

# **Advanced Structural and Wind Engineering**

**June 26-30, 2017**

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



# Program

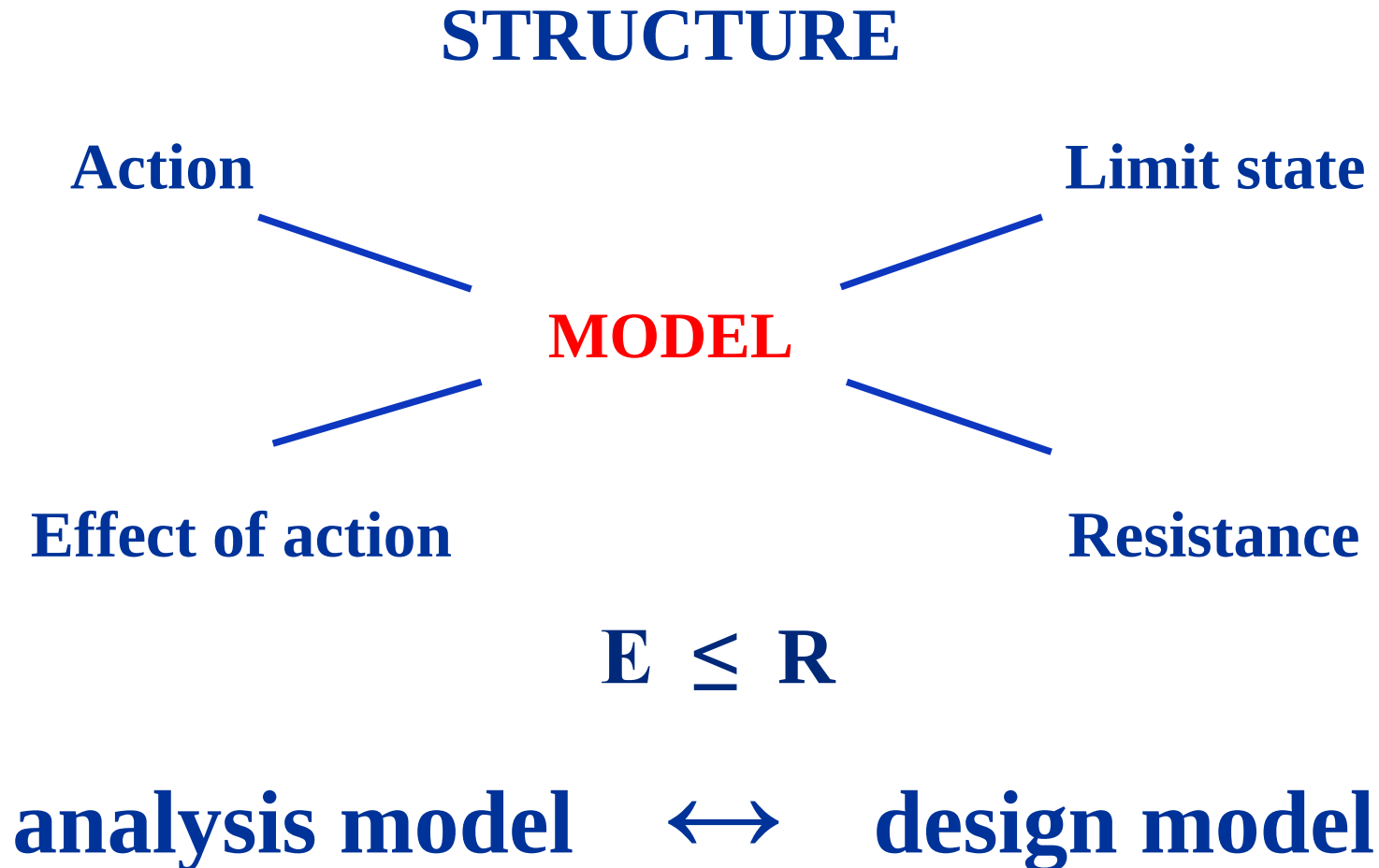
|               | Monday                                                                        | Tuesday                                                                                            | Wednesday                                                                                             | 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 evaluation (Balázs Kövesdi) | Lecture (Prof. Morgenthal)                                                    | Advanced techniques for fabrication simulations - Welding simulation (Néző J.)       |
| 10:45 - 12:15 | FEM based stability design of structures - 1 (László Dunai)                   | Finite element modelling of cold formed steel members in fire situation (Nuno Lopez)               | Design and solutions for bridge monitoring systems + loading test of bridges (Balázs Kövesdi)         | Lecture (Prof. Morgenthal)                                                    | Modelling of the people induced vibrations of structures and vice versa (Uni Osijek) |
| 12:15 - 13:15 | Lunch                                                                         | Lunch                                                                                              | Lunch                                                                                                 | Lunch                                                                         | Lunch                                                                                |
| 13:15 - 14:45 | FEM based stability design of structures - 2. / Bridges (Balázs Kövesdi)      | Fatigue assessment of a steel bridge deck - evaluation of measured database - (Project work pres.) | Project work preparation                                                                              | Lecture (Tajammal Abbas)                                                      | Presentation of project work                                                         |
| 15:00 - 16:30 | Modern bridge erection methods and their improvements and modelling (Lecture) | Bridges on the Danube (László Dunai)<br><br>Guided ship tour - bridges in Budapest                 | Project work preparation                                                                              | Finite element technologies for nonlinear solids and structures (Jose Korlec) |                                                                                      |



# **Computational structural design methodology**

**László Dunai**

# Analysis and design model



# Model uncertainties

**E**

Action characteristic value?  $\gamma_f$

Effect of action model?  $\gamma_{sd}$

 $\gamma_F$ 

$$E_d = \gamma_F \cdot E_k$$

**R**

Material properties char. value?  $\gamma_m$

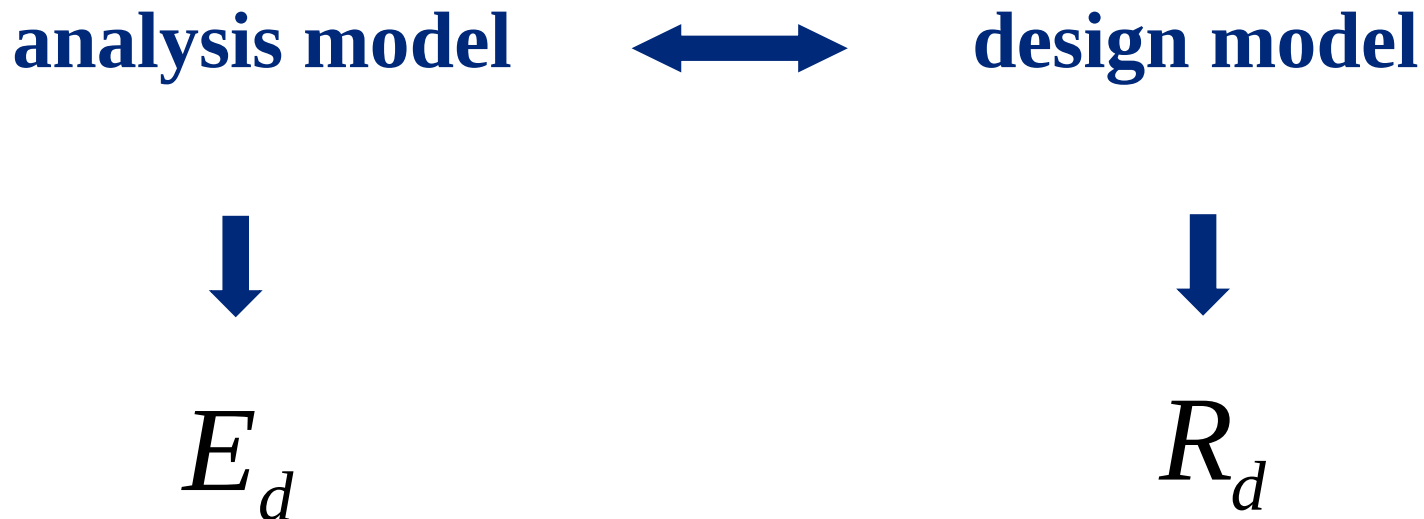
Resistance model?  $\gamma_{Rd}$

 $\gamma_M$ 

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



# Compatibility of models



# 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**

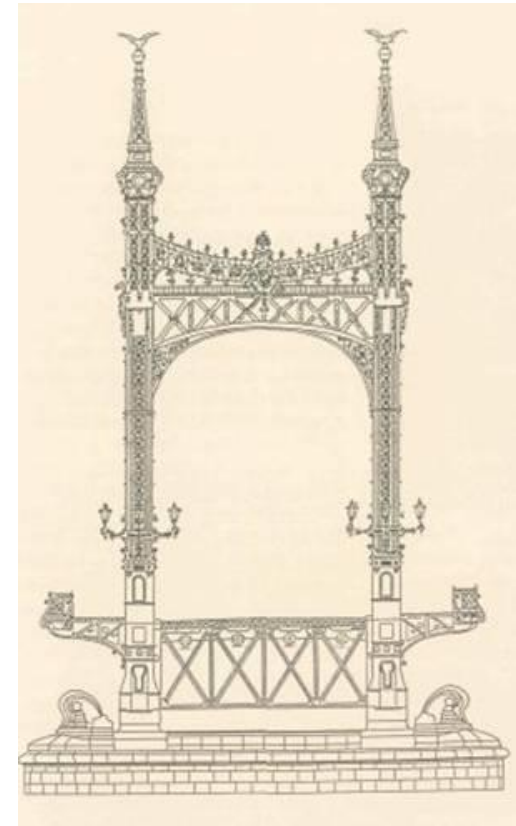
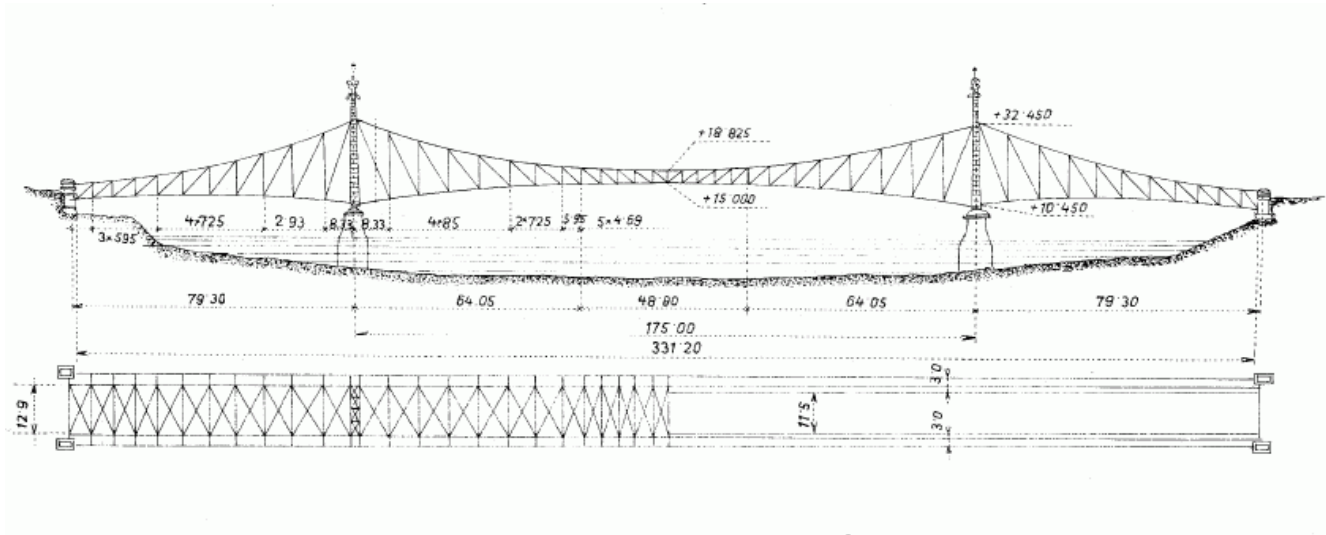


# Liberty bridge

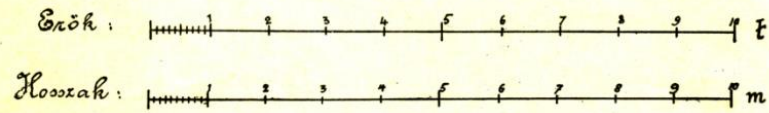
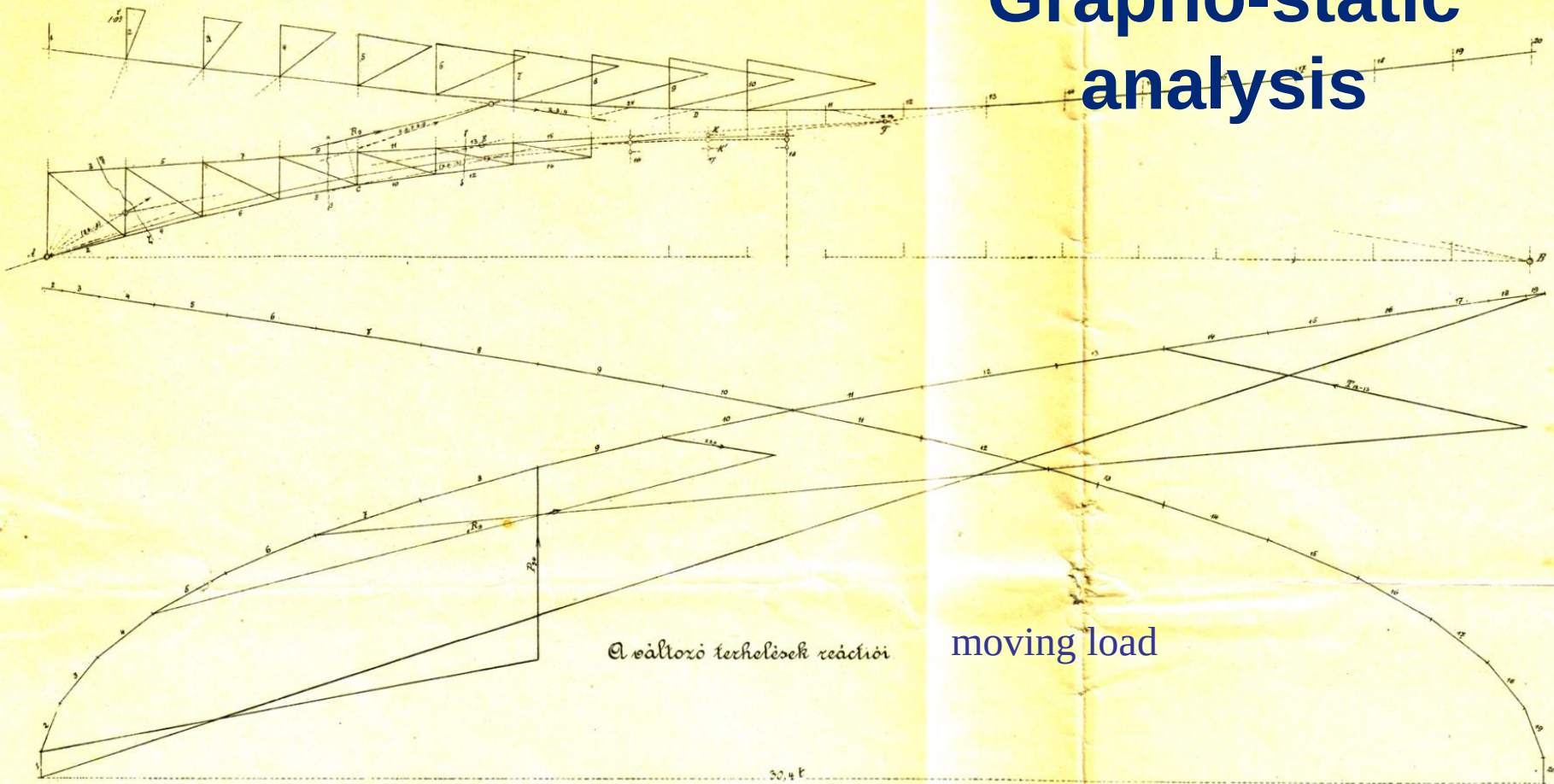


# Original design 1893 → hierarchical structural system

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



# Grapho-static analysis



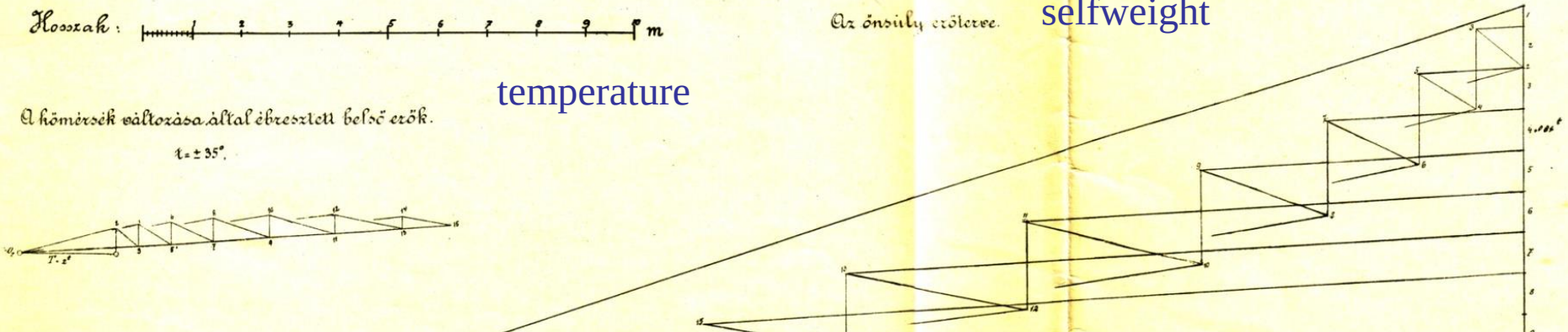
A hőmérséklet változása által ébresztett belső erők.

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

temperature

Az önsúly erőterve.

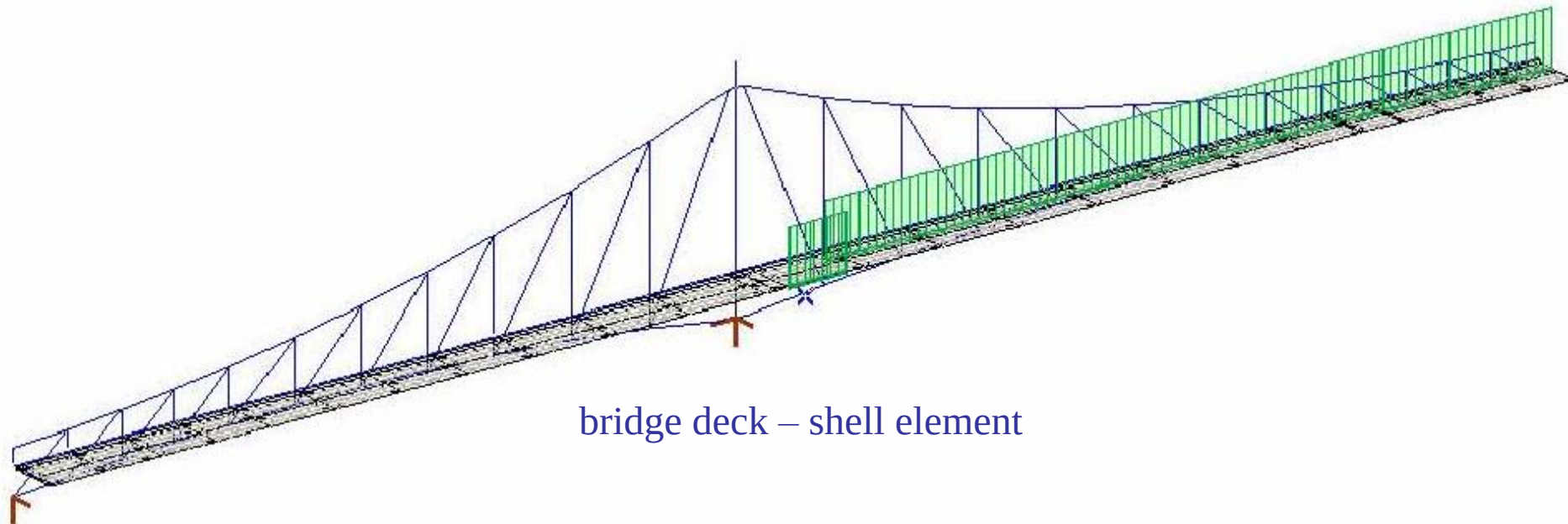
selfweight



# Reconstruction 2007 → integrated structural system

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

main truss – 3D beam element



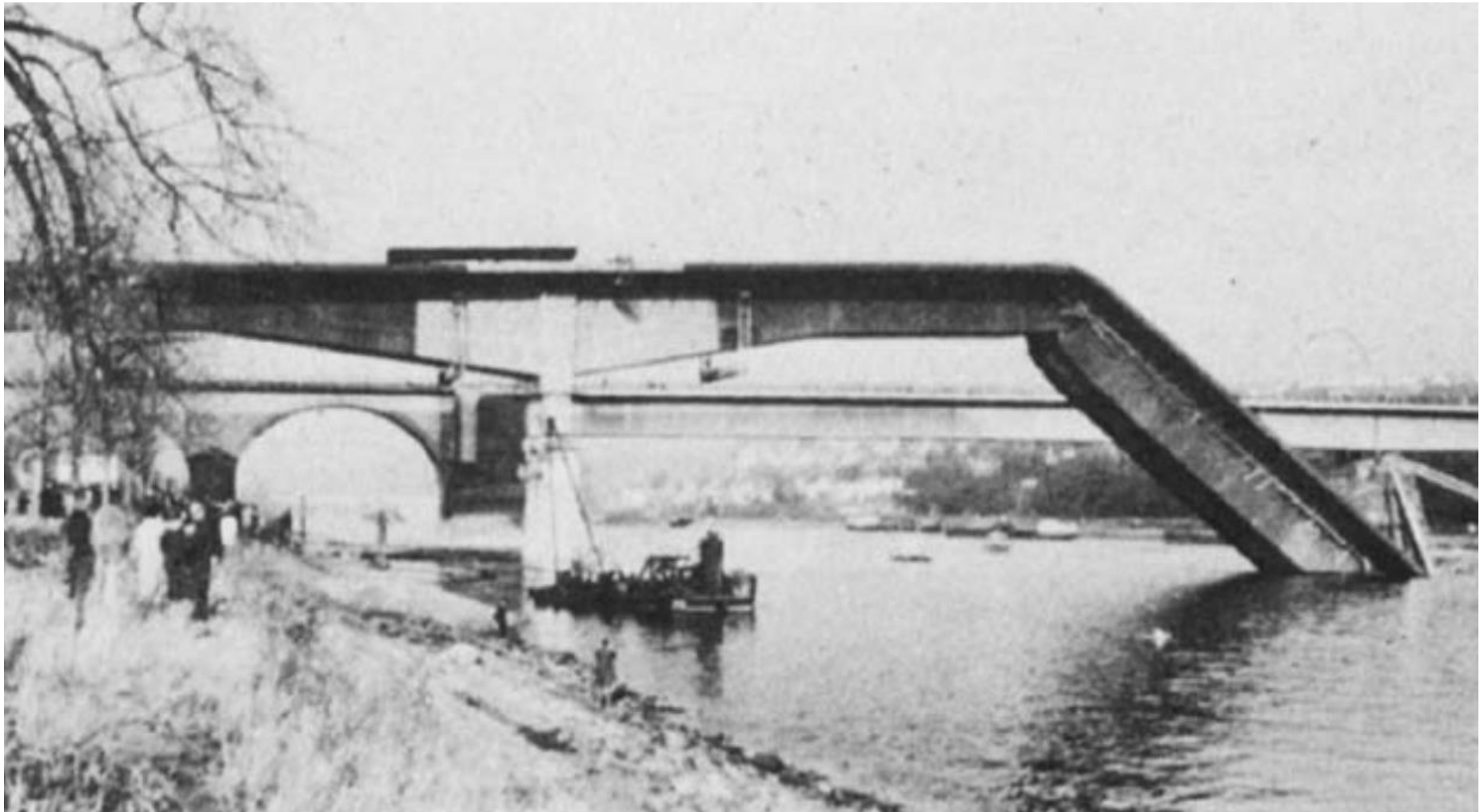
bridge deck – shell element



# 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

## Analysys

- 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



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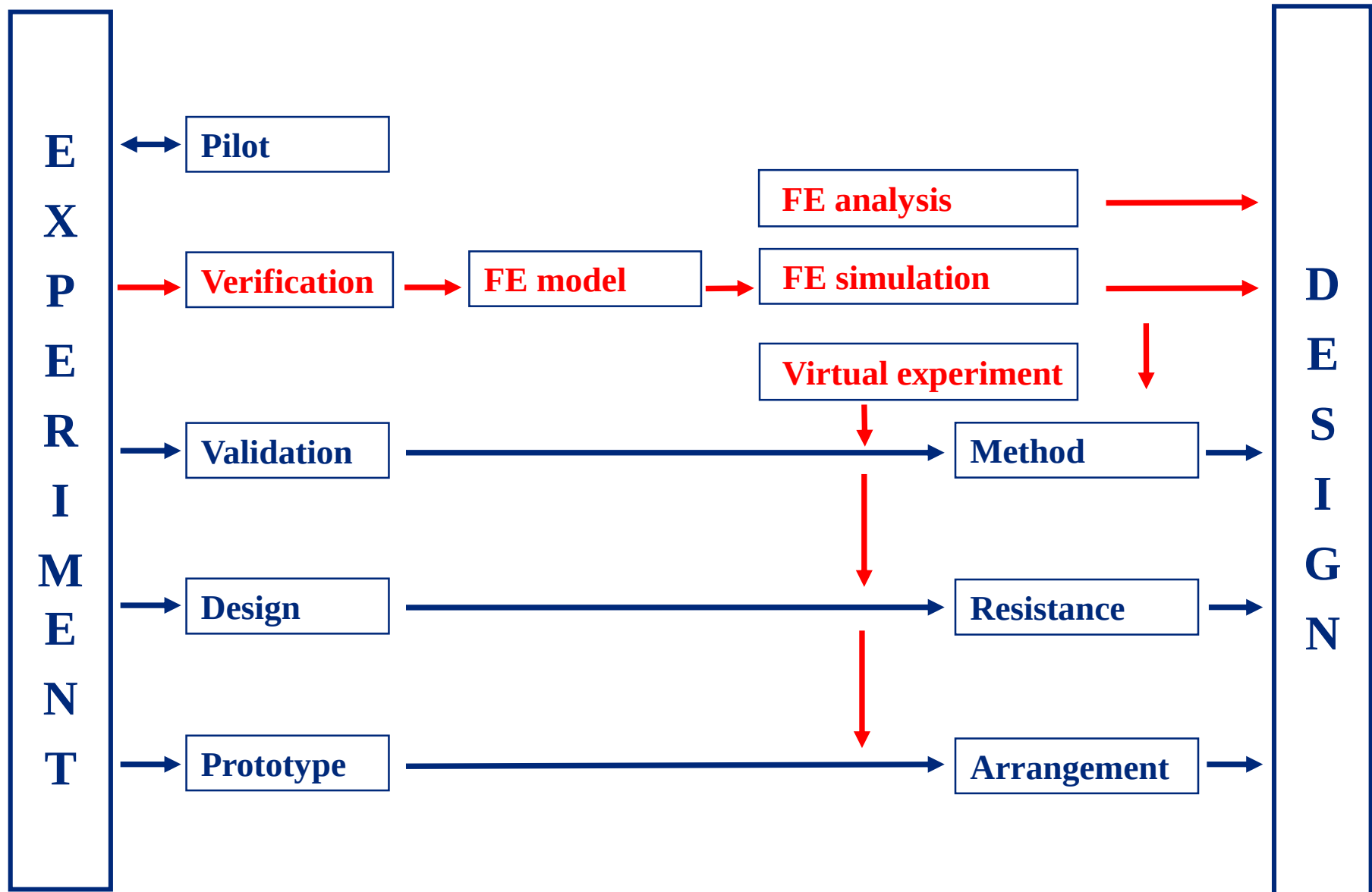
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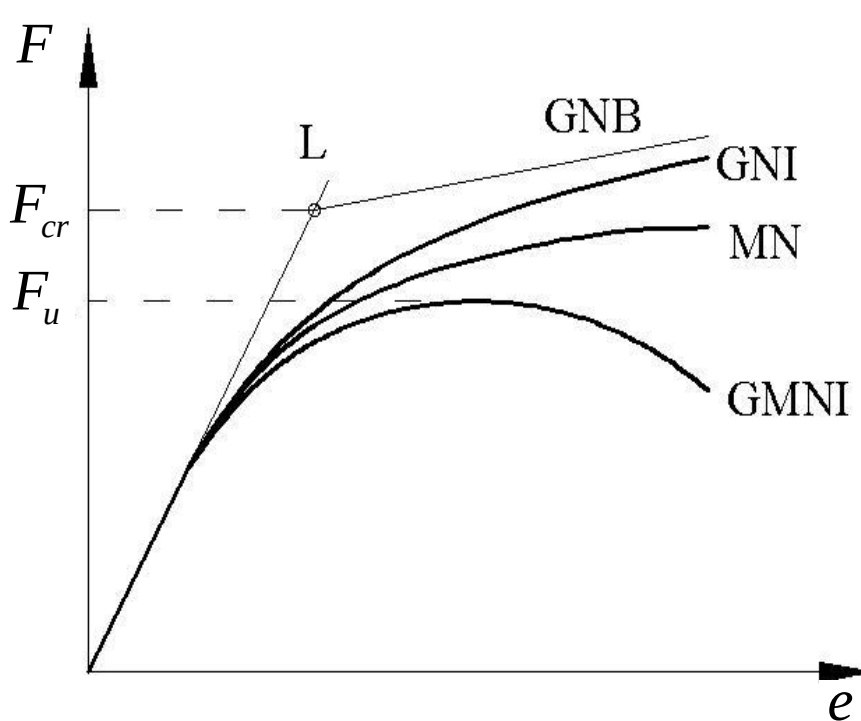
**... contradictions ... surprises ... disputes ...**

# Advanced research/design methodology



# Model – analysis – design

**structure** ➡ **statical model** ➡ **numerical model**  
statical behaviour          numerical method



↓  
**computational analysis**

↕  
**design**



# Models

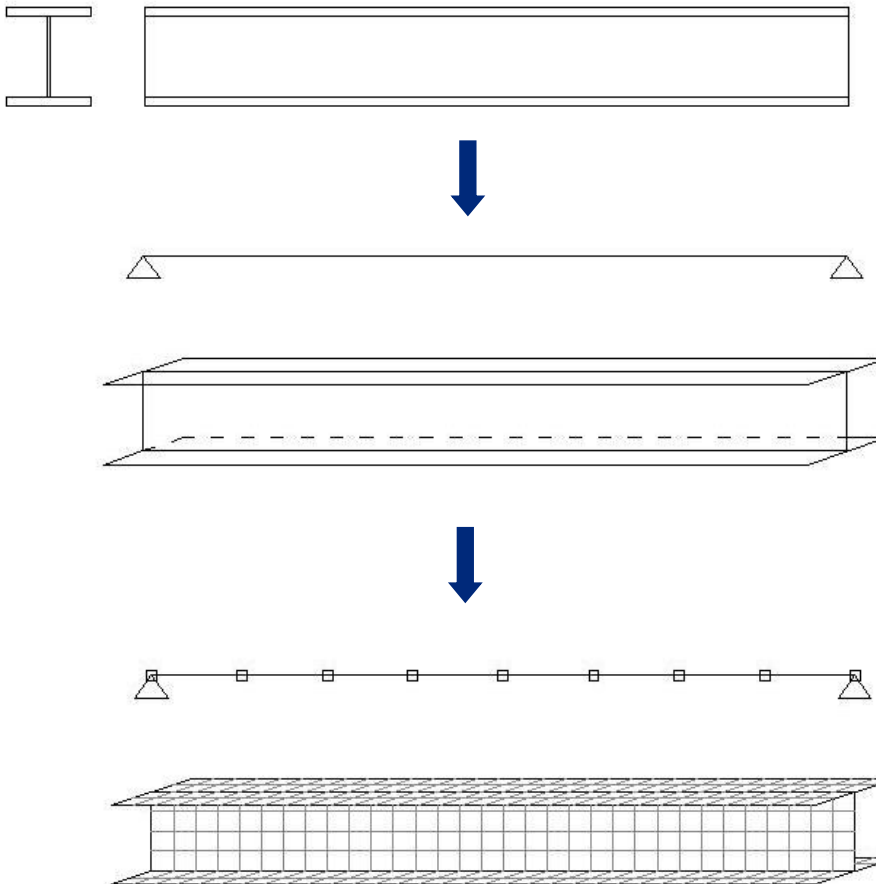
**Geometrical ~**

**Support ~**

**Material ~**

**Load ~**

# Geometrical models



**structure**

**statical model**

**beam**

**surface**

**numerical model**

**beam**

**shell, solid**

# VEM analysis – accuracy

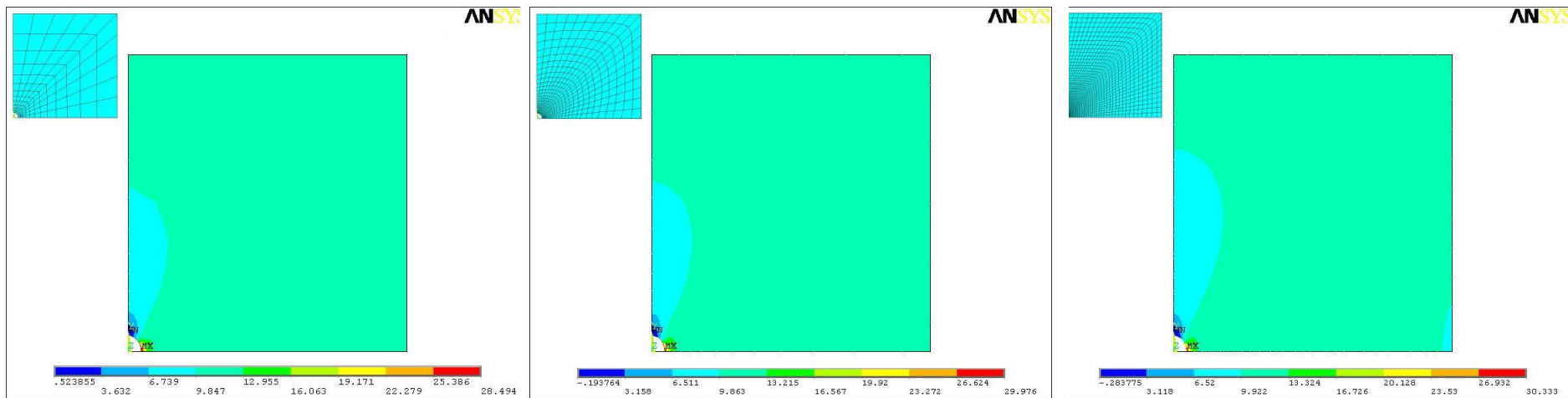
reduction of element size – accuracy – convergence!

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, ...**

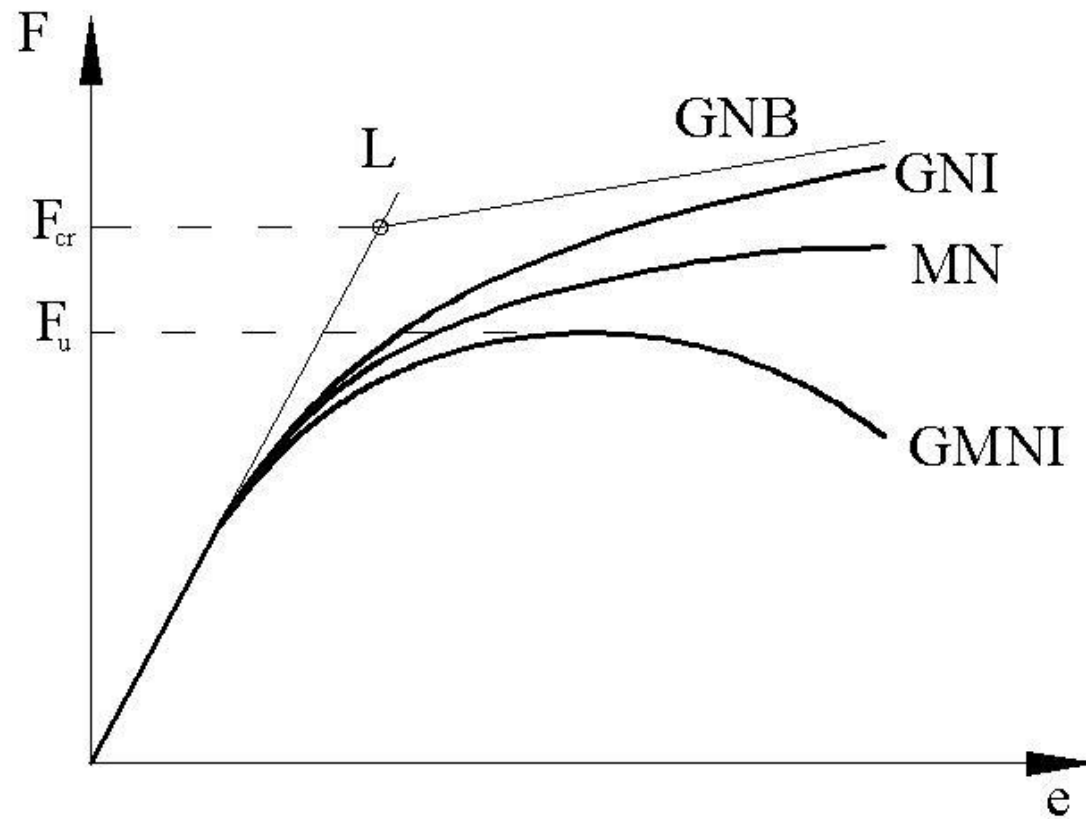
**Structural engineering task programs: analysis + design  
AXIS, CONSTEEL, FEM-Design,  
RSTAB, SOFISTIK, TDV, Midas, ...**



**Link to CAD programs**

**AutoCAD, BOCAD, TEKLA, ...**

# Computational analysis – design



$L$  – linear

$GNB$  – geometrically nonlinear  
buckling

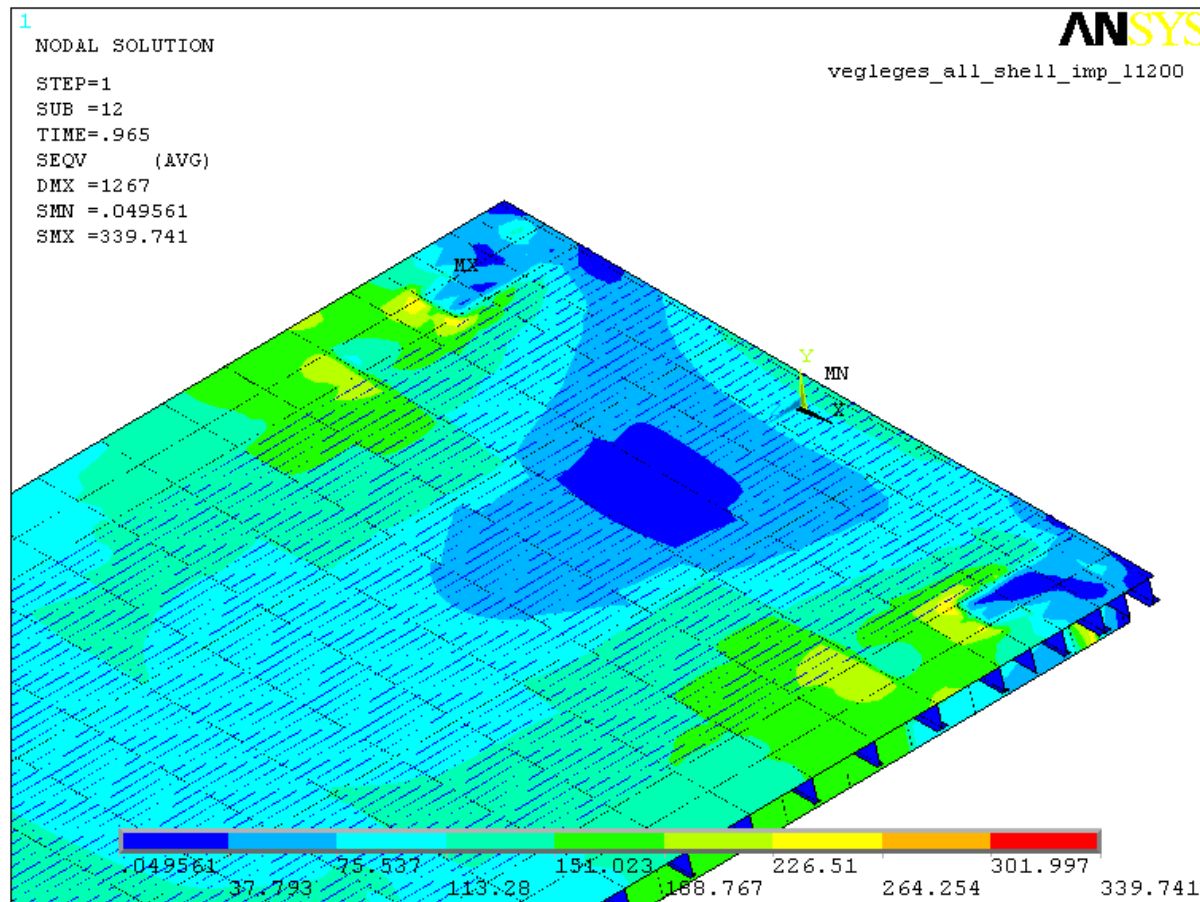
$GNI$  – geometrically nonlinear  
second-order

$MN$  – 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?

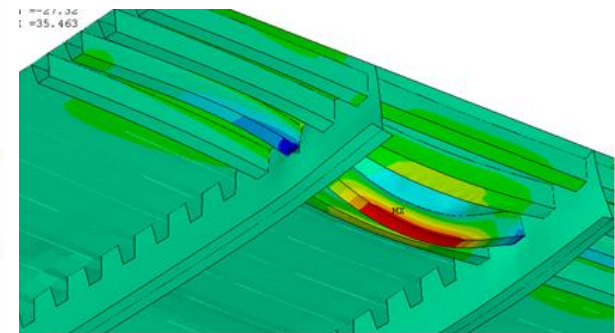
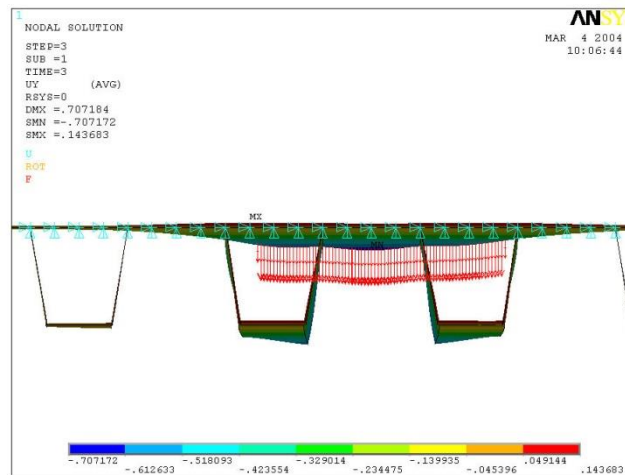
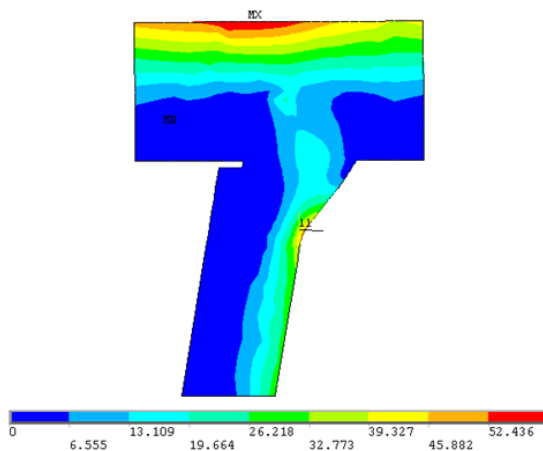
- plastic design?

fatigue limit state

- nominal stress

- geometrical stress (hot-spot stress)

- notch stress



# GNB analysis ↔ design

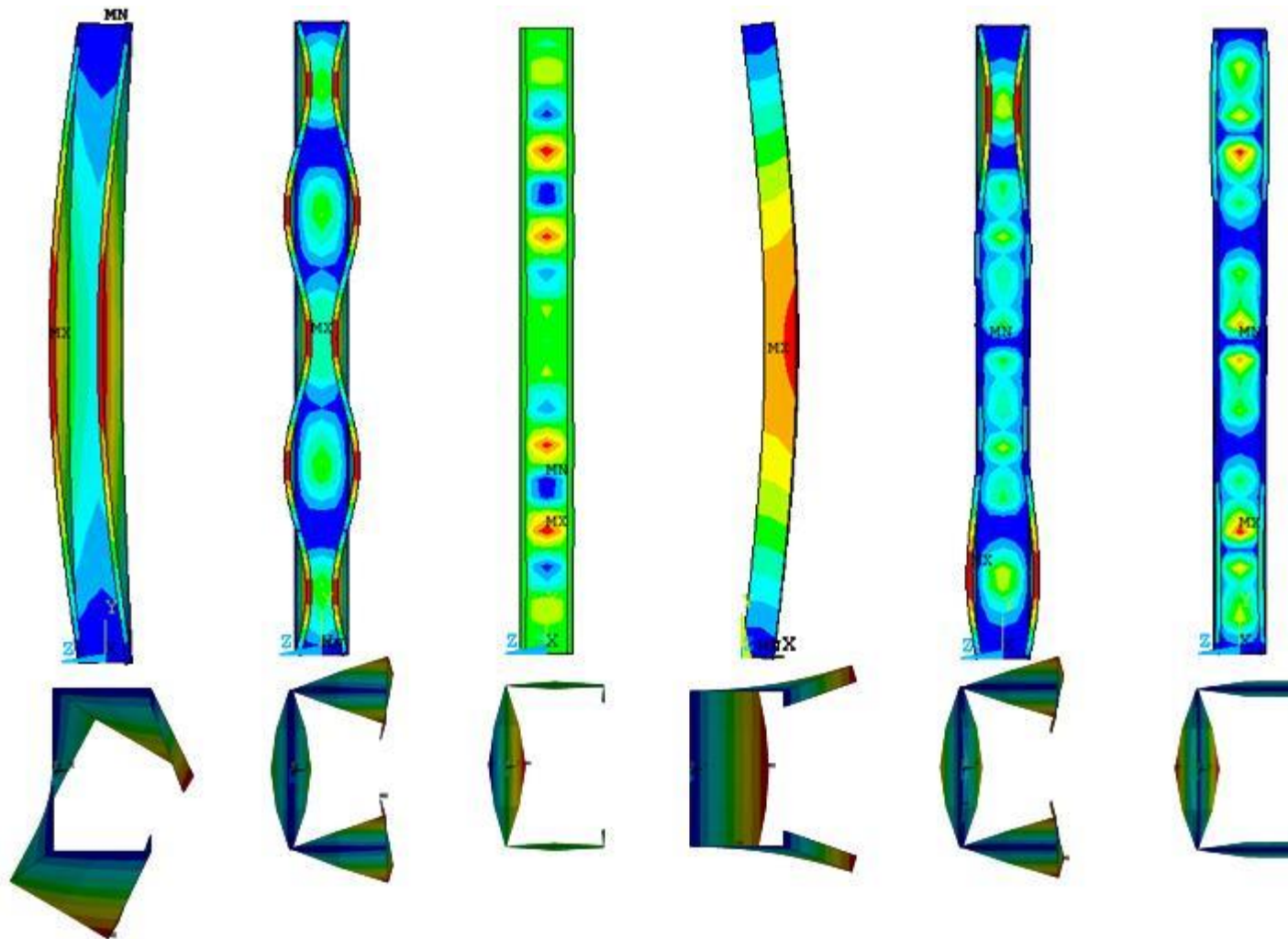
**GNB — bifurcation stability limit state**

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

**reduction factor method**

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

# GNB analysis ↔ design



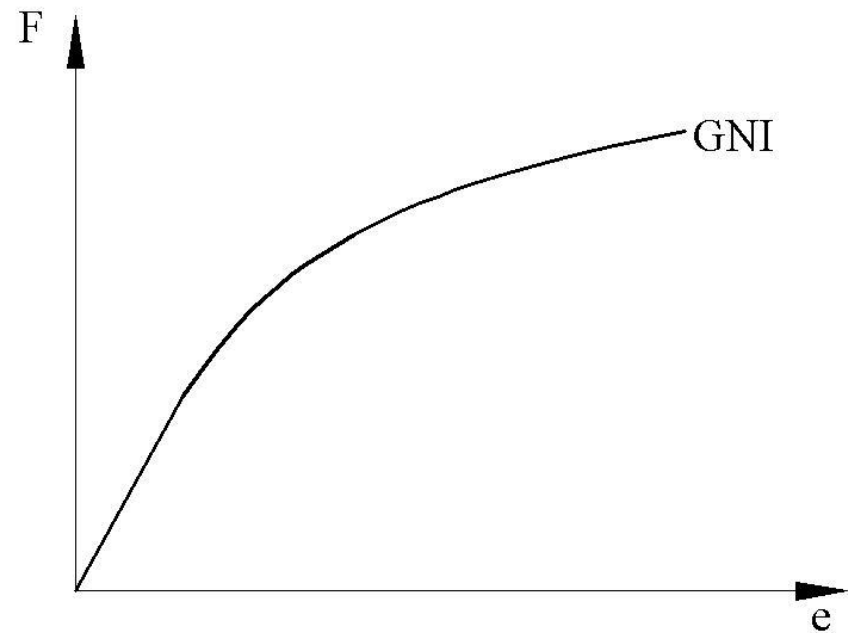
# GNI analysis $\leftrightarrow$ design

**GNI — second order analysis + equivalent imperfections**



**second order internal forces**

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



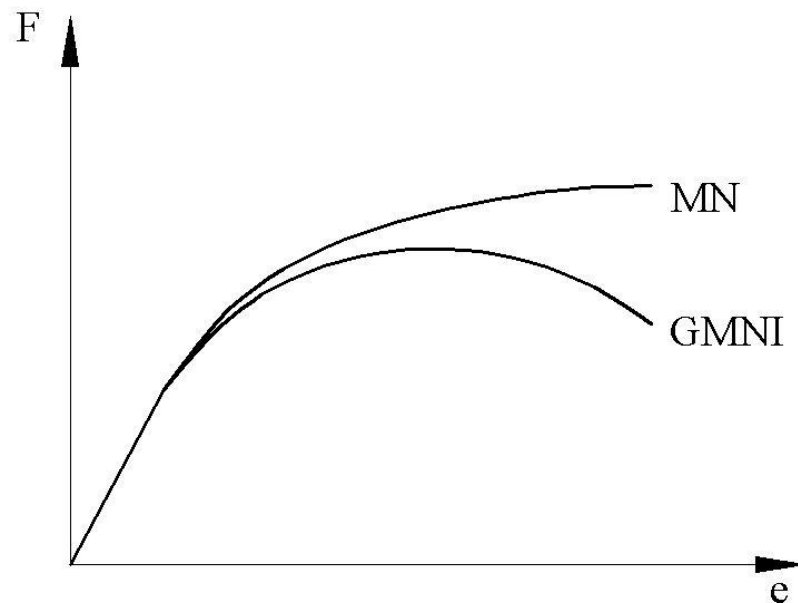
# MN analysis ↔ design

**Beam model**

**plastic design**

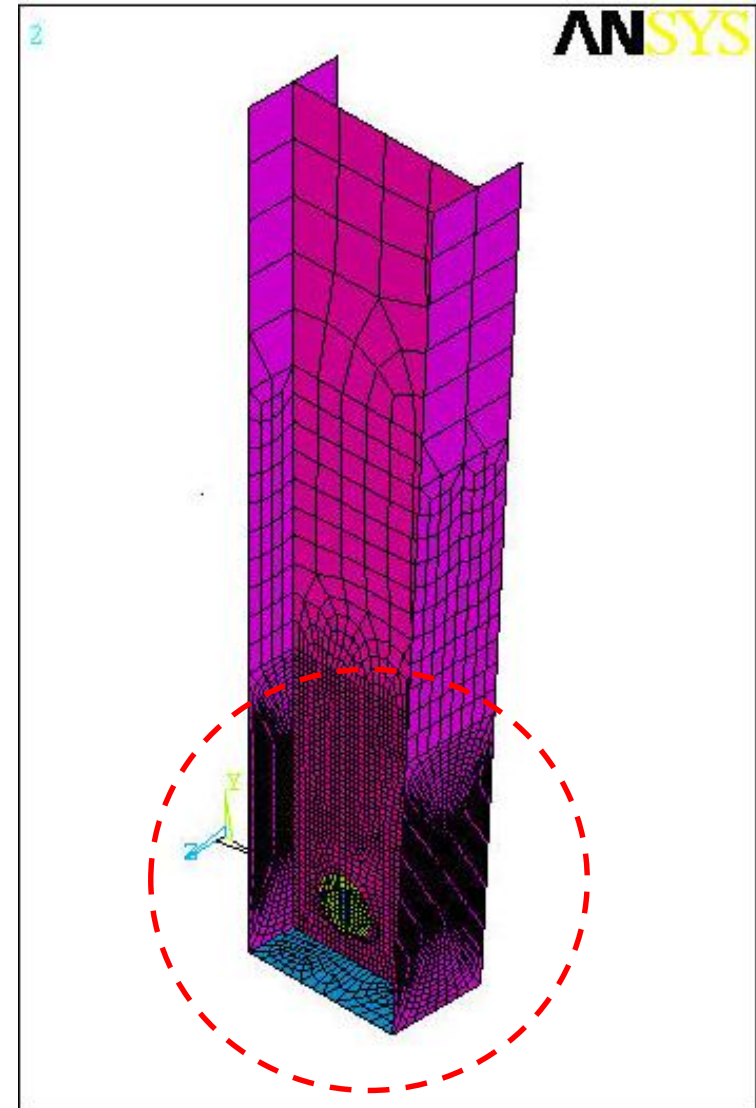
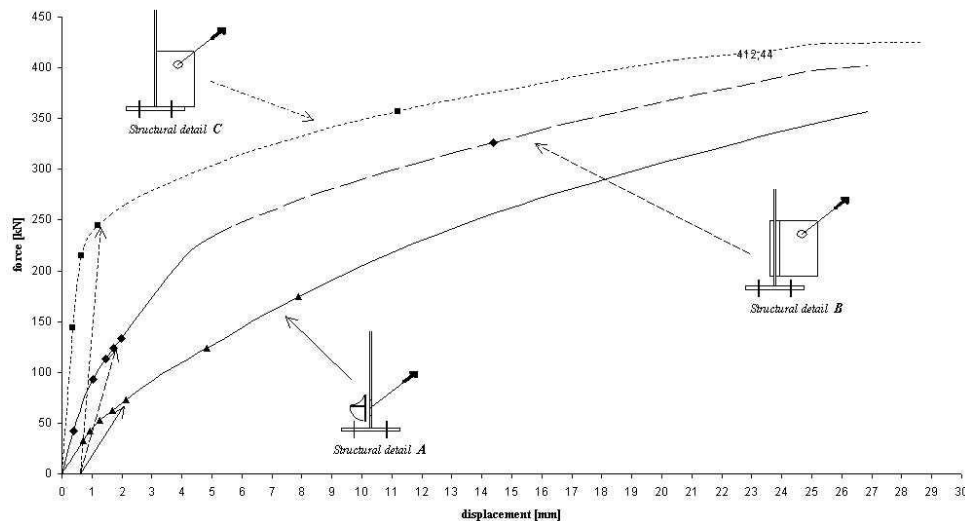
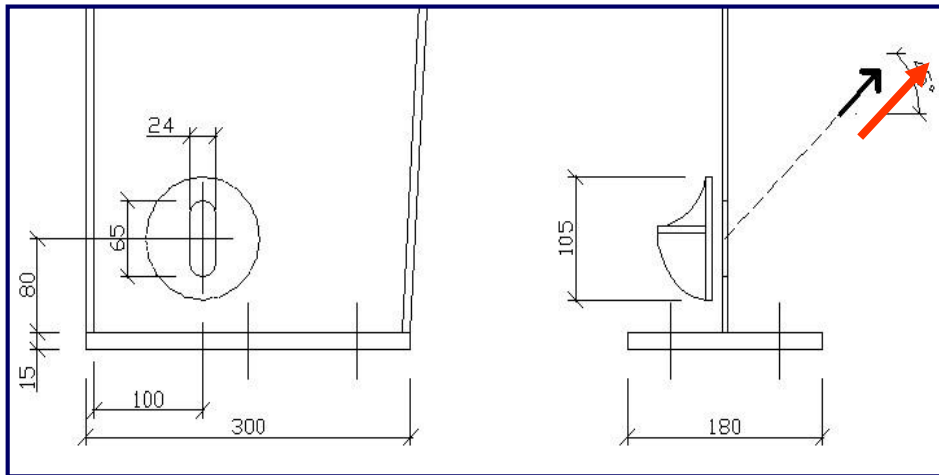
**Advanced model**

**interpretation of plastic limit state ?**



# MN analysis ↔ design

## Frame – bracing rod detail #1



# GMNI analysis ↔ design

**GMNI** geometrical model + geometrical imperfections

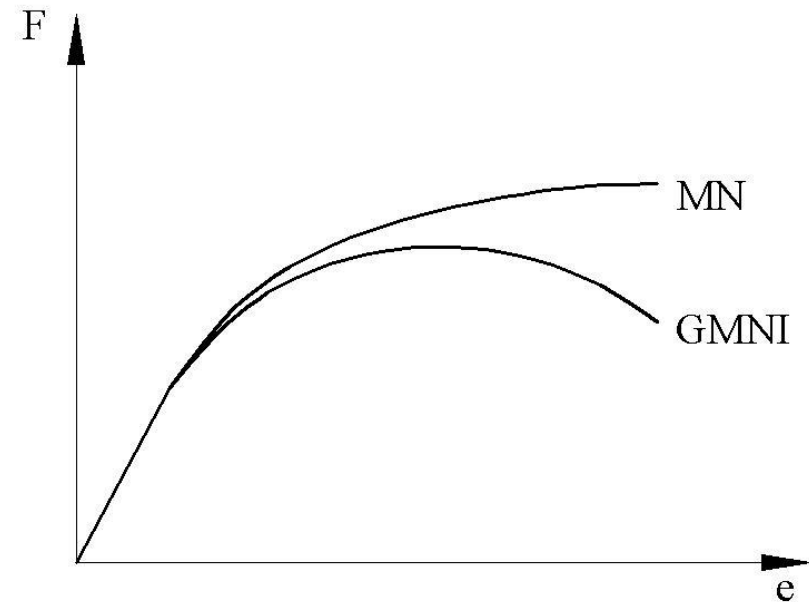


**geometrical and material nonlinear analysis**



**structural behaviour**

**FEM simulation**

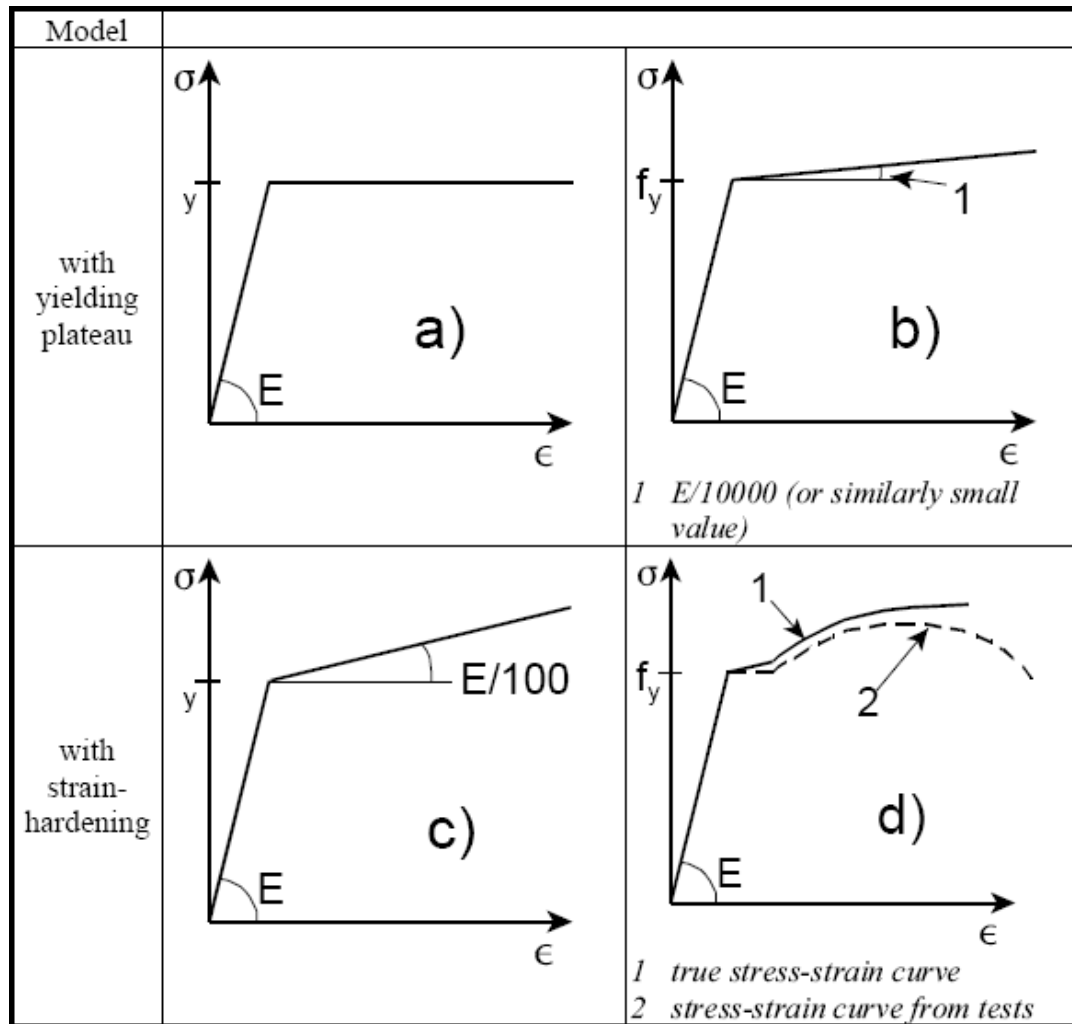


# Plated structure – imperfection

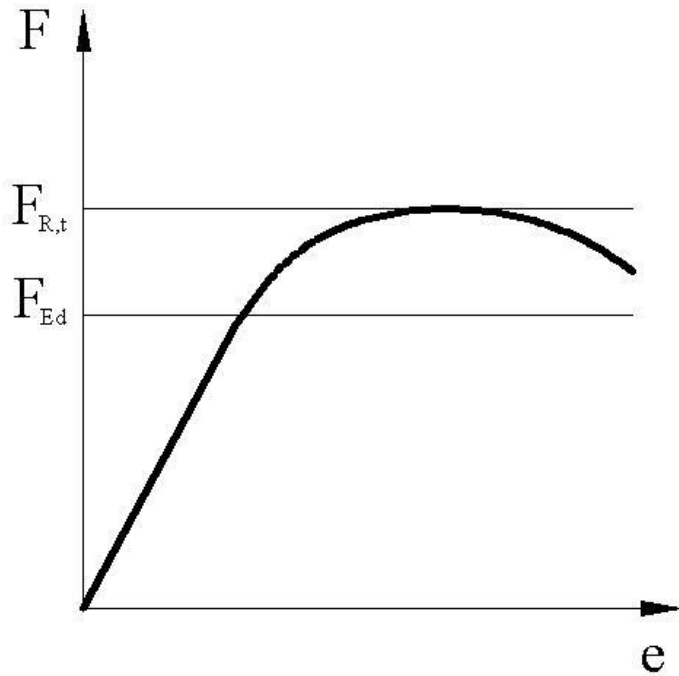
| Type of imperfection                          | Component |
|-----------------------------------------------|-----------|
| global member with length $\ell$              |           |
| global longitudinal stiffener with length $a$ |           |

|                                            |  |
|--------------------------------------------|--|
| local panel or subpanel                    |  |
| local stiffener or flange subject to twist |  |

# 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

$\alpha_1$

- failure mode

$\alpha_2$

# Test based design

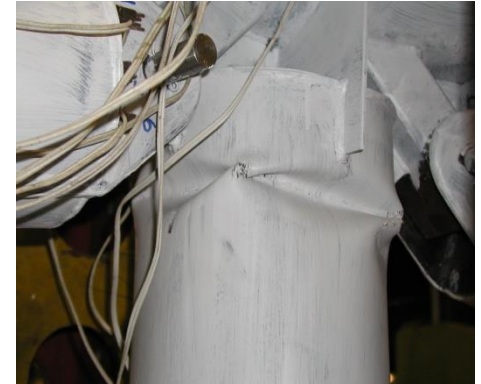
**Real**      **geometrical imperfections**  
**residual stresses**  
**material properties**



**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

László Dunai (H), BME Budapest, AHG-Leader

Leroy Gardner (GB), Delphine Sonck (B), Andreas Taras (A)

Paulo Vila Real (P), Jari Makinen (F), Péter Márai (L)

Michal Jandera (Cz), František Wald (Cz)

Gerhard Lener (A), Hervé Degée (B), Joseph Ndogmo (D), Balázs Kövesdi (H)

Roberto Nascimbene (I), Peter Knoedel (D)

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



## Design by advanced computational analysis



# PhD course program

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|               |                                                                               | Guided ship tour - bridges in Budapest                                                             |                                                                                                       |                                                                               |                                                                                      |



Thank you for your attention!