NLyse

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Nonlinear Analyses for the built environment

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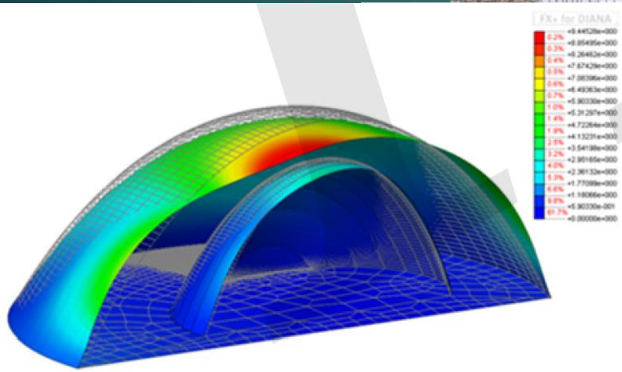
FIB Bulletin 105 Fibre Reinforced Concrete (FRC) State-of-the-Art Report.

Several workgroups and committees worked from the ’90ties of last century to built this report as a guidance for engineers to use FRC in their current projects.

A summary journey through the possibilities, strengths and pitfalls.

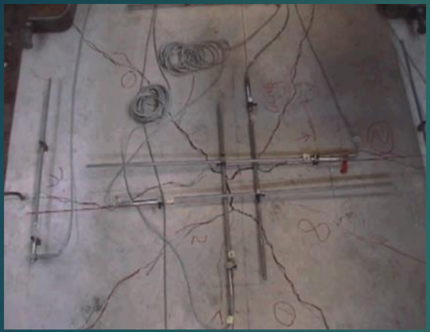
1 Introduction

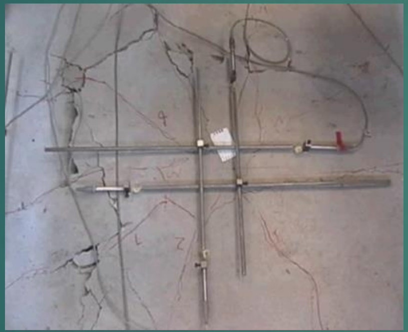
A journey through possibilities

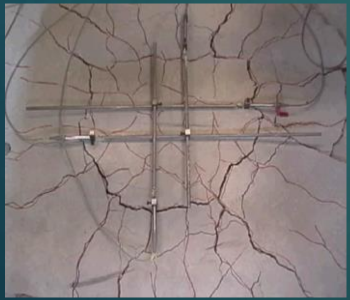


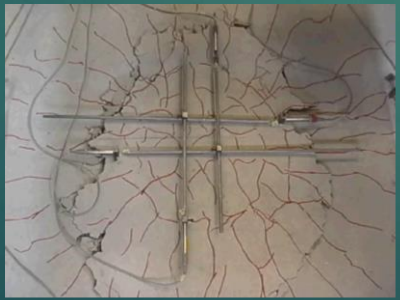
2 Fundamentals

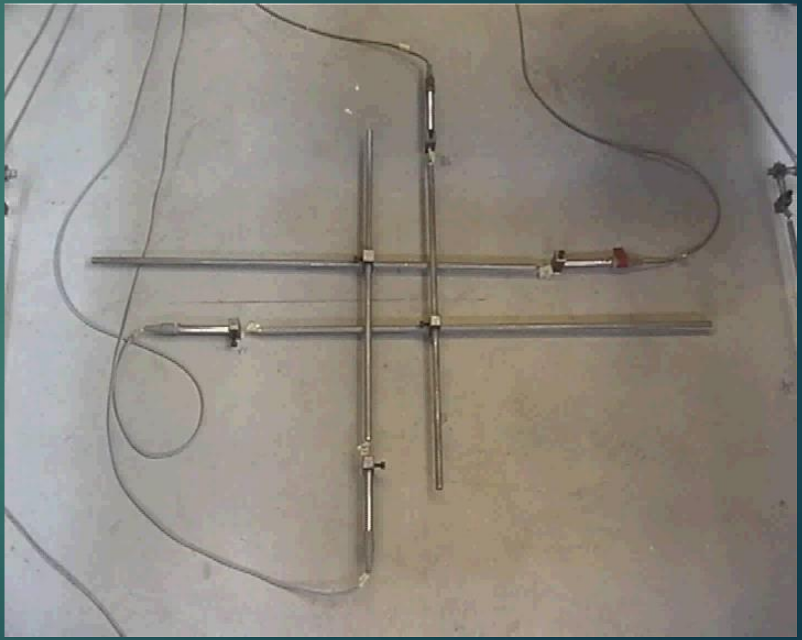
What about the behaviour







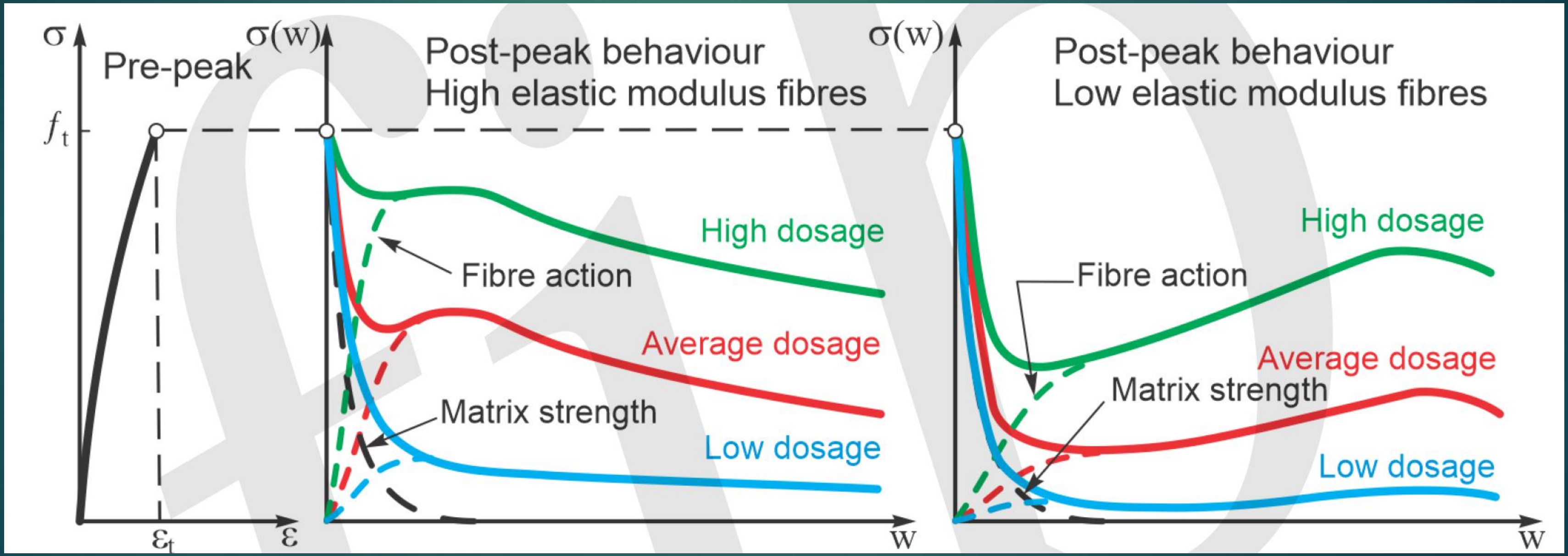




met dank en credits aan ABT voor gegevens

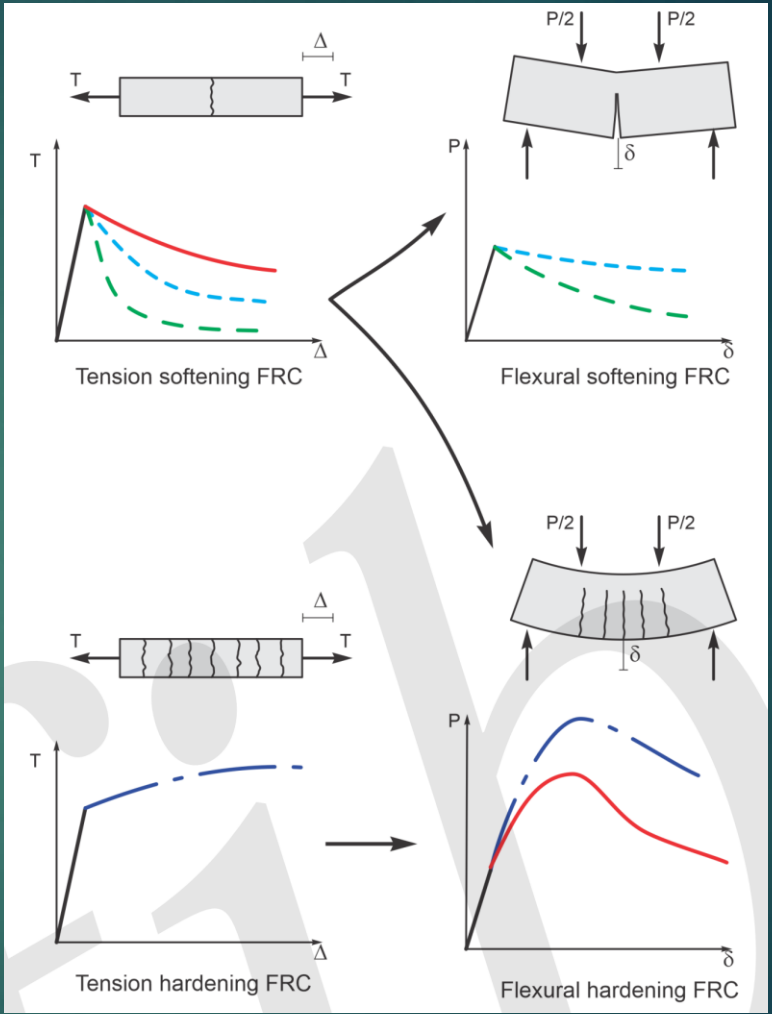
What about Fibres

- Stiffness of fibres related to mother composites
- Length over diameter (L/d) ratio of fibres



What about Fibres

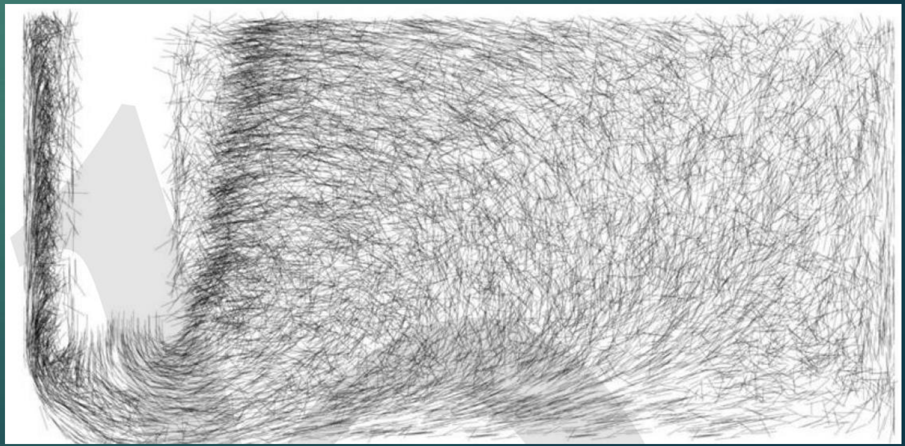
- Effect of fibres tension and bending



What about Fibres

- location variability of dosage (dispersion), orientation direction of fibres

- Fibres are most effective when more material is used in failure plane (plate versus beam)



What about Fibres

Pull-out response (crimped steel fibre)

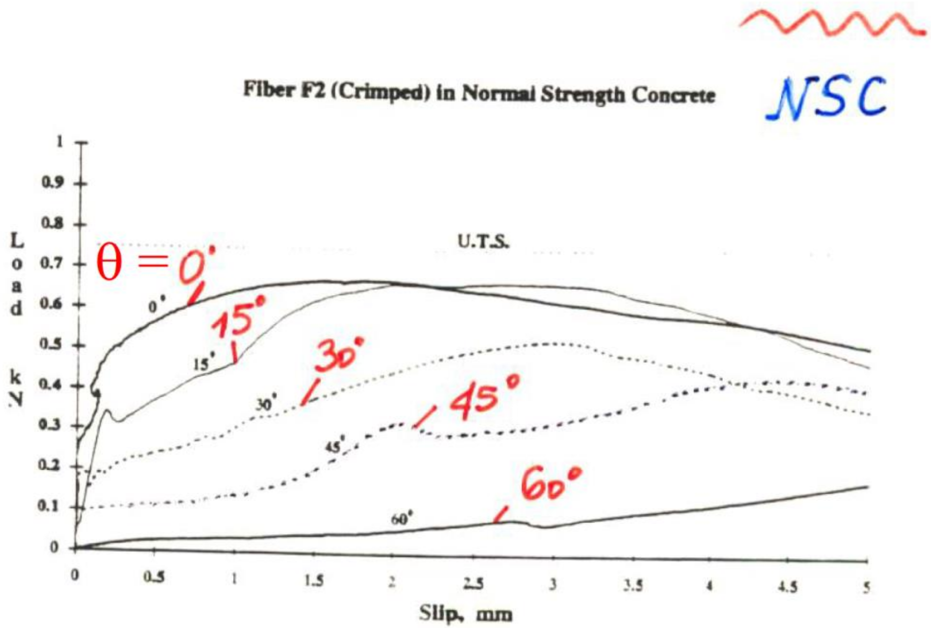
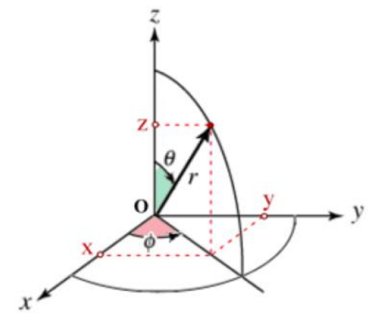


Fig. 7—Bond-slip curves for crimped fiber F2 in normal strength matrix at various inclination angles (1 kip = 4.448 kN; 1 in. = 25.4 mm)



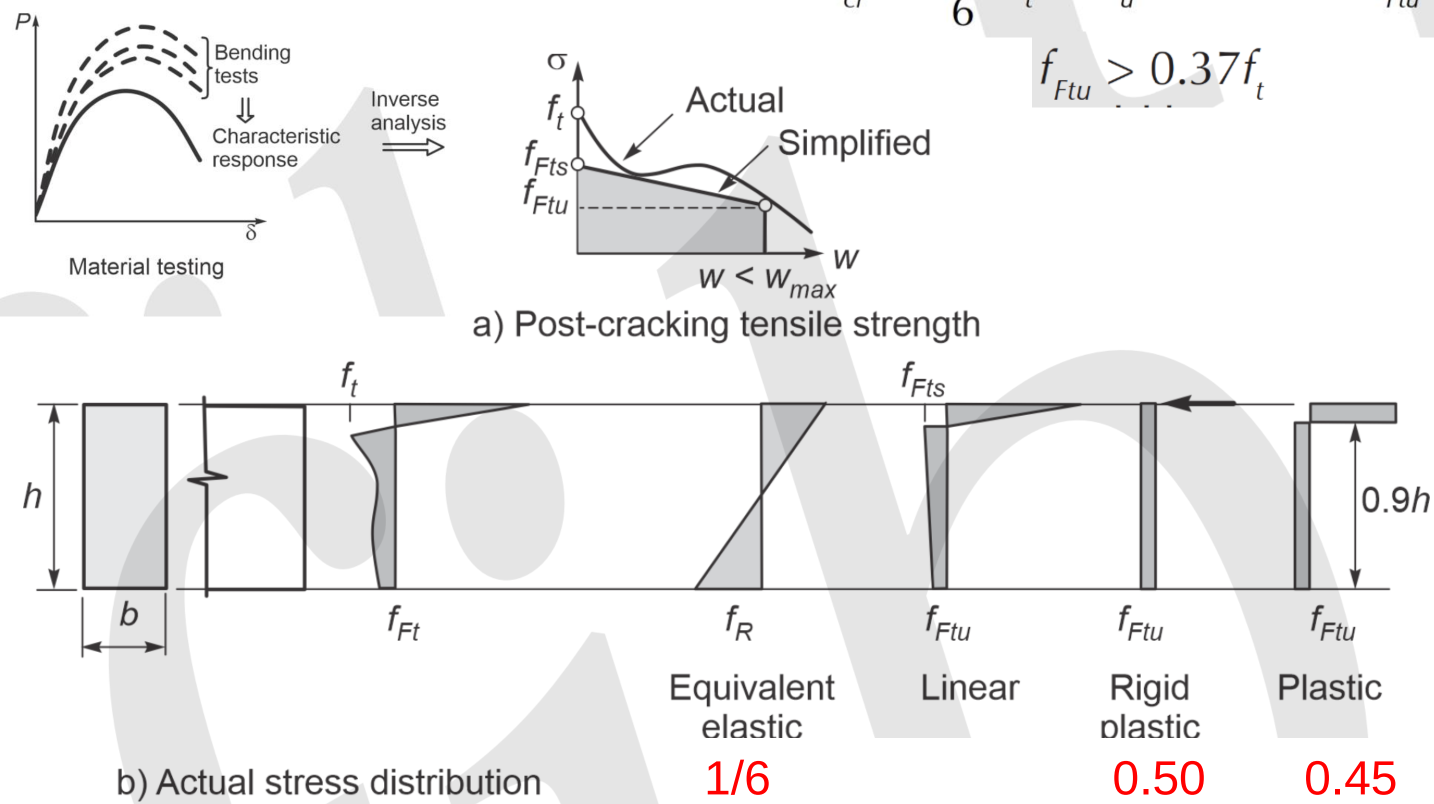
$\varphi = 0$

Characterisation

$$M_u = 0.45b \cdot h^2 \cdot f_{Ftu}$$

$$M_{cr} = \frac{b \cdot h^2}{6} f_t = M_u = 0.45b \cdot h^2 \cdot f_{Ftu}$$

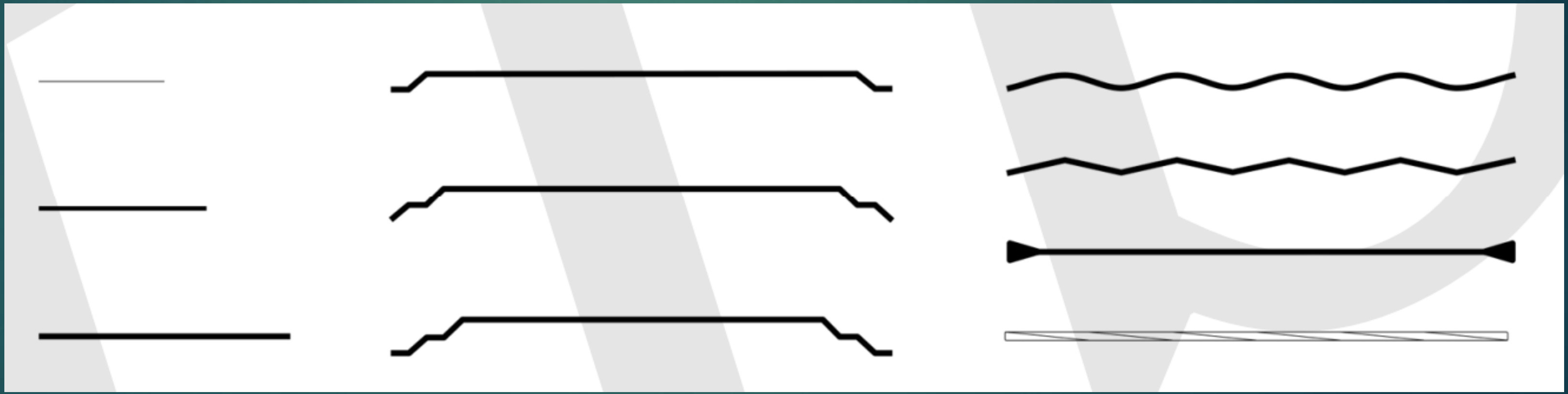
$$f_{Ftu} > 0.37 f_t$$



3 Types of fibre

Shapes

- UHPC straight
- Different anchor shapes
- Slip versus breaking



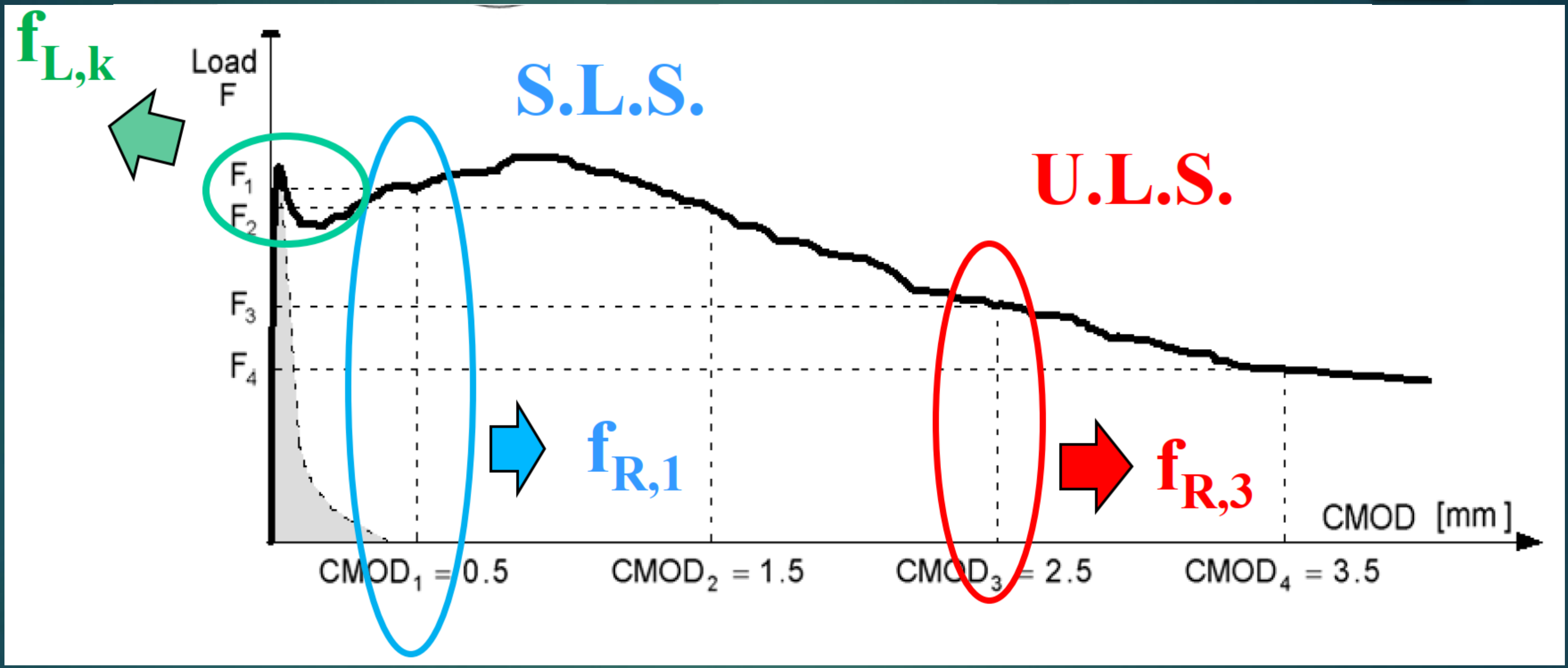
Materials

- Steel (most popular)
  - Variants cut sheet strips, splinters, recycled tyres
- Synthetic (polypropylene) and others
  - In micro (fire) and macro (larger cracks)
- From minerals : Aramid, Basalt, Carbon Glass etc

- Properties
  - Cost, effectiveness
  - deterioration (during placing nor during life time)
  - time depended or thermal-hygrometrical effects
  - alkali resistant

4 identification of mechanical properties (experimental)

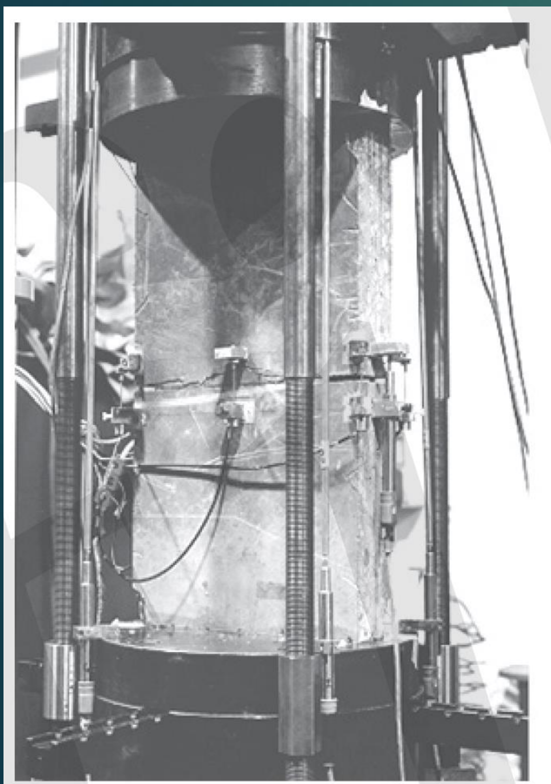
tests

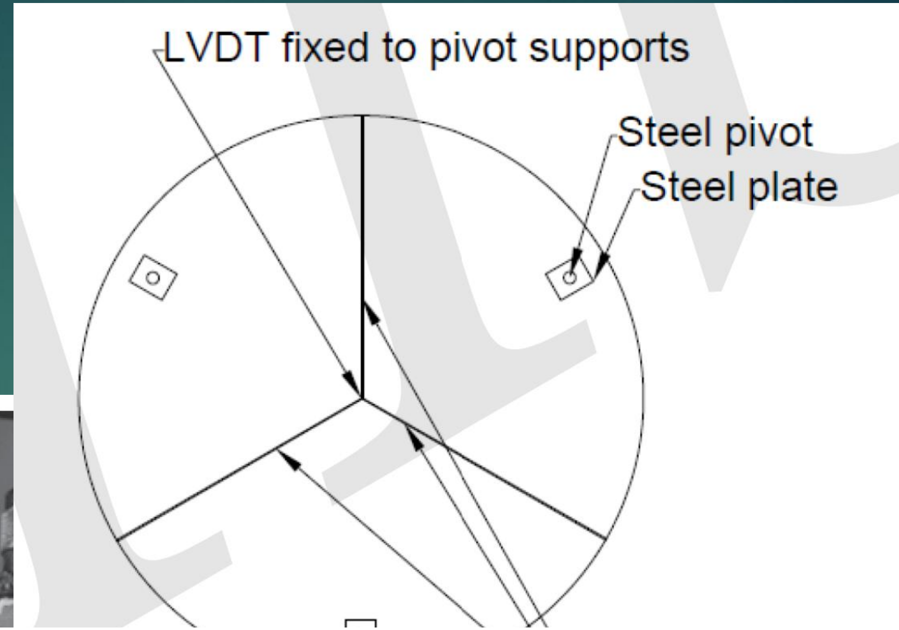


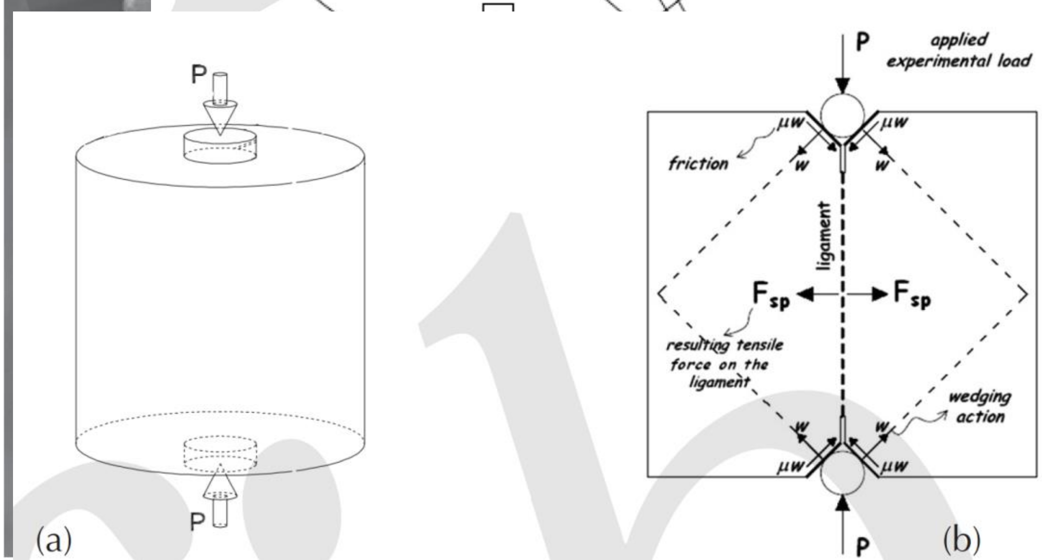
$f_{L,k}$
Load F
S.L.S.
U.L.S.
F_1
F_2
F_3
F_4
$f_{R,1}$
$f_{R,3}$
CMOD [mm]
$CMOD_1 = 0.5$
$CMOD_2 = 1.5$
$CMOD_3 = 2.5$
$CMOD_4 = 3.5$

More tests

- Pro's and cons

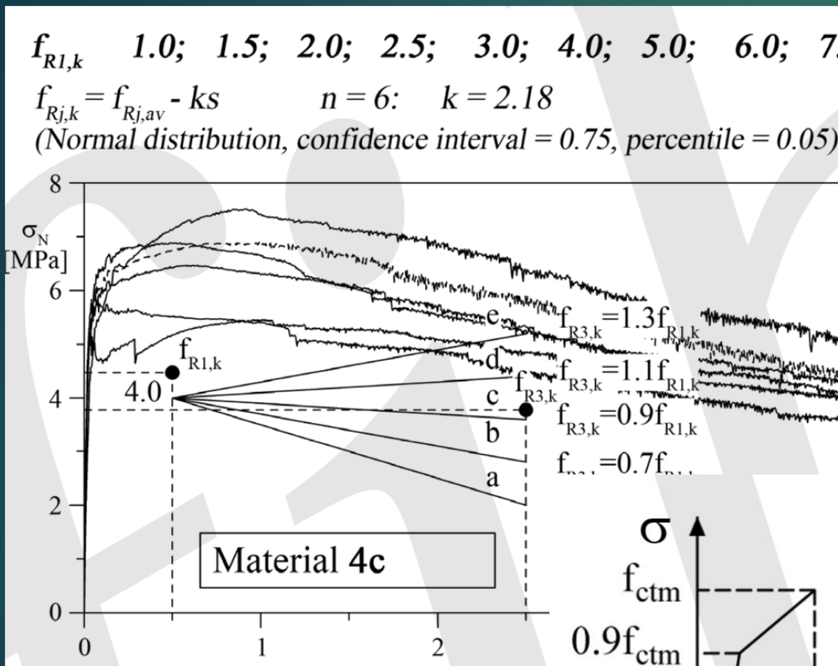


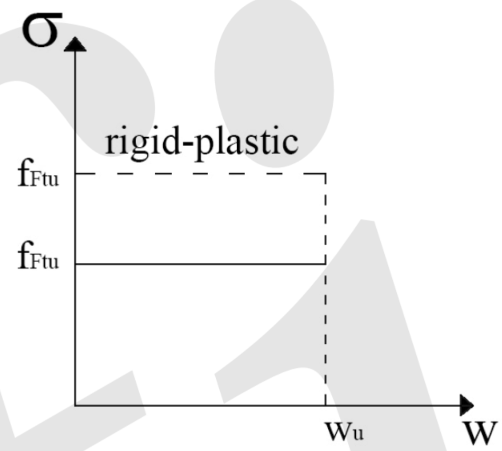


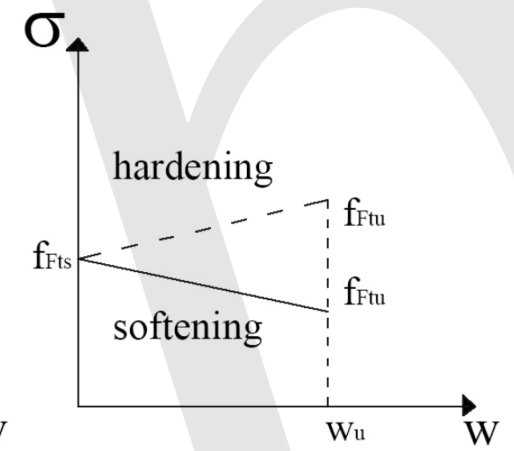


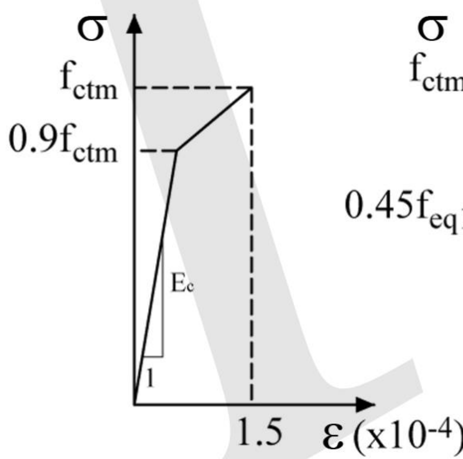
5 background of design approaches

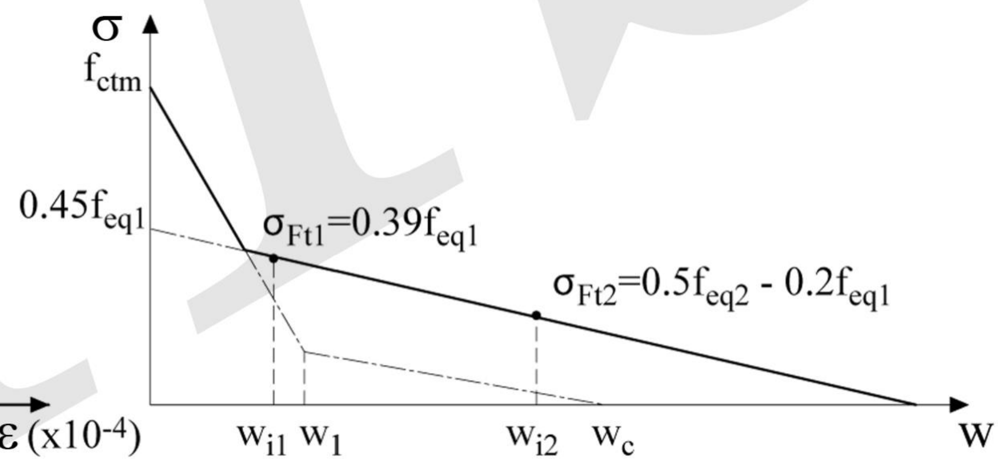
Classification



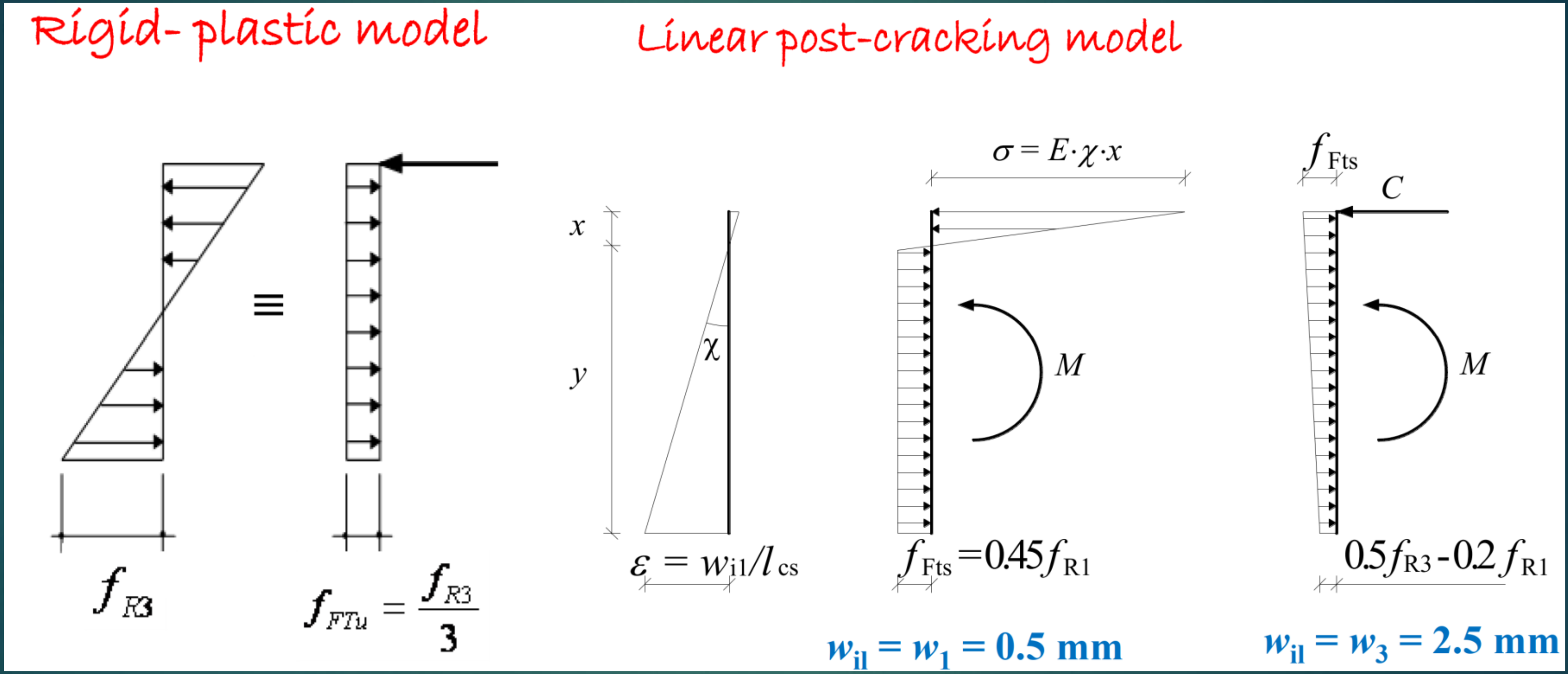






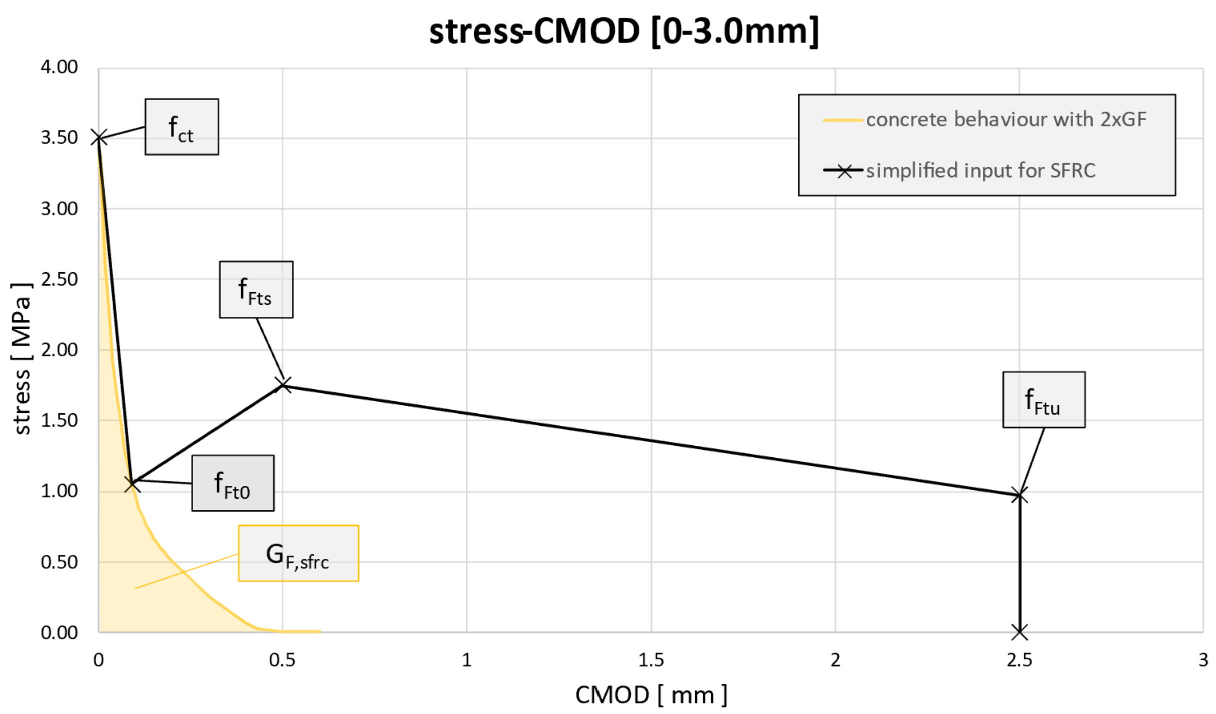


Classification



Classification FEA

Constitutive model



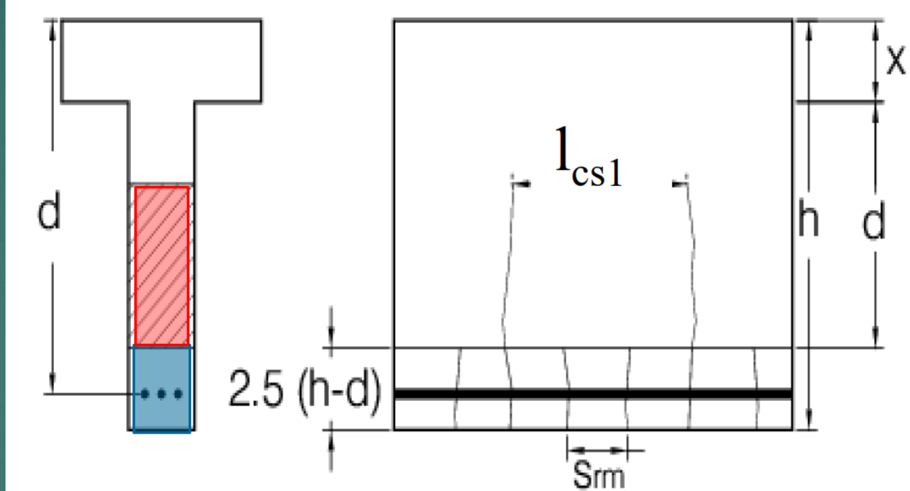
Drop point f_{Ft0} related to f_{Fts}

$f_{Ft0} = \beta * f_{Fts}$

Characteristic length

- From CMOD to strain ?
- W=lcs*e

- Demand on max w<2.5 mm
- Lcs min(h-xu; crack distance)
- e < 25‰



CMOD

- High cross sections chance on pulling out of fibre

6 SLS and ULS

SLS F_{Fts} till 0.5 mm

- The crack pattern can become much more densed
- Smaller crack distance gives smaller cracks
- Fatigue cracks close and reopen with less deterioration

- Dispersion and orientation via k values good practice
  - CC1 ym = 1
  - CC2/CC3 ym = 1.5

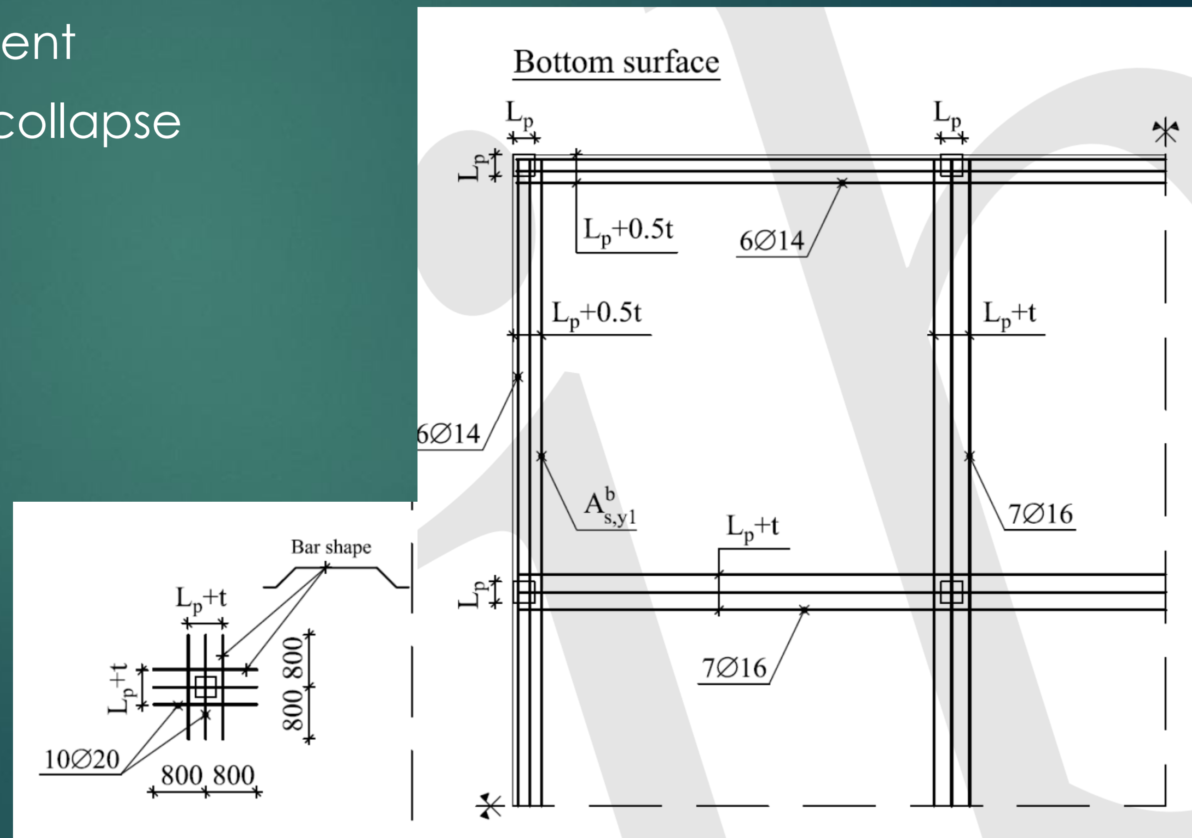
ULS F_{Ftu} till 2.5 mm

- Dispersion and orientation via k values good practice
  - CC1 mean value and ym = 1.5
  - CC2/CC3 characteristic value and ym = 1.5

- Compression failure
- Failure of strain of fibres (pull out)
- Failure of strain of conventional reinforcement

ULS F_{Ftu} till 2.5 mm

- Combination of conventional reinforcement
- Local reinforcement
- Anti progressive collapse



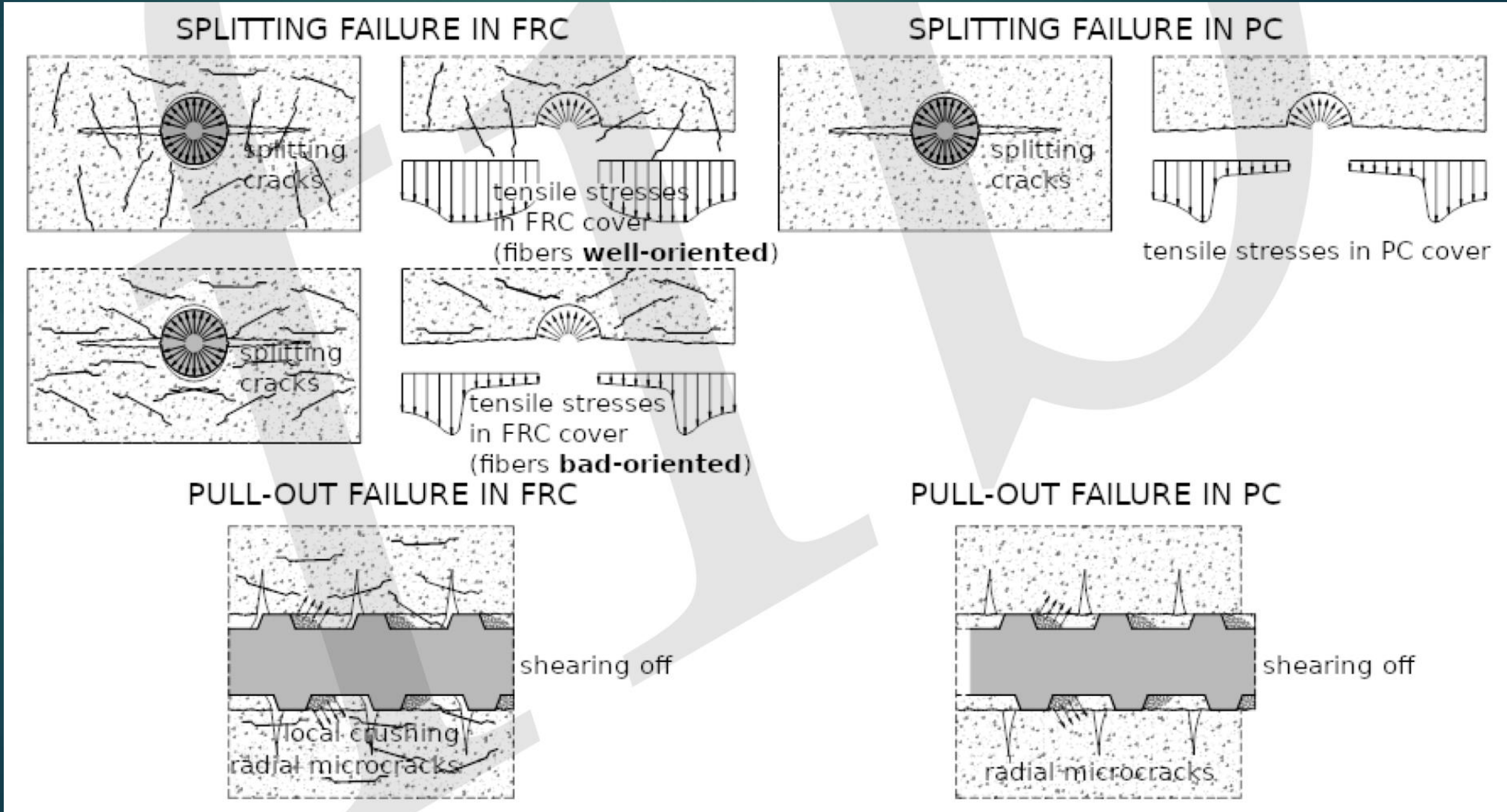
ULS Shear

- SFRC is very effective against shear (or punching)
  - Tensile strength after microcrack
  - Cohesion and dilation effect of fibres bridging the cracks

$$V_{Rd,F} = \left\{ \frac{0.18}{\gamma_c} k \left[100\, \rho_1 \left(1 + 7.5 \boxed{\frac{f_{Ftuk}}{f_{ctk}}} \right) f_{ck} \right]^{\frac{1}{3}} + 0.15\, \sigma_{CP} \right\} b_w \cdot d$$

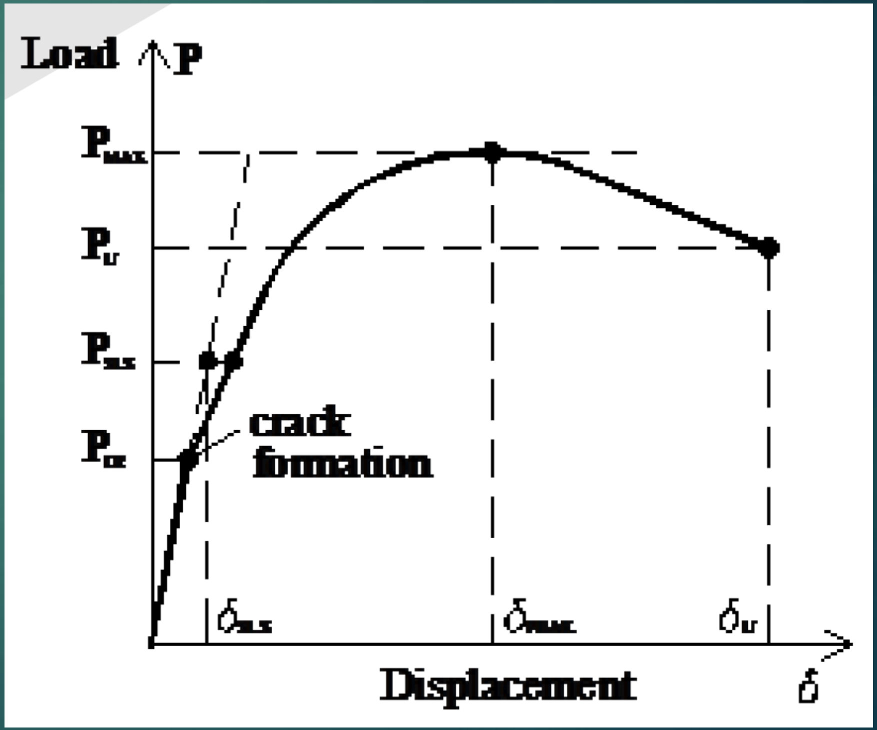
- Studies on Torsion show also a beneficial effect. No rules set yet.

ULS Splitting / bond



ULS Structural ductility

- Displacement $D_{ultimate} > 20\ D_{sls}$ or $D_{peak\text{-}load} > 5\ D_{sls}$



Orientation and distribution

- K factor (negative influence)
  - for slabs, beams and walls is 1.0 (considered in the γm = 1.5 material factor)
- Redistribution factor Krd (positive influence)
  - spreading capacity in multiple directions
  - Larger area of fracture compared to 3 point bending test

Durability

- Steel fibres till 2-3 mm corroded. No connection to other fibres and corrosion is much less in site the structure.
- If necessary galvanised fibres can be used (a bit less effective).

Shrinkage

- Shrinkage often is in the region if tensile without much bending leading to softening in the material.
- One crack that opens.
- Combination with traditional reinforcement enhances the behaviour tremendously

Fibres in fire

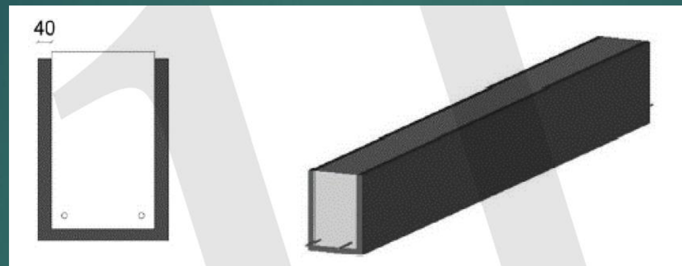
- Spalling
  - PP fibres melt and gives faster evaporation and less gradients of temperature.
  - Steel theoretically will hold the spalling parts a bit, but tests are in contradiction.
- Structural capacity
- There is no indication that FRC will have less structural capacity during fire. The tensile strength of the concrete matrix will hold a bit longer.

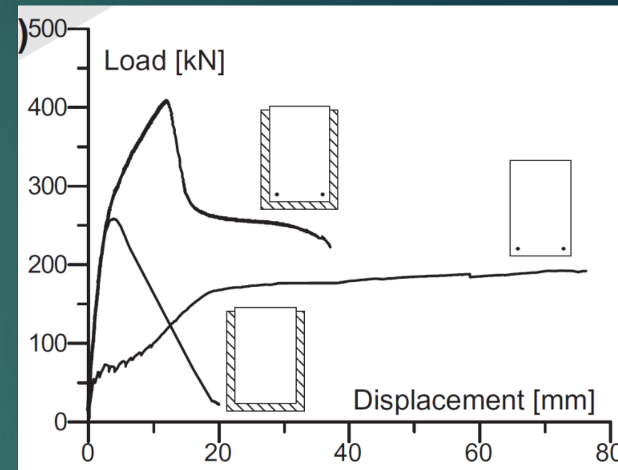
Technological aspects

- A bit more attention necessary
  - Finer aggregates (4-16)
  - A bit more air depending also on fibre type
  - Fibres adding in
    - the batch plant
    - Mixer
      - With a blower / blasting machine
      - On a conveyor belt
      - Thrown from boxes (do not do this!)
- Testing fibre amount with strong magnete

FRC for structural rehabilitation

- (U)HPC

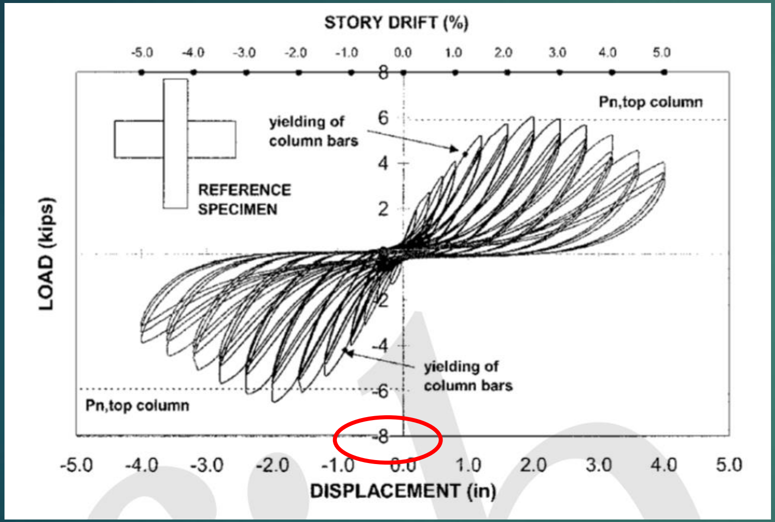


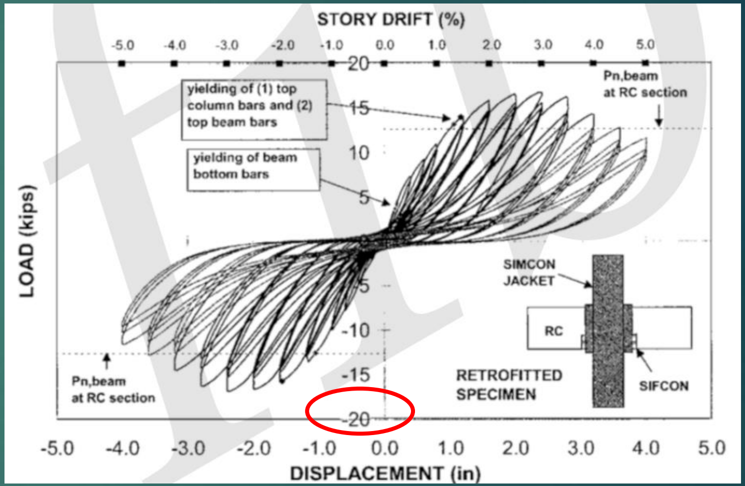


- SIFCON

FRC for structural rehabilitation

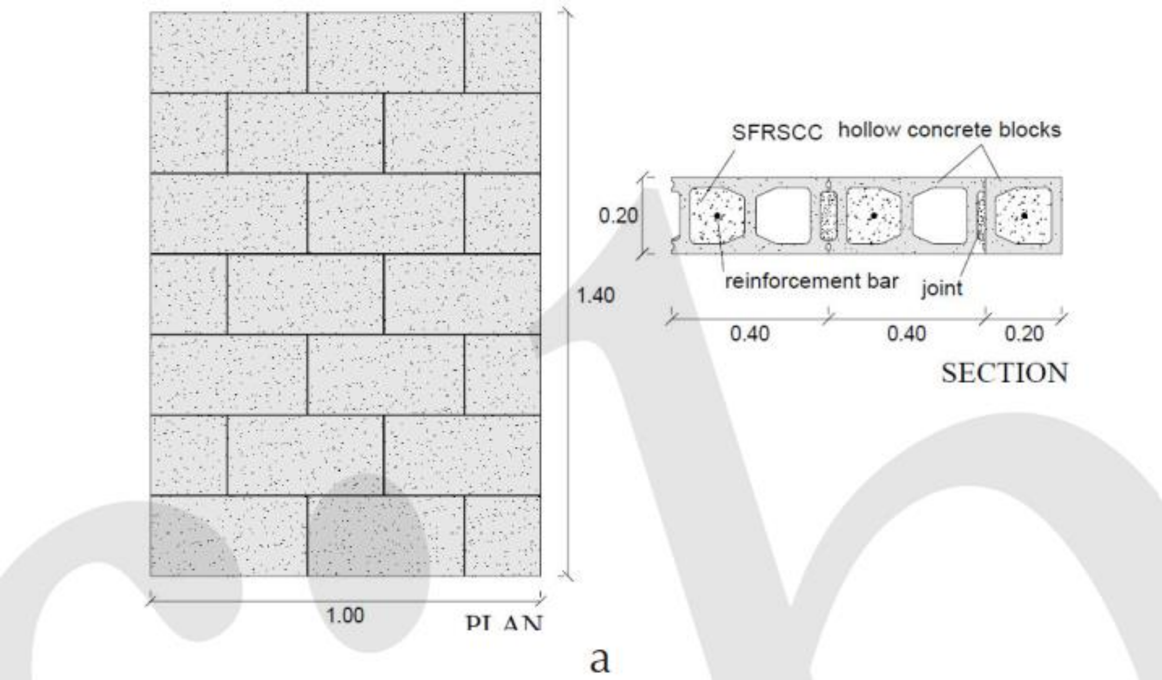
- Seismic





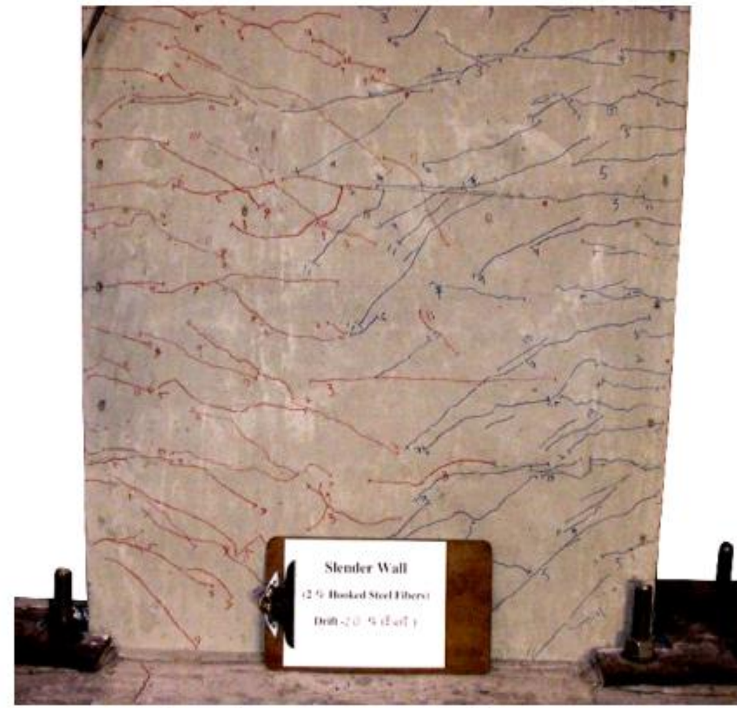
FRC for structural rehabilitation

- Masonry



FRC for structural rehabilitation

a) Reinforced concrete wall

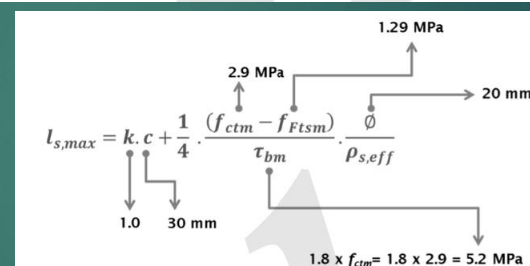


b) Strain-hardening FRC wall

Design examples analytical

- A beam 6 m 0.2*0.3 (w*H) fibres class 2b

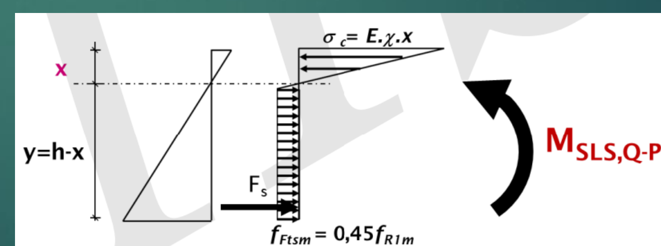
- Lcs = min(1.5*ls,max;h)
- 100 mm



- SLS:

$$f_{Ftud} = \frac{\frac{f_{R3k}}{3}}{\gamma_c}$$

$$f_{Ftud} = \frac{\frac{1.4}{3}}{1.5} = 0.31\,\text{MPa}$$



Design examples analytical

- A beam 6 m 0.2*0.3 (w*H) fibres class 2b
- ULS

$$\lambda \cdot x \cdot \alpha_{cc} \cdot f_{cd} \cdot b = A_{s} \cdot f_{yd} + (h - x) f_{Ftud} \cdot b$$

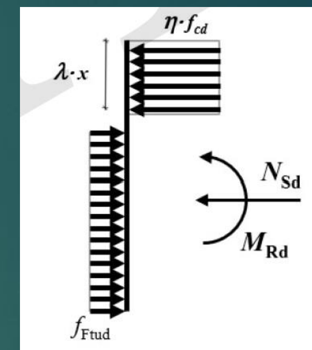
$$0.8 \cdot x \cdot 1.00 \cdot 20 \cdot 200 = 628 \cdot 435 + (300 - x) 0.31 \cdot 200$$

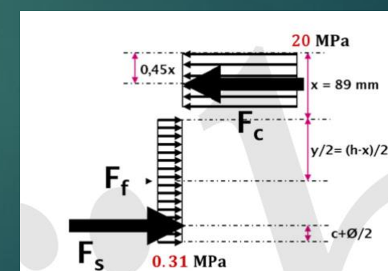
$$x = 89 \text{ mm}$$

$$M_{Rd} = 220 \left(f_{yd} \cdot A_{s} \right) + 154\, f_{Ftud} \left(h - x \right) b$$

$$M_{Rd} = 220 \left(435 \cdot 628 \right) + 154 \cdot 0.31 \cdot 211 \cdot 200$$

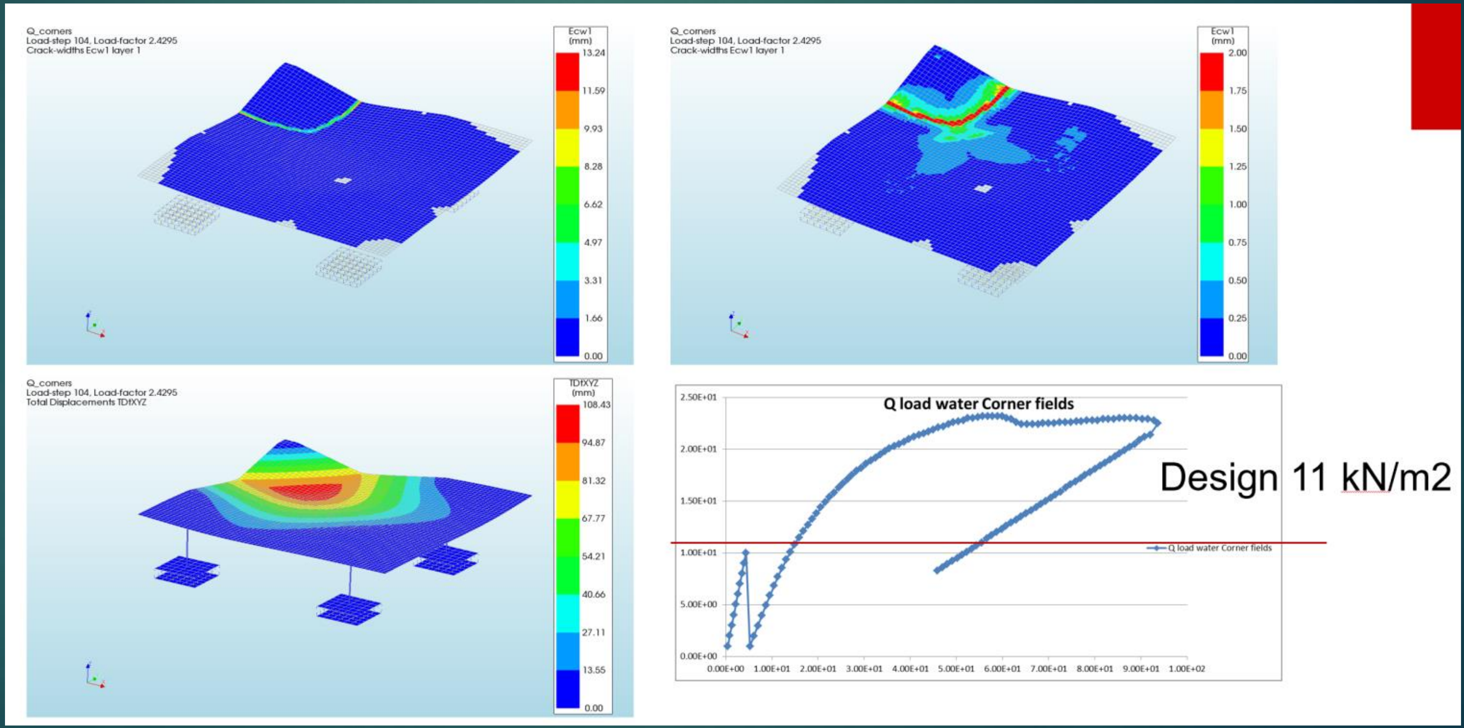
$$M_{rd} = 62 \text{ kNm} > 60.4 \text{ kNm} \left(M_{sd} \right) \qquad \text{ok}$$





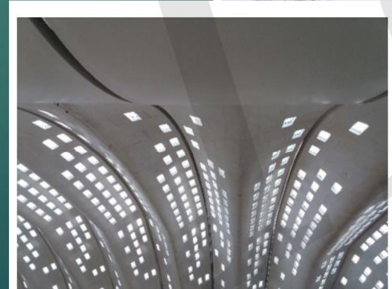
Design examples advanced

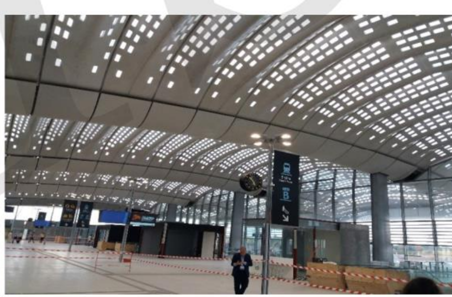
- Step out to other ppt



UHPFRC

- Bridge decks (not with RWS)
- Nice shapes (pumpable)
- Slender 1/38 beams
- Roofing facades
- Stadium
- Trainstation
- Bridge deck overlays (NL RWS)





Questions?

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