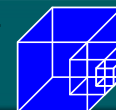


AiF – research project No. 13289

Connections of Unprotected Steel Members to Fire Walls

Alexander Heise



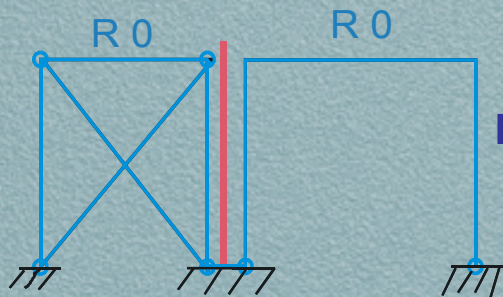
Content

- I. Maximum load bearing capacity (of bolts)
- II. Open slotted holes
- III. Maximum displacement of beams

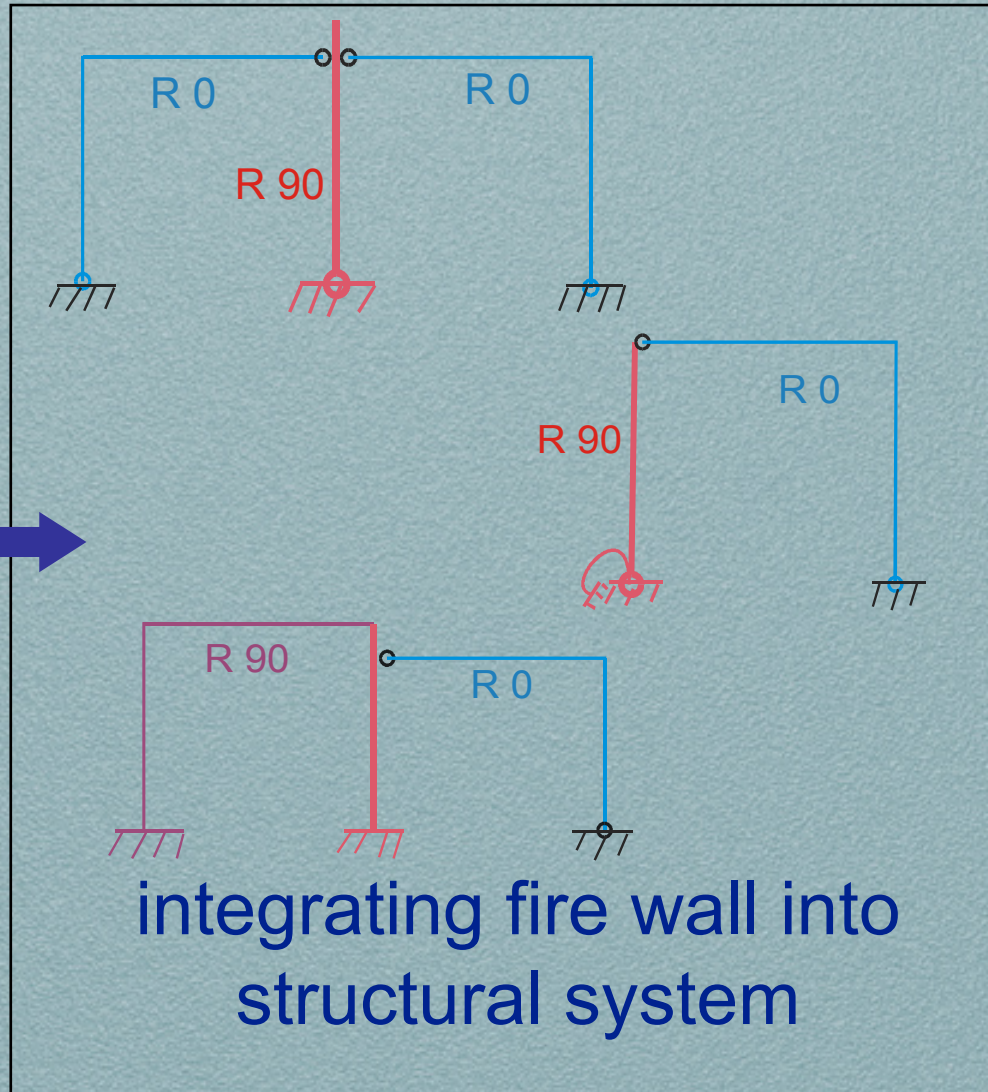
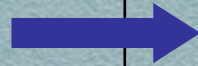


The fire wall must resist the fire although
the steel construction fails





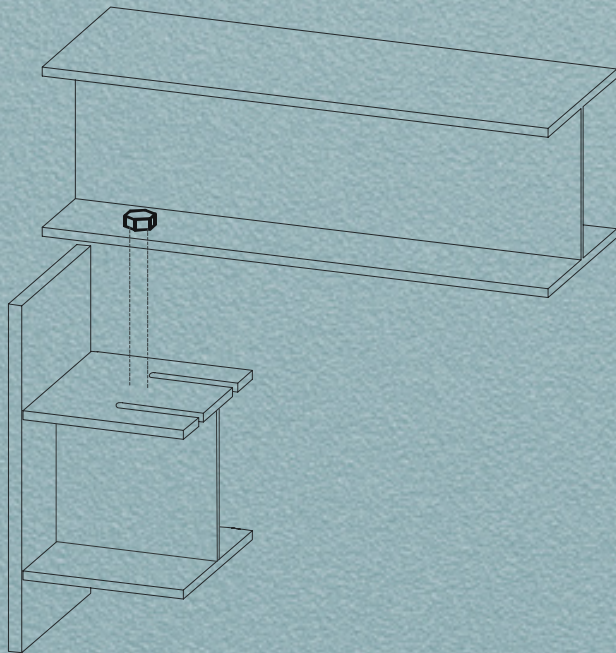
state of the art



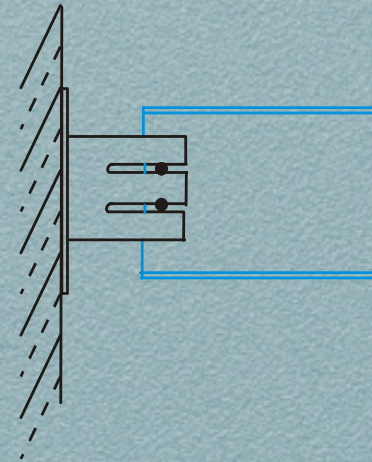
integrating fire wall into structural system

I. connections without pull off loads

supporting beam

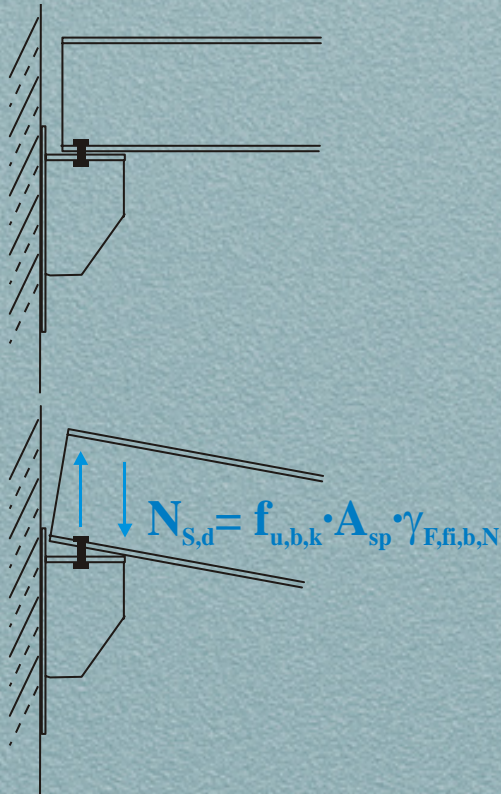


purlin

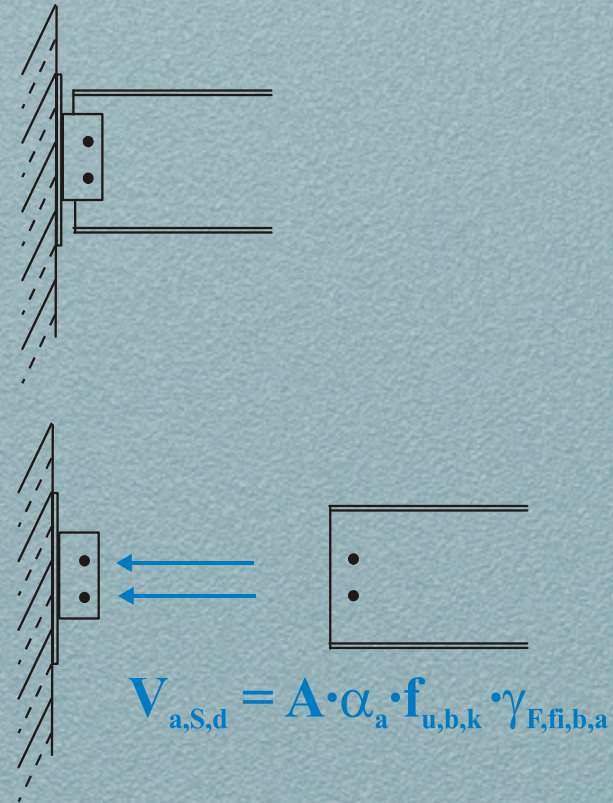


2. maximum load bearing capacity of the connection

supporting beam



purlin



effects of
actions E
in fire

\leq

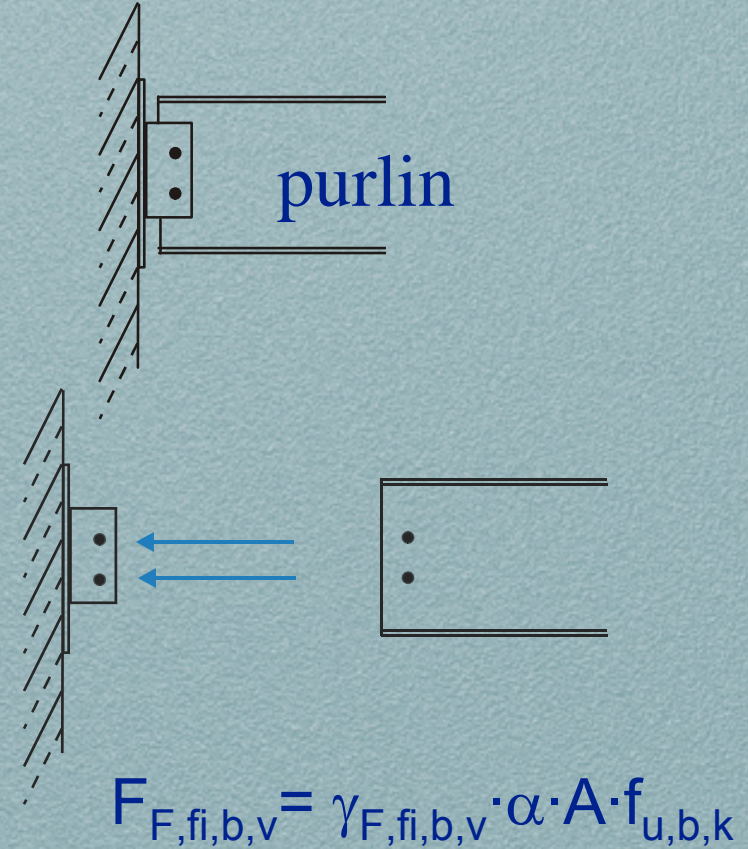
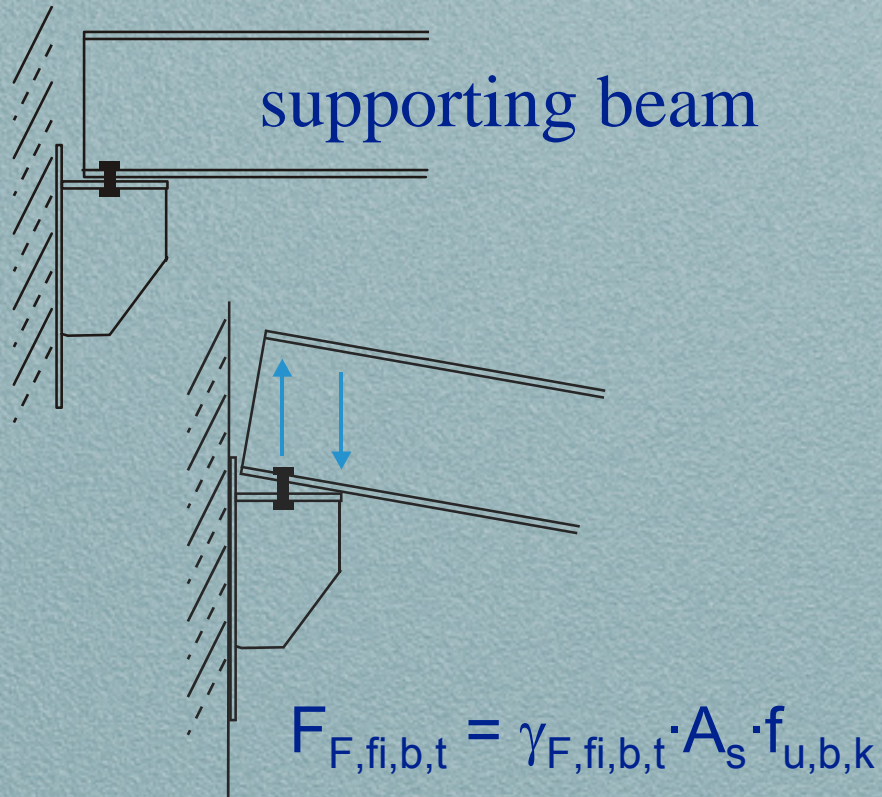
max. bolt bearing
capacity

$E = f(\text{load bearing capacity})$

Design of the fire wall :

$R \geq E$

R Resistance of the fire wall
E max. load bearing capacity of the bolts



Partial safety factors

maximum load bearing capacity of bolts

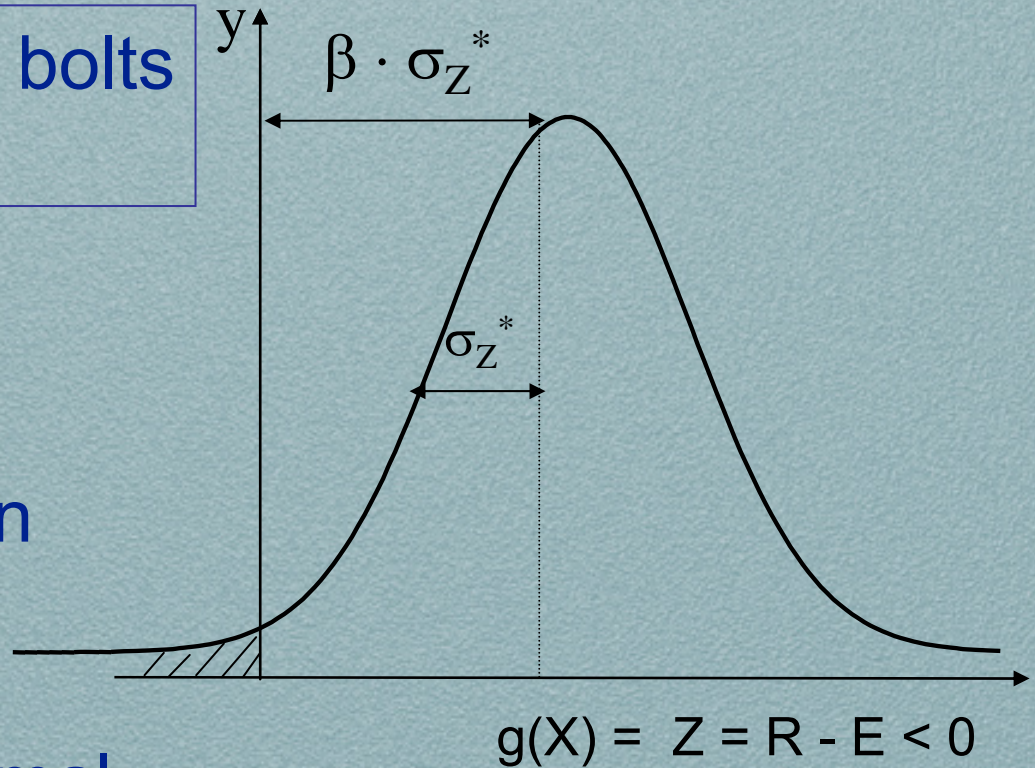
ENV 1991-1 Annex A / ISO 2394

Design value of the bolts

$$F_d = f(\beta, \mu, V_E)$$

β safety index

probability distribution
function of the bolts:



lognormal

μ mean value
 V_E coefficient of Variation

safety index for fire walls separating

industrial buildings

Safety Category

①

$$\beta_{fi} = 2,3$$

other occupancies

Safety Category

②

$$\beta_{fi} = 3,0$$

data base for bolts in shear and tension:

- literature (e.g. Background Documentation EC 3)
- quality assurance of bolt manufacturing companies

number of evaluated tests (total 3175)

grade	tension	shear
4.6	645	216
5.6	92	94
8.8	569	232
10.9	1168	159

bolts in tension

grade	$\sigma_{5\%}$ [N/mm ²]	V [%]
4.6	392	12
5.6	507	9
8.8	839	5
10.9	1049	4

$$F_{F,fi,b,t} = \gamma_{F,fi,b,t} \cdot A_s \cdot f_{u,b,k}$$

$\gamma_{F,fi,b,t}$ (4.6, 5.6, 8.8, 10.9) A_s : stress area

bolts in shear

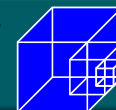
grade	$\tau_{5\%}$ [N/mm ²]	V [%]	α_A [-]
4.6	284	10	0,73
5.6	358	5	0,71
8.8	535	5	0,64
10.9	595	7	0,57

$$F_{F,fi,b,v} = \gamma_{F,fi,b,v} \cdot 0,6 \cdot A_i \cdot f_{u,b,k}$$

$\gamma_{F,fi,b,v}$ (4.6, 5.6, 8.8, 10.9)

$A_i = \begin{cases} A - \text{shank} \\ A_s - \text{stress area} \end{cases}$

safety category	grade	tension $\gamma_{F,fi,b,t}$	shear $\gamma_{F,fi,b,v}$
1 fire walls in industrial buildings	4.6	1,45	1,65
	5.6	1,35	1,40
	8.8	1,25	1,30
	10.9	1,20	1,25
2 fire walls in other occupancies	4.6	1,55	1,70
	5.6	1,40	1,45
	8.8	1,30	1,35
	10.9	1,25	1,30



Design of the fire wall :

$$R \geq E$$

R Resistance of the fire wall

E - max. load bearing capacity of the bolts
- other actions (snow, wind...)

For Safety Categories (1) and (2)

- partial safety factors γ_M
- combination values ψ_{fi}

γ_{RD} partial safety factors (FORM)

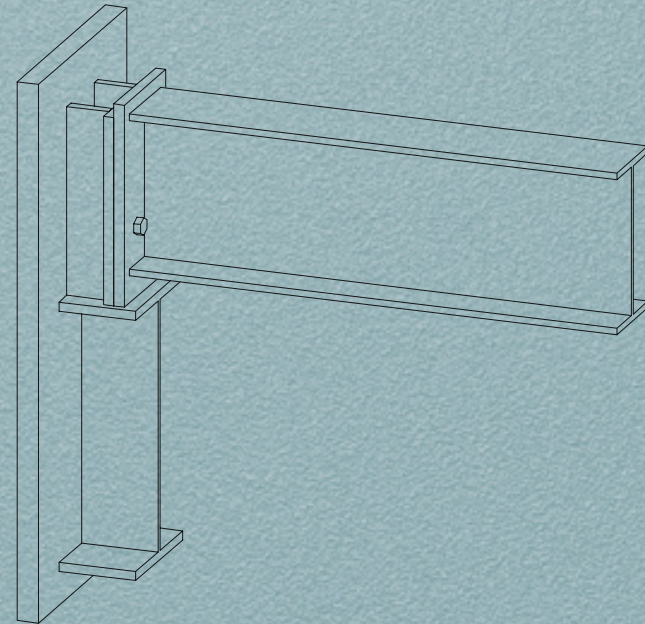
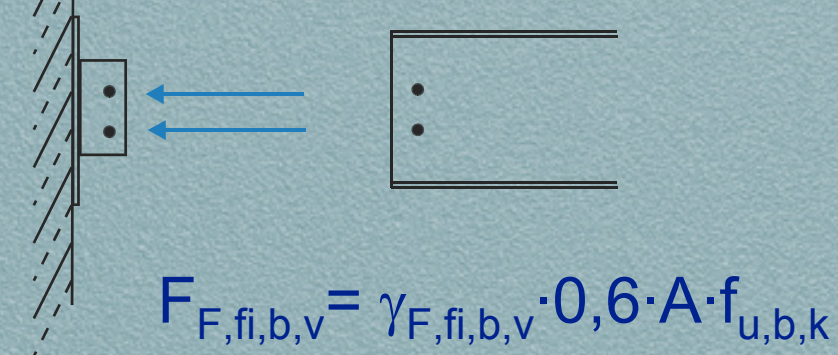
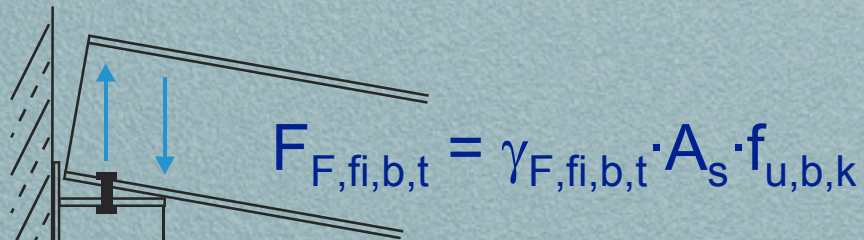
$$R_d = \frac{1}{\gamma_{Rd}} R_{nom}$$

ψ_{fi} combination values (Borghes Castanheta)

$$F_{F,fi,b,t} + F_{F,fi,b,v} + \psi_{b,G} \cdot G_k + \psi_{b,Q} Q_k + \psi_{b,S} S_k$$

Effect of maximum bolt bearing capacity

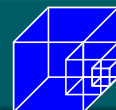
material	SC 1	SC 2	action	ψ_b
	$\gamma_{M,fi}$			
steel	1,0	1,05	permanent load	1,15
bolt tension	1,0	1,10	variable load	0,45
bolt shear	1,0	1,10	snow, temperate	0,75
reinforcing bars	1,0	1,10	snow, maritime	0,30
concrete	1,0	1,25	wind	0,00



1. torsional stiffness

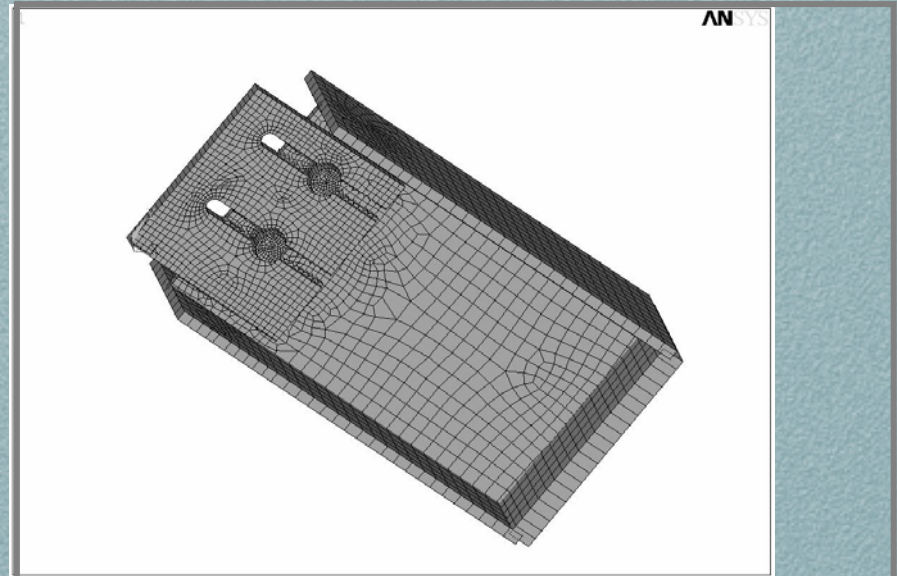
- fork bearing (verification of the beam)
- torsional bearing capacity
(verification of the slotted fin plate)

2. bearing failure of the slotted fin plate





tests

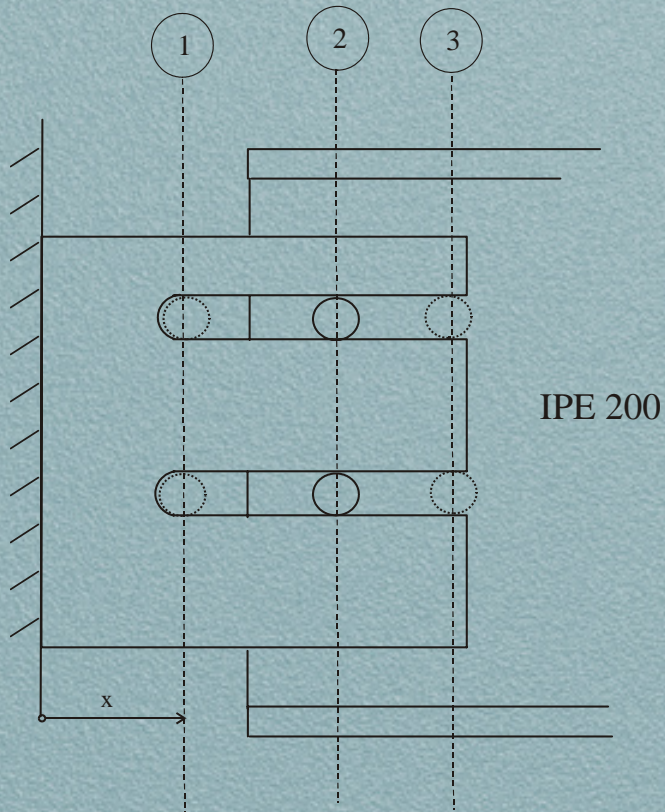


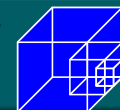
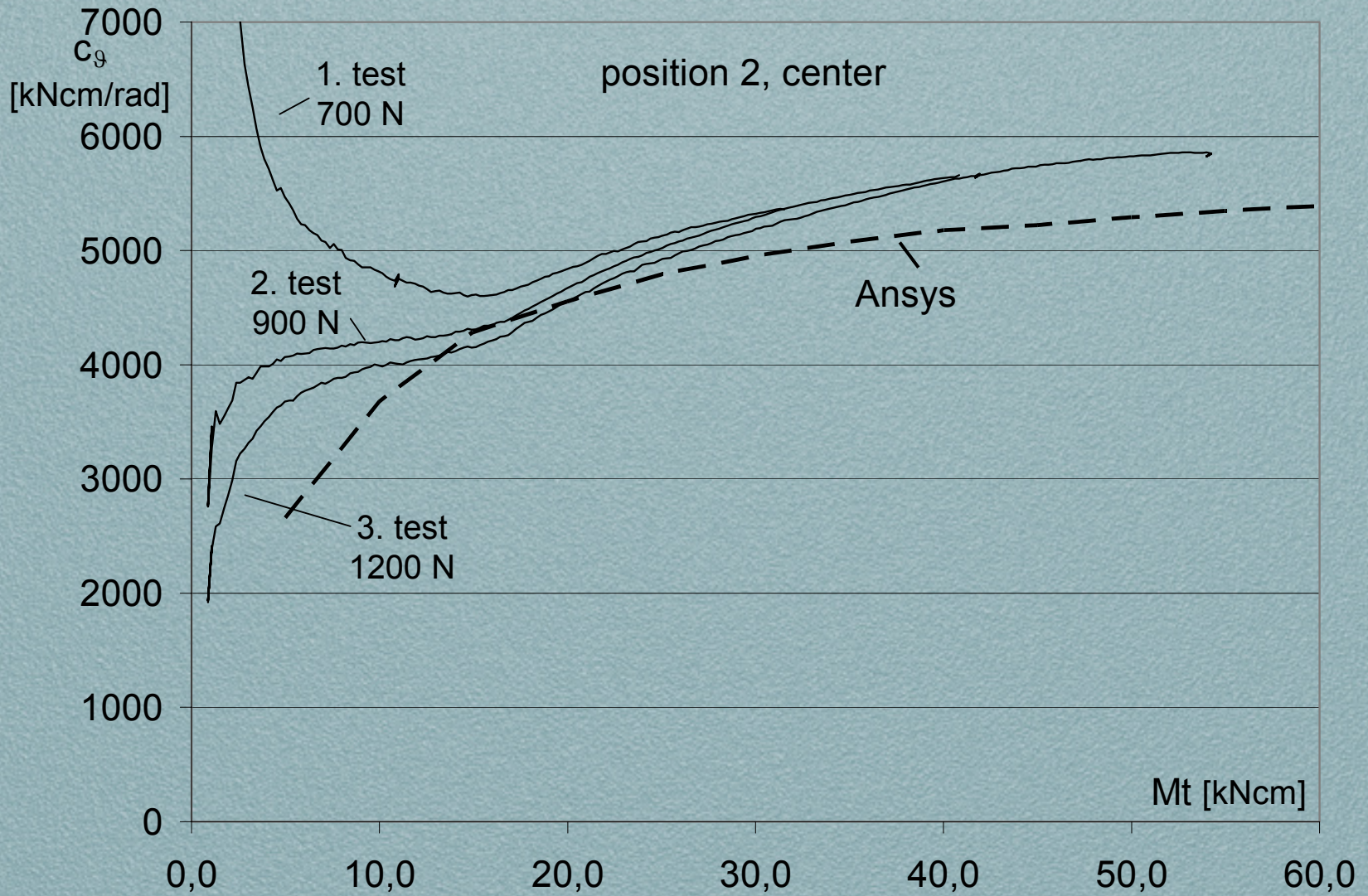
numerical studies (Ansys)

verification of the
numerical model

torsional stiffness

3 different bolt positions
were tested





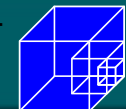
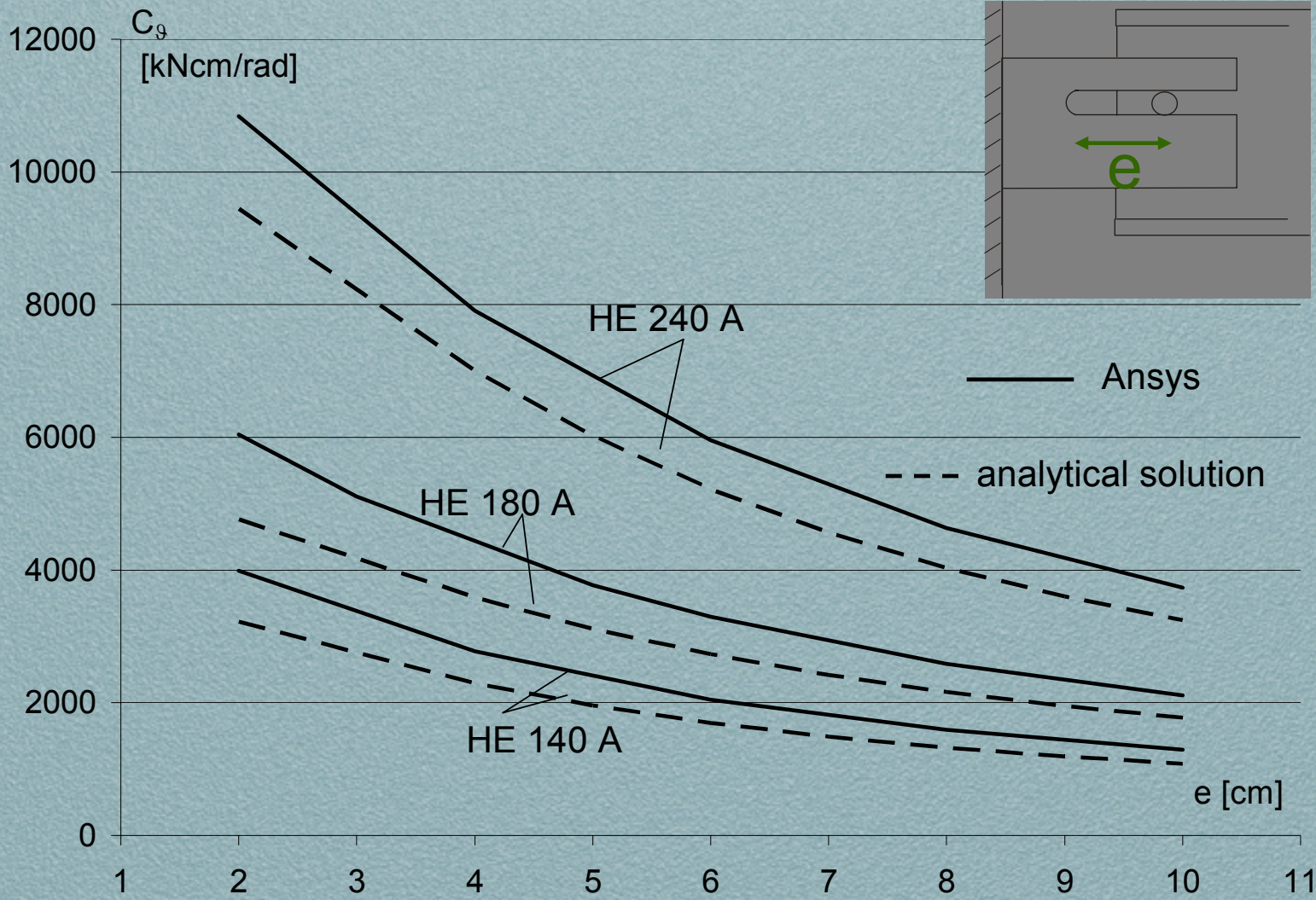
Based on the numerical studies:

analytical solution:

$$C_V = \frac{1}{\vartheta} = \frac{1}{\vartheta_K + \vartheta_T}$$

$$\vartheta_K = \frac{M_x}{EI_\omega \lambda^3} \left(\lambda \cdot l_T - \frac{\sinh(\lambda \cdot l_S) - \sinh(\lambda(l_S - l_T))}{\cosh(\lambda \cdot l_S)} \right) + \frac{M_x}{G \cdot I_{T, \text{Träger}}} (l_S - l_T)$$

$$\vartheta_T = \frac{2M_x}{3Es^3}$$



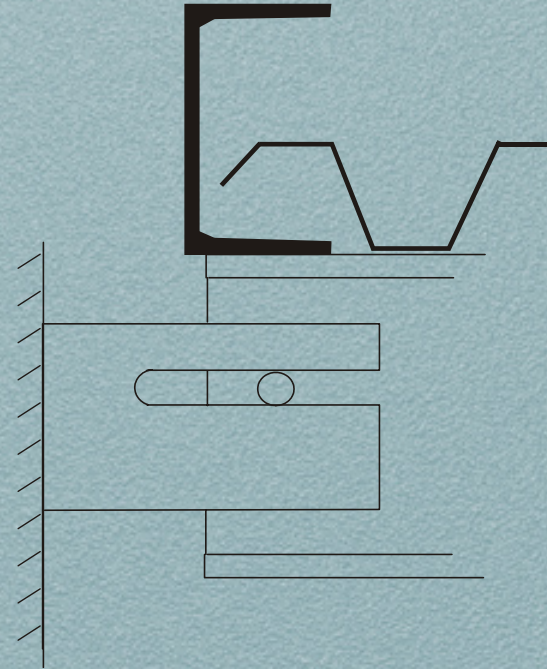
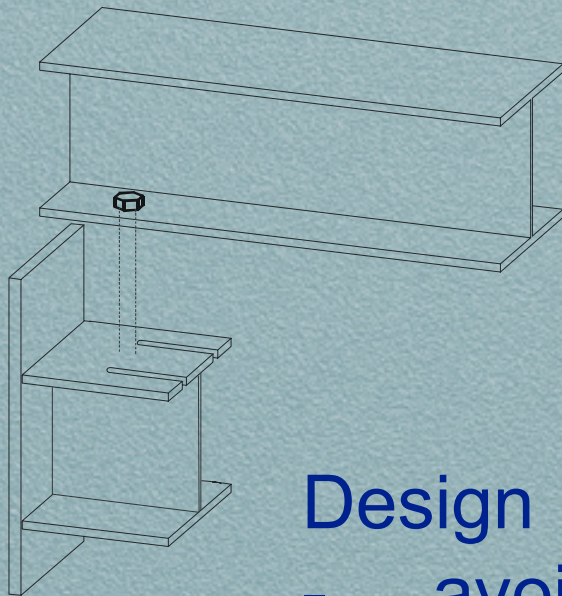
analytical solution:

- Design of the beam:
(verification of lateral torsional buckling)
- Design of the slotted fin plate:
(torsional moment)

$$\frac{R}{E} = \frac{\sigma_{R,t,elastic}}{\sigma_{torsion}} = 30\%$$



Not sufficient resistance
for an economical
design

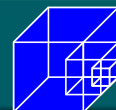


Design :

- avoiding torsion
- stiffening by other components

Bearing resistance of open slotted holes

- The design resistance is determined by tests (Annex Z, ENV 1993-1-1)
- Numerical studies
 - to study the structural behaviour
 - to extend the parameters, covered by the tests



experimental setup:



Test program:

2 tests

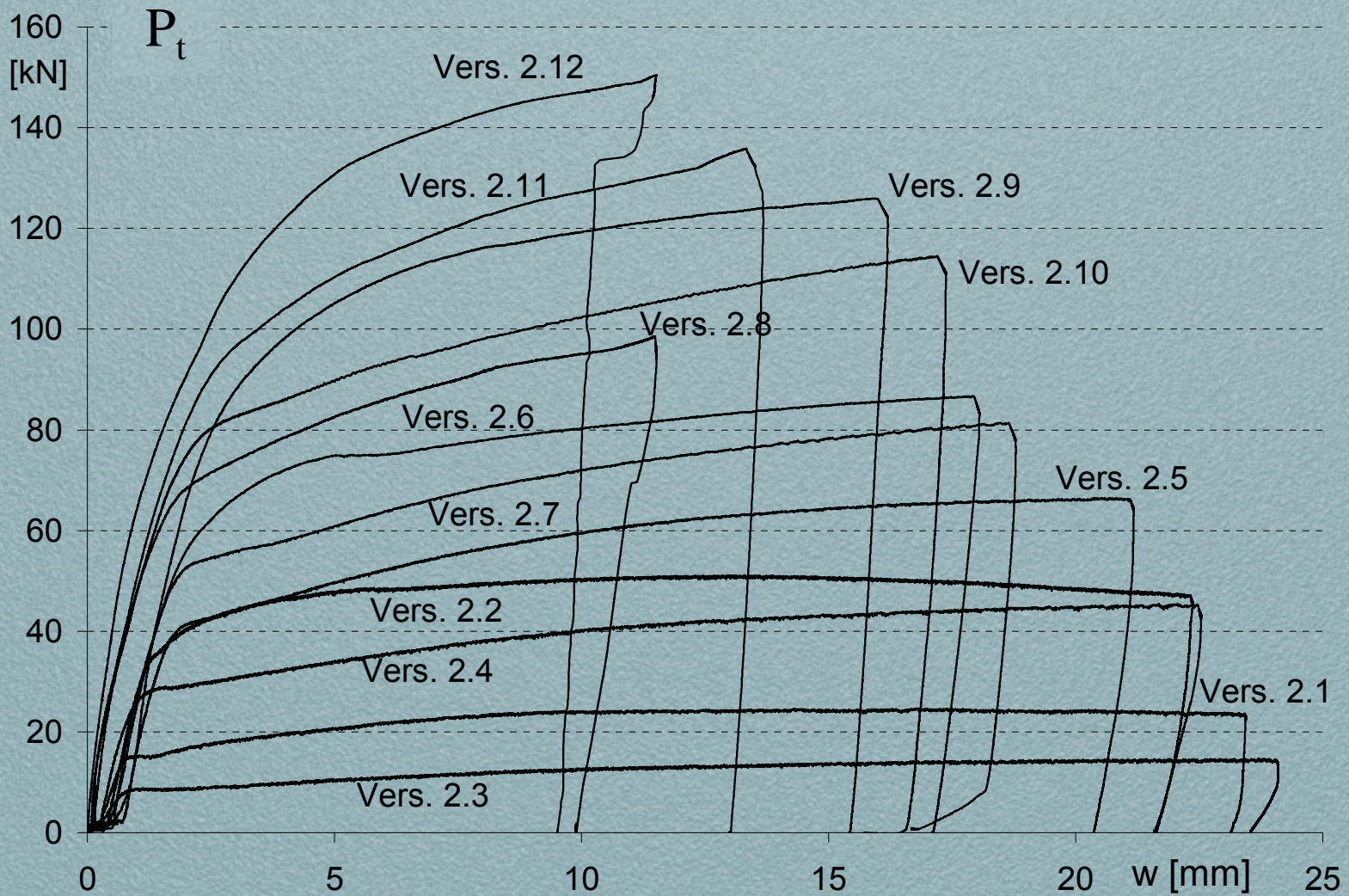
general testing
conditions

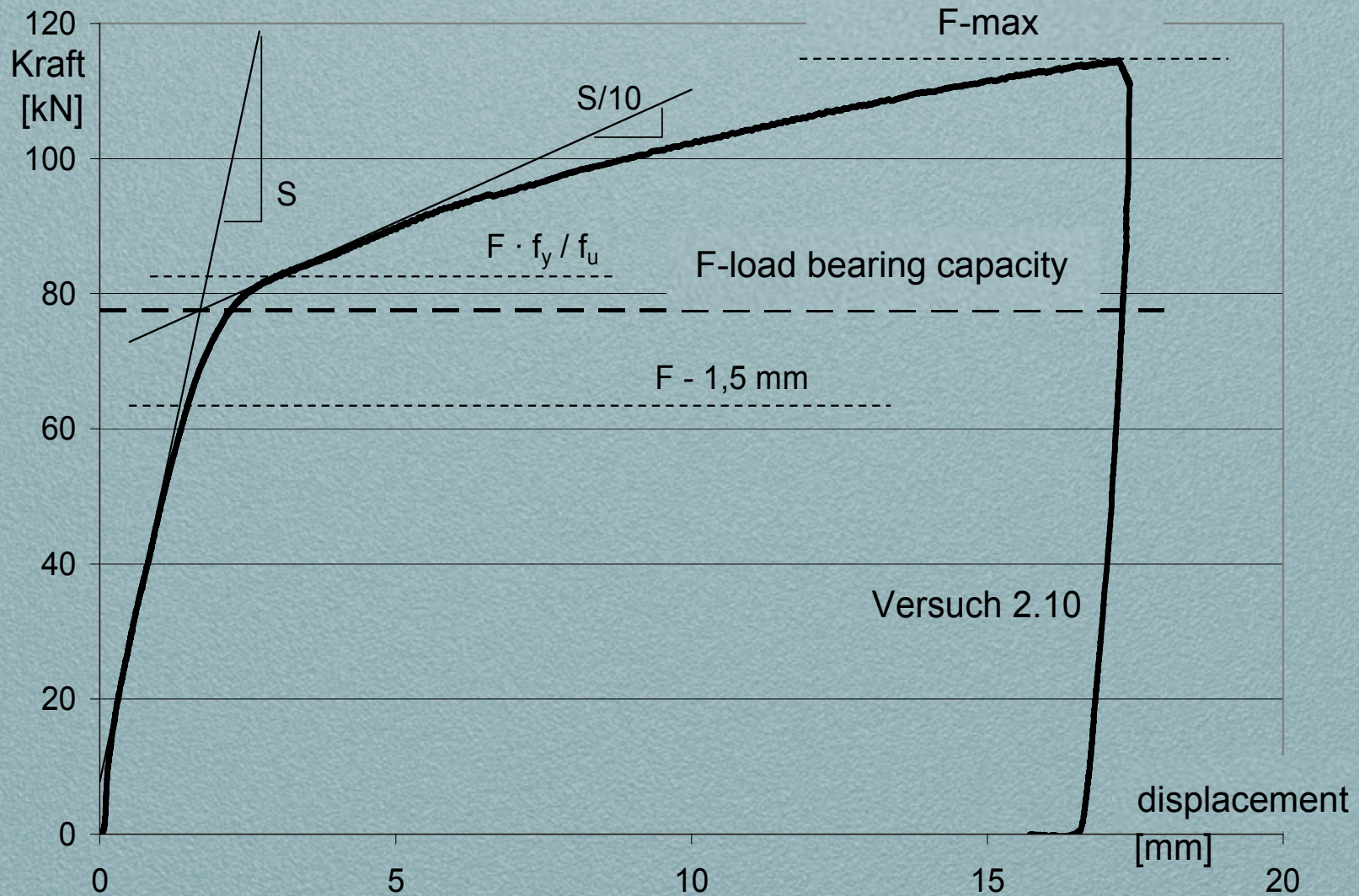


12 tests

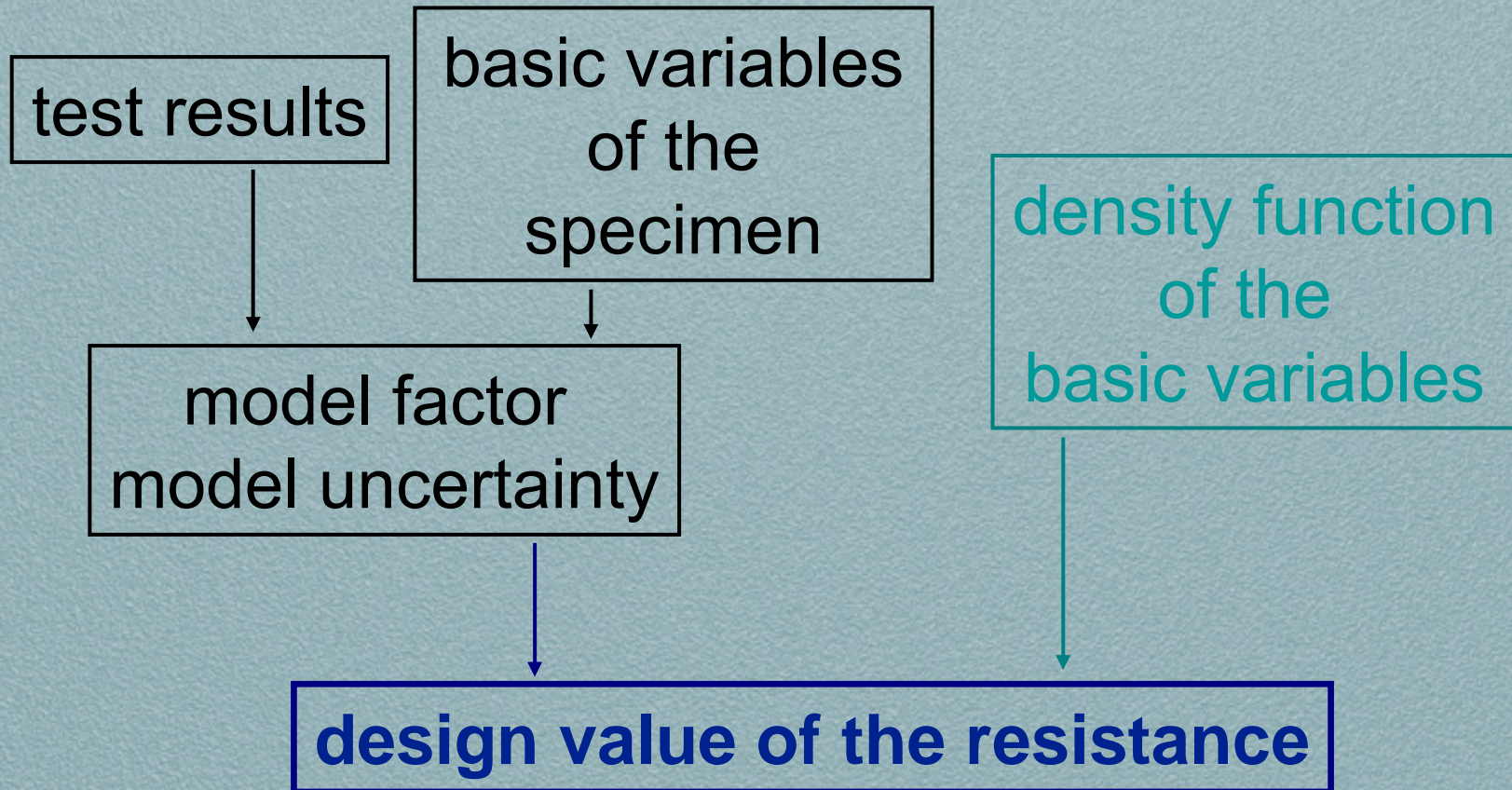
determination of the
design resistance







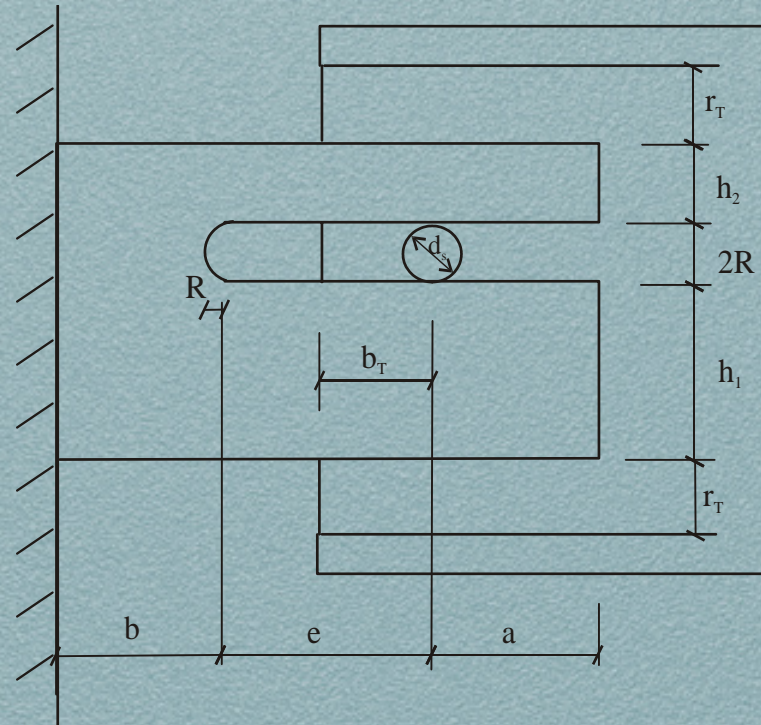
Determination of the design value of the resistance:



design value of the resistance :

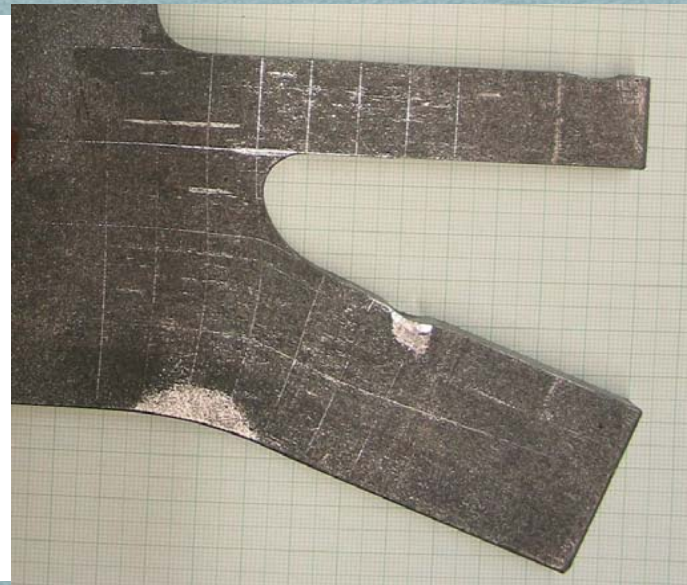
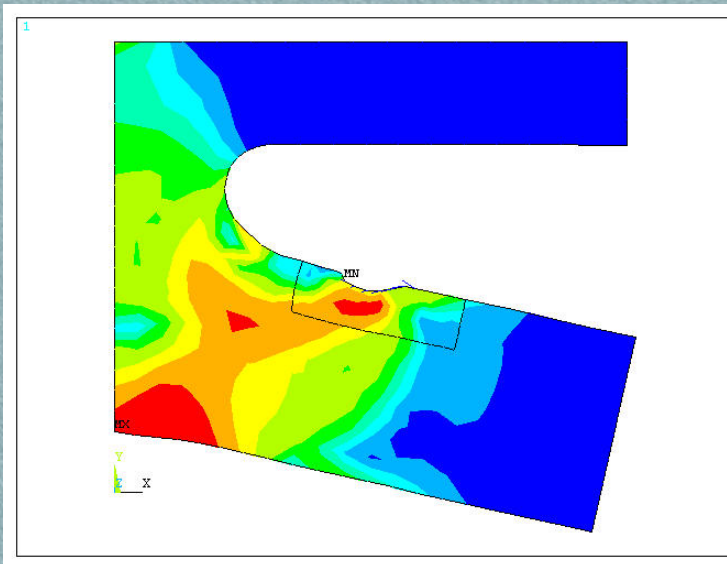
$$P_{t,d} = \frac{1}{\gamma_{Rd}} \frac{h \cdot t \cdot f_y}{\sqrt{16 \frac{e^2}{h^2} + 3}}$$

$$\gamma_{Rd} = 2,5$$



numerical studies:

- diameter of the bolt
- thickness of the plate



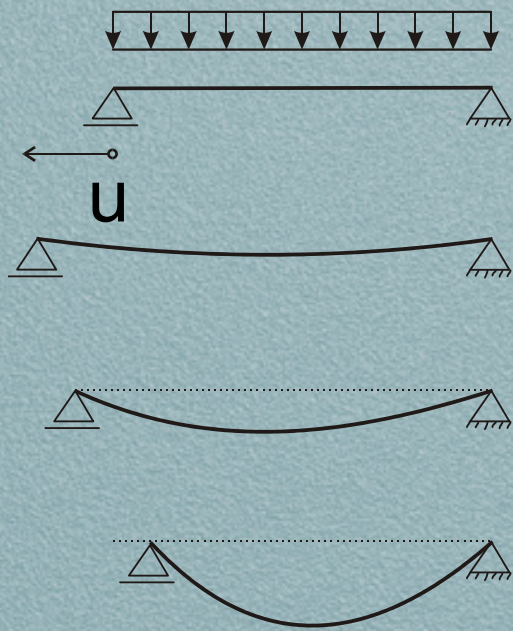
Conclusions:

- load bearing capacity of open slotted holes can be calculated :

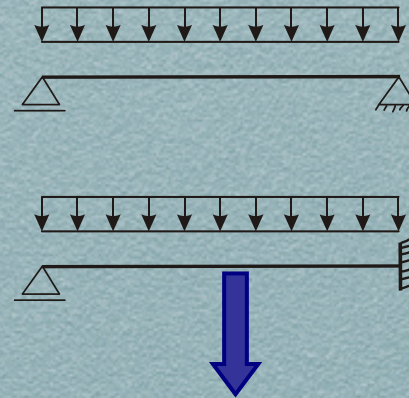
- $$P_{t,d} = \frac{1}{\gamma_{Rd}} \frac{h \cdot t \cdot f_y}{\sqrt{16 \frac{e^2}{h^2} + 3}}$$

- bolt diameter: $\geq 16 \text{ mm}$
- plate thickness: $5 \text{ mm} < t < 15 \text{ mm}$





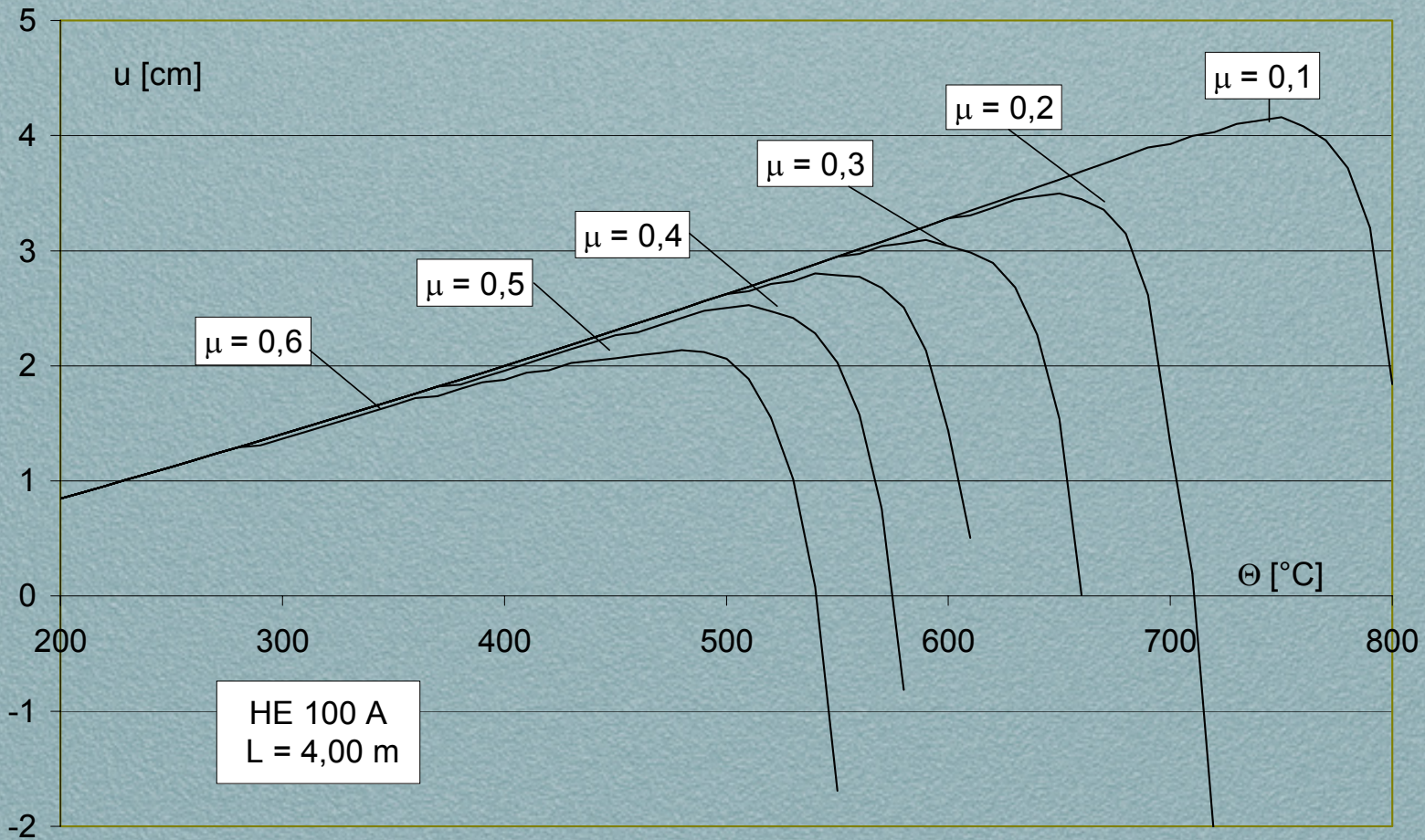
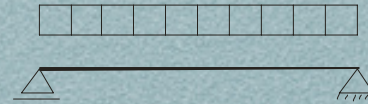
determination of the maximum horizontal displacement:



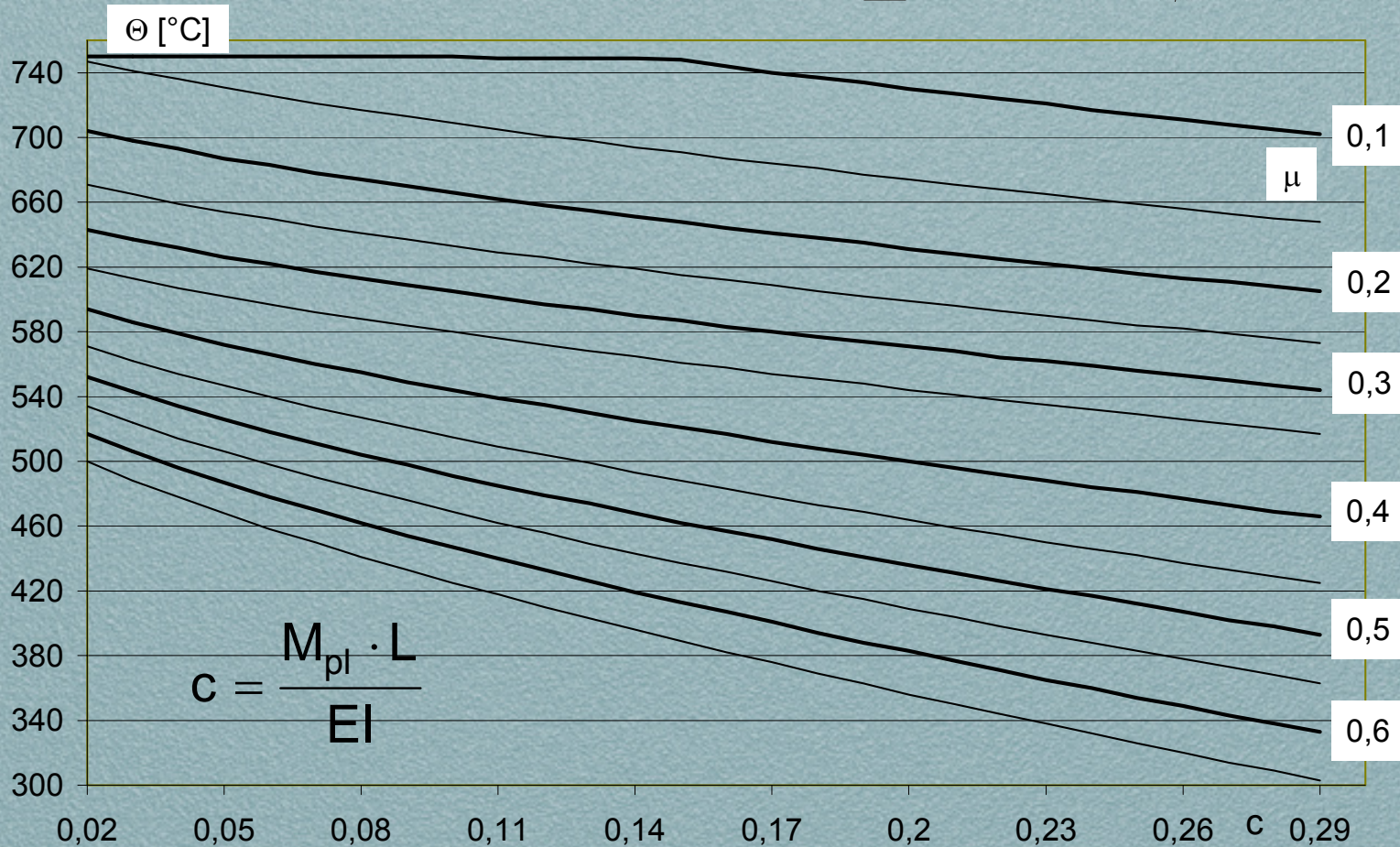
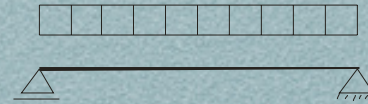
diagrams and formulas to determine:

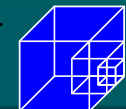
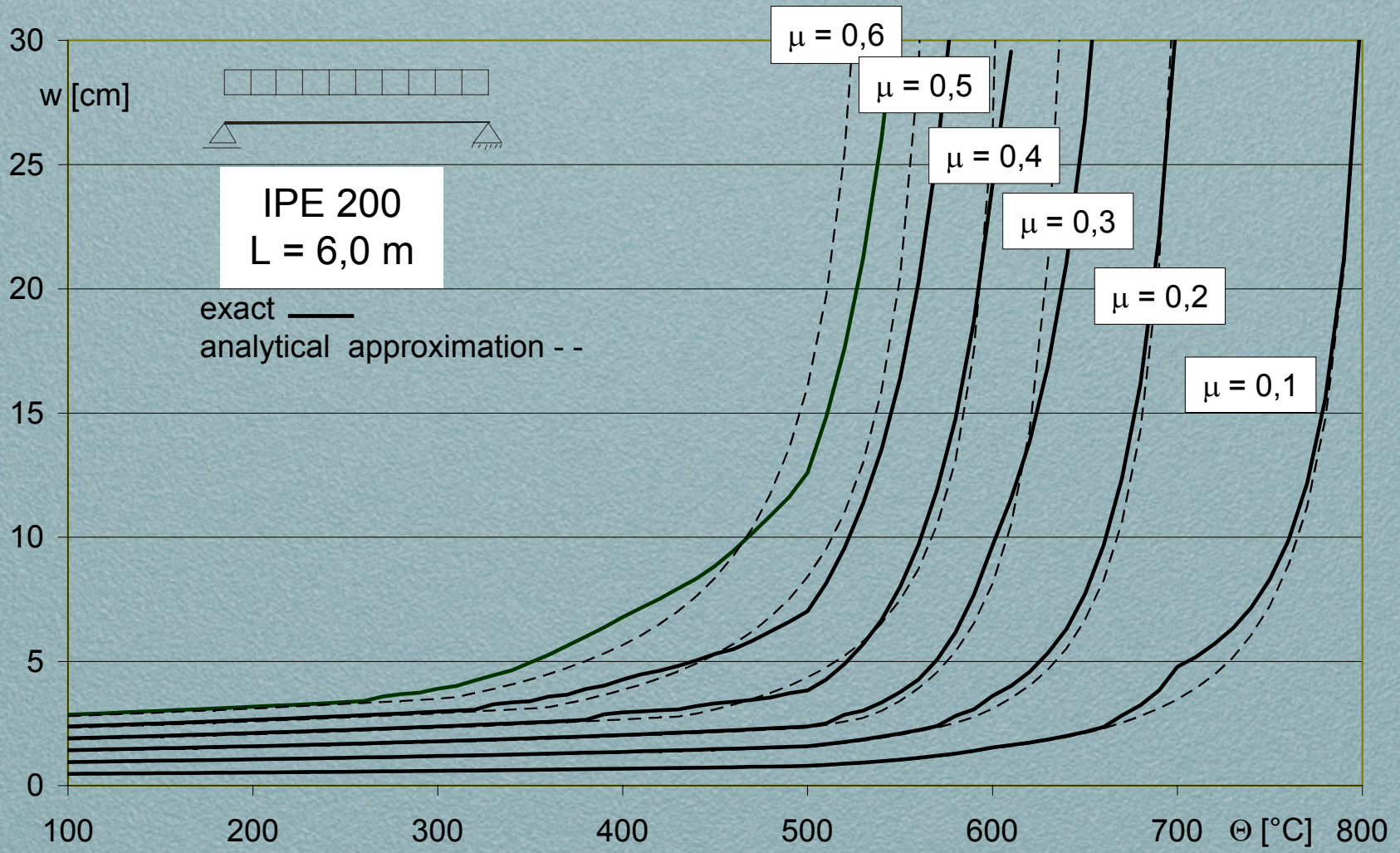
- temperature at maximum displacement
- displacement for a given temperature

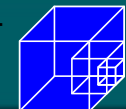
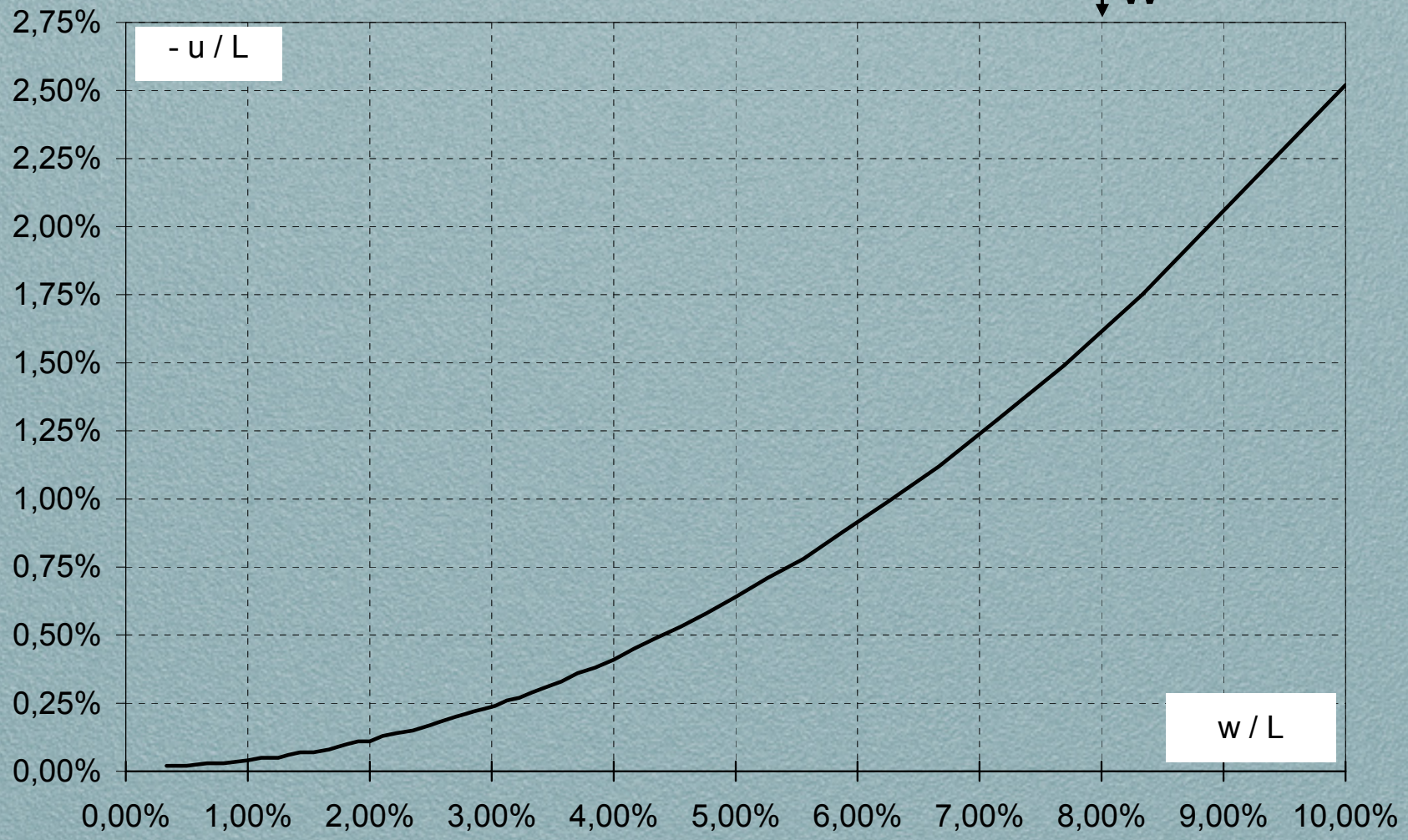
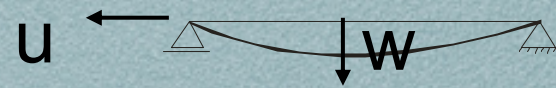
horizontal displacement u:



temperature $\Theta(u_{\max})$:

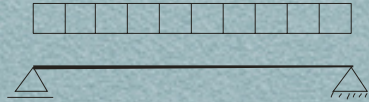






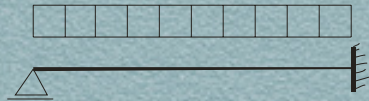
Displacement for a given temperature:

– System:



– - Diagrams and Formulas

– System:

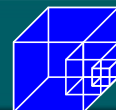


- Diagram Temperature $\Theta(u_{\max})$:

- Thermal elongation EC-3-1-2

The research project has facilitated methods to design breaking points at fire walls:

1. Maximum load bearing capacity of bolts
2. Open slotted holes
3. Maximum displacement of beams



Thank you for your attention

