



Advanced Structural and Wind Engineering

June 25-29, 2018

**Budapest University of Technology and Economics
Department of Structural Engineering**

Program

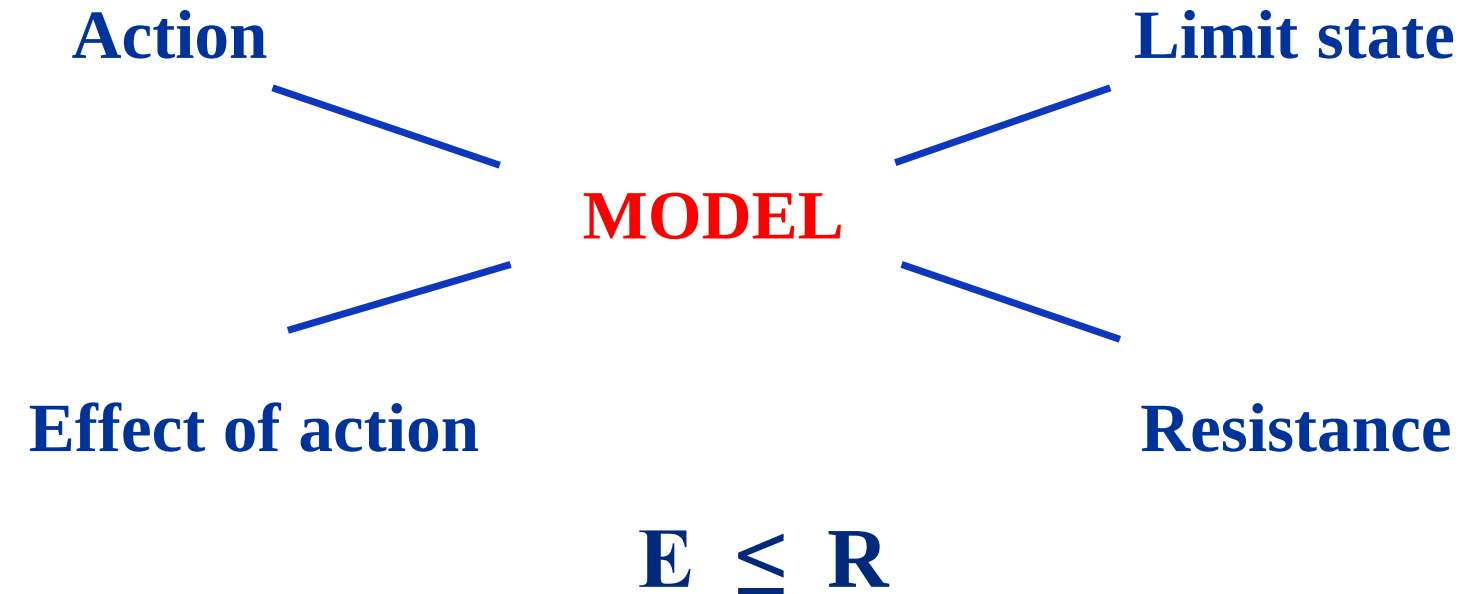
	Monday	Tuesday	Wednesday	Thursday	Friday
9:00 - 10:30	Computational structural design methodology (László Dunai)	Advanced fatigue assessment and design of bridges (Balázs Kövesdi)	Improvement methods for Eurocode based design - parametric study and test result evaluation methods (Balázs Kövesdi)	"Finite element modelling of steel structures in case of fire" (Nuno Lopez)	"GPR Application in Civil and Structural Engineering" (Damir Varevac)
10:45 - 12:15	FEM based stability design of structures - 1 (László Dunai)	Detailed fatigue assessment of a steel bridge deck system (Project work)	Design and solutions for bridge monitoring systems + loading test of bridges (Balázs Kövesdi)	"Numerical Methods for Lateral Torsional Buckling" (Matthias Kraus)	"GPR Application in Civil and Structural Engineering" (Damir Varevac)
12:15 - 13:15	Lunch	Lunch	Lunch	Lunch	Lunch
13:15 - 14:45	FEM based stability design of structures - 2. / Bridges (Balázs Kövesdi)	Project work preparation	Project work preparation	"Numerical Methods for Lateral Torsional Buckling" (Matthias Kraus)	Finalization of project work
15:00 - 16:30	Modern bridge erection methods and their improvements and modelling (Lecture)	Bridges on the Danube (László Dunai)	Project work preparation	"Numerical Methods for Lateral Torsional Buckling" (Practice)	
		Guided ship tour - bridges in Budapest (16:30 -)			

Computational structural design methodology

László Dunai

Analysis and design model

STRUCTURE



analysis model $\leftrightarrow$ **design model**

Model uncertainties

E

Action characteristic value? γ_f

Effect of action model? γ_{sd}



γ_F

$$E_d = \gamma_F \cdot E_k$$

R

Material properties char. value? γ_m

Resistance model? γ_{Rd}



γ_M

$$R_d = \frac{R_k}{\gamma_M}$$



Compatibility of models

analysis model  design model



E_d



R_d

Traditional design methodology

simple model – linear analysis

**„hand calculation” ➡ behaviour characteristics
physical background ?**

limit state – resistance: EXPERIMENT



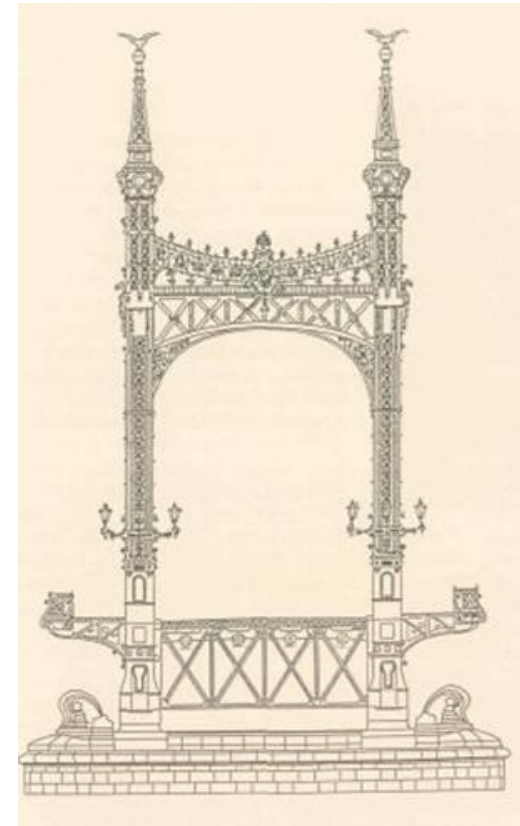
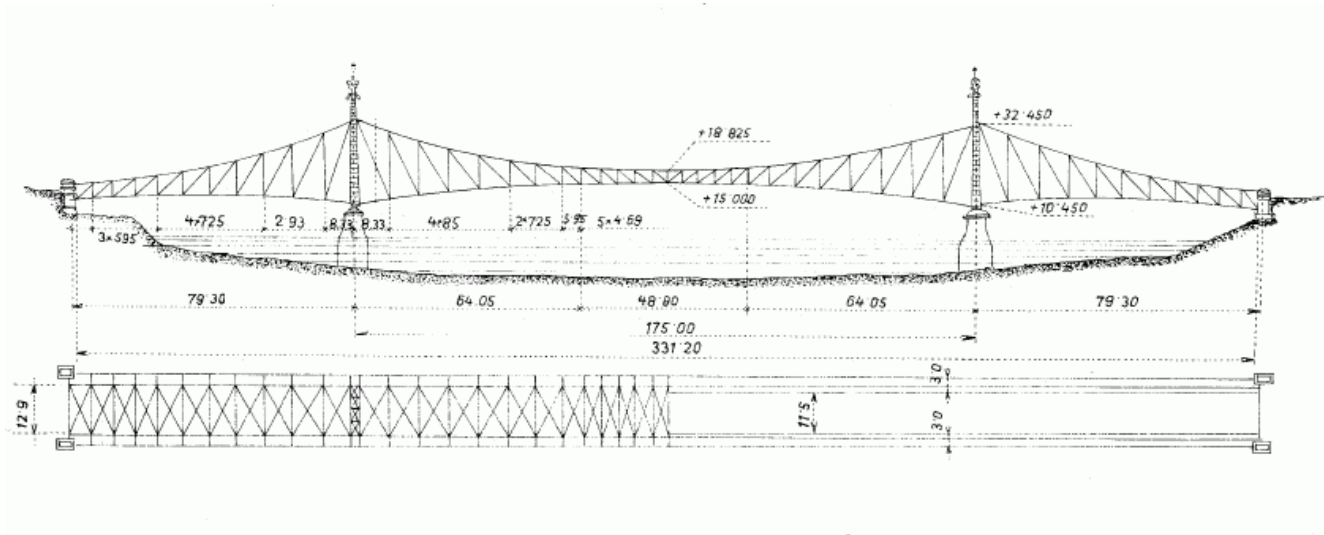
**semi-empirical curves/surfaces
yield, fracture, buckling, fatigue**

Liberty bridge

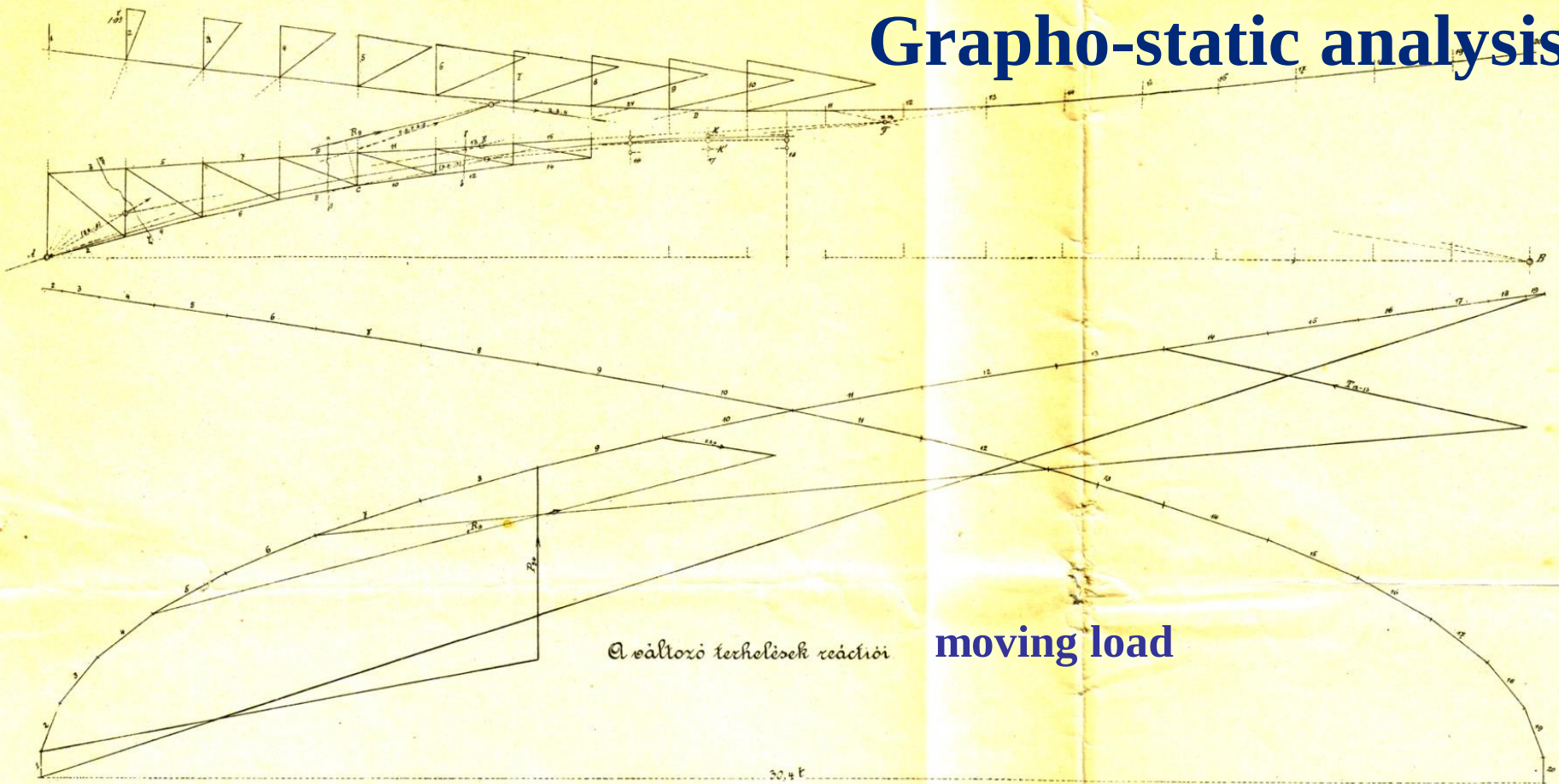


Original design 1893 → hierarchical structural system

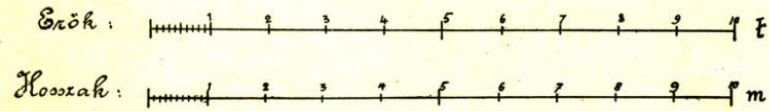
main girder/plane truss – cross-beam/truss – stringer/truss-plate girder – deck



Grapho-static analysis



moving load

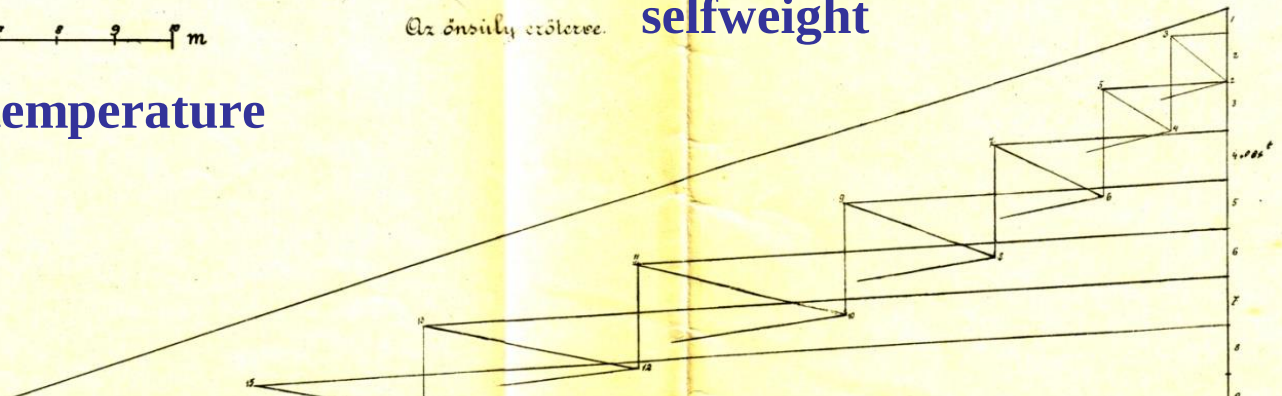
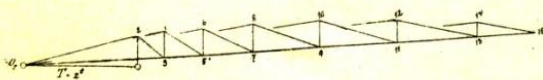


selfweight

temperature

A hőmérséklet változása által ébresztett belső erők.

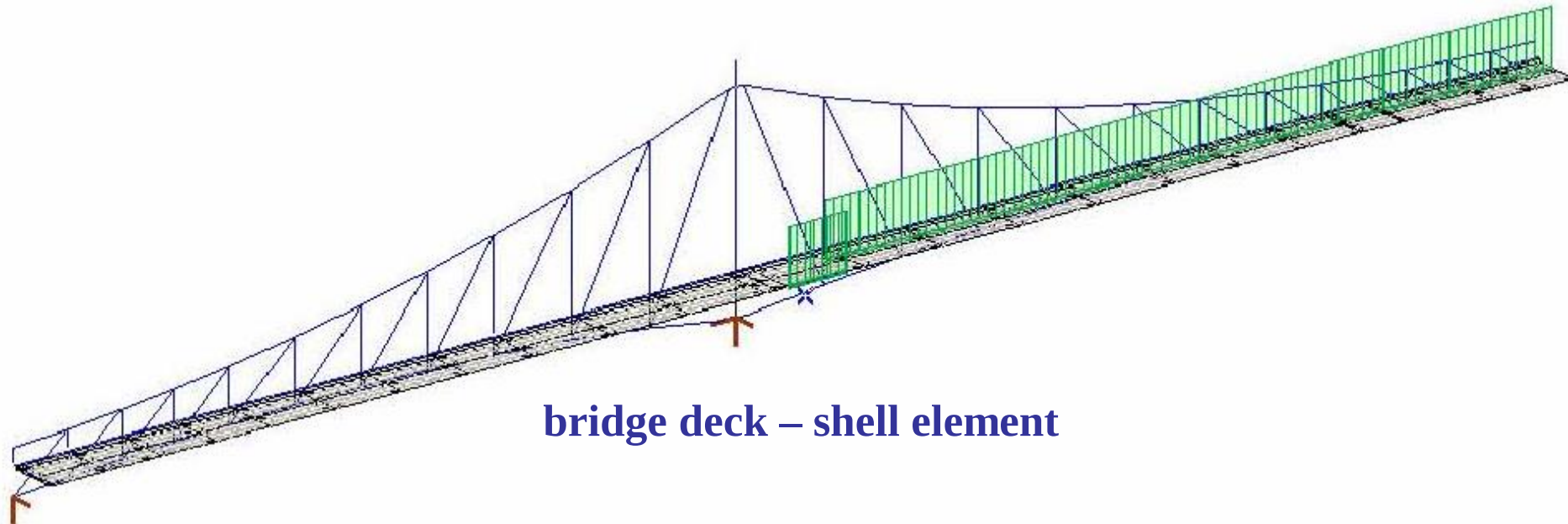
$$t = \pm 35^\circ$$



Reconstruction 2007 → integrated structural system

main girder/plane truss – cross-beam + composite stringer + deck

main truss – 3D beam element

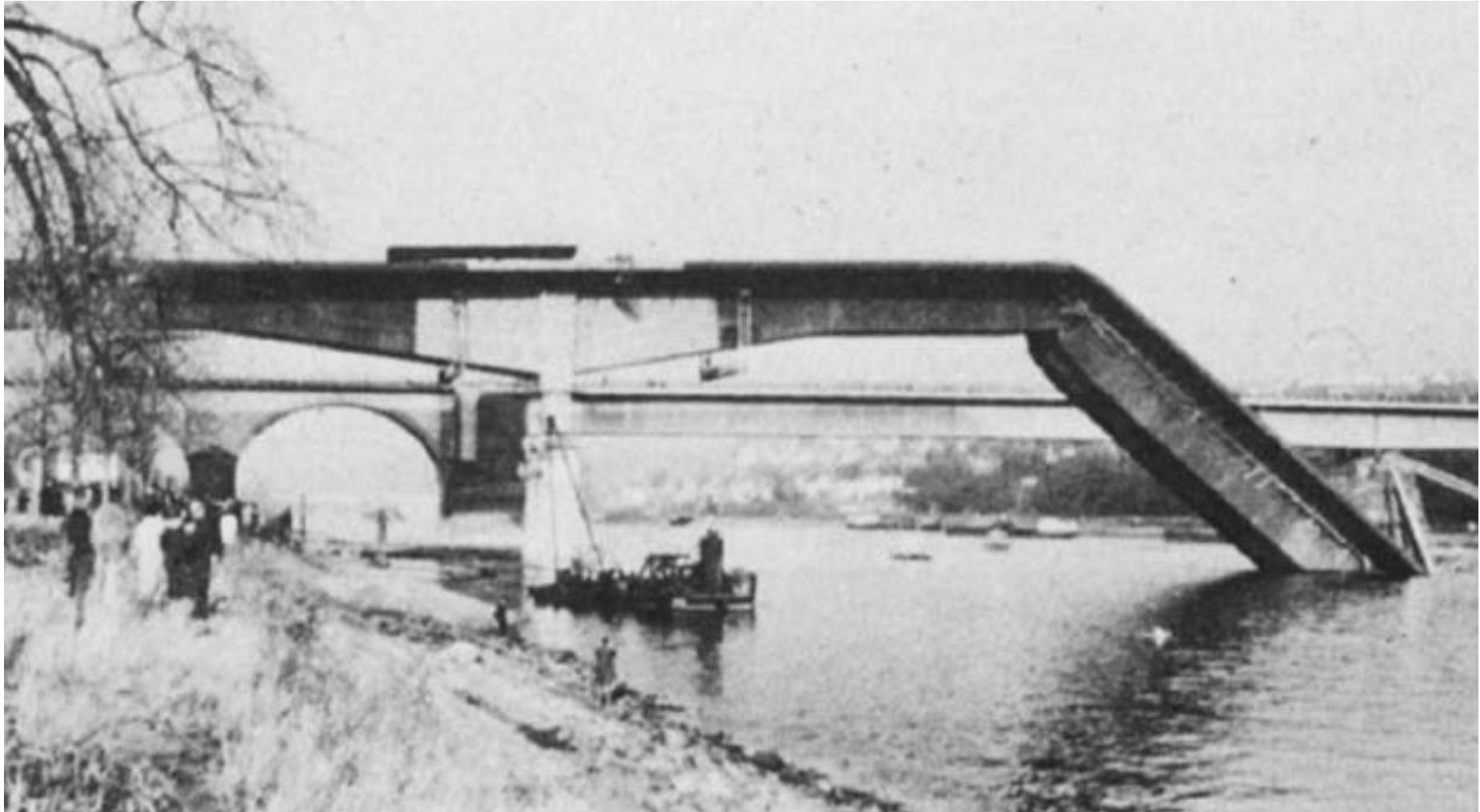


bridge deck – shell element

INTEGRATED STRUCTURAL SYSTEM



COLLAPSES OF BOX GIRDER BRIDGES – 1969-71



Steel structural innovation 1980-

Structure



material
thin-walled products
fabrication/erection technology

Behaviour



novel behavioural mechanisms
ultimate failure modes
complex interaction phenomena

Design

constructional principles
structural modeling
computational analysis and design

Paradigm changes in methodology

Modeling

- „calculable structure” $\leftrightarrow$ novel constructions
- structural model $\leftrightarrow$ numerical model
- action model $\leftrightarrow$ resistance model

Analysis

- hand calculation $\leftrightarrow$ computational analysis
- linear $\leftrightarrow$ nonlinear analysis
- real $\leftrightarrow$ virtual experiment

Design

- traditional methods $\leftrightarrow$ computational analysis
- traditional methods $\leftrightarrow$ novel behavioural modes
- global $\leftrightarrow$ local design methodology

Paradigm changes in methodology

Modeling

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Analízis

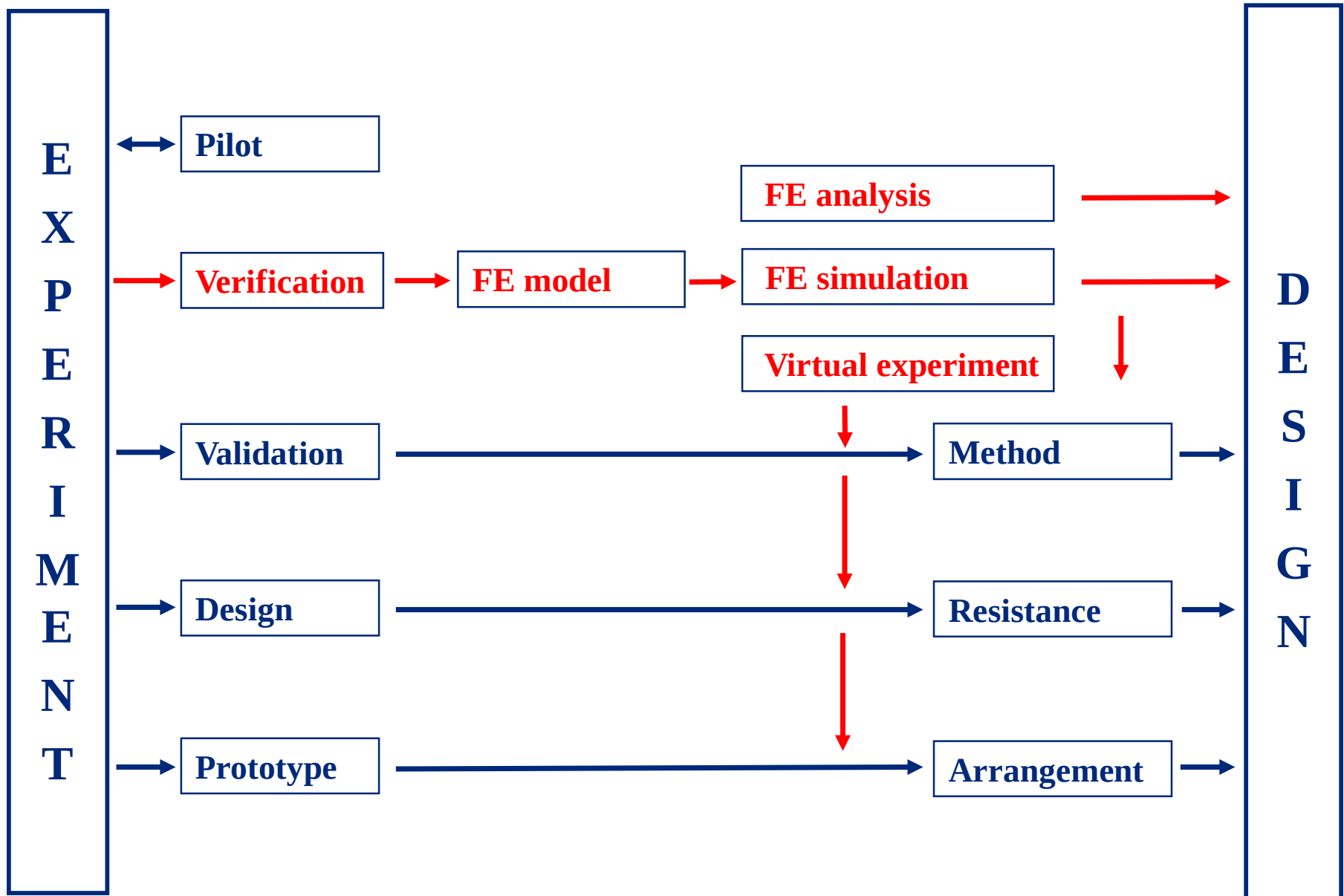
- hand calculation $\leftrightarrow$ computational analysis
- linear $\leftrightarrow$ nonlinear analysis
- real $\leftrightarrow$ virtual experiment

Design

- traditional methods $\leftrightarrow$ computational analysis
- traditional methods $\leftrightarrow$ novel behavioural modes
- global $\leftrightarrow$ local design methodology

... contradictions ... surprises ... disputes ...

Advanced research/design methodology

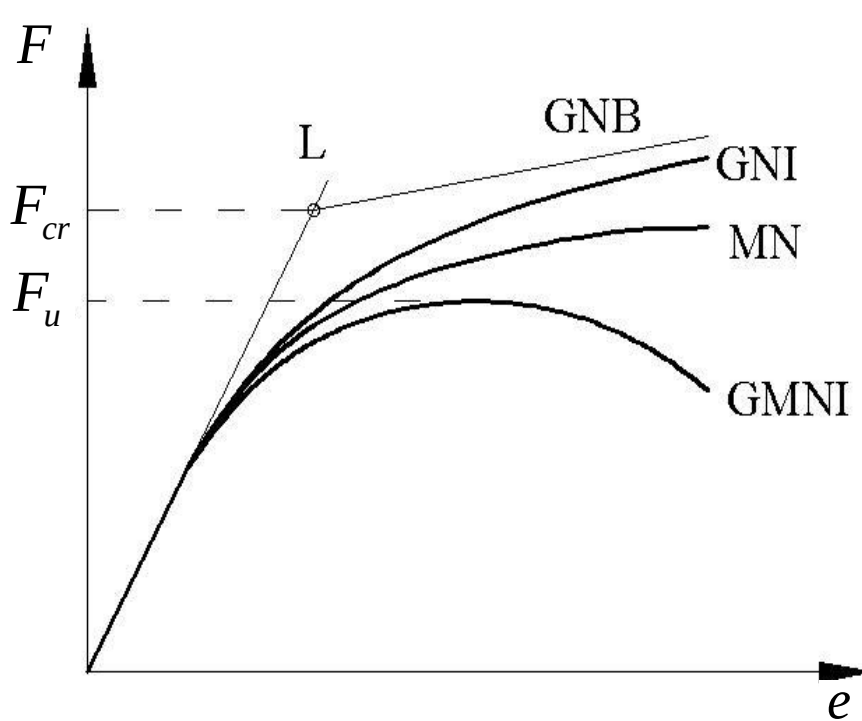


Model – analysis – design

structure $\Rightarrow$ statical model $\Rightarrow$ numerical model

statical behaviour

numerical method



computational analysis



design

Models

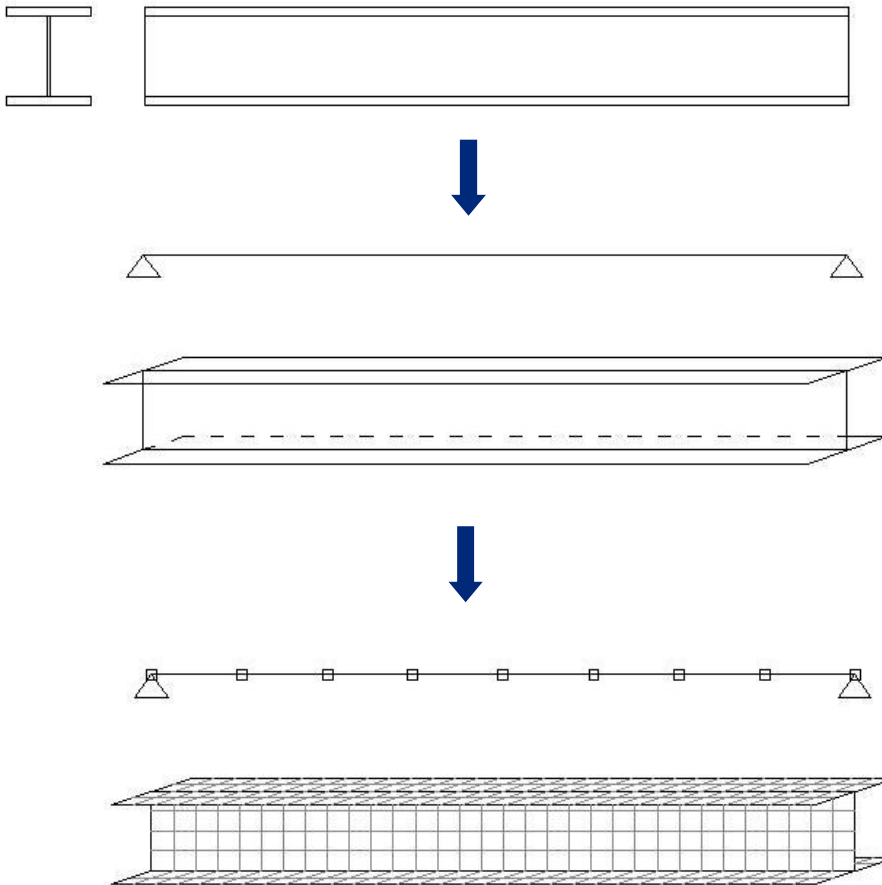
Geometrical ~

Support ~

Material ~

Load ~

Geometrical models



structure

statical model

beam

surface

numerical model

beam

shell, solid

VEM analysis – accuracy

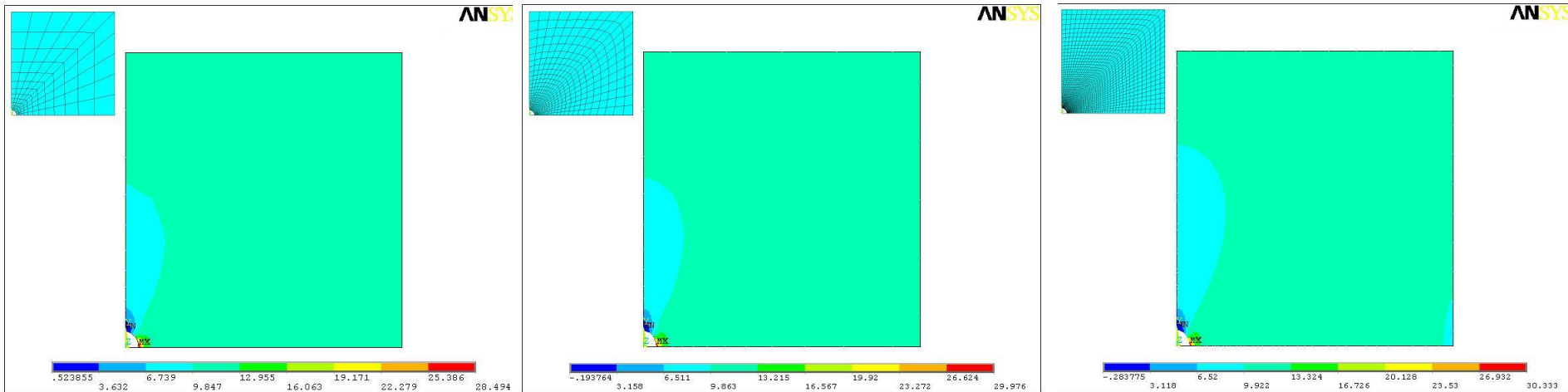
reduction of element size – accuracy – convergence!

number of unknowns increasing – hardware capacity



efficiency

Mathematical and engineering accuracy!



FEM development

- 1950~** intuitive – rigid element, spring connections
- 1960~** Zienkiewicz
functional analysis, university programs
- 1980~** FEM software available on mainframe computers
- 1990~** personal computers: spreading application
- 2000~** FEM „black box”; interface development:
 - CAD links
 - design modules
 - practical application

FEM software

**General purpose programs: ABAQUS, ANSYS, COSMOS,
LUSAS, MARC, NASTRAN, ...**

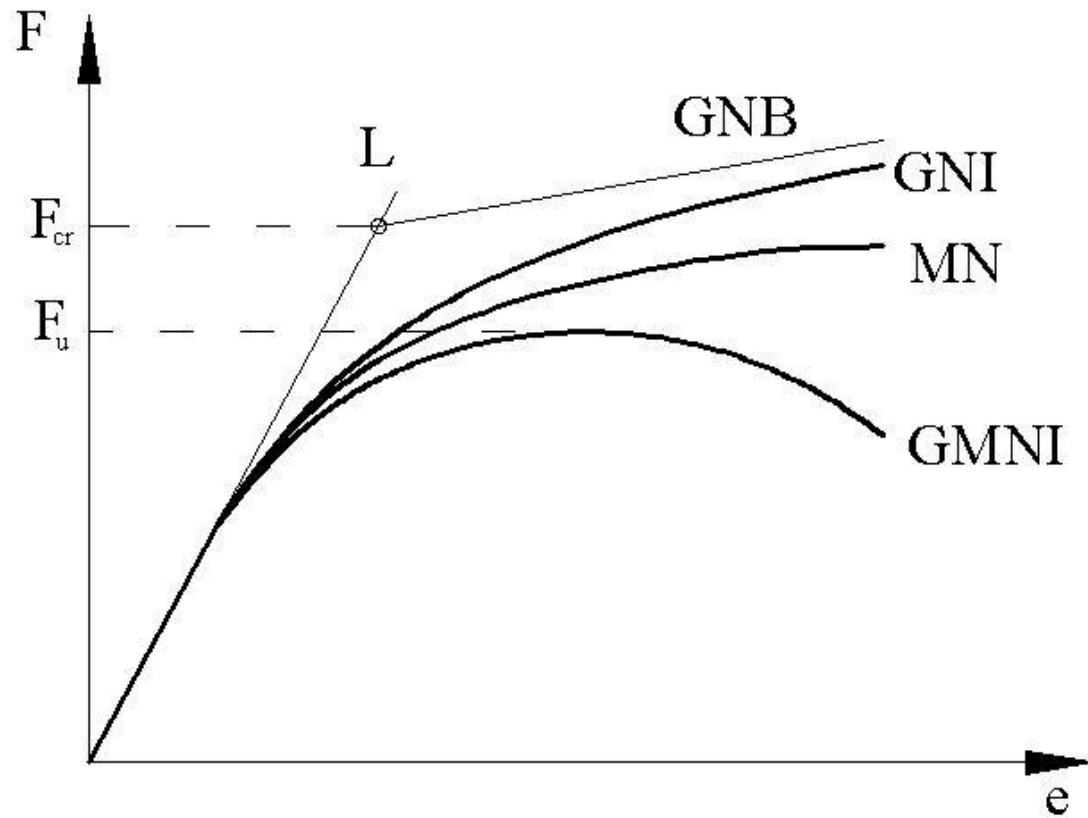
**Structural engineering task programs: analysis + design
AXIS, CONSTEEL, FEM-Design,
RSTAB, SOFISTIK, TDV, Midas, ...**



Link to CAD programs

AutoCAD, BOCAD, TEKLA, ...

Computational analysis – design



L – linear

**GNB – geometrically nonlinear
buckling**

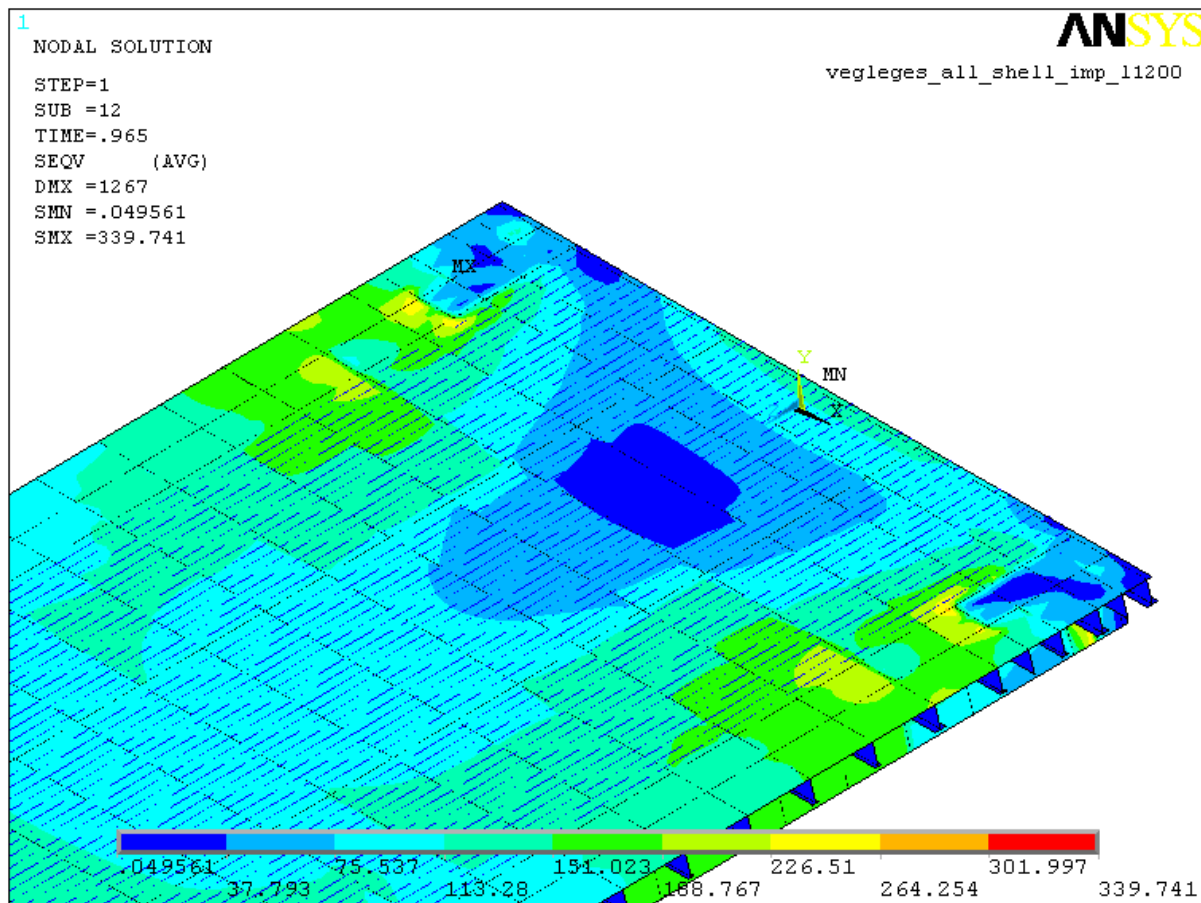
**GNI – geometrically nonlinear
second-order**

MN – material nonlinear

**GMNI – geom. and material
nonlinear, imperfect**

L analysis ↔ design

shell FE model: shear-lag



L analysis ↔ design

stress concentration

strength limit state

- elastic design?

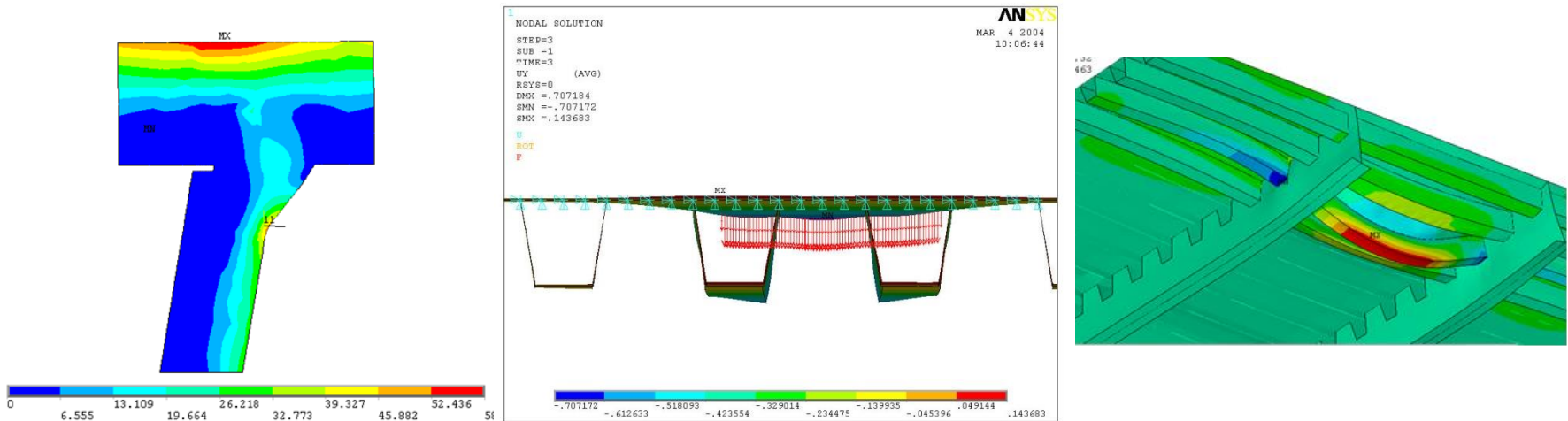
- plastic design?

fatigue limit state

- nominal stress

- geometrical stress (hot-spot stress)

- notch stress



GNB analysis ↔ design

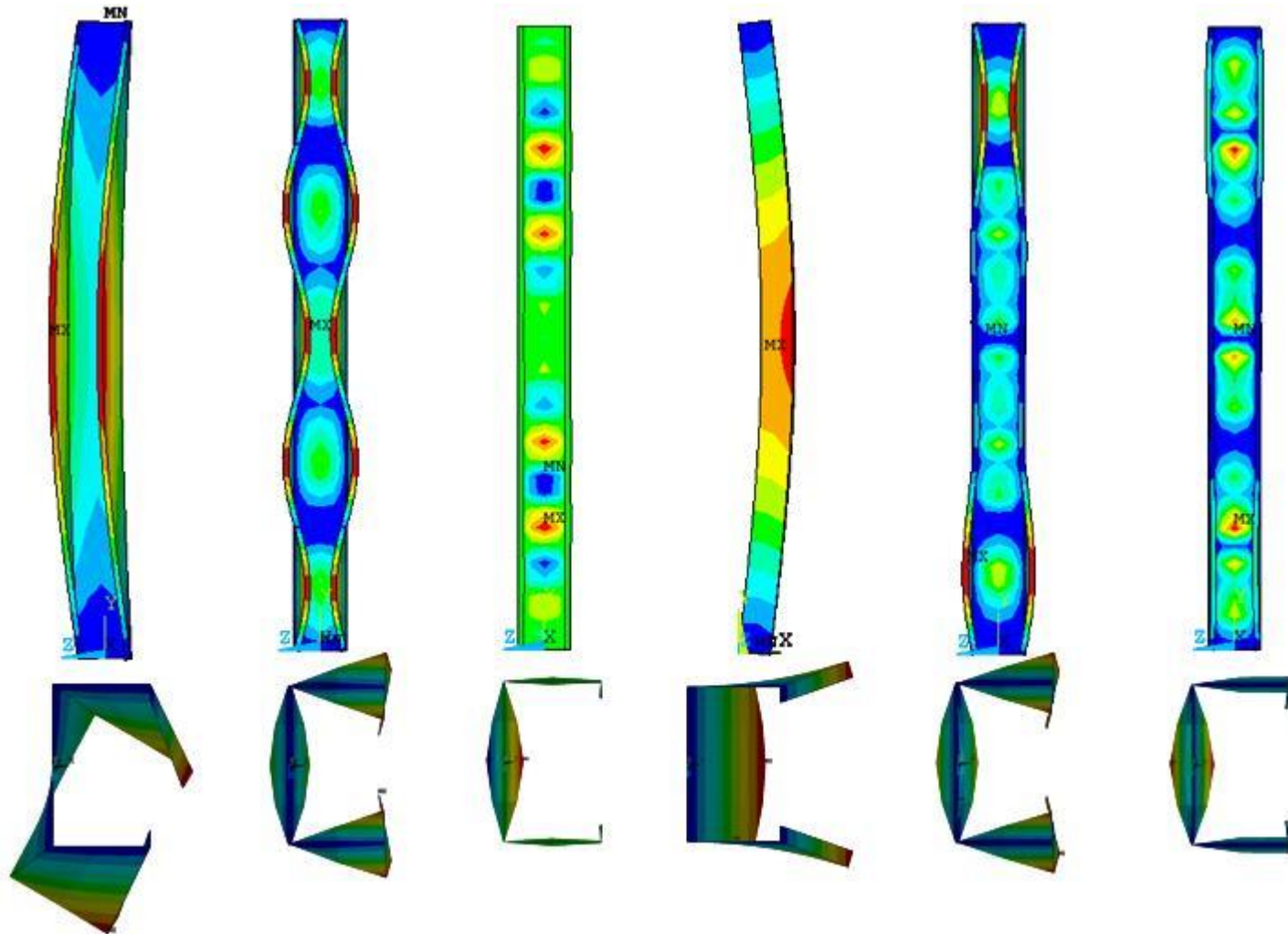
GNB — bifurcation stability limit state

$$\begin{array}{c} \downarrow \\ \sigma_{cr} \end{array} \rightarrow \bar{\lambda} = \sqrt{\frac{f_y}{\sigma_{cr}}} \rightarrow \chi$$

reduction factor method

advanced model $\textcircled{\sigma_{cr}}$ — interpretation?

GNB analysis ↔ design



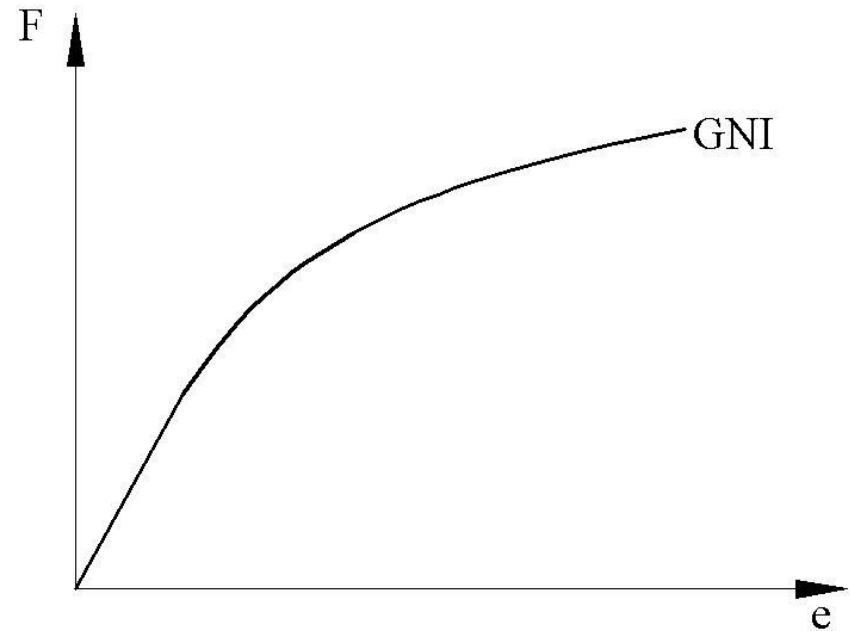
GNI analysis $\leftrightarrow$ design

GNI — second order analysis + equivalent imperfections



second order internal forces

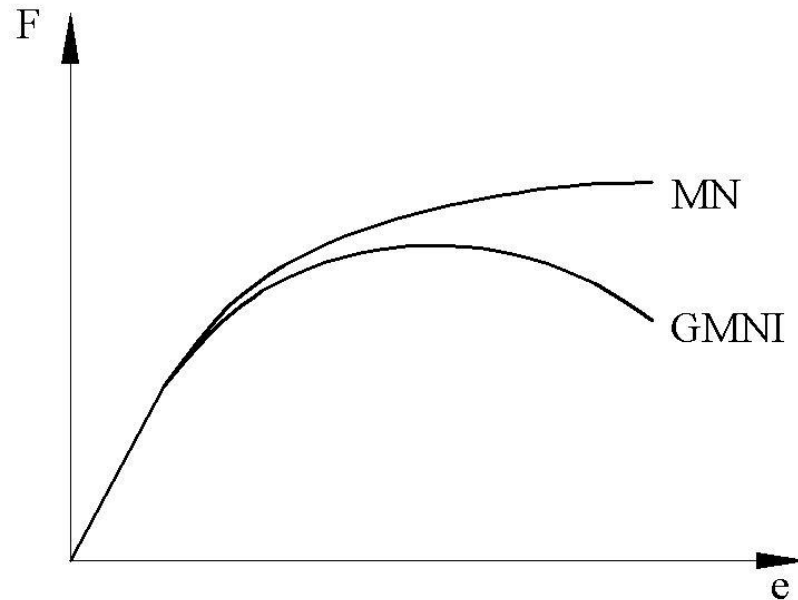
**stability $\leftrightarrow$ strength
limit state**



MN analysis ↔ design

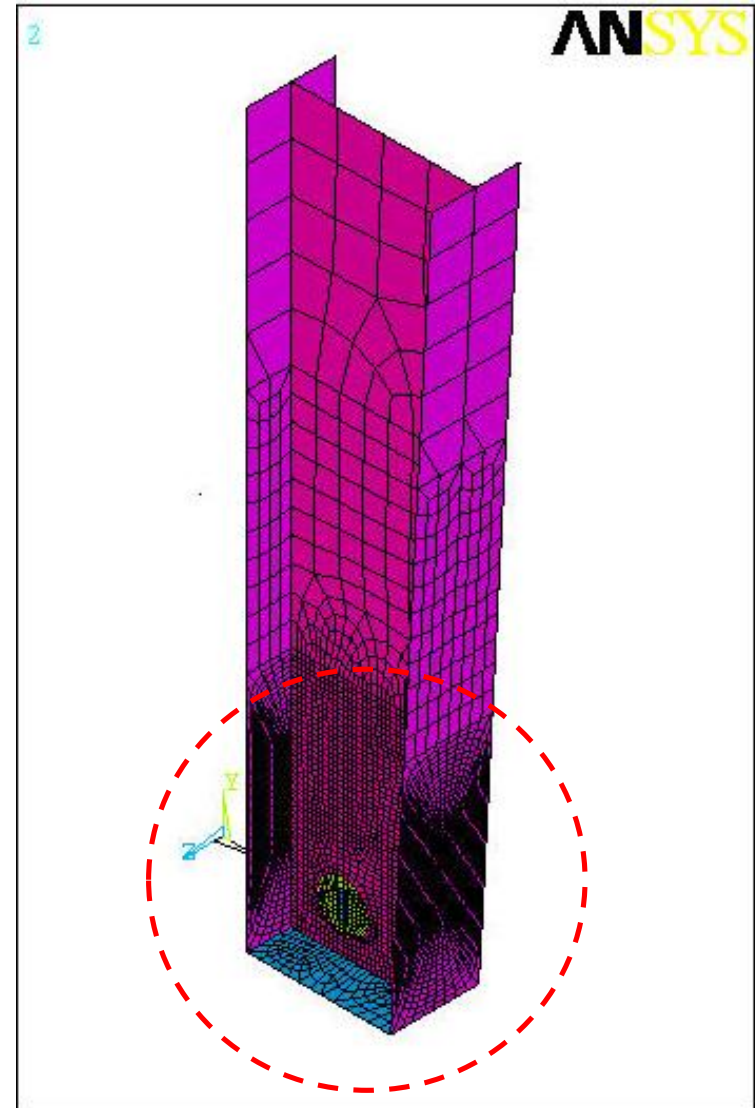
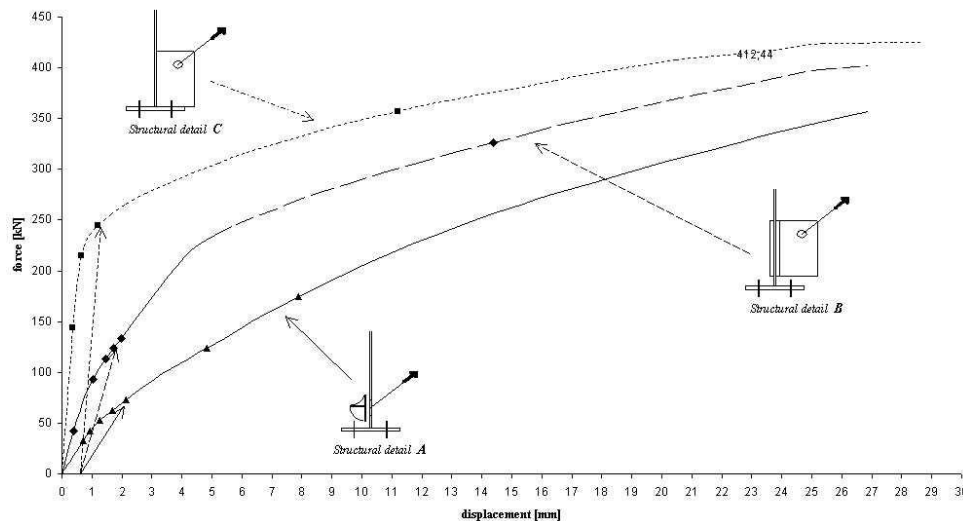
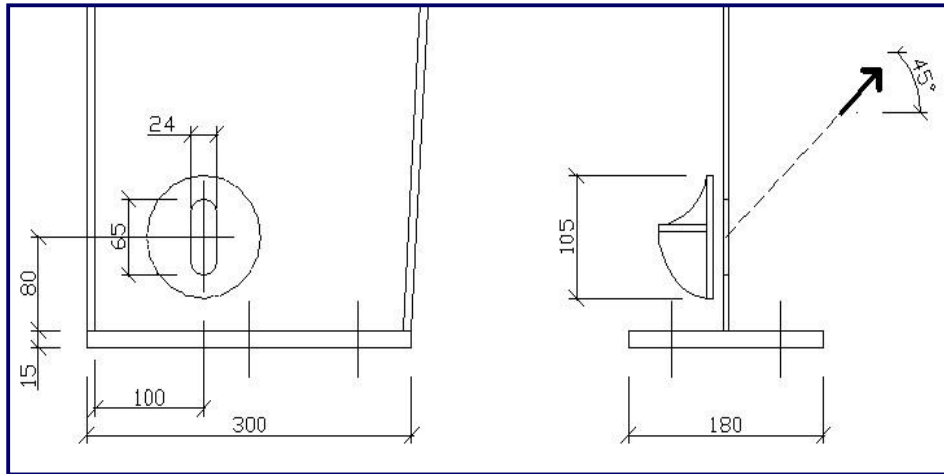
Beam model plastic design

Advanced model interpretation of plastic limit state ?



MN analysis ↔ design

Frame – bracing rod detail #1



GMNI analysis ↔ design

GMNI geometrical model + geometrical imperfections

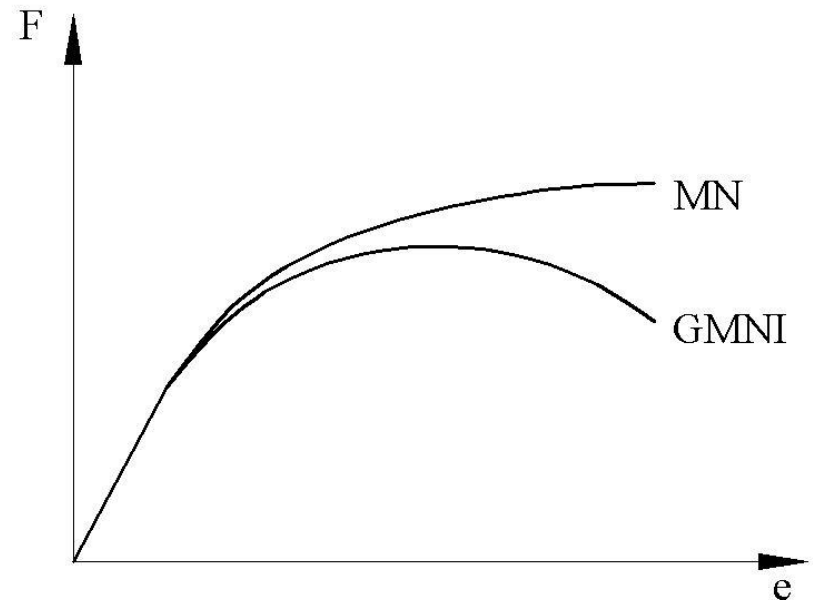


geometrical and material nonlinear analysis

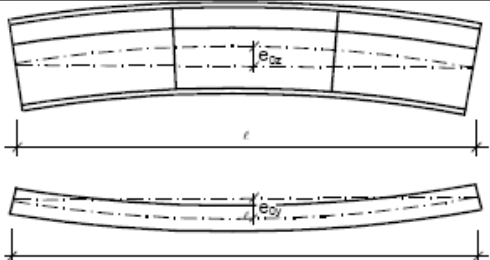
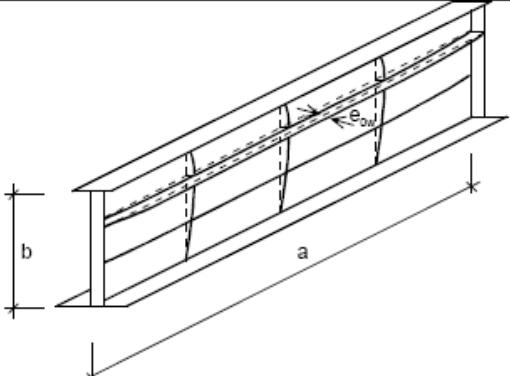


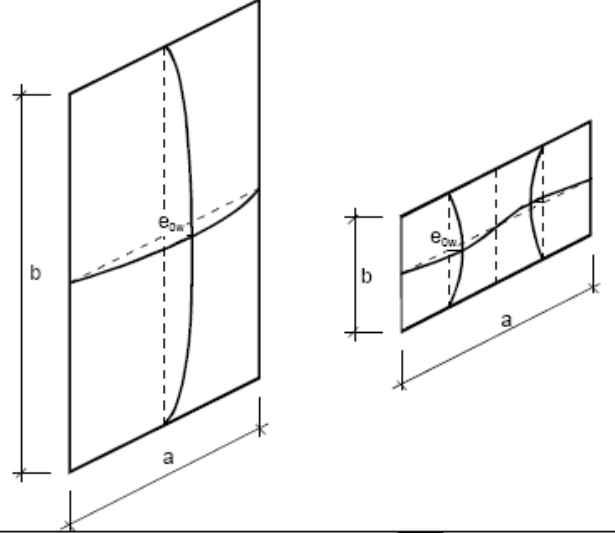
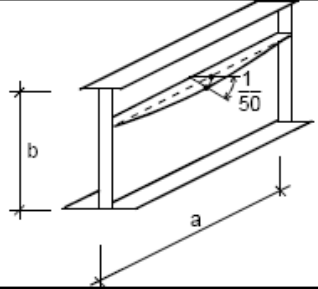
structural behaviour

FEM simulation

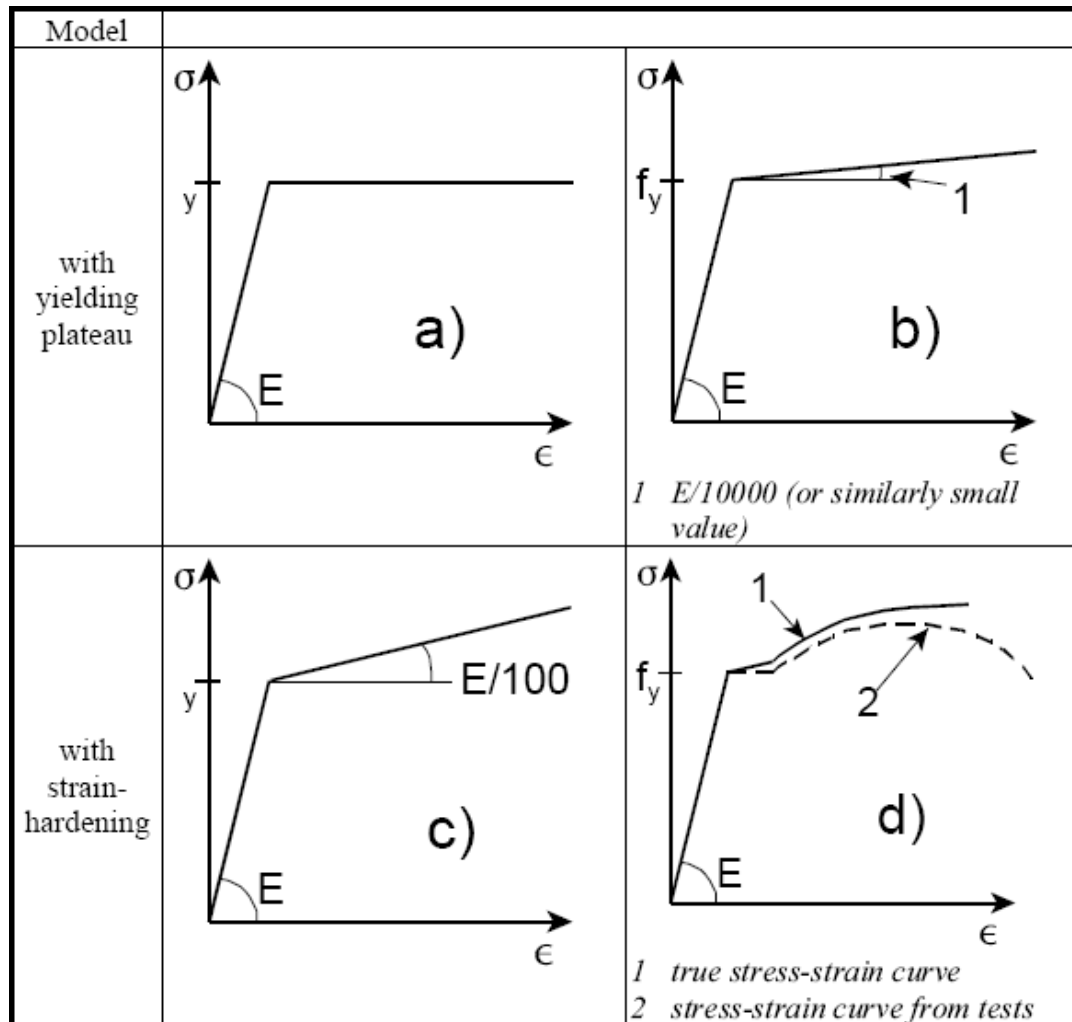


Plated structure – imperfection

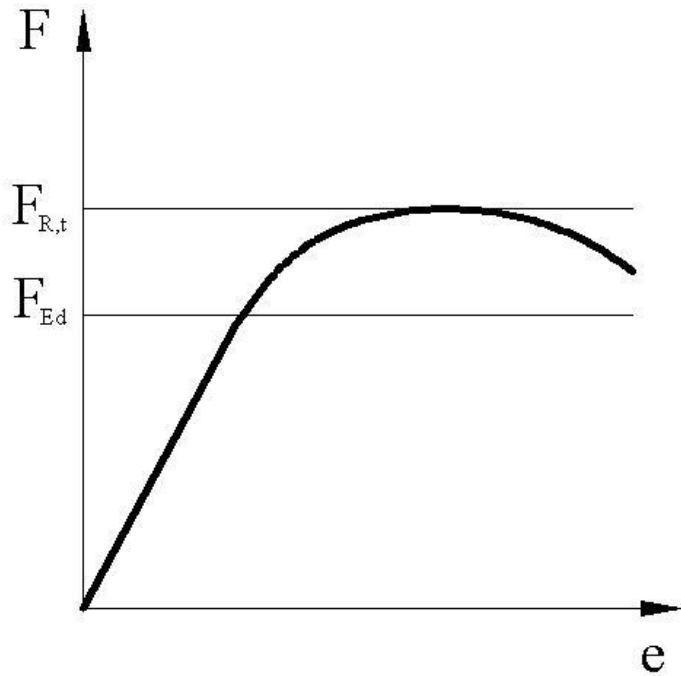
Type of imperfection	Component
global member with length ℓ	 The diagram shows two views of a global member of length ℓ. The top view shows a curved member with an imperfection e_{α} (curvature). The bottom view shows a twisted member with an imperfection e_{β} (twist).
global longitudinal stiffener with length a	 The diagram shows a global longitudinal stiffener of length a and height b. It illustrates an imperfection e_{α} (curvature) along its length.

local panel or subpanel	 The diagram shows a local panel or subpanel of length a and height b. It illustrates two types of imperfections: e_{α} (curvature) and e_{β} (twist).
local stiffener or flange subject to twist	 The diagram shows a local stiffener or flange of length a and height b. It illustrates an imperfection of $\frac{1}{50}$ (twist) along its length.

Standardized material model



FEM simulation – result



Design load F_{Ed}

Ultimate load by simulation $F_{R,t}$

$$\alpha_u = \frac{F_{R,t}}{F_{Ed}}$$

Safety against failure

$$\alpha_u \geq \alpha_1 \cdot \alpha_2$$

Reliability - accuracy of model

α_1

- failure mode

α_2

Test based design

Real geometrical imperfections
 residual stresses
 material properties



GMNI analysis – VIRTUAL experiment



test based design



Conclusions

- **Results of advanced models --- traditional design methods?**
- **Advanced computational models – verification**
- **Application: knowledge and experience – numerical modeling and analysis.**
- **Research and standardization: computational analysis and design methods of Eurocode**

Standardization

Eurocode 3 – new generation 2020

Verification by Finite Elements CEN/TC 250/SC 3/AHG

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Cornelia D-Stavridis (GB), Adam Jan Sadowski (GB)



EN 1993-1-14 Design assisted by finite element analysis

PhD course program

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		Guided ship tour - bridges in Budapest (16:30 -)			

Thank you for your attention!