SSCS 2012 Numerical Modeling Strategies for Sustainable Concrete Structures
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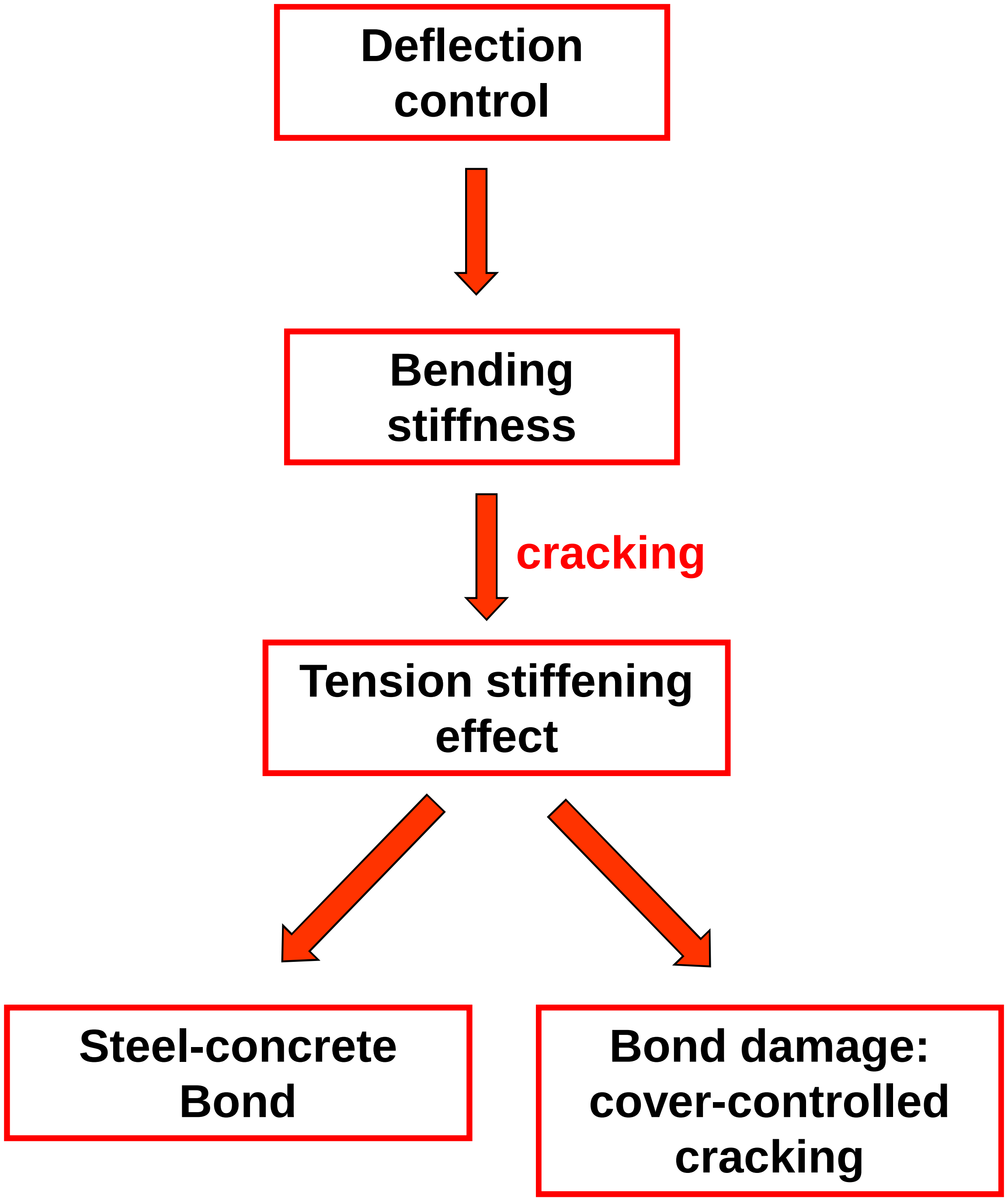
NUMERICAL MODELING OF REINFORCED CONCRETE BEAM RESPONSE TO REPEATED LOADING INCLUDING STEEL-CONCRETE INTERFACE DAMAGE

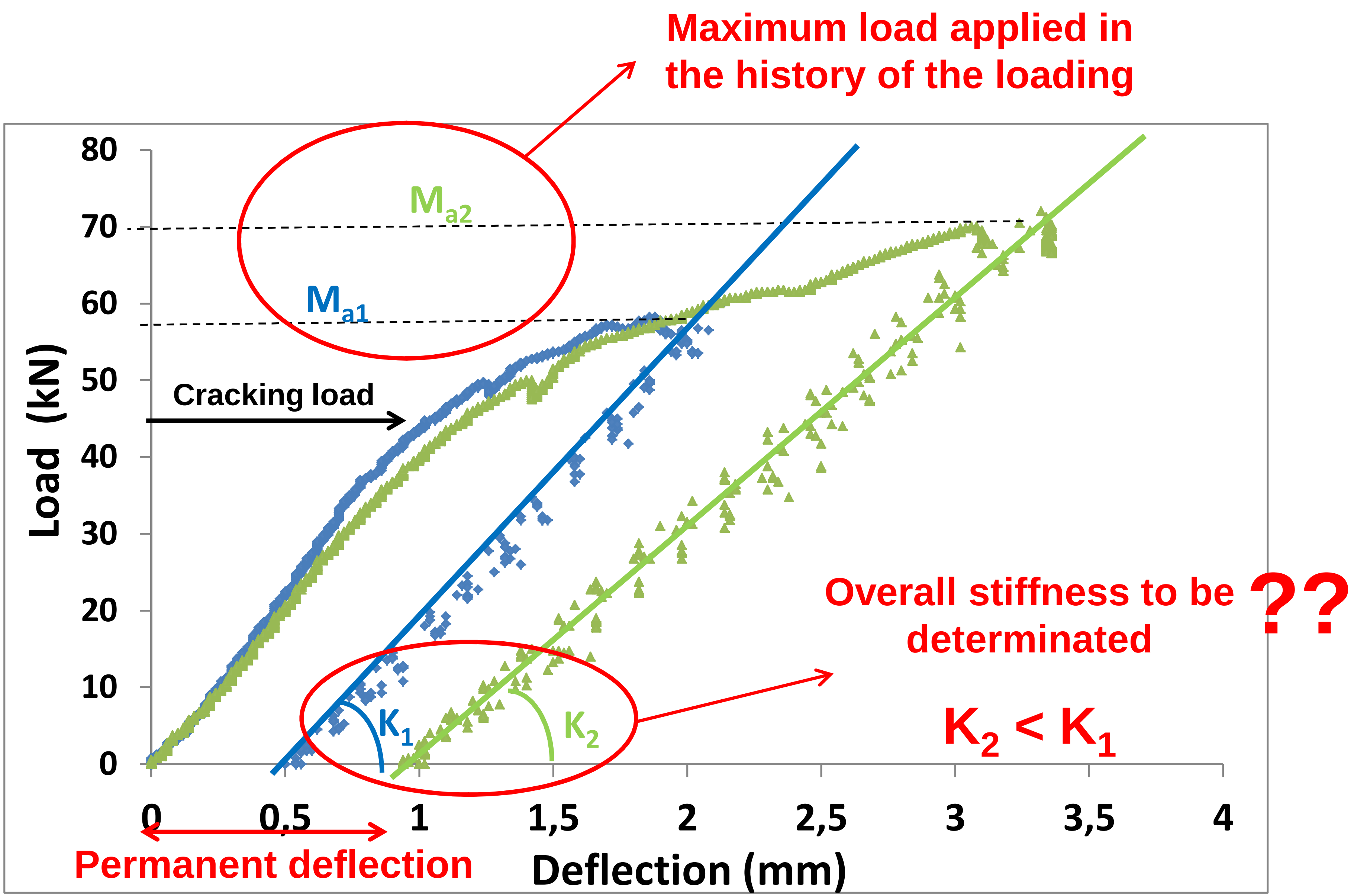
A. CASTEL, R.I. GILBERT, G. RANZI, S. FOSTER

UNSW THE UNIVERSITY OF NEW SOUTH WALES SYDNEY · CANBERRA · AUSTRALIA
Université Nice Sophia Antipolis
THE UNIVERSITY OF SYDNEY

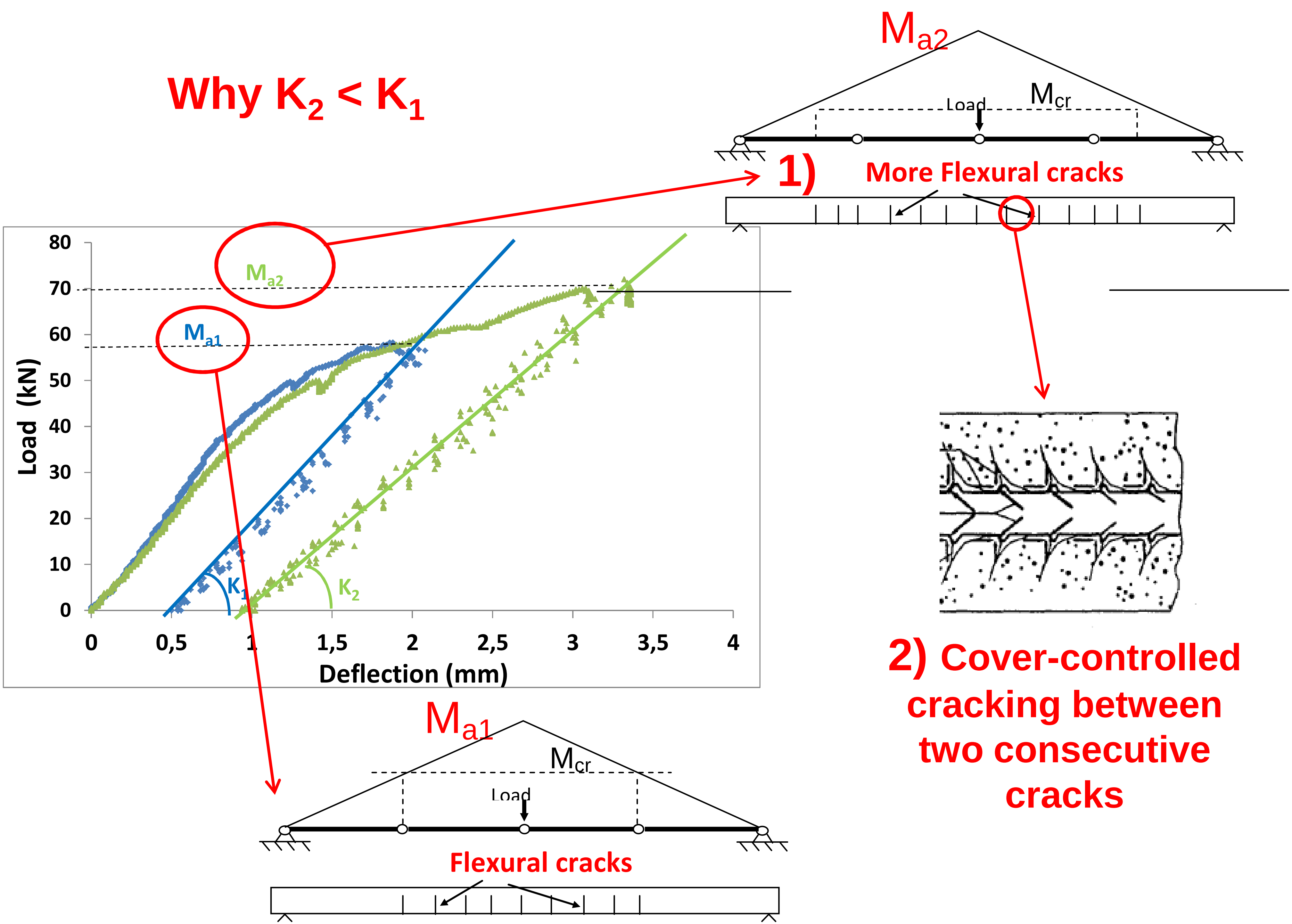
Reinforced concrete serviceability



Bending stiffness under repeated loading



Overall Bending stiffness under repeated loading



Experimental program

6 RC-Beams tested → Short term tests

→ Long term response

Concrete: (with OPC)

Compressive strength = 45 Mpa

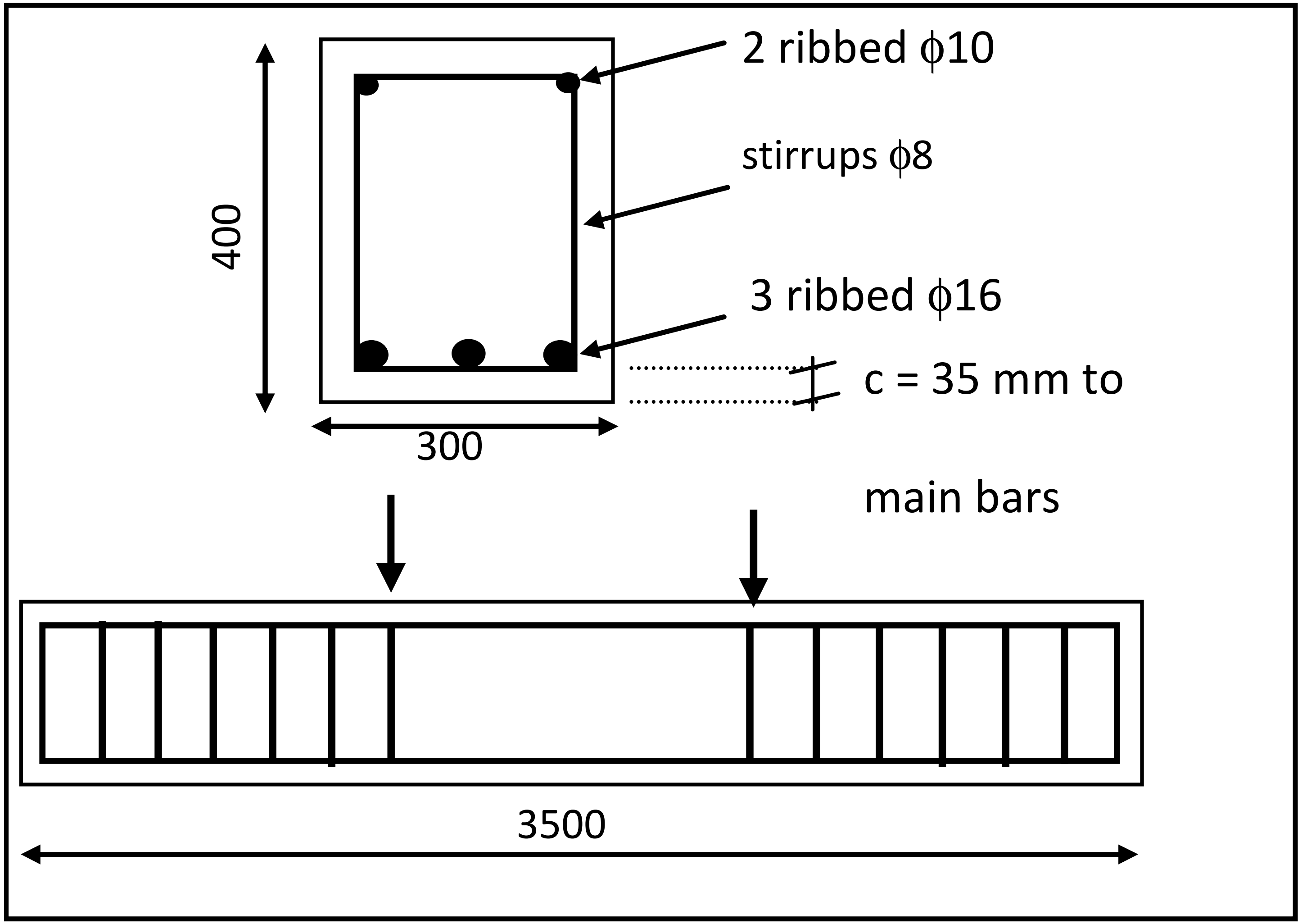
Elastic Modulus = 33 GPa

Steel reinforcing bars:

Elastic limit = 500 MPa

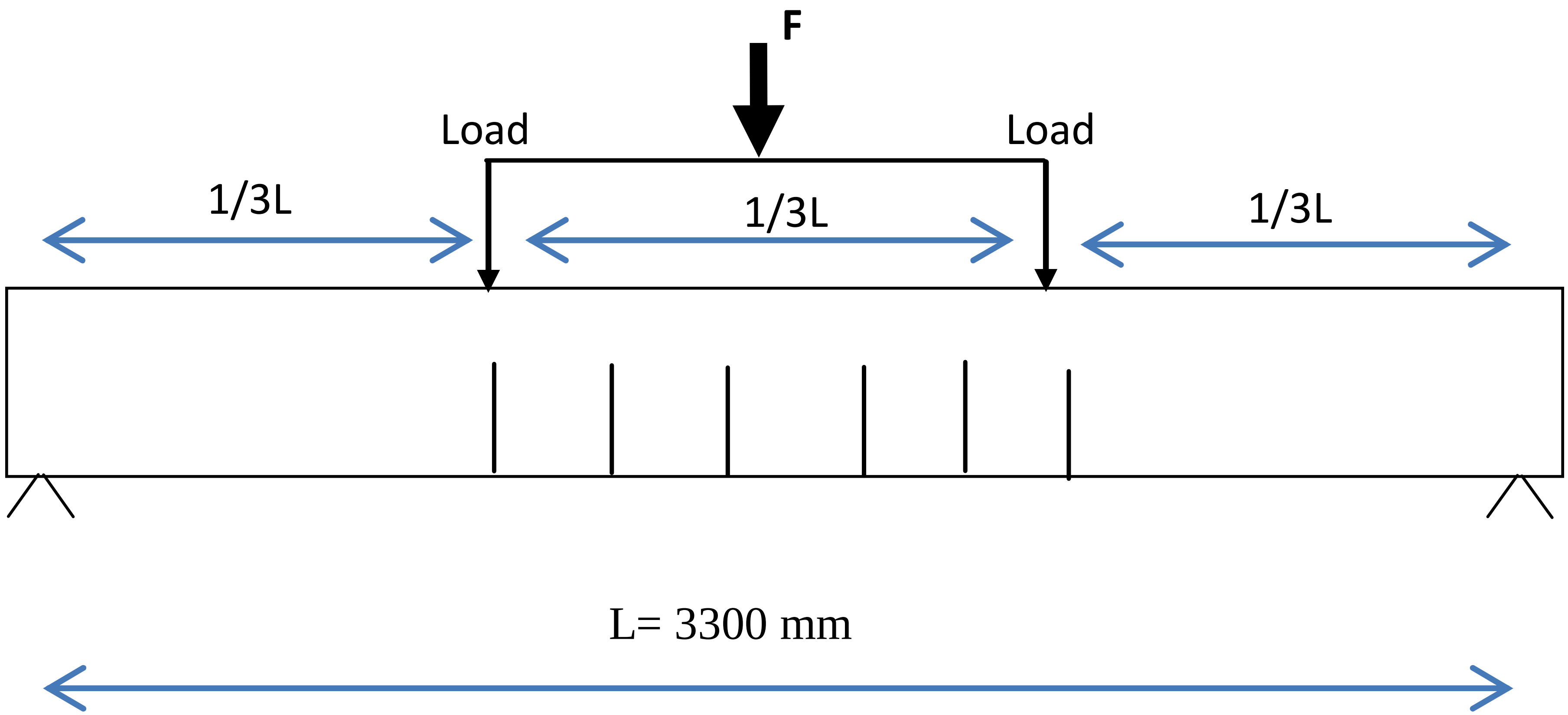
Bar diameter (ribbed bars) = 16 mm

Experimental program



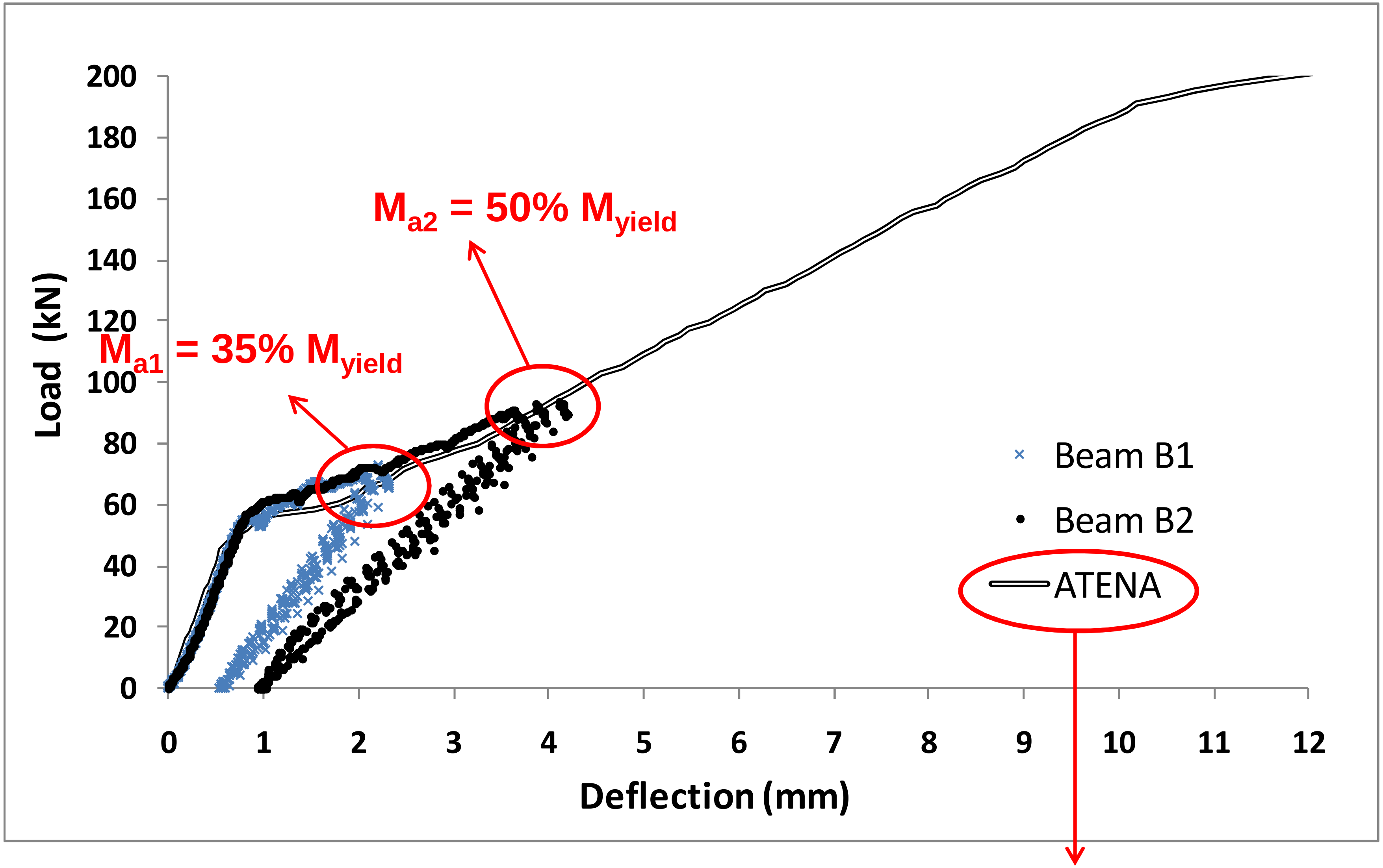
RC-Beams tested

Experimental program



Experimental program

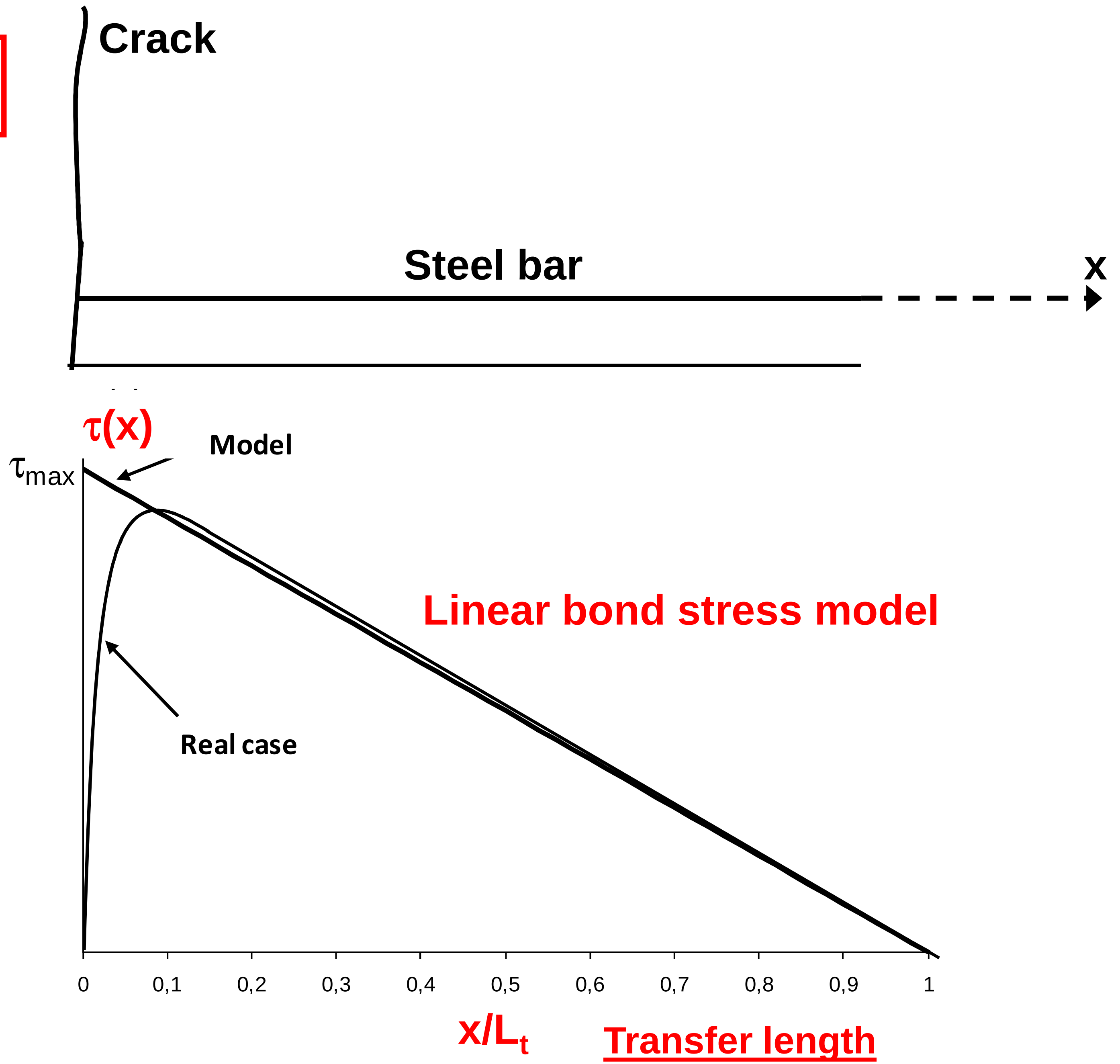
Two maximum load values applied



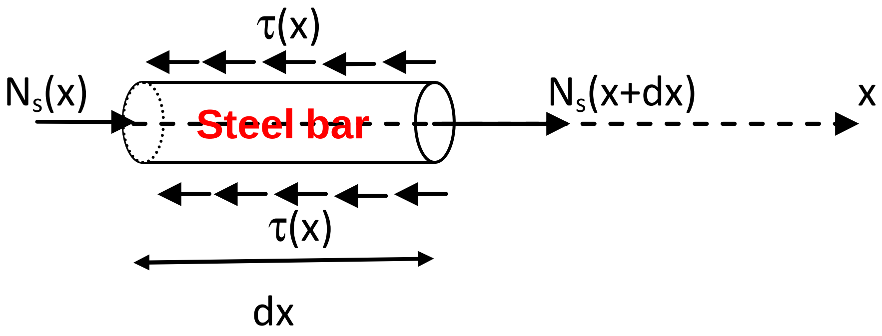
Envelop curve : monotonic loading increase up to failure

Overall stiffness modelling under repeated loading

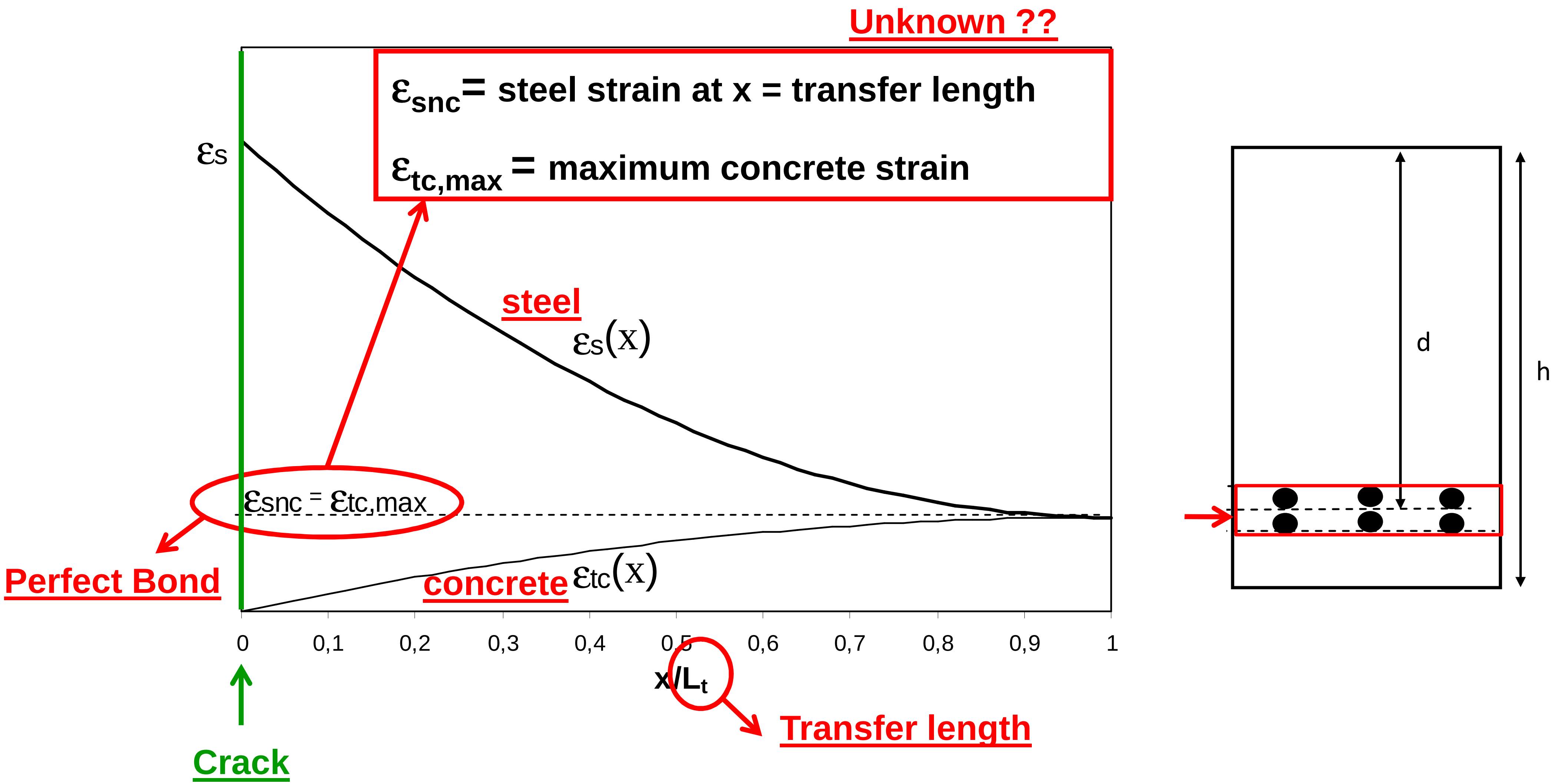
Local scale



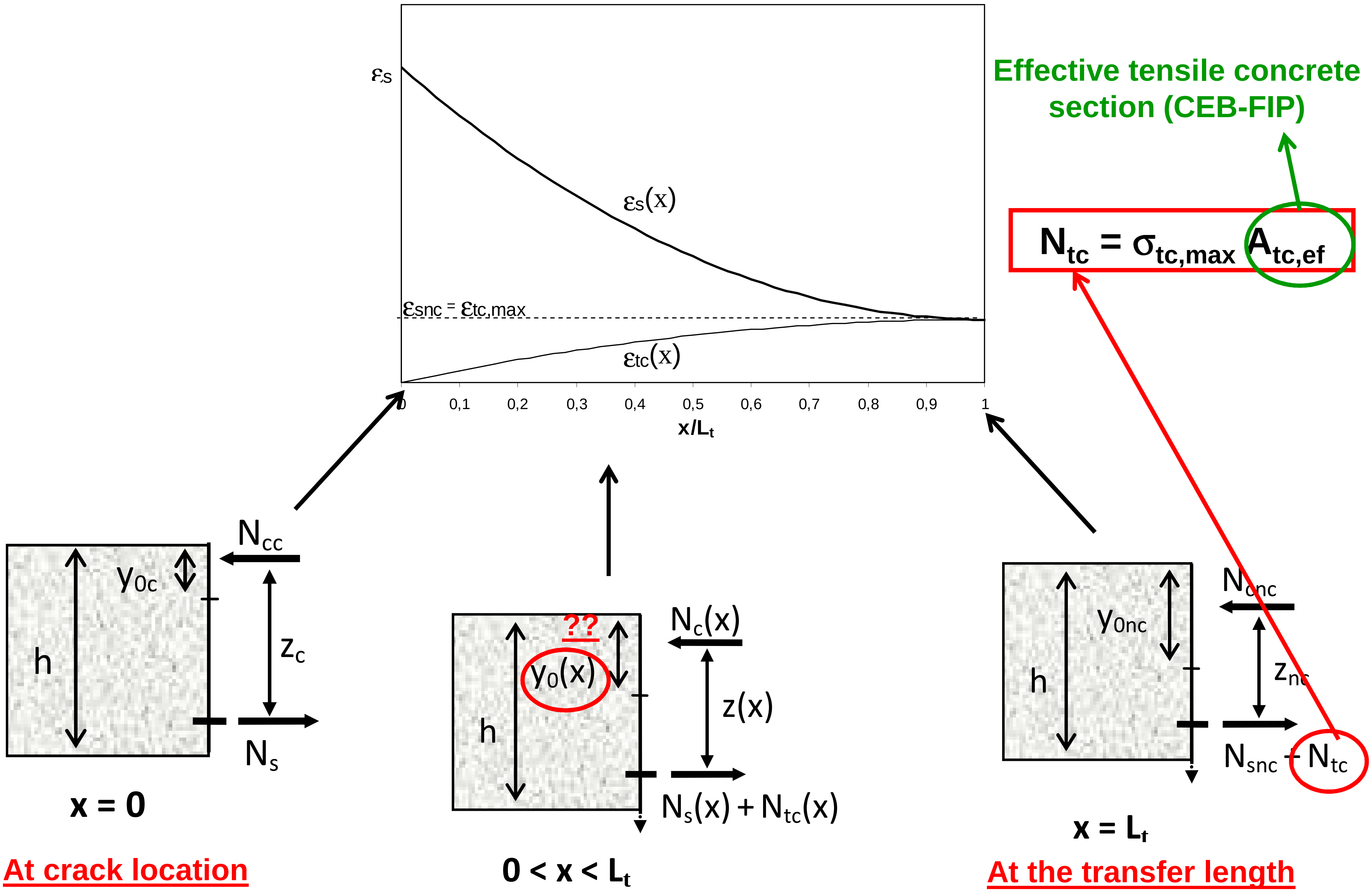
Steel & concrete strains



$$\tau(x) = \frac{\phi}{4}\frac{d\sigma_s(x)}{dx}$$

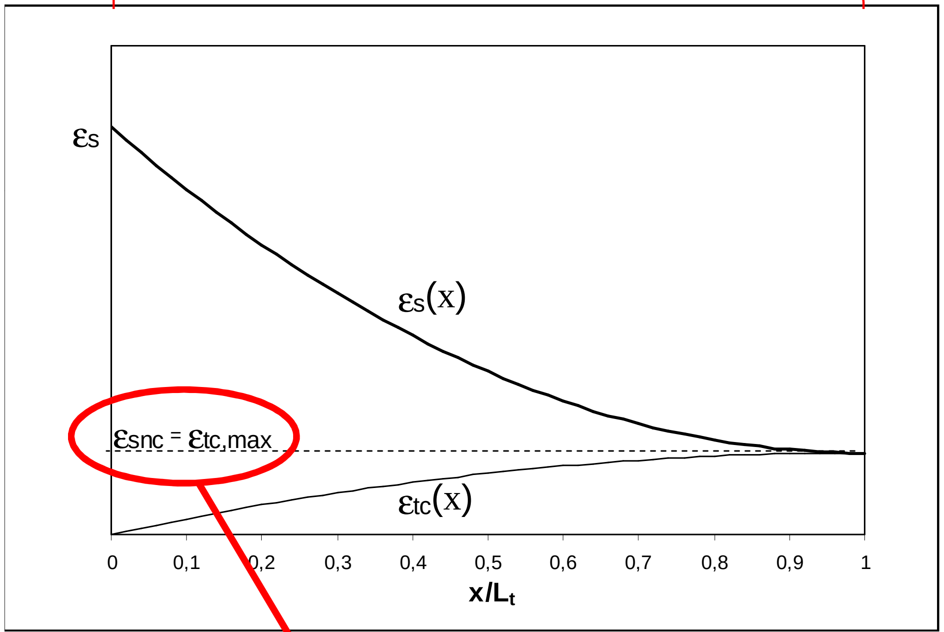


Neutral axis depth & normal strains

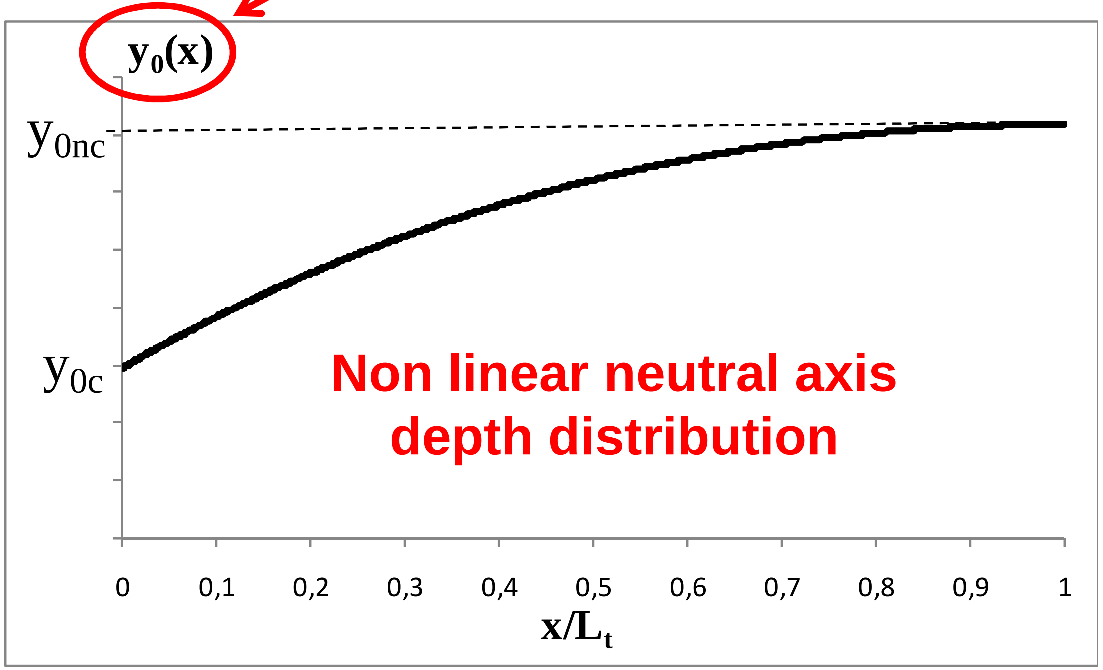


Neutral axis depth & normal strains

Assumption: same bending moment



$$N_s z_c = (N_s(x) + N_{tc}(x))\, z(x) = (N_s + N_{tc})\, z_{nc}$$



$$\varepsilon_{snc} = \varepsilon_{tc,max} = \frac{\varepsilon_s}{\frac{z_{nc}}{z_c}\left[1 + \frac{A_{tc,ef}}{\alpha_e A_s}\right]}$$

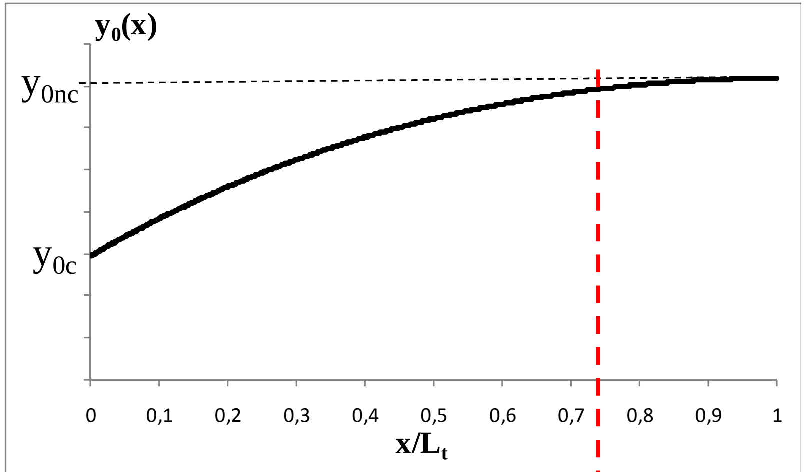
Effective tensile concrete section (CEB-FIP)

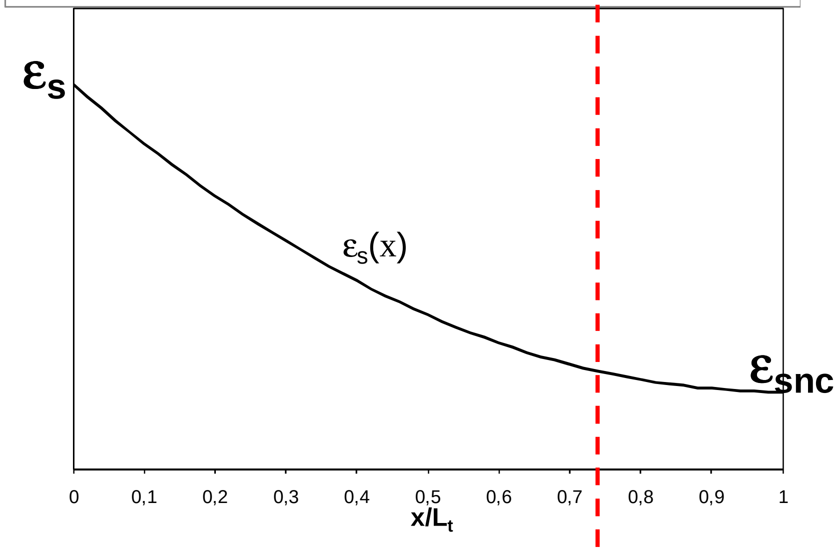
Overall stiffness modelling under repeated loading

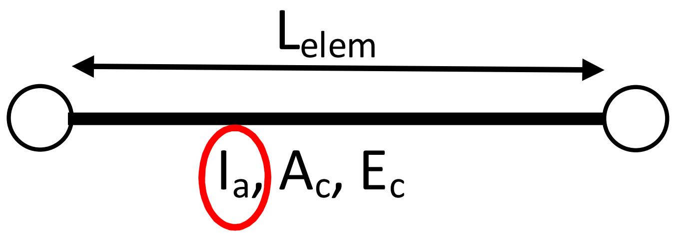
Global scale → **Average curvature between two cracks**

↓

Average Inertia I_a of the F.E.





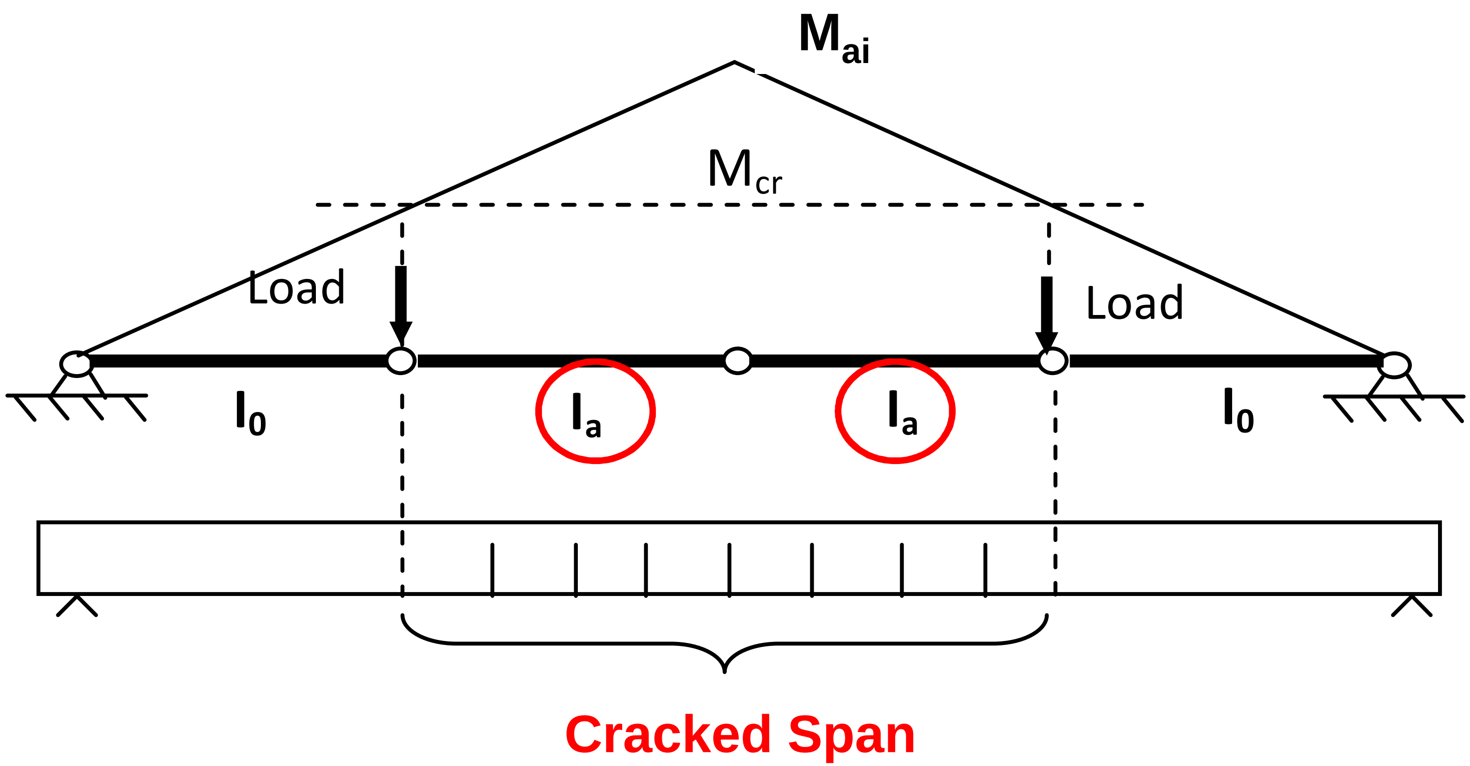


$$I_a = \frac{\dfrac{(d - y_{0a})}{(d - y_{0c})} I_c}{1 - C_H \left[1 - \dfrac{z_c \alpha_e A_s}{z_{nc}(\alpha_e A_s + A_{tc,ef})} \right]}$$

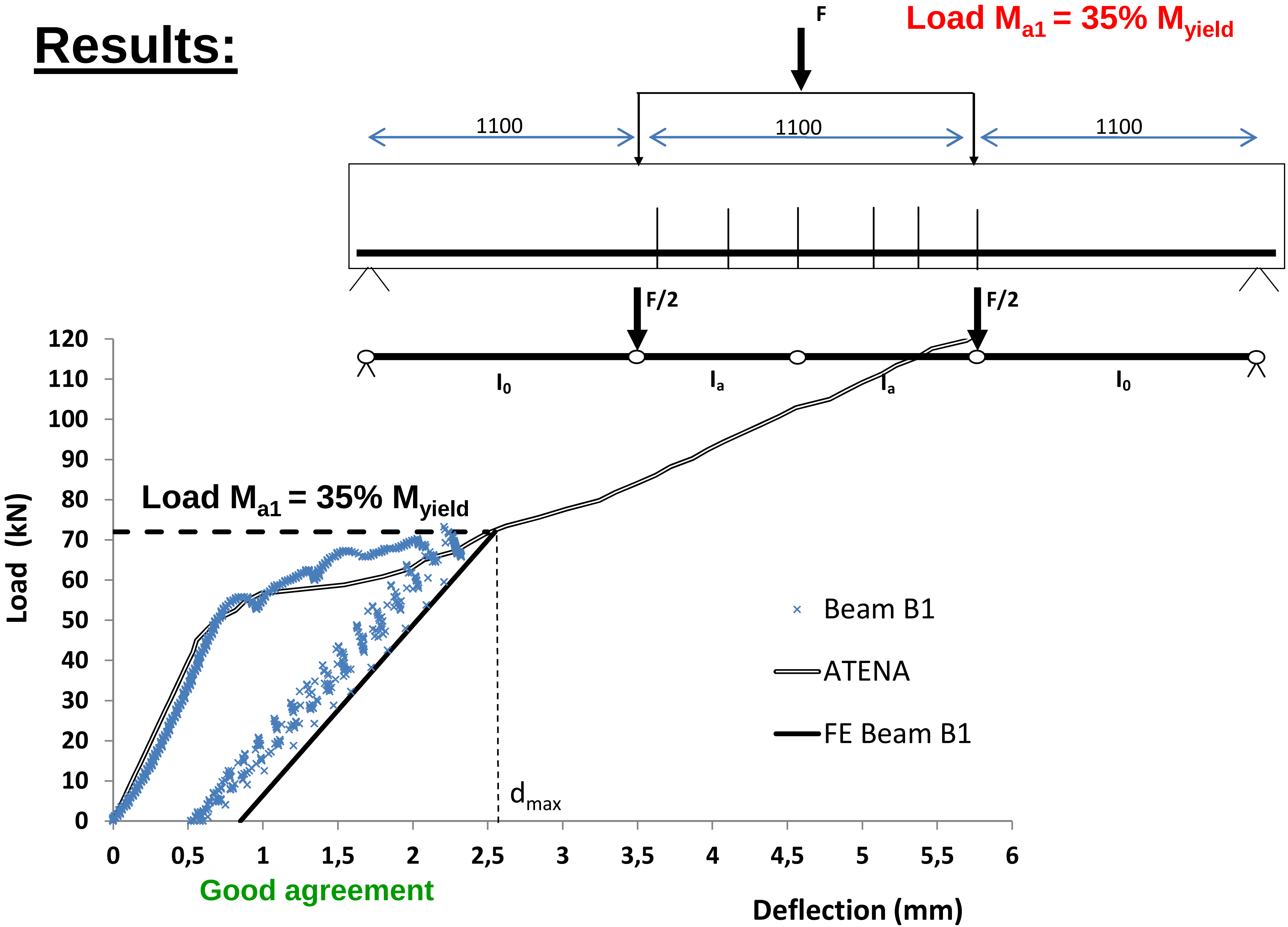
Homogenisation Coefficient $C_H = 0{,}66$

$(L_{elem}/2)/L_t = 0{,}75$ (CEB-FIP)

Overall stiffness calculation after cracking

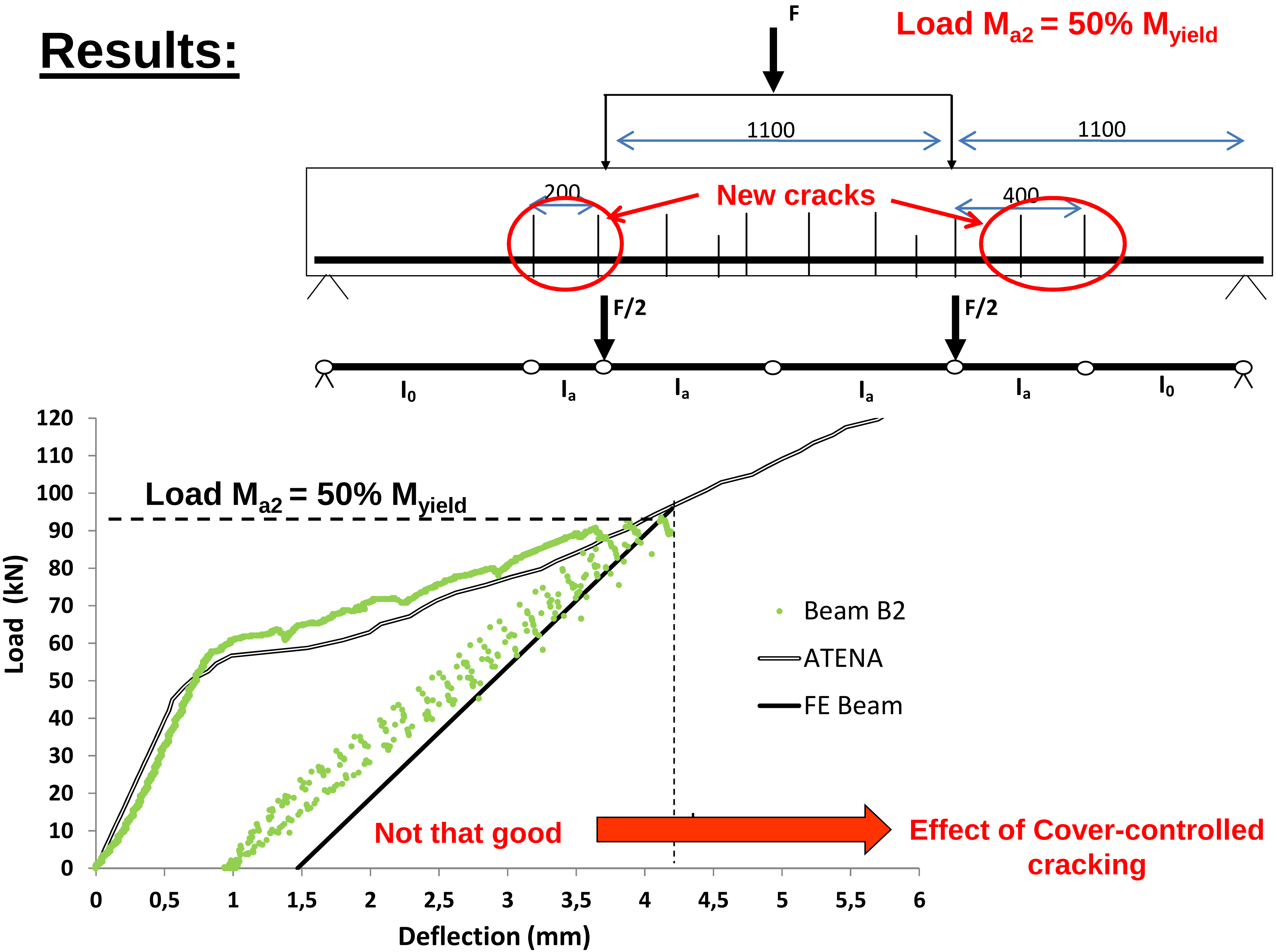


Results:



Good agreement

Results:


Load M_{a2} = 50% M_{yield}
F
1100
1100
200
New cracks
400
F/2
F/2
l_0
l_a
l_a
l_a
l_a
l_0
Load M_{a2} = 50% M_{yield}
Load (kN)
Deflection (mm)
Beam B2
ATENA
FE Beam
Not that good
Effect of Cover-controlled cracking
0
10
20
30
40
50
60
70
80
90
100
110
120
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6

Steel-concrete bond damage

When ?

$$\varepsilon_{snc} = \varepsilon_{tc,max} = \frac{\varepsilon_s}{\frac{z_{nc}}{z_c}\left[1 + \frac{A_{tc,ef}}{\alpha_e A_s}\right]}$$ = concrete ultimate tensile strain

Steel stress leading to cover-controlled cracking

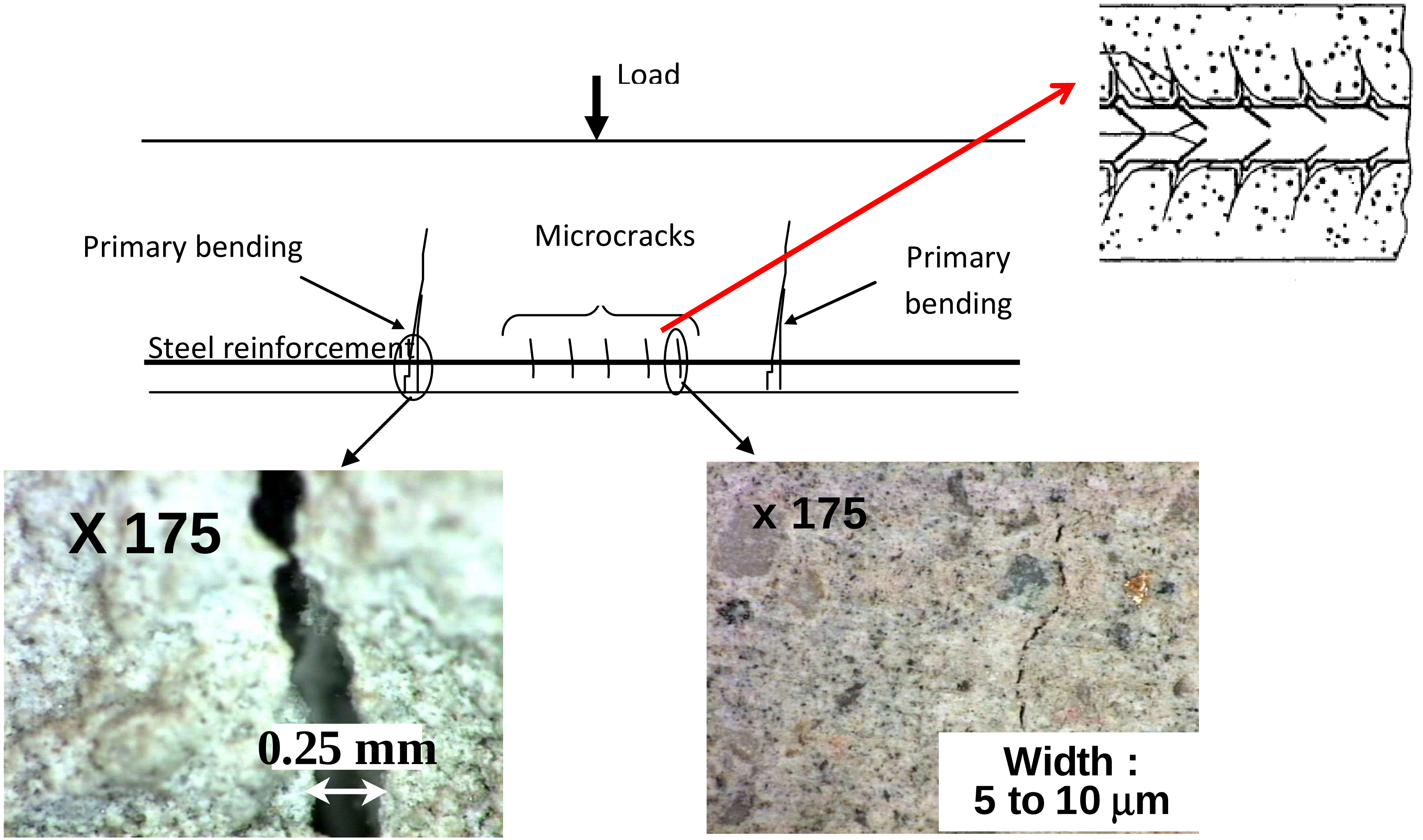
Concrete tensile strength

$$\sigma_{s,ccc}(f_{tc}) = \frac{z_{nc}}{0.9 z_c}\left[\alpha_e + \frac{A_{tc,ef}}{A_s}\right] f_{tc}$$

Bending moment leading to cover-controlled cracking

$$M_{ccc} = \frac{I_c \sigma_{s,ccc}}{\alpha_e (d - y_{0c})}$$

<u>Where ?:</u> between primary cracks



Damage propagation modeling:

Steel-concrete bond damage $(1-\mathbf{D_c})\,\varepsilon_{snc} = \varepsilon_{tc,max}$ $0 \le D_c \le 1$

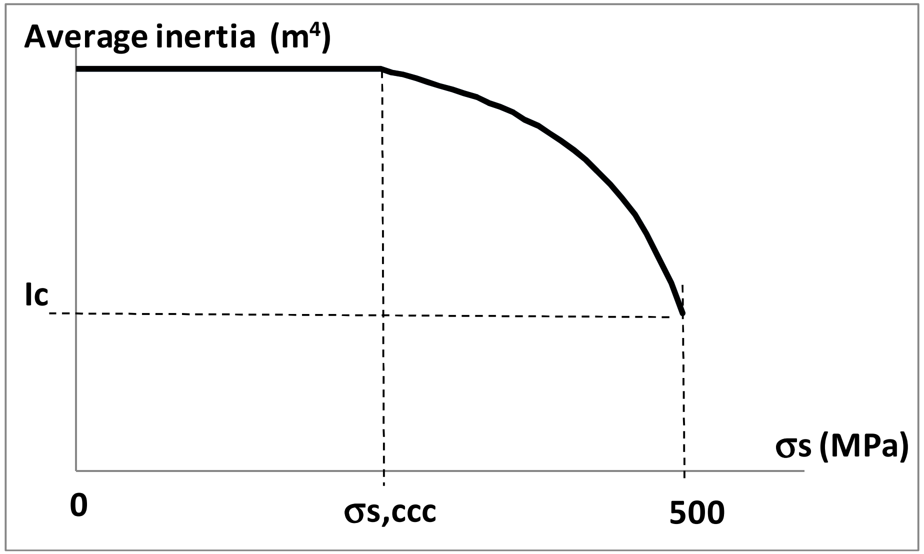
Bond damage propagation versus loading

$$D_c = 0 \quad \text{If } \sigma_s < \sigma_{s,ccc}$$

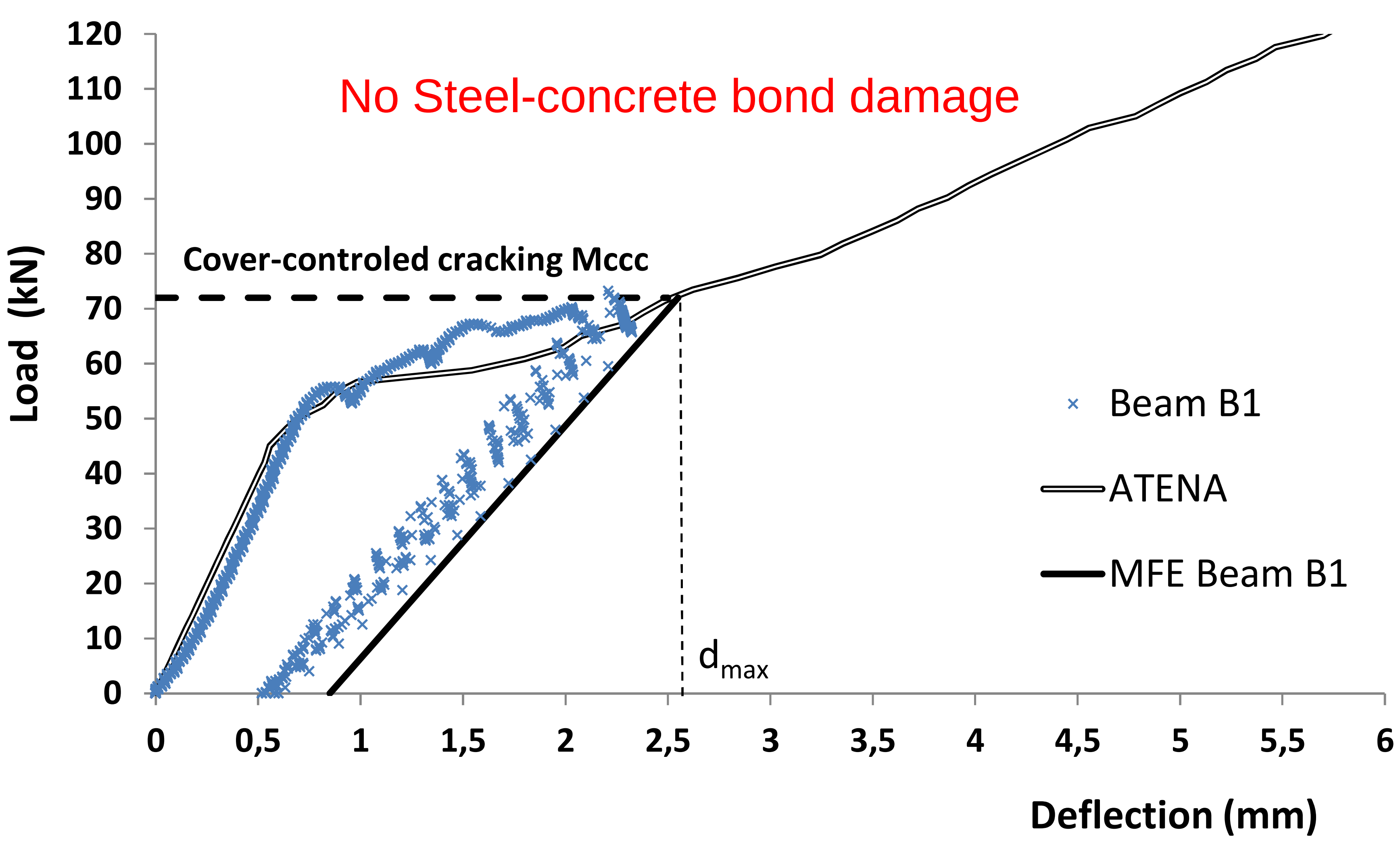
$$D_c = \frac{\sigma_s - \sigma_{s,ccc}}{500 - \sigma_{s,ccc}} \quad \text{If } \sigma_s > \sigma_{s,ccc}$$

(Wu and gilbert, Engineering Structures, Vol.33 Issue 12, 2011)

Average inertia reduction versus steel stress

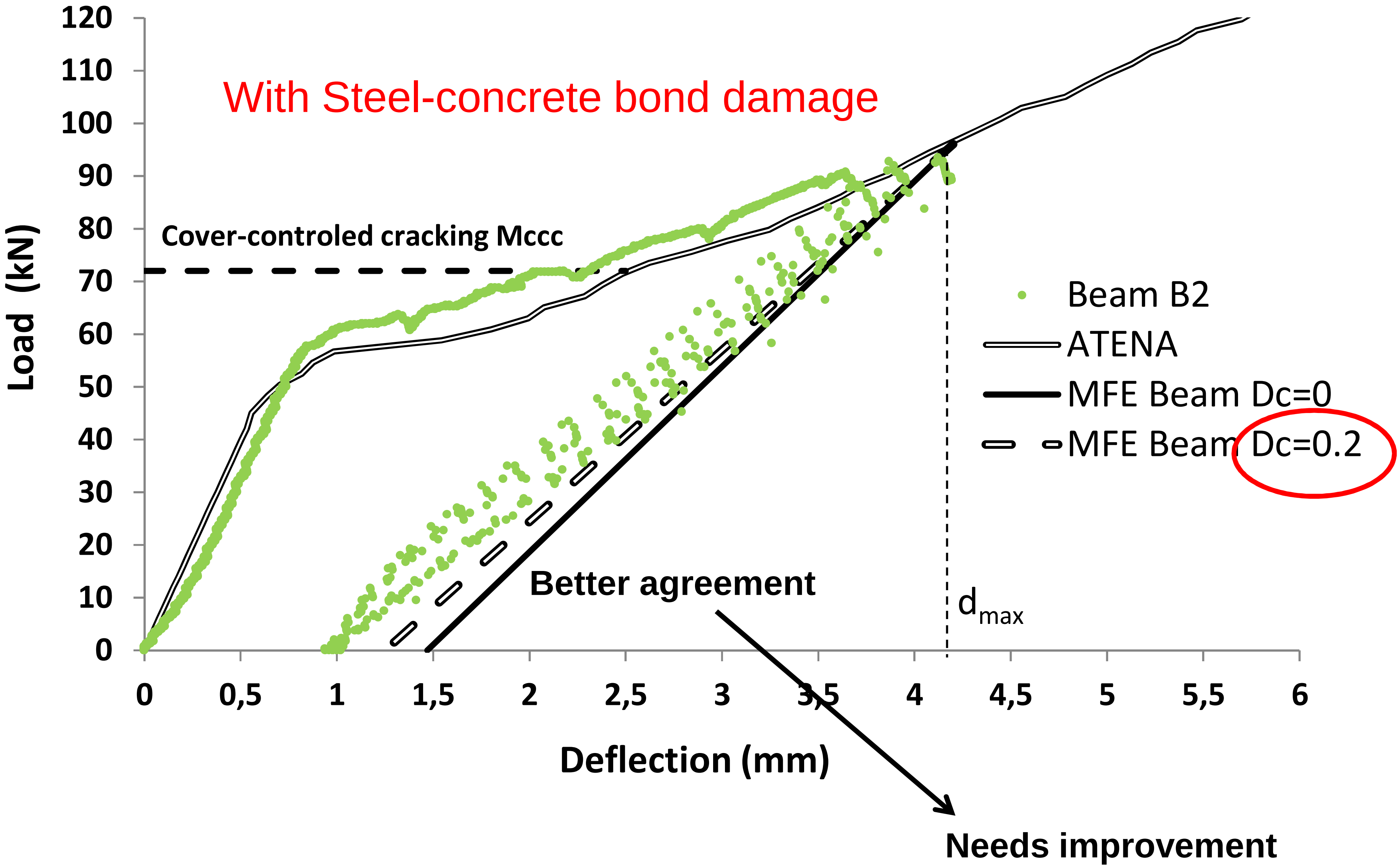


Results:



No Steel-concrete bond damage
Cover-controled cracking Mccc
Load (kN)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
d_{max}
Deflection (mm)
Beam B1
ATENA
MFE Beam B1

Results:



With Steel-concrete bond damage
Cover-controled cracking Mccc
Load (kN)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
Deflection (mm)
Beam B2
ATENA
MFE Beam Dc=0
MFE Beam Dc=0.2
d_{max}
Better agreement
Needs improvement