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Enhanced design method for the patch loading resistance of girders with corrugated webs

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Introduction

1, Structural layout of hybrid-bridges with corrugated web and its numerous advantages.

2, Aim of the research work

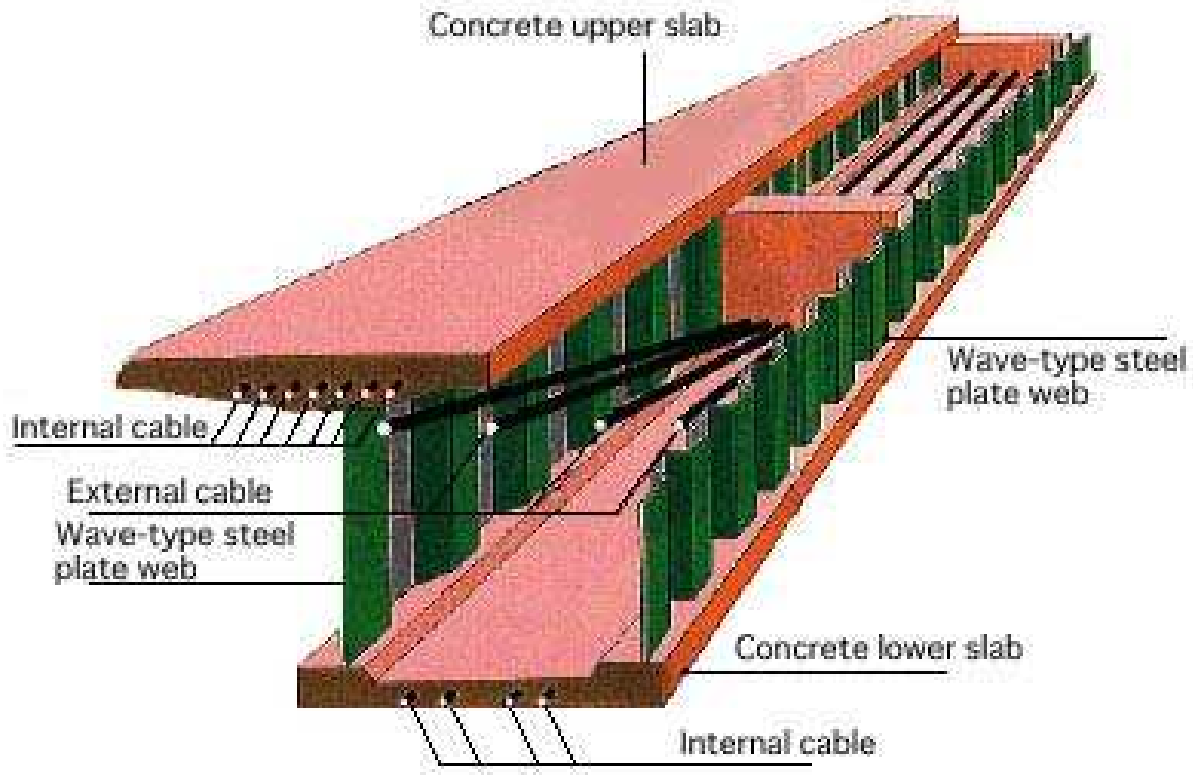
3, State of the previous investigations

4, Developed numerical models and numerical investigations

5, Modified design method based on previous investigations and current numerical results

Hybrid bridges

Corrugated steel plate is a widely used structural element. In the last 20 years it has spread in the field of bridges.

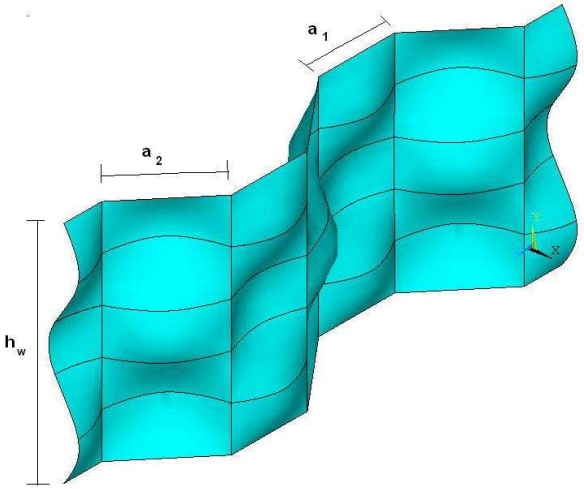


Both flanges are completed from prestressed reinforced concrete.

Web is made from corrugated steel plate.

Advantages of hybrid-bridges

1, Due to steel webs → smaller selfweight



- → lower structural depth
- → increased span
- → slenderness can be increased
- → prestressing force stays in the flanges

2, Due to web corrugation → increased buckling resistance

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number of stiffeners and diaphragms can be reduced.

3, Due to concrete flanges → higher stiffness

Aim of the research work

Bridge erection technique: Incremental launching process

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All cross sections one time over a support

↓

Buckling problem of the web

↙ ↘

Application of the corrugated web

Numerous bearing stiffeners

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No design formula for patch loading resistance

State of the previous investigations

1, No investigations on patch loading of hybrid bridges.

2, Experiments are only on steel girders with corrugated webs.

3, Focus of previous investigations → frame structures

Experimental investigations:

17 tests: 6 by Aravena und Edlund (1987),
6 by Kähönen (1988),
5 by Elgaaly und Seshadri (1997).

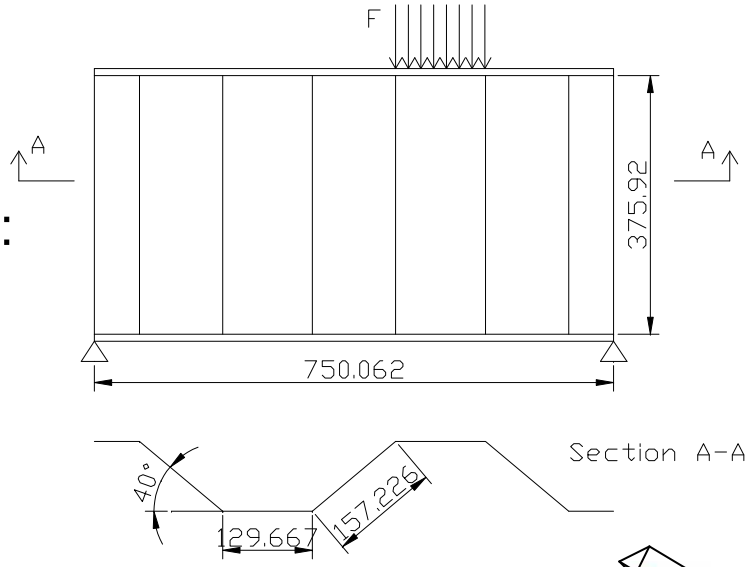
Numerical investigations: Elgaaly and Seshadri (1997)
Luo and Edlund (1996)

All investigations are focused on frame structures → Extended for hybrid bridges

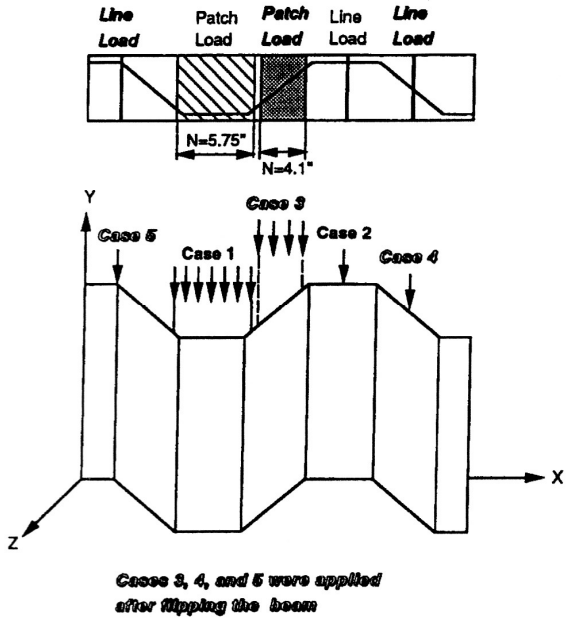
Numerical model development

Experiments of Elgaaly and Seshadri:

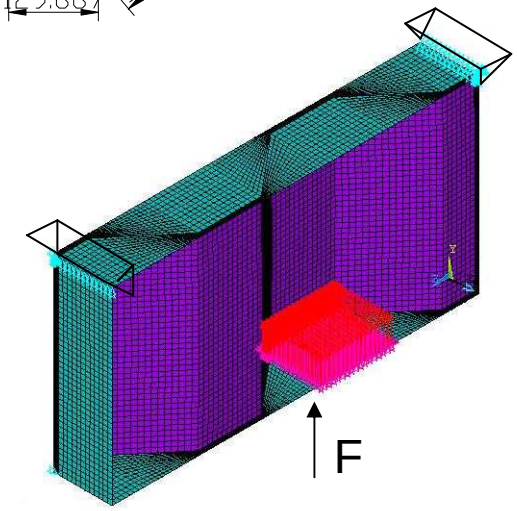
test specimen:



load introduction locations



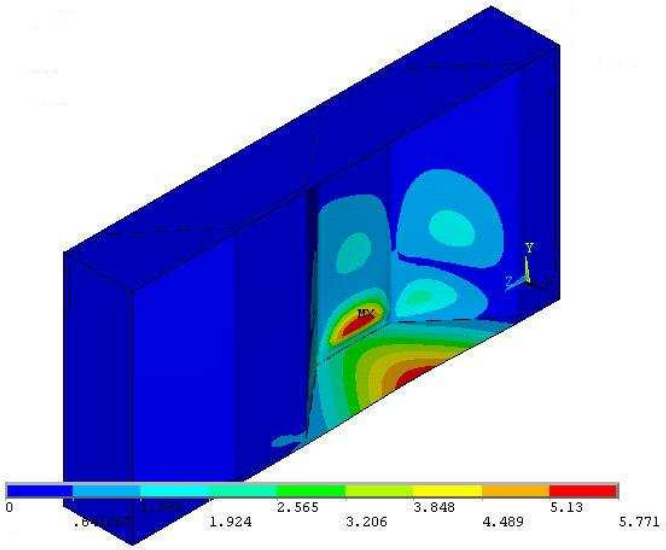
Developed model

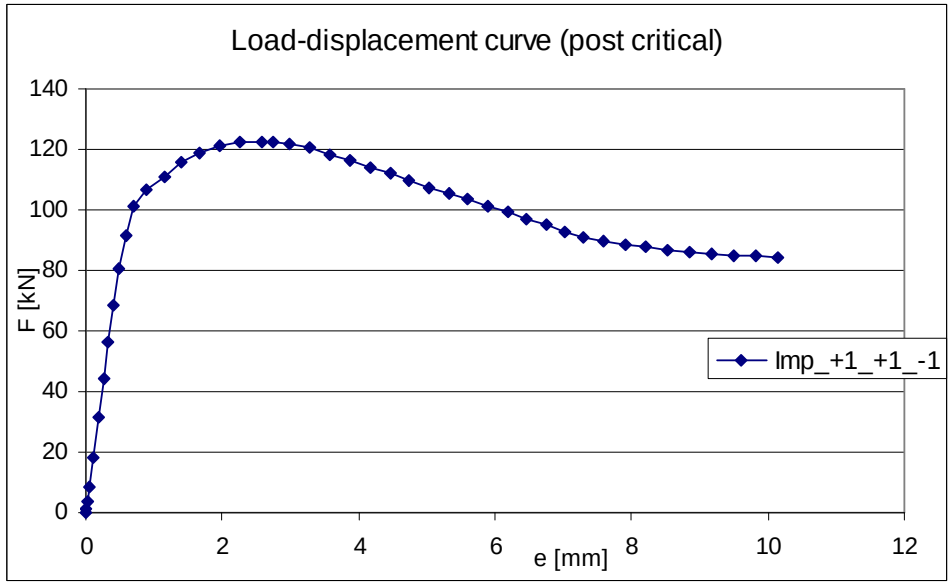


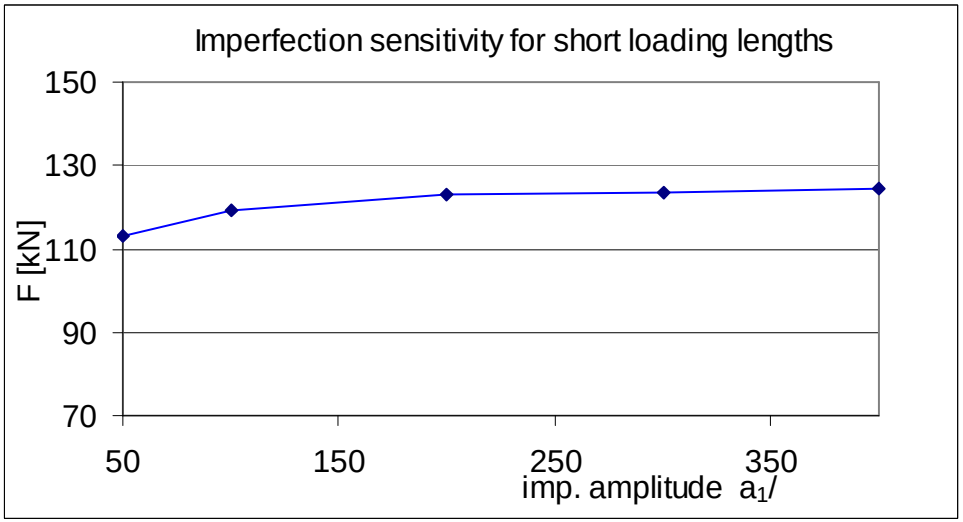
- Shell model
- Nonlinear analysis
- Geometric imperfections
- Material nonlinearities

Modell verification

Typical failure mode







Comparison of numerical and test results

F_{FEM}=122,8-128,2 kN

F_{EXP}=131,3kN

Numerical parametric study

Numerical parametric study is executed in order to analyse the patch loading resistance in the parameter range used in bridges.

Analysed parameter range:

1, corrugation angle: α=15°-65°

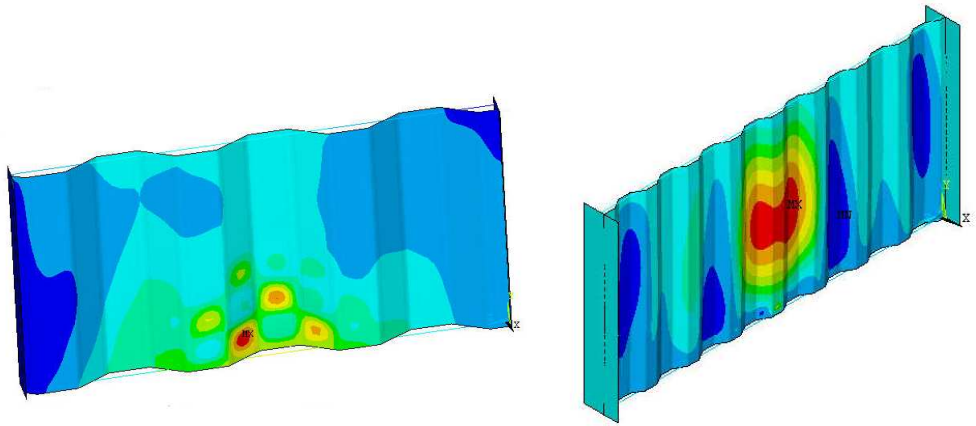
2, web slenderness ratio: h_w/t_w=500;400;300;200

3, fold slenderness ratio: a_1/t_w=7-117;
a_1=50 mm-350 mm

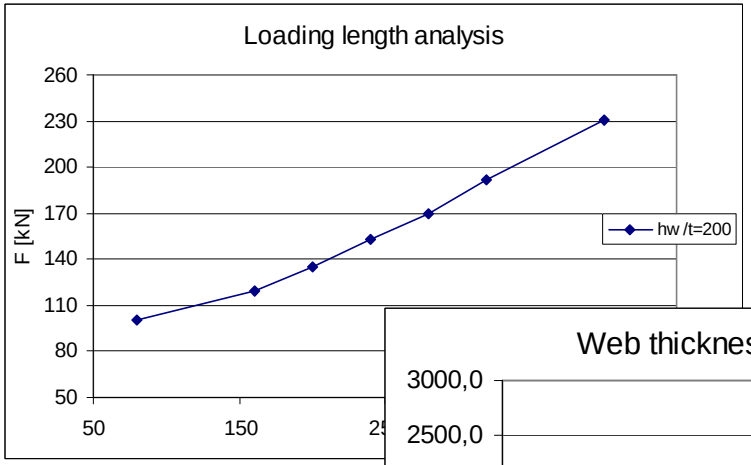
4, loading length: ss/h_w=0,4; 0,6; 0,7
ss=600mm; 900mm; 1200mm

Results - 1.

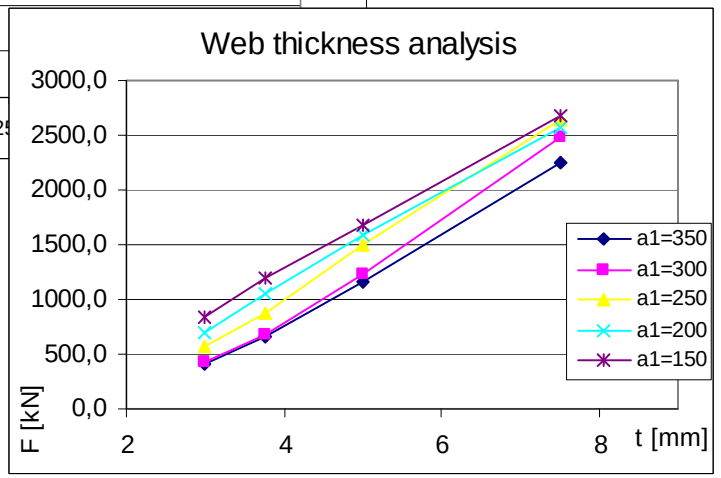
1, Failure modes are different depending on the web and fold slenderness ratios.



2, Increasing loading length increases the patch loading resistance.

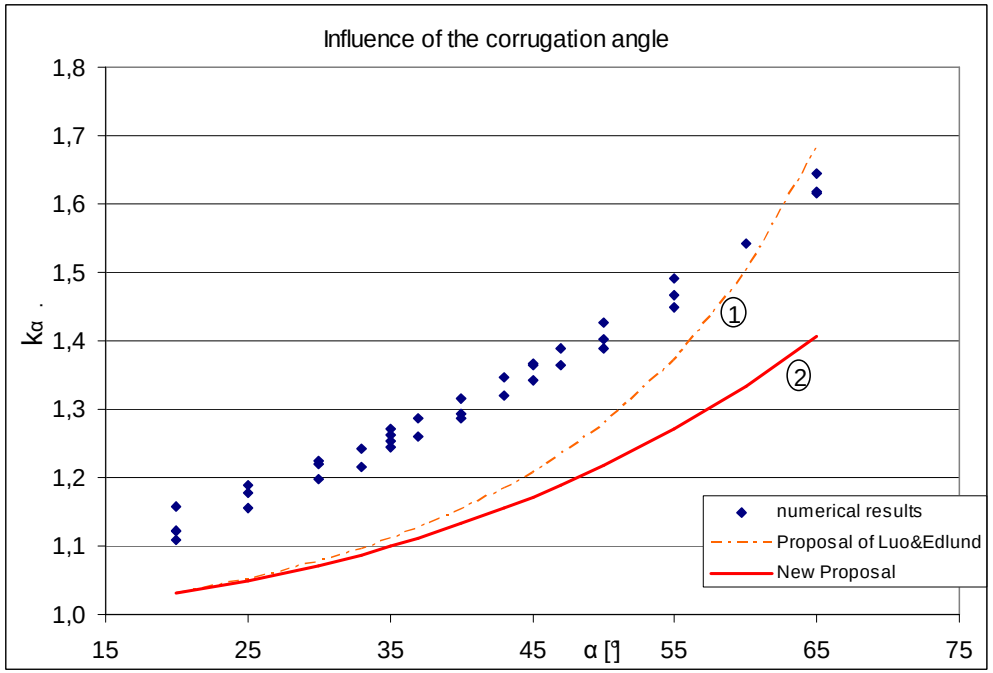


3, Increasing web thickness increases the patch loading resistance.

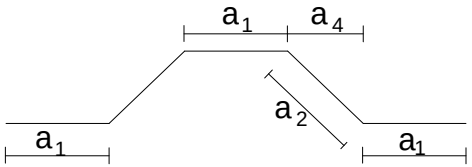


Results - 2.

4, Increasing corrugation angle increases the patch loading resistance.



Relation can be described by: $k_\alpha = \dfrac{a_1 + a_2}{a_1 + a_4}$



Design method - 1.

Different design proposals are compared to the numerical calculations.

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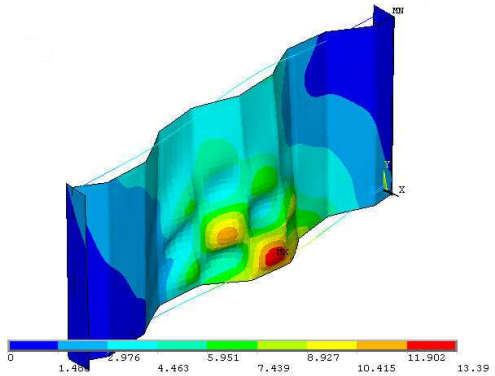
Best design proposal for long loading length → Proposal of Kähönen if the failure mode is local buckling

$$R_d = (R_{d1} + R_{d2} + R_{d3}) \cdot k_0 \cdot \frac{k_r}{\gamma_M}$$



Problems:

1, Global buckling is missing → Excluded by geometric parameters.

2, Corrugation angle influence → Design method is extended.

3, Formula does not follow the EUROCODE principles in case of buckling analysis → Transformed to the EC3 stability analysis.

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New buckling curve is derived.

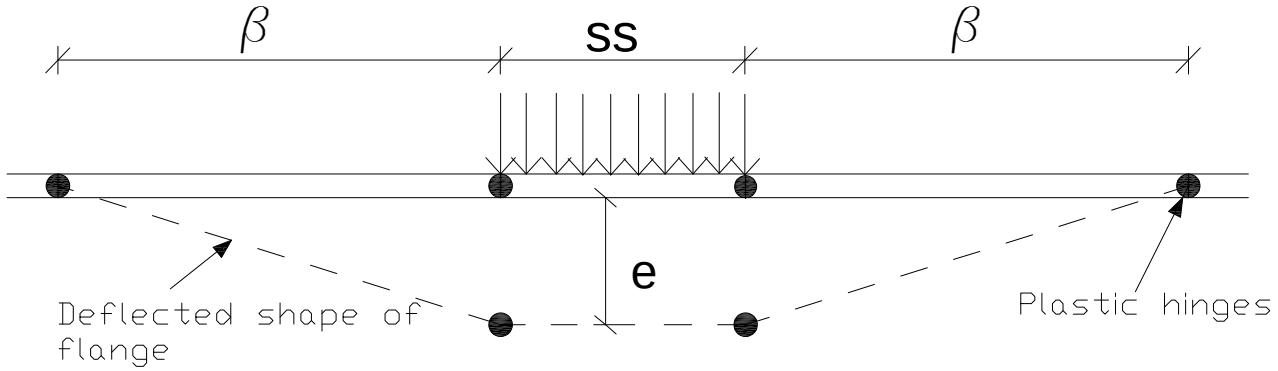
Design method - 2.

1, Failure mode is depending on the global and local slenderness ratios.

↳ The global buckling can be excluded with geometrical parameter ranges.

Limit function for the minimum fold length: $a_i \geq \left(\frac{h_w}{t_w} + 260 \right) \cdot \frac{t_w}{11.5}$ → Failure mode: Local buckling

2, Design method is based on the four plastic hinge mechanism (according to Rockey and Roberts)



$$R = \sqrt{4 \cdot M_{pl.f} \cdot t_w \cdot f_{yw}} + f_{yw} \cdot t_w \cdot (s_s + \beta)$$

Design method - 3.

Resistance of the web

$$R_w = f_{yw} \cdot t_{wep} \cdot s_s \cdot k_w$$

$$t_{wep} = \rho \cdot t_w$$

A new buckling curve is derived based on the formula of Kähönen:

$$\overline{\lambda} = \sqrt{\frac{f_{yw}}{\sigma_{cr}}}$$

$$\rho = \frac{1.9}{\overline{\lambda}} - \frac{0.798}{\overline{\lambda}^2} \quad \text{if} \quad \overline{\lambda}_p > 1.273$$

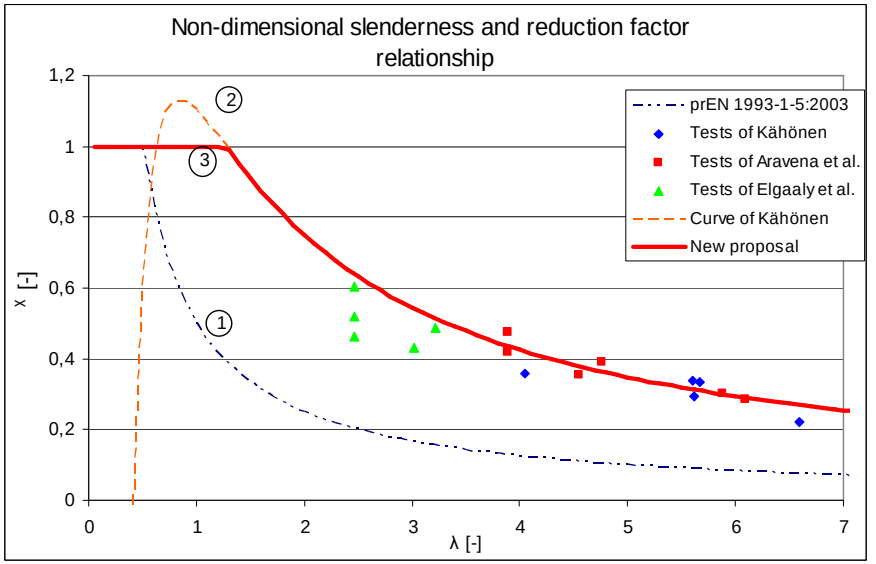
$$\rho = 1.00 \quad \text{if} \quad \overline{\lambda}_p \leq 1.273$$

$$\sigma_{cr} = \frac{k_\sigma \cdot \pi^2}{12 \cdot (1 - \upsilon^2)} \cdot E \cdot \left(\frac{t_w}{a_i}\right)^2 \qquad k_\sigma = \frac{1}{0.9} = 1.11\overline{1}$$

Resistance of the flange

$$R_{fl} = \sqrt{4 \cdot M_{plf} \cdot \rho \cdot t_w \cdot f_{yw}}$$

$$M_{plf} = \frac{b_f \cdot t_f^{\,2}}{4} \cdot f_{yf}$$



Design method - 4.

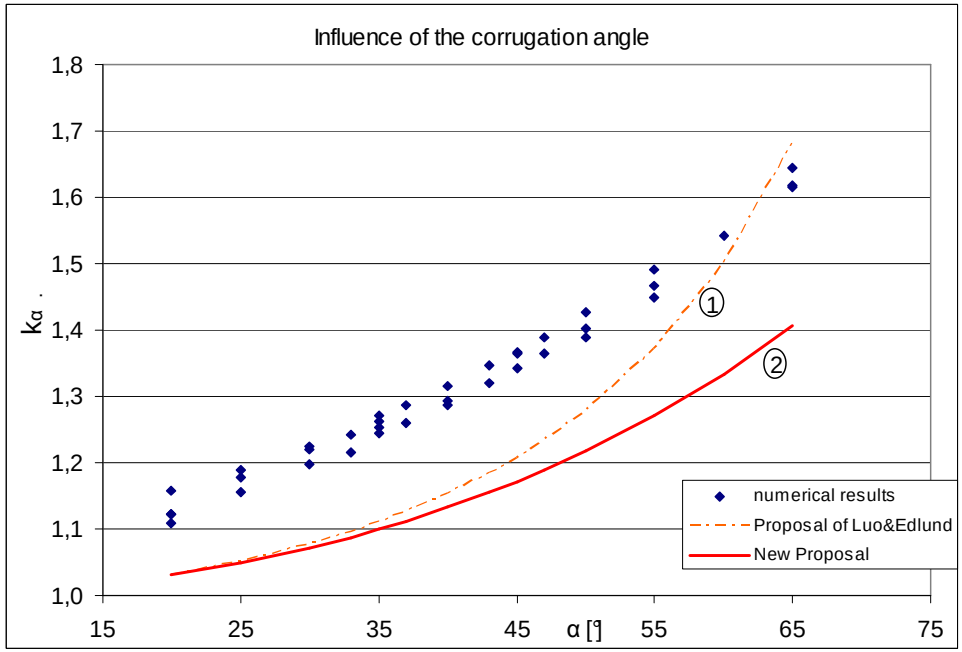
3, Corrugation angle has a significant influence on the patch loading resistance, but the previous design methods did not consist it.

Only Luo and Edlund developed an empirical design formula for the corrugation angle influence ⟶ Curve Nr. 1.

Our proposal according to the numerical calculations:

$$k_\alpha = \frac{a_1 + a_2}{a_1 + a_4}$$ ⟶ Curve Nr. 2.

$$R_w = \rho \cdot ss \cdot t_w \cdot f_{yw} \cdot k_\alpha$$



Summary

1, Patch loading resistance of girders with corrugated webs was analysed.

2, Numerical model was developed.

3, Numerical parametric study was conducted to analyse the structural behaviour.

4, Modified desing method for patch loading resistance was developed.

Thank you for your attention!