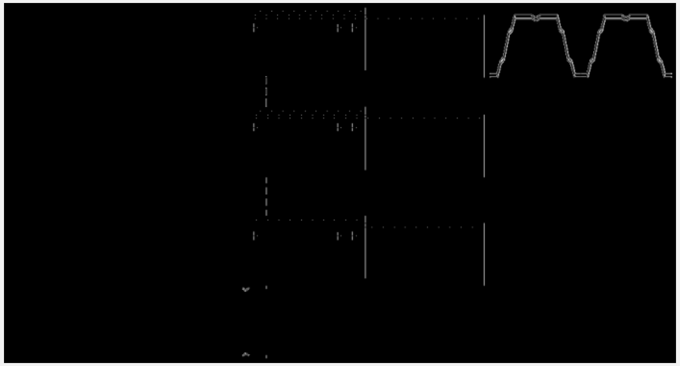
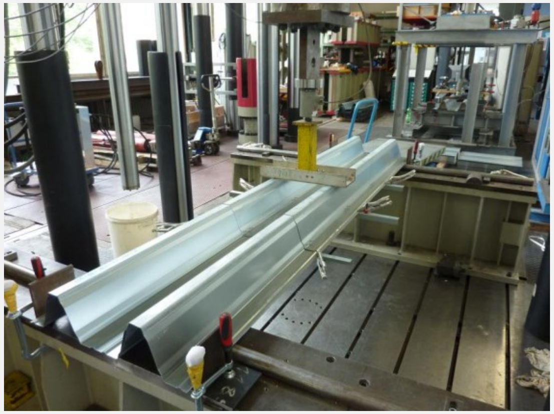
GRISPE PLUS

VALORISATION OF KNOWLEDGE FOR SPECIFIC PROFILED STEEL SHEETS

Assembled profiles

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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- Experimental works during GRISPE project
- Design method for assembled profiles

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Contextual introduction

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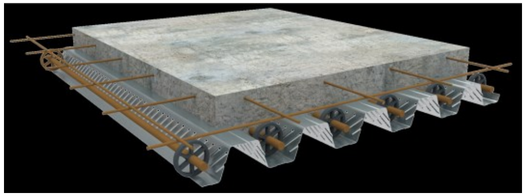
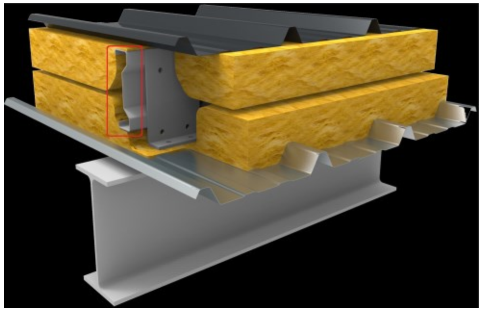
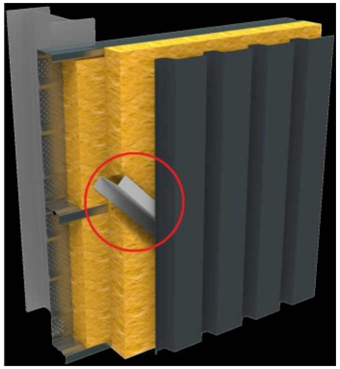
- Flooring application:
  - Composite floor deck:



  - Dry floor deck:

- Purlins and spacers:





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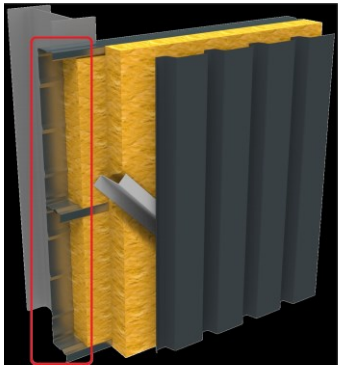
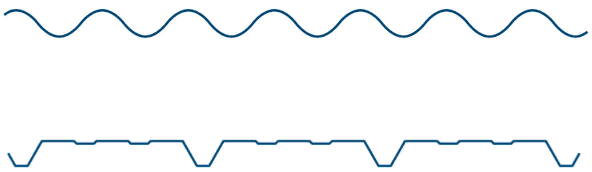
Contextual introduction

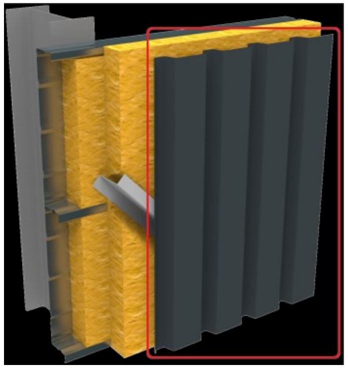
Range of products – Cold Formed Steel sections

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



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





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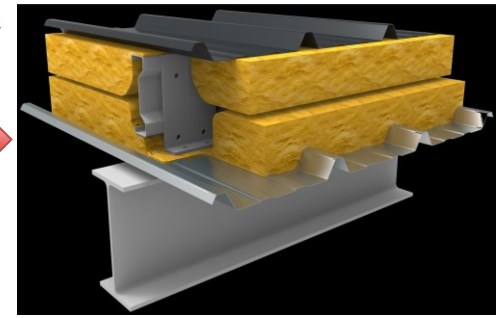
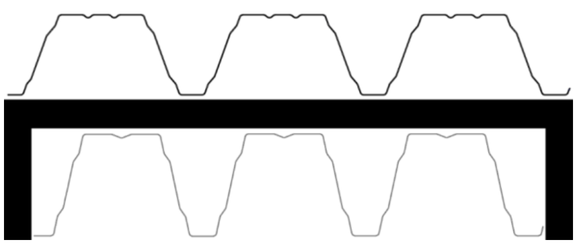
Contextual introduction

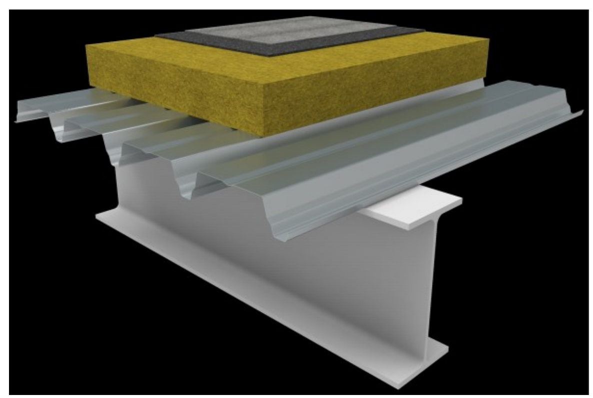
Range of products – Cold Formed Steel sections

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



  - Flat roof with trapezoidal deck:





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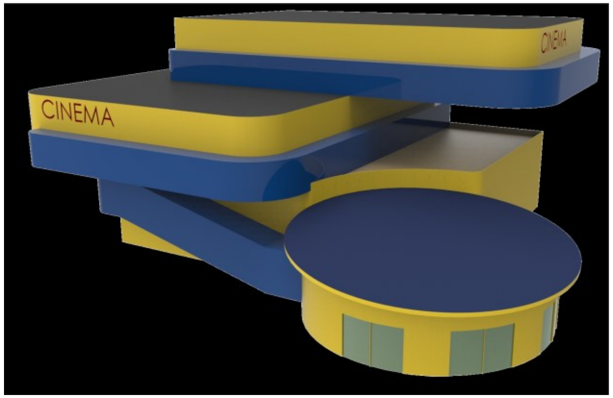
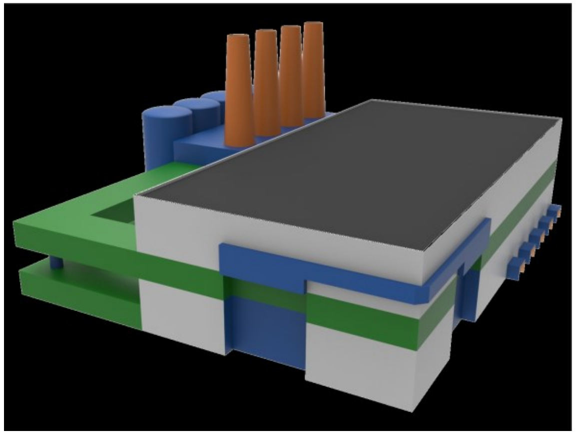
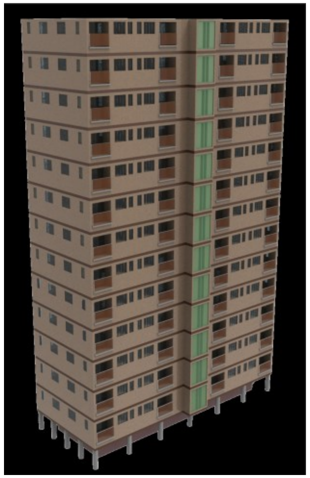
- Commercial and public area application:



- Industrial or residential application:





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Contextual introduction

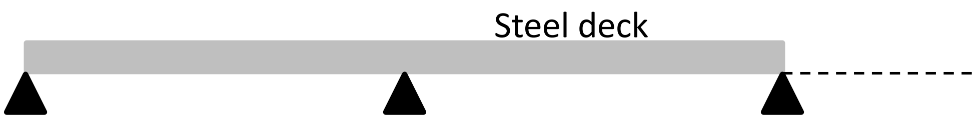
Actual design of trapezoidal steel deck for flat roof

- Loadings are determined according Eurocodes:
  - EN 1990 + EN 1991-1-1 + EN 1991-1-3 + EN 1991-1-4….
  - …and their national annex

- Choice of the deck according its resistance calculated according EN 1993-1-3 and national annexe

- This resistance is established for one deck

- Consequently the better performance ⇨ 2 (or more) spans configuration:



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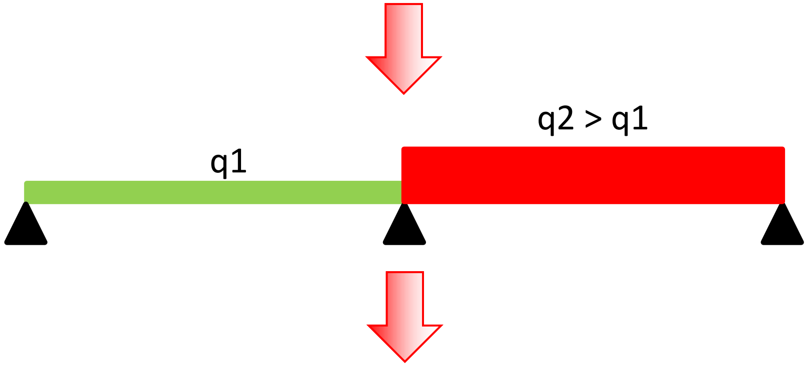
Contextual introduction

Problematic situations drive to a reduction of performance

- Local area on roof with more elevated loading (“Wind + Snow” effect) :



How avoid increasing thickness ?

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Contextual introduction

Problematic situations drive to a reduction of performance

- Isostatic case due to location changes of:
  - smoke extractors

- Consequences:
  - Characteristic resistance values not sufficient

How avoid increasing thickness ?

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Contextual introduction

Troubleshooting using calculation solution ?

- Can Eurocode provides solutions ?
  - Actually : NO
  - But some guidance or information are allowable in national standards

- Objective of GRISPE Project :
  - Propose intermediate support joint solutions
  - Determine the consequence on the intermediate support behaviour
  - Establish design procedures to calculate their benefits

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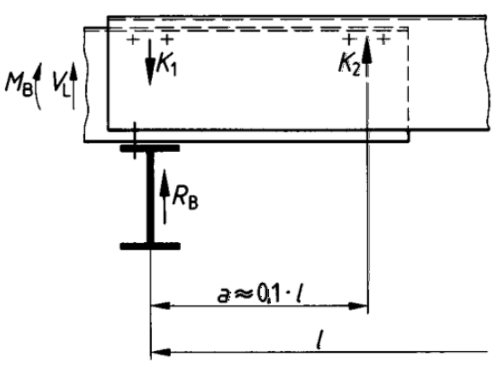
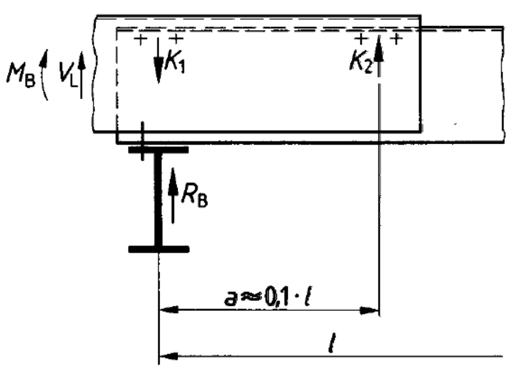
Contextual introduction

Actual solution in German national standard + EN 1090-4

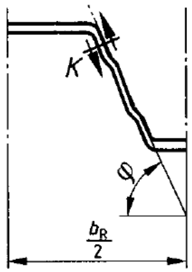
- Joint according to DIN 18807-3 (DIN), and included in EN 1090-4 § B.8 :
  - Permitted in the area of support (moment resisting connection)
  - Ultimate limit state of the whole structure remains unaltered
  - 2 variants :



Cantilevered end of profile underneath



Cantilevered end of profile on top



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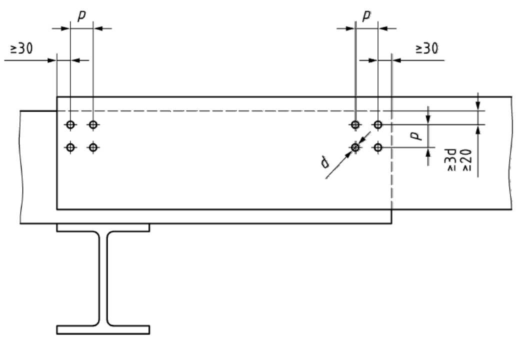
Contextual introduction

Actual solution in German national standard + EN 1090-4

- Joint according to DIN 18807-3 (DIN), and included in EN 1090-4 § B.8:
  - Design of sheeting and connections as follow:



- Cantilevered end of profile underneath:

$$K = maxK_i = \frac{|M_B|}{2 \cdot a \cdot \sin\varphi} \cdot b_R$$

- Cantilevered end of profiled on top:

$$K = maxK_i = \frac{\left|\frac{M_B}{a} + V_L\right|}{2 \cdot \sin\varphi} \cdot b_R$$

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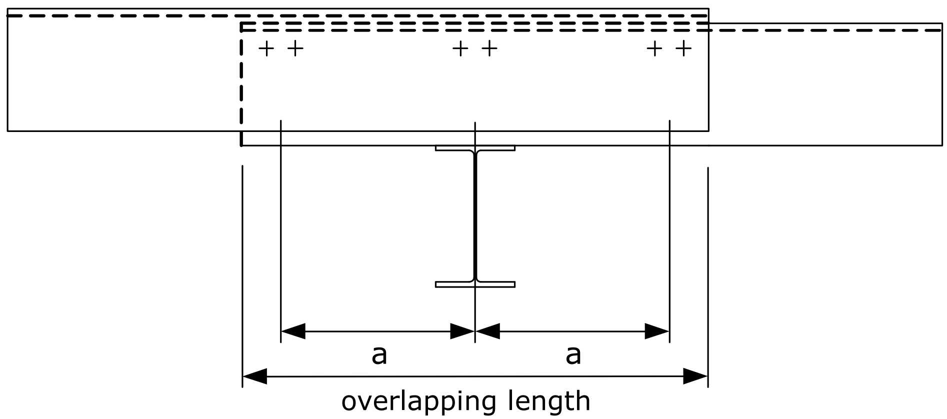
Contextual introduction

Feedback from metal frame engineers and installers

- Overlap joint (OL):



- Overlapping length 2·a at both sides of the support
- Load-bearing capacity increases compared with a single continuous profile

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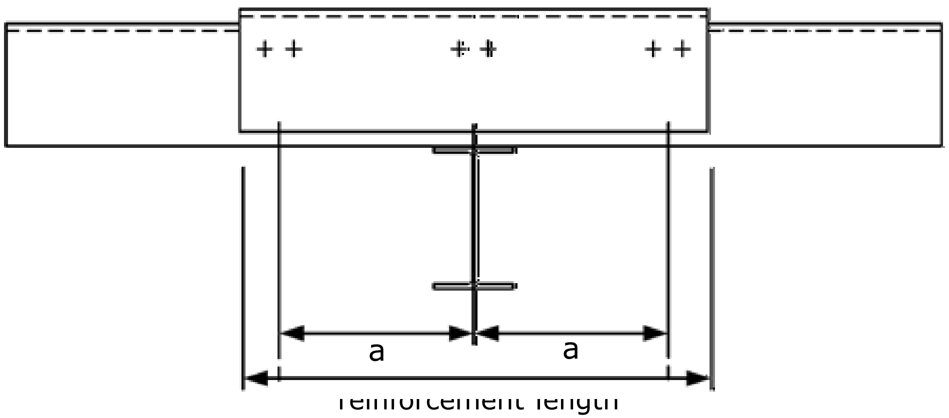
- Continuous profile with local reinforcement (CR):



- Overlapping length 2·a at both sides of the support
- Load-bearing capacity increases compared with a single continuous profile

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Experimental works during GRISPE project

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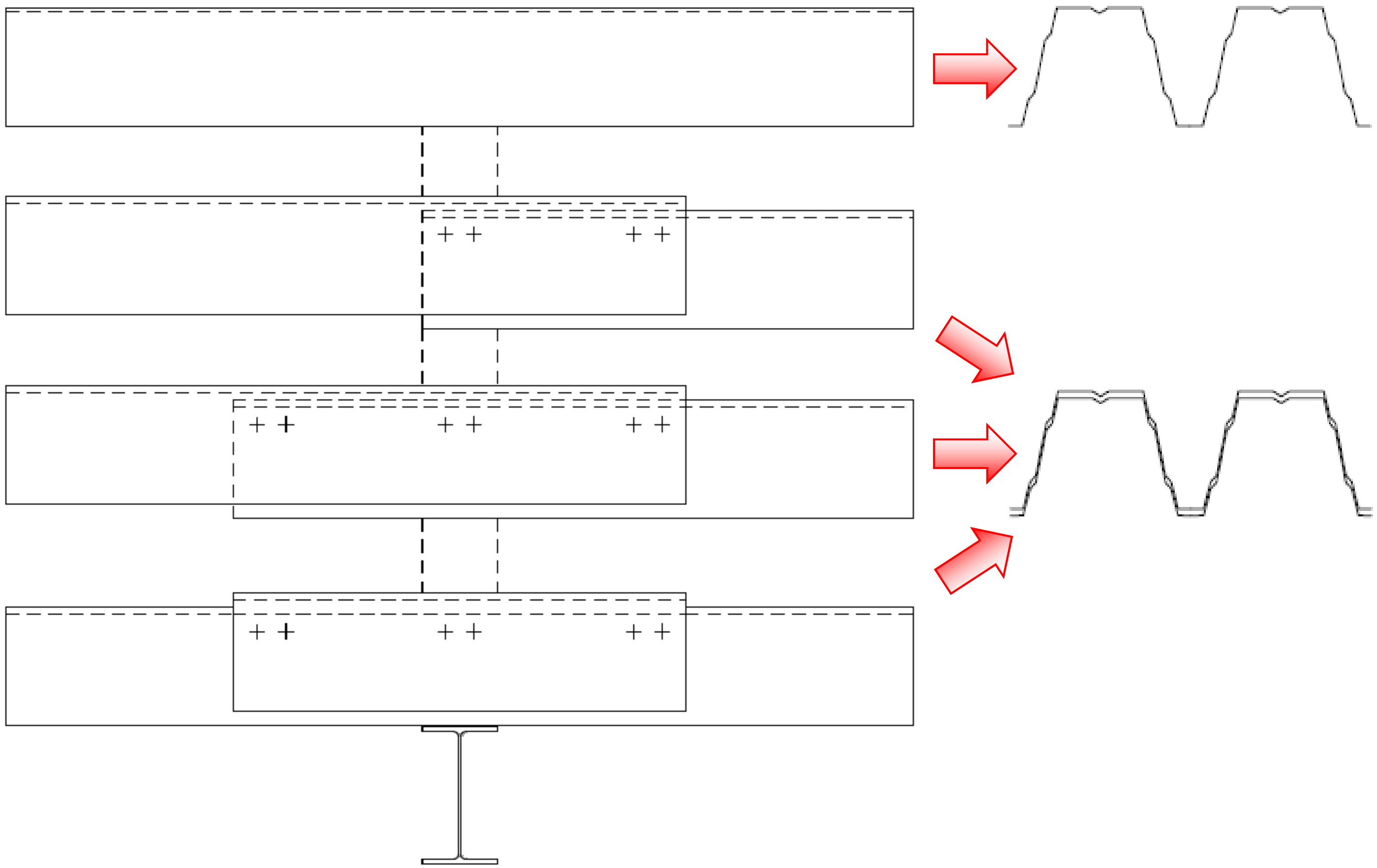
GRISPE Project – experimental works

Tested assemblies

- Reference test = continuous deck:
  - Continuous
  - DIN joint
  - OL joint
  - CR joint



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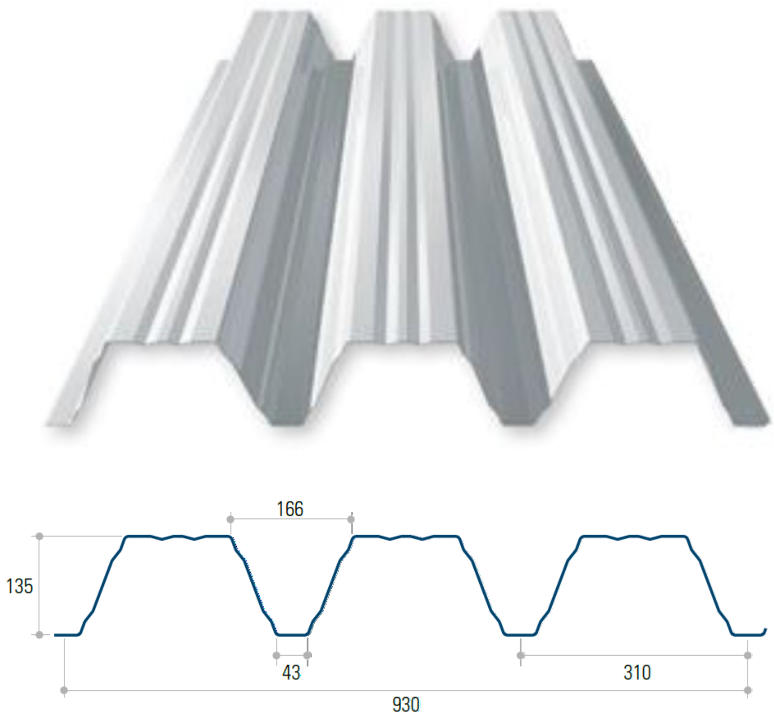
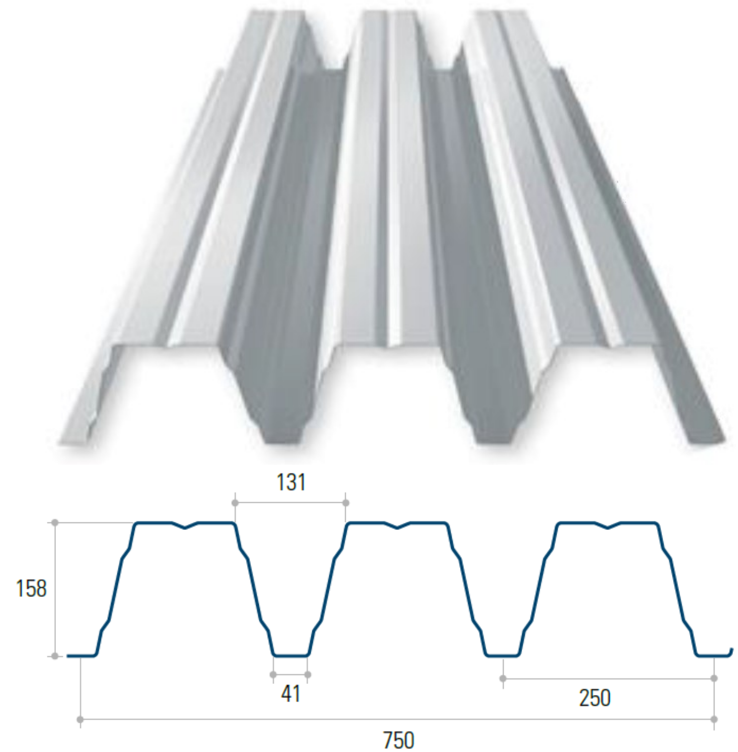
GRISPE Project – experimental works

Selected profiles

- Higher and smaller angle of the web:



Joris Ide 137/310



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- 2 thicknesses: 0,75 mm and 1,00 mm

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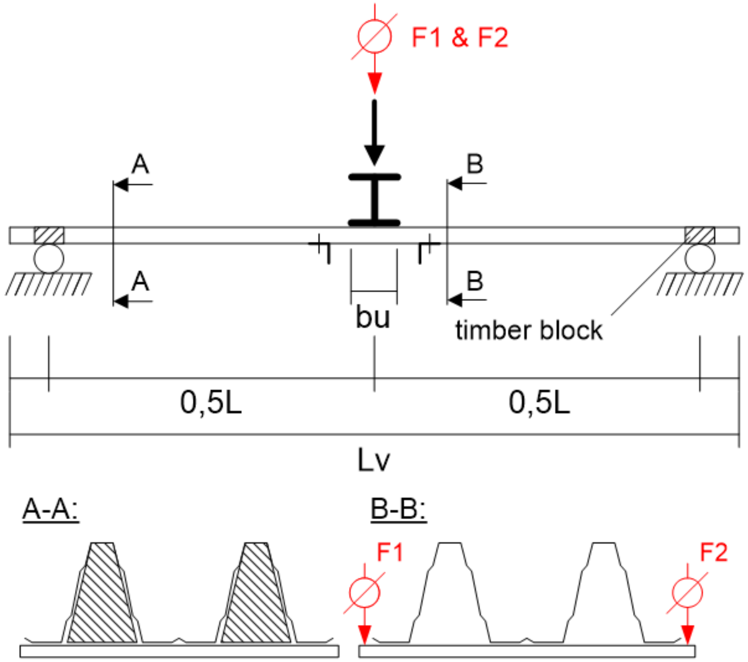
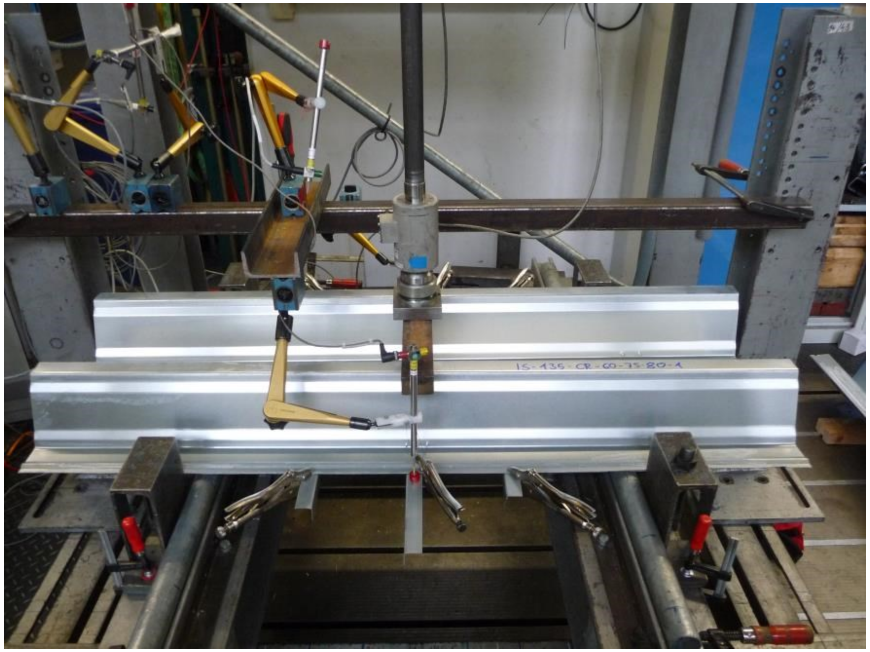
GRISPE Project – experimental works

Load-bearing behaviour at intermediate support

- 3-point bending tests according to EN 1993-1-3 § A.2.4:





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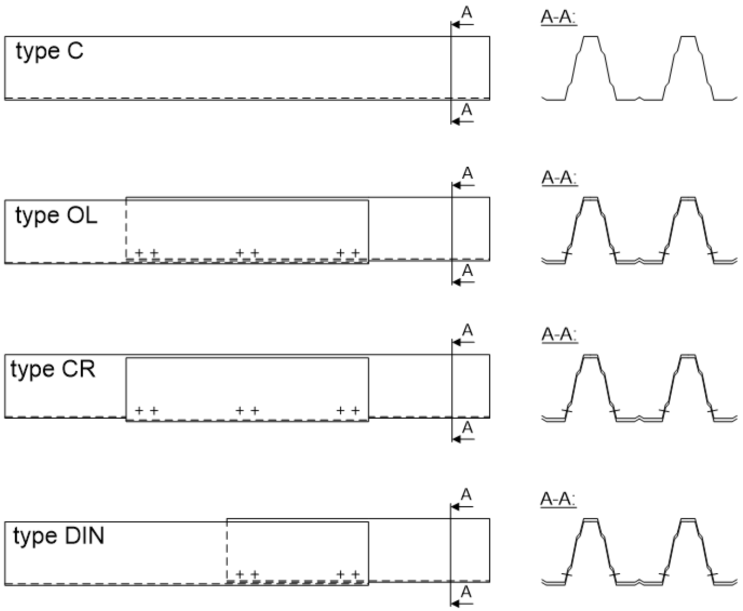
GRISPE Project – experimental works

Parameters of the tests

- 3 types of assemblies (+ reference)
- Sheet thickness (0,75 mm & 1,00 mm)
- Profile type (135/310 & 158/250)
- Support width b_u (60 mm & 160 mm)
- Span length (800 mm to 3 200 mm)



- Tests supplemented with tensile tests

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GRISPE Project – experimental works

Adjustment of test results

- According EN 1993-1-3 § A.6.2:

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

- According EN 1993-1-3 § A.6.3:

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

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

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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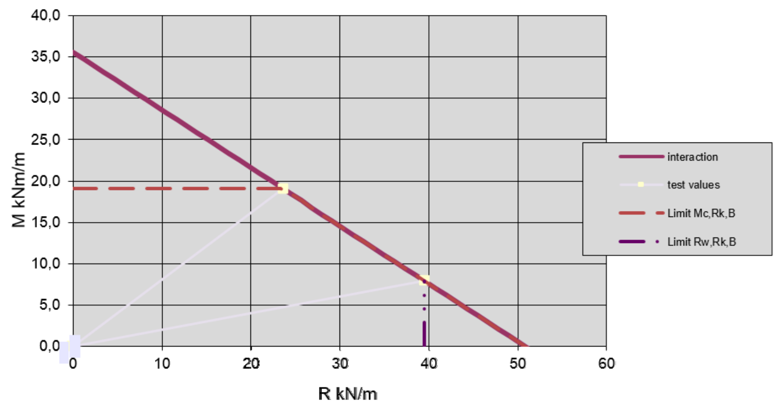
GRISPE Project – experimental works

Characteristic values

- 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
  - g self-weight of the test specimen
- M/R diagram interaction :



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- Continuous profile:

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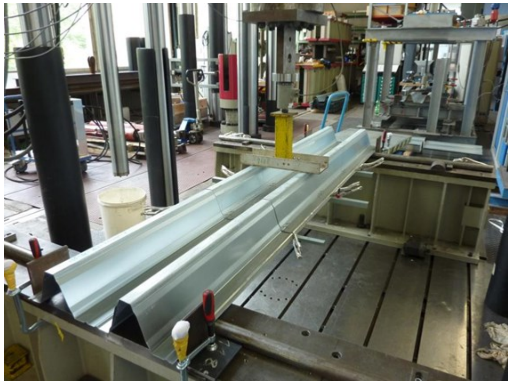
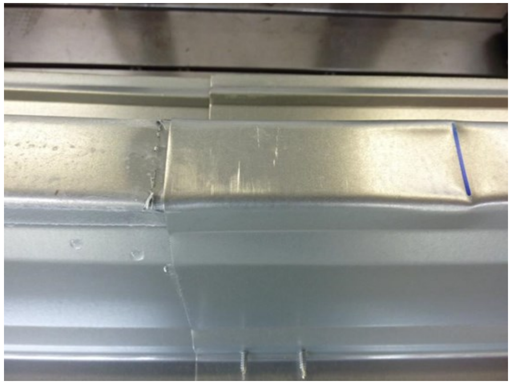
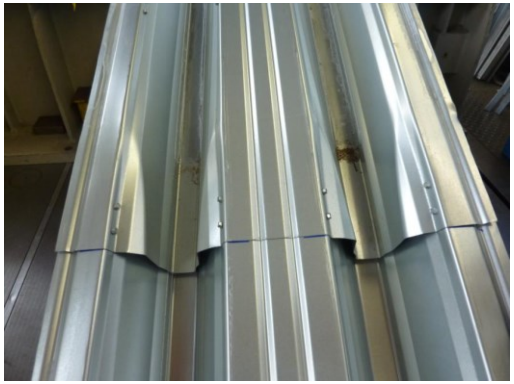
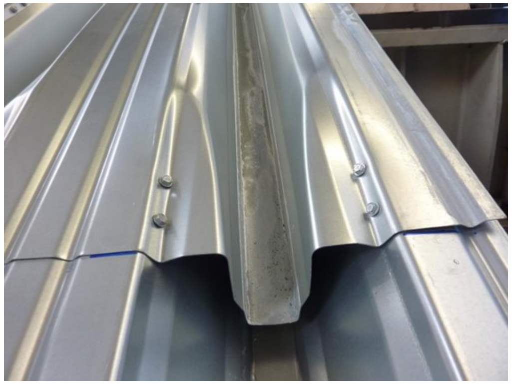
- DIN joint:

Overlap length sufficiently long

Overlap too short

Only for cantilevered end of profile on top

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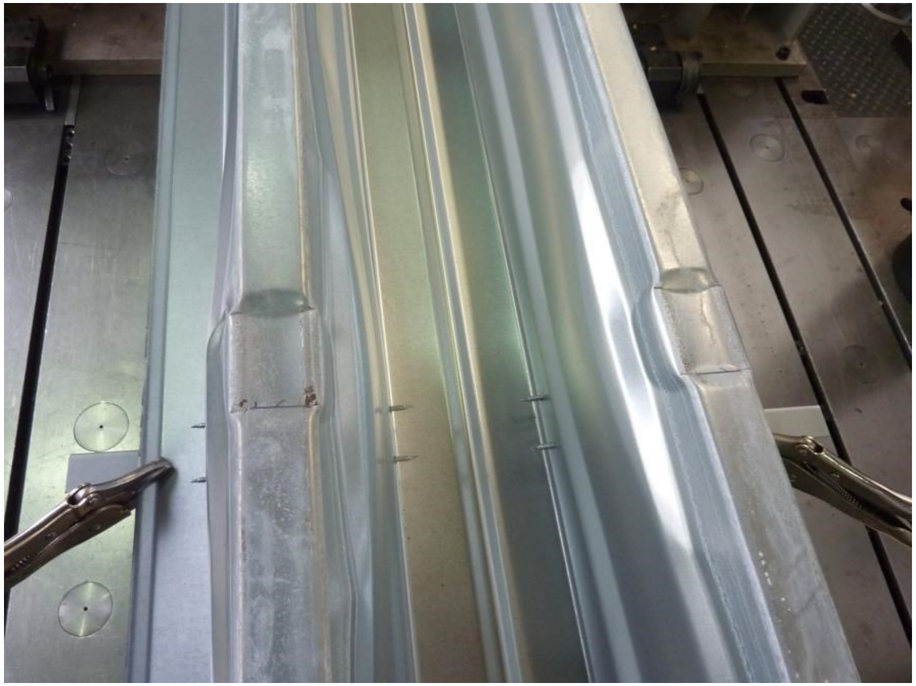
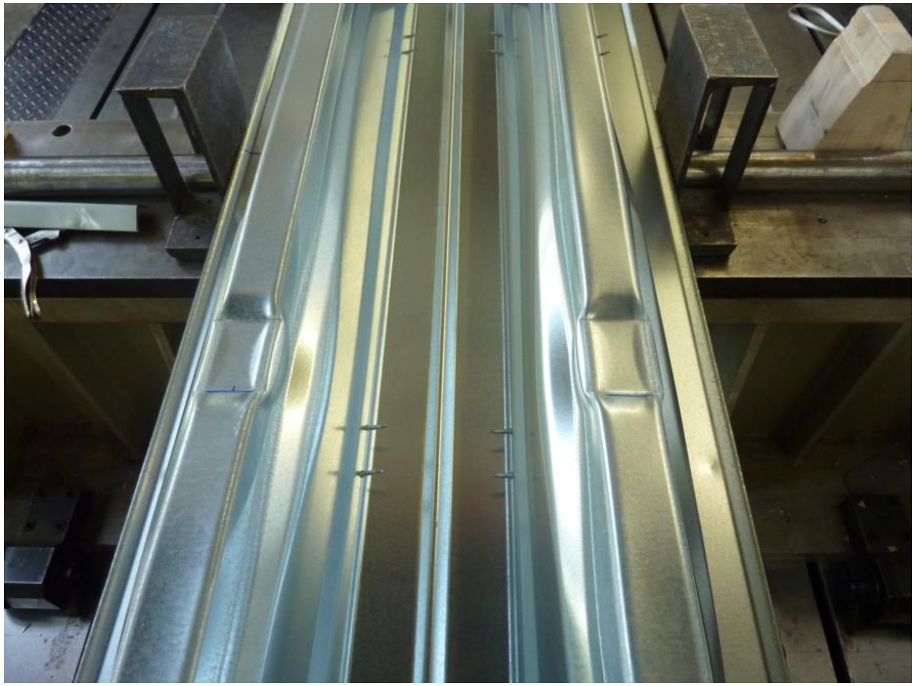
GRISPE Project – experimental works

Failure modes

- Double overlap joint (OL) and continuous profile with local reinforcement (CR) = same behaviour:





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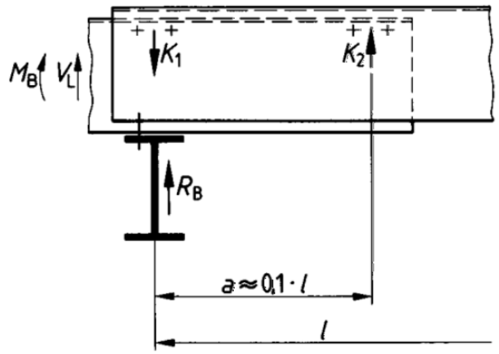
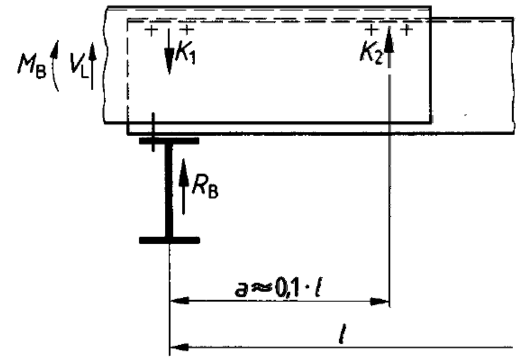
GRISPE Project – experimental works

Main conclusions based on test results

- DIN joint:





  - provides the same load bearing capacity as continuous profile with an overlap sufficiently long
  - Overlap length should be designed in a way that web crippling at the end of the overlap is excluded
  - The sufficient overlap length should be checked by an additional verification of the shear force at the end of the overlap

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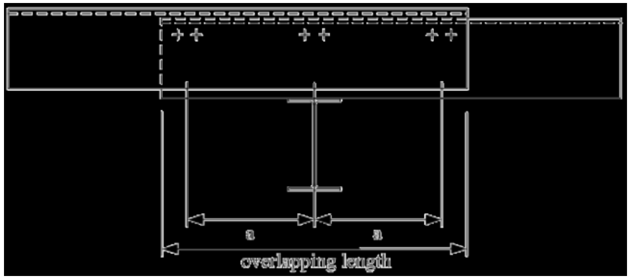
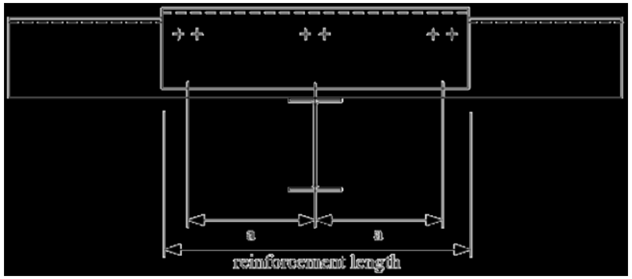
GRISPE Project – experimental works

Main conclusions based on test results

- Assemblies with double cross section (OL and CR):





- Provides 90 % of the resistance of the continuous profile (to be multiplied by 2 ⇦ 2 cross section assembled)
- Overlap length should be designed in a way that web crippling at the end of the overlap is excluded
- The sufficient overlap length should be checked by an additional verification of the shear force at the end of the overlap

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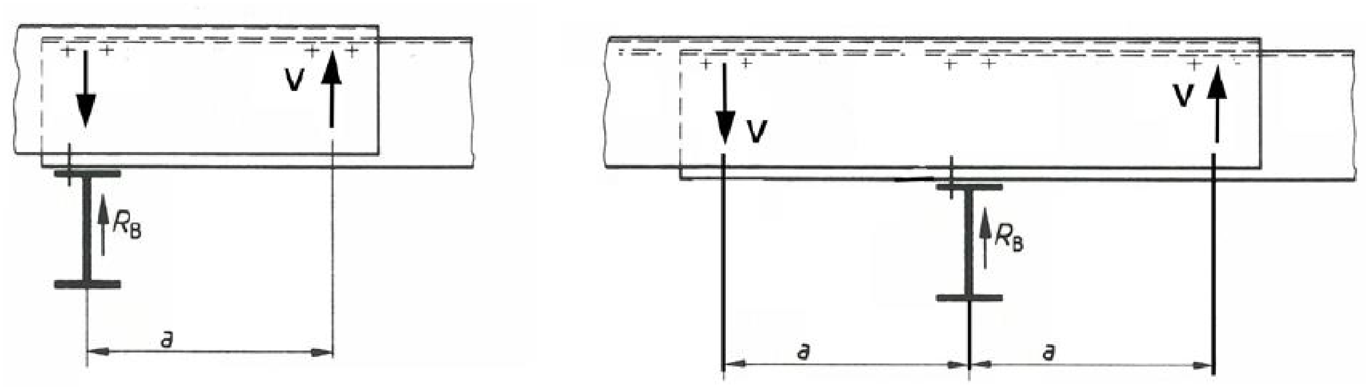
GRISPE Project – experimental works

Main conclusions based on test results

- Verification of the shear force at the end of the overlap:



- DIN joint: $F = M_{c,Rk,B}/a$

- OL and CR joints: $F = M_{c,Rk,B}/(2 \cdot a)$

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Design method for assembled profiles

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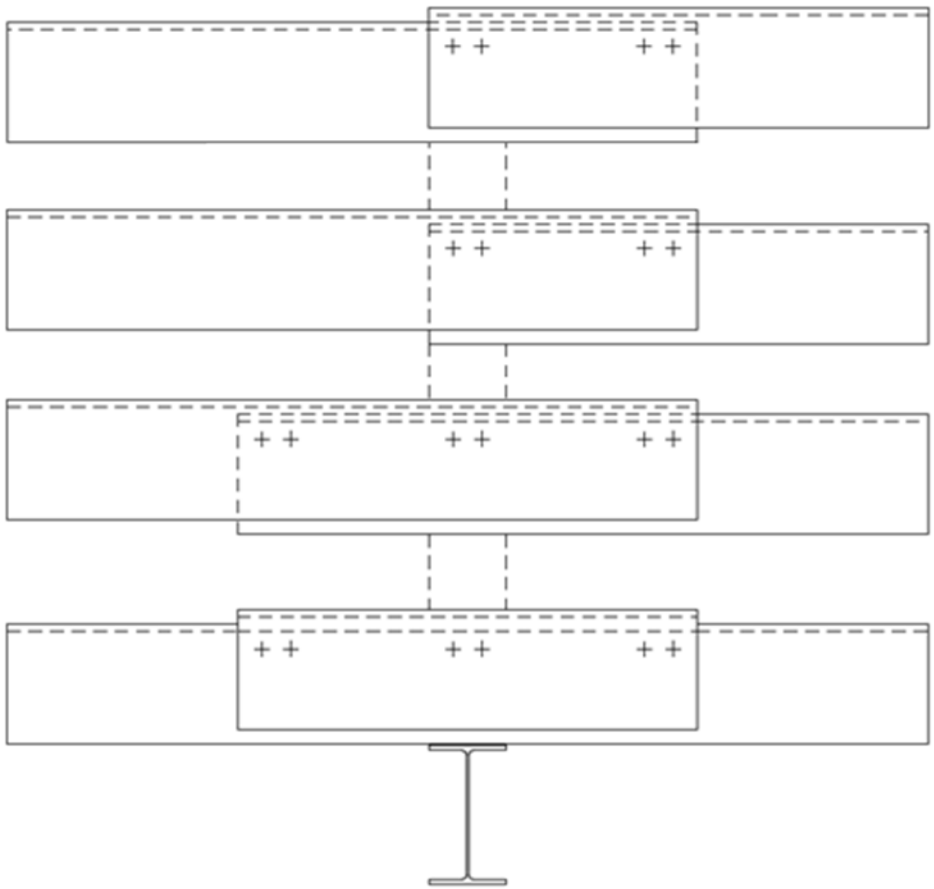
Design method for assembled profiles

Field of application



- With uniformly distributed loads

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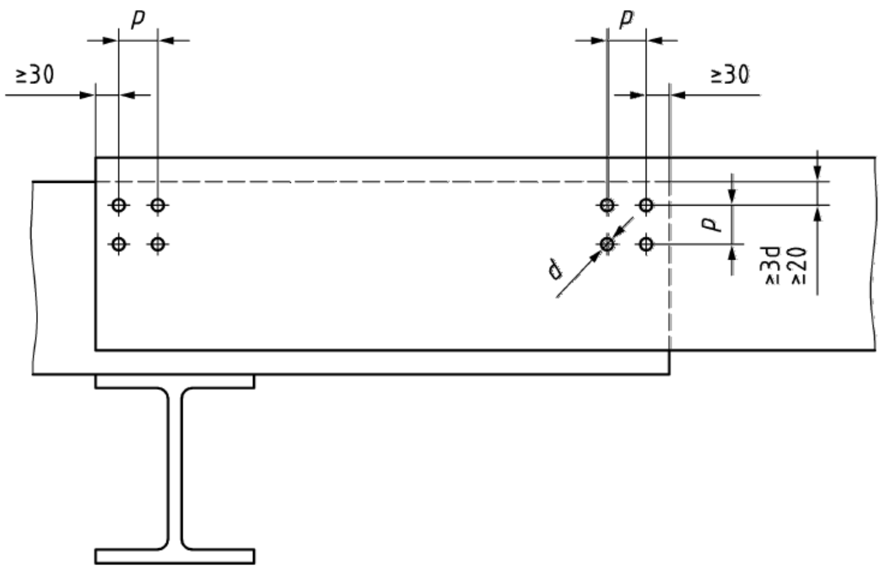
Design method for assembled profiles

Field of application

- ***<u>For ALL studied joint (DIN, OL, CR):</u>***

- Edge and hole spacings for statically effective overlapping



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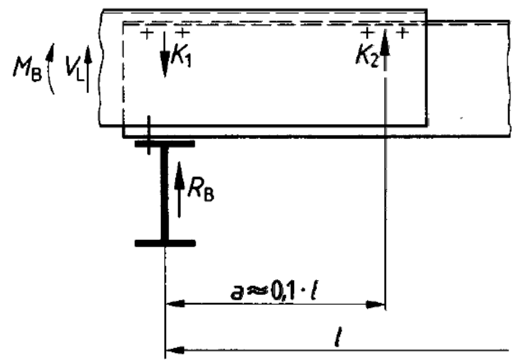
Design method for assembled profiles

DIN joint design – cantilevered end of profile on top



- Step 1 ⇨ Verification of the resistance of the assembly in the support axis with the help of $M_{Rd,B}$ and $R_{w,Rd,B}$ of the continuous profile:

  - Downward loading:

$$\frac{M_{B,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{R_{B,Ed}}{R_{w,Rd,B}} \leq 1{,}00 \qquad \frac{M_{B,Ed}}{M_{B,Rd}} + \frac{R_{B,Ed}}{R_{w,Rd,B}} \leq 1{,}25$$

  - Uplift loading:

$$\frac{M_{B,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{V_{L,Ed}}{V_{w,Rd}} \leq 1{,}00 \qquad \frac{M_{B,Ed}}{M_{B,Rd}} + \frac{V_{L,Ed}}{V_{w,Rd}} \leq 1{,}25$$

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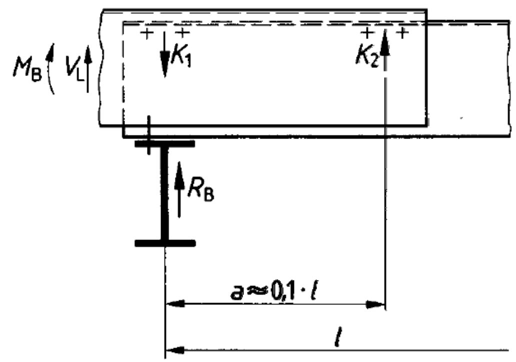
Design method for assembled profiles

DIN joint design – cantilevered end of profile on top



- <u>Step 2 ⇨ Verification of web crippling only for downward loading</u>:

  - With $R_{w,Rk,B}$ of the opposite profile position (in general negative position) for the maximum support width, in general l_{aB} = 160 mm

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

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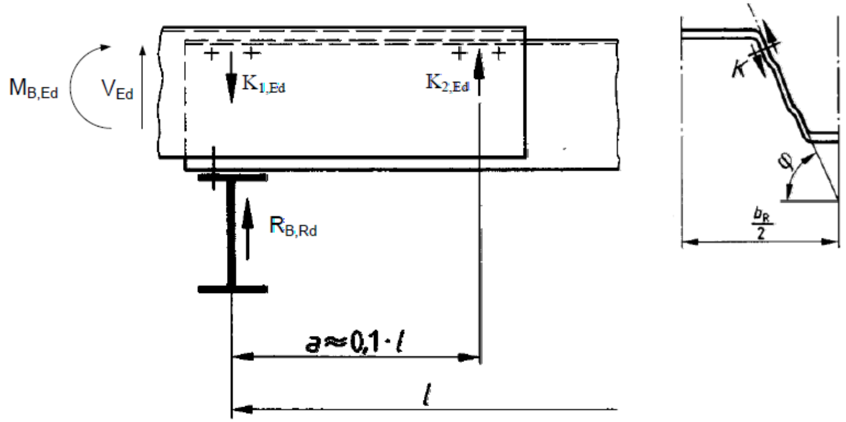
Design method for assembled profiles

DIN joint design – cantilevered end of profile on top



- Step 3 ⇨ Verification of the connection K_{Ed} only for downward loading (in one web):

$$K_{Ed} = \max K_i = \frac{\left| \frac{M_{B,Ed}}{a} + V_{L,Ed} \right|}{2 \cdot \sin \varphi} \cdot b_R \leq \sum F_{V,Rd}$$

  - With $\Sigma F_{V,Rd}$ the shear resistance of the screws

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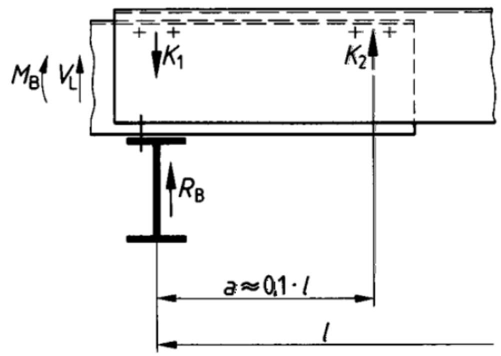
Design method for assembled profiles

DIN joint design – cantilevered end of profile underneath



- Step 1 ⇨ Verification of the resistance of the assembly in the support axis with the help of $M_{Rd,B}$ and $R_{w,Rd,B}$ of the continuous profile:

  - Downward loading:

$$\frac{M_{B,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{R_{B,Ed}}{R_{w,Rd,B}} \leq 1{,}00 \qquad \frac{M_{B,Ed}}{M_{B,Rd}} + \frac{R_{B,Ed}}{R_{w,Rd,B}} \leq 1{,}25$$

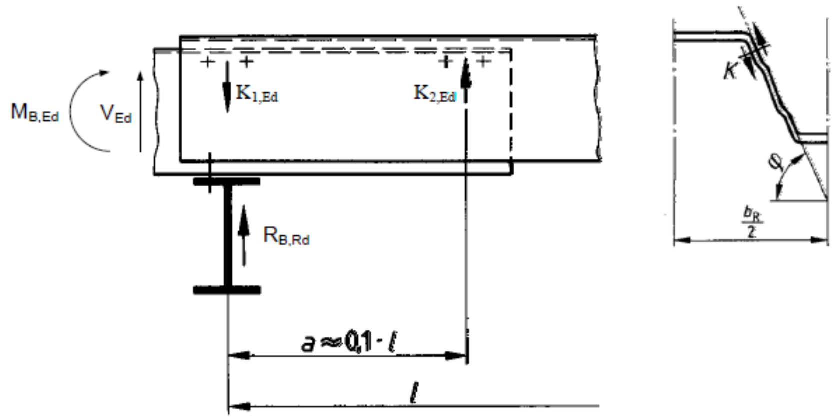
  - Uplift loading:

$$\frac{M_{B,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{V_{L,Ed}}{V_{w,Rd}} \leq 1{,}00 \qquad \frac{M_{B,Ed}}{M_{B,Rd}} + \frac{V_{L,Ed}}{V_{w,Rd}} \leq 1{,}25$$

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

Design method for assembled profiles

DIN joint design – cantilevered end of profile underneath



- <u>No Verification of web crippling is needed (no step 2)</u>

- <u>Step 3 ⇨ Verification of the connection K_{Ed} only for downward loading (in one web)</u>:

$$K_{Ed} = \max K_i = \frac{\left|\frac{M_{B,Ed}}{a}\right|}{2 \cdot \sin\varphi} \cdot b_R \leq \sum F_{V,Rd}$$

  - With $\Sigma F_{V,Rd}$ the shear resistance of the screws

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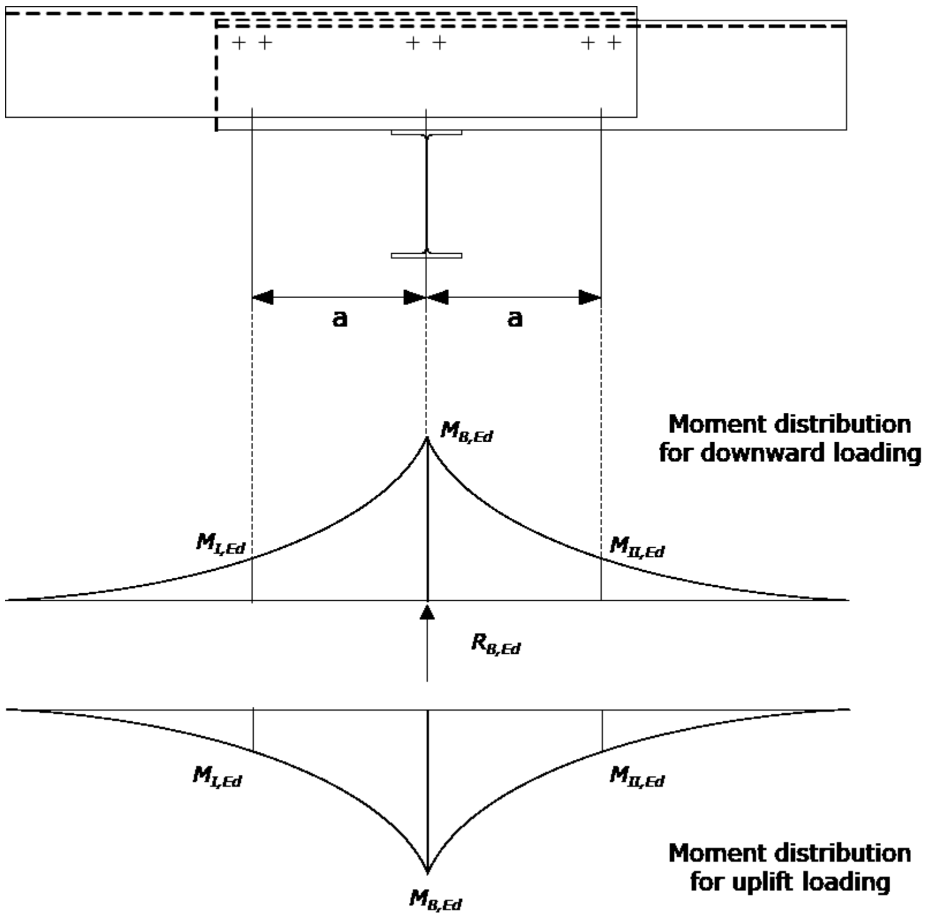
Design method for assembled profiles

OL joint design – double overlap joint

- Step 1 ⇨ Determination of the bending moment distribution under desing loads like for continuous sheets ⇨ $M_{B,Ed}$ / $R_{B,Ed}$ / $M_{1,Ed}$ / $M_{2,Ed}$:



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Design method for assembled profiles

OL joint design – double overlap joint

- Step 2 ⇨ Verification of the profiles at the support axis with 90 % of the resistance of the overlapping profiles:

  - Downward loading:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} \leq 1{,}00 \qquad \frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} \leq 1{,}00$$

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} \leq 1{,}25$$

  - Uplift loading:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} \leq 1{,}00 \qquad \frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} \leq 1{,}00$$

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} \leq 1{,}25$$

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Design method for assembled profiles

OL joint design – double overlap joint

- Step 3 ⇨ Verification of resistance of the assembly at the ends of the overlap with $M_{I,Ed}$, $M_{II,Ed}$, and the line loads introduced by K_i:

$$F_{Ed} = \frac{M_{B,Ed}}{2 \cdot a}$$

- For downward loading: F_{Ed} = tension force on the webs:

$$\frac{M_{I,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{M_{II,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}00 \qquad \frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}25 \qquad \frac{M_{II,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}25$$

- For uplift loading: F_{Ed} = compression force on the webs:

$$\frac{M_{I,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{M_{II,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}00 \qquad \frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}25 \qquad \frac{M_{II,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}25$$

- *Both cases of loading considering the resistance values of the profile in the opposite position at intermediate supports*

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Design method for assembled profiles

OL joint design – double overlap joint

- Step 4 ⇨ Verification of web crippling:

  - Uplift loading = no verification of web-crippling is needed

  - Downward loading:

    - With $R_{w,Rk,B}$ of the opposite profile position (in general negative position) for the maximum support width, in general l_{aB} = 160 mm:

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

- Step 5 ⇨ Verification of the connection K_{Ed} for both cases of loading (in one web):

$$K_{Ed} = \max K_i = \frac{|M_{B,Ed}|}{4 \cdot a \cdot \sin\varphi} \cdot b_R \leq \sum F_{V,Rd}$$

- With $\Sigma F_{V,Rd}$ the shear resistance of the screws

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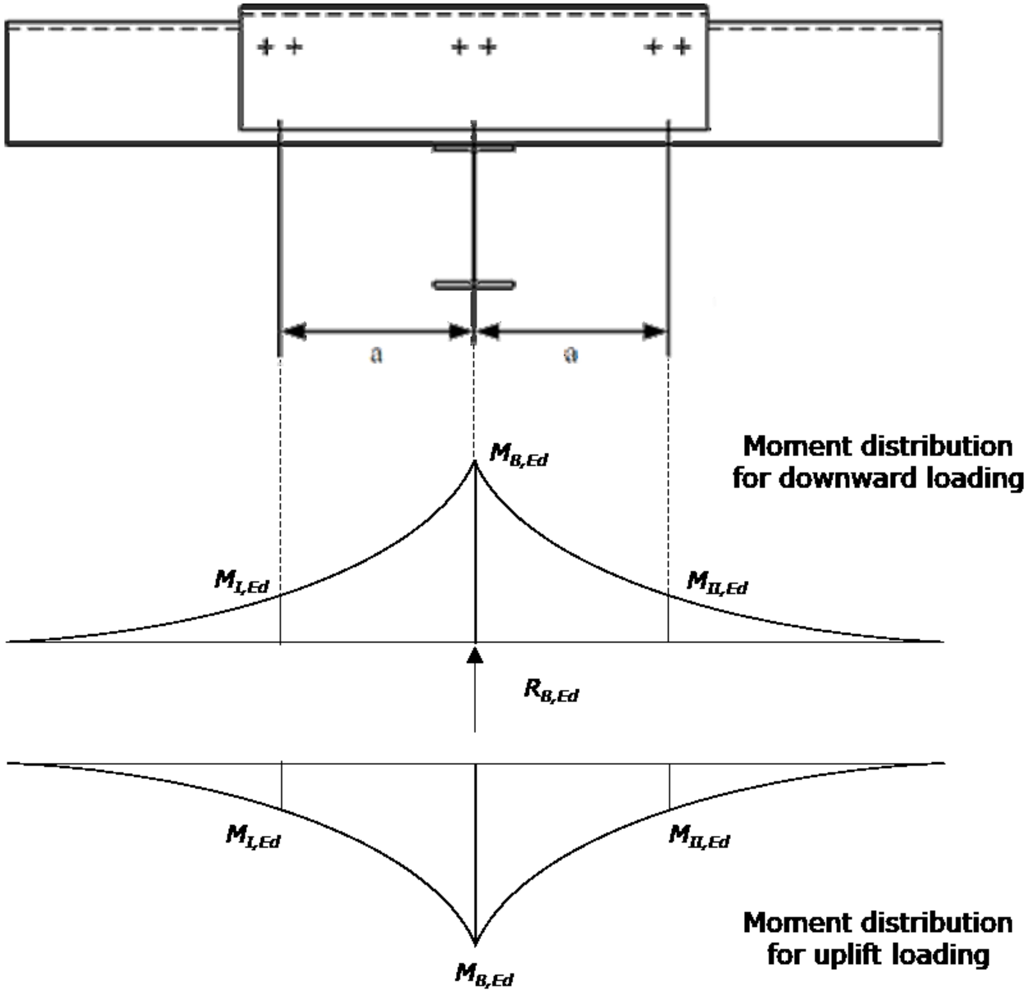
Design method for assembled profiles

CR joint design – Continuous profile with local Reinforcement

- Step 1 ⇨ Determination of the bending moment distribution under desing loads like for continuous sheets ⇨ $M_{B,Ed}$ / $R_{B,Ed}$ / $M_{1,Ed}$ / $M_{2,Ed}$:



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Design method for assembled profiles

CR joint design – Continuous profile with local Reinforcement

- Step 2 ⇨ Verification of the profiles at the support axis with 90 % of the resistance of the overlapping profiles:

  - Downward loading:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} \leq 1{,}00 \qquad \frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} \leq 1{,}00$$

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{R_{B,Ed}}{0{,}9 \cdot \sum R_{w,Rd,B}} \leq 1{,}25$$

  - Uplift loading:

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} \leq 1{,}00 \qquad \frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} \leq 1{,}00$$

$$\frac{M_{B,Ed}}{0{,}9 \cdot \sum M_{B,Rd}} + \frac{V_{L,Ed}}{0{,}9 \cdot \sum V_{w,Rd}} \leq 1{,}25$$

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Design method for assembled profiles

CR joint design – Continuous profile with local Reinforcement

- Step 3 ⇨ Verification of resistance of the assembly at the ends of the overlap with $M_{I,Ed}$, $M_{II,Ed}$, and the line loads introduced by K_i:

$$F_{Ed} = \frac{M_{B,Ed}}{2 \cdot a}$$

- For downward loading: F_{Ed} = tension force on the webs :

$$\frac{M_{I,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{M_{II,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}00 \qquad \frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}25 \qquad \frac{M_{II,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{V_{w,Rd}} \leq 1{,}25$$

- For uplift loading: F_{Ed} = compression force on the webs:

$$\frac{M_{I,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{M_{II,Ed}}{M_{B,Rd}} \leq 1{,}00 \qquad \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}00 \qquad \frac{M_{I,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}25 \qquad \frac{M_{II,Ed}}{M_{B,Rd}} + \frac{F_{Ed}}{R_{w,Rd,B}} \leq 1{,}25$$

- *Both cases of loading considering the resistance values of the profile in the opposite position at intermediate supports*

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Design method for assembled profiles

CR joint design – Continuous profile with local Reinforcement

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- With $\Sigma F_{V,Rd}$ the shear resistance of the screws

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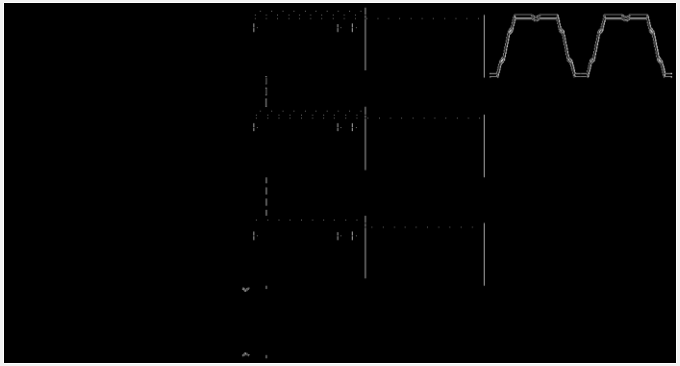
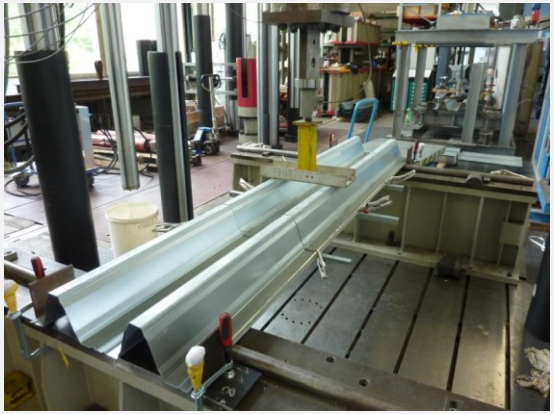
GRISPE PLUS

VALORISATION OF KNOWLEDGE FOR SPECIFIC PROFILED STEEL SHEETS

Assembled profiles

Ph. D. Thibault RENAUX – Joris Ide





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