GRISPE PLUS

VALORISATION OF KNOWLEDGE FOR SPECIFIC PROFILED STEEL SHEETS

Corrugated Sheeting

Ph. D. Thibault RENAUX – Joris Ide

The project has received financial support from the European Community (RFCS programme) under grant agreement No 754092

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Contextual introduction

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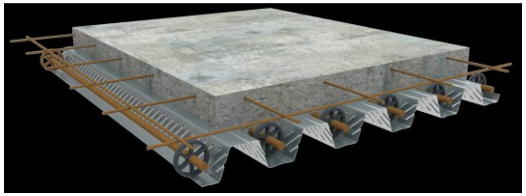
Contextual introduction

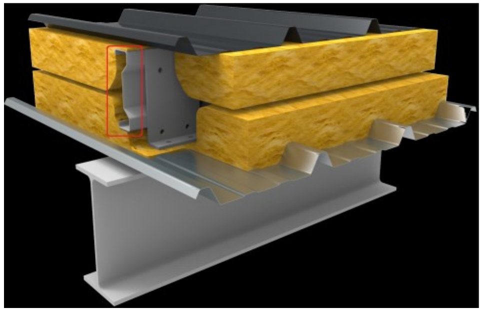
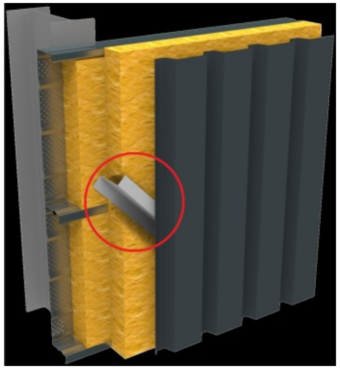
Range of products – Cold Formed Steel sections

- Flooring application:
  - Composite floor deck:




  - Dry floor deck:

- Purlins and spacers:

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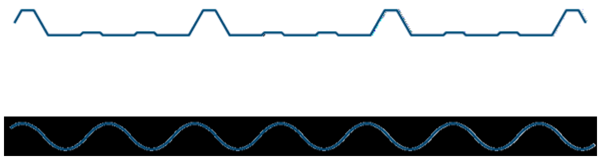
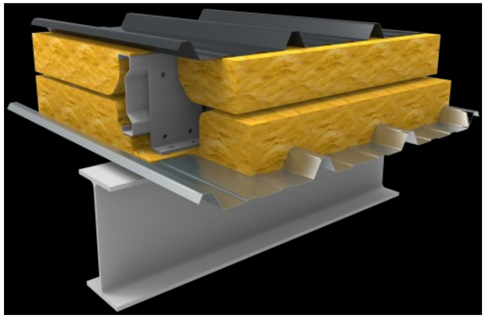
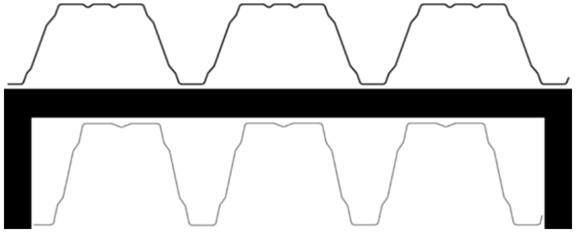
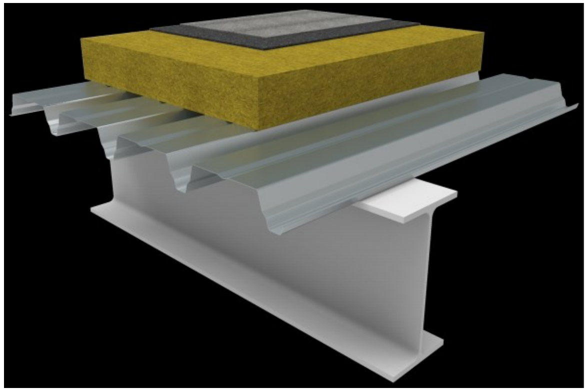
- Roofing application:
  - Single of double skin pitch roof with sinusoidal or trapezoidal profiles:





  - Flat roof with trapezoidal deck:





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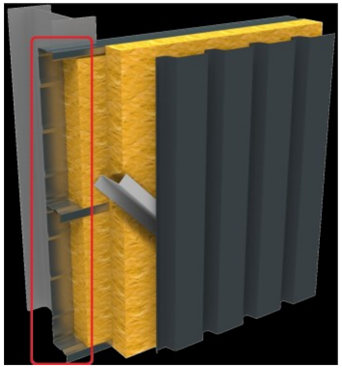
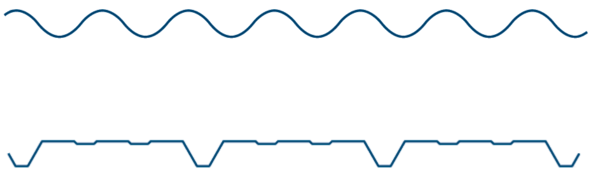
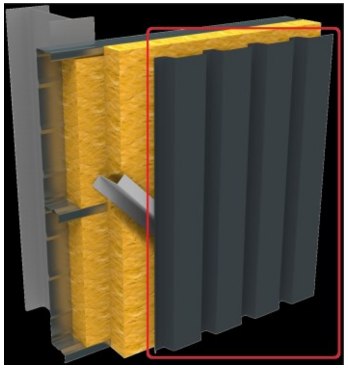
- Wall and cladding application:
  - Liner trays for internal skin:



  - Trapezoidal and sinusoidal profiles for single skin or external skin:





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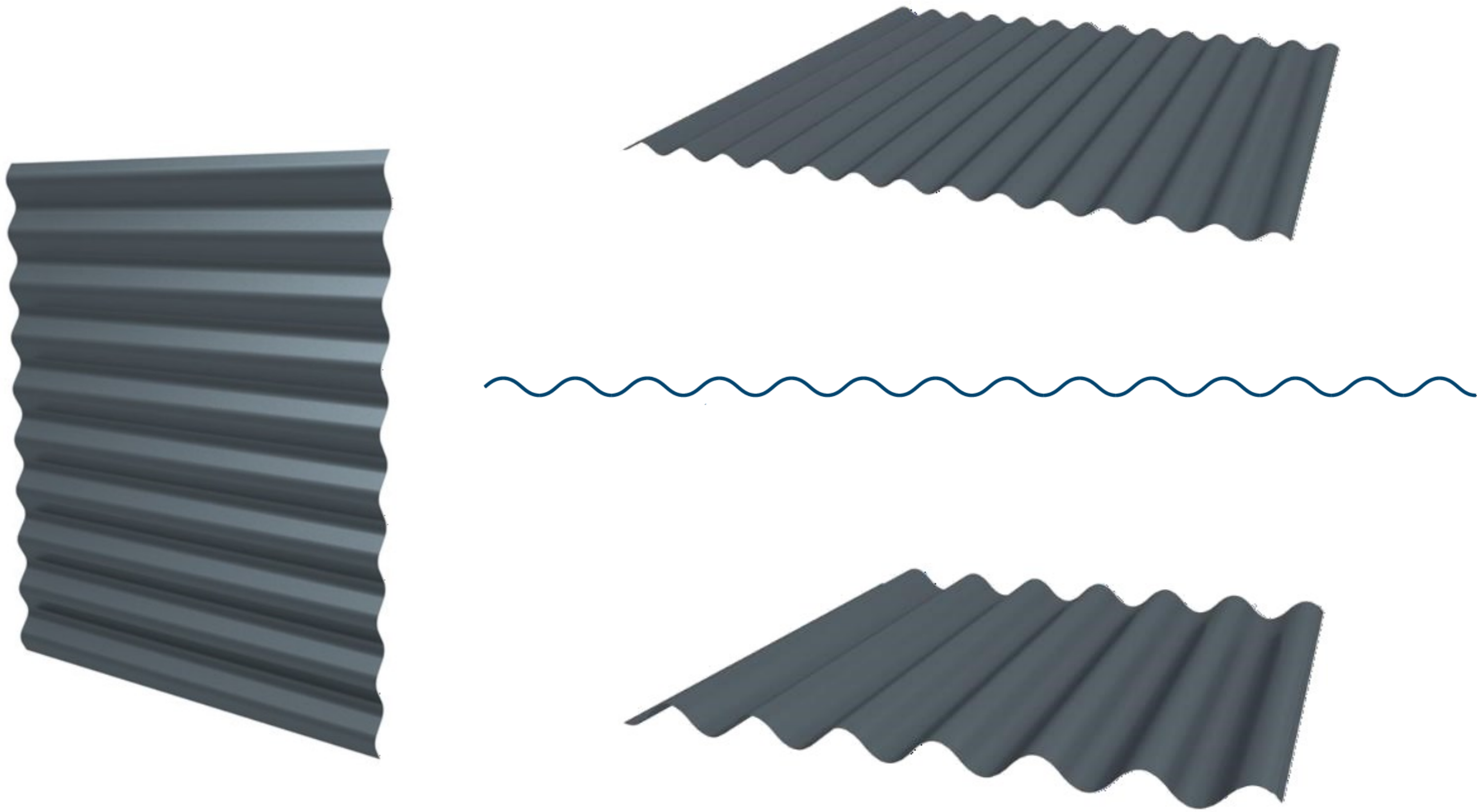
What is a corrugated steel sheet ?

⇨Product having a continuous curve



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Industrial buildings:

SNC Pont d'Ouit – Architect: DGA-Architecture

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Contextual introduction

Examples of application

- Residential buildings:

Aiguillon Construction
Architect: Christophe Rousselle Architecte

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- Comercial buildings:

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Sport infrastructure buildings:

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<u>**But**</u> actual European design rules don't prescribe calculation method (see EN 1993-1-3) !

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Contextual introduction

State of the art

- DIN 59231

- Article in the revue “Revue de Construction Métallique” n°1-2012:

  - Calculation method developed in comparison with FEM

- Silo approach ⇨ EN 1993-4

- Swedish Code for Light Gauge Metal Structures StBK-N5

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Performed works during GRISPE project

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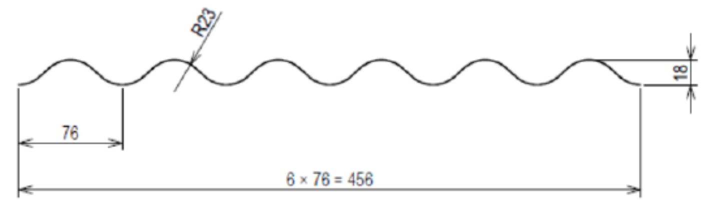
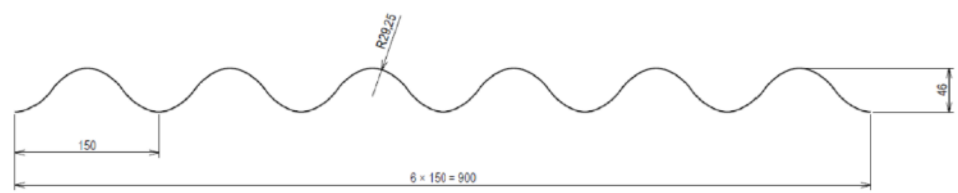
GRISPE Project – performed works

Selected profiles

- 2 classical corrugated steel sheets are studied:
  - 18 mm depth / radius of 23 mm / 76 mm pitch



  - 46 mm depth / radius of 29,25 mm / 150 mm pitch



- Supplier: Bacacier

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GRISPE Project – performed works

Tests campaign

- Test program:

According EN 1993-1-3

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

- Supplemented by tensile tests

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GRISPE Project – performed works

Adjustement of test results

- According EN 1993-1-3 § A.6.2:

$$R_{adj,i} = R_{obs,i}/\mu_R$$

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

- According EN 1993-1-3 § A.6.3.1:

$$s = \left[\sum_{i=1}^{n} \left(R_{adj,i} - R_m\right)^2 / (n-1)\right]^{0,5}$$

$$R_k = R_m +/- \; k \cdot s$$

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

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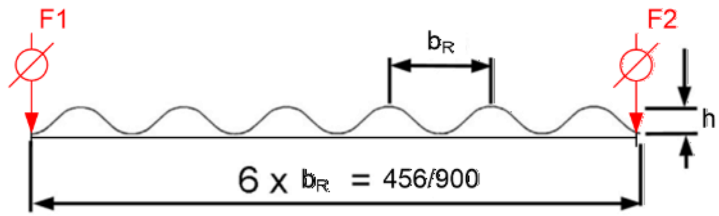
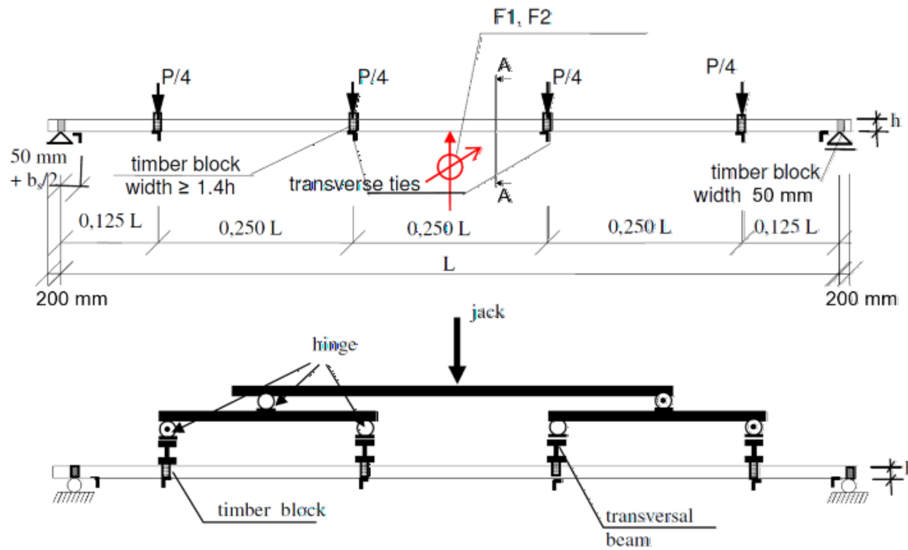
GRISPE Project – performed works

Single span test

- To determine the bending moment capacity:





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GRISPE Project – performed works

Single span test – calculation of the bending moment

- Maximum bending moment in span (single span tests):

$$M_{c,Rk,F} = \frac{F_{u,k}}{b_V} \cdot \frac{L}{8} + \frac{g \cdot L_V \cdot (2 \cdot L - L_v)}{8}$$

  - $M_{c,Rk,F}$ characteristic bending moment in span
  - $F_{u,k}$ characteristic load (including preload)
  - b_V width of the test specimen
  - L_V length of the test specimen
  - L span length
  - q self-weight of the test specimen

- Two modes of failure occurred: Yielding or Buckling of the compressed part

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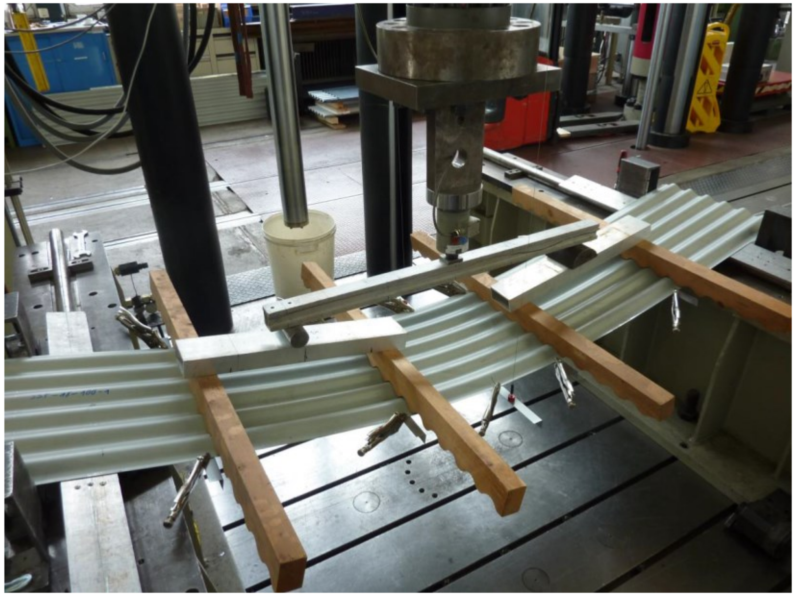
GRISPE Project – performed works

Single span test – failure mode by yielding



Profile 18.76 – 1,00 mm

- For small R/t ratio ⇨ failure by yielding in midspan (no buckling)

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GRISPE Project – performed works

Single span test – failure mode by buckling

Profile 18.76 – 0,63 mm

Profile 46.150 – 1,00 mm

- For great R/t ratio ⇨ failure by local buckling

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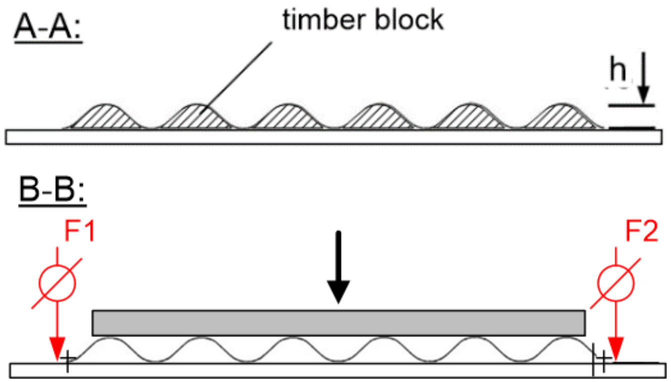
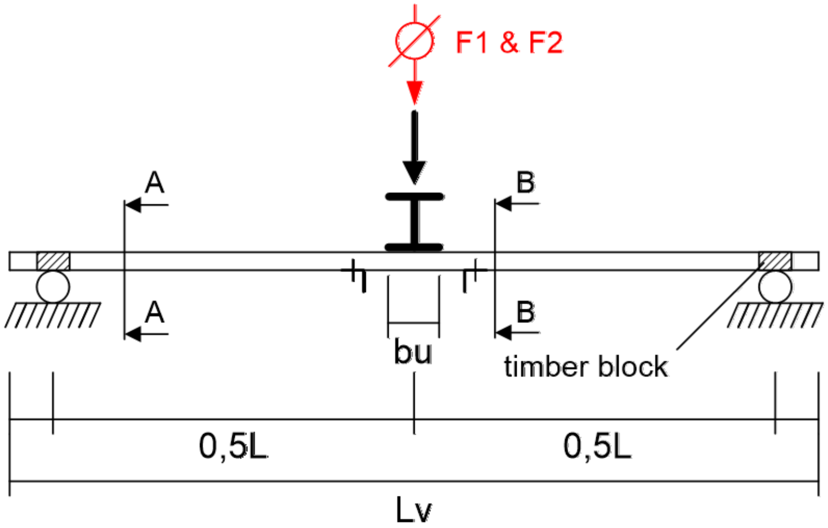
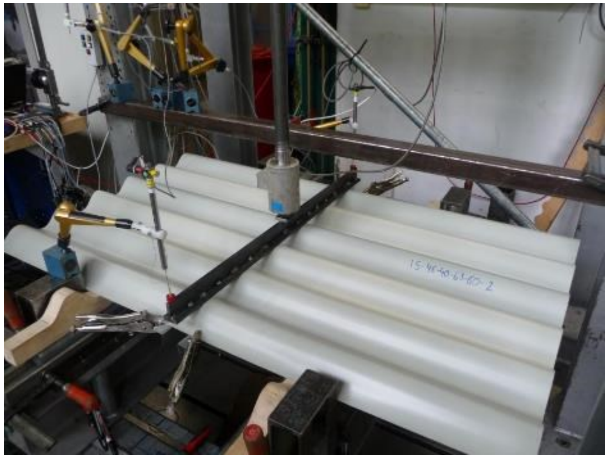
- Test under downward loading:







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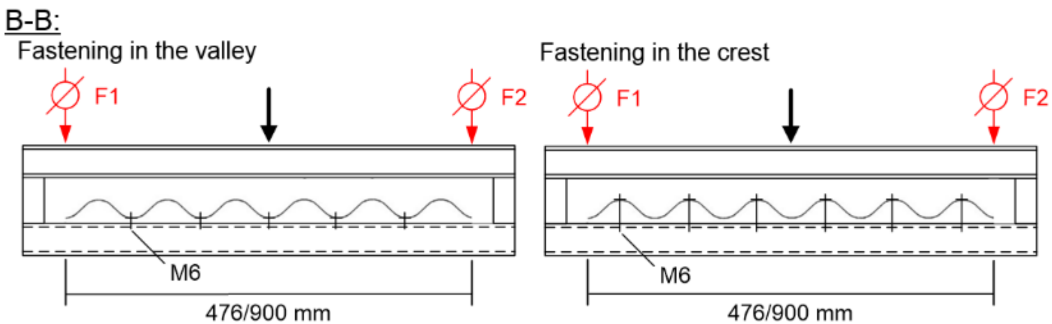
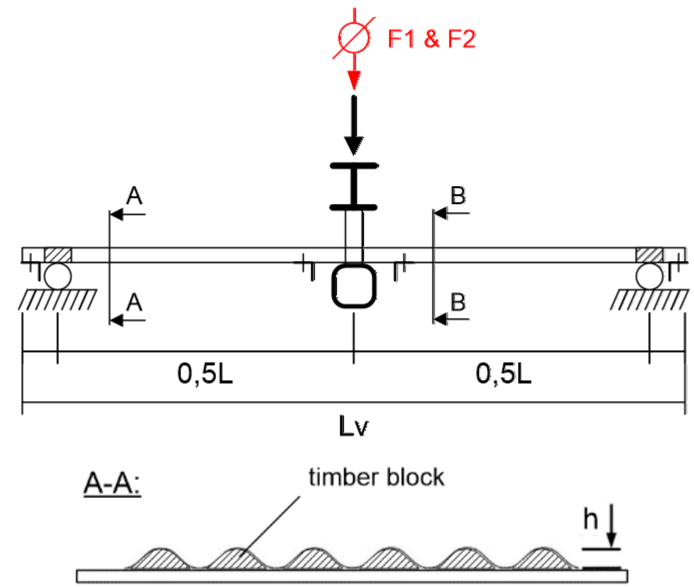
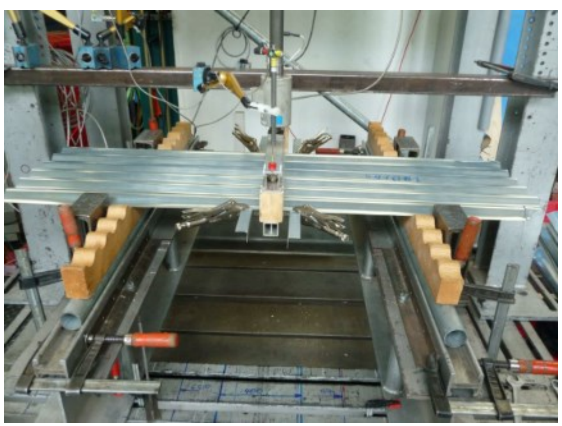
- Test for uplift loading:







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GRISPE Project – performed works

Intermediate support test - formulas

- Support reaction for intermediate support test: $R_{w,Rk,B} = F_{u,k}/b_V$

- Bending moment at support: $M_{c,Rk,B} = R_{w,Rk,B} \cdot \frac{L}{4} + \frac{g \cdot L_V \cdot (2L - L_v)}{8}$

  - $R_{w,Rk,B}$ characteristic support reaction at intermediate support
  - $M_{c,Rk,F}$ characteristic bending moment at intermediate support
  - $F_{u,k}$ characteristic load (including preload)
  - b_V width of the test specimen
  - L_V length of the test specimen
  - L span length (400 / 600 / 800 / 1 000 mm)
  - g self-weight of the test specimen

- Failure dominated by local deformations and buckling of the compressed part

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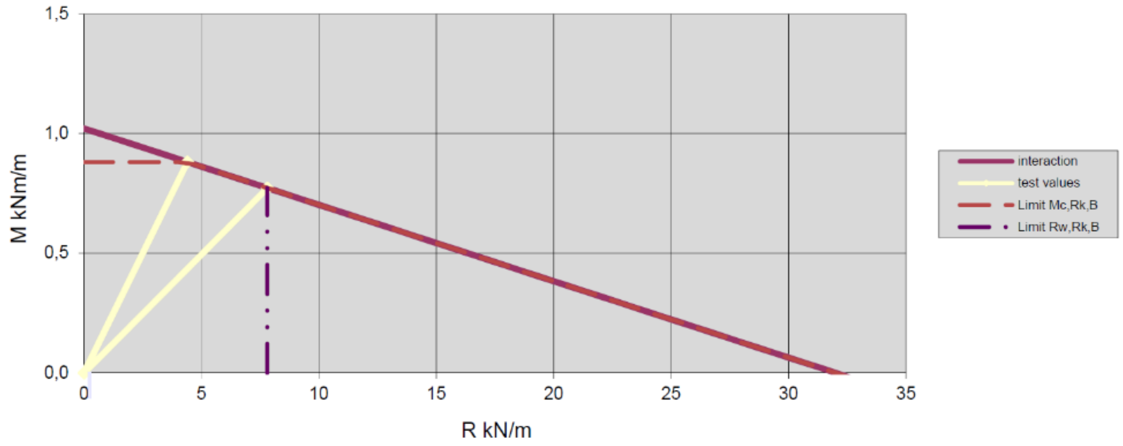
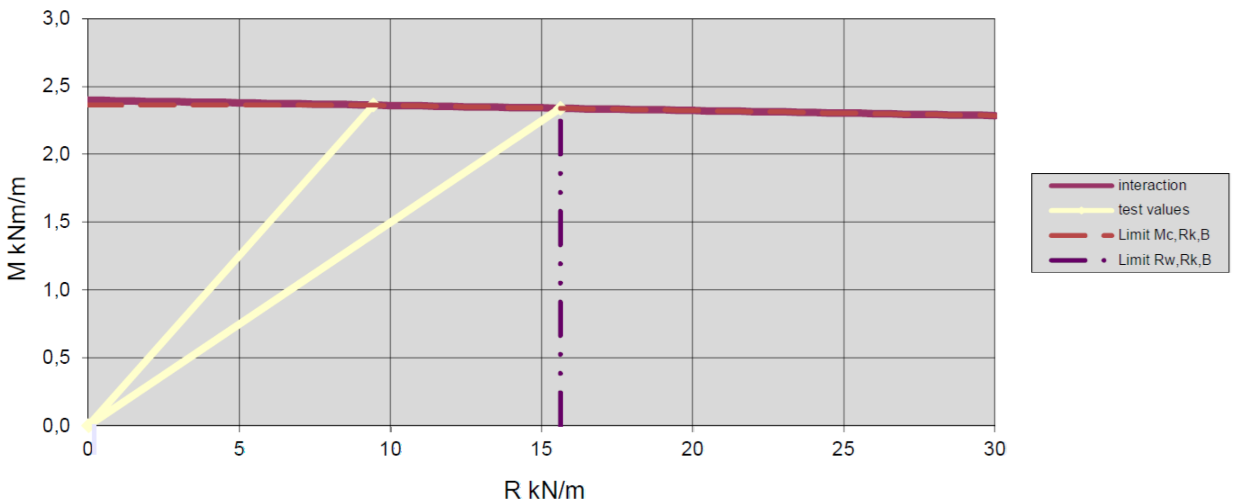
GRISPE Project – performed works

Intermediate support test - diagram of post processing

- Example of a interaction diagram M/R:





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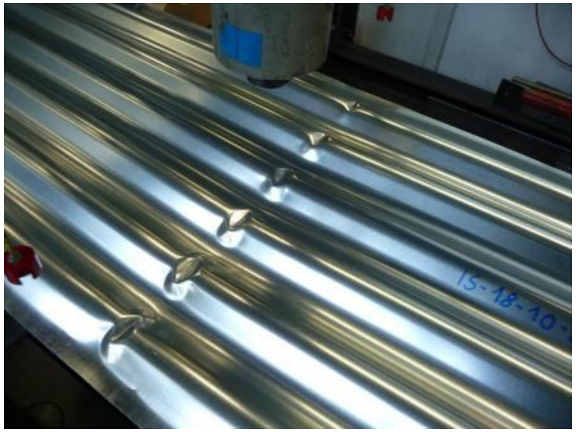
GRISPE Project – performed works

Intermediate support test – Failure modes

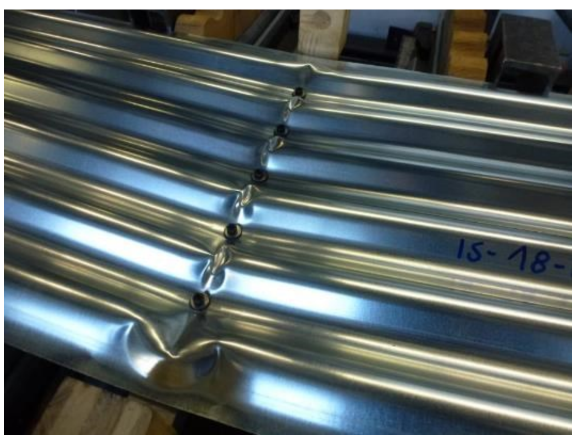
- For downward loading:



Profile 18.76 – 0,63 mm / 10 mm width of support

Profile 46.150 – 1,00 mm / 10 mm width of support

- For uplift loading:



Profile 18.76 – 0,63 mm – fixing in valley

Profile 18.76 – 0,63 mm – fixing in crest

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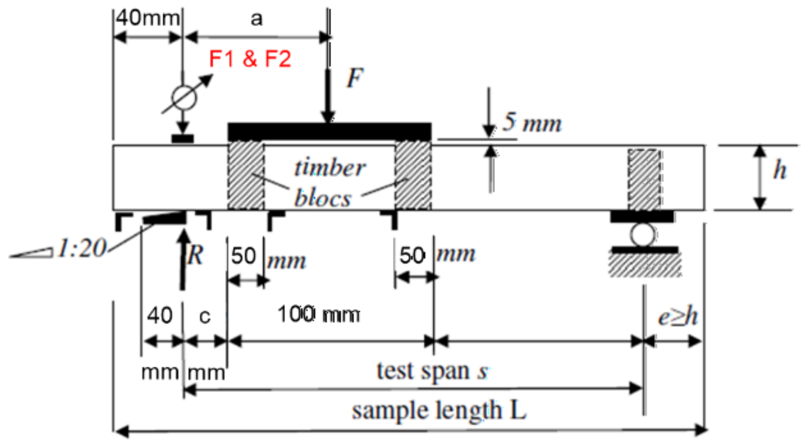
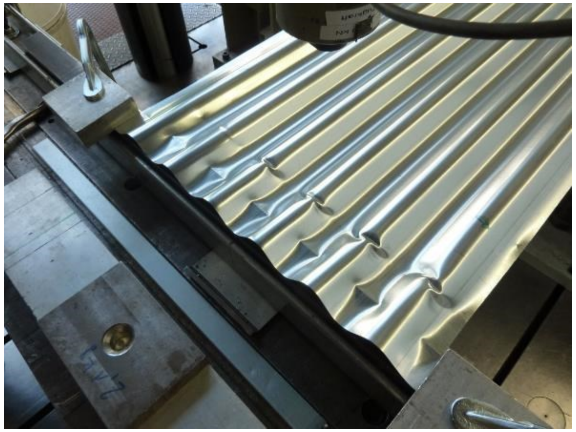
GRISPE Project – performed works

End support test

- Princip and example of failure:





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- End support reaction:

$$R_{w,Rk,A} = \frac{F_{u,k}}{b_V} \cdot \frac{(s-a)}{s}$$

- $R_{w,Rk,A}$ characteristic support reaction at end support
- $F_{u,k}$ characteristic load (including preload)
- b_V width of the test specimen
- a distance between load axis and support axis
- s span length

- The self-weight of the test specimen is neglected

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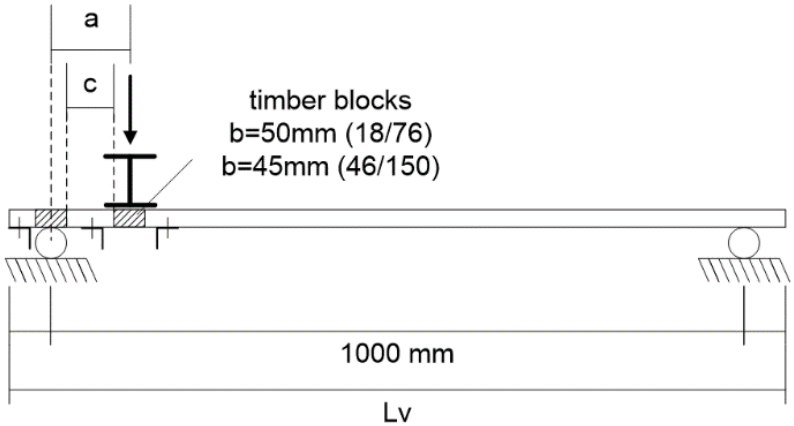
- Princip and example of failure :



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GRISPE Project – performed works

Shear test - formula

- Maximum shear force at the support:

$$V_{w,Rk} = \frac{F_{u,k}}{b_V} \cdot \frac{(s-a)}{s}$$

- $V_{w,Rk}$ characteristic shear force at end support
- $F_{u,k}$ characteristic load (including preload)
- b_V width of the test specimen
- a distance between load axis and support axis
- s span length

- the self-weight of the test specimen is neglected

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GRISPE Project – performed works

Main conclusions based on test results and state of the art

- Two calculation method for design corrugated sheets in isostatic bending:

  - First method is based on a Swedish approach

  - Second method consider the “Eurocode” silo approach defined with a field of application calibrated on the tests done during GRISPE project

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Main conclusions based on test results and state of the art

- For the behaviour of corrugated sheets on intermediate support:
  - The bending moment resistance at internal support under uplift loading with fixing in valley = bending moment in span under downward loading
  - The results don't show a clear rule as too many parameter interfere
  - More tests are necessary to reach a viable conclusion
  - Reduction of the ultimate bending moment is influenced geometric parameters
- For the shear behaviour and reaction on support: results don't allow to find a law

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Design method for corrugated sheets

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Design method for corrugated sheeting

Isostatic steel sheet – complete method

- Design procedure for the bending moment capacity in span:

- If $R/t < 0{,}04 \times E/f_{yb}$ ⇨ the cross section need not be checked for local buckling

- In this case, the characteristic bending moment is determined by:

$$M_{c,Rk} = W_y \cdot f_{yb}$$

- With W_y the section modulus of the gross cross section

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Design method for corrugated sheeting

Isostatic steel sheet – complete method

- If $R/t \geq 0{,}04 \times E/f_{yb}$ ⇨ For ULS: the characteristic bending moment can be calculated using the reduced compressive stress σ_c (StBK-N5):

$$M_{c,Rk} = W_y \cdot \sigma_c$$

- With:
  - coefficient η — $\eta = 0{,}19 + 0{,}67/\sqrt{1 + R/(100 \cdot t)}$
  - the buckling stress: — $\sigma_{elr} = 0{,}60 \cdot \eta \cdot E \cdot t/R$
  - the slenderness ratio: — $\alpha = \sqrt{f_{yb}/\sigma_{elr}}$
  - for $\alpha \leq 0{,}30$ — $\sigma_c = f_{yb}$
  - for $0{,}30 < \alpha < 1{,}10$ — $\sigma_c = (1{,}126 - 0{,}419 \cdot \alpha) \cdot f_{yb}$
  - For $1{,}10 \leq \alpha$ — $\sigma_c = (0{,}8/\alpha^2) \cdot f_{yb}$

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Design method for corrugated sheeting

Isostatic steel sheet – complete method

- If $R/t \geq 0{,}04 \times E/f_{yb}$ ⇨ For SLS: the moment of inertia I_y is calculated knowing W_y:

$$W_y = \frac{4 \cdot I_y \cdot t}{(b_R \cdot h_w/2)}$$

- W_y is determined consideering the characteristic bending moment using a reduced stress of $f_{yb}/1{,}5$

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Design method for corrugated sheeting

Isostatic steel sheet – Simplifed method for restrictied application

- If conditions:
  - Profile installed as single span girder <u>and</u>
  - Uniformly distributed loads <u>and</u>
  - Ratio R/t $\leq 0{,}1 \cdot E/f_{yb}$ <u>and</u>
  - Steel core thickness $t_{cor} \geq 0{,}55$ mm <u>and</u>
  - Profile height 18 mm $\leq h \leq$ 46 mm <u>and</u>
  - Profile pitch 76 mm $\leq p \leq$ 150 mm

- Are respected, the following procedure may be adopted:
  - Moment of inertia per unit width: $I_y = 0{,}13 \cdot t \cdot h^2$
  - Section modulus per unit width: $W_y = 0{,}26 \cdot t \cdot h$
  - Characteristic bending moment: $M_{c,Rk} = W_y \cdot f_{yb}$

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Design method for corrugated sheeting

Hyperstatic steel sheet

- For the bending moment resistance at internal support under “uplift” loading with fixing in valley:

$$M_{c,Rk,B} = M_{c,Rk,F}$$

- Actually no calculation method for other cases due to test results not sufficient to conclude for the M/R interaction

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