Development in Codes for New and Existing Concrete Structures – fib MC2020

29 Sept 2017 Sao Paolo, Brazil

SERVICEABILITY – CRACK CONTROL

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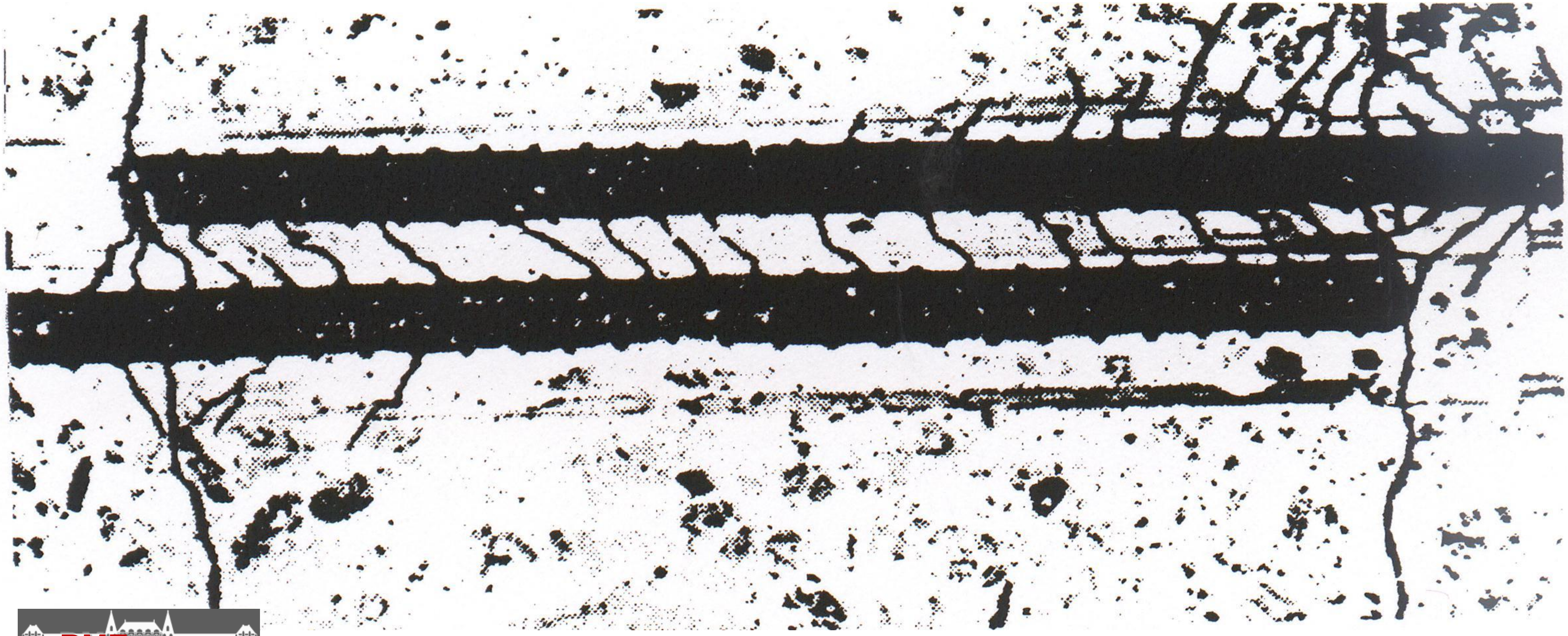
Budapest University of Technology and Economics

Every engineer in the world knows about

GOTO CRACKS

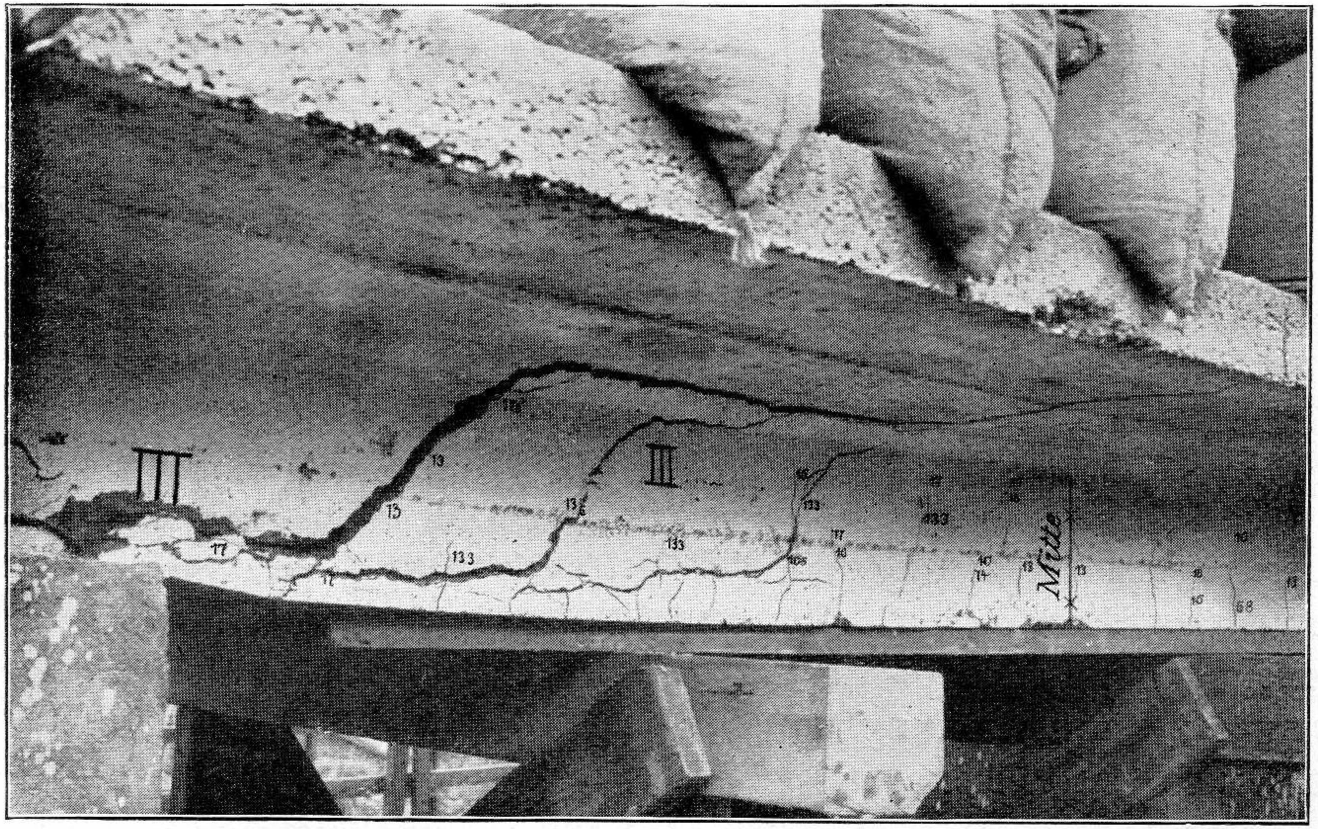
(Goto,1971)

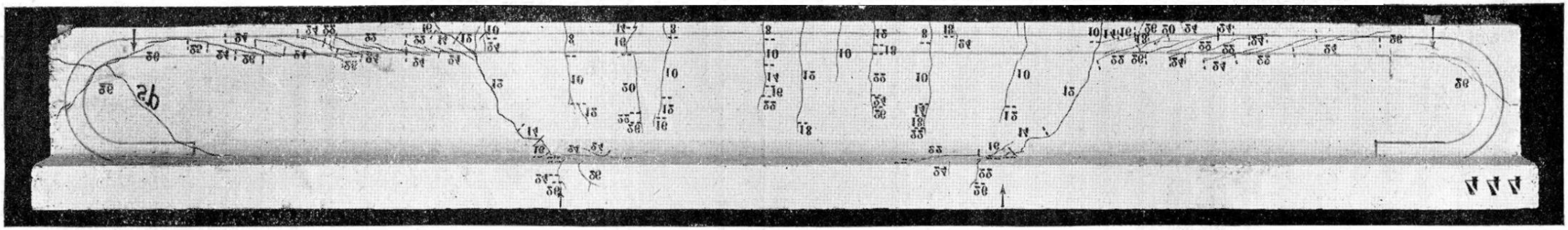
Indication of difference between micro cracks and macro cracks



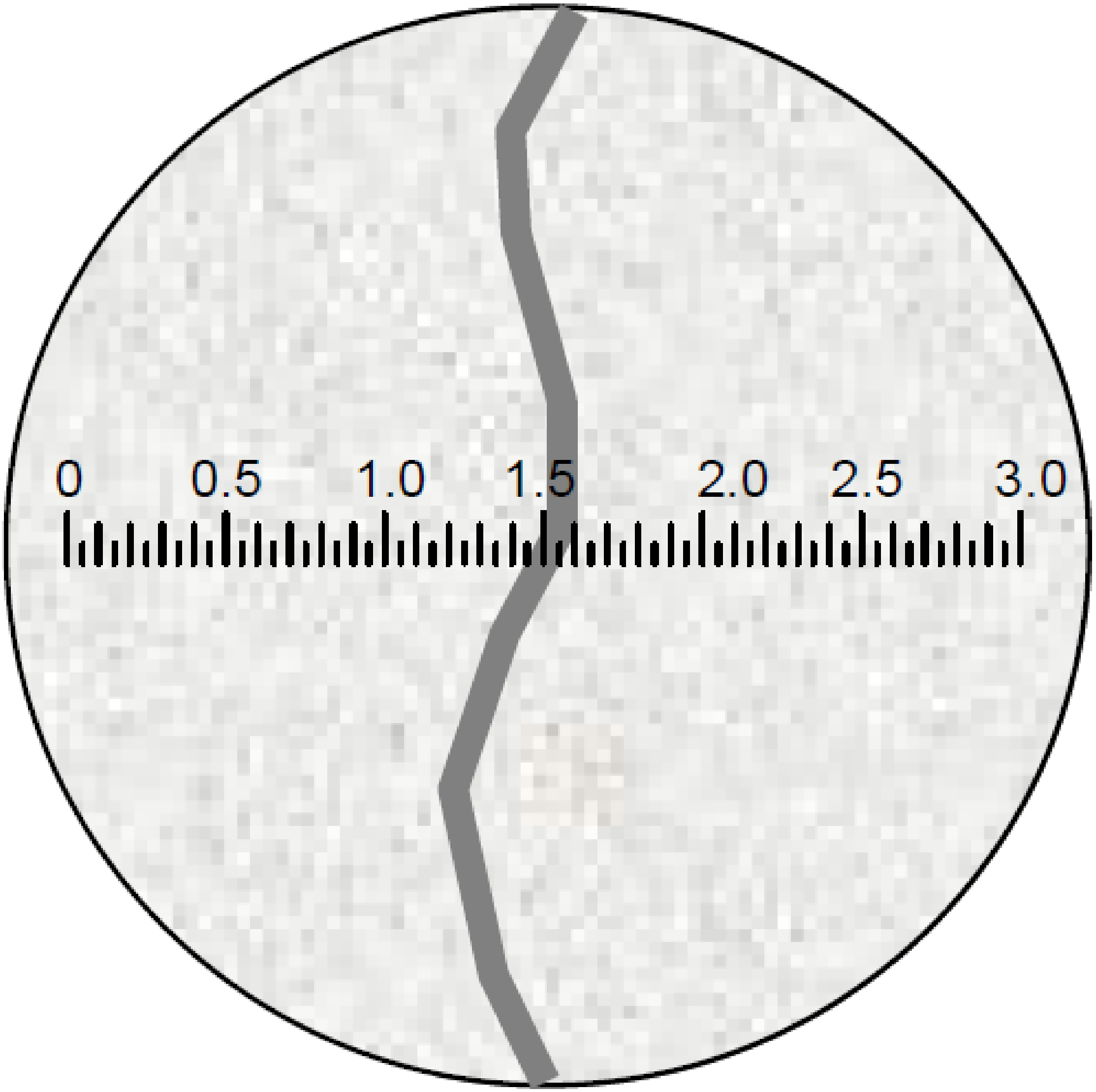
Cracking in structures: **MÖRSCH (1908)**

(Der Eisenbetonbau, seine Theorie und Anwendung)

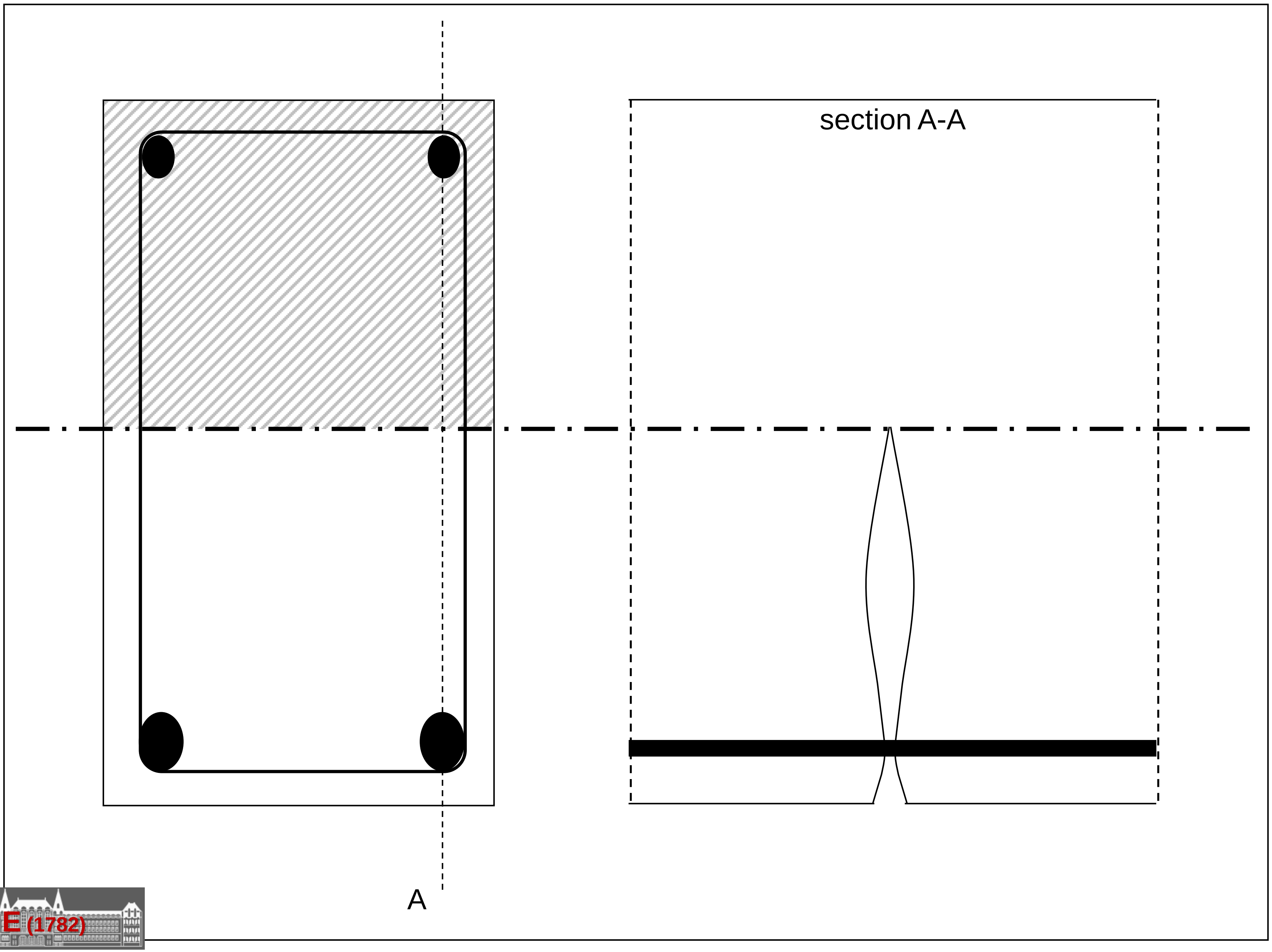




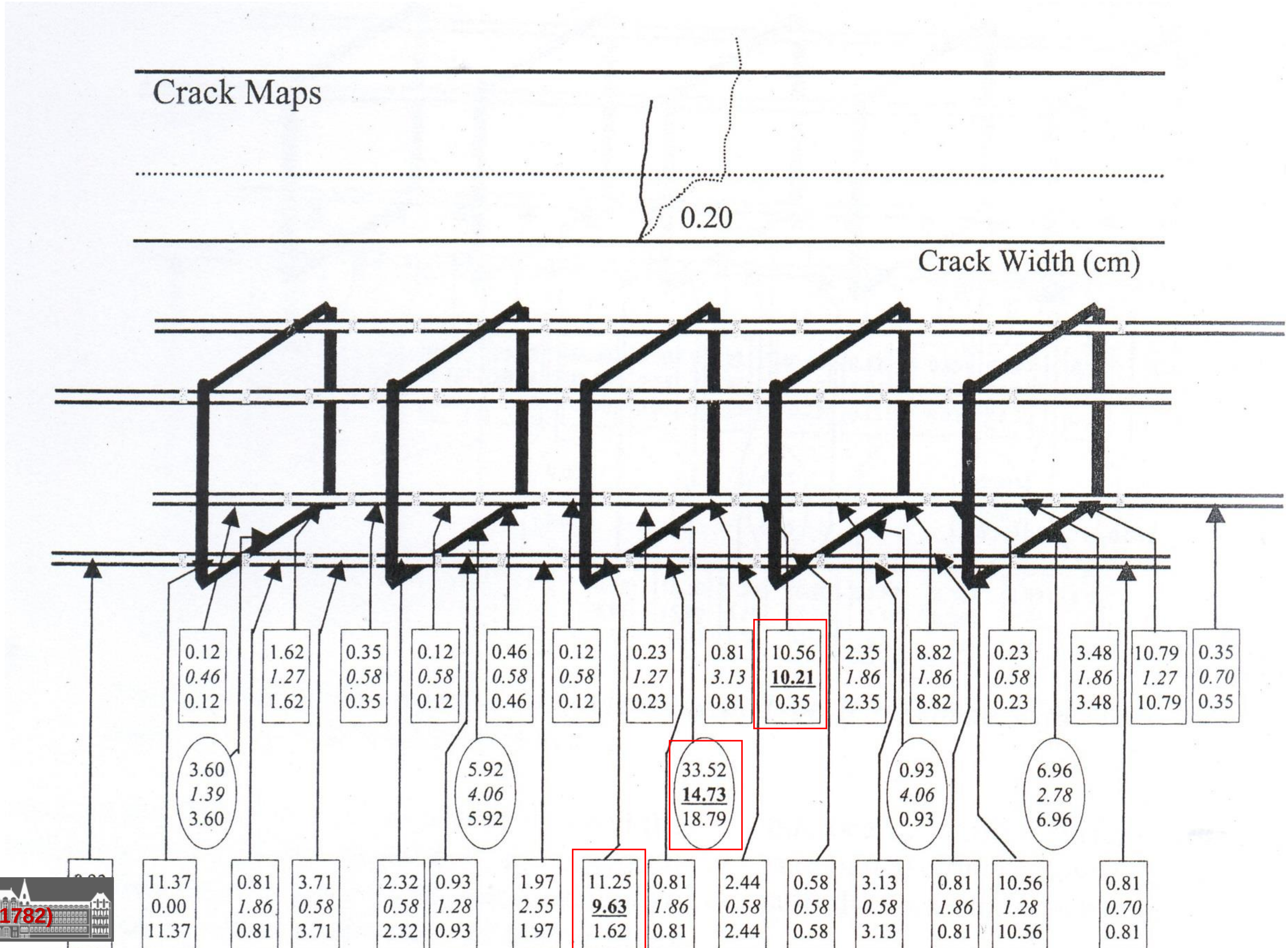
Cracks are visable



SHAPE OF FLEXURAL CRACK AND COVER THICKNESS



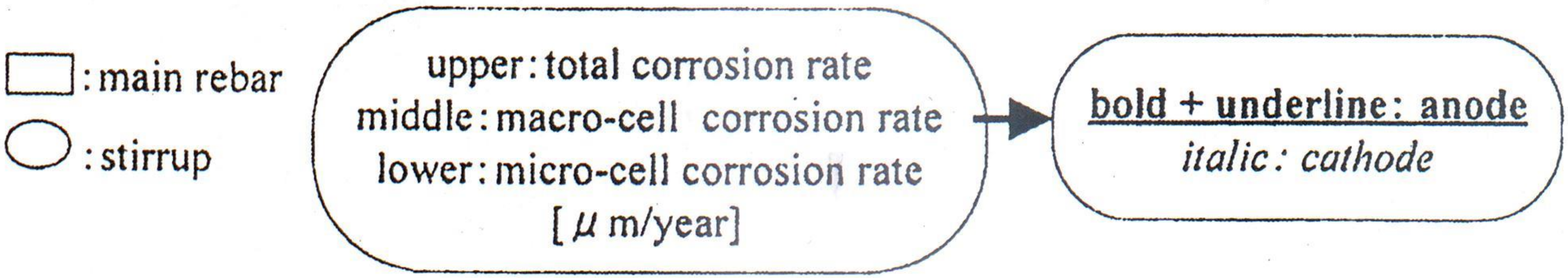
MEASURED CORROSION RATES
(Otsuki, Miyazoto, Diola, Suzuki, 2000)

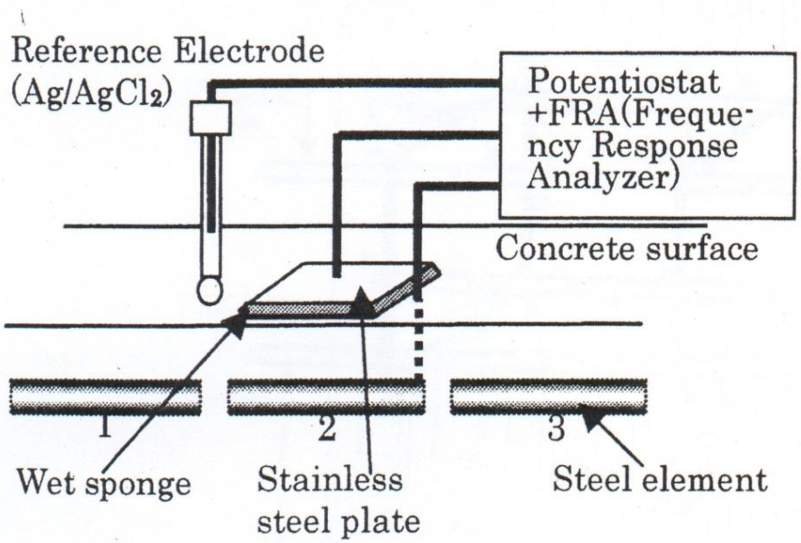


MEASURED CORROSION RATES

(Otsuki, Miyazoto, Diola, Suzuki, 2000)

The corrosion rates of main reinforcing bars and stirrups near a bending crack were clarified.





<u>Micro-cell:</u> current refers to the current flowing in the cell when only one steel component is involved.

<u>Macro-cell:</u> the total electric current flowing through all the adjacent steel components.

MEASURED CORROSION RATES

(Otsuki, Miyazoto, Diola, Suzuki, 2000)

-The influences of bending cracks and w/c on the corrosion rates of reinforcing bars were very large.

- In the vicinity of a bending crack a macrocell was formed and the corrosion rate increased remarkably.

-Since alkali content increases with the decrease in w/c, the corrosion rate slows down with low w/c.

Our everyday life is full of worries about cracks

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Cracking in the nature:

Pine Island-Glacier (PIG)

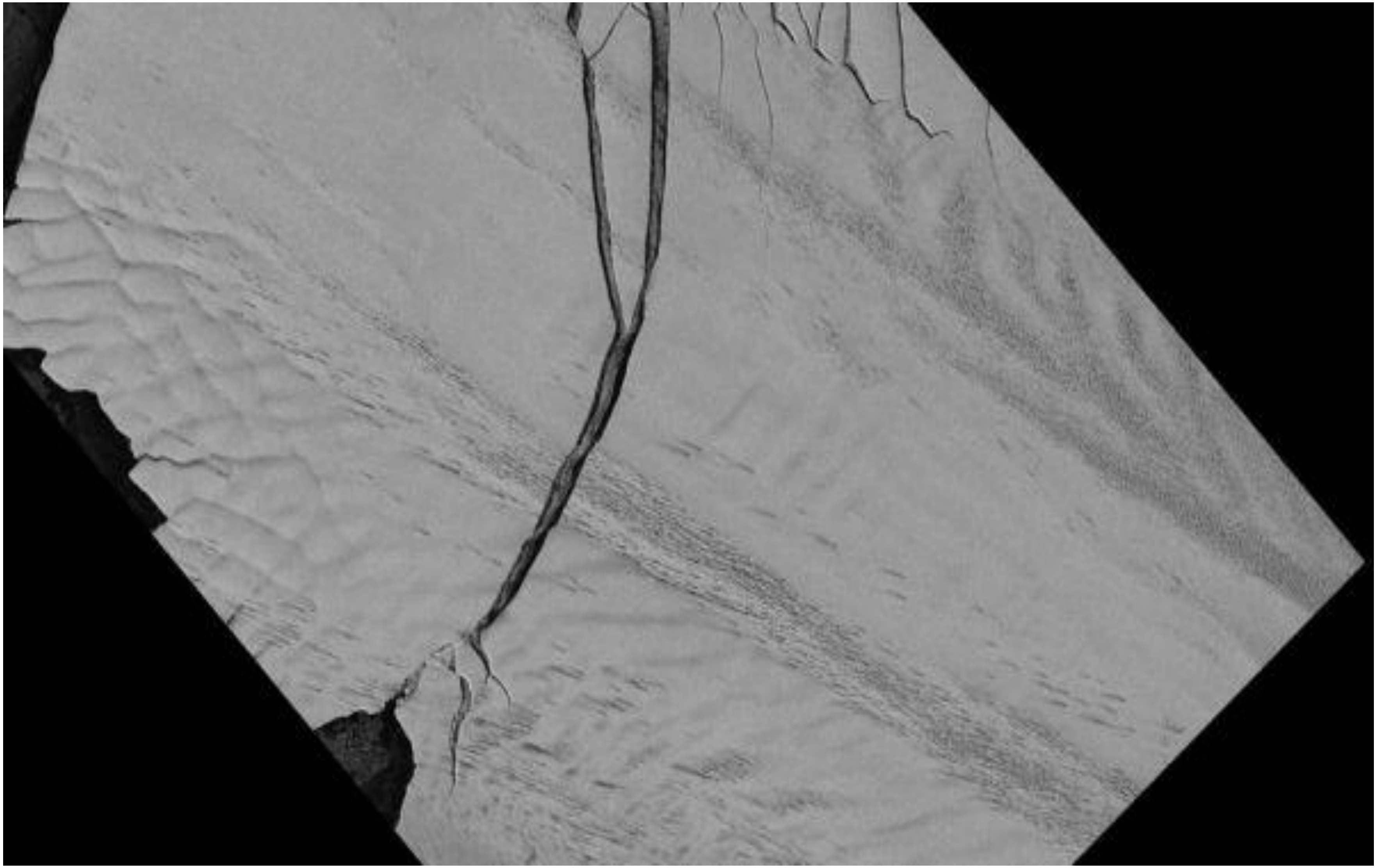
In the Antarktis

a crack produced separation of ice

10 July 2013, Wednesday - 13:54

http://richpoi.com/cikkek/tudomany/uj-jeghegy-szuletett-a-deli-sarkvideken.html

720 km2 ice cracked away in the Antarktis

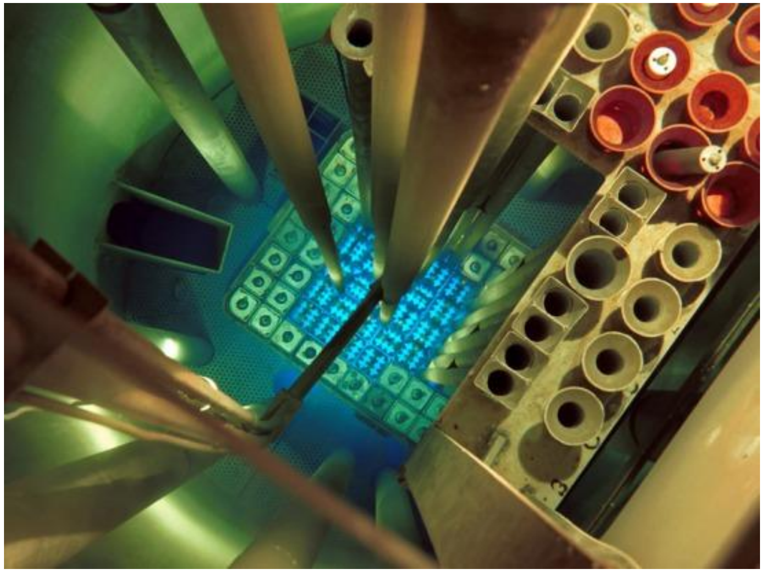


Pine Island-Glacier (PIG)

NUCLEAR SAFETY

The Institute of Nuclear Techniques (INT) of the Budapest University of Technology and Economics

http://www.geolocation.ws/v/P/82487827/bme-tanreaktor/en



http://letoltendo.postr.hu/geekturiszt-seta-a-reaktor-korul

BME (1782)

Budapest University of Technology and Economics

Fracture Behaviour of Radiolytically Oxidised Reactor Core Graphites: A View[1]

[1]A Hodgkins, [2]TJ Marrow, [3]MR Wootton, [3]R Moskovic, [3,4]PEJ Flewitt,

[1]Serco TAS, Faraday Street, Birchwood Park, Warrington, WA3 66A, UK

[2]Materials Performance Centre, School of Materials, The University of Manchester, Manchester, M13 9PL, UK

[3]Magnox North Ltd, Oldbury Naite, Oldbury-on-Severn, Bristol, BS35 1RQ UK

[4]Dept of Physics, HH Wills Laboratory, University of Bristol, Bristol, BS8 1TL, UK

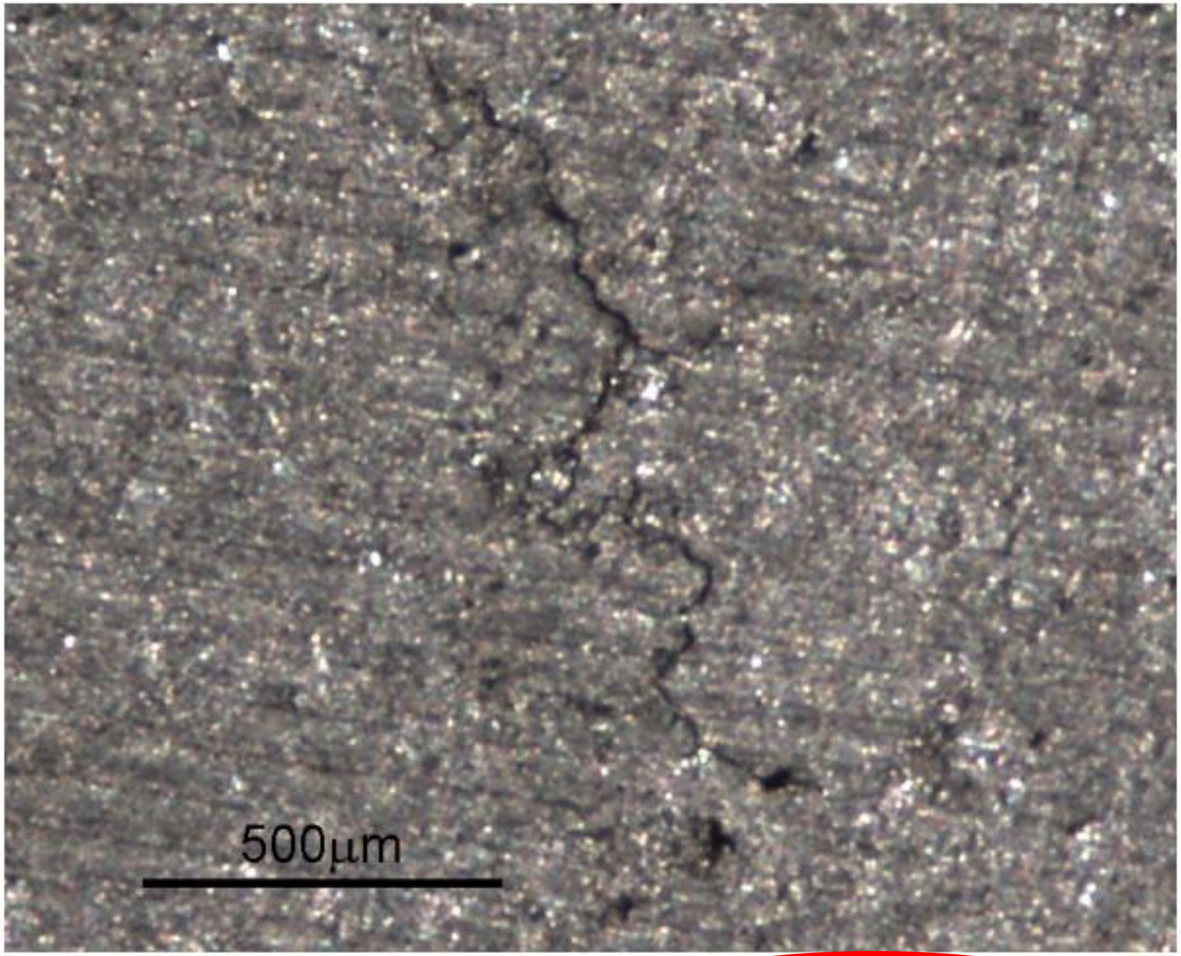


Figure 7 Optical micrograph showing the early stage of cracking in virgin PGA graphite.

CEOS Project

1/ shear wall under *monotonic* shear loading
2/ shear wall under *cyclic* shear loading

STUDIES:
- Cracking under mon load
- Free shrinkage
- Restrained shrinkage
- Thermo-hydro effects
- Alternating cyclic load

MEASUEREMENTS:
- LVDTs,
- VibrAting gauges,
- Optical sensors,
- Acoustic sensors

A/ Shear walls:

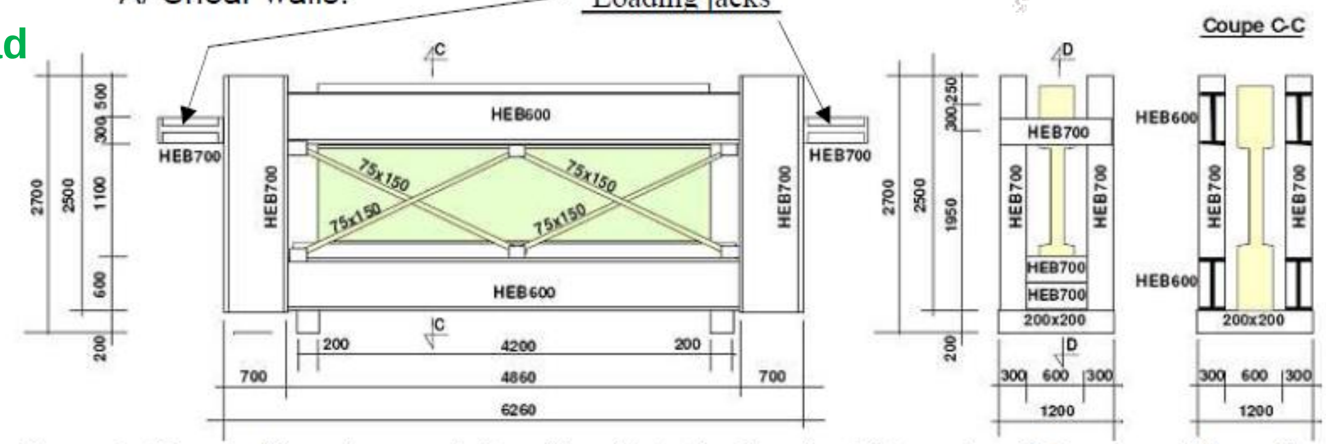


Figure 1: Shear wall specimens – left: wall on its testing bench- right: sectional elevation of the wall

3/ large beam specimens *loaded in flexion after free shrinkage* (figure 2 & 3)
4/ large beam specimens with *restrained shrinkage* (figure 4)

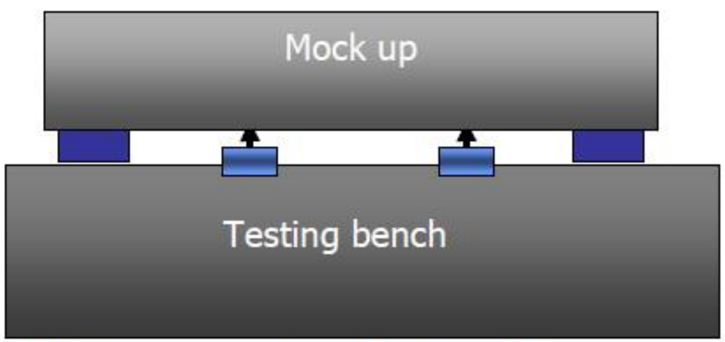


Figure 2: Large beam, scheme of the test

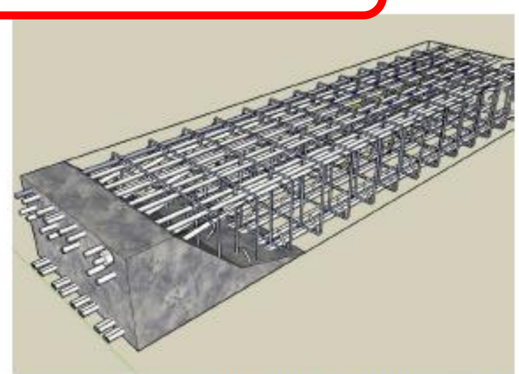


Figure 3: geometry and reinforcement scheme for the free shrinkage specimens

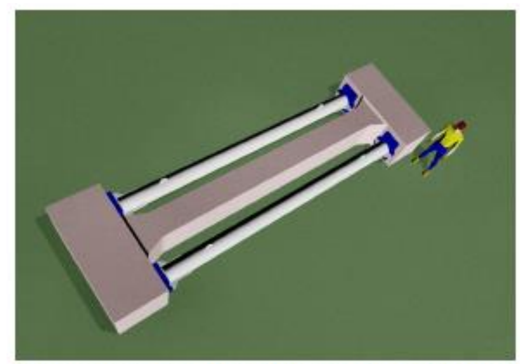


Figure 4: I geometry for the restrained shrinkage specimens and restrained system

ConCrack4: OBSERVATIONS

PROJET NATIONAL CEOS.fr

ConCrack 4
-
20-21 March

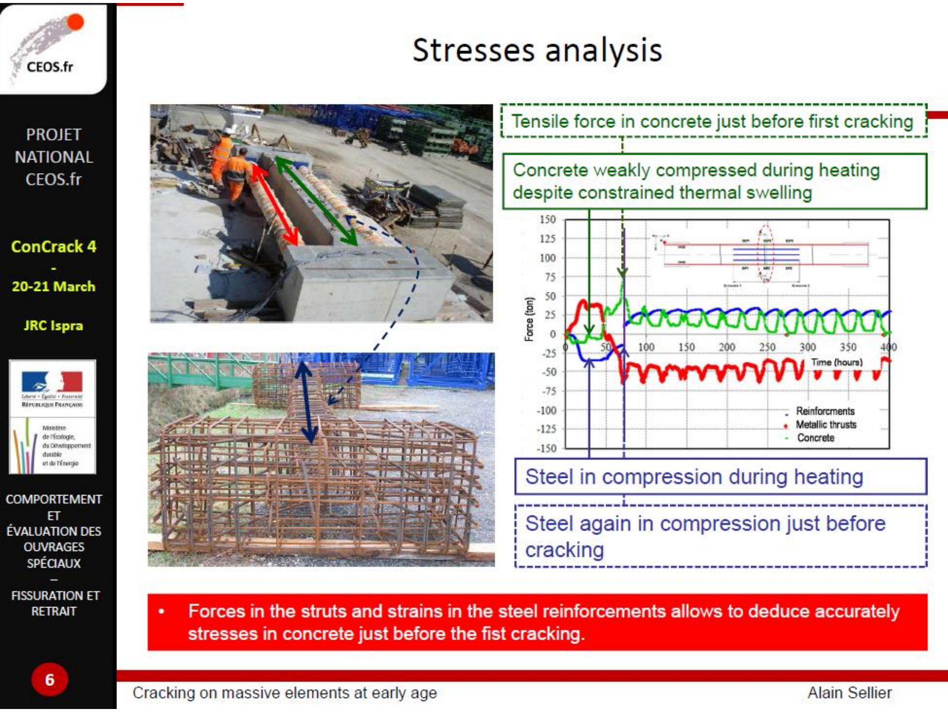
JRC Ispra

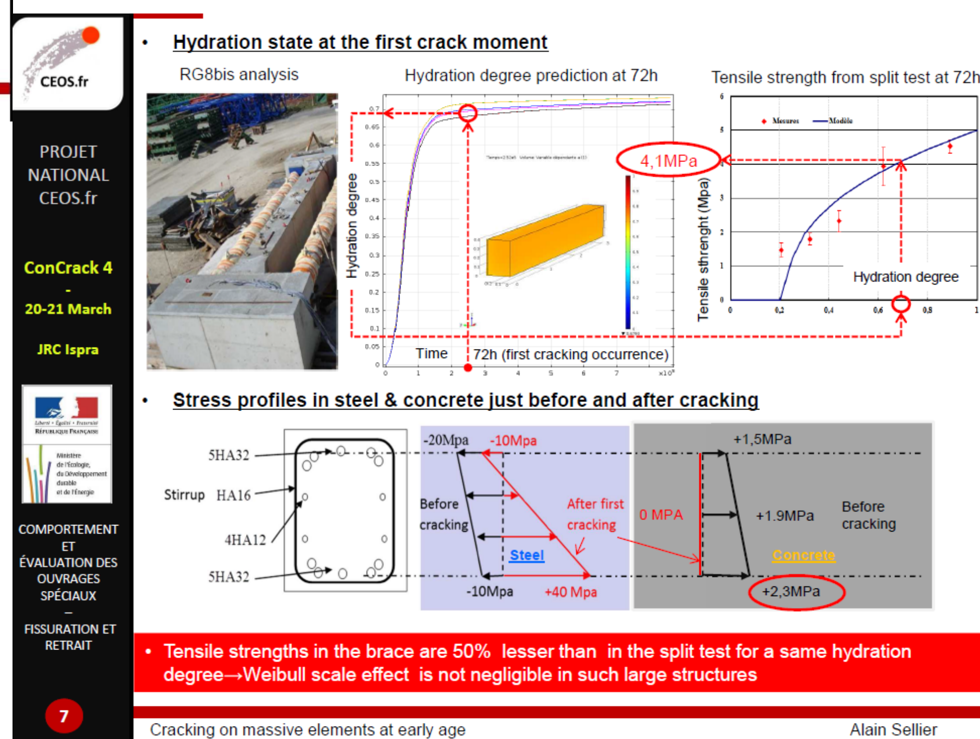
COMPORTEMENT ET ÉVALUATION DES OUVRAGES SPÉCIAUX
–
FISSURATION ET RETRAIT

Part 2. Main conclusions

- Crack spacing
  - **Both EC2 and MC2010 overestimate crack spacing**
  - Results are better with MC2010
- Strain difference
  - Both EC2 and MC2010 **underestimate the strain**, above all MC2010
  - **Tension stiffening** seems to be **overestimated** in both codes
- Crack width
  - EC2 **overestimates** crack width
  - MC2010 **slightly underestimates** crack width

ConCrack4: OBSERVATIONS





ConCrack4: OBSERVATIONS

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ConCrack 4 - 20-21 March

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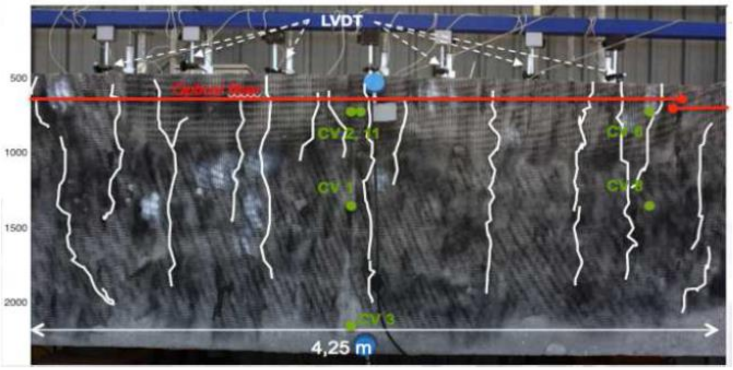
COMPORTEMENT ET ÉVALUATION DES OUVRAGES SPÉCIAUX – FISSURATION ET RETRAIT

Presentation of RL beams CEOS.fr

- **Instrumentation**



Classical instrumentation (displacement sensors, long base optical fibres, gauges on rebars, vibrating wires….)

+ **Digital Image Correlation (DIC)** enabling measurement of the crack pattern with an accuracy of ≈0.05 mm for massive blocks

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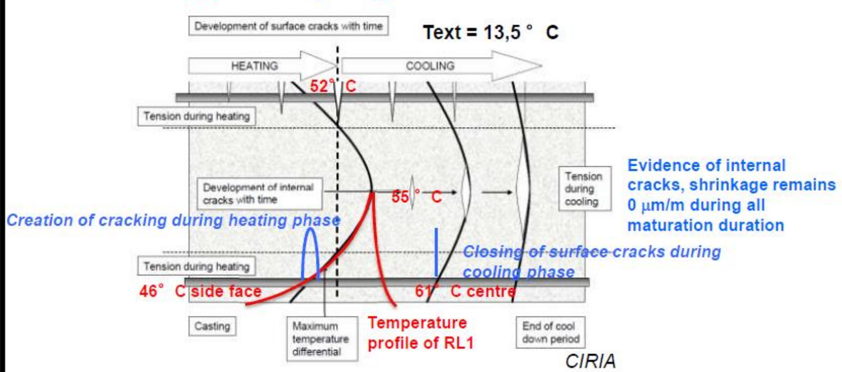
COMPORTEMENT ET ÉVALUATION DES OUVRAGES SPÉCIAUX – FISSURATION ET RETRAIT

Influence of early age behaviour – RL1

Early age behaviour of RL1:

- **Micro-craking on surface during heating phase**
  - Important temperature differential from lower part of the beam and side face and outdoor temperature
  - Relaxation and tension of rebars
- **Microcracking at core during cooling phase**



CAUSES OF CRACKING

1. Technological plastic shrinkage

(early age) plastic settlement…

2. Loads and imposed deformations

(hardened concrete)

3. Volumetric changes in concrete

temperature differences

AAR, ASR…

NEEDS FOR CRACK CONTROL

- **tightness** (water and gas)
- **durability**

  propagation of corrosion

  permeability, chloride ingress…

  Where is the limit?

- **appearance**

Water and gas tightness

WATER TIGHT-NESS?

WATER TIGHT-NESS?

WATER TIGHT-NESS?

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SELF HEAL-ING?

Pontoons need to swim

There are many other reasons of cracks In concrete structures in early ages and in service

Cracking between concretes of different ages

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Cracking from stress concentrations

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Wall

Railway sleeper

Tram panel

Airport

runway

HPC edge beam

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Precast form joints

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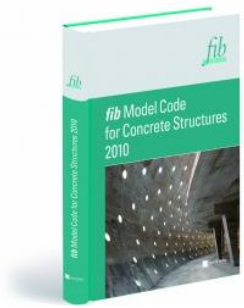
SERVICEABILITY LIMIT STATES (SLS)

The states beyond which specified demands for a structure or a structural component related to its

<u>normal use or function</u> are no longer met.

SLS criteria are related to



- **Unaceptable deformations or deflections**
  - → impair functionality
  - → damage to non-structural elements
  - → discomfort to people
  - → effect appearance

- **Excessive cracking and slip in connections**
  - → affect efficiency
  - → affect tightness
  - → affect appearance, but
  - → does not effect structural safety

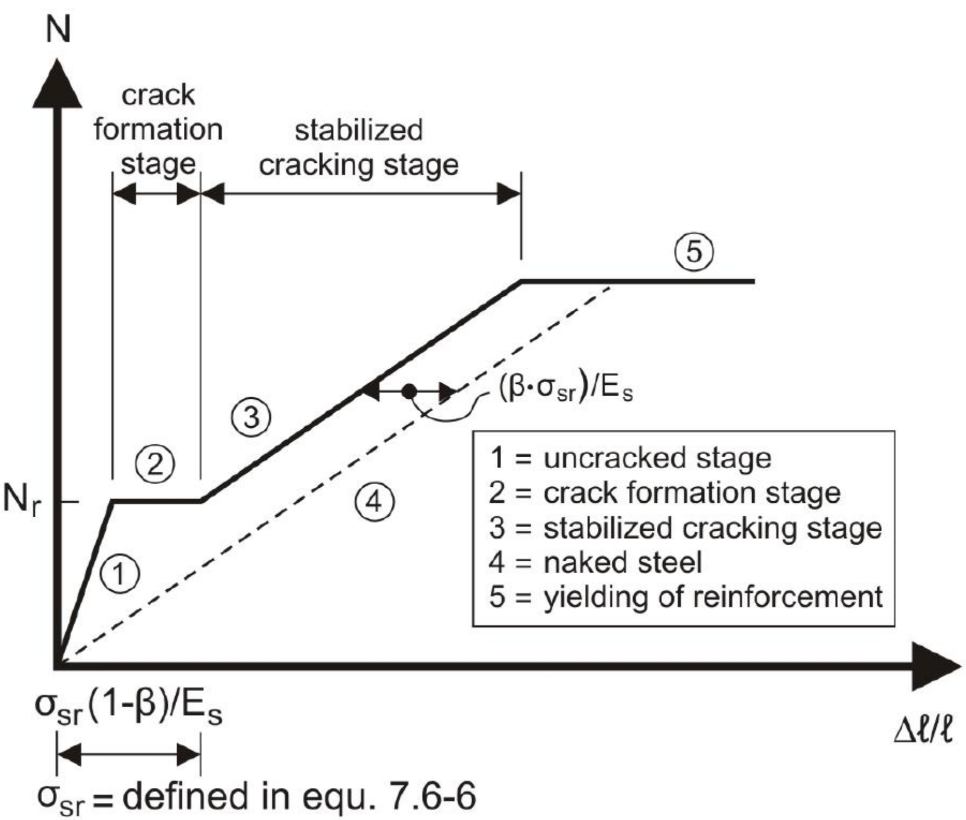
- **Exessive vibrations**
  - → impair user’s comfort and structural effectivess

DEFINITION OF CRACK WIDTH

$$w = \int_0^{s_r} \left[\varepsilon_s(x) - \varepsilon_c(x) \right] dx$$

7.6 DESIGN: SLS - Cracking and deflecions

Tensile force-strain diagram



Crack control

$$w_d = 2l_{s,\max}(\varepsilon_{sm} - \varepsilon_{cm} - \varepsilon_{cs})$$

$$l_{s,\max} = k \cdot c + \frac{1}{4} \cdot \frac{f_{ctm}}{\tau_{bm}} \cdot \frac{\phi_s}{\rho_{s,ef}}$$

$$\varepsilon_{sm} - \varepsilon_{cm} - \varepsilon_{cs} = \frac{\sigma_s - \beta \cdot \sigma_{sr}}{E_s} + \eta_r \cdot \varepsilon_{sh}$$

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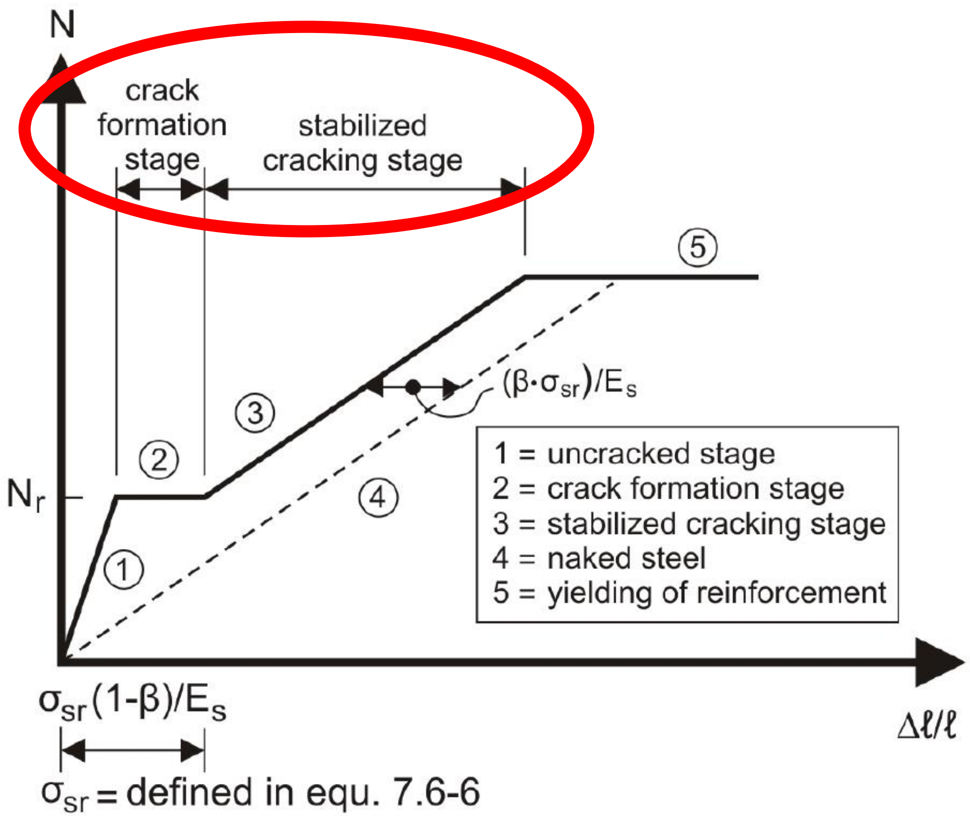

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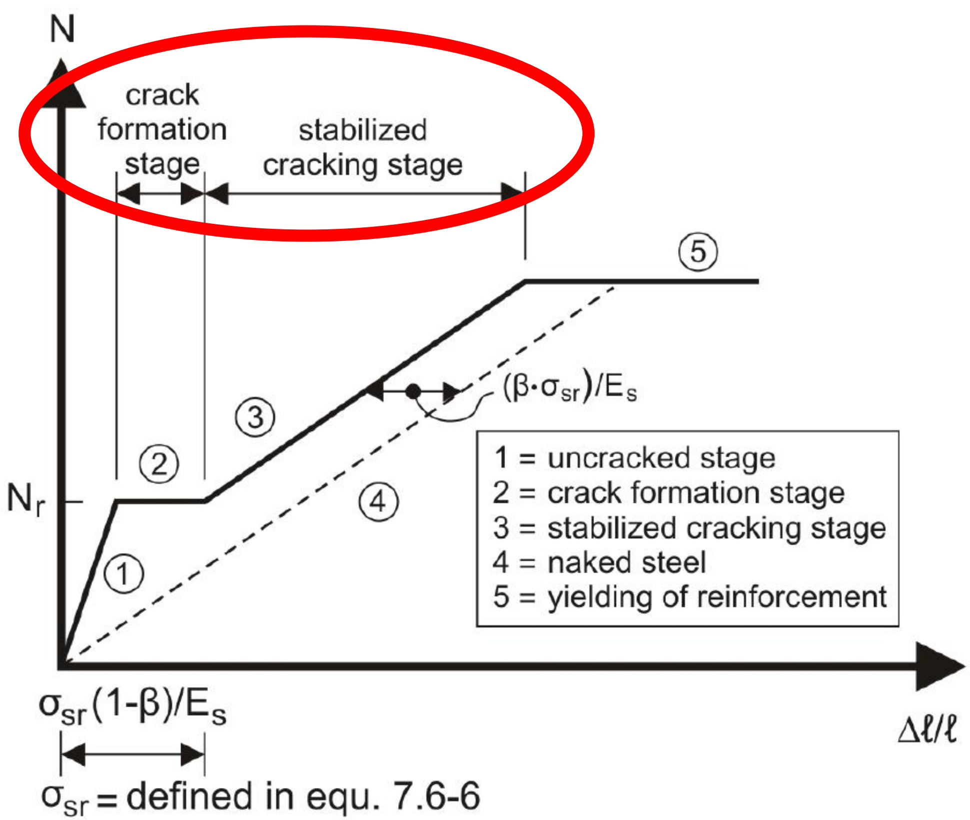
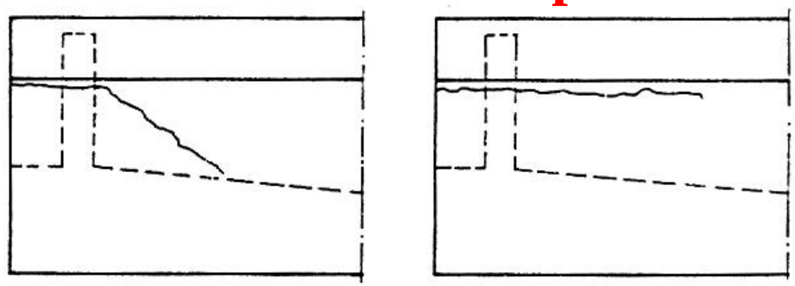
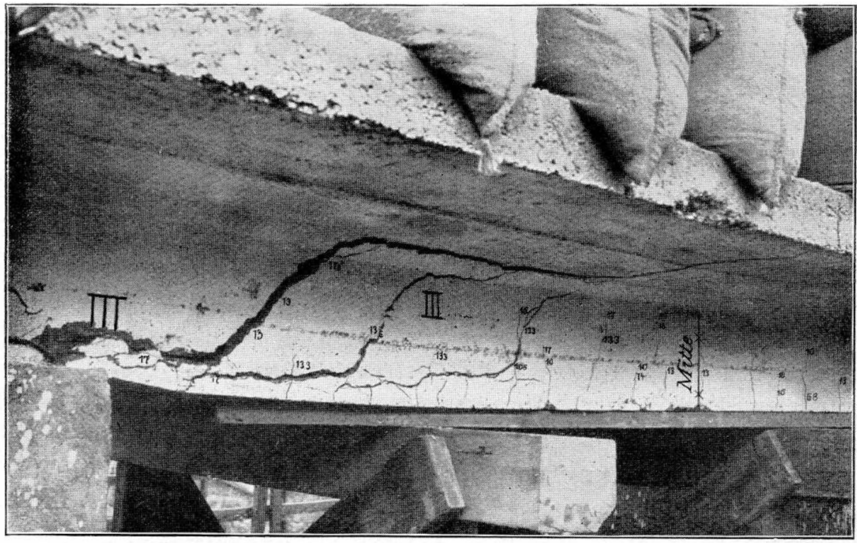


Crack formation phase



Stabilized cracking



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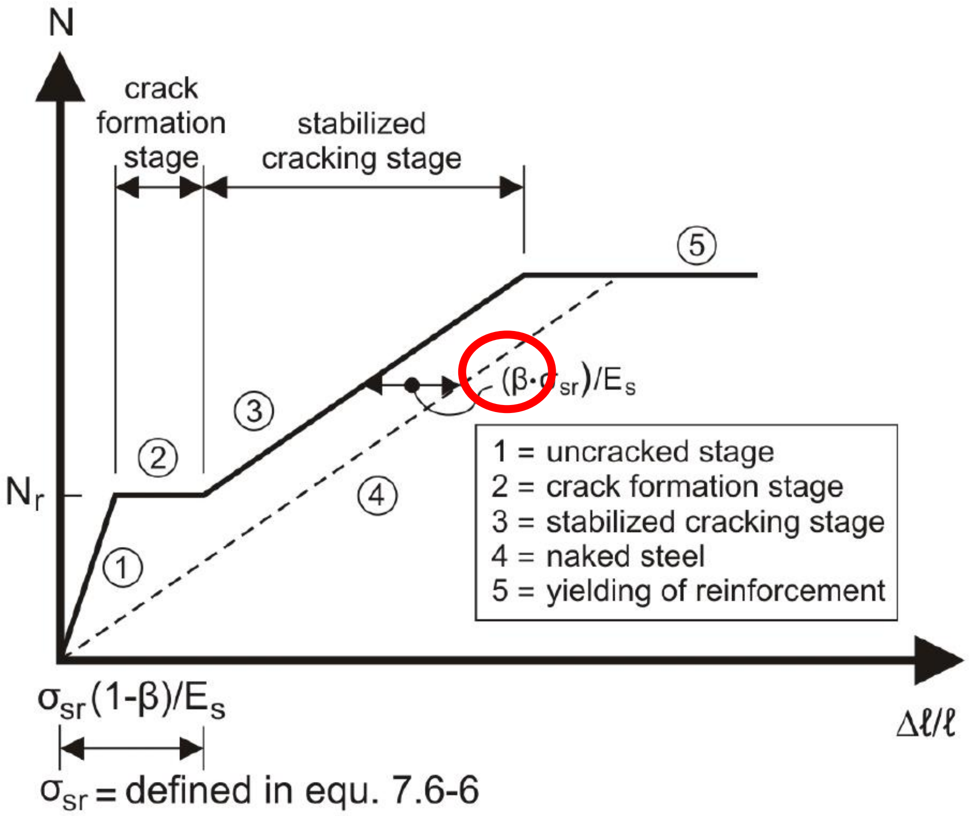

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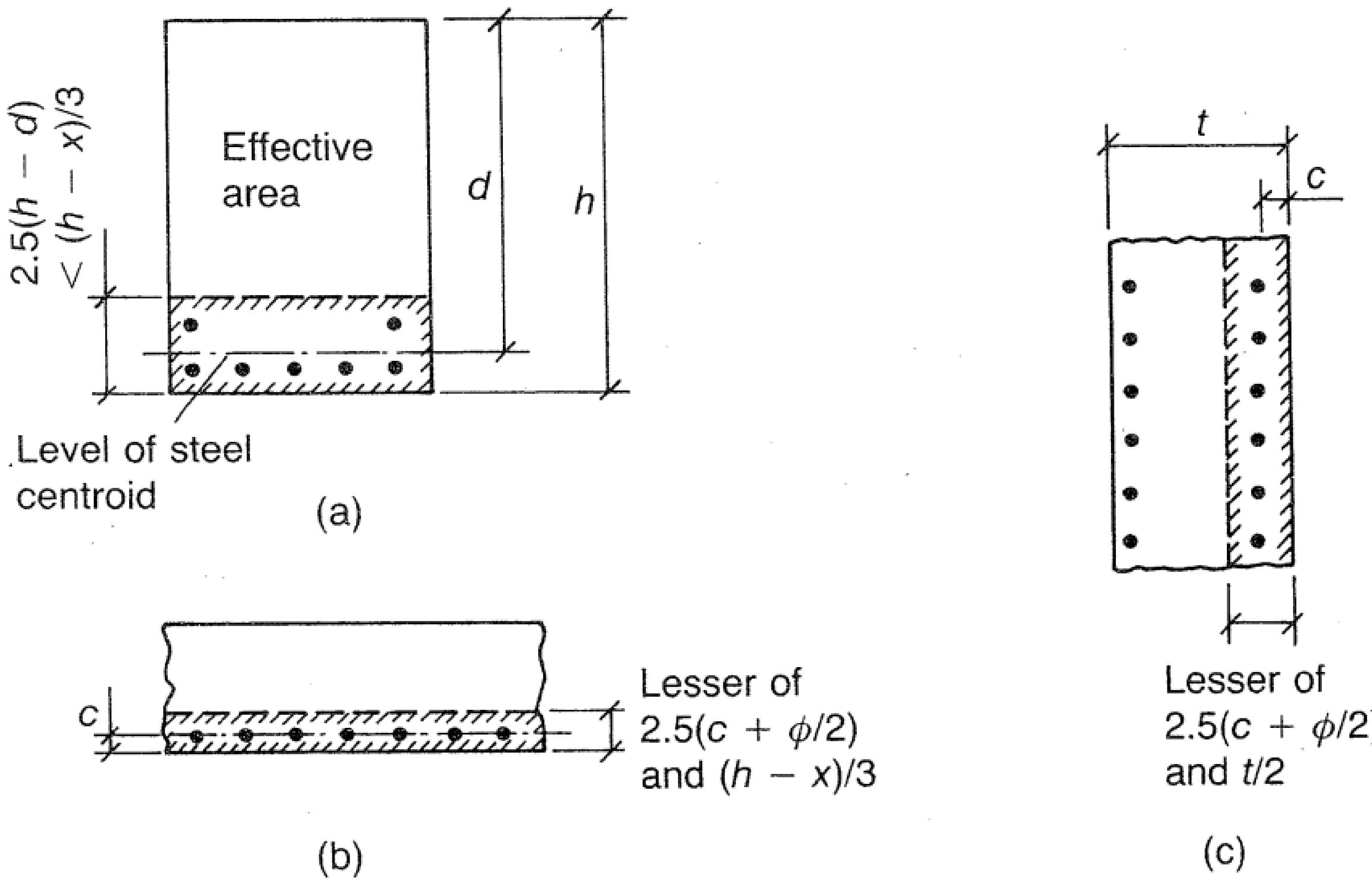
Effective concrete area in tension



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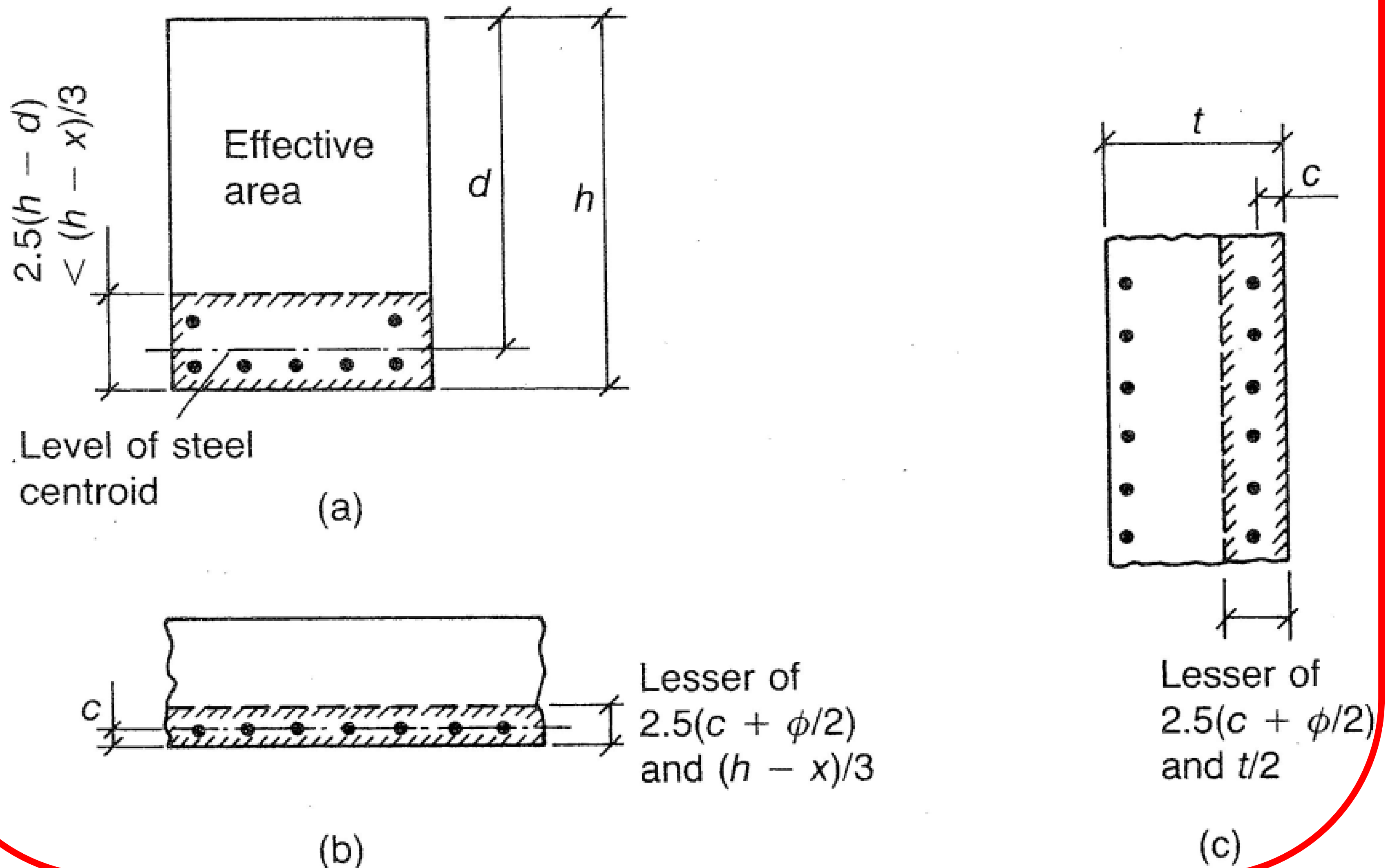

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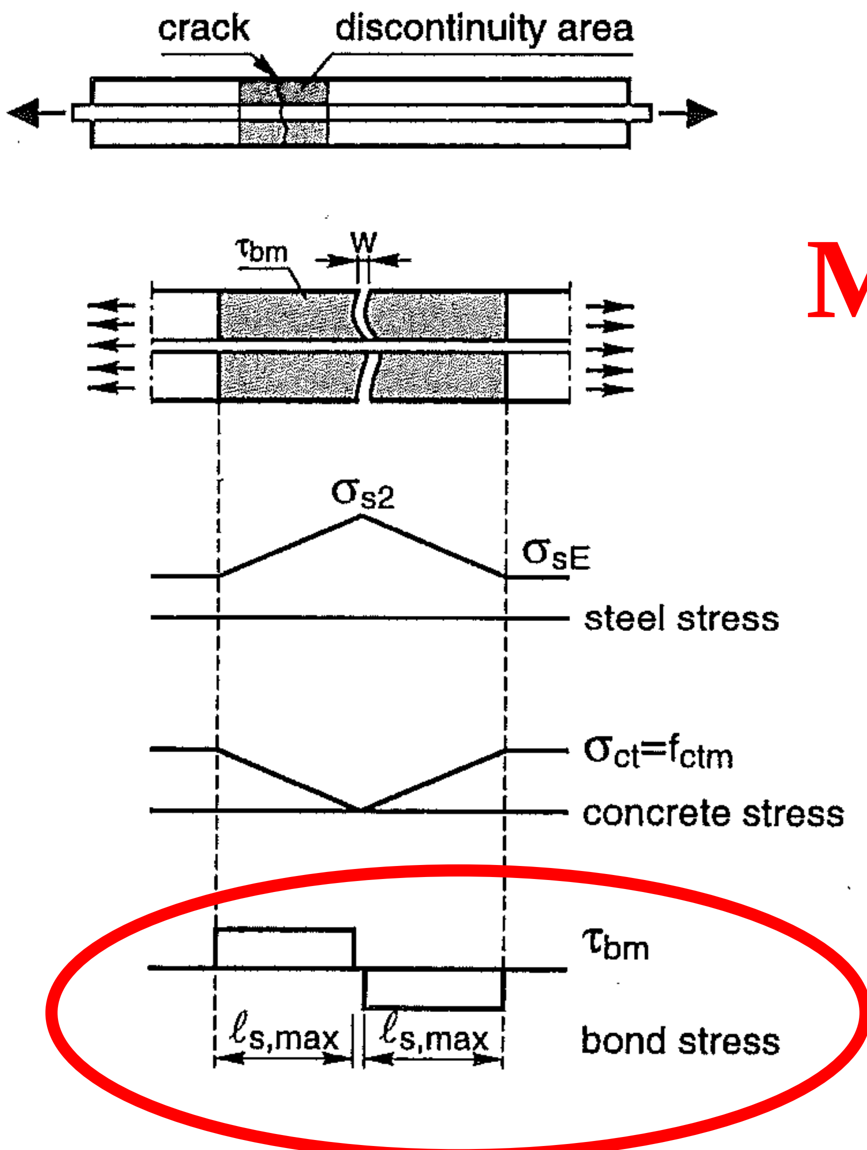
The tie model



MC2010

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Values for τ_{bm}, β and η_r for deformed reinforcing bars

	Crack formation stage	Stabilized cracking stage
Short term, instantaneous loading	$\tau_{bm} = 1{,}8 \cdot f_{ctm}(t)$ $\beta = 0.6$ $\eta_r = 0$	$\tau_{bm} = 1{,}8 \cdot f_{ctm}(t)$ $\beta = 0.6$ $\eta_r = 0$
Long term, repeated loading	$\tau_{bm} = 1{,}35 \cdot f_{ctm}(t)$ $\beta = 0.6$ $\eta_r = 0$	$\tau_{bm} = 1{,}8 \cdot f_{ctm}(t)$ $\beta = 0.4$ $\eta_r = 1$

$$\varepsilon_{sm} - \varepsilon_{cm} - \varepsilon_{cs} = \frac{\sigma_s - \beta \cdot \sigma_{sr}}{E_s} + \eta_r \cdot \varepsilon_{sh}$$

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Crack width limits (wlim) (in mm) for RC and PC members with bonded prestressing steel

(Table 7.6-1 of MC2010). Exposure classes are given according to Table 4.7-2 of MC2010 and ISO 22965-1.

	RC	PL1	PL2	PL3
X0	0.3	0.2	0.3	0.3
XC	0.3	0.2	0.3	0.3
XD	0.2	$\sigma < 0$ *	0.2	0.2
XS	0.2	$\sigma < 0$ *	0.2	0.2
XF	0.2	$\sigma < 0$ *	0.2	0.2

* *Stress in concrete at the level of prestressed reinforcement*

RC: For non-prestressed reinforcement

PL1: For all prestressing reinforcement used in environments which have relatively low aggressiveness and which are well protected by the structures

PL2: For all other prestressing reinforcement in all other combinations of environments and/or exposure and protection not included in protection levels PL1 and PL3 provided by the structures

PL3: For all prestressing reinforcement used in aggressive environment and/or severe exposure and with low protection provided by the structures

Crack width limits (wlim) (in mm) for RC and PC members with bonded prestressing steel

(Table 7.6-1 of MC2010). Exposure classes are given according to Table 4.7-2 of MC2010 and ISO 22965-1.

	RC	PL1	PL2	PL3
X0	0.3	0.2	0.3	0.3
XC	0.3	0.2	0.3	0.3
XD	0.2	$\sigma < 0$ *	0.2	0.2
XS	0.2	$\sigma < 0$ *	0.2	0.2
XF	0.2	$\sigma < 0$ *	0.2	0.2

** Stress in concrete at the level of prestressed reinforcement*

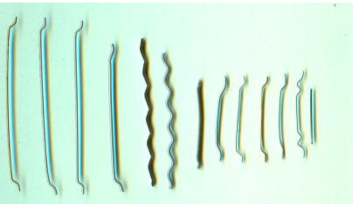
RC: For non-prestressed reinforcement

PL1: For all prestressing reinforcement used in environments which have relatively low aggressiveness and which are well protected by the structures

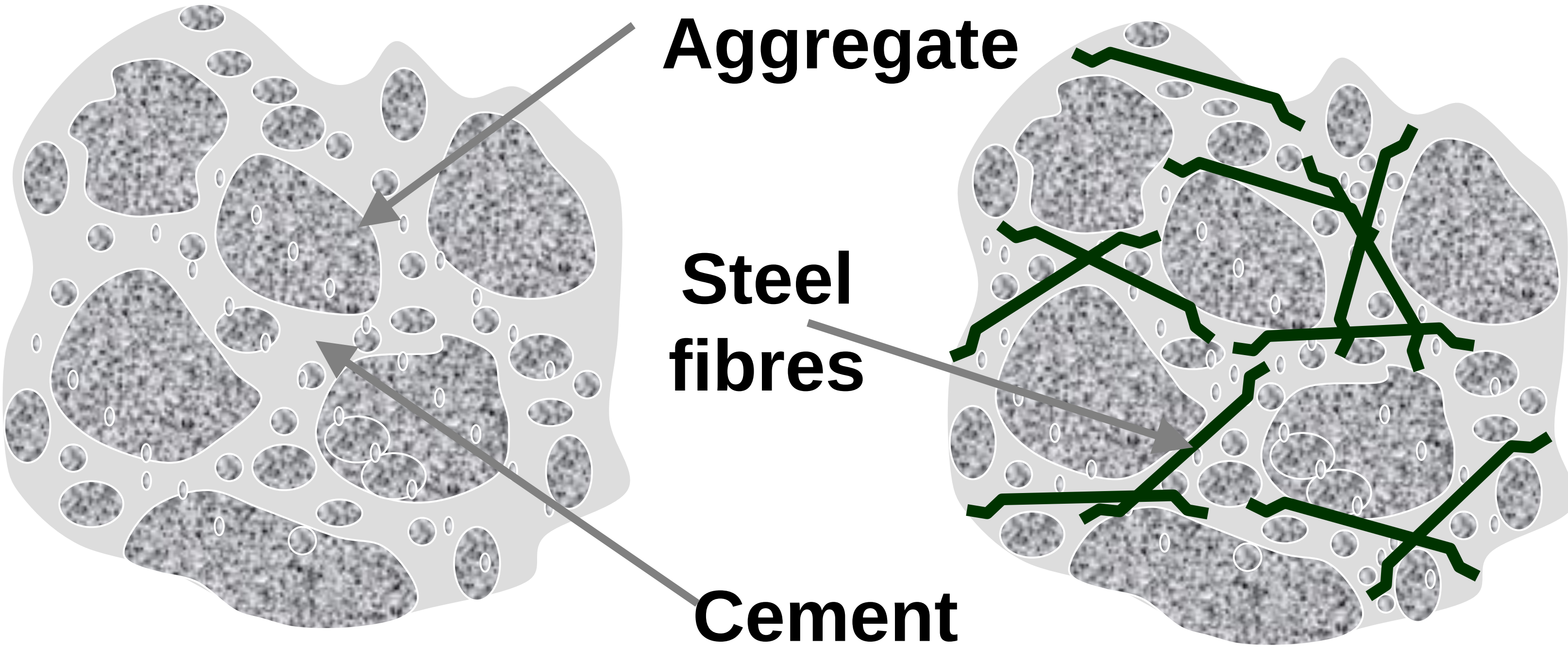
PL2: For all other prestressing reinforcement in all other combinations of environments and/or exposure and protection not included in protection levels PL1 and PL3 provided by the structures

PL3: For all prestressing reinforcement used in aggressive environment and/or severe exposure and with low protection provided by the structures


BOND

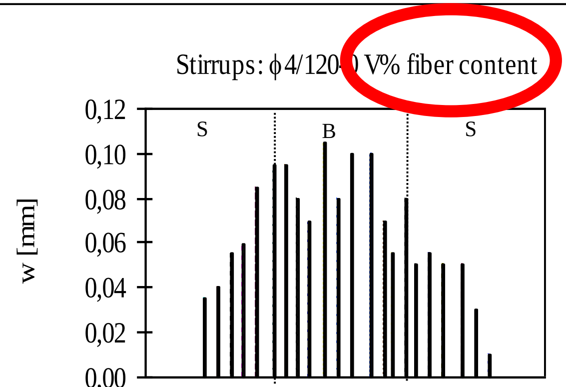


CRACKING
IN
STEEL FIBRE REINFORCED CONCRETE

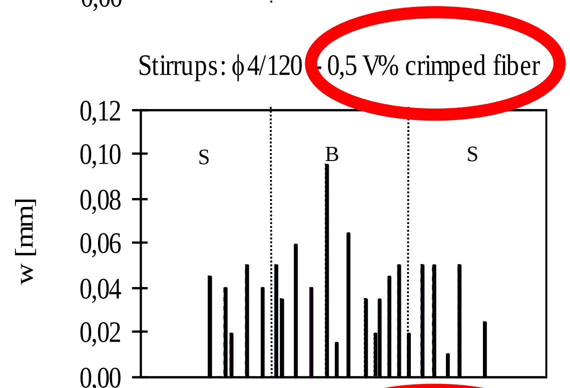


Plain concrete **Steel fibre reinforced concrete**

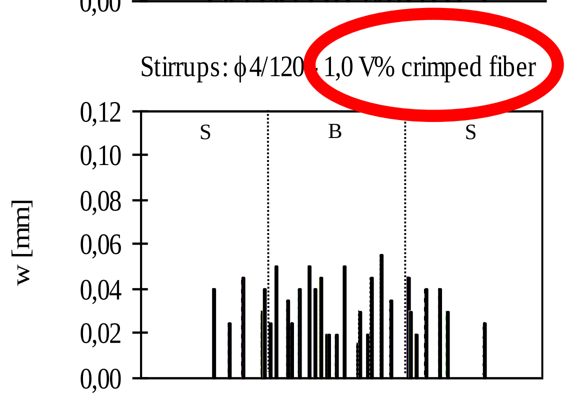
CRACK DISTRIBUTION (Kovács, Balázs, 2004)



	CRACKS		
	S+B	B	S
No.	22	9	13
Σw[mm]	1.45	0.74	0.71
w_m [mm]	0.066	0.082	0.055
s_w [mm]	82	67	92

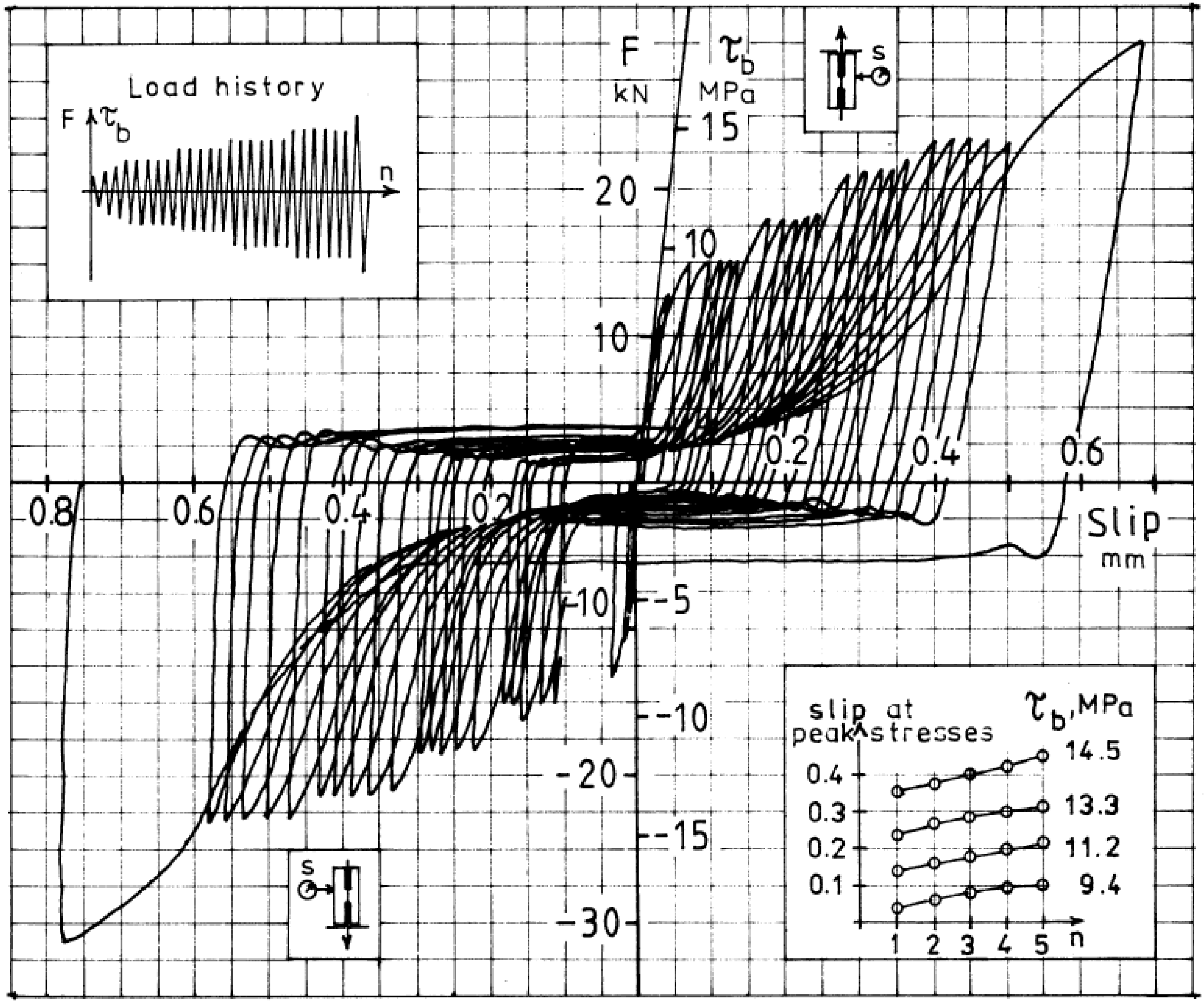


	CRACKS		
	S+B	B	S
No.	23	9	14
Σw[mm]	0.945	0.445	0.500
w_m [mm]	0.041	0.049	0.036
s_w [mm]	78	67	86



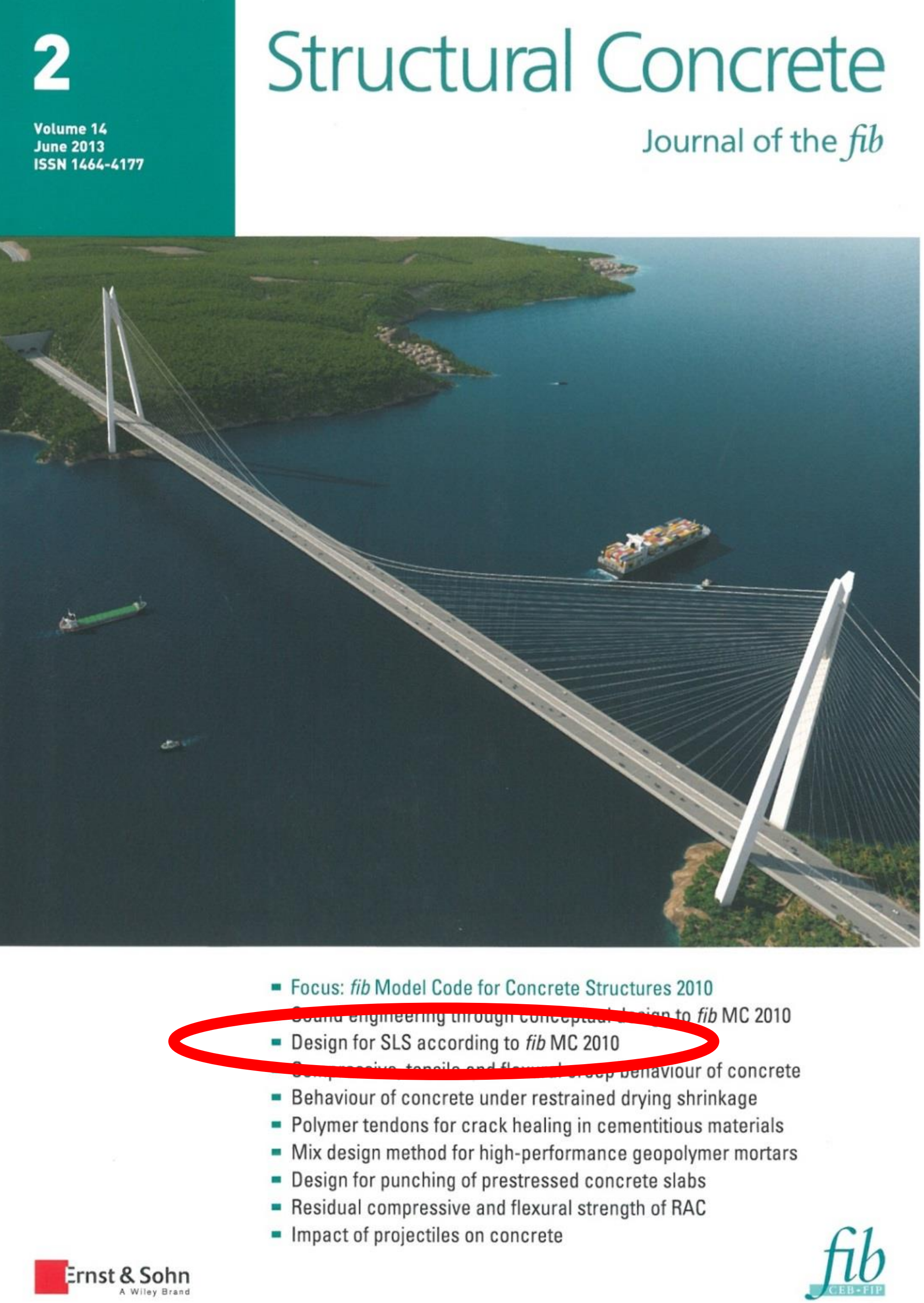
	CRACKS		
	S+B	B	S
No.	30	17	13
Σw[mm]	1.030	0.585	0.445
w_m [mm]	0.034	0.034	0.034
s_w [mm]	60	35	92

Reversed cyclic loading produces increase in slip and crack widths

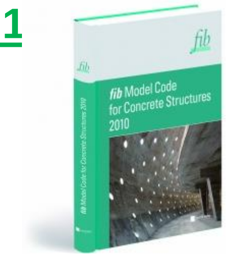


9—Force-controlled load reversals: d_b *= 6 mm (0.63 in.) deformed bar;* f_y *= MPa (58 ksi);* f_c' *= 25 MPa (3.6 ksi);* $l_b = 2d_b$

(Balázs, 1991)

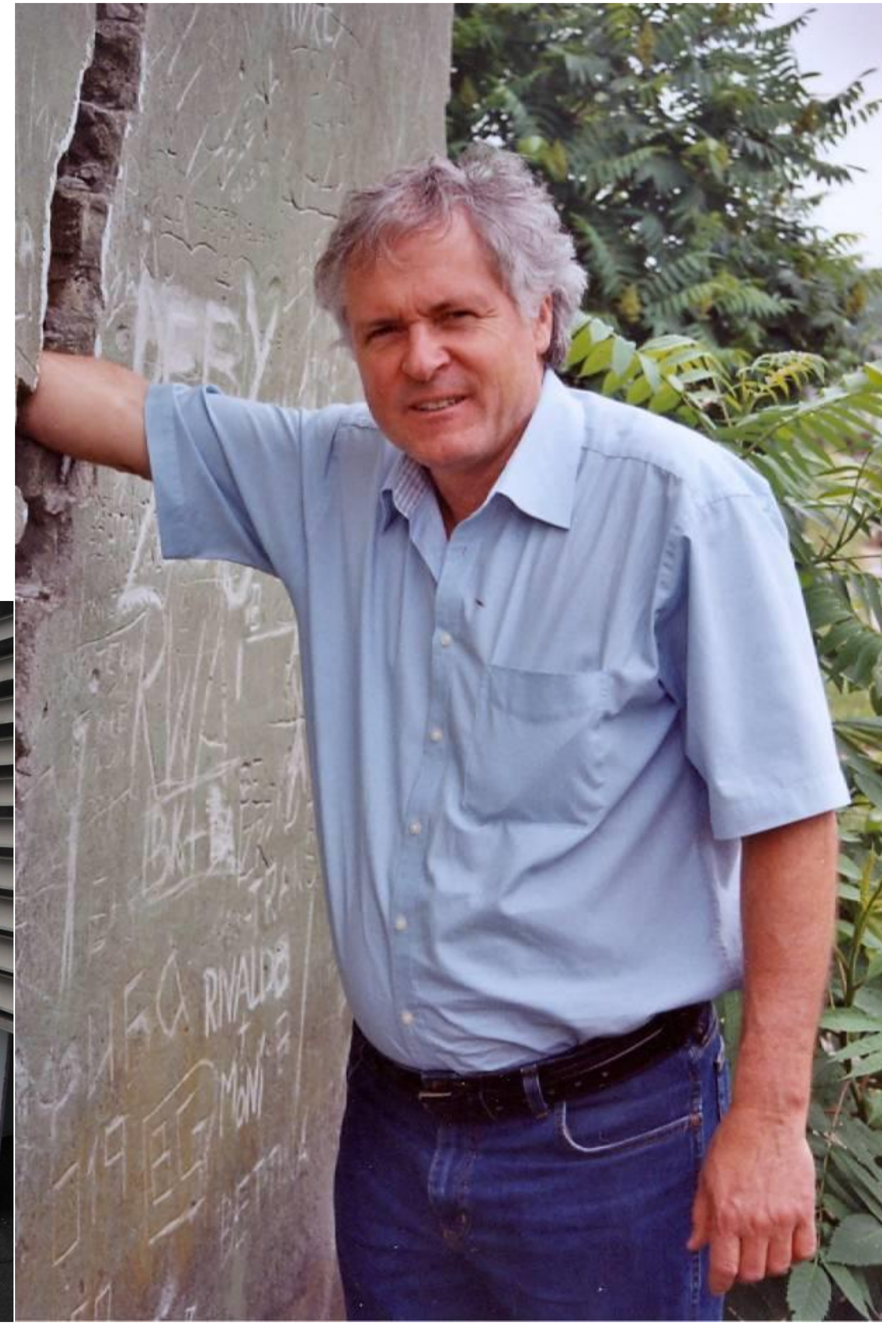


Members of *fib* Task Group 2.1 „Serviceability Models”



CZ:	**Vítek, J., Cervenka, V.; Kohountková, A;**
F:	**Bisch, P.; Torrenti, J.-M.**
	Toutlemond, F.; Lorrain, M.
D:	**Eckfeldt, L.; Fehling, E.;**
	Ozbolt, J.; Windisch, A.;
H:	**Balázs, G.L.; Borosnyói,A.; Lenkei,P.**
I:	**Ceroni, F.; Debernardini, P. G.;**
	Pecce, M.; Taliano, M.,
	Chiorino, M.
J:	**Ueda, T.**
E:	**Caldentey, A. P., Mari-Bernat, A.; Torres, L.**
CH:	**Burdet, O.; Burns, C.**
Tun:	**Daoud, A.**
UK:	**Beeby†, A. W.; Lark, B.**

Thanks
Be careful with cracks



CONCLUSIONS

ConCrack4: ASPECTS

Water and gas tightness

Alternate loading

Scale effects (massive structures)

Crack pattern (visible cracks, microcracks)

Modification of stress field by cracking

Infl. of cover, cover for two layers of rf.

Shrinkage at early age

Diff. in tension and flexure, Curvature

Influence of fibres on cracking

Further development of models should be machanically (chemically) based.

Thank you

DRAFT PROGRAM for the WORKSHOP *fib* MC2020 –Sao Paulo, Brazil 29 September 2017

Developments in Codes for New and Existing Concrete Structures - fib MC2020

Date: 29/09/2017 from 8h30 to 18h10

Venue: Milleniun Convention Center– São Paulo
Realization: ***fib***, Abcic e ABECE
Support: ABNT CB -18 e CB-02, IBRACON, ALCONPAT, ASOCRETO, LATRILEM and others.
Official Language – English/Portuguese with simultaneous translation

8h15-8h30:	Registration & coffee
8h30-9h00:	Welcome & Opening addresses – Iria Doniak (*fib* Presidium and ABCIC President), Jefferson Dias (ABECE President) and Hugo Corres Peiretti (*fib* President)
9h00 – 9h35:	General introduction to the aspirations for fib MC2020 - Agnieszka Bigaj-van-Vliet
9h35 – 10h05	Advancing the fib Model Code for Concrete Structures – New and old concrete materials - Harald Müller
10h05 – 10h35	Shear and punching provisions – level of approximation approach - Aurelio Muttoni
10h35-10h50:	Coffee Break
10h50-11h10:	Brazilian participation program "From MC2010 to MC2020"– Fernando Stucchi
11h10-11h40:	Overview of Brazilian standardization for structural concrete - Inês Battagin (Superintendent of ABNT CB-18)
11h40-12h10:	Latino American perspectives – Antonio Dieste - Uruguay – *Title to be defined*
12h10-12h25:	Coffee Break
12h25-12h55:	Latino American perspectives – Carlos V. Cifuentes – Chile - Reinforced concrete structures: Design and construction failures; causes and responsibilities.
12h55-13h25:	Seismic design and assessment and MC 2020 – Giuseppe Mancini
13h25-14h25:	Lunch
14h25-14h55:	Serviceability – Crack control – Gyorgy Balazs
14h55-15h25:	Sustainability - *Title to be defined* - Akio Kasuga
15h25-16h05:	Existing structures – Paulo Helene and Fernando Stucchi
16h05-16h35:	Existing structures – Conservation and remedial work - Agnieszka Bigaj-van-Vliet
16h35-16h55:	Coffee Break
16h55-17h55:	Group discussion - Facilitators: Fernando Stucchi (*fib* Brazilian National Member Group) and Agnieszka Bigaj-van-Vliet
17h55-18h10:	Closure - Hugo Corres Peiretti and Fernando Stucchi

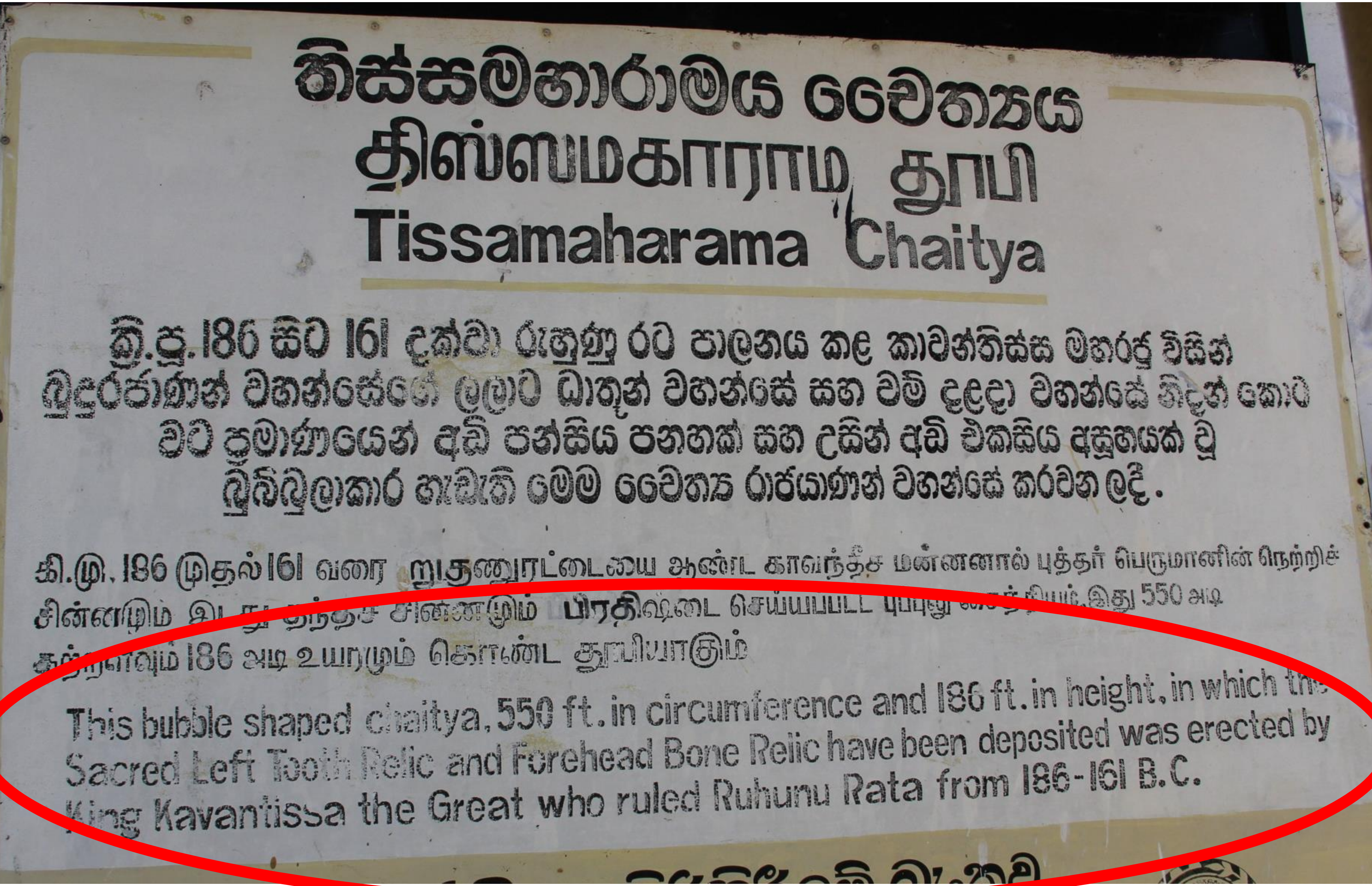
INTRODUCTION

I kindly invite you for an excursion in the word of

cracking

Example for: excessive cracking and deformations + good strengthening

Cracking in structures:



Cracking in structures:

ConCrack4: OBSERVATIONS

PROJET NATIONAL CEOS.fr

ConCrack 4 - 20-21 March

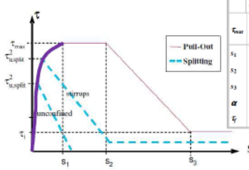
JRC Ispra

COMPORTEMENT ET ÉVALUATION DES OUVRAGES SPÉCIAUX – FISSURATION ET RETRAIT

- **Assumptions:**
  - Uniform stress distribution in the concrete section
  - Steel-concrete bond law:

$$\tau(x) = \tau_{max}\left(\frac{s(x)}{s_1}\right)^{\alpha}$$

"Model Code 2010"



	$\varepsilon_s < \varepsilon_{s,y}$	
	Good bond cond.	All other bond cond.
τ_{max}	$2.5\sqrt{f_{cm}}$	$1.25\sqrt{f_{cm}}$
s_1	1.0mm	1.8mm
s_2	2.0mm	3.6mm
s_3	c_{clear} 1)	c_{clear} 1)
α	0.4	0.4
τ_f	$0.40\,\tau_{max}$	$0.40\,\tau_{max}$

- **Differential equation on the steel-concrete slip s(x):**

$$s''(x) - \frac{4(1+n\rho)}{\phi E_s}\tau(x) = 0 \qquad \text{with} \quad n = \frac{E_s}{E_c} \quad \text{and} \quad \rho = \frac{A_s}{A_c} \approx \frac{A_s}{A}$$

- **The transfer length $l_t = s_{r,max}/2$ becomes**

$$l_t = \left(\frac{1+\alpha}{1-\alpha}\frac{f_{ctm}}{4\rho\tau_{max}}\right)^{\frac{1-\alpha}{1+\alpha}}(\phi s_1^{\alpha})^{\frac{1}{1+\alpha}}\left(\frac{2(1-\alpha)^2(1+n\rho)}{1+\alpha}\frac{\tau_{max}}{E_s}\right)^{\frac{-\alpha}{1+\alpha}}$$

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Generic considerations on cracking based on tie experiments

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COMPORTEMENT ET ÉVALUATION DES OUVRAGES SPÉCIAUX – FISSURATION ET RETRAIT

- **Parameter « γ_c »: non uniform concrete stress distribution**

$$\gamma_c = \frac{\sigma^c_{mean}}{\sigma^c_{max}} = \frac{A_{c,eff}}{A_c} = \frac{\rho}{\rho_{eff}} \leq 1$$

γ_c = ratio between the effective and the total concrete area

- **In general, γ_c depend on the considered section (i.e. on the distance from the nearest crack)**
- **For simplicity, assume γ_c = constant. One obtains**

$$l_t = \left(\frac{1+\alpha}{1-\alpha}\frac{\gamma_c f_{ctm}}{4\rho\tau_{max}}\right)^{\frac{1-\alpha}{1+\alpha}}(\phi s_1^{\alpha})^{\frac{1}{1+\alpha}}\left(\frac{2(1-\alpha)^2\left(1+\frac{1}{\gamma_c}n\rho\right)}{1+\alpha}\frac{\tau_{max}}{E_s}\right)^{\frac{-\alpha}{1+\alpha}}$$

If $\alpha = 0{,}35$ and $s_1 = 1\,mm$

$$l_t \approx 0{,}73\left(\frac{\gamma_c}{\rho}\right)^{\frac{1}{2}}\phi^{\frac{3}{4}} \qquad (l_t \text{ and } \phi \text{ in meters})$$

22

Generic considerations on cracking based on tie experiments

Silvano Erlicher

ConCrack4: OBSERVATIONS

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COMPORTEMENT ET ÉVALUATION DES OUVRAGES SPÉCIAUX – FISSURATION ET RETRAIT

HOW TO APPLY MC10 (or EC2) FOR SHEAR WALLS???

When a more refined model is not available, the following expression for $l_{s,max}$ may be used:

$$\ell_{s,max,\theta} = \left(\frac{\cos\theta}{\ell_{sx,k}} + \frac{\sin\theta}{\ell_{sy,k}} \right)^{-1} \quad (7.6\text{-}8)$$

where:

θ denotes the angle between the reinforcement in the x-direction and the direction of the principal tensile stress

$\ell_{sx,k}$, $\ell_{sy,k}$ denote the slip lengths in the two orthogonal directions, calculated according to Eq. (7.6-4)

The design crack width can then be calculated from:

$$w_d = 2 \cdot l_{s,max,\theta} (\varepsilon_{\perp} - \varepsilon_{c,\perp}) \quad (7.6\text{-}9)$$

where:

$\varepsilon_{\perp}$ and $\varepsilon_{c,\perp}$ represent the mean strain and the mean concrete strain, evaluated in the direction orthogonal to the crack (Figure 7.6-6).

7.6.4.4.3 Orthogonal reinforcement directions

If the cracks in a member reinforced in two orthogonal directions are expected to form at an angle which differs substantially (> 15°) from the direction of the reinforcement, the approximation by Eq. (7.6-8) and (7.6-9) may be used to calculate $l_{s,max}$ and w_d.

①

②

$$l_{s,max} = k \cdot c + \frac{1}{4} \cdot \frac{f_{ctm}}{\tau_{bms}} \cdot \frac{\phi_s}{\rho_{s,ef}}$$

③

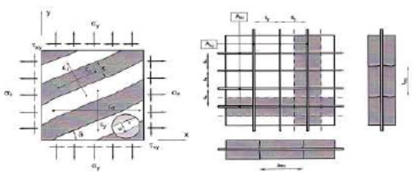

Figure 7.6-6: Basis for calculation of crack width for reinforcement deviating from the direction orthogonal to the crack

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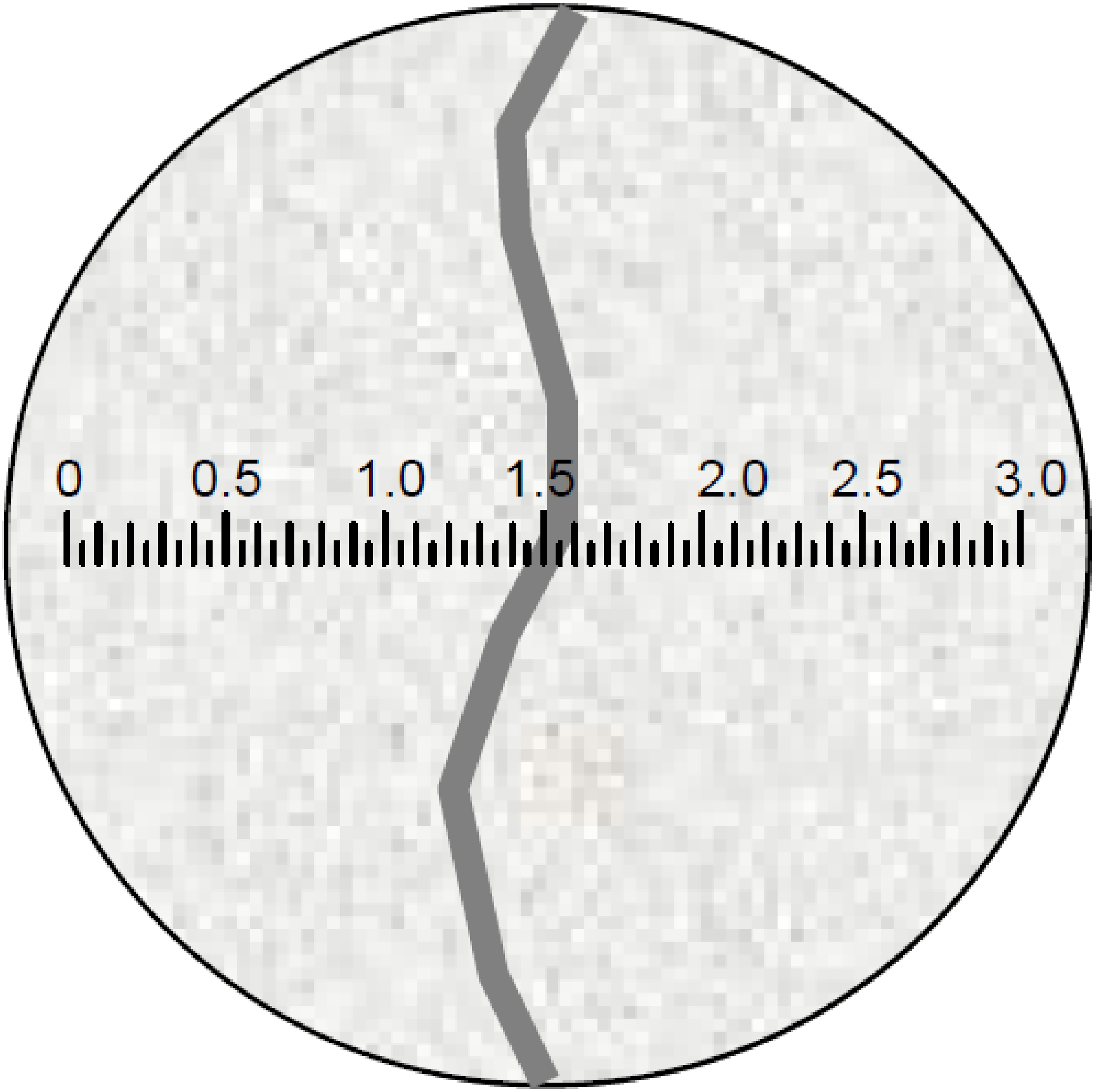
COMPORTEMENT ET ÉVALUATION DES OUVRAGES SPÉCIAUX – FISSURATION ET RETRAIT

CONCLUSIONS FOR THE APPLICATION OF MC10 / EC2

- THE VECCHIO & COLLINS ASSUMPTION IS AN ACCEPTABLE APPROXIMATION, BUT WITHIN A DOMAIN OF APPROX. 40° OF AMPLITUDE CENTRED ON THE OPTIMUM REBARS ARRANGEMENT
- MC10 FORMULA FOR CRACKS SPACING GIVES BETTER RESULTS THAN PRESENT EC2
- TO APPLY THE FORMULA, TAKING THE MEAN COVER (between the two layers of rebars) IS ACCEPTABLE
- ANY IMPROVEMENT OF FORMULAE FOR TIES (spacing and width) WILL BENEFIT TO THE WALL CRACKING ASSESMENT
- EC2 SHOULD ALLOW FOR MORE PRECISE APPROACHES
- FORMULAE ARE PROPOSED FOR THE ASSESMENT OF MEAN DIFFERENTIAL STRAINS FOR CRACK WIDTH

Cracks are visibale



INTRODUCTION

I kindly invite you for an excursion in the word of

cracking

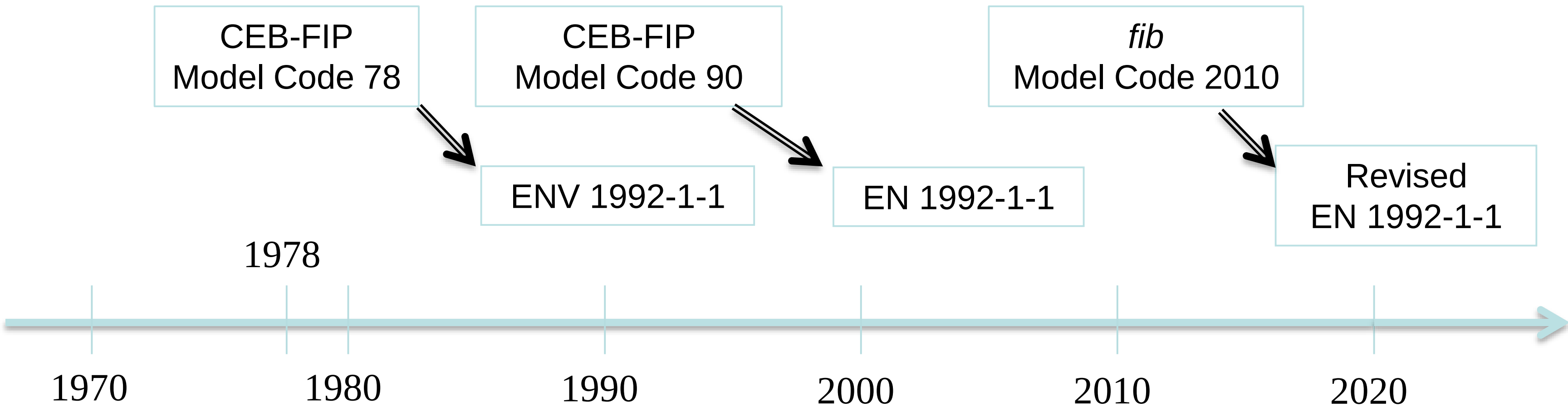
MC2010


fib
fib
fib Model Code for Concrete Structures 2010
fib Model Code for Concrete Structures 2010

fib is a pre-normative organization

G. L. Balázs

STRONG INFLUENCE OF *fib* (CEB-FIP) MODEL CODES ON CODE DEVELOPEMENTS



MC78 and MC90 were used in Brazil partly as national codes

Collaboration with Asian Model code

Collaboration with African Model code

Model Codes are used as reference documents both in research and in design