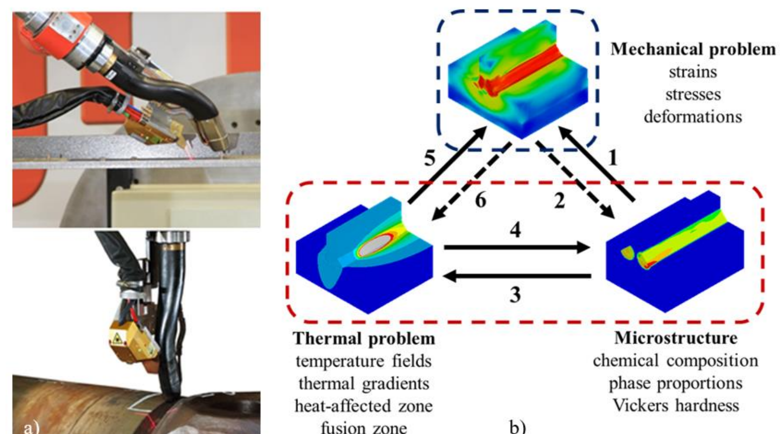
MTA-BME Lendület New Generation Steel Bridges Research Group - Introduction



Dr. Kövesdi Balázs

Research aims

Background and motivation:

Steel bridge industry is going through a significant change primarily due to three main reasons:

(i) Industry 4.0 and digitalization of the construction industry has changed design/manufacturing processes;

(ii) appearance of new materials and manufacturing methods;

(iii) the appearance of new bridge types and structural solutions.

Definition of „New generation steel bridges":

The new developments in the fields of

(i) material science,

(ii) manufacturing technology,

(iii) design theory,

(iv) new structural systems

are producing a new generation of steel bridges.

Focus of the research plan:

(i) on the theoretical basis of steel bridge design,

(ii) implementation of new methodologies into the design theories,

(iii) renewal of traditional design methods having well-established theoretical backgrounds but with considering innovative technological solutions – FEM-based design.

Research aims

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(iii) the appearance of new bridge types.

Definition of „New generation steel bridges”:

The new developments in the fields of

(i) material science, → high strength steel

(ii) manufacturing technology, → innovation in welding processes – welding simulations

(iii) design theory, → FEM-based design

(iv) new structural systems → hybrid girders; corrugated web girders

are producing a new generation of steel bridges.

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(ii) implementation of new methodologies into the design theories,

(iii) renewal of traditional design methods having well-established theoretical backgrounds but with considering innovative technological solutions – FEM-based design.

Members of the Research Group

Main members of the research program:

Balázs Géza Kövesdi, PhD (head of the team; senior researcher)

Balázs Somodi, PhD (young researcher) → Leader of high strength steel division

Dénes Kollár, PhD (young researcher) → Leader of innovative manufacturing division

Bence Jáger, PhD (young researcher) → Leader of new structural solutions division

Student members of the program:

Mohammad Radwan, PhD student → topic: interaction of global and local stability problems

Iham Alkubaisy, new PhD student (2022-) → topic: design of hybrid steel girders

Ali Seyed, new PhD student (2022-)

+ 3-4 MSc students / year during diploma semester

Relations between research topics

		FEM-based design	*Analytical solutions*
Research fields	Laboratory test program	Usage in numerical modelling	Usage in design theory development
High strength steel and hybrid structures	Tests on hybrid girders	Modeling of HSS and hybrid girders mixing NSS and HSS	Generalization of buckling curves Theory for hybrid girders
Manufacturing specialties		Modeling of manufacturing - 1. welding of HSS girders - 2. welding of corrugated web	Theory for simulation based design from manufacturing to utimate resistance
Numerical model based design	Tests on corrugated web girders	- Modelling and design for stress concentration - Imperfections for HSS structures - Material models for hybrid girders	
New structural solutions		Lateral torsional buckling of corrugated web girders	LTB theory for corrugated web girders Hybrid girders with corrugated webs

Two laboratory test programs are embedded in the global research strategy and shows the correlation between the different research fields and beneficiaries from the laboratory tests.

Design theory of high-strength steel structures

Design theory of high-strength steel structures

Background

Flexural buckling resistance of columns with square box-sections

Experimental program

Numerical research program (deterministic, stochastic)

Analytical design method developed

$$\chi = \frac{1}{2} \cdot \left(\Phi_{RS} - \sqrt{{\Phi_{RS}}^2 - \frac{4 \cdot k_{fy}}{\lambda^2}} \right)$$

$$\Phi_{RS} = k_{fy} + \left(\frac{1}{\lambda^2} + \frac{k_{shape} \cdot \lambda_1(f_y)}{2 \cdot L_{div} \cdot \lambda} \right)$$

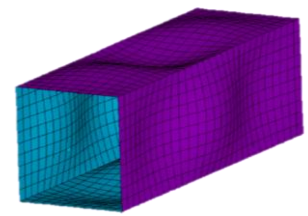
$$k_{fy} = 1 - red(\lambda) \cdot k_{RS}$$

B. Somodi PhD

Plate buckling resistance of square box-sections

Numerical research program (deterministic, stochastic)

Partial safety factor γ_{M1} *determination*



B. Somodi ÚNKP (Structures)

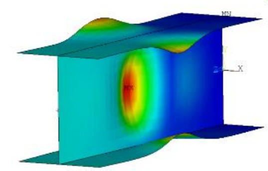
Flexural buckling resistance of columns with rectangular sections

Numerical research program (deterministic)

B. Somodi ÚNKP (Eurosteel)

Plate buckling resistance of I-sections

Numerical research program (deterministic, stochastic)



B. Somodi ÚNKP (ÉPKO)

Global and local stability phenomena of high-strength steel welded box-sections

Numerical research program (equivalent geometric imperfection development)

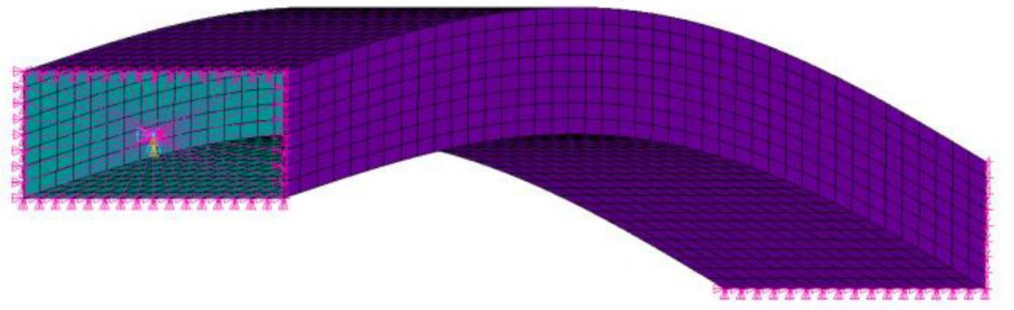
M. Radwan (Periodica Polytechnica; Structures)

Design theory of high-strength steel structures

Flexural buckling resistance of columns with rectangular sections

Research program

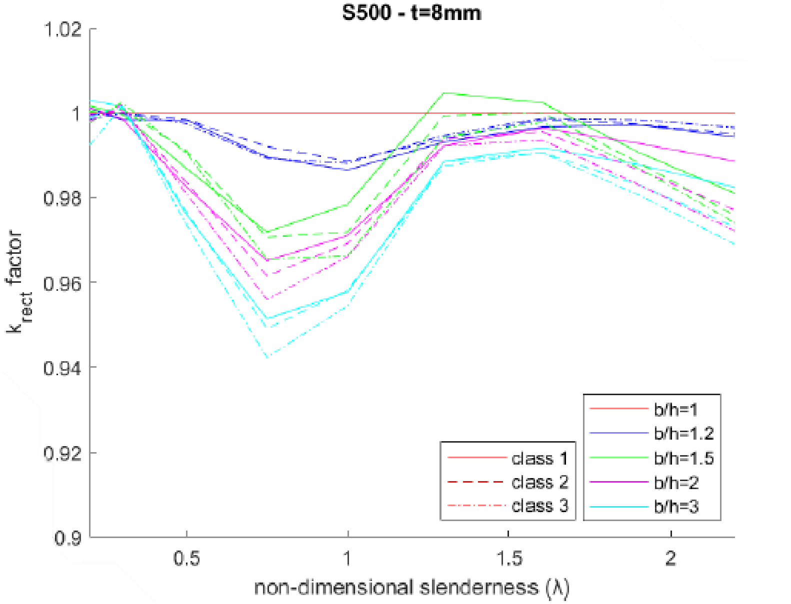
- *Examination the effect of rectangularity on the column buckling resistance*
- *Main examined parameter is aspect ratio b/h*
- *Other parameters:*
    - *steel grade (S235 – S960)*
    - *cross-section class (1 - 3)*
    - *plate thickness*
    - *global slenderness*



Results

- *Aspect ratio could effect the normalized column buckling resistance by up to 5-8%, which is currently not considered by standards*
- *This effect is strongly dependent by the residual stress*

The residual stress pattern of rectangular box-sections should be further researched



Design theory of high-strength steel structures

Experimental research program for rectangular sections

Residual stress measurement on rectangular sections

- *overall 18 specimens*
- *5 rectangular specimens (S460, b/h ≠ 1)*
- *6 hybrid specimens (S235-S355-S460)*
- *7 control specimens (square, S460)*
- *b/t ratio varied between 20 and 50*
- *length ≈ 3×max(b,h)*

t-λ-fy-b/h	fy_g	fy_ö	h	b	t	b/t	b/h
6-z-460	460	460	120	120	6	20	1
6-z-h	235	460	120	120	6	20	1
6-z-h2	235	355	120	120	6	20	1
6-k-460	460	460	220	220	6	36.7	1
6-k-h	235	460	220	220	6	36.7	1
4-z-460	460	460	120	120	4	30	1
4-z-h	235	460	120	120	4	30	1
4-k-460	460	460	200	200	4	50	1
4-k-h	235	460	200	200	4	50	1
8-z-460	460	460	200	200	8	25	1
8-z-h	235	460	200	200	8	25	1
10-z-460	460	460	250	250	10	25	1
12-z-460	460	460	300	300	12	25	1
6-z-460-1.2	460	460	100	120	6	20	1.2
6-z-460-1.25	460	460	120	150	6	25	1.25
6-z-460-1.5	460	460	120	180	6	30	1.5
6-z-460-2	460	460	120	240	6	40	2
6-z-460-3	460	460	100	300	6	50	3

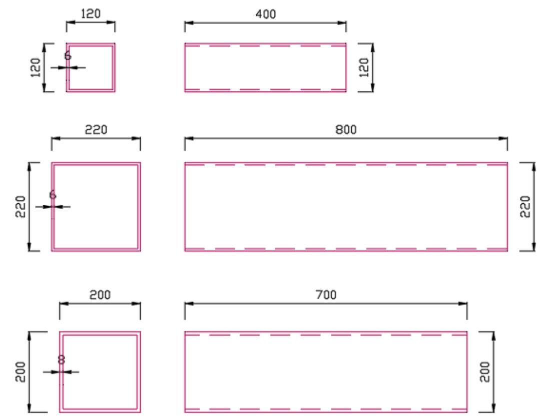
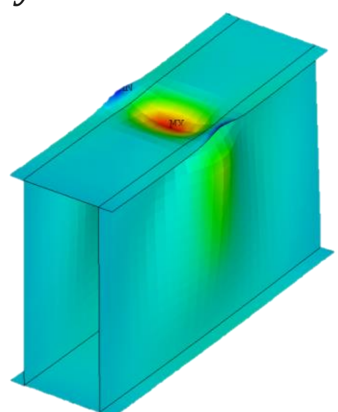
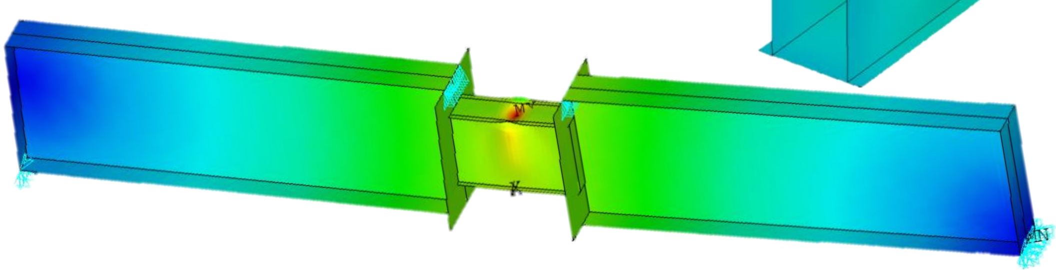
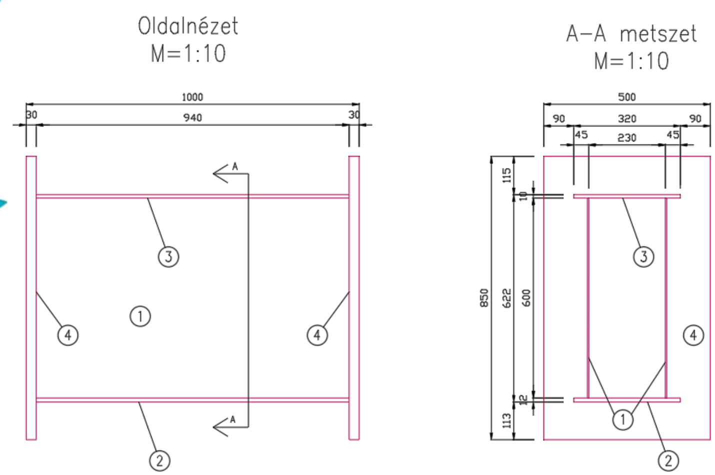


Plate buckling tests of bended rectangular hybrid sections

- *overall 14 specimens*
- *12 hybrid specimens (S235-S355-S460)*
- *2 control sepcimens (S235, S460)*
- *3 different cross-section (t=4,6,8)*
- *6 specimens for pure bending*
- *8 specimens for bending+shear*





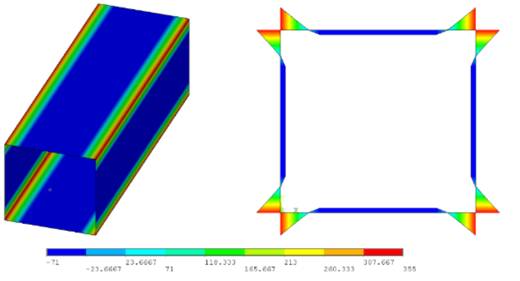


Design theory of high-strength steel structures

Expected research results

New residual stress models

Based on: experimental research program
numerical bases - welding simulation



Improved analytical resistance models:

$$\chi = \frac{1}{2} \cdot \left(\Phi_{RS} - \sqrt{{\Phi_{RS}}^2 - \frac{4 \cdot k_{fy}}{\lambda^2}} \right)$$

$$\Phi_{RS} = k_{fy} + \left(\frac{1}{\lambda^2} + \frac{k_{shape} \cdot \lambda_1(f_y)}{2 \cdot L_{div} \cdot \lambda} \right)$$

$$k_{fy} = 1 - red(\lambda) \cdot k_{RS}$$

- flexural buckling resistance

- plate buckling resistance

- global and local buckling interaction resistance

Improved FEM-based design rules

- equivalent geometric imperfections for global and local buckling

Extending the theory for hybrid girders →

Based on: experimental research program
deterministic and stochastic numerical investigations

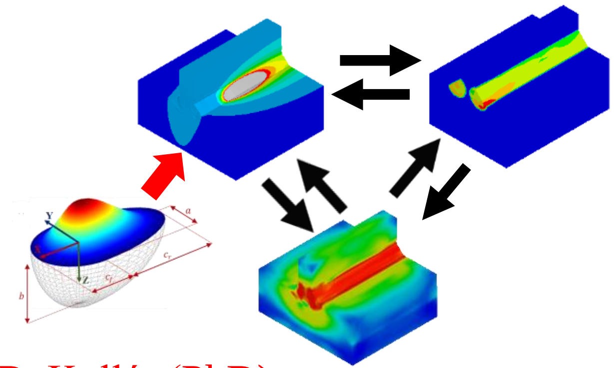
New manufacturing specialties in the design theory

New manufacturing specialties in the design theory

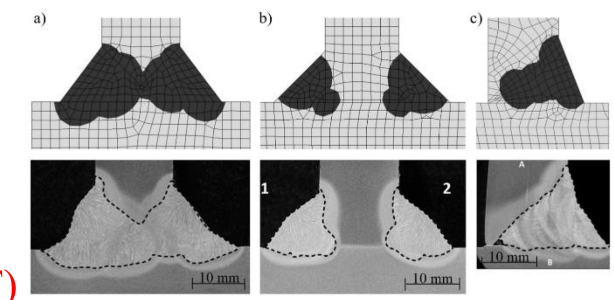
Background

Development of finite element framework

Virtual manufacturing (deterministic thermometallurgical and mechanical analysis - TMM) D. Kollár (PhD)



Virtual testing of welded assemblies (deterministic GMNIA) D. Kollár (PhD)



Development of weld process model

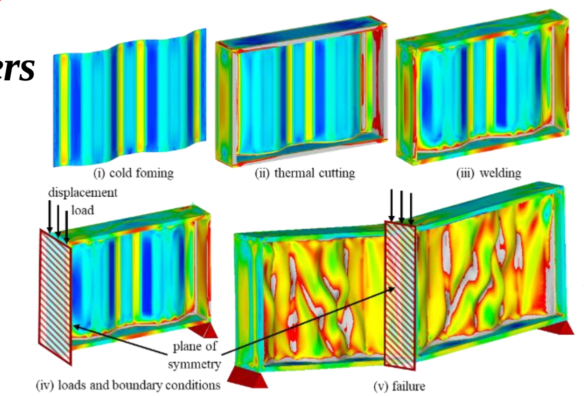
Experimental program on weld shape and res. stresses

Taking welding variables and parameters into account in heat source model parameters (deterministic) D. Kollár (IJAMT)

Virtual manufacturing and testing of trapezoidal corrugated web girders

Experimental program on residual stresses

Taking manufacturing specialities into account in residual stresses, geometrical imperfections and shear buckling resistance (NSS, deterministic) D. Kollár (TWS)



New manufacturing specialties in the design theory

Research aim 1 – *Small-scale local models*

Square and rectangular box sections

1. NSS
2. HSS

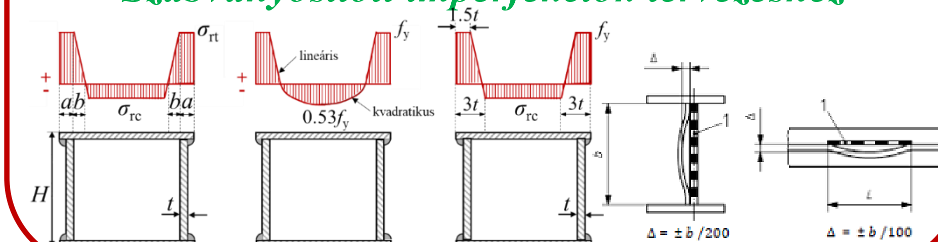
Corrugated web girders

1. HSS
2. Hybrid (NSS + HSS)

Gyártásszimuláció eredménye
Virtuális gyártmány

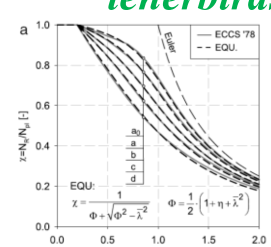
Sajátfeszültség és geometriai imperfekciók

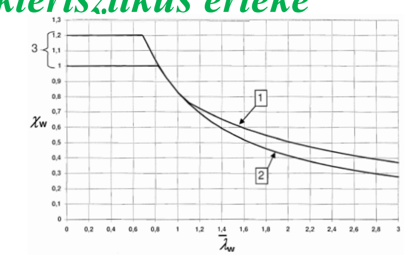
Szabványosított imperfekciók tervezéshez

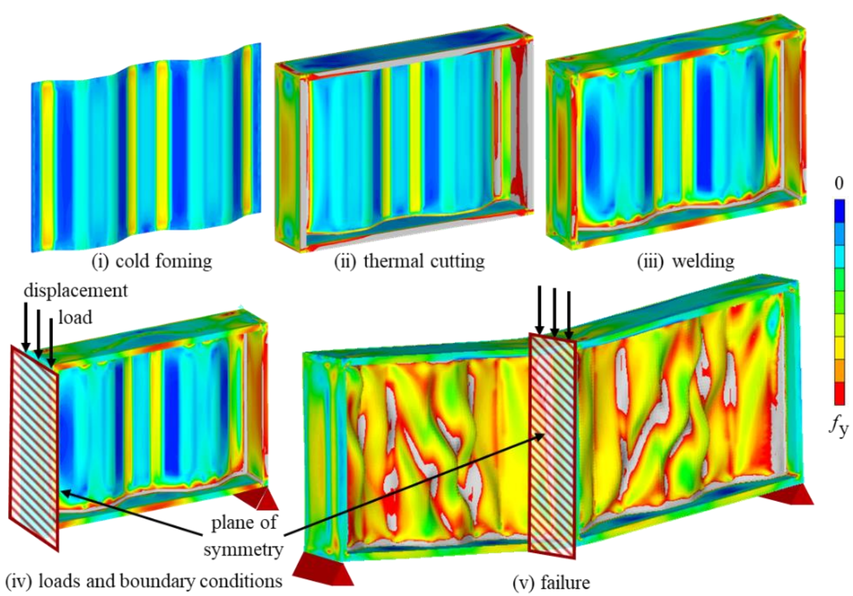


Teherbírási szimuláció (GMNIA) eredménye
Virtuális kísérlet
Szabványosított imperfekciók alkalmazása

teherbírás karakterisztikus értéke

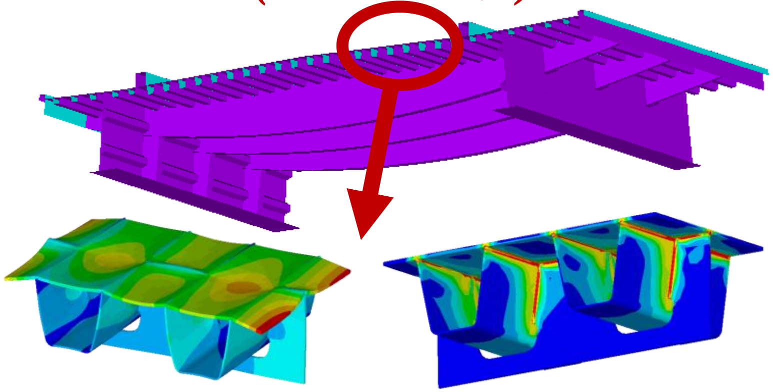






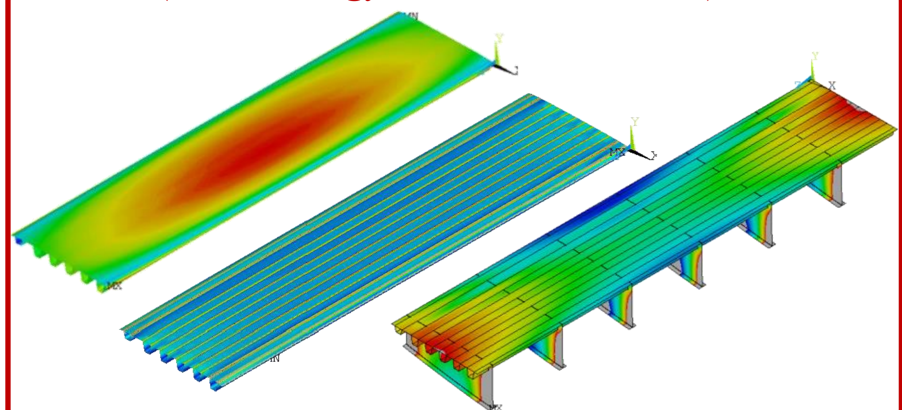
New manufacturing specialties in the design theory

Hídszerkezeti részletmodell (TMM analízis)



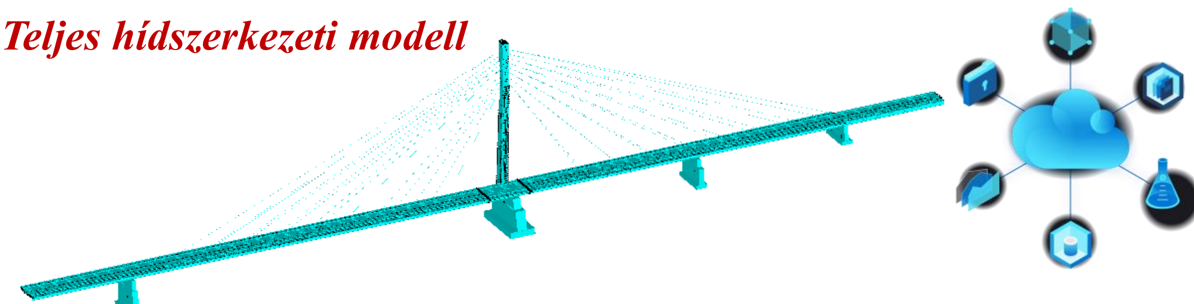
Új generációs acélhidak pontosított gyártásszimulációja

Szegmensmodell (TMM & egyszerűsített analízis)



Egyszerűsített gyártásszimulációs eljárás fejlesztés szegmensmodellre

Teljes hídszerkezeti modell



Fejlett TMM analízis nagyléptékű modellen (Cloud computing, HPC)

Numerical modelling-based design theory

Numerical modelling-based design theory

Activities linked to development process of prEN 1993-1-14 within CEN/TC250/SC3/WG22.

a, standard (code) version

↓

Mainly based on the current standard parts and added materials which are ready and validated for FE calculations and simulations.

↓

Text was written mainly based on current materials approved by all WG-s Instructions & validation & confirmation by all members of WG22 and SC3

↓

EN 1993-1-14

b, background document

↓

The document summarizes all the background informations which are currently the state-of-art for FEM-based design.

Purpose:
- collection of state-of-art results
- explanations to the code
- background for further improvements

↓

Technical Report

Scientific document based on research results

Consideration of stress concentration

Global imperfection

L/1000 + residual stresses

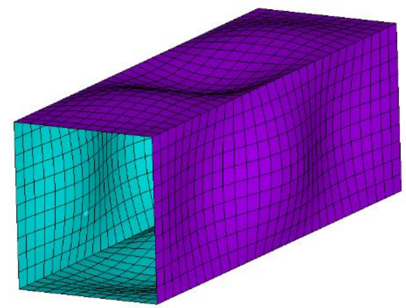
or

equivalent geometric bow imperfection

Buckling curve according to Table 6.2	elastic analysis e_0 / L	plastic analysis e_0 / L
a_0	1 / 350	1 / 300
a	1 / 300	1 / 250
b	1 / 250	1 / 200
c	1 / 200	1 / 150
d	1 / 150	1 / 100

Problem: Developed for GNIA and not GMNIA.

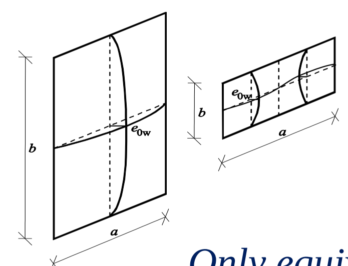
Local imperfection



no proposal

or

equivalent geometric imperfection
min(a/200; b/200)



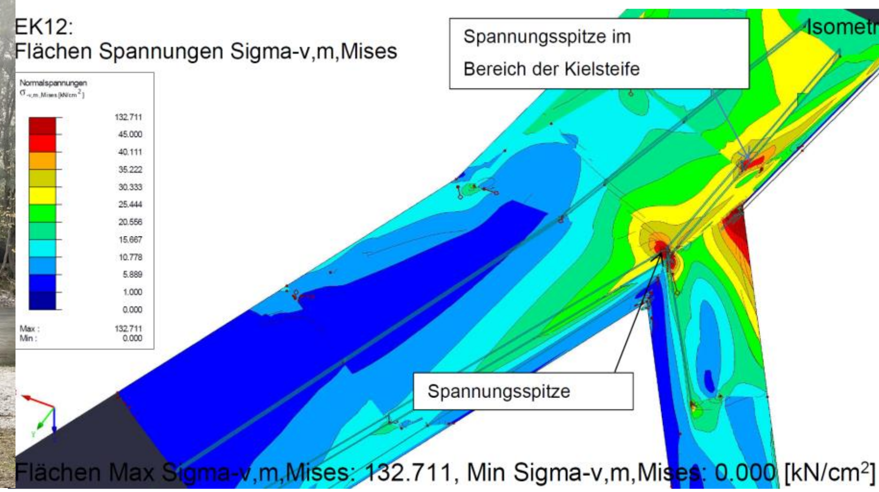
Only equivalent imperfection is developed and verified to GMNIA.

New equivalent geometric imperfections are required for GMNIA - steel grade independent (S235 – S960).

Consideration of stress concentration

Improved models → **stress concentrations** → **design methodology**

$$\sigma_{eq,Ed} \leq \frac{f_{yk}}{\gamma_{M0}} = f_{yd}$$



Differences in stress concentrations: numerical singularities → calculation errors

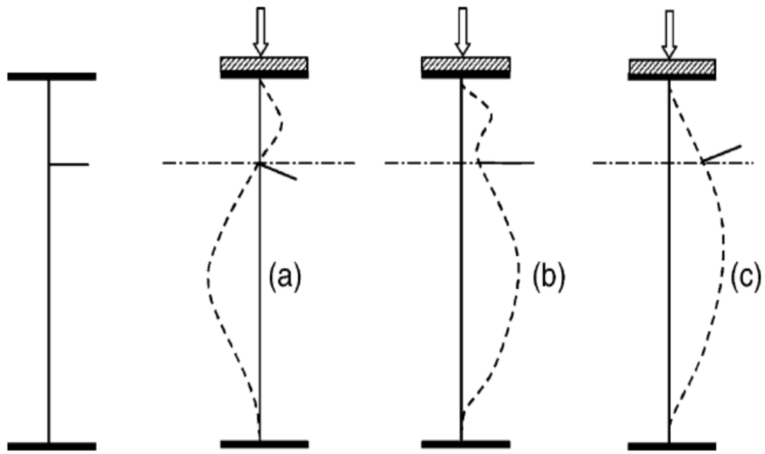
physical stress peaks → real physical properties to be considered

Research aims: *Development of separation strategies.*

Development of design criteria for stress peaks based on max. allowed elongations.

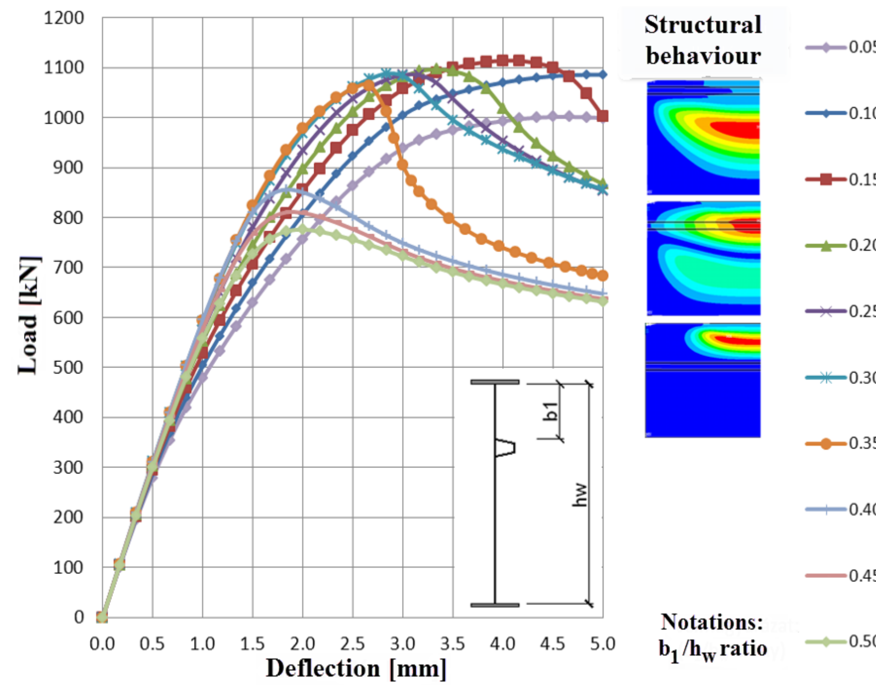
Improved patch loading resistance model

Lehetséges tönkremeneteli módok



lokális horpadás *interakció* *globális horpadás*

felső lemezmező *alsó lemezmező*



Failure mode depends on:

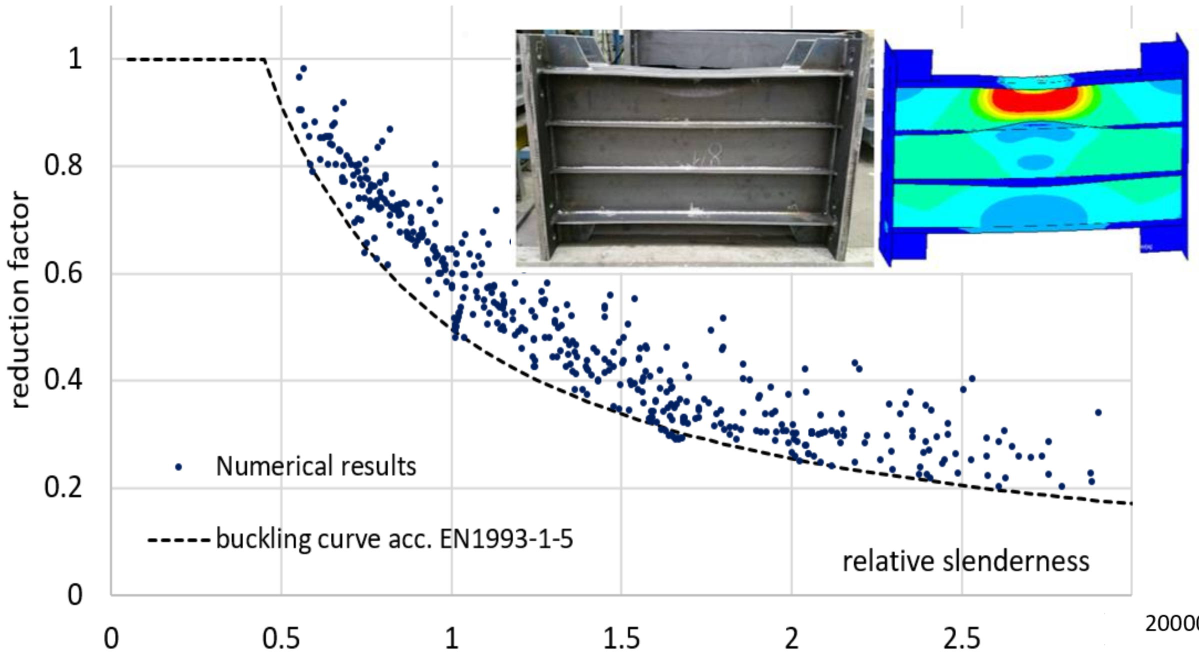
- *location of stiffener (b_1/t_w)*
- *number of stiffeners*
- *stiffener stiffness (weak/strong)*
- *loading length (s_s/b_1)*
- *web panel aspect ratios*

Design method should be able to:

- *separate failure modes (decide which one happens)*
- *follow the right trends (sometimes contradictings, e.g. stiffener location)*
- *current design method follows only one trend.*

5 different failure modes – 1 design method

Improved patch loading resistance model



Current EN 1993-1-5:2022

$$\bar{\lambda}_F = \sqrt{\frac{l_y \cdot t_w \cdot f_{yw}}{F_{cr}}}$$

$$\chi_F = \frac{1.0}{\varphi_F + \sqrt{\varphi_F^2 - \bar{\lambda}_F}} \leq 1.0$$

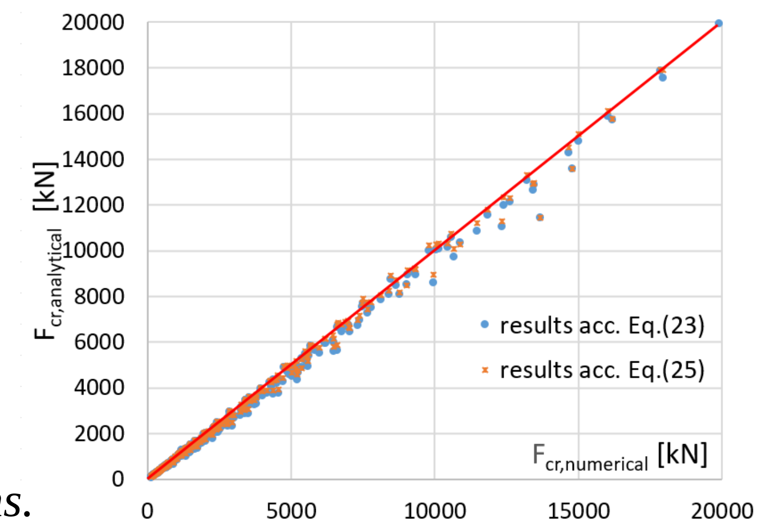
$$\varphi_F = \frac{1}{2}\left(1 + \alpha_{F0} \cdot \left(\bar{\lambda}_F - \bar{\lambda}_{F0}\right) + \bar{\lambda}_F\right)$$

$$F_{cr} = 0.9 \cdot k_F \cdot E \cdot \frac{t_w^3}{b_1}$$

$$\gamma_s \geq 13 \cdot \left(\frac{a}{h_w}\right)^3 + 210 \cdot \left(0.3 - \frac{b_1}{a}\right)$$

$k_F = 4.0 + 3.0 \cdot \frac{s_s}{b_1}$ for closed section stiffeners

$k_F = 4.0 + 2.0 \cdot \frac{s_s}{b_1}$ for open section stiffeners



Further research aim:

Generalization of the developed design equations.

Design theories for new structural solutions

Design theories for new structural solutions

Tools
- *experimental testing*
- *numerical modelling*
- *therorectical investigation*

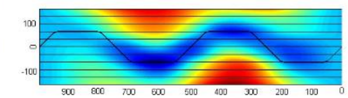
Background

M-V-F interaction resistance calculation method

B. Jáger PhD

- *interaction curve*
- *FEM-based design*

→ *new EC3-1-5*

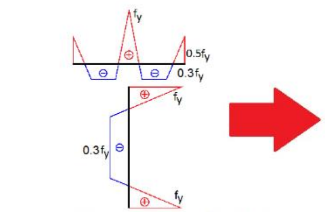


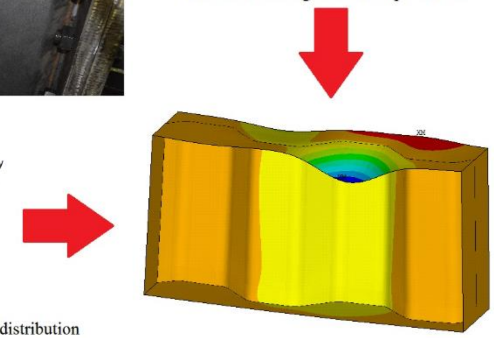
Flange buckling resistance calculation method

B. Jáger PhD

- *buckling coefficient*
- *cross-section classification*
- *buckling curve development*
- *FEM-based design*

→ *for NSS*

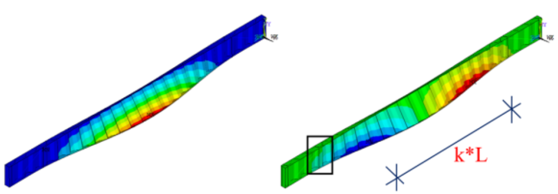


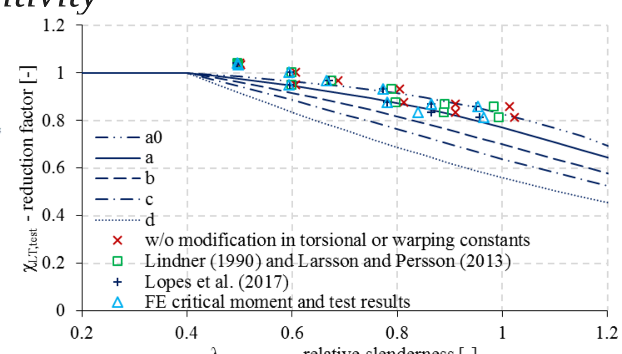


Lateral-torsional buckling resistance calculation methods

- *elastic critical moment – pure bending*
- *buckling curve*
- *imperfection sensitivity*

(?) partial answers





Design theories for new structural solutions

Problem statement - research aims

Lateral-torsional buckling resistance

- *torsional properties of corrugated web girders*
- *elastic critical moment – different boundary and loading conditions*
- *buckling curve for LTB*
- *new equivalent imperfections for FEM-based design*
- *hybrid girders with HSS flanges and NSS corrugated web*

Lack of information in the literature

Flange buckling resistance of HSS flanges

- *buckling coefficient*
- *cross-section classification*
- *buckling curve development*
- *new equivalent imperfections for FEM-based design*

Only for NSS

Combined flange buckling and lateral-torsional buckling

- *reduction effect of flange buckling on LTB strength*

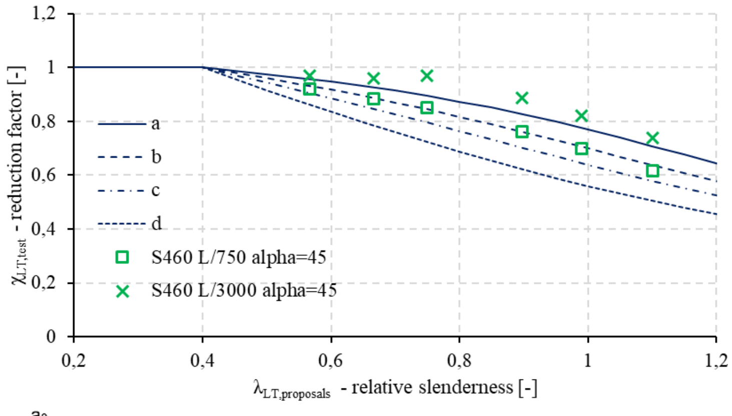
Lack of information in the literature

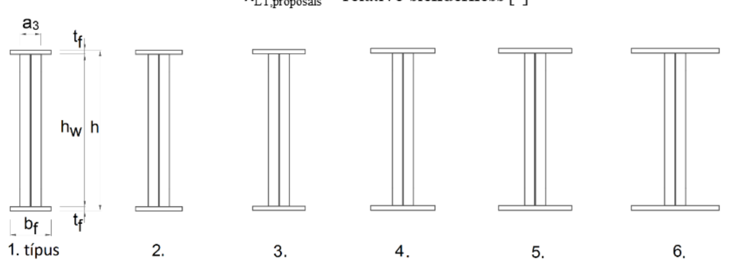
Design theories for new structural solutions

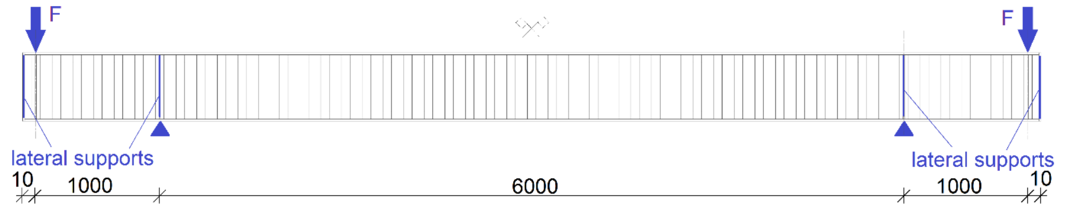
Research plan - experimental

Experimental program - design

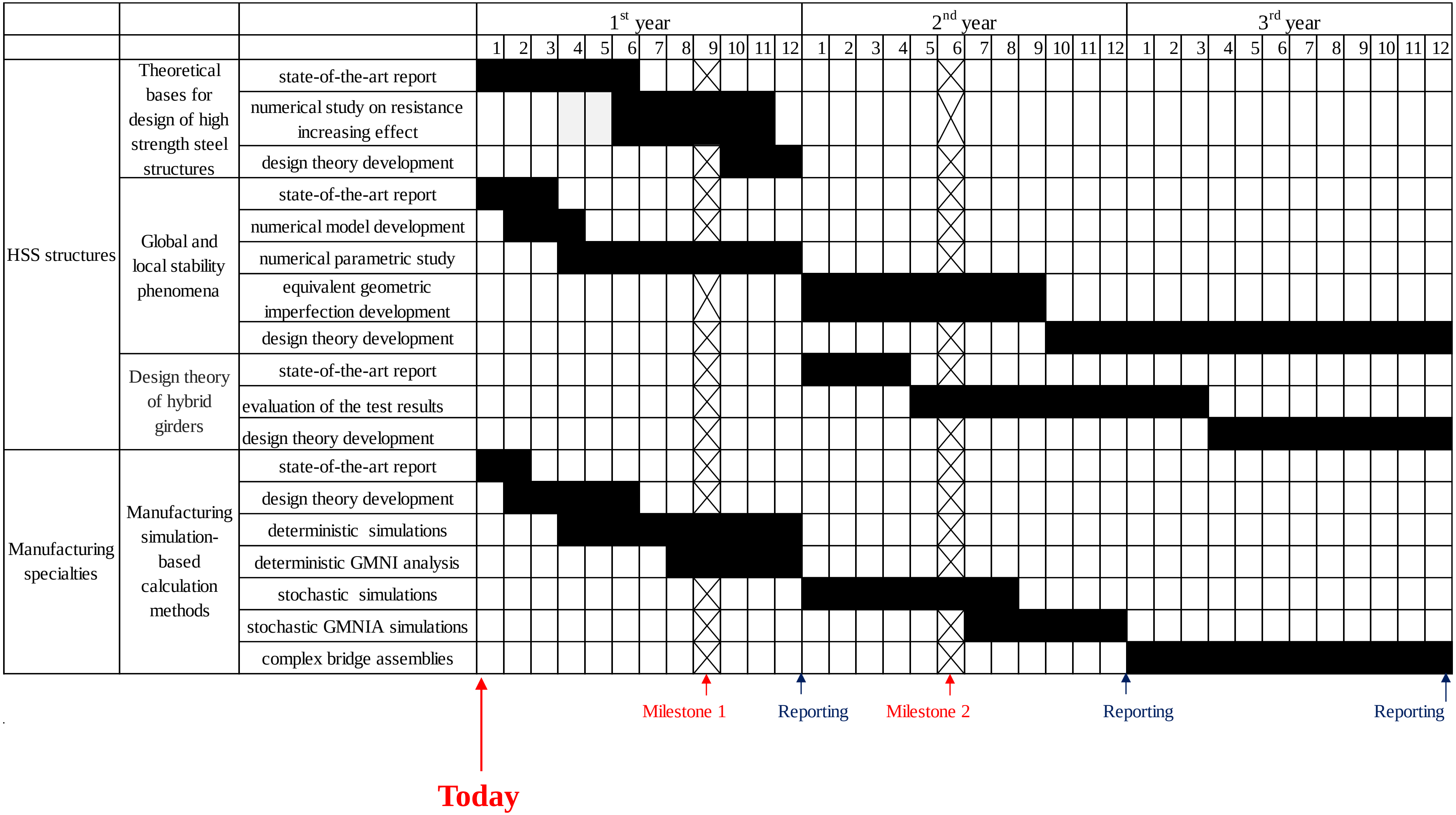
- *12 full-scale test specimens*
- *total length: 8 m*
- *steel: S235, S355, S460*
- *corrugation angle: 30-45-60 degree*
- *relative slenderness: 0.4-1.2*







Research schedule



International relations and applications

1. Design theory of high-strength steel structures

Theoretical bases for high-strength steel structures → *Application to CEN/SC3/WG12 B. Somodi*

Global and local stability phenomena of high-strength steel welded hollow sections

CEN/TC250/SC3/WG5 presentation: 28.09.2021 B. Kövesdi

Design theory for hybrid steel girders

Cooperation with University of Hasselt (H. Degée)

2. New manufacturing specialties in the design theory

Welding simulation-based numerical analysis for resistance calculation

Cooperation with University of Lisbon (J. Pedro)

3. Numerical modelling-based design theory

Design theories for steel plated structures

Interaction of column and plate-like behaviour of longitudinally stiffened plates

Cooperation with BME Department of Structural Mechanics - S. Ádány

Cooperation with University of Stuttgart

CEN/TC250/SC3/WG5 presentation: 28.09.2021 B. Kövesdi / V. Pourostad / U. Kuhlmann

FEM-based design background

CEN/TC250/SC3/WG22 presentation: 08.10.2021 B. Kövesdi / L. Dunai

Patch loading resistance

Cooperation with UPC Barcelona (R. Chacón)

Expected scientific contributions and measures

Publications:

At least 1-2 research papers within each main research fields in international scientific journals (Q1 or Q2 journals).

PhD degrees:

3 Candidates running/starting now + 1 new PhD student each year

Scientific measures – current status:

	B. Kövesdi	B. Somodi	D. Kollár	B. Jáger
Total number of scientific publications	133	26	20	36
in journal papers (Q1 / Q2)	51	11	6	14
Total Impact factor	104.86	19.46	11.33	26.32
Number of citations all/independent	574/451	166/127	40/26	213/176

Thank you for your attention!