F – V interaction of girders with trapezoidally corrugated webs

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Introduction

- Previous research activities
  - Investigation of the patch loading resistance
    - Development of FE based design method
    - Development of analytical design method
- Problem statement and research aims (F-V interaction)
- Literature overview
- Numerical modelling and structural behaviour
- Development of an F-V interaction curve
- Summary of the research work and possible further subjects

Previous research activities

Literature overview

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Experimental program

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Numerical model development

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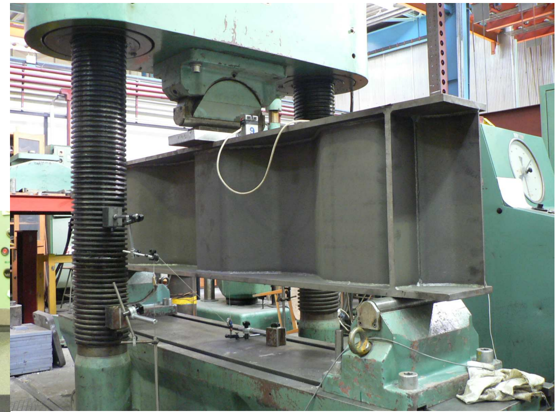
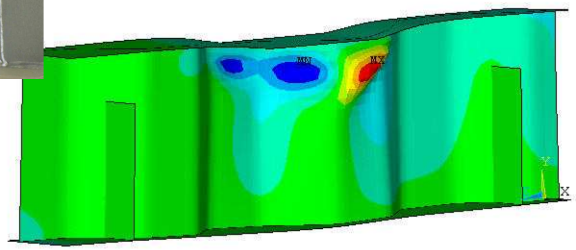
Numerical parametric study (determination of the geometric parameters which have influence on the patch loading resistance)





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FE based design method (Uni Budapest)

-Proposals for possible imperfection shapes and applicable magnitudes.

Analytical design method (Uni Stuttgart)

$$R = R_w + R_f =$$

$$\rho \cdot ss \cdot t_w \cdot f_{yw} \cdot k_\alpha + 2 \cdot \sqrt{4 \cdot M_{plf} \cdot \rho \cdot t_w \cdot f_{yw}}$$

Research aim

1. Design method of Kähönen

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

$$R_{d1} = k_w \cdot \sigma_{yw} \cdot t_{wep} \cdot a$$

$$R_{d2} = 2 \cdot t_f \cdot \sqrt{k_w \cdot \sigma_{yw} \cdot k_f \cdot \sigma_{yf} \cdot t_{wep} \cdot b_f}$$

$$R_{d3} = -0.07 \cdot \sigma_f \cdot b_f \cdot t_f$$

- Developed for building structures.
- Does not follow the steps of the EC3 stability analysis (design methods with reduction factors).
- Possible interactions are considered in the design method. k_o; k_w; k_r; R_{d3}

2. Enhanced design method

Based on design method of Kähönen+ numerical calculations + own experiments

$$\bar{\lambda}_p = \sqrt{\frac{f_{yw}}{\sigma_{cr}}} \qquad \sigma_{cr} = \frac{k_\sigma \cdot \pi^2}{12 \cdot (1 - \upsilon^2)} \cdot E \cdot \left(\frac{t_w}{a_i}\right)^2$$

→ Pure patch loading resistance without interactions.

$$R = R_w + R_f = \rho \cdot ss \cdot t_w \cdot f_{yw} \cdot k_\alpha + 2 \cdot \sqrt{4 \cdot M_{plf} \cdot \rho \cdot t_w \cdot f_{yw}}$$

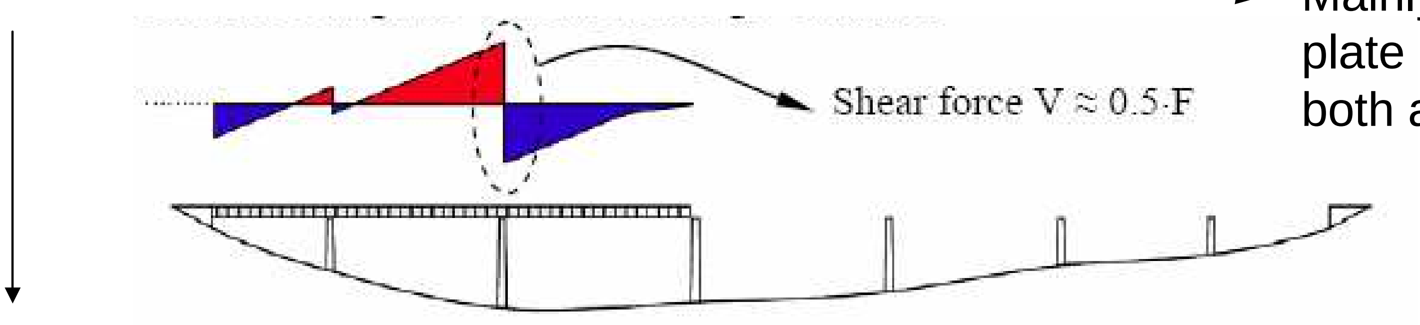
Research aim: Development of interaction equations.

(F+V ; F+M)

Problem statement

In the practice during launching of a bridge structure large shear (V) and transverse force (F) can be introduced at the same cross section .

Mainly the web plate is loaded by both actions.



Interaction should be considered in the design.

1. There are no recommendations in the EN1993-1-5 for the F-V interaction (neither for flat web nor for corrugated web girders).

2. In the literature only a limited numer of investigations are available dealing with this topic, especially for corrugated web girders.

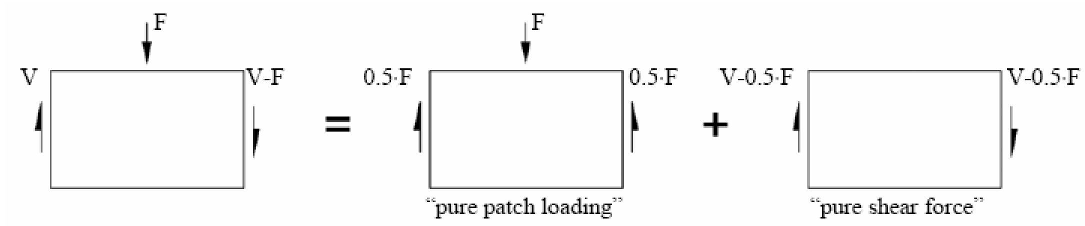
Aim: New (F+V) interaction curve for trapezoidally corrugated webs.

Research strategy

- Literature overview and experimental background
- Numerical model development
- Analysis of the structural behaviour
- Numerical parametric study
- Developement of the F-V interaction curve

Literature overview

1. Analysis of the combined loading ⟶ subdivided into two basic load cases



Basis of the separation is that the shear stresses due to "pure transverse force" are already included in the patch loading resistance model and a reduction of the load carrying capacity is caused only by the additional shear stresses coming from "pure shear force".

2. Analysis of Elgaaly and Seshadri

Based on experiments

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20 numerical calculations

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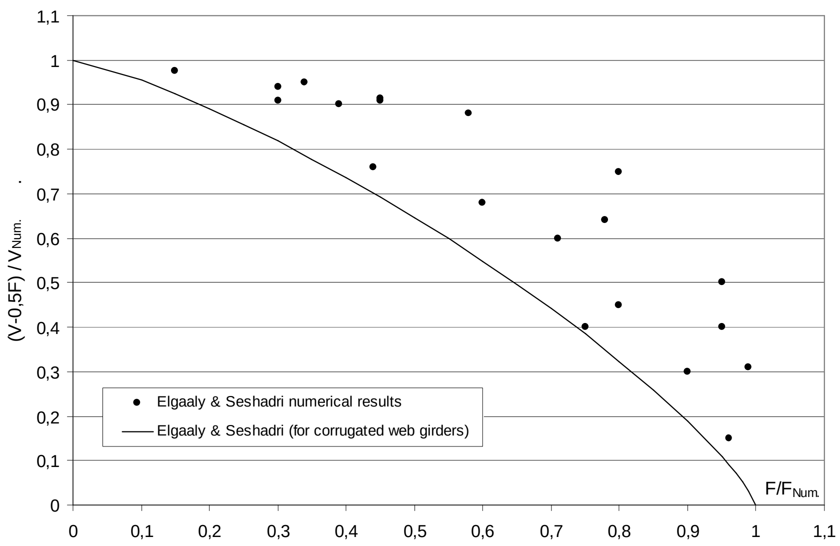
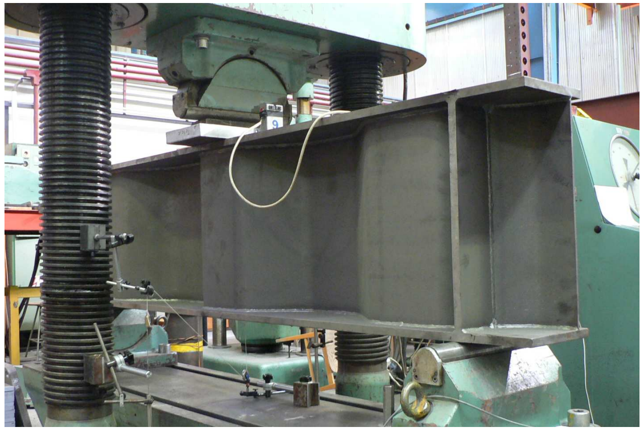
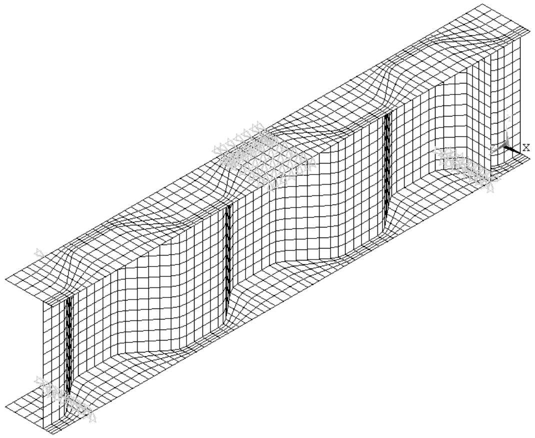
$$\left(\frac{V-0.5\cdot F}{V_R}\right)^{1.25}+\left(\frac{F}{F_R}\right)^{1.25}\leq 1.0$$

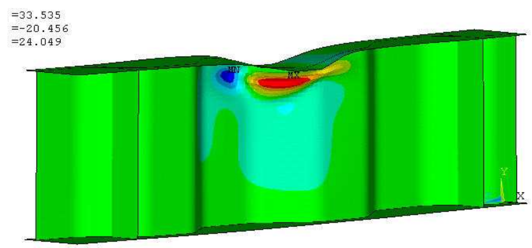


Numerical modelling

Test specimen → Numerical model → Numerical simulation

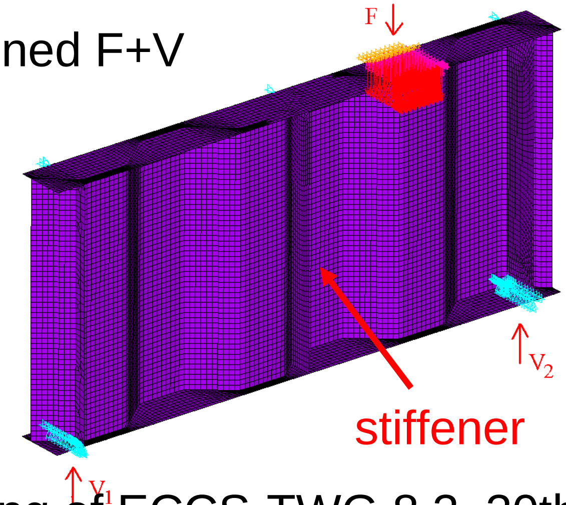






Modell verification

Investigation of combined F+V

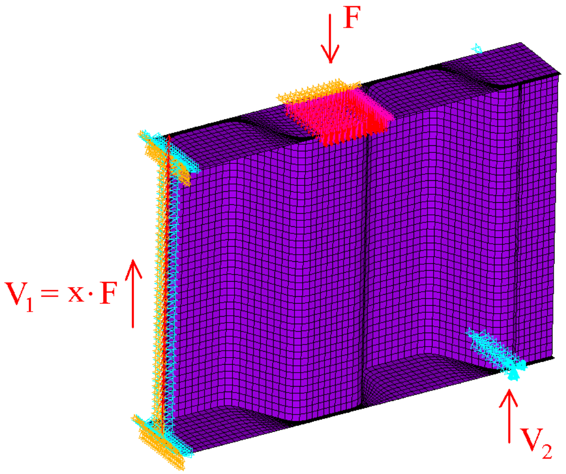


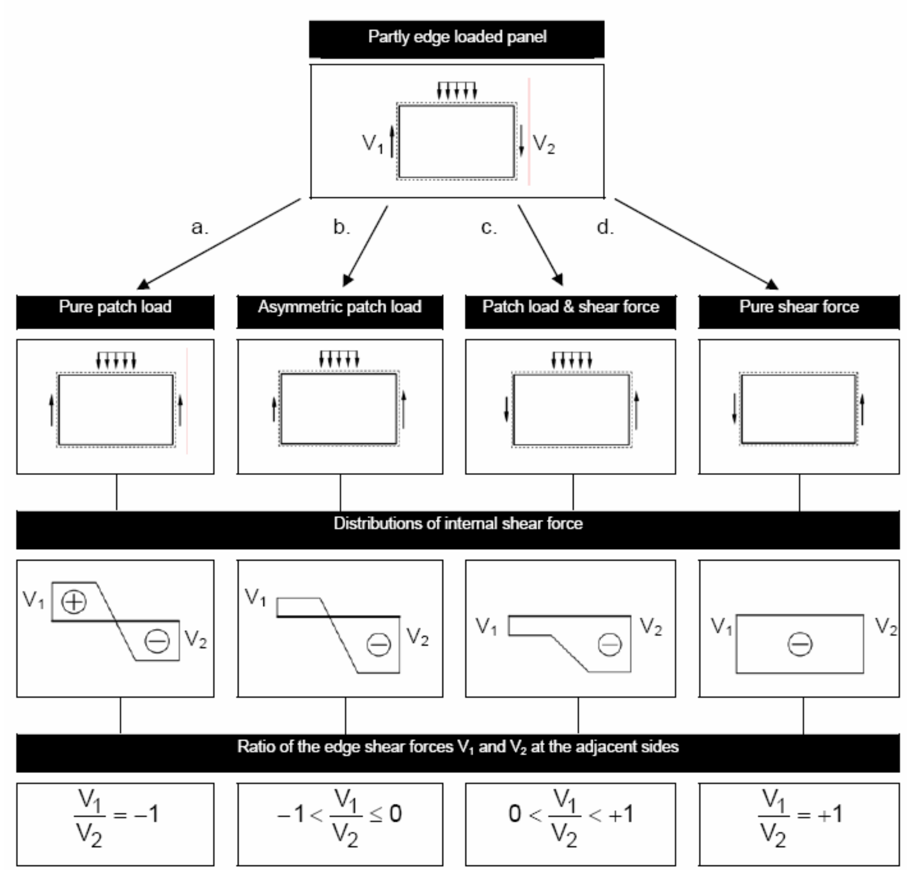
→ Numerical parametric study by different geometries and loading conditions.

Numerical modelling

Modelling of the half girder → 1. Reduced model.

2. By defining the parameter x, many shear force distributions can be analysed.



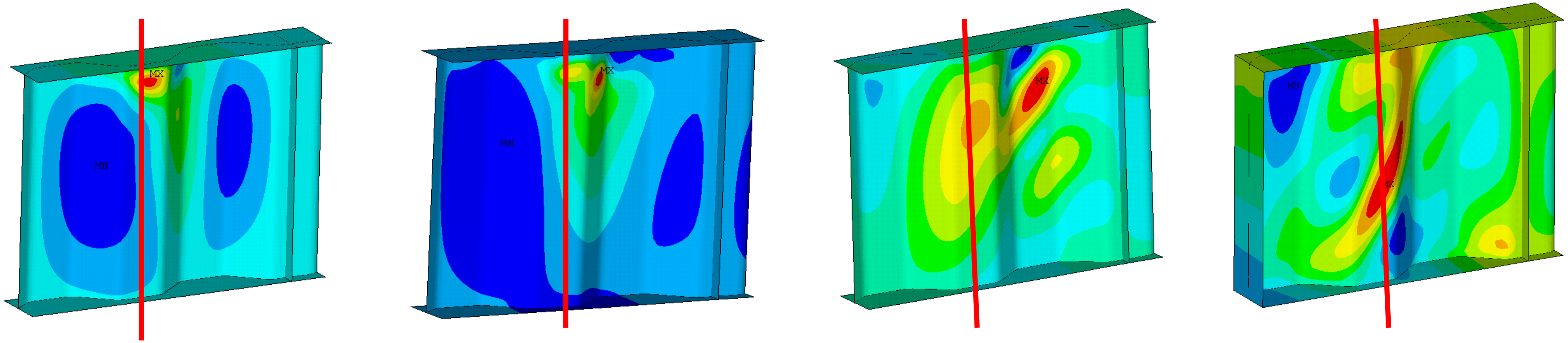


Analysed parameter range:

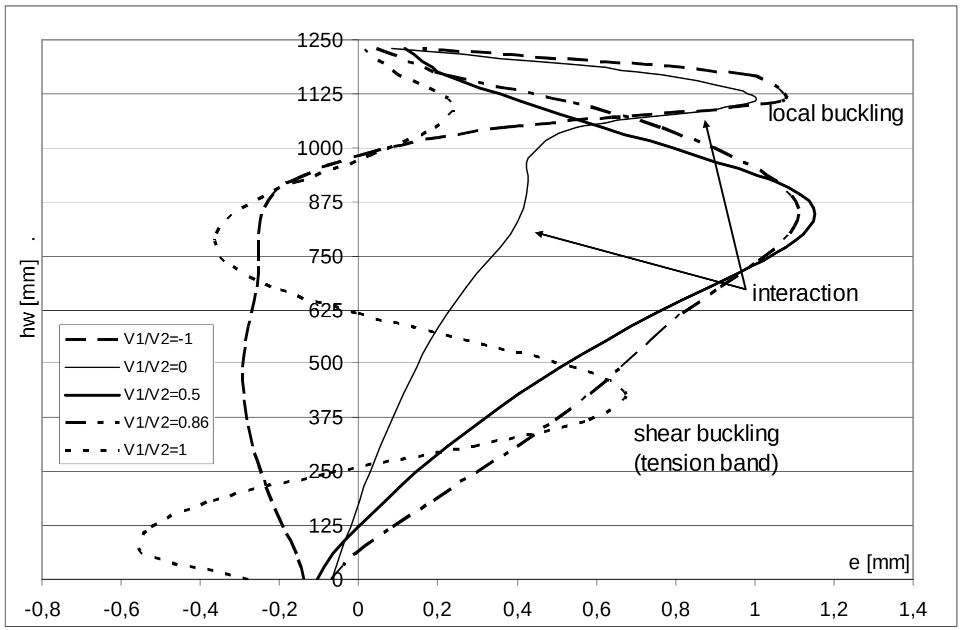
- h_w/t_w: 100-125-150-200-250
- a_1/t_w: 15-20-25-30-35
- α: 20°-30°-40°-60°
- ss/h_w: 0.2-0.4-0.5-0.6-0.8
- V_1/V_2: between -1 ; 1

Structural behaviour

$V_1/V_2=-1$ $V_1/V_2=0$ $V_1/V_2=0.5$ $V_1/V_2=1$

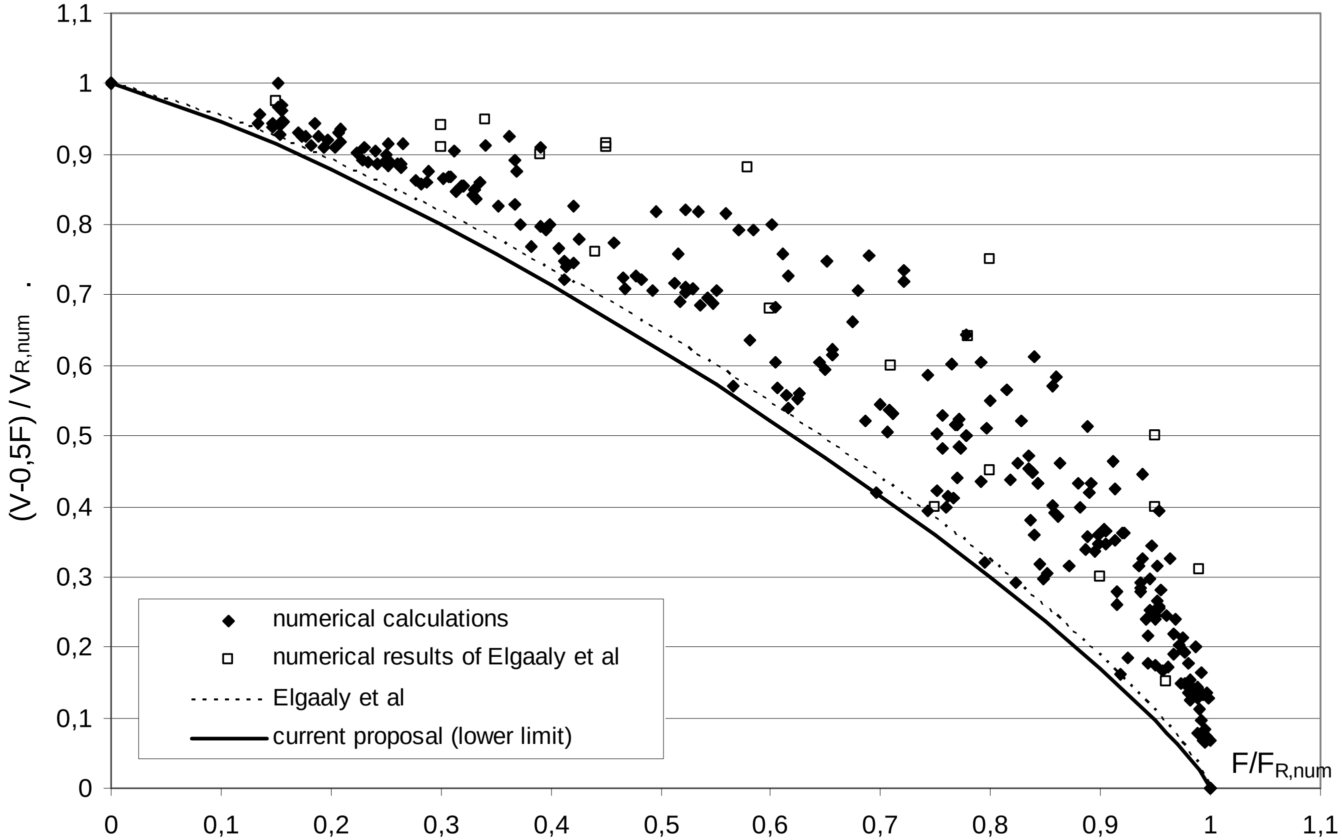


Lateral displacements along a parallel fold:



Analysis of the interaction

Evaluation of the numerical calculations (using the separation methodology)

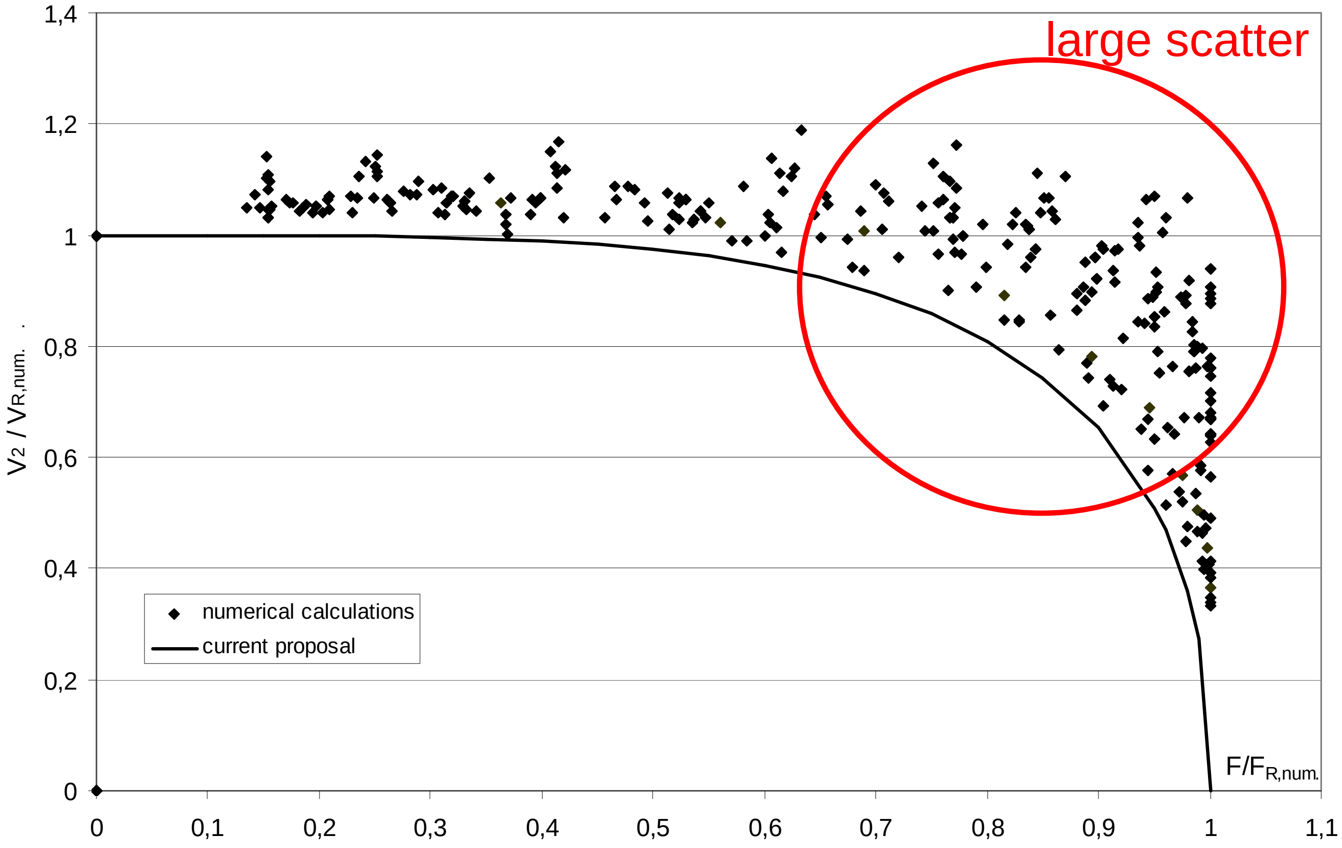


1. Proposed interaction equation:

$$\left(\frac{V - 0.5 \cdot F}{V_R}\right)^{1.2} + \left(\frac{F}{F_R}\right)^{1.2} \leq 1.0$$

Analysis of the interaction

Evaluation of the numerical calculations (without the separation methodology)

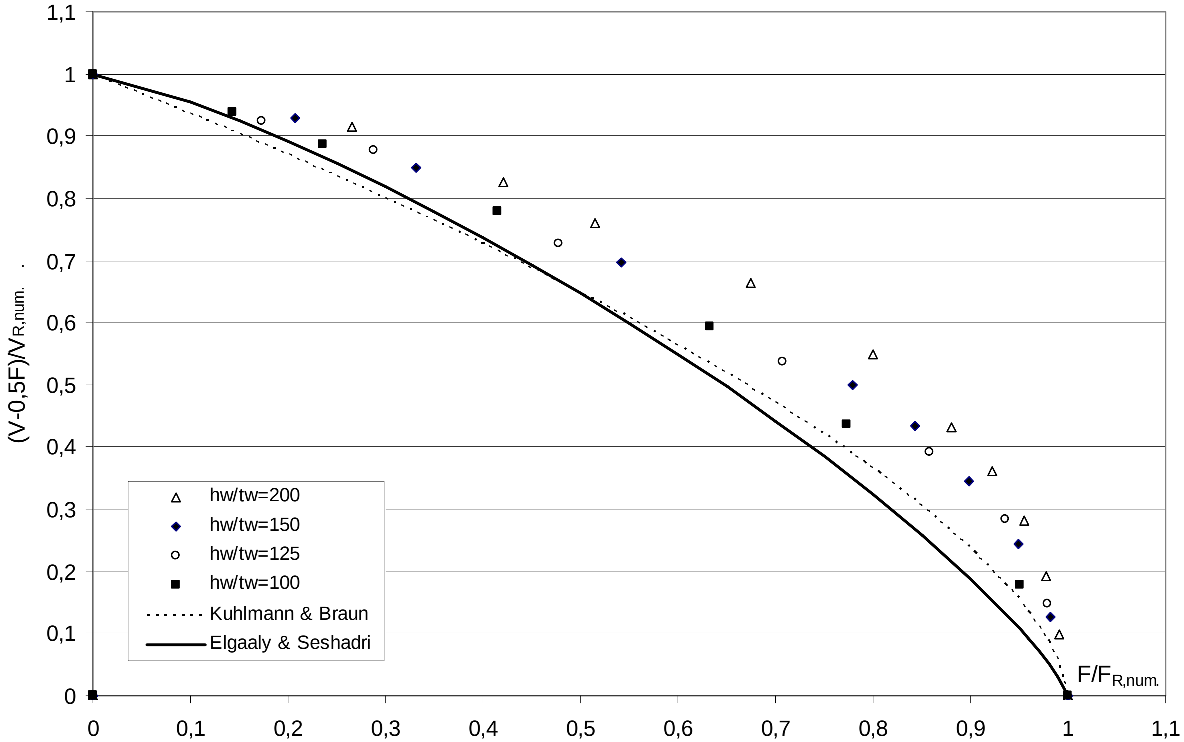


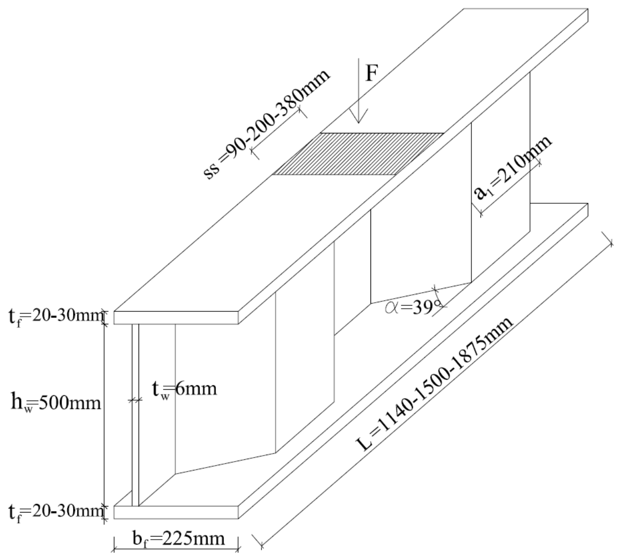
Proposed interaction equation:

$$\left(\frac{V_{\max}}{V_R}\right)^{2.5} + \left(\frac{F}{F_R}\right)^{4} \leq 1.0$$

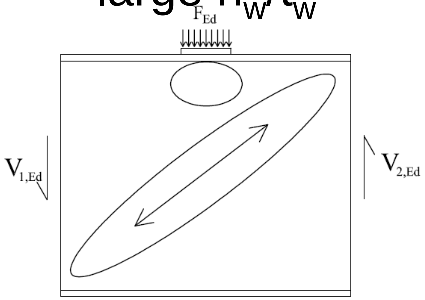
Analysis of the geometric parameters

Effect of the web ratio: h_w/t_w

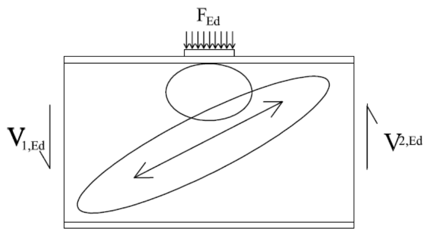




large h_w/t_w

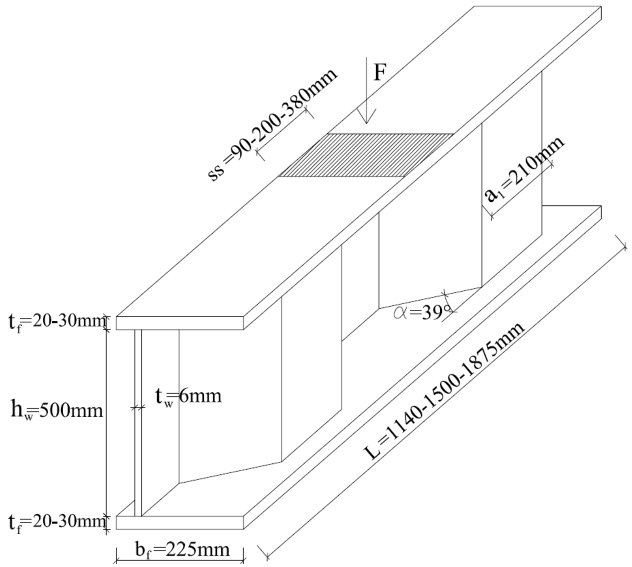


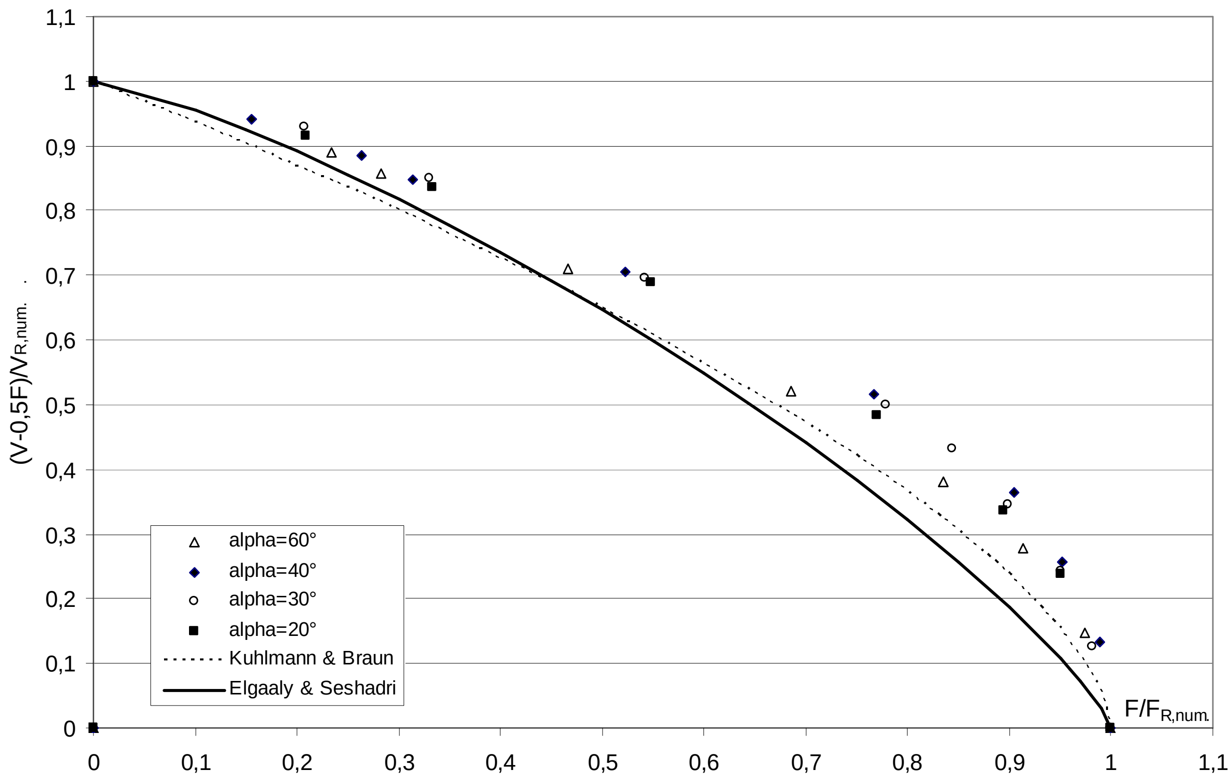
small h_w/t_w



Analysis of the geometric parameters

Effect of the corrugation angle:



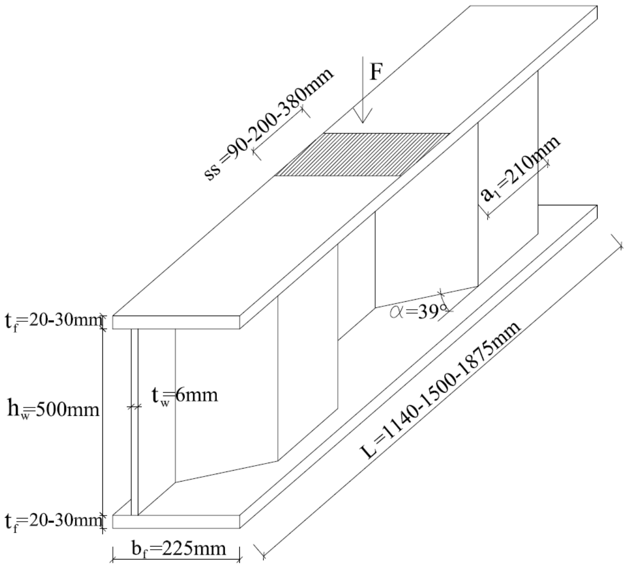


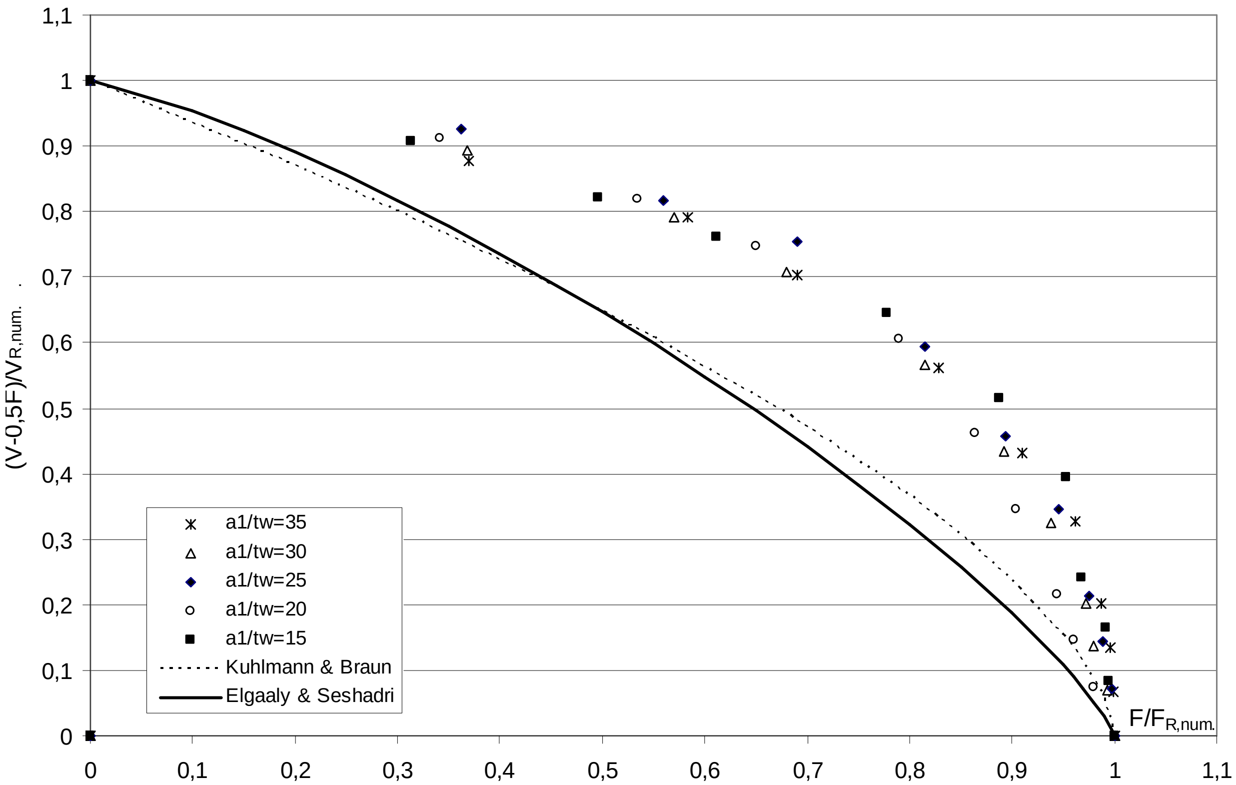
Influence is quite small.

larger corrugation angle → stronger interaction criterion

Analysis of the geometric parameters

Effect of the fold ratio: a_1/t_w

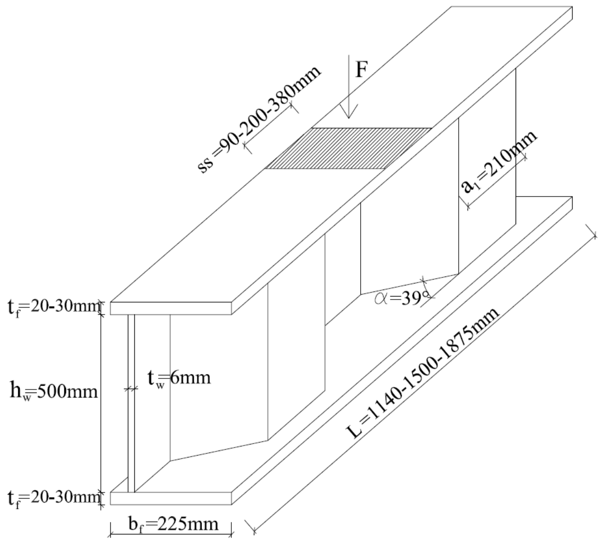


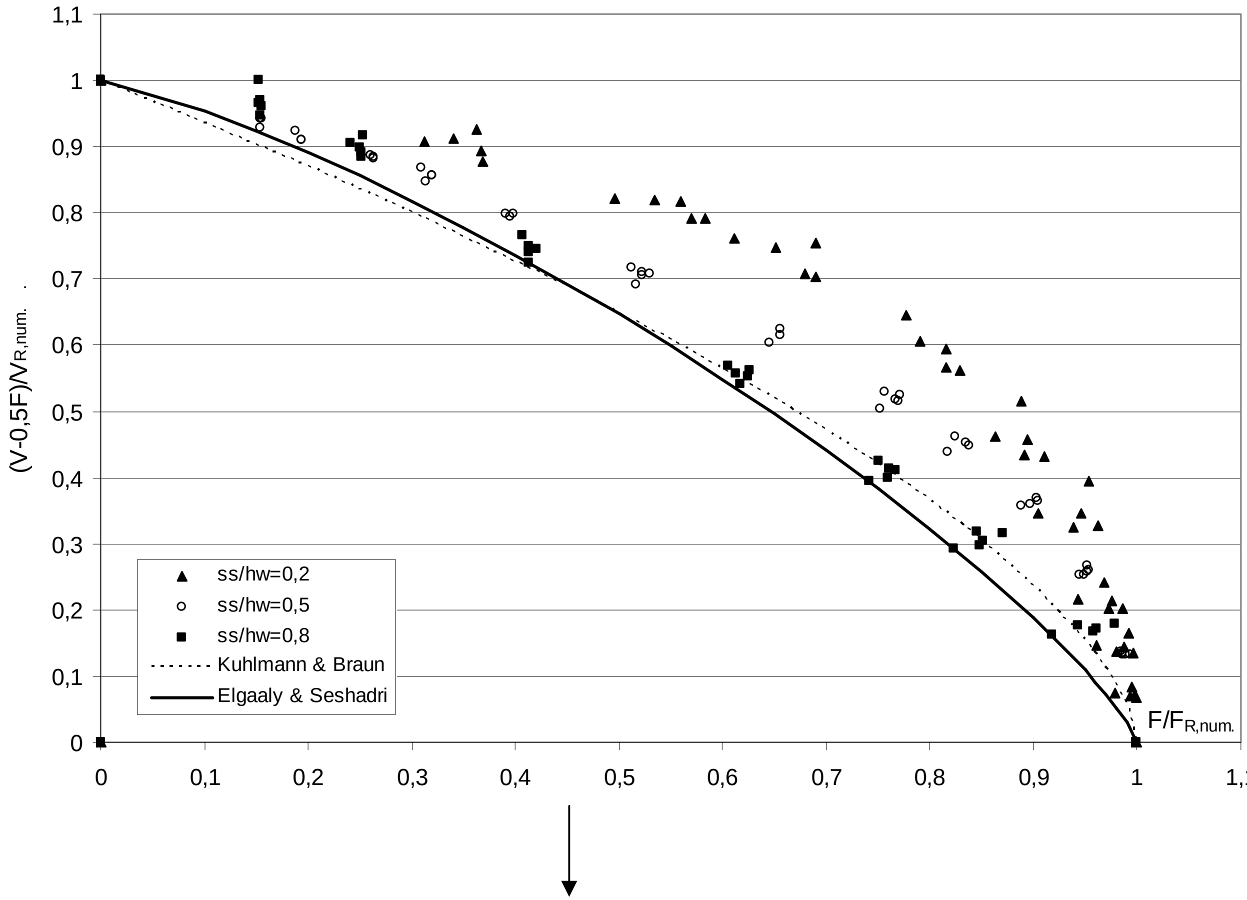


Influence is negligible.

Analysis of the geometric parameters

Effect of the loading length: ss/h_w





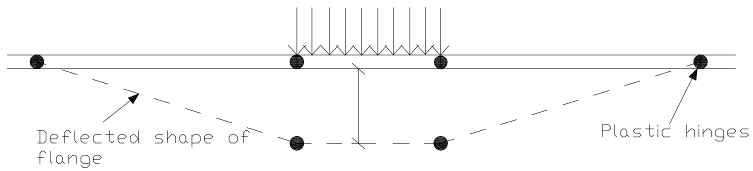
larger loading length → stronger interaction criterion

Interaction of shear and transverse forces

Shear resistance → Mainly depending on the web plate.

Patch loading resistance → - Resistance of the web

- Resistance of the flange



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Flange contribution can be dominant

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If the flange is dominant → web carries only a smaller part of the applied load

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Shear resistance can be larger.

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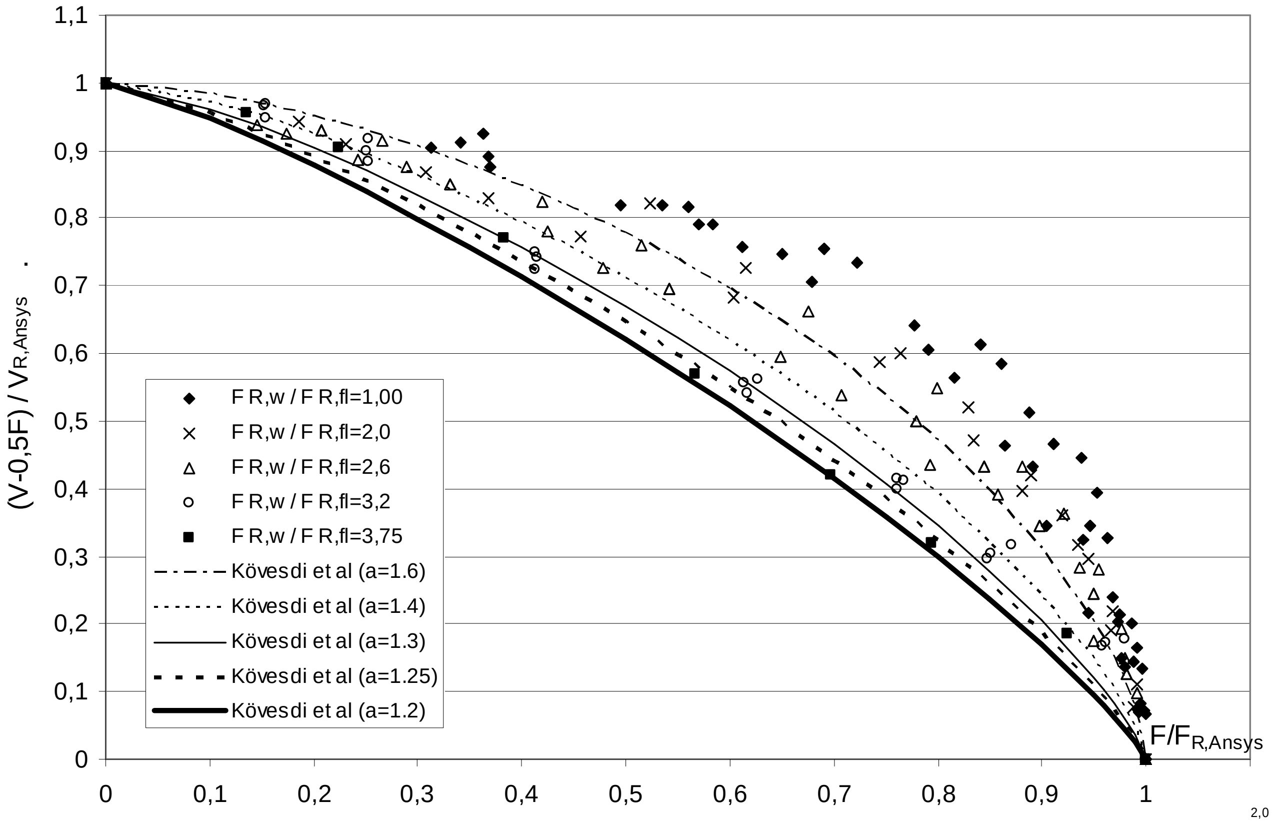
Interaction criteria can be weaker.

Conclusion:

Interaction criterion can be expressed by the ratio of flange and web contributions in the patch loading resistance.

Interaction of shear and transverse forces

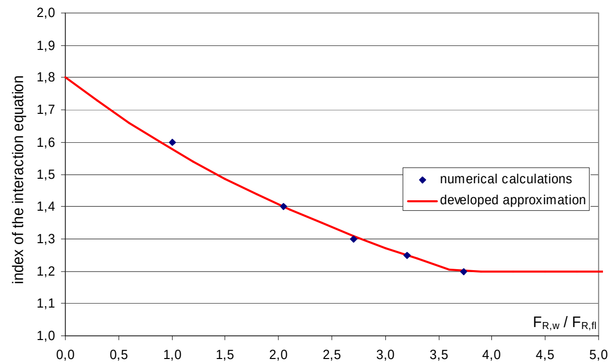


Proposed interaction equation:

$$\left(\frac{V-0.5\cdot F}{V_R}\right)^a+\left(\frac{F}{F_R}\right)^a\leq 1.0$$

Determination of the index:

$$a=e^{-0.25\cdot\left(\frac{F_{R,w}}{F_{R,fl}}\right)}+0.8 \qquad \text{but} \qquad a>1.2$$



Summary

1. Literature overview
2. Numerical model development
3. Analysis of the structural behaviour
4. Numerical parametric study
5. Parameters which have influence on the structural behaviour
6. Development of interaction curve

Further research subject

Interaction of bending and patch loading (F+M).

Thank you for your attention!