Budapest University of Technology and Economics
Department of Structural Engineering

Universität Stuttgart
Institute of Structural Design

Model development for determination of the patch loading resistance of hybrid girders with corrugated webs

Balázs Kövesdi

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Introduction

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

2, Aim of the research work

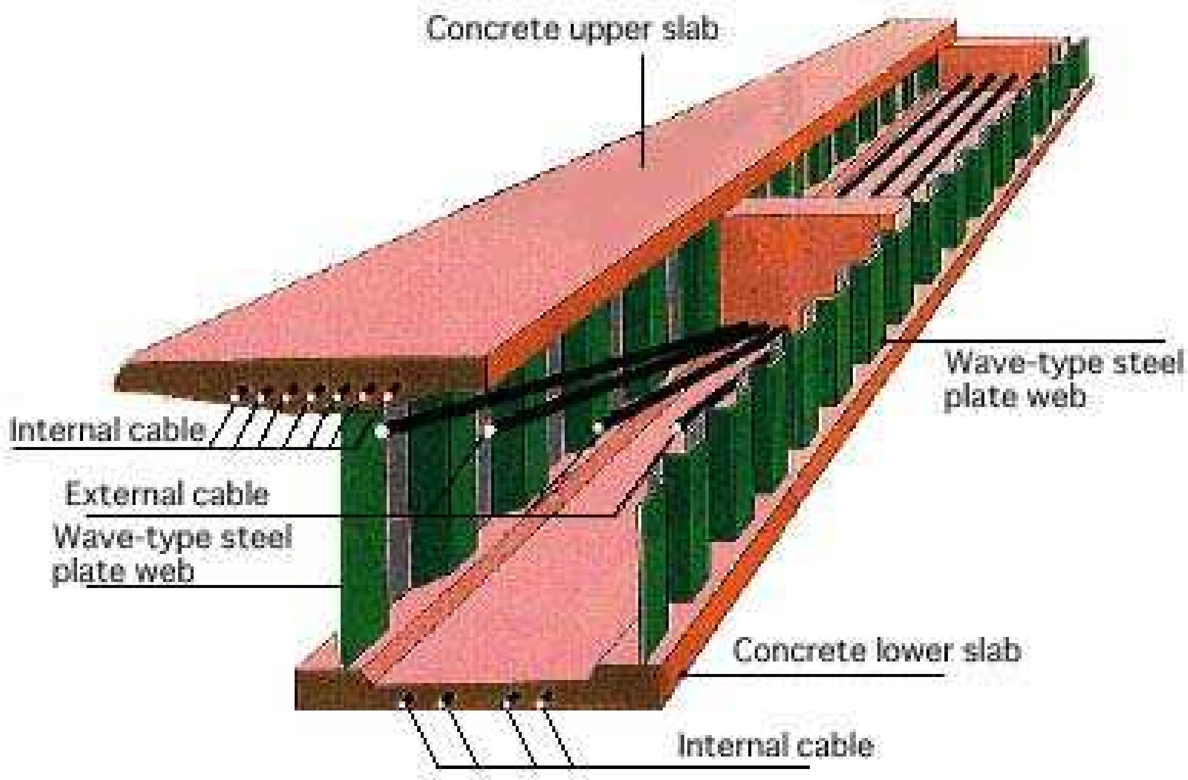
3, State of the previous investigations

4, Numerical models
- model development
- applied finite elements
- support and load conditions
- applied imperfections
- model verification
- model simplification method

5, Numerical investigations

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.

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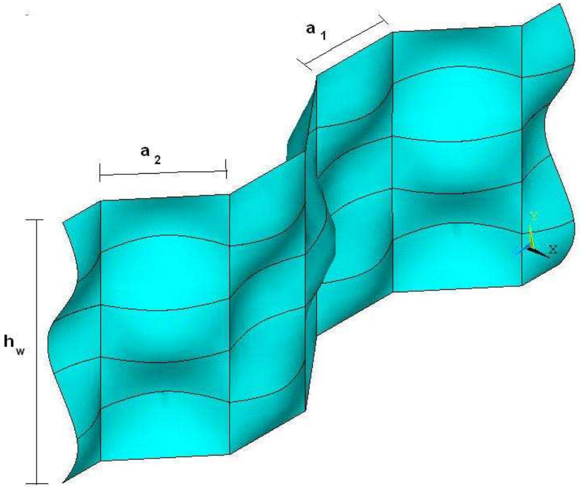
Numerous bridges all over the word

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

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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 available 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).

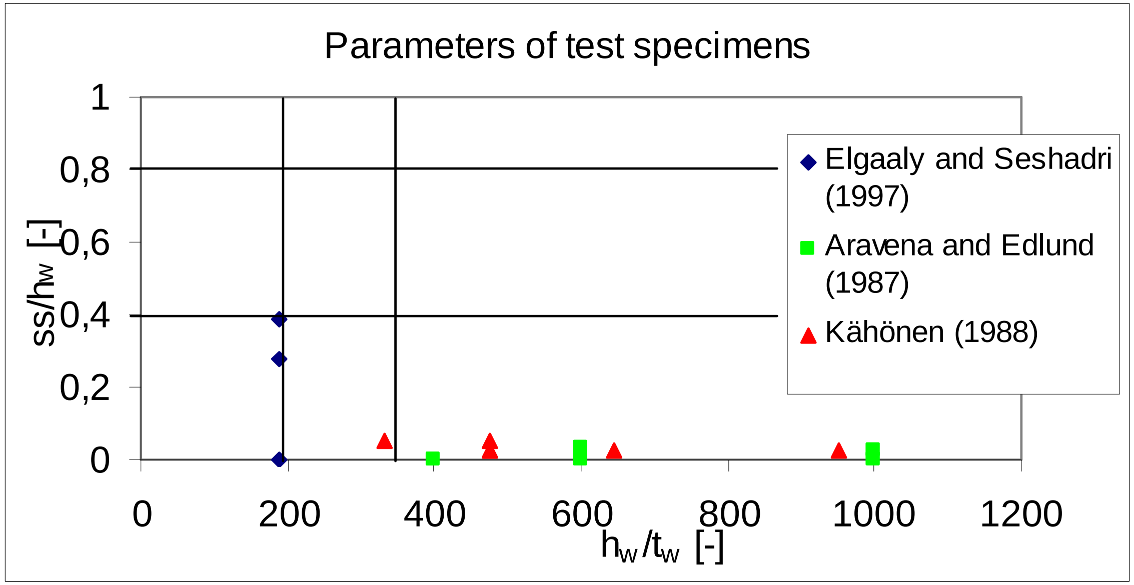
Numerical investigations: Elgaaly and Seshadri (1997)
Luo and Edlund (1996)

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

Differences between experiments and hybrid bridges

1. Loading length → Executed tests: short loading length
→ Hybrid bridges: long loading length

2. Global slenderness ratio

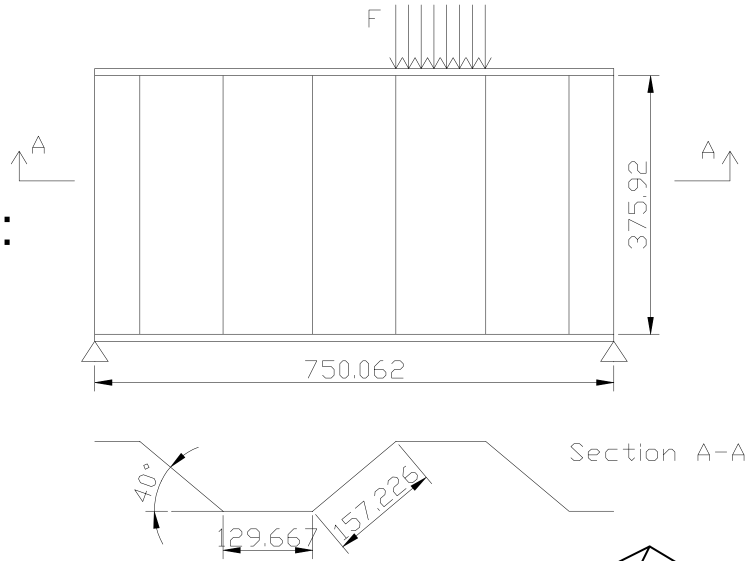


3. Stiffness of the flange → Steel girders: flange yielding with web crippling
→ Hybrid bridges: no interaction

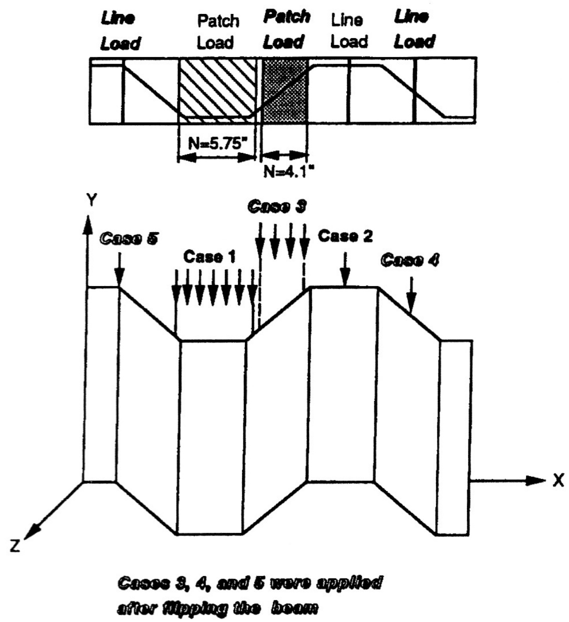
Numerical model development – 1.

Experiments of Elgaaly and Seshadri:

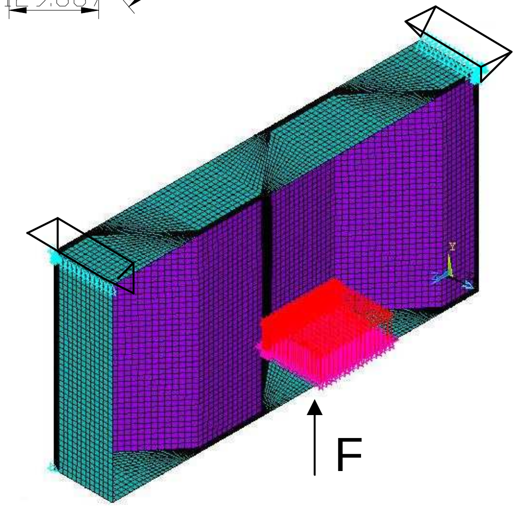
test specimen:



load introduction locations



Developed model

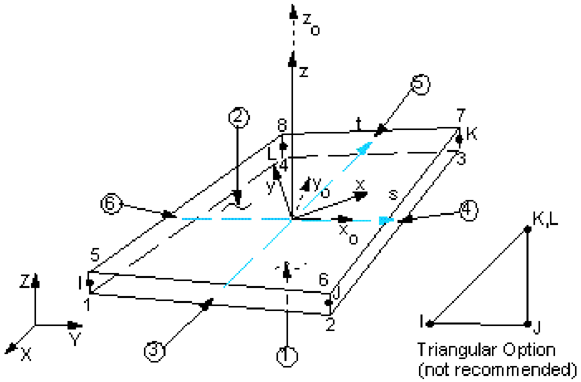


- Shell model
- Nonlinear analysis
- Geometric imperfections
- Material nonlinearities

Numerical model development – 2.

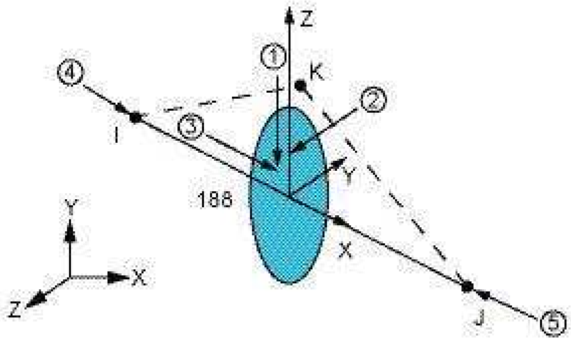
Applied finite elements

Shell 181



- plated element with four nodes
- bending and membrane capabilities
- in-plane and normal loads are permitted
- six degrees of freedom at each node
- stress stiffening and large deflection capabilities
- optimal for nonlinear analyses

Beam 188

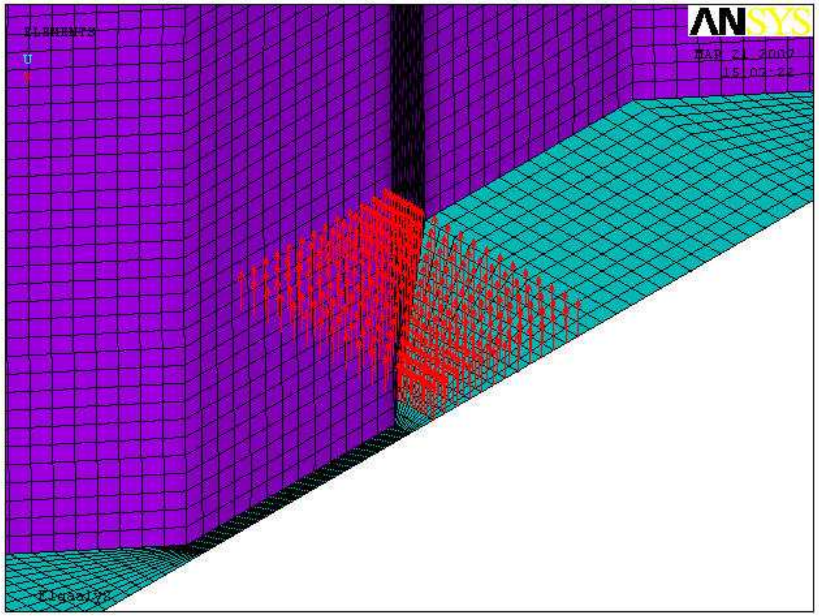


- linear beam element with two nodes
- six or seven degrees of freedom at each node
- based on Timoshenko´s beam theory
- shear deformation effects are included
- optimal for large deflection analyses

Numerical model development – 3.

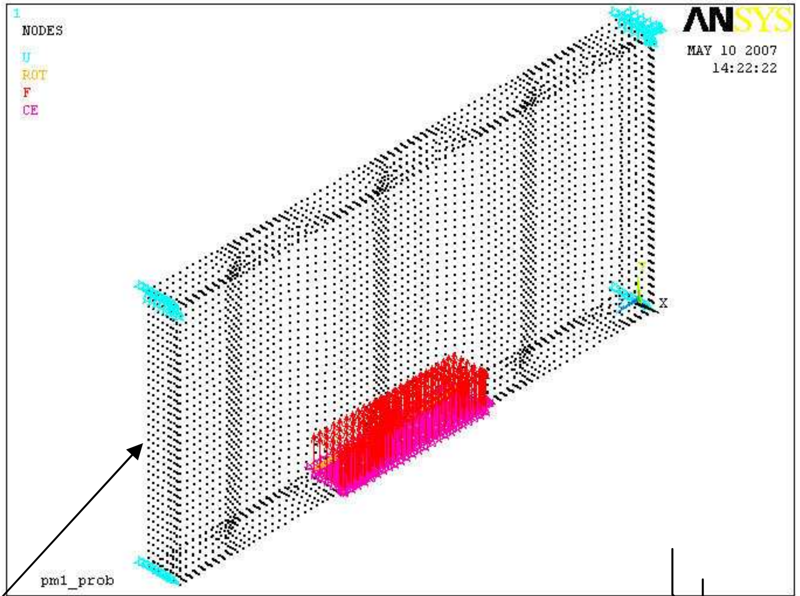
Load model

uniformly distributed node loads
along the whole flange width



Support conditions

- single span
- simply supported
- statically determined girders



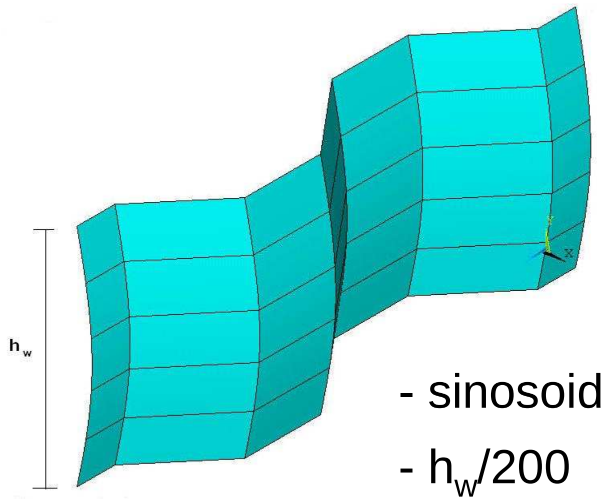
Stiffeners
agains warping
and crippling

Numerical model development – 4.

Imperfections according to EC3 1-5 → user defined
→ eigenforms

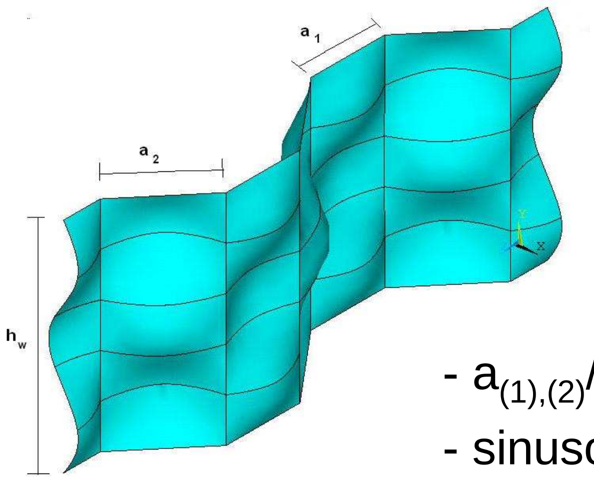
Failure mode: local and global buckling → local imperfection
→ global imperfection

Global imperfection



- sinosoidal wave
- $h_w/200$

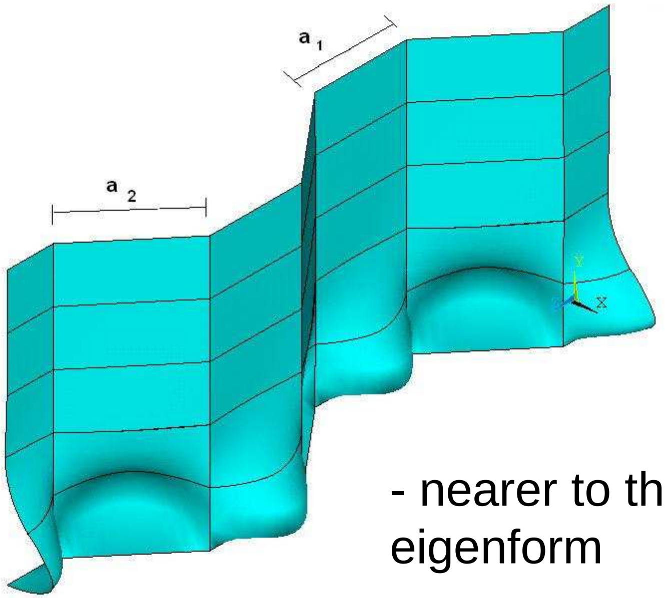
Local imperfection type 1.



- $a_{(1),(2)}/200$
- sinusoidal waves

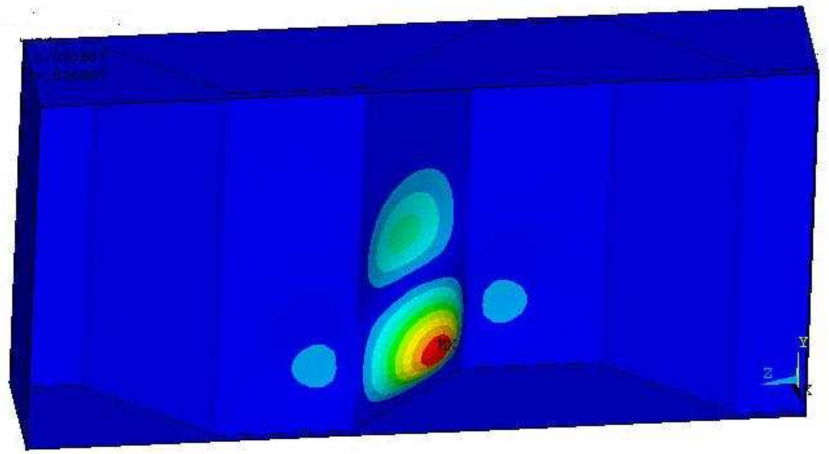
Numerical model development – 5.

Local imperfection type 2.



- nearer to the eigenform
- $y = e^{-x} \cdot \sin(x)$
- $a_{(1),(2)}/200$

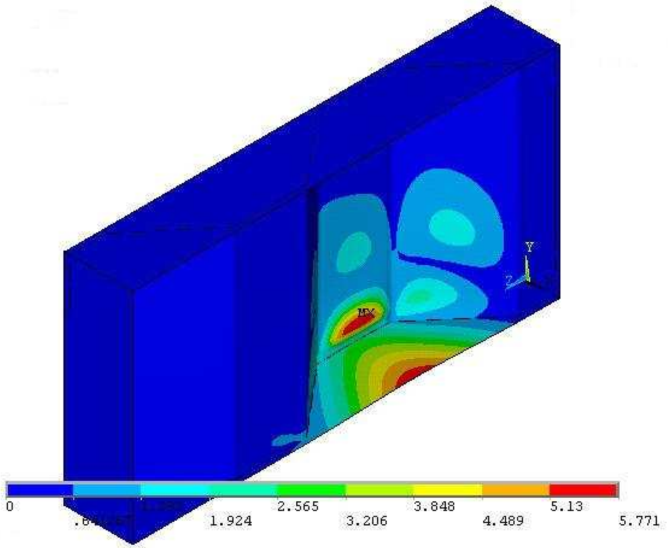
First local eigenmode



- EC3 permits to use eigenmodes
- any global eigenmode in the first 100
- typical local imperfection shape

Model verification

Typical failure mode



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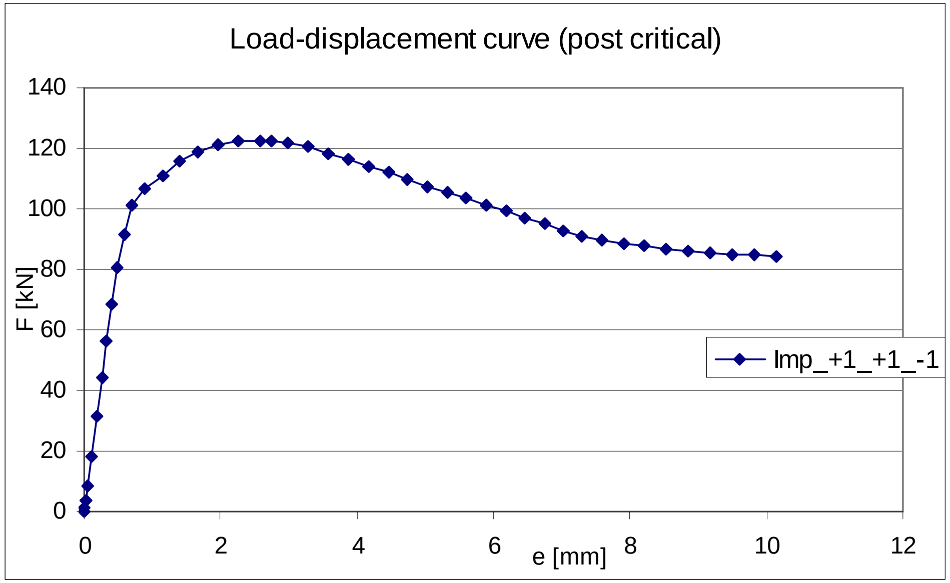
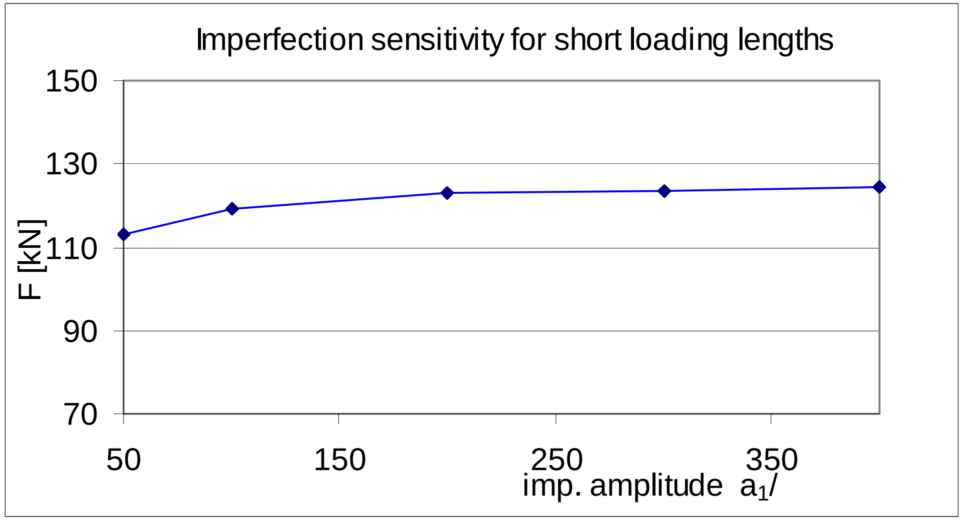
Comparison of numerical and test results

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

F_{EXP}=131,3kN





Modelling of the flange

Failure mode of hybrid bridges:

→ Web crippling

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Aim: to eliminate the flange buckling

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Stiffening of the flange

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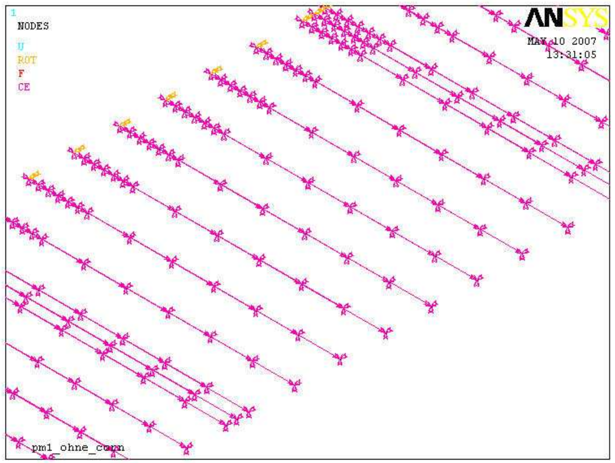
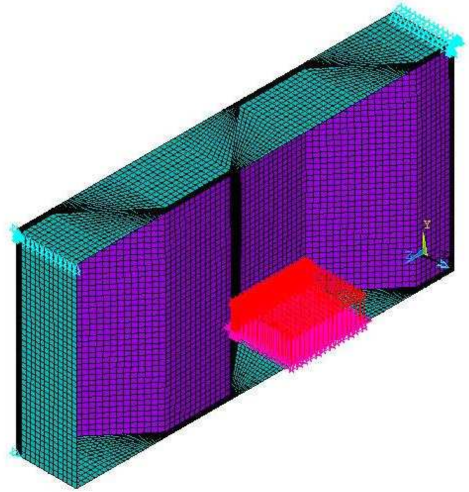
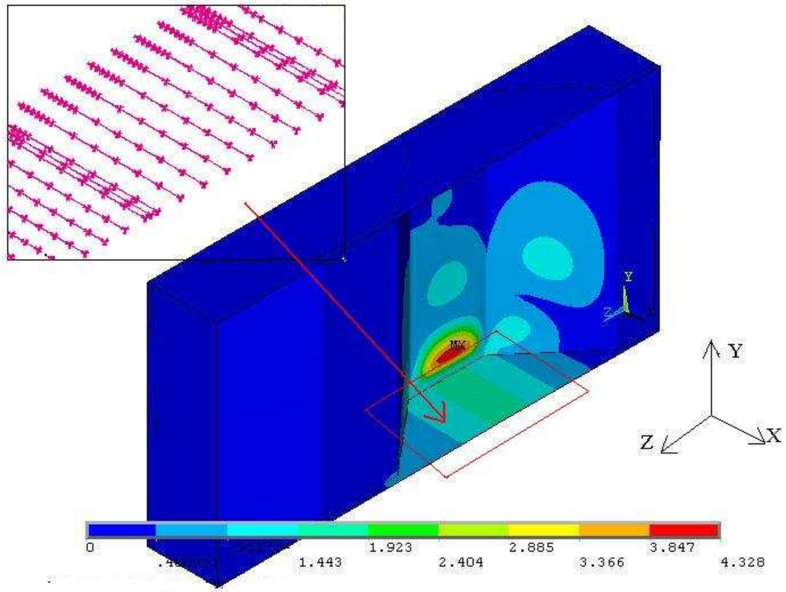
Applied rigid elements



Model:



Failure mode:



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;

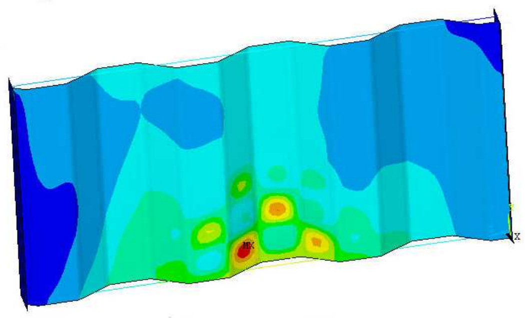
a_1=50 mm-350 mm

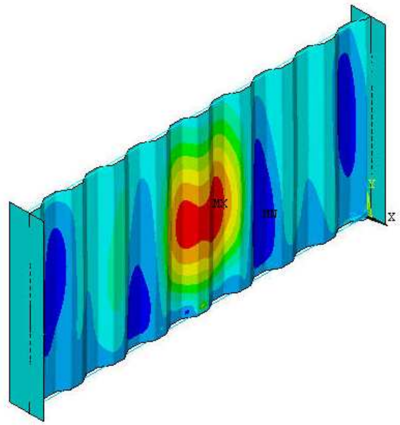
4, loading length: ss/h_w=0,4; 0,6; 0,7

ss=600mm; 900mm; 1200mm

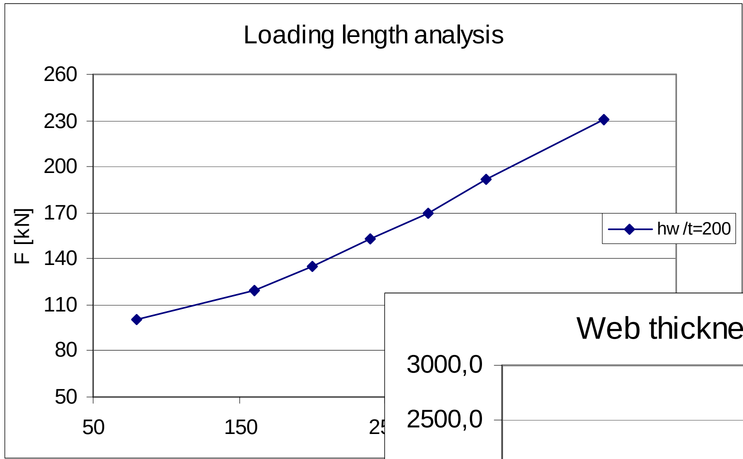
Results - 1.

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

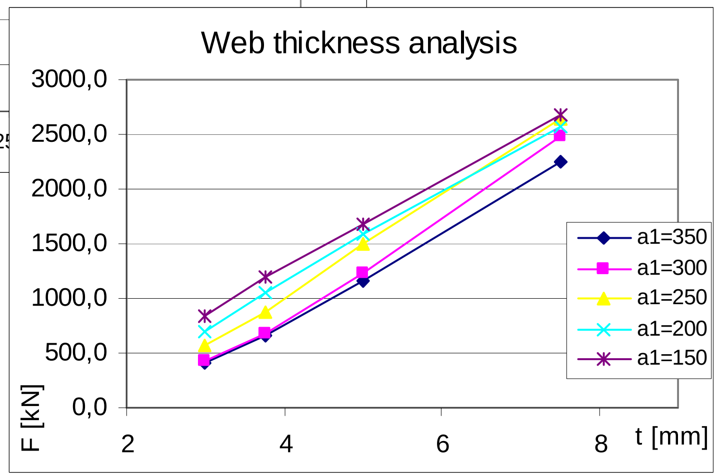




2, Increasing loading length increases the patch loading resistance.

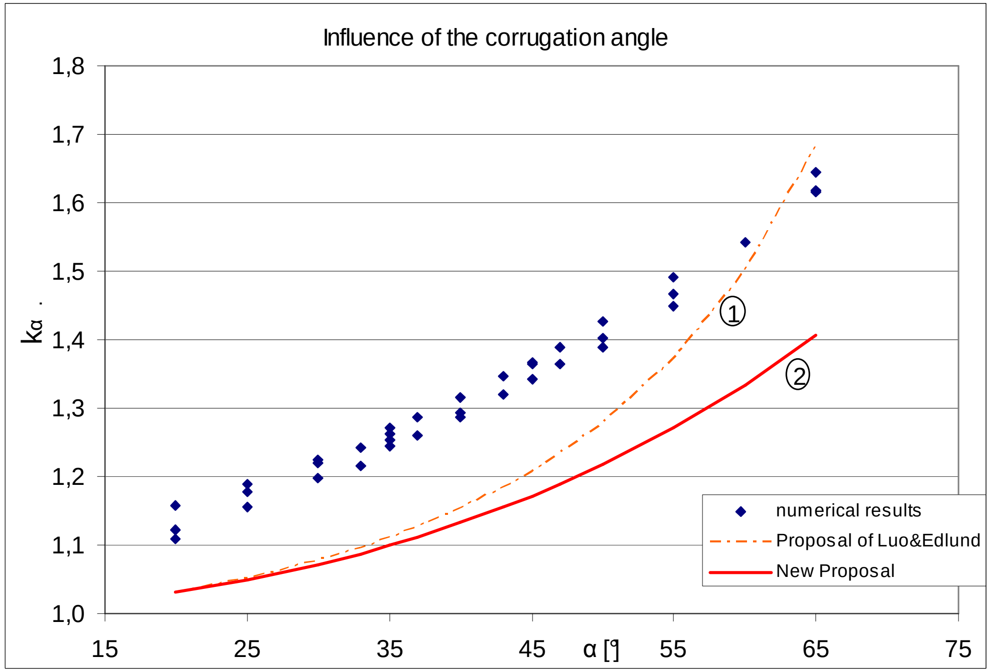


3, Increasing web thickness increases the patch loading resistance.

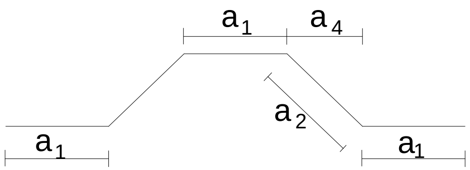


Results - 2.

4, Increasing corrugation angle increases the patch loading resistance.



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



Reduction of the calculation time

Flange behavior like a beam

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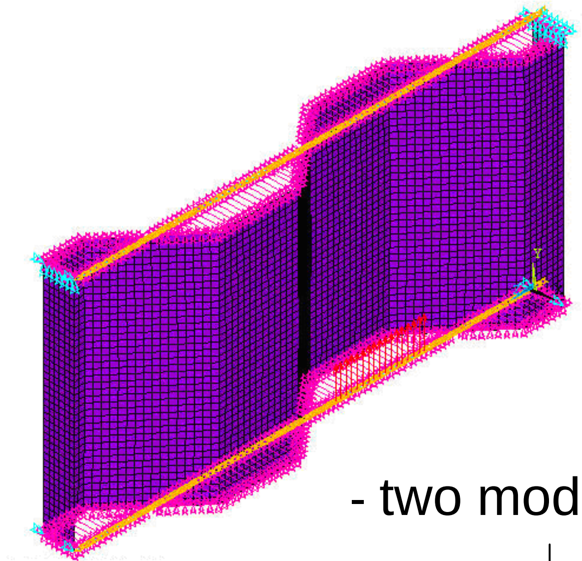
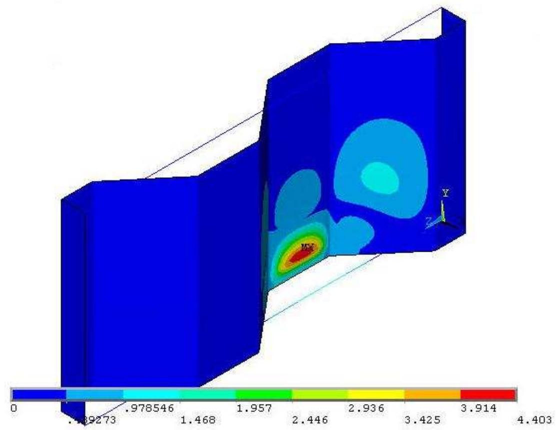
modelling of the flange with beam elements

Geometry of the numerical model



Typical failure mode



- two models lead
  - to the same failure modes
  - to the same load carrying capacity

↓

calculation time reduced by 60%

Summary

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

2, Numerical model was developed.

3, Steps of the modelling and the properties of the numerical model was presented.

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

Thank you for your attention!