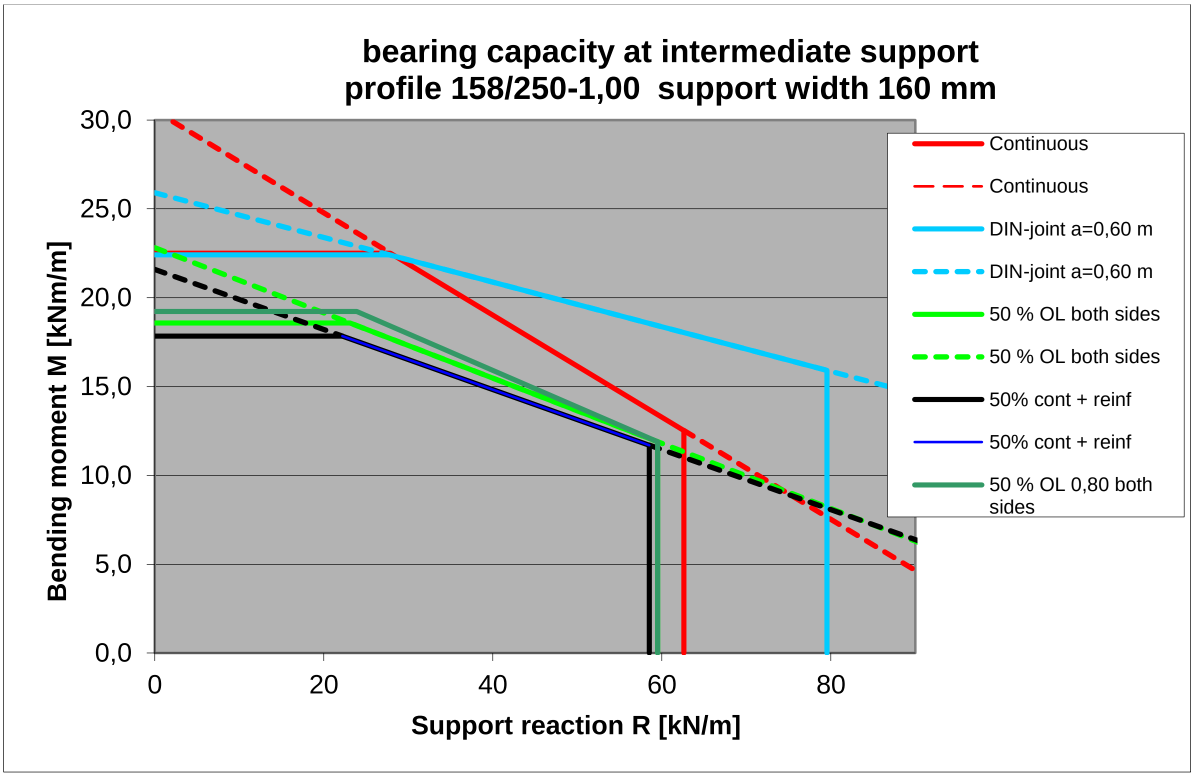


Fig. 19: M-R-interaction for profile JID 158.250-1,00 mm, support width 160 mm

Profile	158.250	thickness	1,00 mm	support width	160 mm
Type of assembly -	bending moment $M_{c,Rk,B}$ kNm/m	relative bending moment %	shear force at end of overlap F kN/m	0.5 R_{wRkB} kN/m	ratio F/(0,5 R_{wRkB}) -
Continuous	22,510	100,0	-	26,70	-
DIN a = 0,6 m	22,419	99,6	37,37	26,70	1,40
DIN a = 0,8 m	-	-	-	-	-
OL a = 0,6 m	37,152	165,0	30,96	26,70	1,16
OL a = 0,8 m	38,441	170,8	24,03	26,70	0,90
CR a = 0,6 m	35,687	158,5	29,74	26,70	1,11

Table 13: Comparison of the tested assemblies; profile JID 158.250-1,00 mm, support width 160 mm

The DIN-joint is at least on the same level as the reference profile, even with the short overlap 0,60 m. For the assemblies OL and CR with doubled cross section, the overlap length must be increased to achieve nearly the reference profile.

Conclusions:

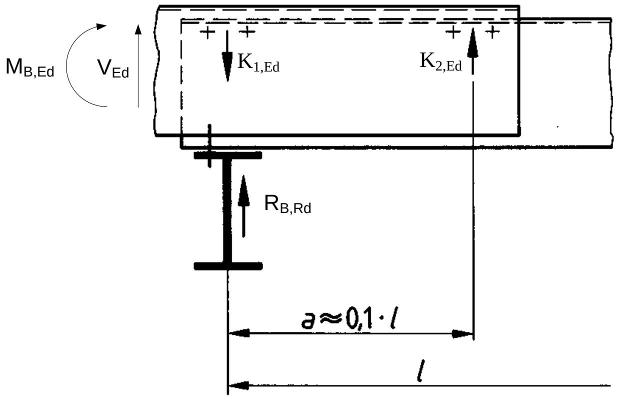
1. The DIN-joint provides the same load bearing capacity as the continuous profile, if the overlap is long enough. The sufficient overlap length should be checked by an additional verification of the shear force at the end of the overlap.

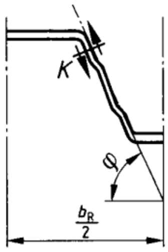
2. The assemblies with doubled cross section don't achieve the double resistance of the continuous profile in spite of an increased overlap length. Therefore, the bending moment resistance of one profile should be estimated by 90% of the reference profile. The overlap length should be designed in a way, that web crippling at the end of the overlap is excluded.

6 Recommended design procedure

A Assembly with overlap on one side (DIN-joint)

A1 cantilever above





a) Verification of the profile with the design resistance values ($M_{Rd,B}$, $R_{w,Rd,B}$) of the continuous profile in the support axis taking into account the influence of support reaction (M-R-interaction).

b) Check of the free end of the cantilever, if the line load introduced by the connections K_i may create web crippling

- Downward load = negative bending moment

  web crippling at the end of the cantilever

  $F_{Ed} = M_{B,Ed}/a < 0,5\, R_{w,Rd,B}$

  $R_{w,Rd,B}$ is the ultimate support reaction at intermediate supports in the opposite profile position (in general negative position) for the max. support width, in general l_{aB} = 160 mm (determined in GRISPE [1], that the design resistance $R_{w.Rd,B}$(160 mm) is suitable for this verification)

- Uplift load = positive bending moment
  No web crippling possible at the end of the cantilever

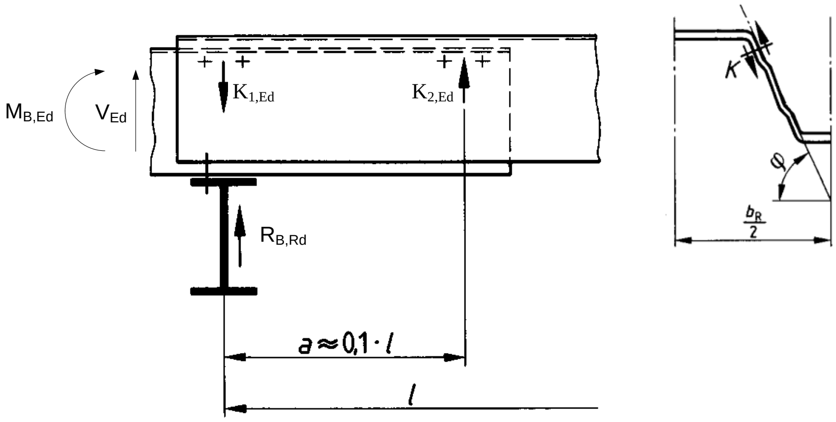
c) Verification of the connections K_{Ed}

$$K_{Ed} = \max K_i = \frac{\left|\frac{M_{B,Ed}}{a} + V_{L,Ed}\right|}{2 * \sin\varphi} * b_R \text{ (Verification in one web)}$$

$$\frac{K_{Ed}}{\Sigma F_{v,Rd}} \leq 1,0$$

with $\Sigma F_{v,Rd}$ shear resistance of the screws

A2 cantilever underneath



a) Verification of the profile with the design resistance values ($M_{Rd,B}$, $R_{w,Rd,B}$) of the continuous profile in the support axis taking into account the influence of support reaction (M-R-interaction).

b) Check of the free end of the cantilever, if the line load introduced by the connections K_i may create web crippling

- Downward load = negative bending moment
  No web crippling possible at the end of the cantilever

- Uplift load = positive bending moment
  No web crippling possible at the end of the cantilever

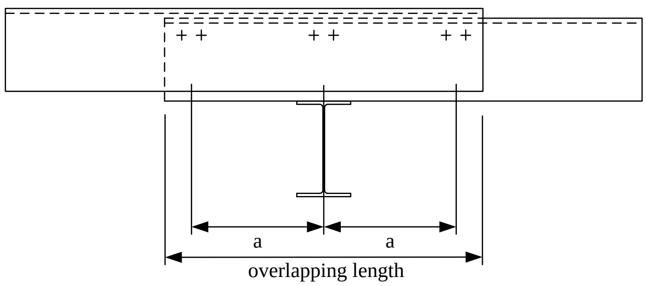
c) Verification of the connections K_{Ed}

$K_{Ed} = \max K_i = \frac{|M_{B,Ed}|}{2*a*\sin\varphi} * b_R$ (Verification in one web)

$$\frac{K_{Ed}}{\Sigma F_{v,Rd}} \leq 1{,}0$$

with $\Sigma F_{v,Rd}$ shear resistance of the screws

B Overlap joint



a) Determination of the bending moment distribution under design loads like for continuous sheets (The influence of the higher bending stiffness at the overlapping area, which is partly compensated by the slip and/or elastic deformations at the connections, is neglected). Results: $M_{B,Ed}$; $R_{B,Ed}$; $M_{1,Ed}$; $M_{2,Ed}$

b) Verification of the profiles at the support axis with 90 % of the resistance of the overlapping profiles (factor 0,9 determined in GRISPE [1]) taking into account the influence of the support reaction (M-R-interaction):

$M_{B,ED} \leq 0{,}9 \sum M_{Rd,B}$; $R_{B,ED} \leq 0{,}9 \sum R_{wRd,B}$; M-R-interaction

c) Verification of the continuous profiles at the ends of the overlap with the bending moments $M_{1,Ed}$ or $M_{2,Ed}$ and the line loads introduced by the connections K_i: $F_{Ed} = M_{B,Ed} / (2\ a)$. Depending of the direction of the load F_{Ed} relative to the web of the profile, the M-R-interaction or the M-V-interaction has to be verified.

For downward load, F_{Ed} is acting as a tension force on the webs of the continuous profiles; M-V-interaction has to be verified.

For uplift load, F_{Ed} is acting as a compression force on the webs of the continuous profiles; M-R-interaction has to be verified.

In both load cases, the resistance values of the profile in the opposite position at intermediate supports apply for these verifications.

d) Check of the free end of the cantilever, if the line load introduced by the connections K_i may create web crippling

- Downward load = negative bending moment

web crippling at the end of the upside cantilever

$F_{Ed} = M_{B,Ed}/(2a) < 0{,}5\ R_{w,Rd,B}$

$R_{w,Rd,B}$ is the ultimate support reaction at intermediate supports in the opposite profile position (in general negative position) for the max. support width, in general l_{aB} = 160 mm (determined in GRISPE [1], that the design resistance $R_{w.Rd,B}$(160 mm) is suitable for this verification)

No web crippling possible at the end of the cantilever underneath

- Uplift load = positive bending moment

No web crippling possible, neither at the upside cantilever nor at the cantilever underneath.

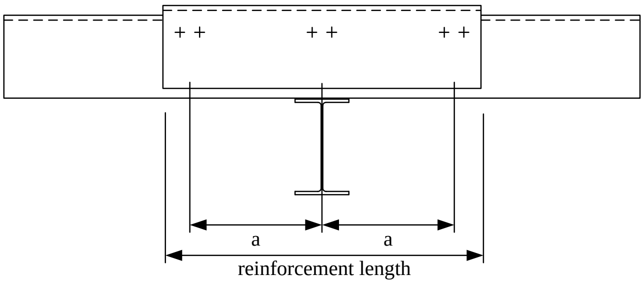
e) Verification of the connections K_{Ed}
With

$K_{Ed} = \max K_i = \frac{|M_{B,Ed}|}{4 * a * \sin\varphi} * b_R$ (Verification in one web)

$\frac{K_{Ed}}{\Sigma F_{v,Rd}} \leq 1,0$

with $\Sigma F_{v,Rd}$ shear resistance of the screws

C Continuous profile with local reinforcement



a) Determination of the bending moment distribution under design loads like for continuous sheets (The influence of the higher bending stiffness at the overlapping area, which is partly compensated by the slip and/or elastic deformations at the connections, is neglected). Results: $M_{B,Ed}$; $R_{B,Ed}$; $M_{1,Ed}$; $M_{2,Ed}$

b) Verification of the profiles at the support axis with 90 % of the resistance of the overlapping profiles (factor 0,9 determined in GRISPE [1]) taking into account the influence of the support reaction (M-R-interaction):

$M_{B,ED} \leq 0,9 \sum M_{Rd,B}$; $R_{B,ED} \leq 0,9 \sum R_{wRd,B}$; M-R-interaction

c) Verification of the continuous profile at the ends of the overlap with the bending moments $M_{1,Ed}$ or $M_{2,Ed}$ and the line loads introduced by the connections Ki: $F_{Ed} = M_{B,Ed} / (2 a)$. Depending of the direction of the load F_{Ed} relative to the web of the profile, the M-R-interaction or the M-V-interaction has to be verified.

For downward load, F_{Ed} is acting as a tension force on the webs of the continuous profile; M-V-interaction has to be verified.

For uplift load, F_{Ed} is acting as a compression force on the webs of the continuous profile; M-R-interaction has to be verified.

In both load cases, the resistance values of the profile in the opposite position at intermediate supports apply for these verifications.

d) Check of the free end of the cantilever, if the line load introduced by the connections K_i may create web crippling

- Downward load = negative bending moment
  web crippling at the end of both cantilevers

$F_{Ed} = M_{B,Ed}/(2a) < 0{,}5\ R_{w,Rd,B}$

$R_{w,Rd,B}$ is the ultimate support reaction at intermediate supports in the opposite profile position (in general negative position) for the maximum support width, in general l_{aB} = 160 mm (determined in GRISPE [1], that the design resistance $R_{w.Rd,B}$(160 mm) is suitable for this verification)

- Uplift load = positive bending moment
  No web crippling possible at the end of both cantilevers

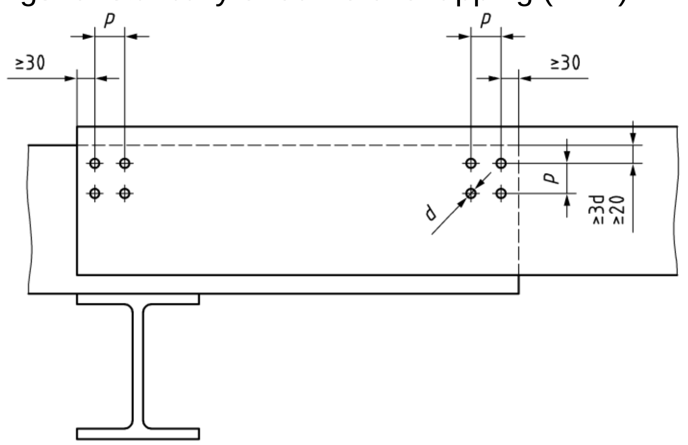
e) Verification of the connections K_{Ed}
with

$$K_{Ed} = \max K_i = \frac{|M_{B,Ed}|}{4 * a * \sin\varphi} * b_R \text{ (Verification in one web)}$$

$$\frac{K_{Ed}}{\Sigma F_{v,Rd}} \leq 1{,}0$$

with $\Sigma F_{v,Rd}$ shear resistance of the screws

Edge and hole spacings for statically effective overlapping (1.-4.)



7 References

[1] Deliverable D 2.3: Test report. Assembled profiles. KIT, 31.05.2015

[2] EN 1993-1.3: Eurocode 3 – Design of steel structures. Part 1.3: General rules – supplementary rules for cold-formed members and sheeting

[3] DIN 18807 part 1 and part 3: Trapezoidal sheeting in buildings; steel trapezoidal sheeting.

[4] Type approval T14-018 for JORIS IDE trapezoidal profiles. Landesdirektion Sachsen, Landesstelle für Bautechnik, Leipzig, 12.07.2014

Annex: Detailed test evaluation