Some aspects of robustness of RC structures

Geoffrey Decan and Luc Taerwe

Workshop Zürich – COST Action TU0601 – 05/02/2008

Outline

- Introduction
- RC slabs
- Scope of research on RC beams
- Modelling of beams
- Global behaviour of frames under fire conditions
- Conclusions

personal reflection

“poor” designer in regular design situation is faced with…

- Eurocodes
- local regulations
- guides of good practice
- ISO
- CEN
- ASCE
- ACI
- COST documents
- ……

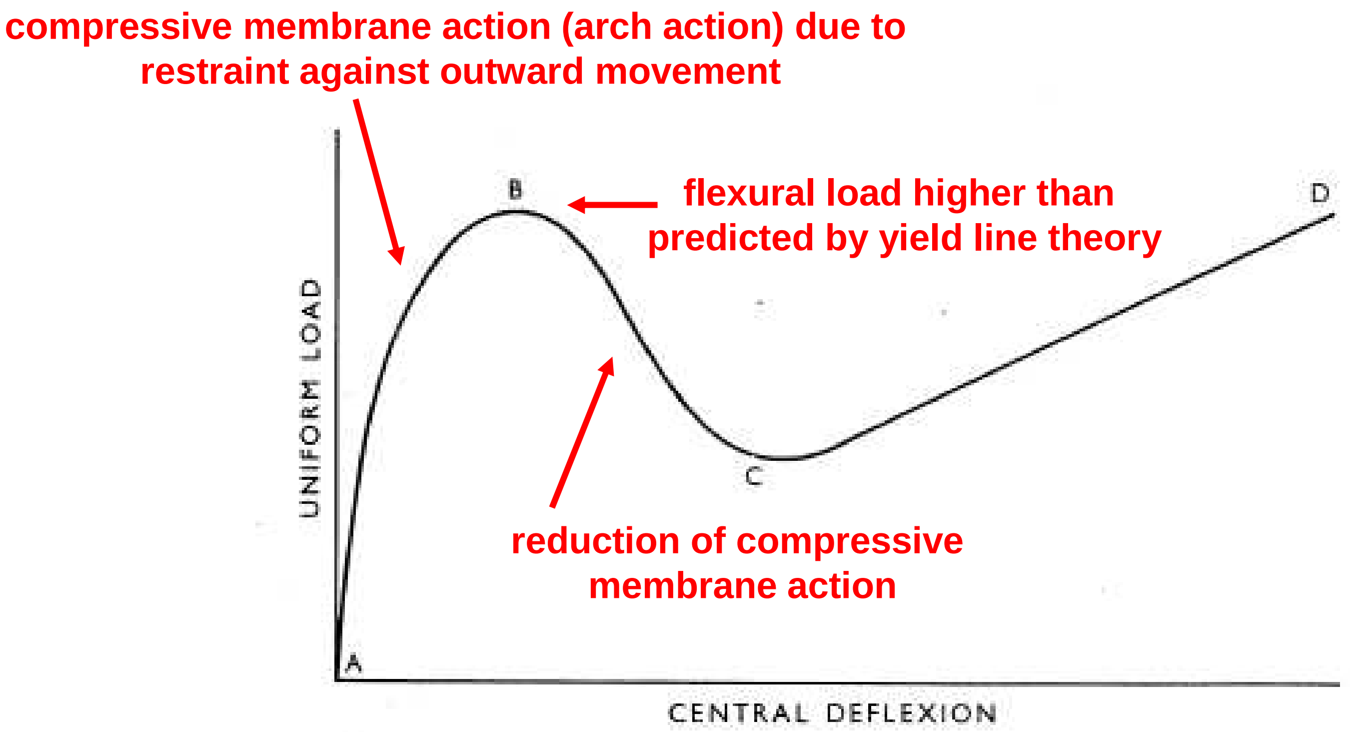
now we tell him: your design is not complete
what about ROBUSTNESS?

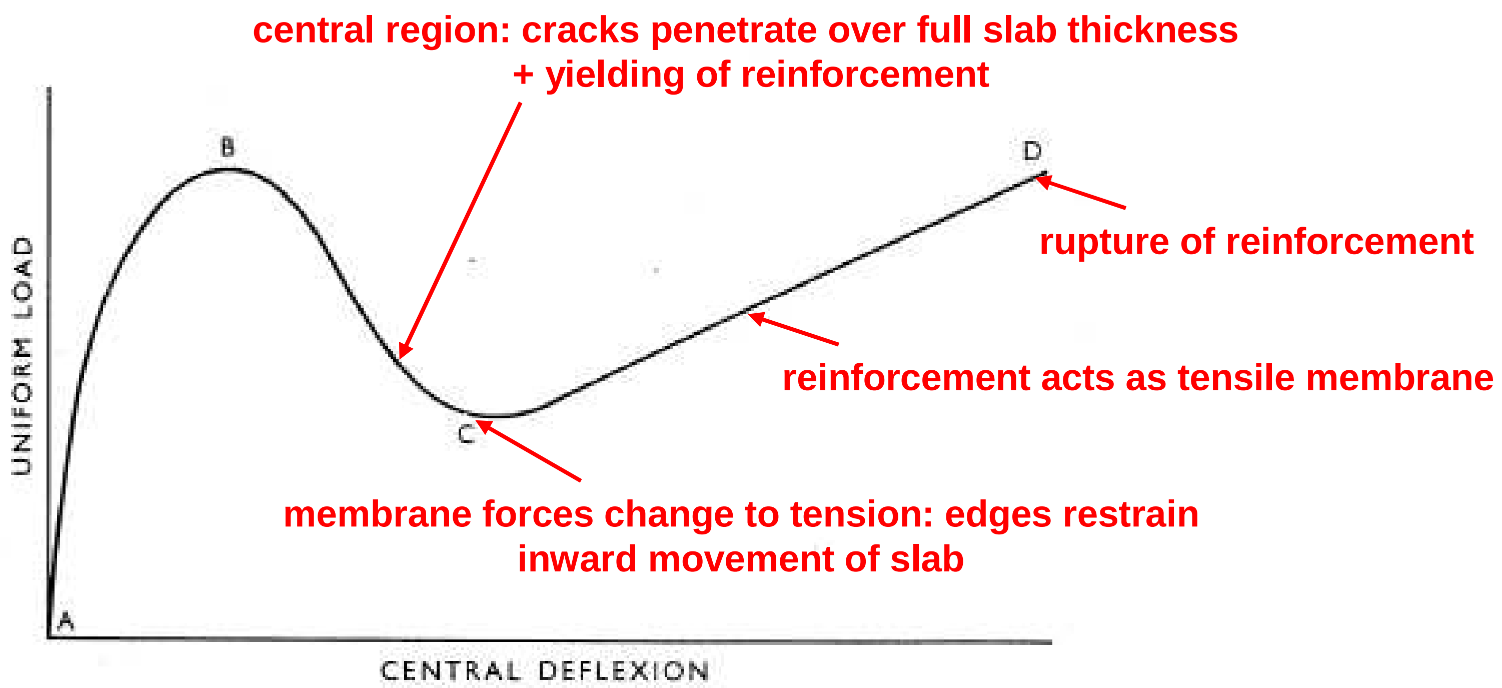
Take into account
- extreme loads >> design values *(heavy tail in distribution??)*
- other types of loads *(blast, impact, undefined accidental loads…)*
- human error *(design, execution,…)*
- change of geometry: “missing” members

“fuzzy” concepts

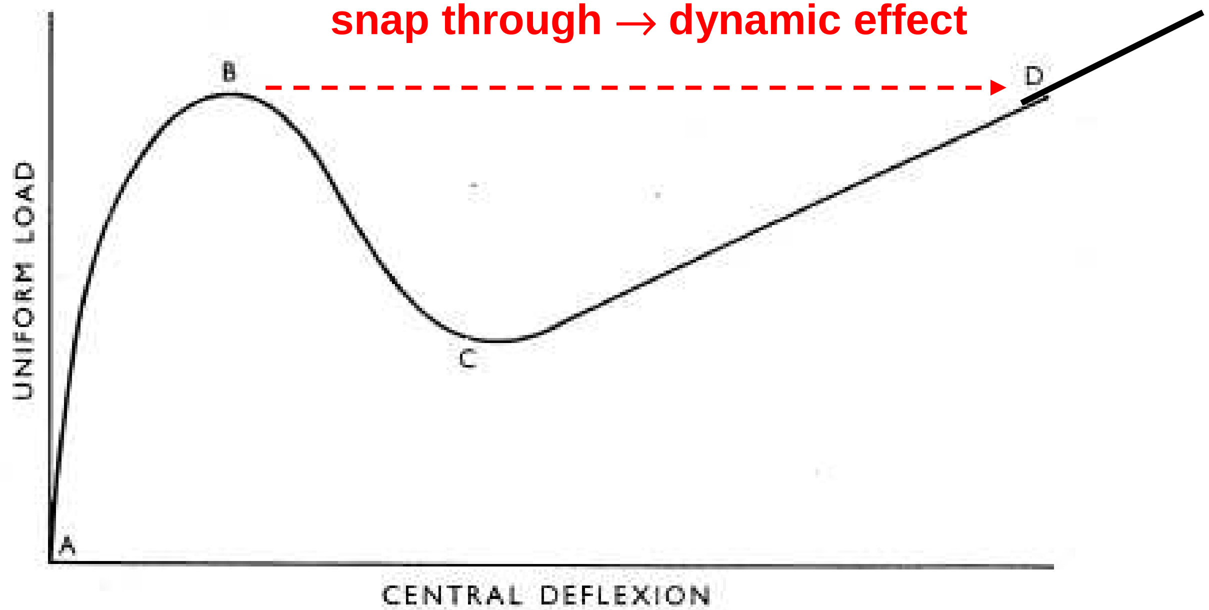
can we require this for every project?
>> robustness classes? *(cfr. Eurocode 0: RC, CC, IL,…)*

Concrete slab with edges restrained against lateral displacement (stiffness of surrounding panels)

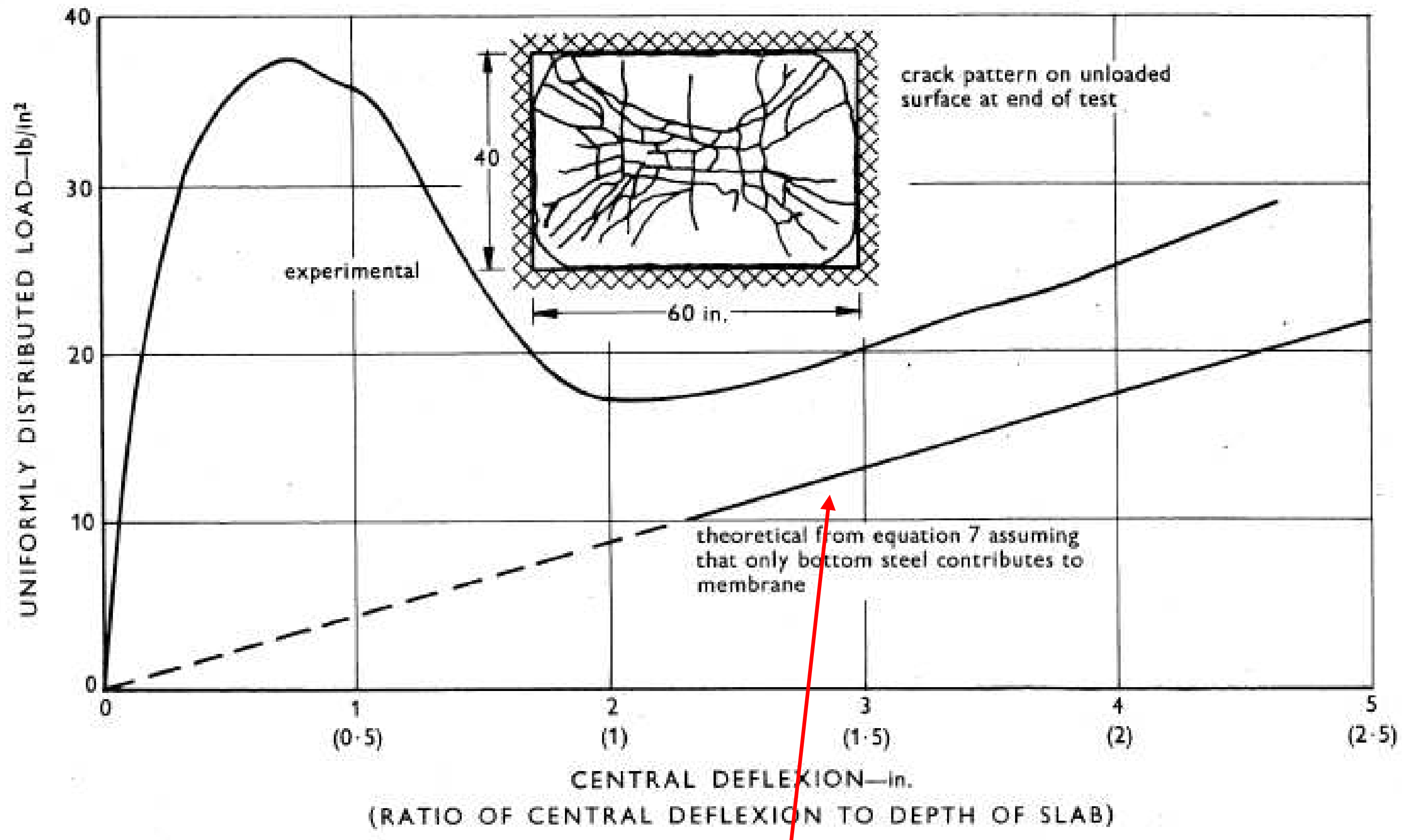



central region: cracks penetrate over full slab thickness
+ yielding of reinforcement
B
D
rupture of reinforcement
UNIFORM LOAD
reinforcement acts as tensile membrane
C
membrane forces change to tension: edges restrain
inward movement of slab
A
CENTRAL DEFLEXION

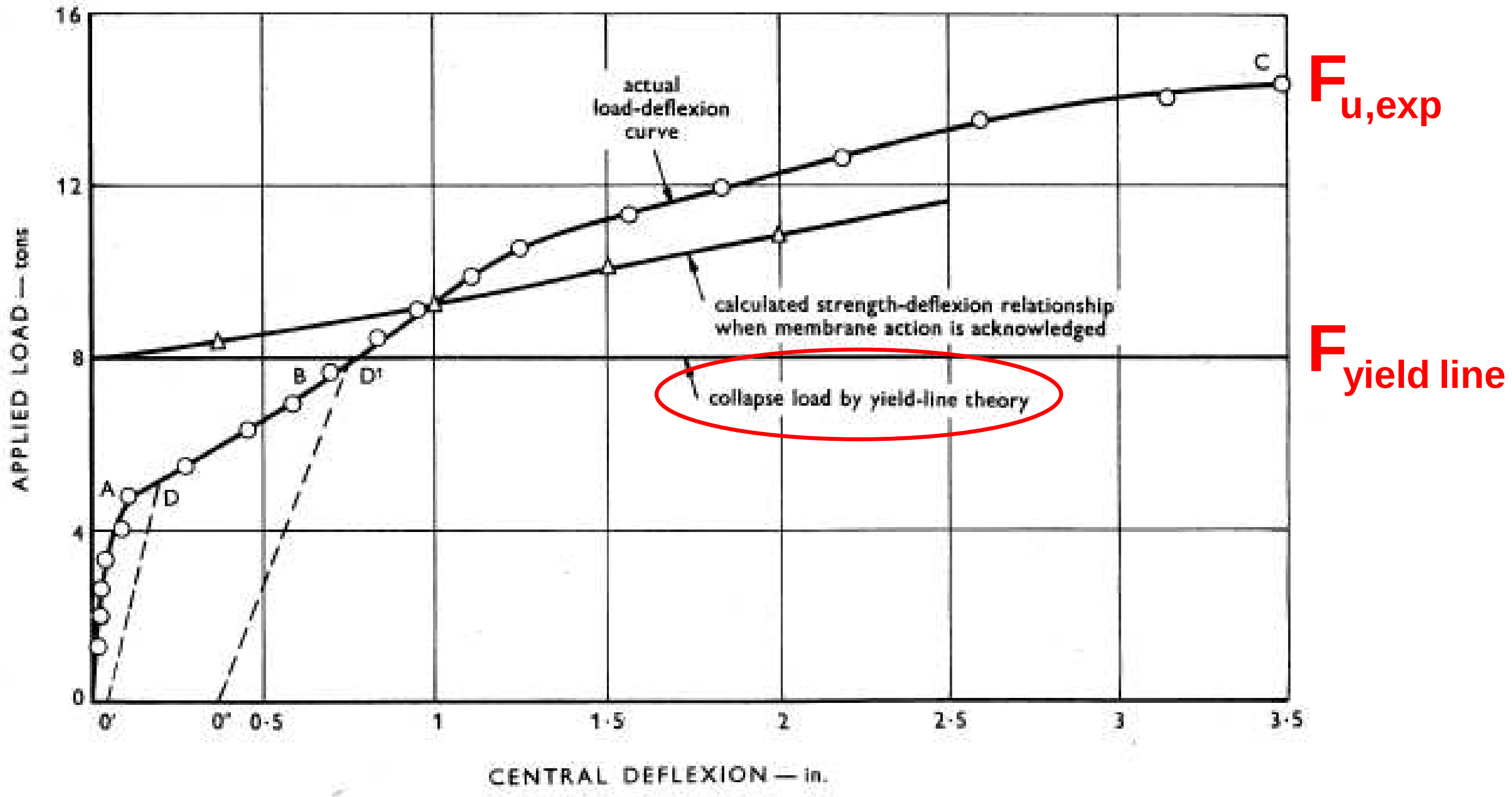
gravity loading



Tests by R. Park (MCR 1964)



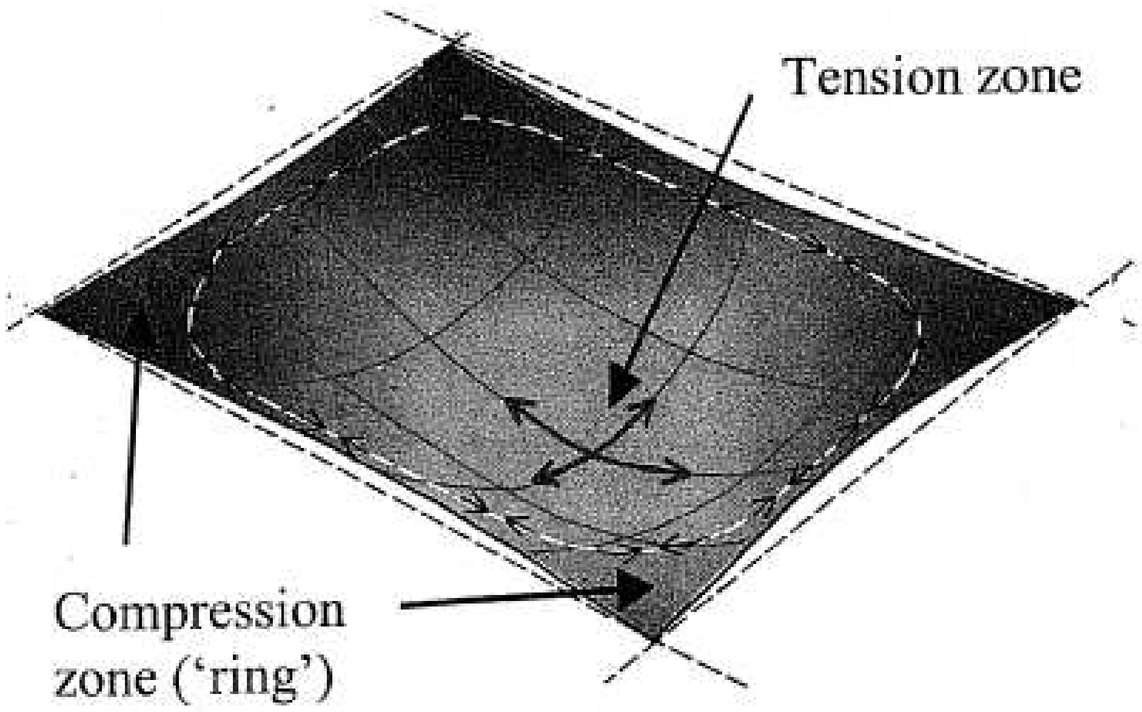
pure tensile membrane action; neglecting strain - hardening



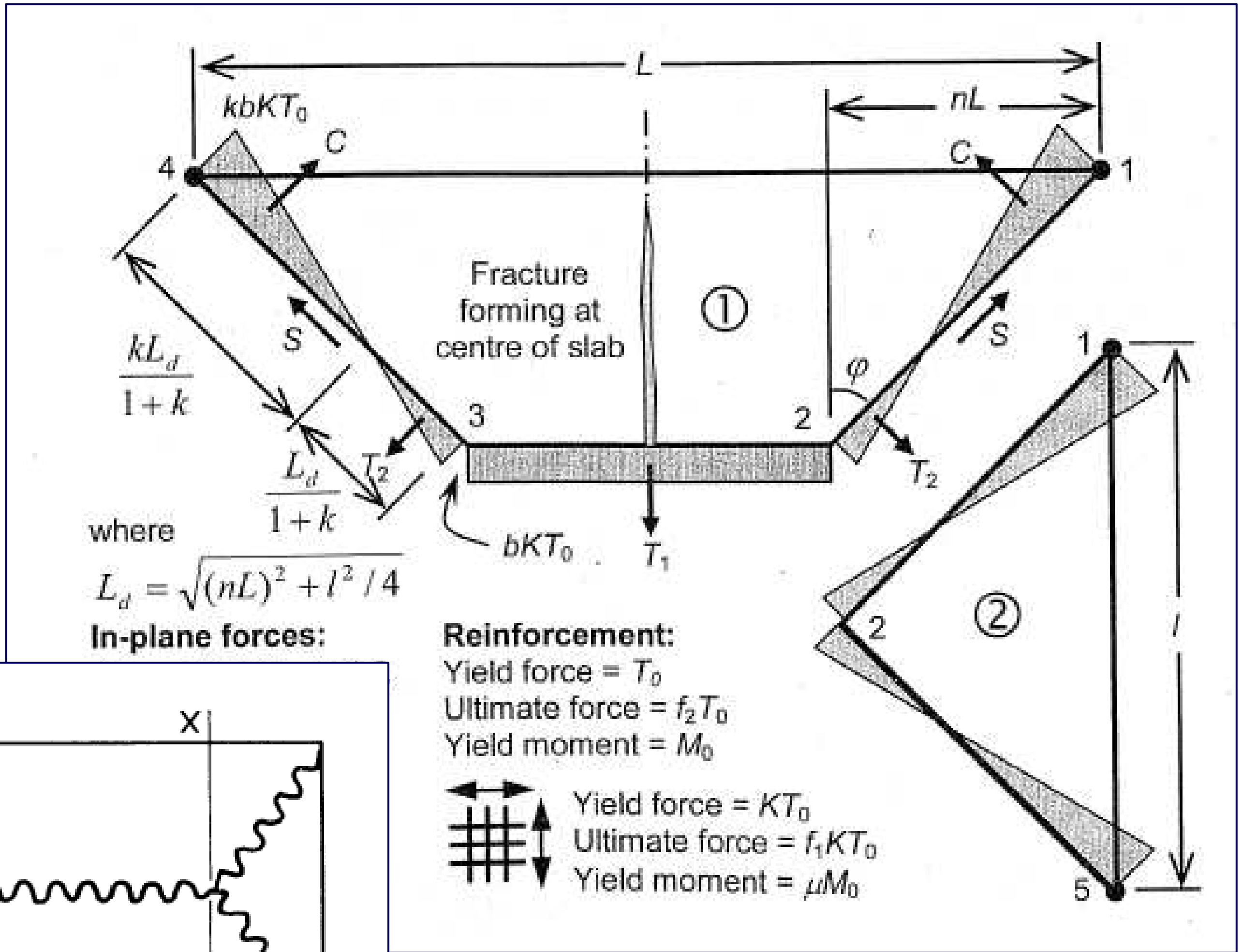
$$\text{inherent robustness} = \frac{F_{u,exp}}{F_{yield\ line}}$$

if taken into account in regular design: too large deflections at SLS

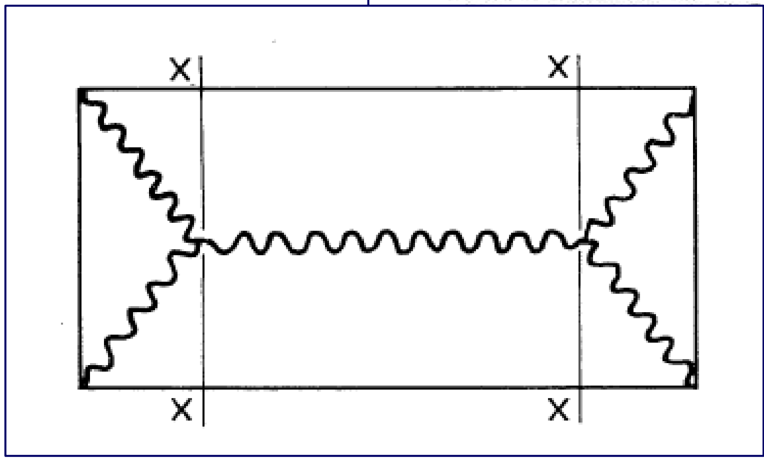
membrane action in unrestrained slabs (large displacements)



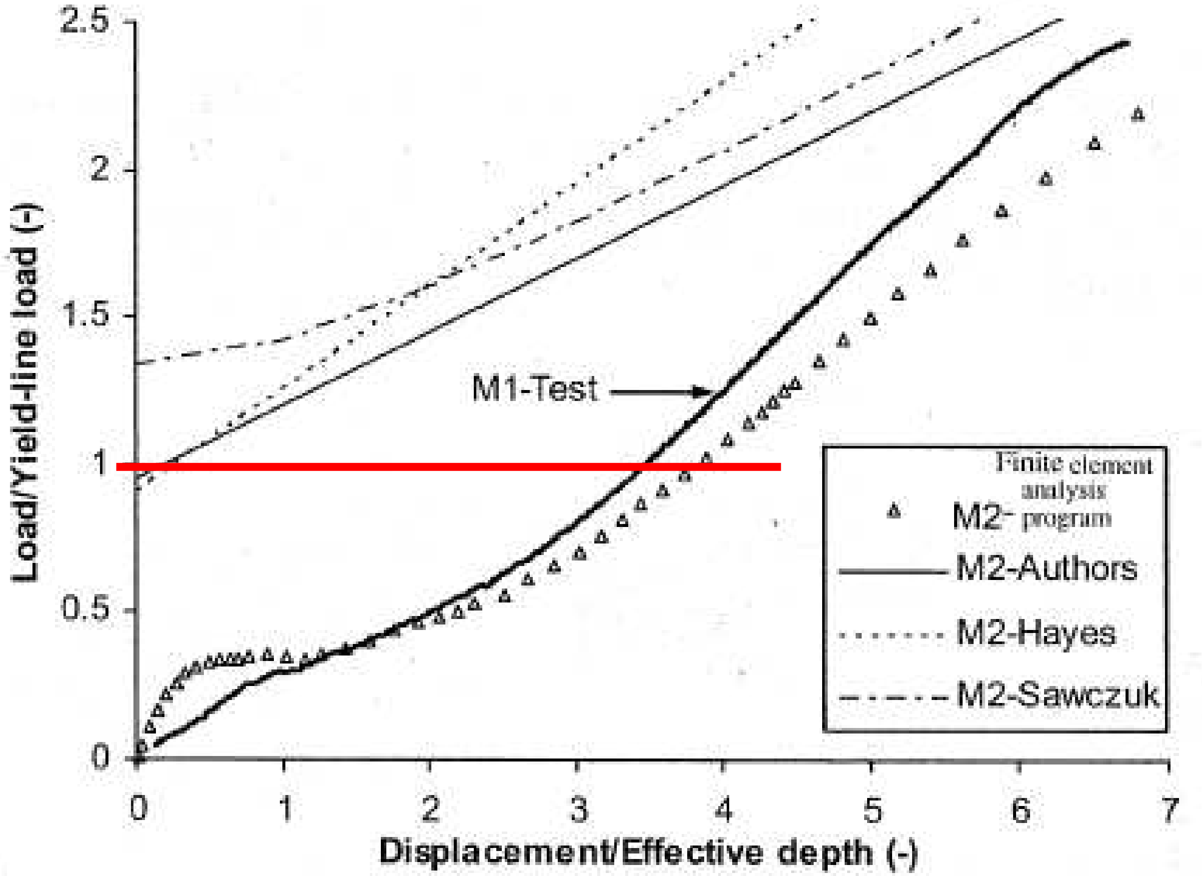
C.G. Baily, W.S. Toh, B.M. Chan
ACI Structural Journal, Jan-Feb 2008



L
nL
$kbKT_0$
C
C
4
1
Fracture forming at centre of slab
①
S
S
φ
$\frac{kL_d}{1+k}$
3
2
1
T_2
T_2
$\frac{L_d}{1+k}$
where
bKT_0
T_1
$L_d = \sqrt{(nL)^2 + l^2/4}$
②
2
l
In-plane forces:
Reinforcement:
Yield force = T_0
Ultimate force = f_2T_0
Yield moment = M_0
Yield force = KT_0
Ultimate force = f_1KT_0
Yield moment = μM_0
5



X
X
X
X



UNIVERSITEIT GENT

Scope of research:

Design codes for RC structures provide rules for

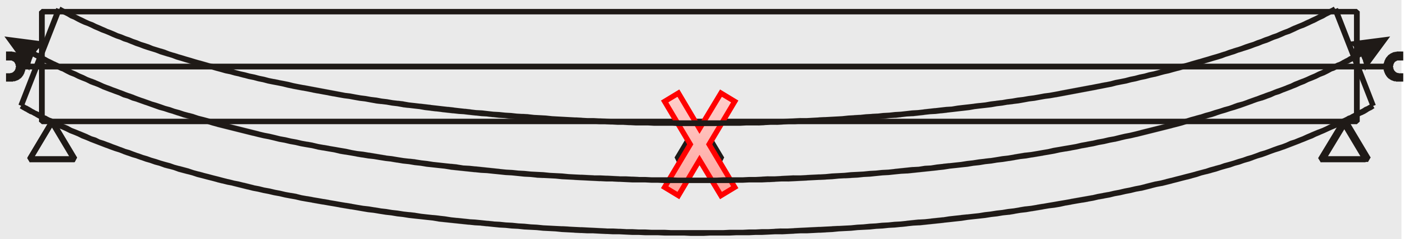
- minimum amount of reinforcing steel
- detailing rules e.g. reinforcement arrangement at intermediate and end supports of beams and slabs, in columns and walls etc.
- ductility conditions
- reinforcement requirements for fire design

Do these code provisions contribute to robustness?

If so: basic robustness with only marginal extra cost

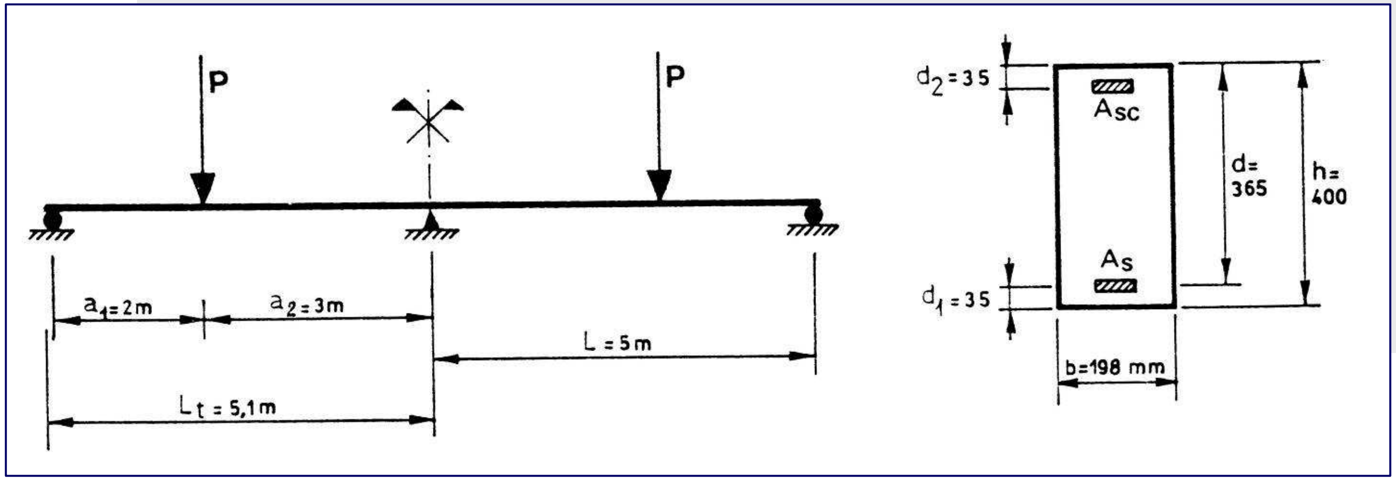
Beams with horizontal constraints

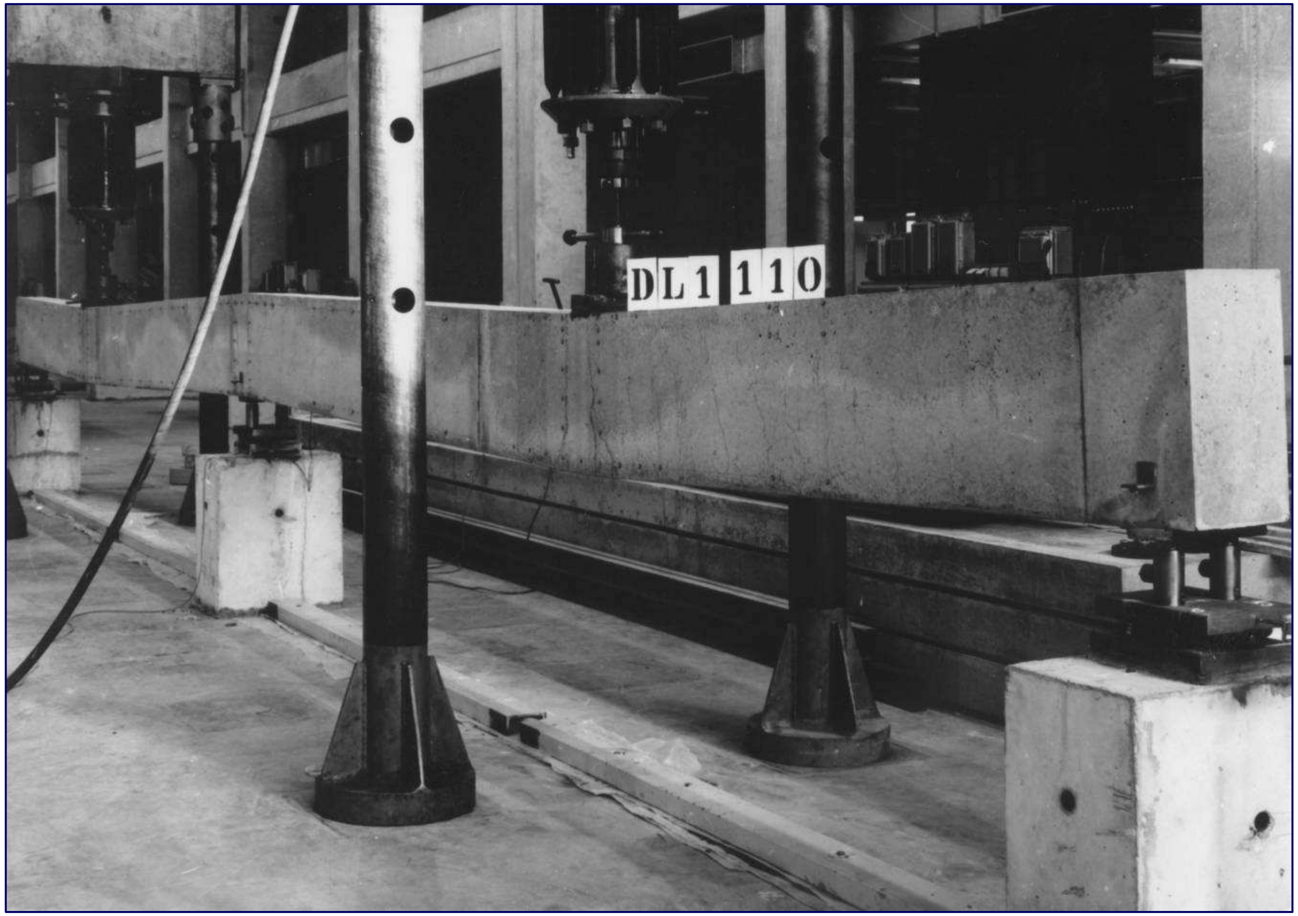
- tying (tension ties provisions in EC2)
- anchorage



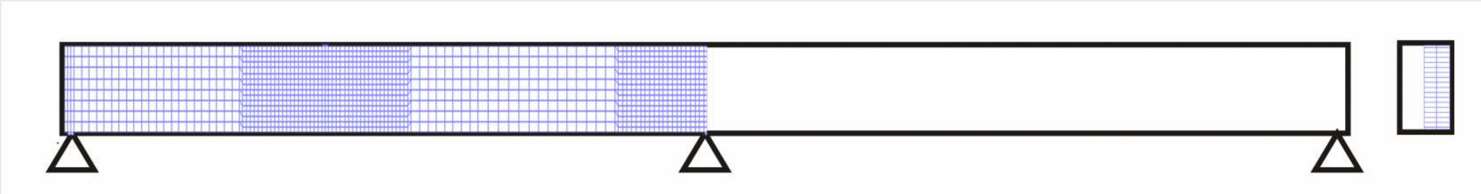
Modelling

- continuous RC beams with two equal spans of 5m length cross section: 400 mm x 198 mm
- subjected to two point loads
- reinforcement calculated according to EC2
- variations of reinforcement detailing were considered

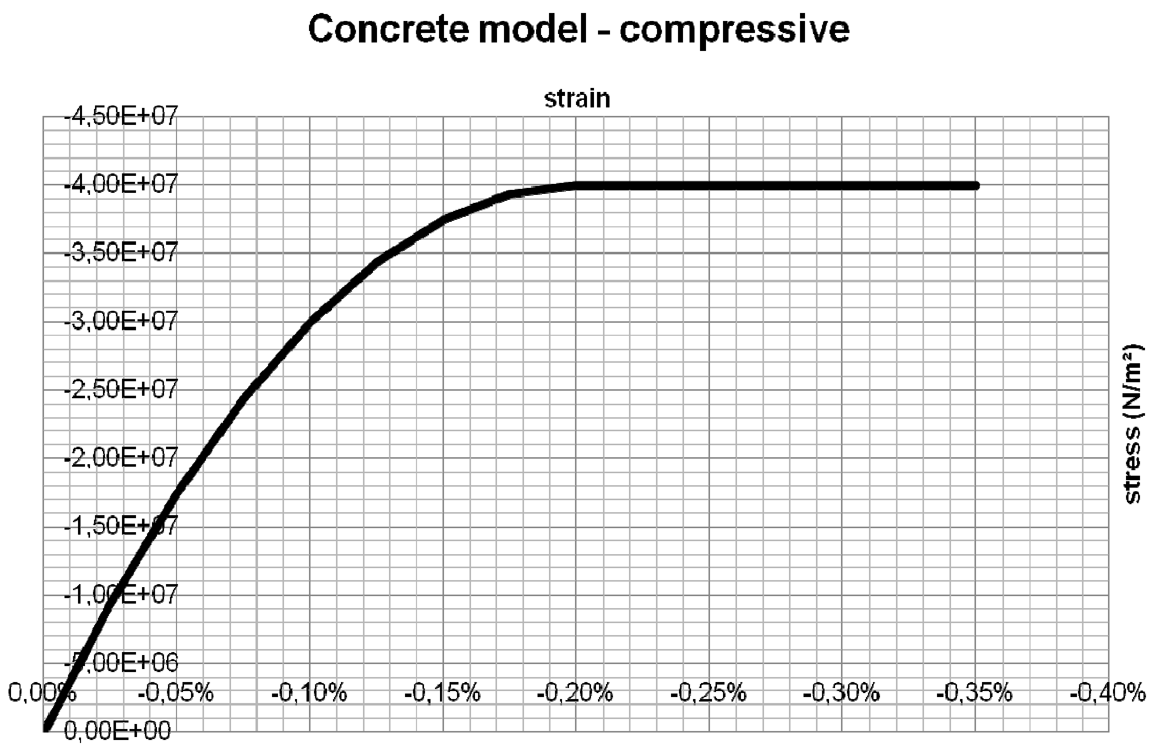



DL1 110

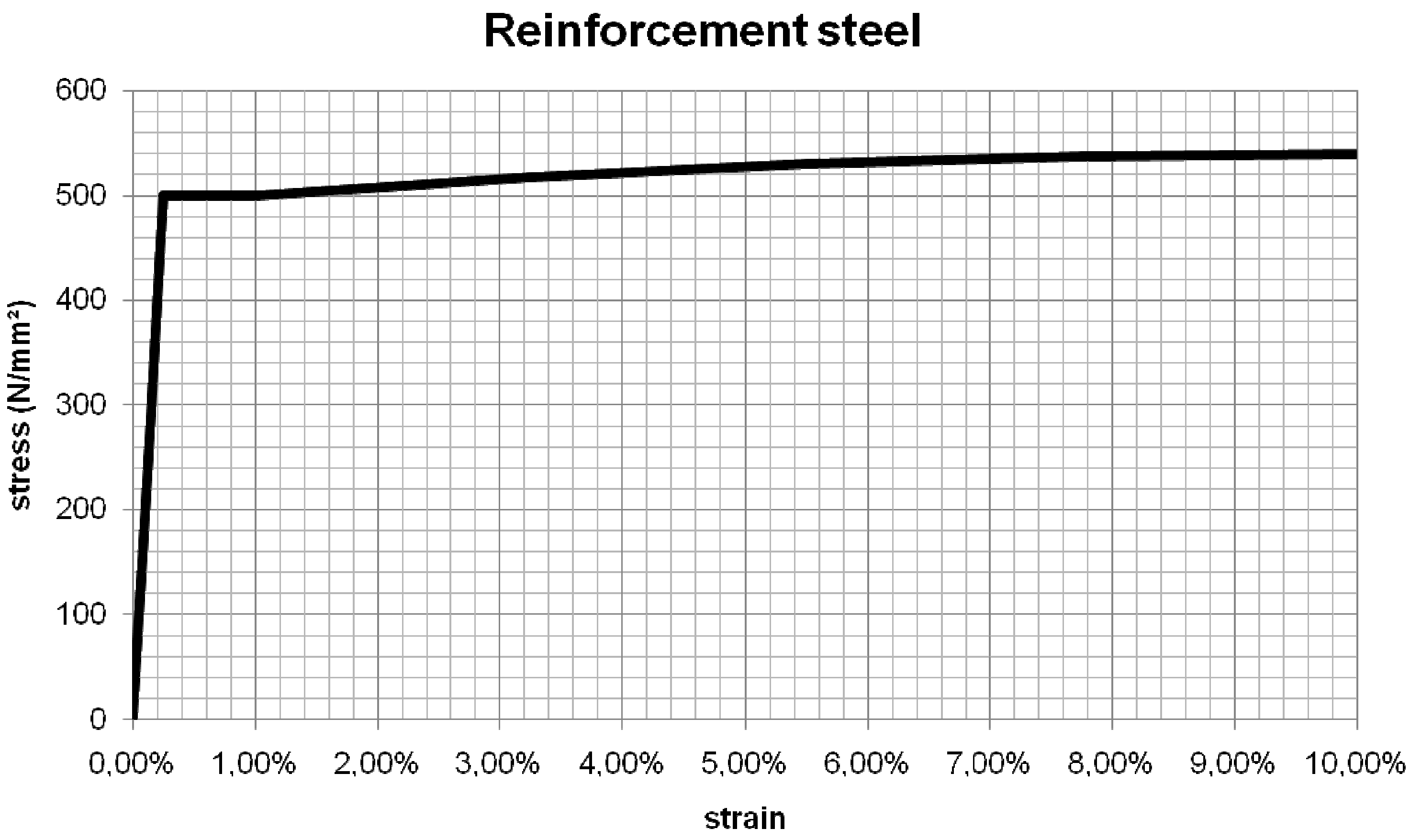
- Symmetry: only ¼ modelled



- mesh refinement where plastic hinges may occur
- **removal of central support (column)** approximated with static non-linear analysis
- horizontal restraint (infinite rigidity)

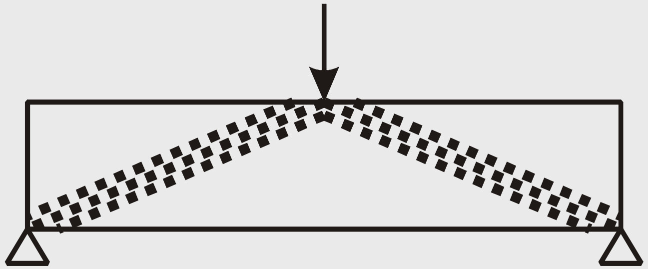


Hordijk model for tension softening


Reinforcement steel
600
500
400
300
200
100
0
stress (N/mm²)
0,00%
1,00%
2,00%
3,00%
4,00%
5,00%
6,00%
7,00%
8,00%
9,00%
10,00%
strain

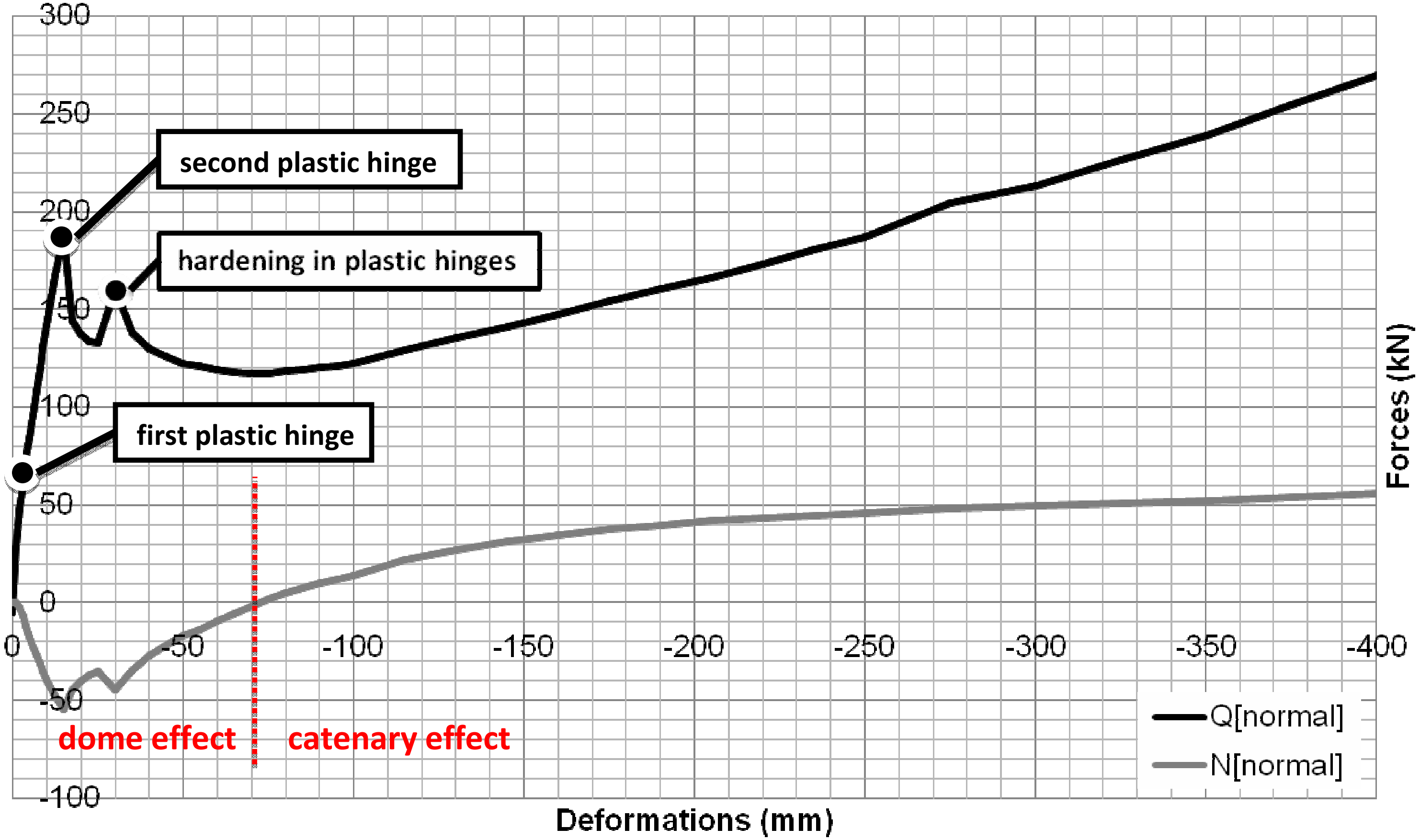
Results

- horizontal constraint
  - ➢ small deformation: arch effect

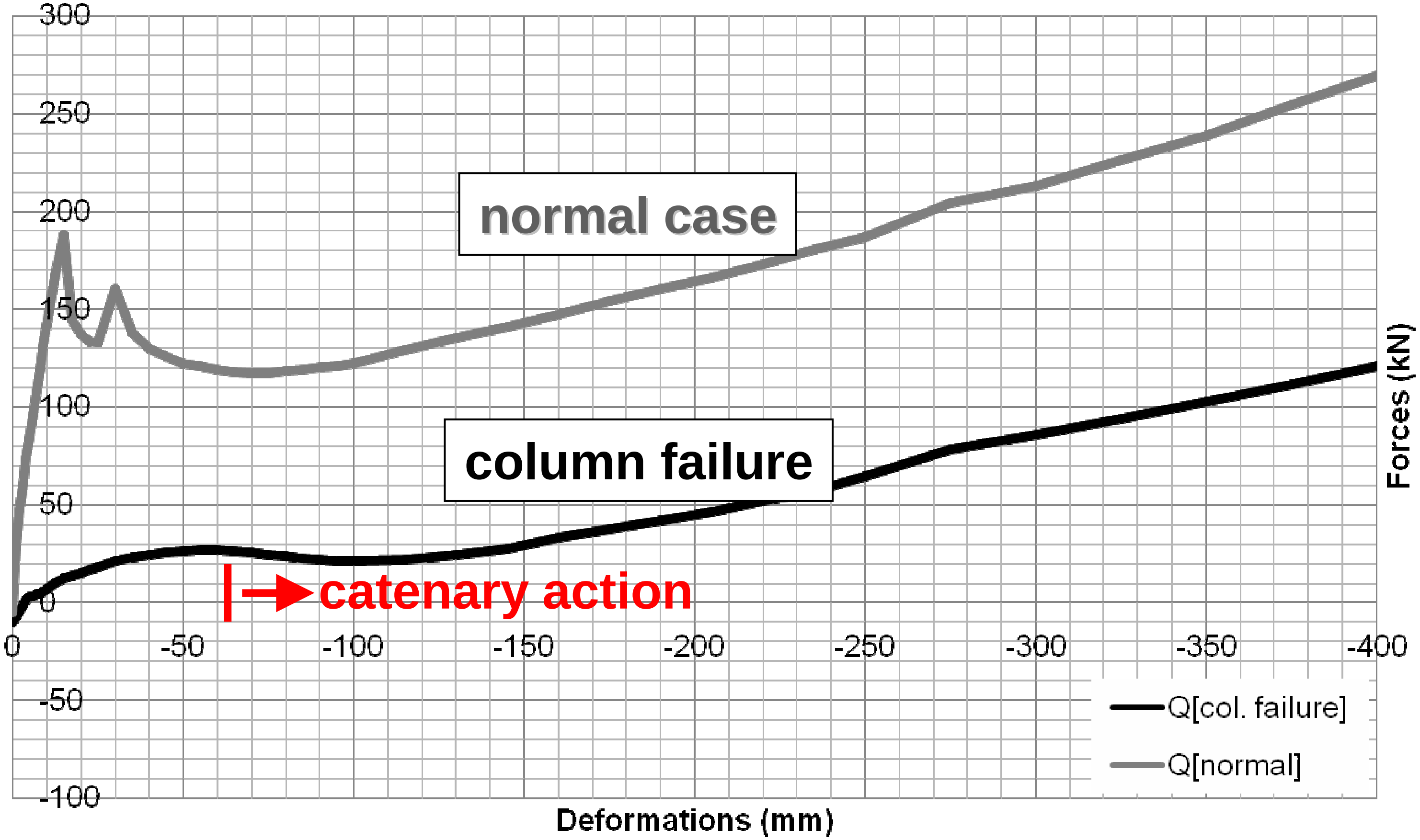


  - ➢ large deformation: catenary effect

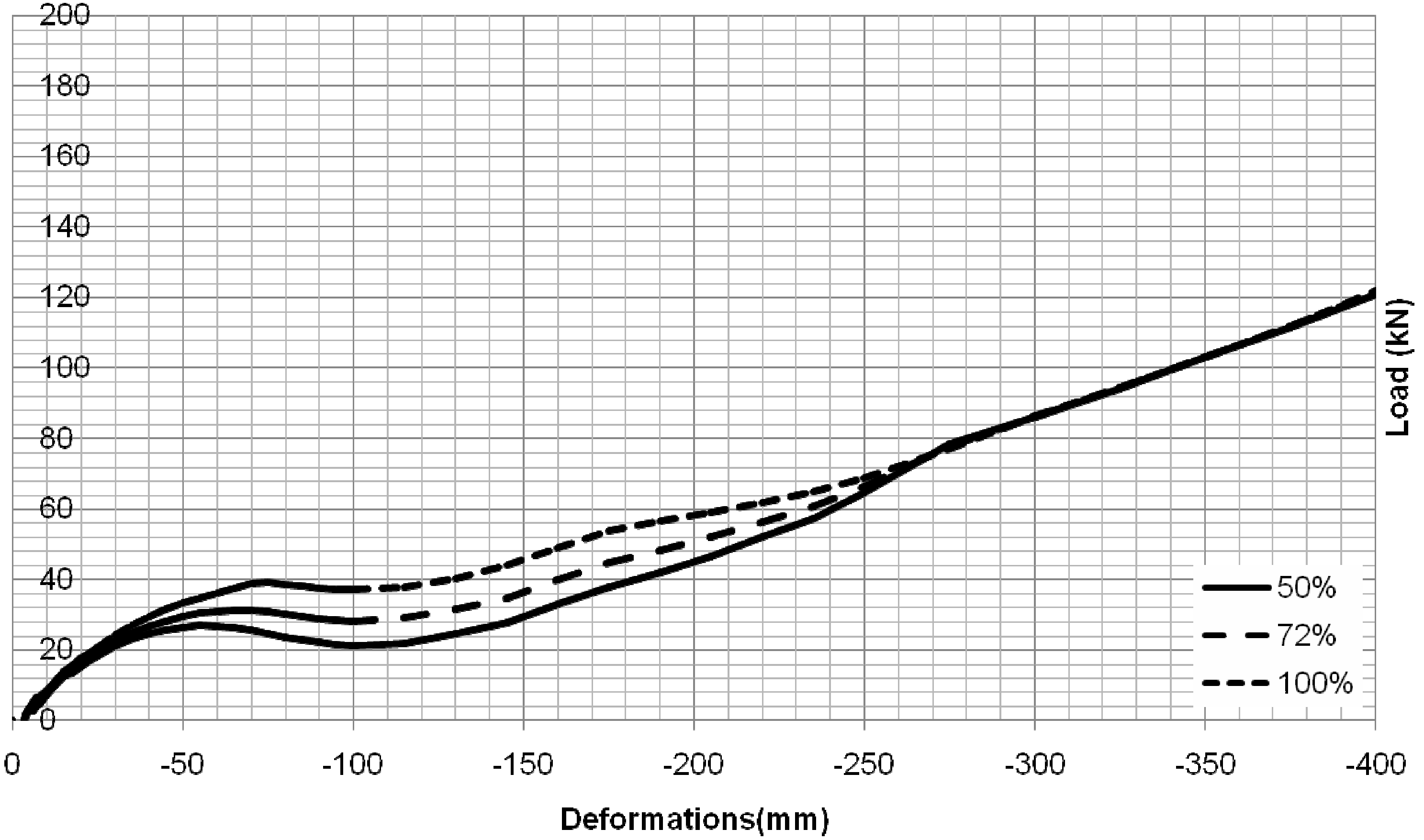
normal case: central support in place

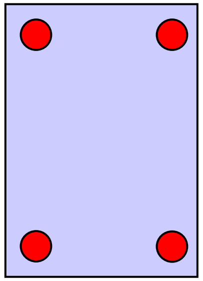


accidental case: central support removed



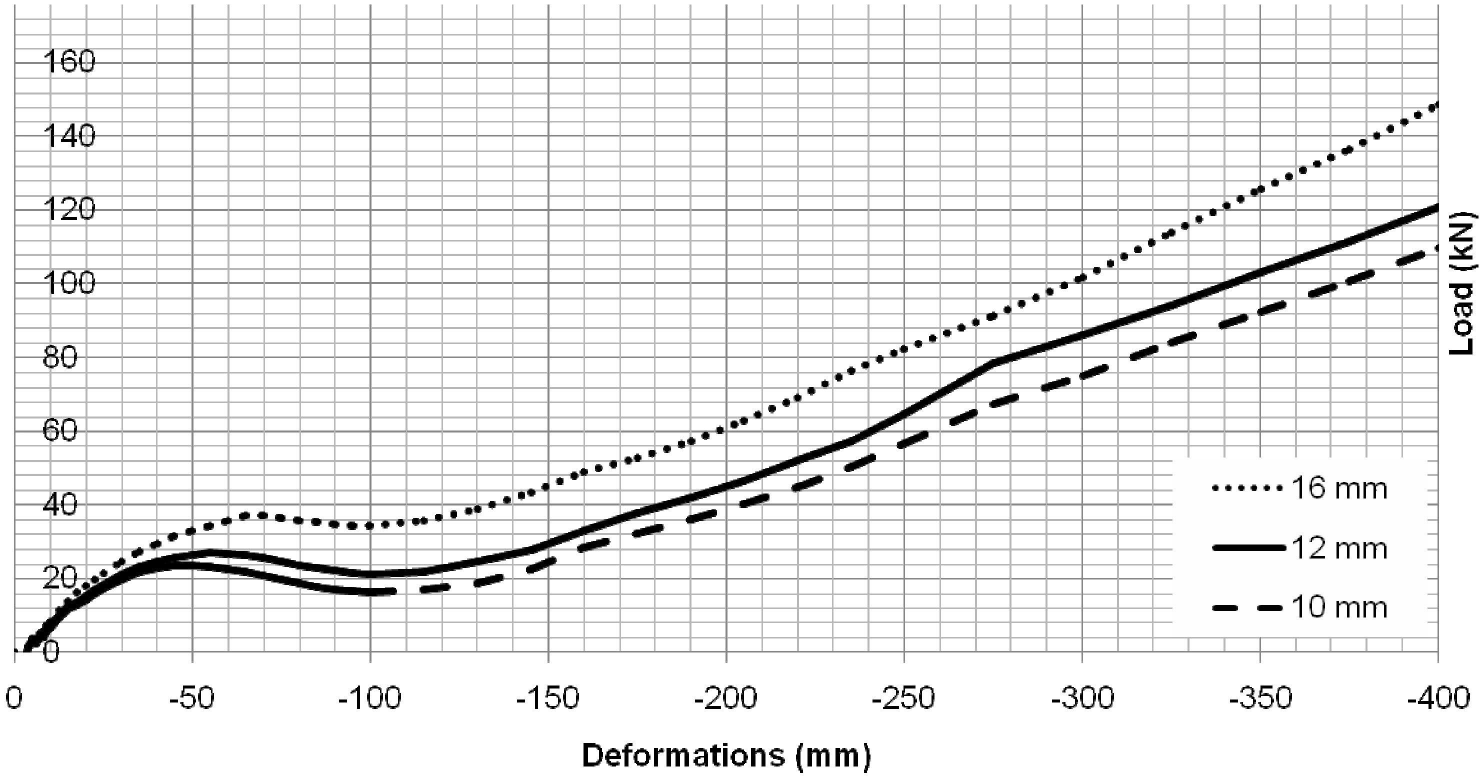
influence of amount of bottom reinforcement continued over central support





bars continuous over full length of beam

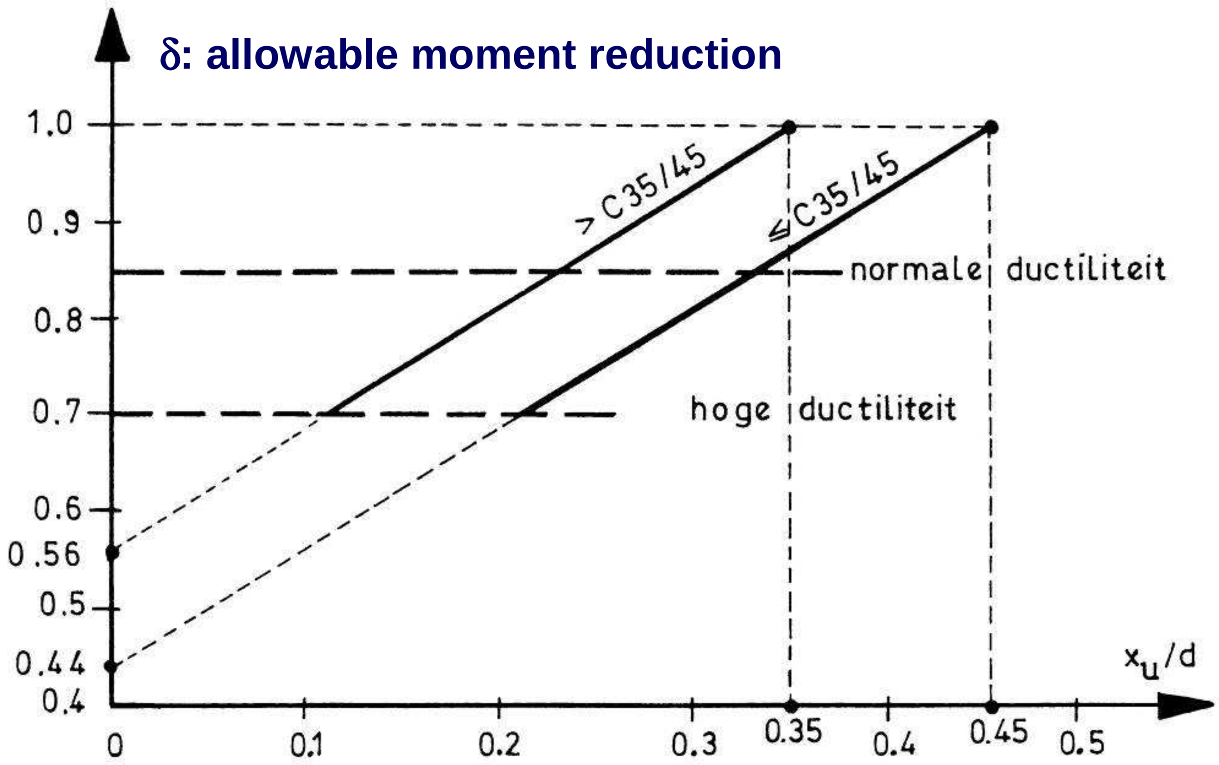
influence of bar diameter



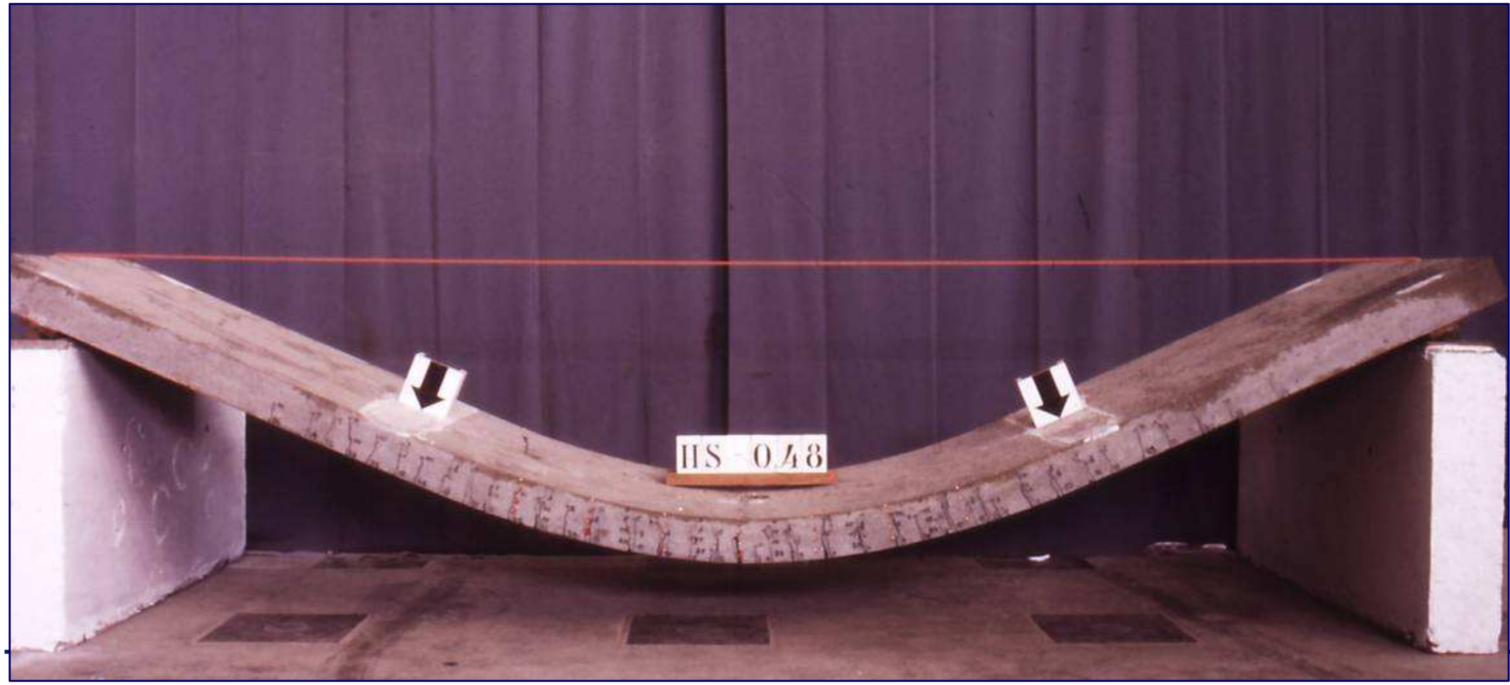
Ultimate load and deflection dependent on ductility of reinforcing steel

normal ductility : $\varepsilon_{uk} \geq 2{,}5$ % en $(f_t/f_y)_k \geq 1{,}05$

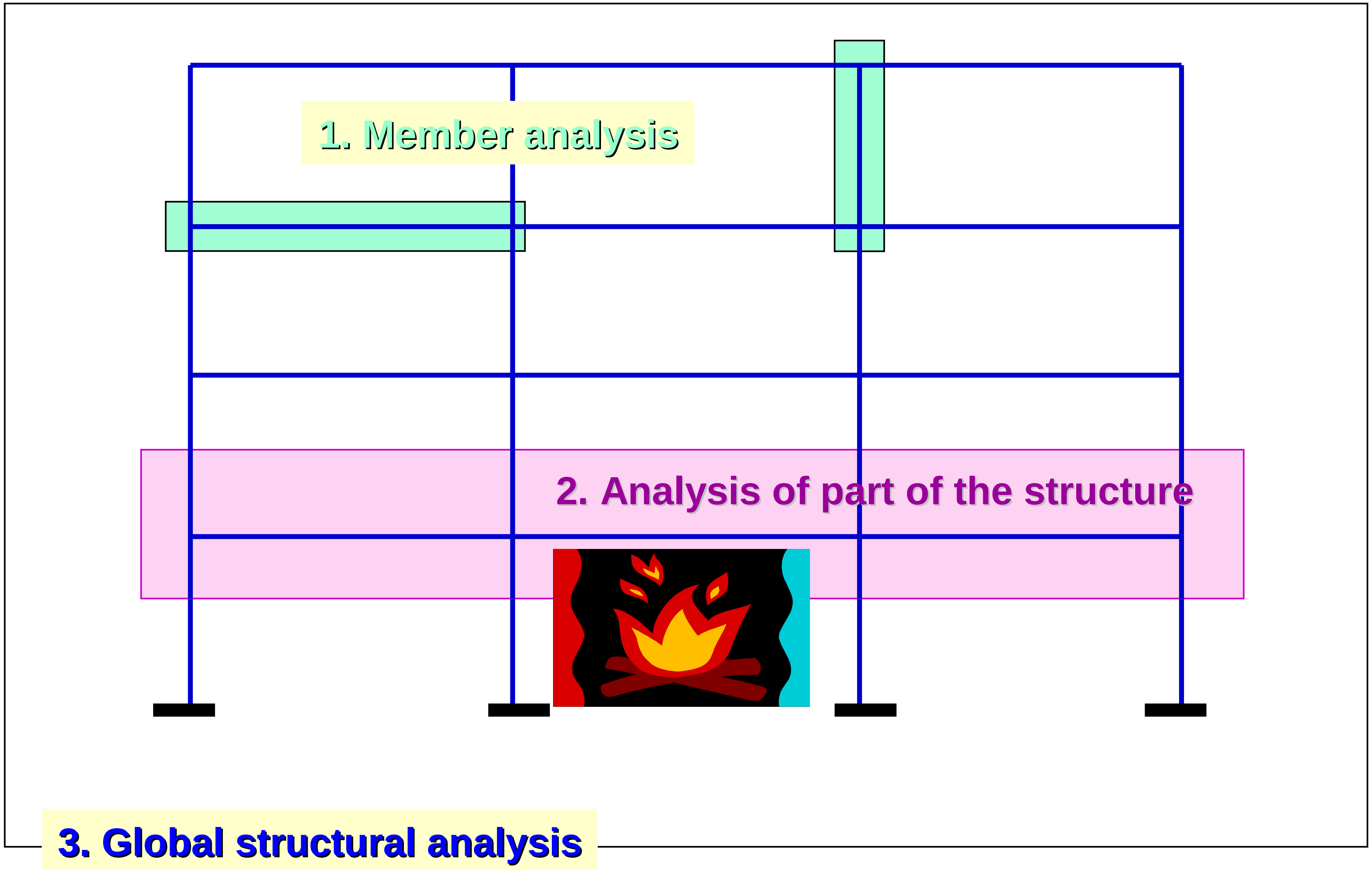
high ductility : $\varepsilon_{uk} \geq 5{,}0$ % en $(f_t/f_y)_k \geq 1{,}08$




σs
fy
fyd
strain-hardening
εyd
εu
εs


HS - 048

STRUCTURAL FIRE DESIGN (EN 1991-1-2)



fib Working Party 4.3.2

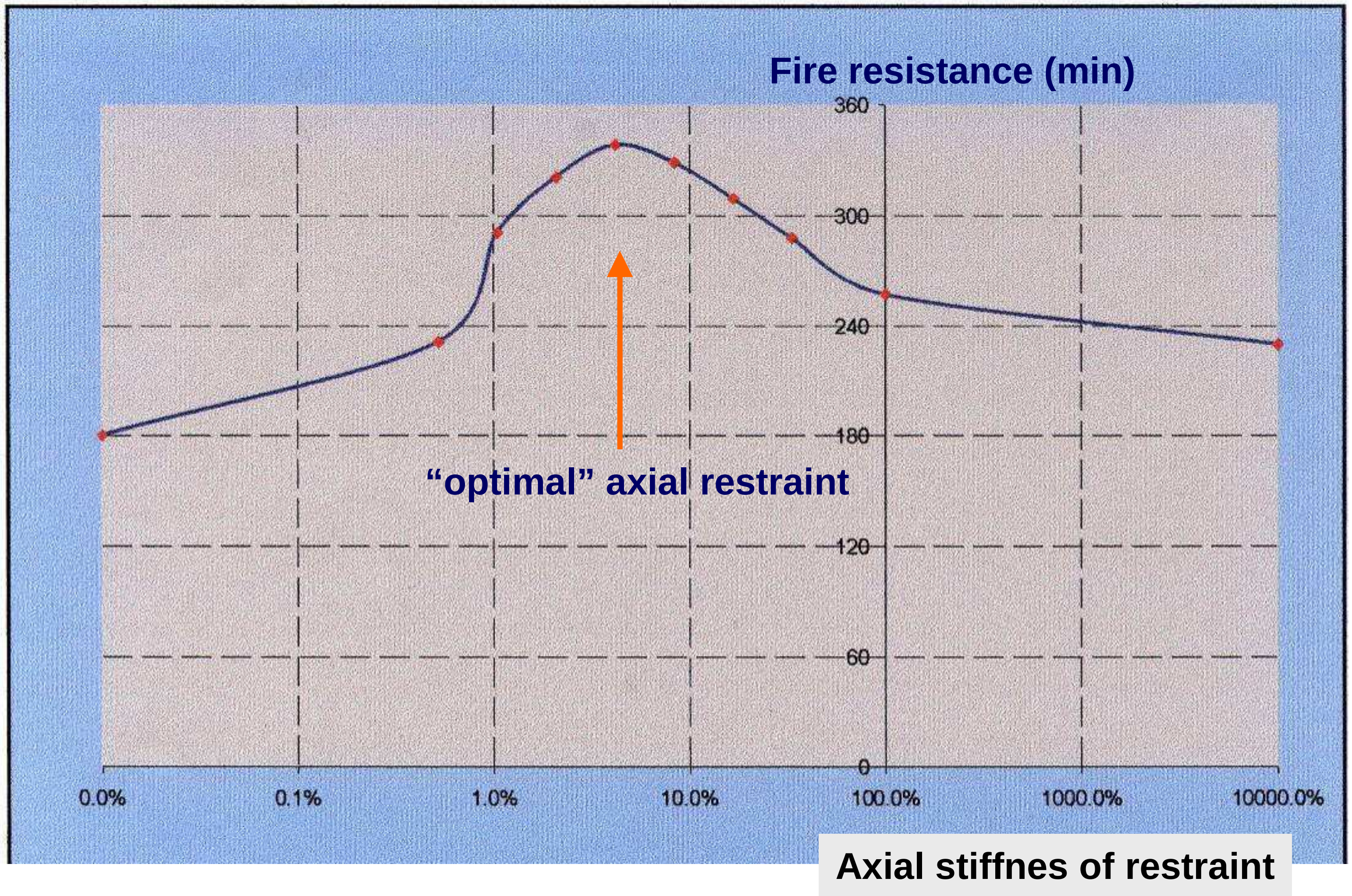
Influence of axial and rotational restraints on global structural behaviour

⇓

Parametric FE study on indirect actions in
continuous beams and in frames by Paolo Riva (University of Bergamo)

⇓

Axial restraint generally has a beneficial effect on fire resistance of beams



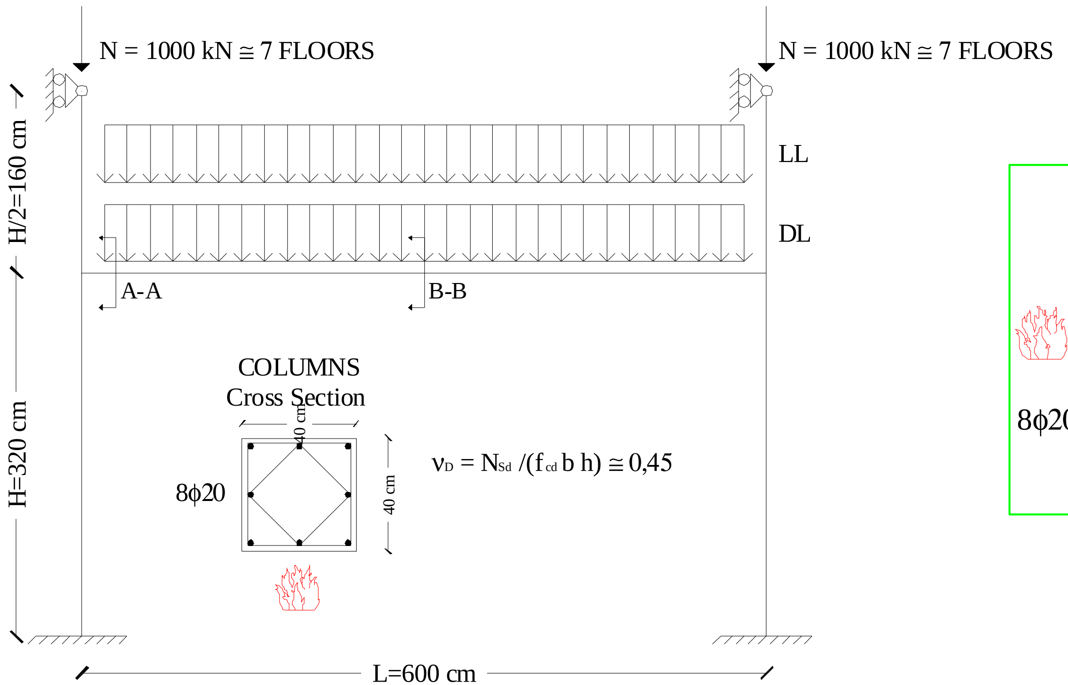
Results by Jean-Marc Franssen

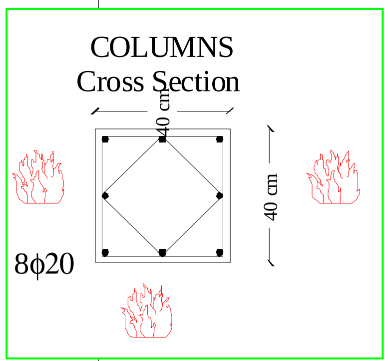
MATERIALS: Concrete C30/37 Reinforcing steel B500B	REI 60

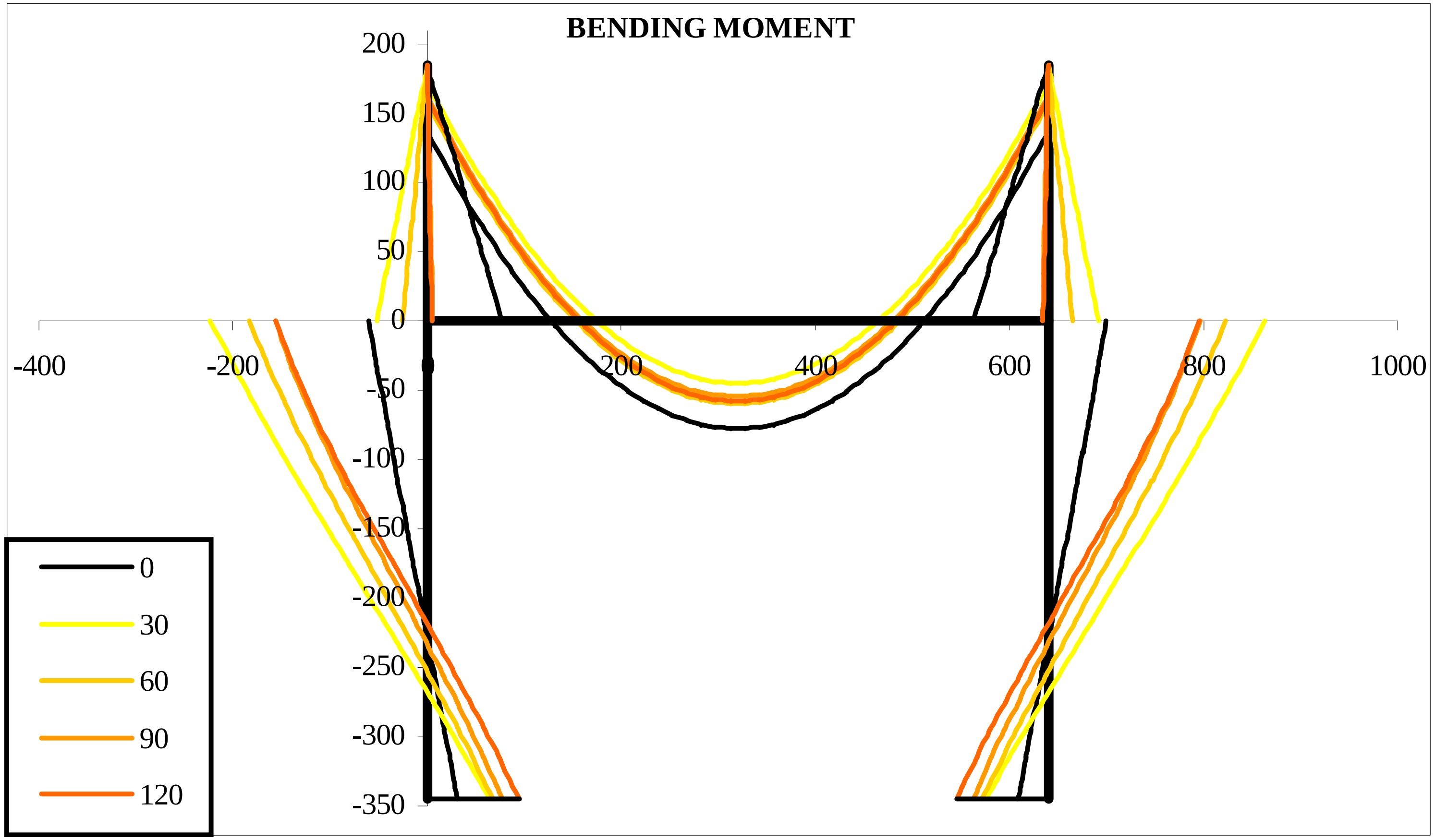
STRUCTURAL MODELS

LOADS:

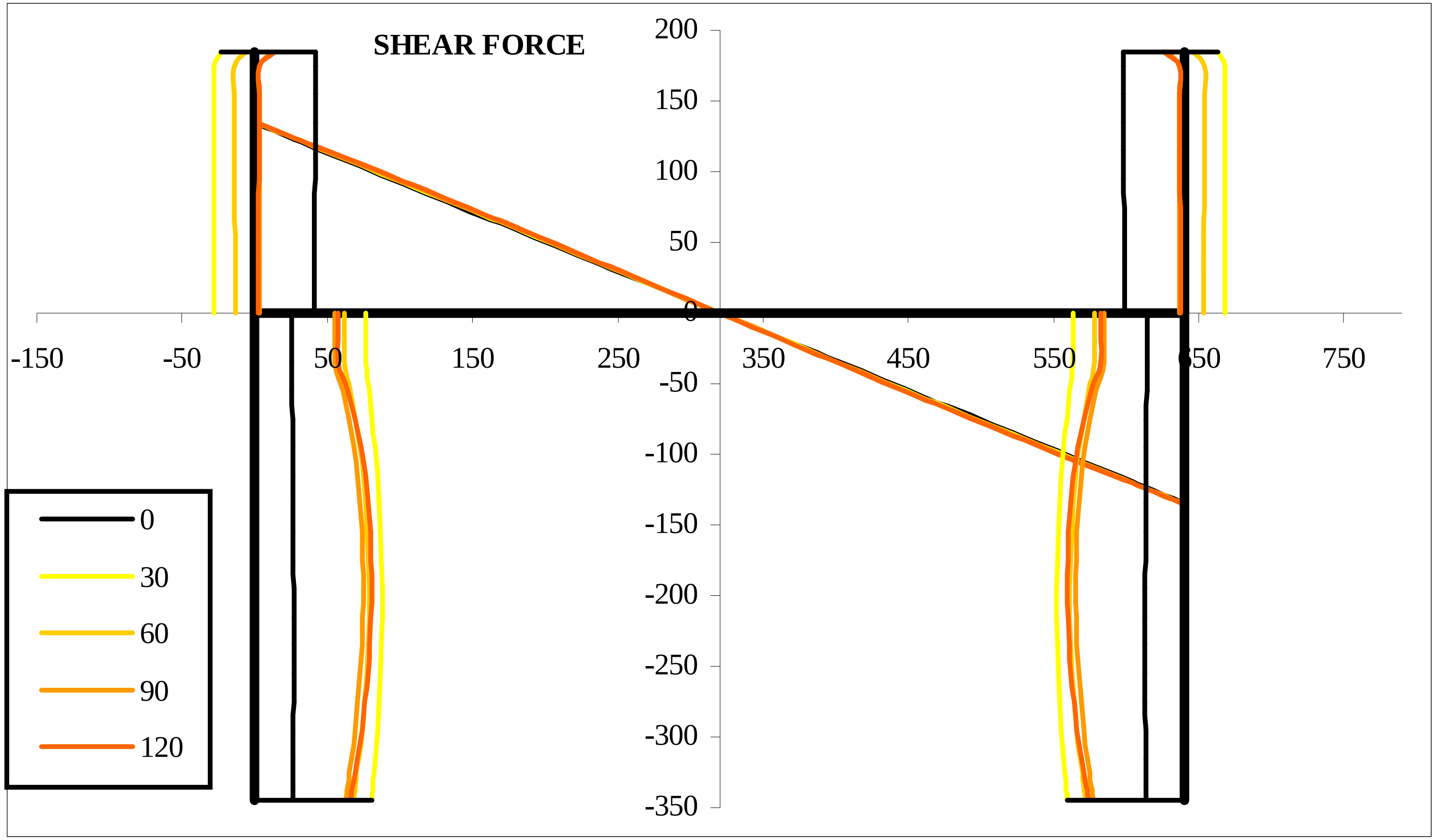
Rectangular section	DL = 36 kN/m	LL = 12 kN/m
Rectangular section + slab	DL = 36 kN/m	LL = 12 kN/m
One way slab	DL = 7.25 kN/m^2	LL = 4 kN/m^2







- **Bending moments in lower columns x 7 due to beam thrust**
- **Bending moments in upper columns change sign**



Shear force in lower columns x 4 -> danger of shear failure
(detailing according to seismic provisions?)

Conclusions

- membrane action of slabs provides additional load carrying capacity
- catenary action in beams provides additional load carrying capacity → need of tools to asses the carrying capacity of members subjected to large deformations
- some degree of catenary/membrane action can be achieved by minimum reinforcement already recommend by EC
- accidental fire situation: robustness is important when considering global structural behaviour