RIVESTIMENTI IN ANELLI DI CONCI PREFABBRICATI DI GALLERIE REALIZZATE CON TBM

Brescia, 23 Giugno 2022

Aula Magna Ingegneria - Università di Brescia (UniBs)

ORGANIZZATORI

Collegio dei tecnici della Industrializzazione Edilizia

Società Italiana Gallerie
Italian Tunnelling Society

Ordine INGEGNERI della provincia di Brescia

CON IL PATROCINIO DI

UNIVERSITÀ DEGLI STUDI DI BRESCIA

fib CEB-FIP Fédération Internationale du Béton

MEDIA PARTNER

ingenio informazione tecnica e progettuale

SAIE Bologna, 19/22 ottobre 2022

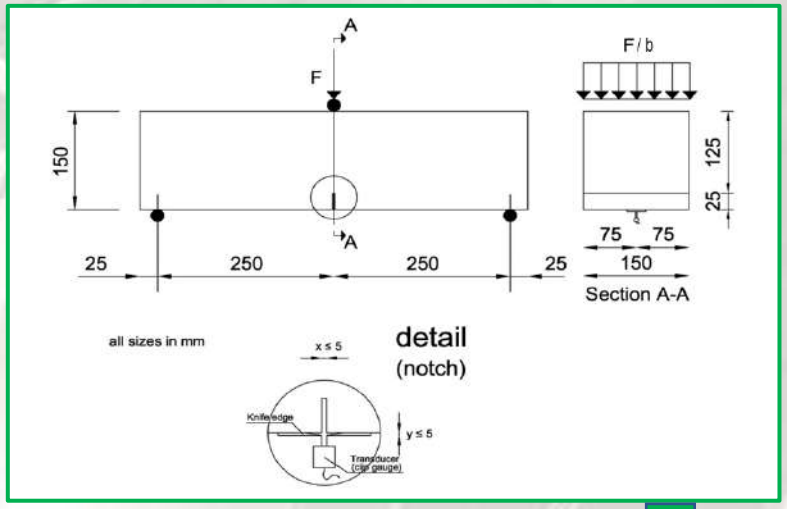
PRESENTAZIONE

POLITECNICO MILANO 1863

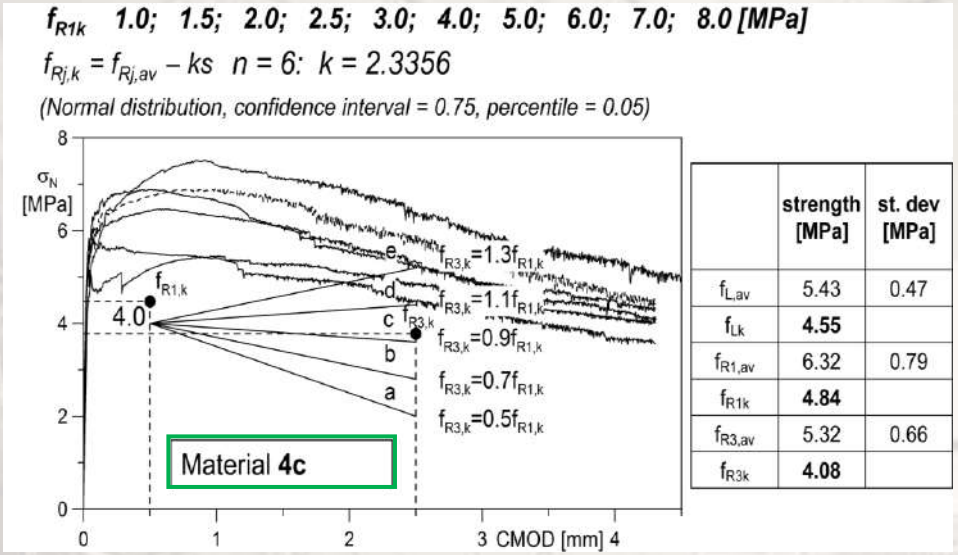
Marco di Prisco
Dipartimento di Ingegneria Civile e Ambientale
Ordinario di Tecnica delle Costruzioni

Progettazione strutturale: dimensionamento e verifiche per tipologie di armatura alternative (fibre in acciaio, sintetiche o ibride, barre in acciaio e GFRP). Durabilità, agenti aggressivi, correnti vaganti. **Prove di laboratorio e test in sito. Documenti di riferimento**

1. Perché usare le fibre nel rivestimento a conci prefabbricati
2. Fibre di acciaio o fibre polimeriche?
3. Solo fibre o soluzioni ibride con armatura continua?
4. Armatura continua in acciaio o in FRP?
5. Cosa è meglio per garantire la durabilità?
6. Quali normative?
7. Esistono riferimenti ulteriori?



$$f_{R,j} = \frac{3F_j\, l}{2b\,h_{sp}^2}$$



	strength [MPa]	st. dev [MPa]
$f_{L,av}$	5.43	0.47
f_{Lk}	**4.55**	
$f_{R1,av}$	6.32	0.79
f_{R1k}	**4.84**	
$f_{R3,av}$	5.32	0.66
f_{R3k}	**4.08**	

Reference test

EN 14651

h_{sp} = 125 mm

b = 150 mm

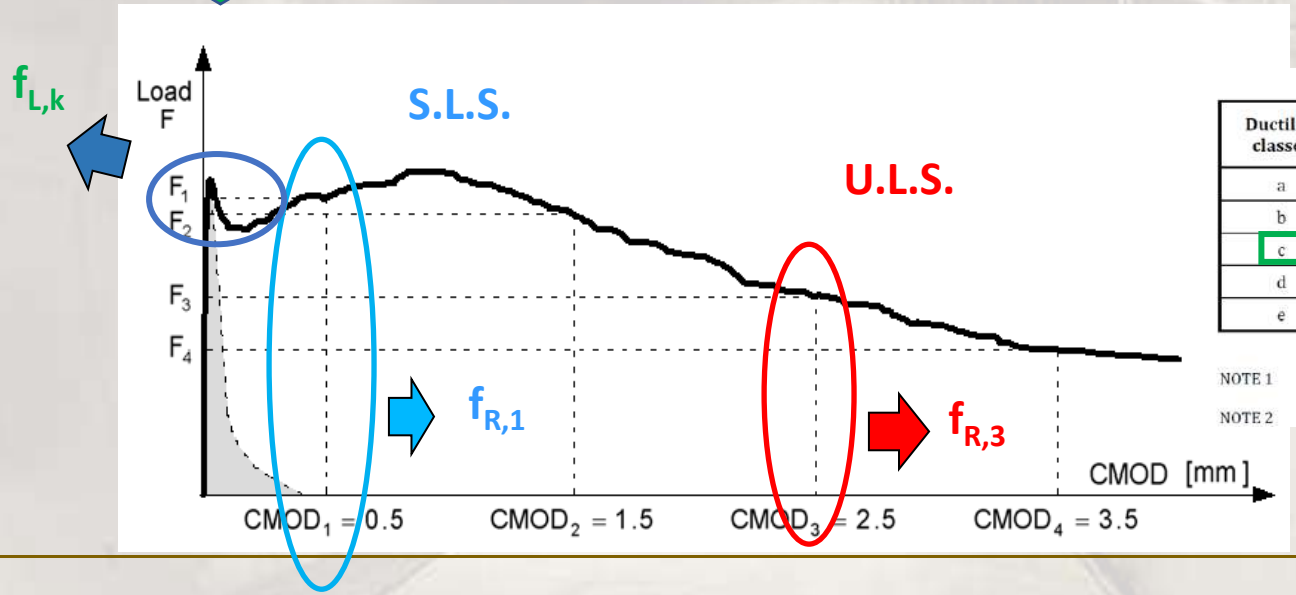


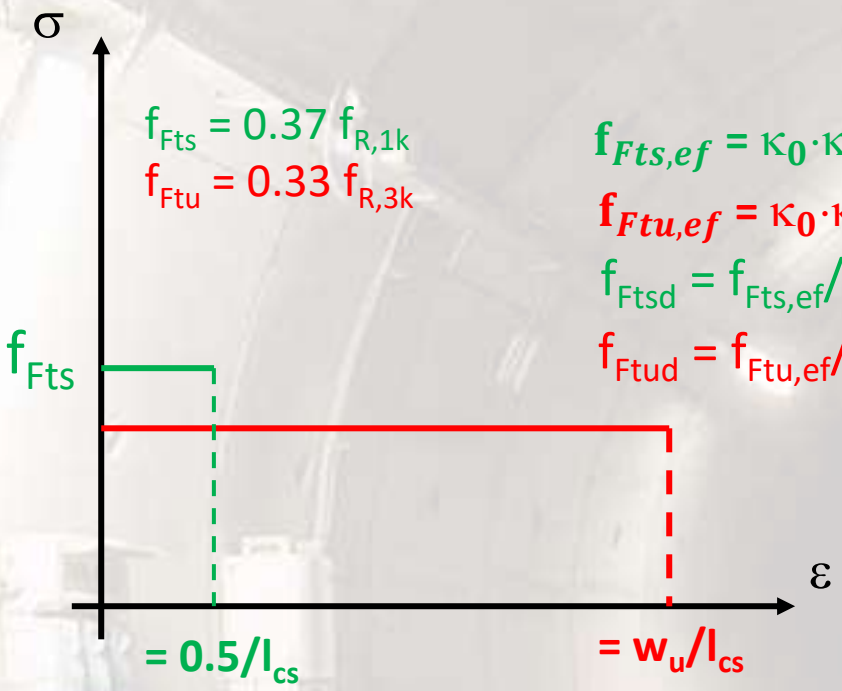
Table L.2 — Residual strength classes for SFRC

Ductility classes	Characteristic residual flexural strength $f_{R,1k}$									Analytical formulae
	1,0	1,5	2,0	2,5	3,0	4,0	5,0	6,0	8,0	
a	0,5	0,8	1,0	1,3	1,5	2,0	2,5	3,0	4,0	$f_{R,3k} = 0,5 f_{R,1k}$
b	0,7	1,1	1,4	1,8	2,1	2,8	3,5	4,2	5,6	$f_{R,3k} = 0,7 f_{R,1k}$
c	0,9	1,4	1,8	2,3	2,7	3,6	4,5	5,4	7,2	$f_{R,3k} = 0,9 f_{R,1k}$
d	1,1	1,7	2,2	2,8	3,3	4,4	5,5	6,6	8,8	$f_{R,3k} = 1,1 f_{R,1k}$
e	1,3	2,0	2,6	3,3	3,9	5,2	6,5	7,8	10,4	$f_{R,3k} = 1,3 f_{R,1k}$

NOTE 1 All strength classes apply unless a National Annex excludes specific classes.

NOTE 2 Intermediate classes can be used, if included in a National Annex.

Leggi constitutive adottate line guida approvate dal C.S.LL.PP. (coerenti con EC2)



$f_{Fts} = 0.37\ f_{R,1k}$

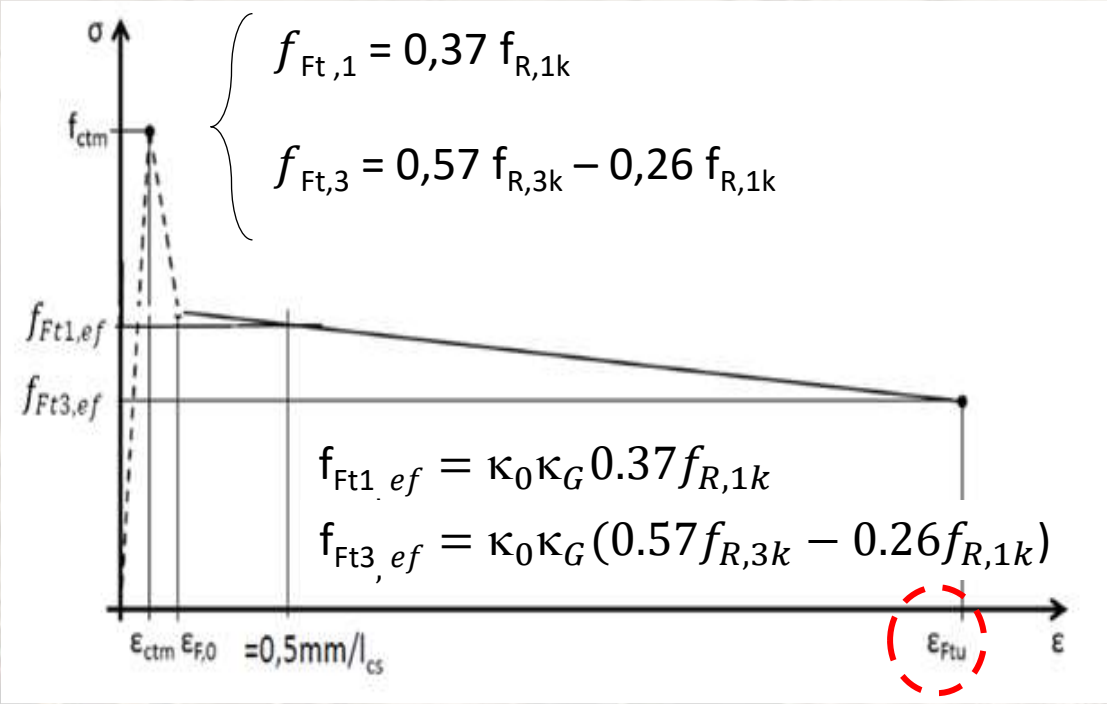
$f_{Ftu} = 0.33\ f_{R,3k}$

$f_{Fts,ef} = \kappa_0 \cdot \kappa_G \cdot 0,37 \cdot f_{R,3k}$

$f_{Ftu,ef} = \kappa_0 \cdot \kappa_G \cdot 0,33 \cdot f_{R,3k}$

$f_{Ftsd} = f_{Fts,ef}/\gamma_{SF}$

$f_{Ftud} = f_{Ftu,ef}/\gamma_{SF}$



$f_{Ft,1} = 0,37\ f_{R,1k}$

$f_{Ft,3} = 0,57\ f_{R,3k} - 0,26\ f_{R,1k}$

$f_{Ft1,ef} = \kappa_0 \kappa_G 0.37 f_{R,1k}$

$f_{Ft3,ef} = \kappa_0 \kappa_G (0.57 f_{R,3k} - 0.26 f_{R,1k})$

$\varepsilon_{Ftu} = w_u/l_{cs} \leq 2,5\ \mathrm{mm}/l_{cs} \leq \varepsilon_{Ftud}$

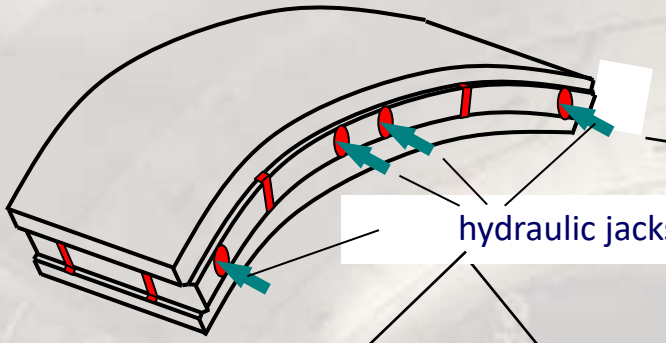
$\kappa_G = 1 + 0.5\ A_{ct}\ [m^2] \leq 1,25$

$f_{Ft1d} = f_{Ft1,ef}/\gamma_{SF}$

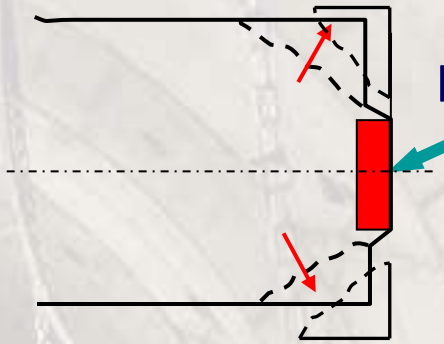
$f_{Ft3d} = f_{Ft3,ef}/\gamma_{SF}$

$l_{cs} = \min\{s_{rm}, y\}$

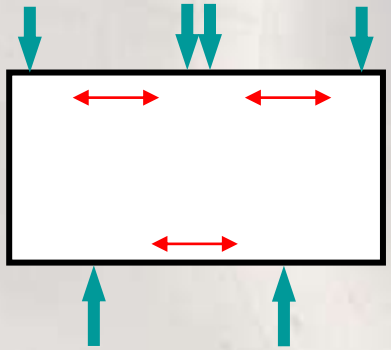
F.E. approach: l_{cs} = *localization limiter*



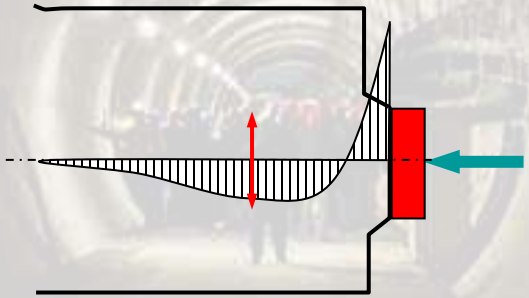
spalling



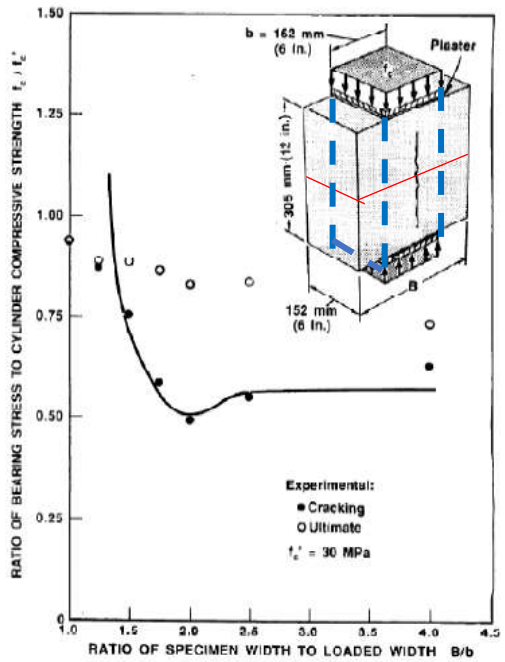
in-plane actions (placing situation)



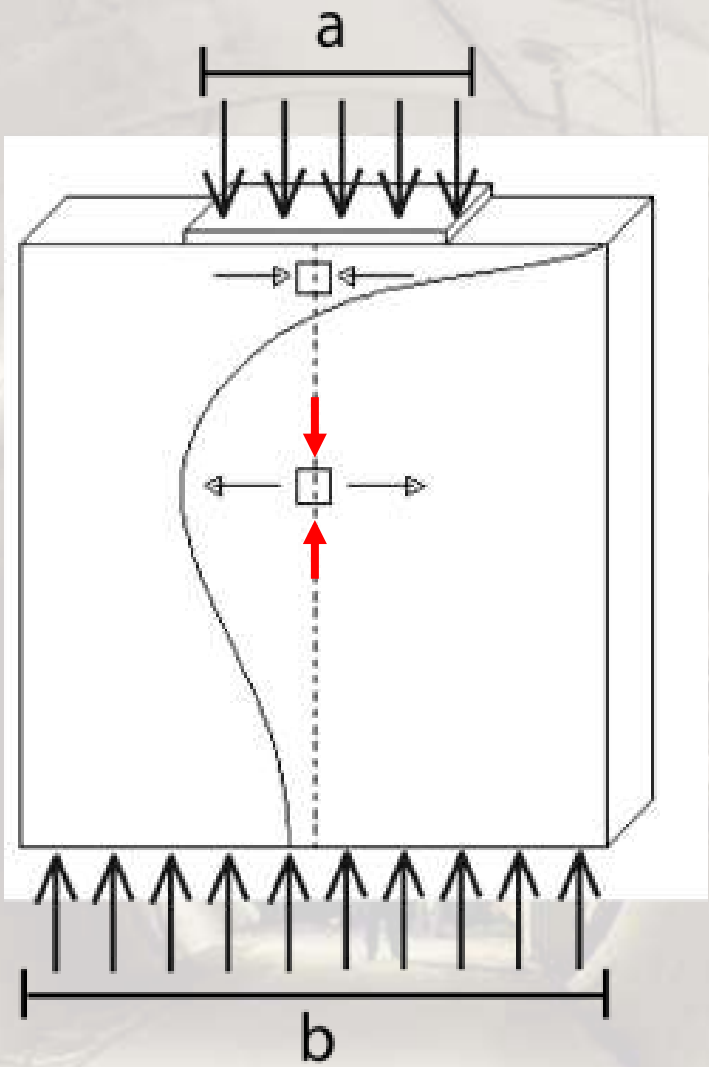
splitting



by Schnutgen (Bochum), 2000



Influence of self generated transverse tension on the cracking load and ultimate load of a specimen of plain concrete (Adebar et al. 1990)



Comportamento biassiale del calcestruzzo

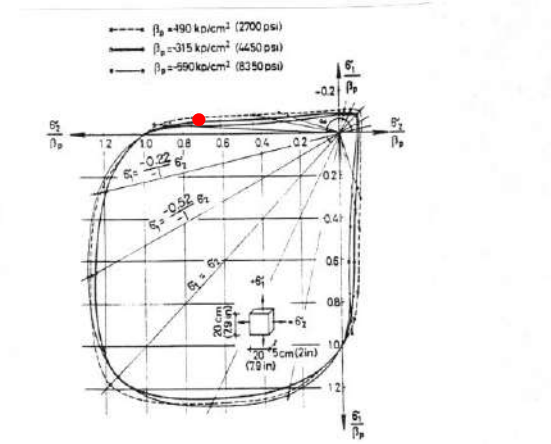
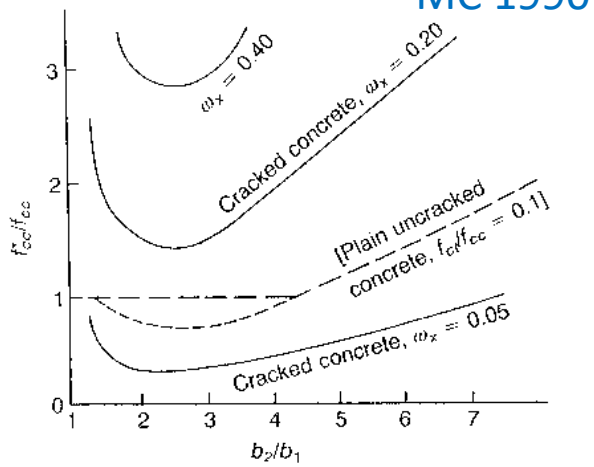
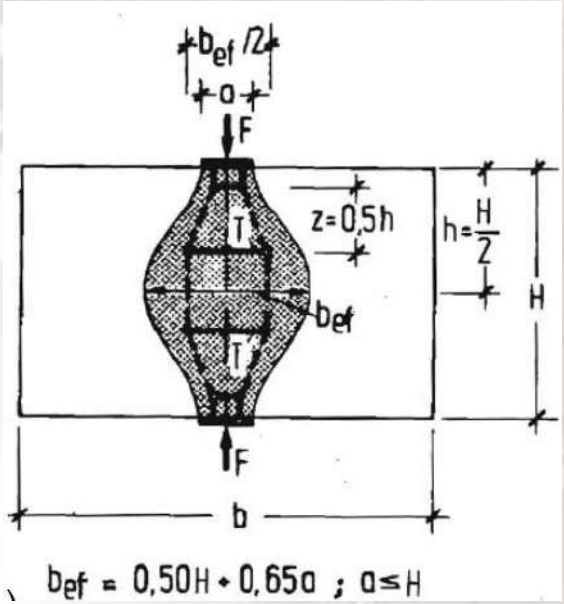


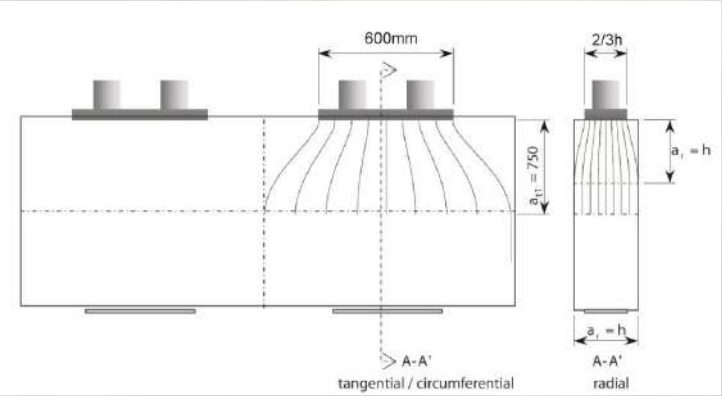
Fig. 6—Biaxial strength of concrete; results of experimental investigation

MC 1990



Bottle shaped strut



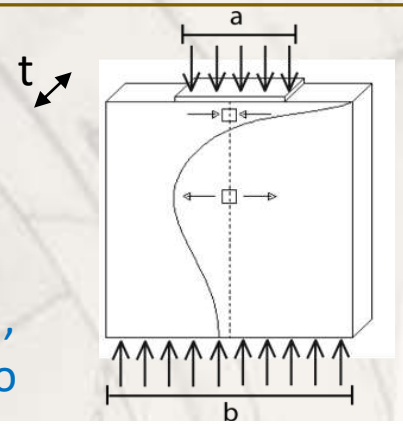


by T. Leutbecher, E. Fehling, Kassel 2012

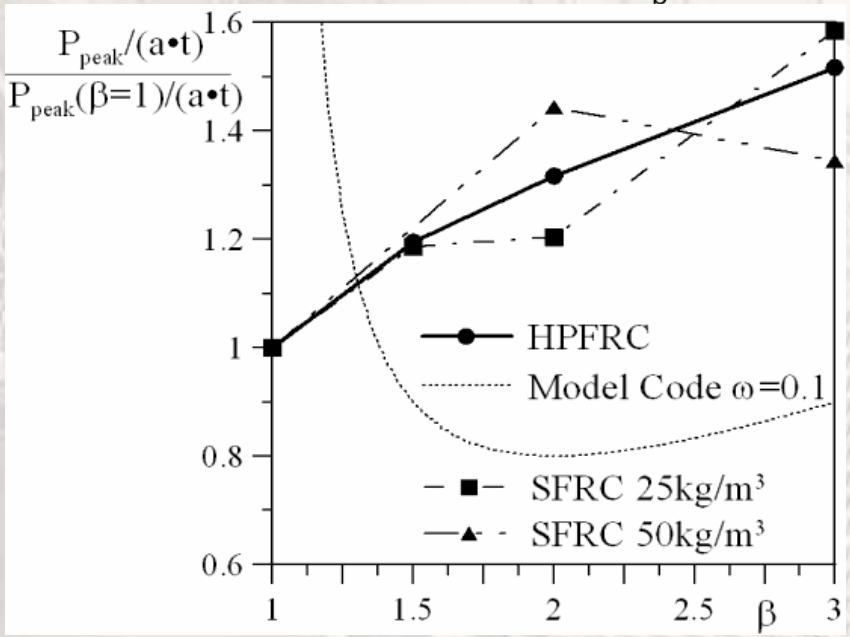
b/a	$\sigma_{c,max}/f_c$				
	NSC	HSC	UHSC	UHPC-1-HT	UHPC-2-HT
2.3	0.89	0.6	0.41	0.87	0.96
4.7	1.18	0.59	0.38	1.04	1.44
6.9	1.75	0.73	0.56	1.28	1.66
10.7	2.48	1.15	0.81	1.73	2.22

Fehling, E., Schmidt, M., Walraven, J., Leutbecher, T., Fröhlich, S., Ultra-High Performance Concrete UHPC: Fundamentals, Design, Examples, (2015) Ultra-High Performance Concrete UHPC: Fundamentals, Design, Examples, pp. 1-188.

di Prisco, M., Colombo M., Steel-fibre role in the D-regions, Proceedings of the International Conference ConMat05 and Mindess Symposium, Vancouver, Canada, 2005, pp. 1-10.



by M. di Prisco et al., Politecnico di Milano

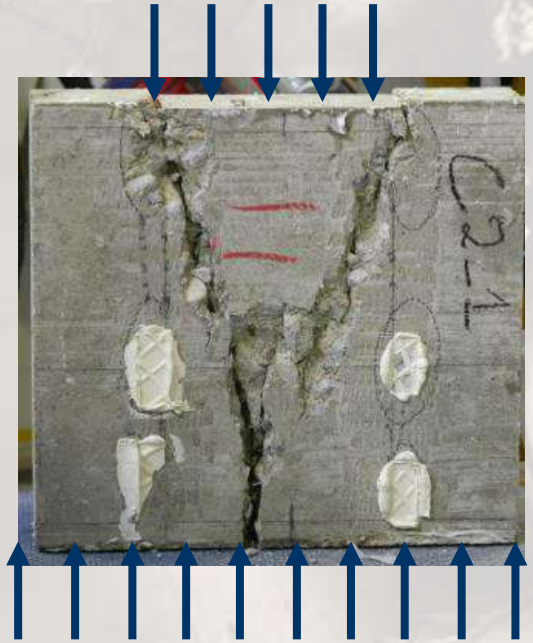


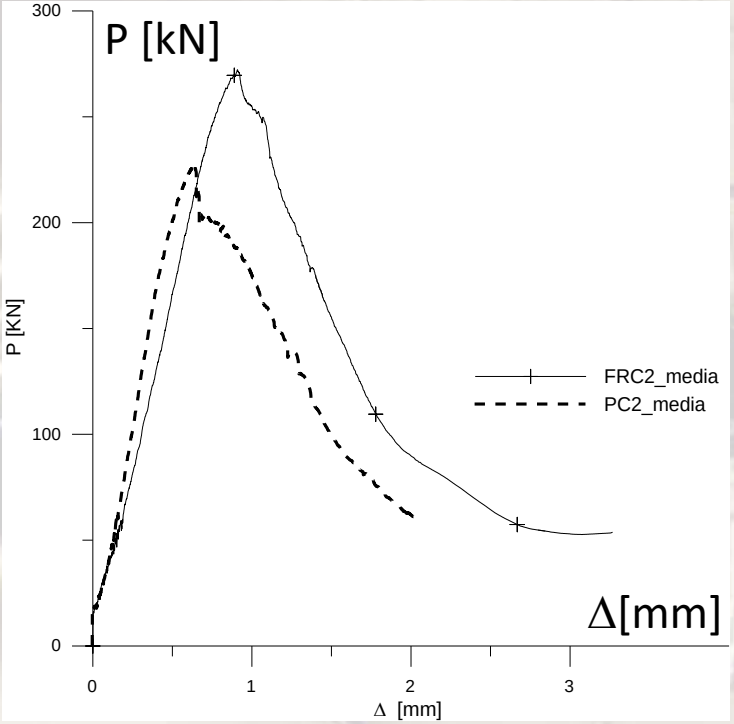
6.5 Design with strut and tie models

6.5.3 Ties {new clause (4)}

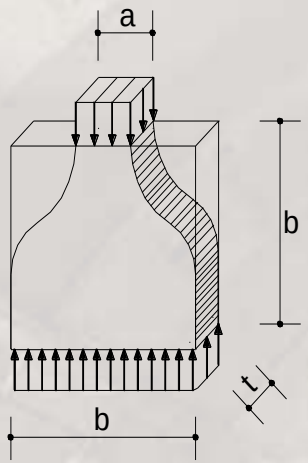
Tensile forces derived from strut- and-tie models may be covered by steel fibre actions alone if the calculated concrete stresses assuming linear elastic material behaviour as well as an ultimate limit state of stresses do not exceed F_{Ftsd}.

Otherwise up to 30% of the tensile forces might be covered by fibre effects assuming a stress of F_{Ftsd} in the concrete areas involved. For the residual tensile force bar reinforcement has to be provided and properly distributed.

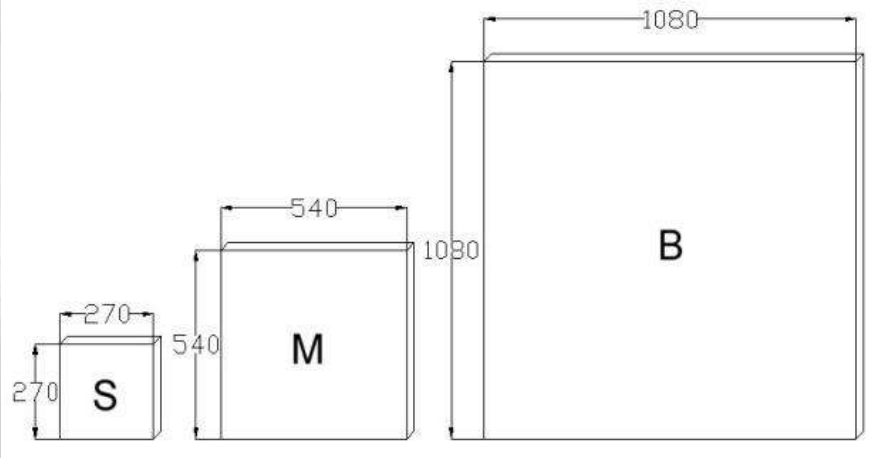




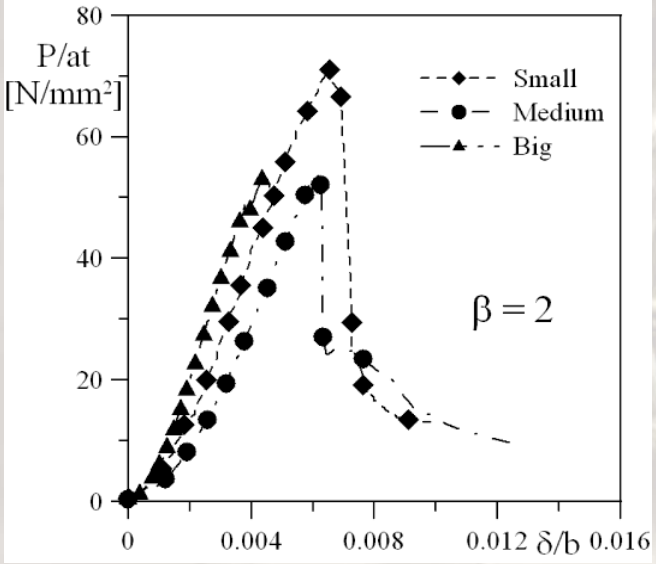
Colombo, M., di Prisco, M.
D-zones in HPFRC
(2012) RILEM Bookseries, 2, pp. 205-212.

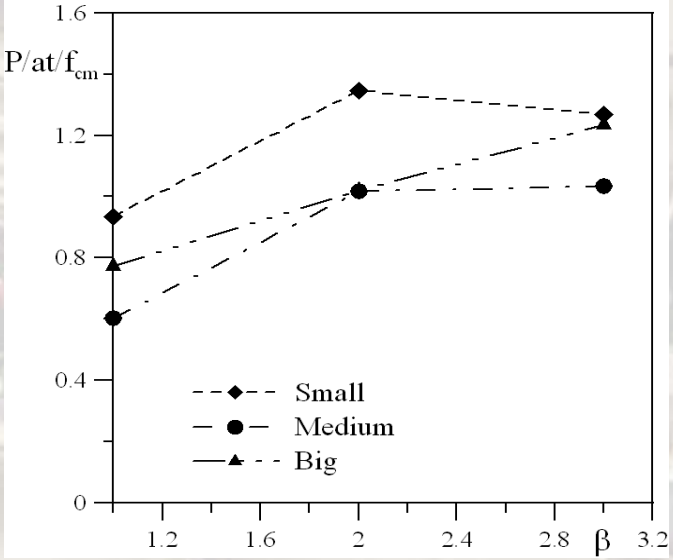


t= 60 mm
$\beta = b/a$



Size Effect





Traina, Leonard A., Mansour, Shahin A., Biaxial strength and deformational behavior of plain and steel fiber concrete, (1991), ACI Materials Journal, 88 (4), pp. 354-362.

by Traina and Mansour, 1991

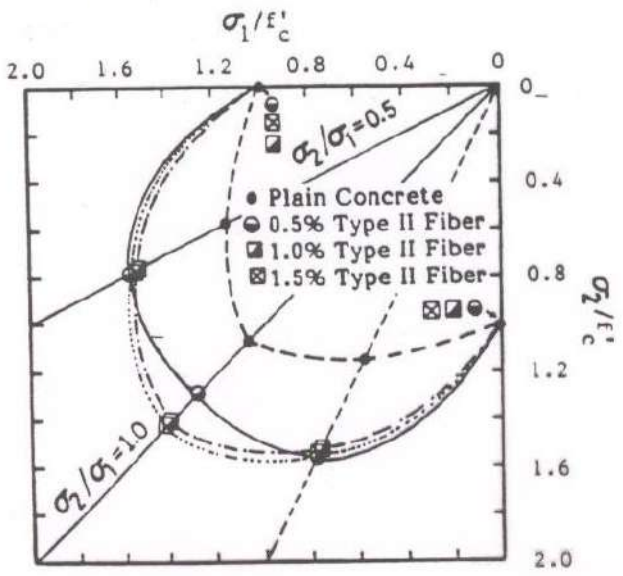


Fig. 5(b)—Biaxial strength envelopes for plain and Type II fiber concretes

0.77/25.4

$\frac{\ell}{d} = 33$

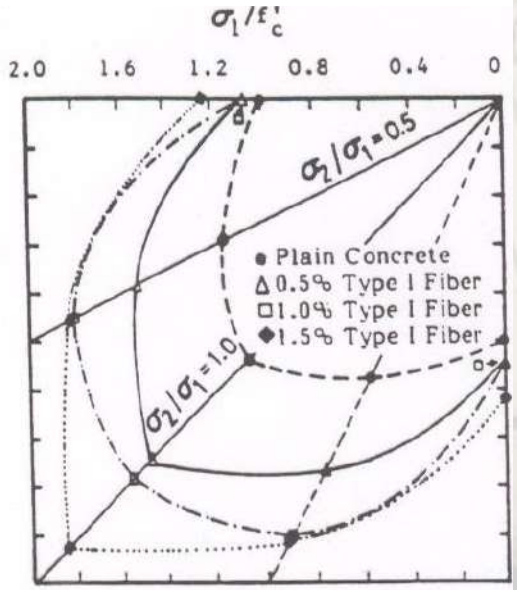
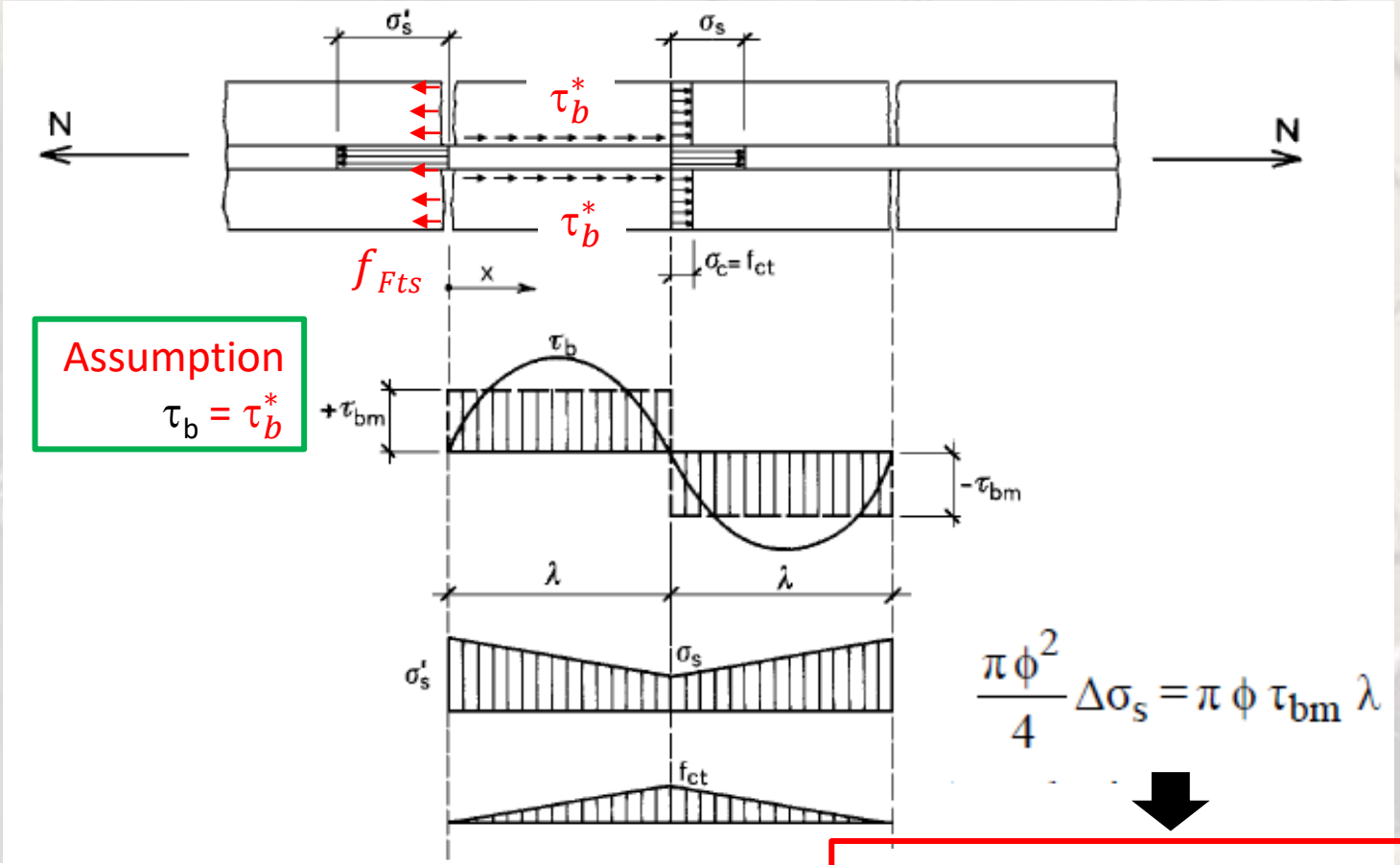


Fig. 5(a)—Biaxial strength envelopes for p
Type I steel fiber concretes

30/0.5

$\frac{\ell}{d} = 60$



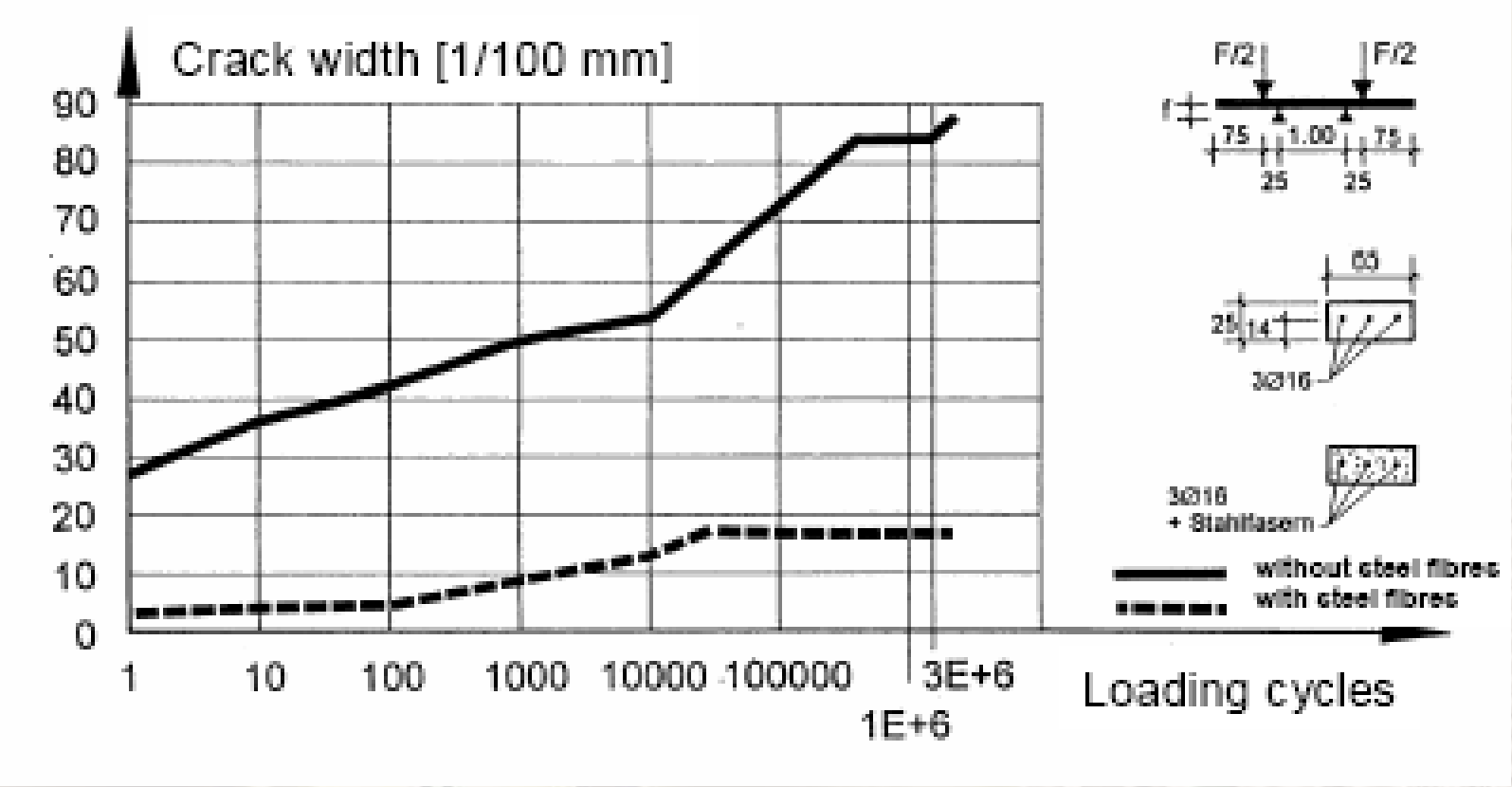
Assumption

$\tau_b = \tau_b^*$

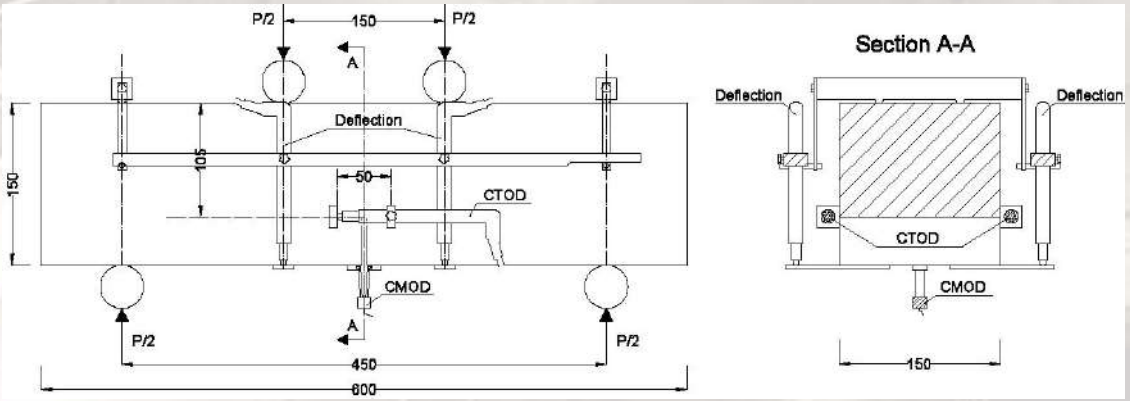
$$\frac{\pi \phi^2}{4} \Delta\sigma_s = \pi \phi \tau_{bm} \lambda$$

$$\Delta\sigma_s = \sigma'_s - \sigma_s = \frac{1}{\rho_s} (f_{ct} - f_{FTs})$$

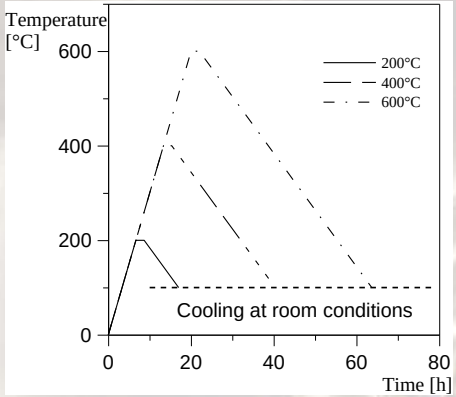
$$\lambda = \frac{\phi}{4} \frac{\Delta\sigma_s}{\tau_{bm}} = \frac{1}{4} \frac{\phi}{\rho} \frac{(f_{ct} - f_{FTs})}{\tau_{bm}}$$

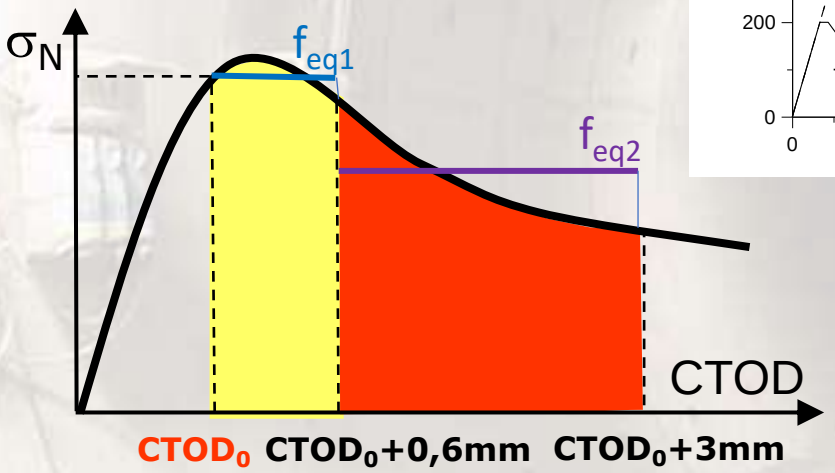


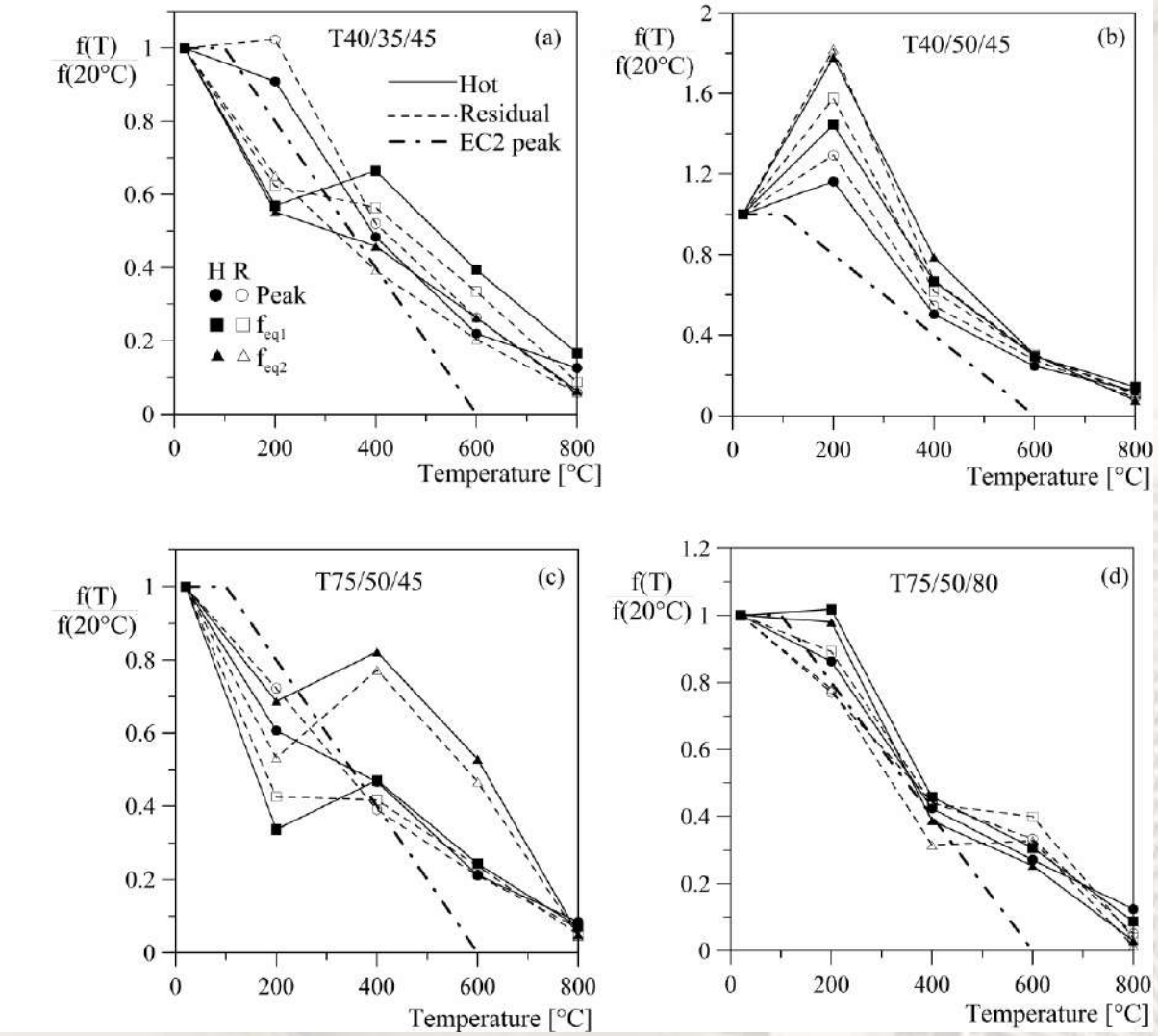
by Falkner, TU Braunschweig 2006



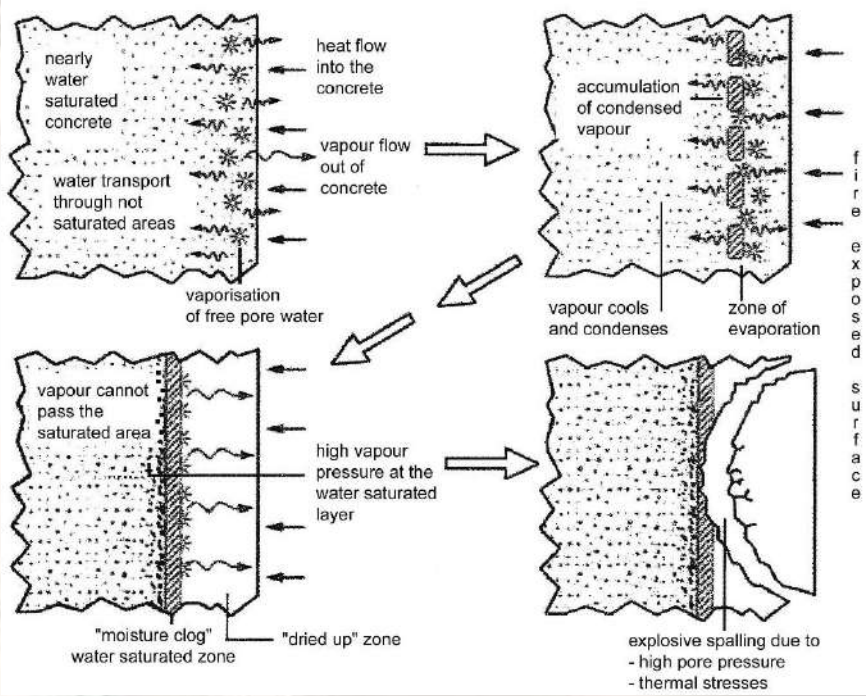
Colombo, M., di Prisco, M., Felicetti, R., SFRC exposed to high temperature: Hot vs. residual characterization for thin walled elements, (2015) Cement and Concrete Composites, 58, pp. 81-94.



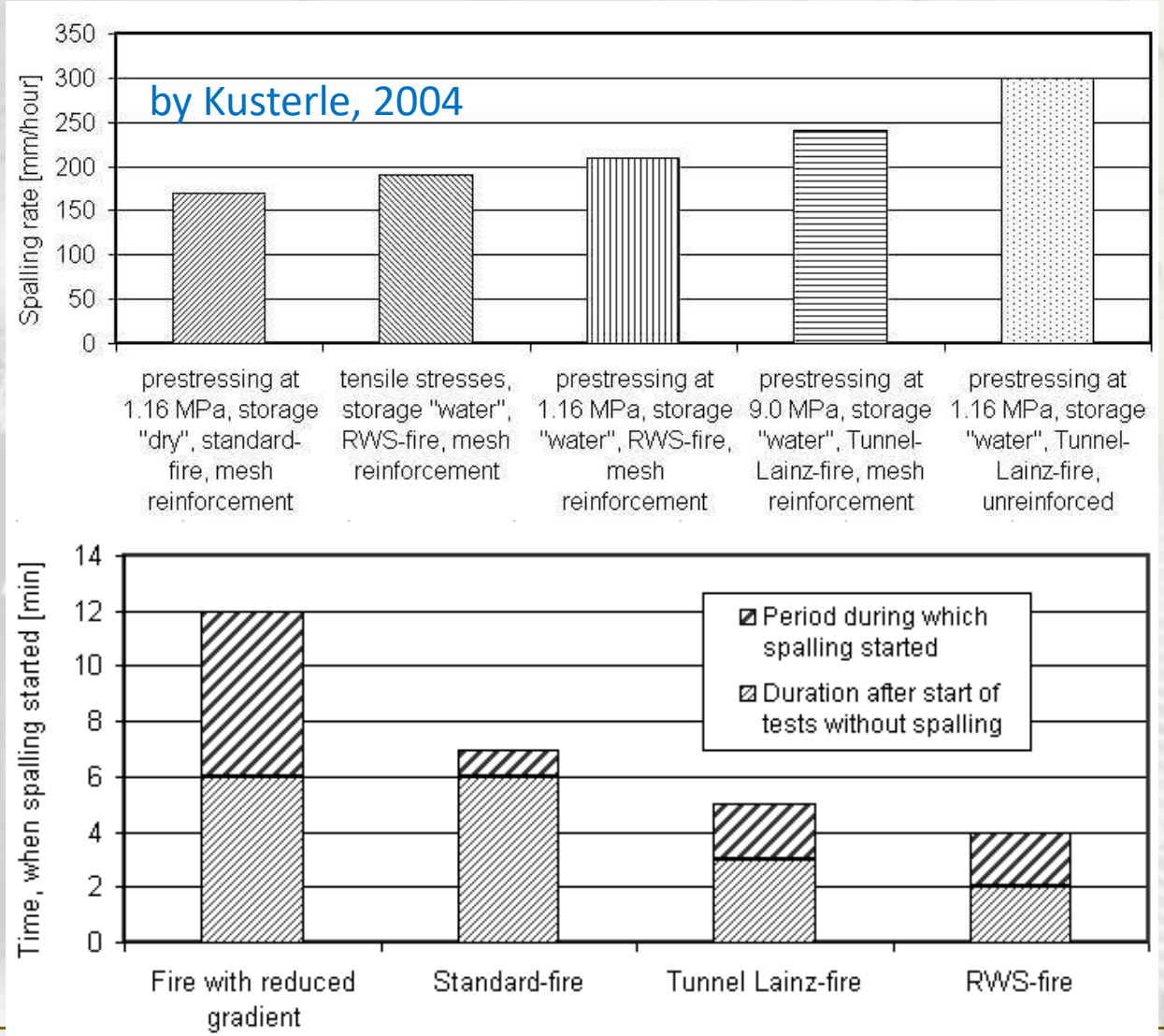




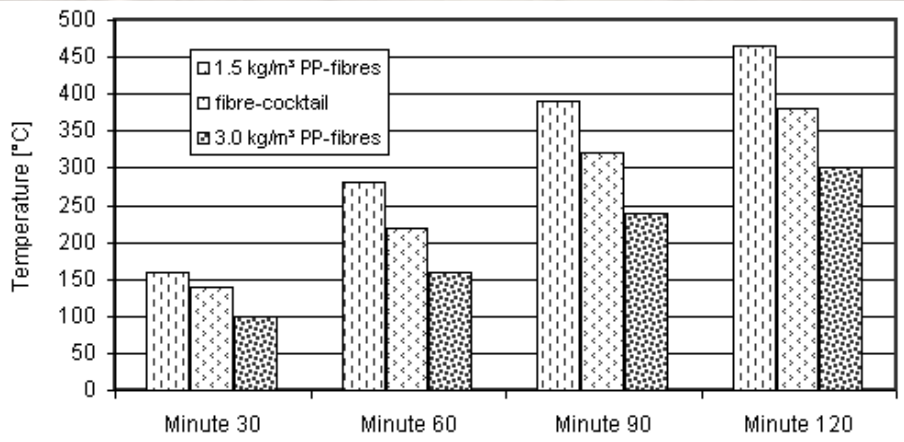
Explosive spalling



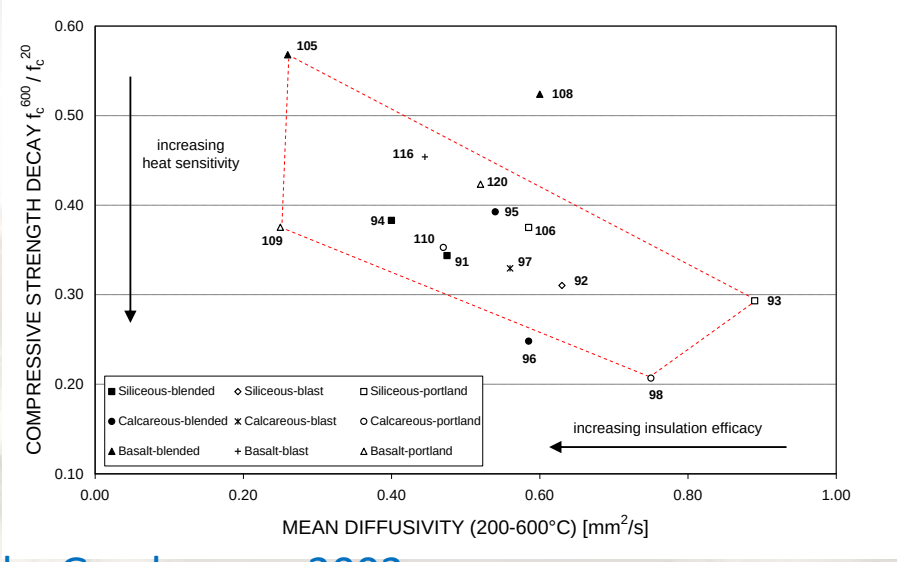
Shorter and Harmathy, 1961, Schneider, 2002, Consolazio, 1997



Kusterle, W. et al (2004), Fire Resistance of Fibre-reinforced, Reinforced, and Pre-Stressed Concrete. Austrian Federal Ministry of Transportation, Infrastructure, and Technology (Ed.): Road Research Report 544 (Strassenforschung Heft 544), Vienna, Austria.



by Kusterle, 2004



by Gambarova, 2002

0 kg

2 kg

3 kg

Polypropylene fibres

di Prisco, M., Tomba, S., Bonalumi, P., Meda, A., On the use of macro synthetic fibres in precast tunnel segments, (2015) Proceedings of the International Conference FIBRE CONCRETE, 2015-January, pp. 478-483.

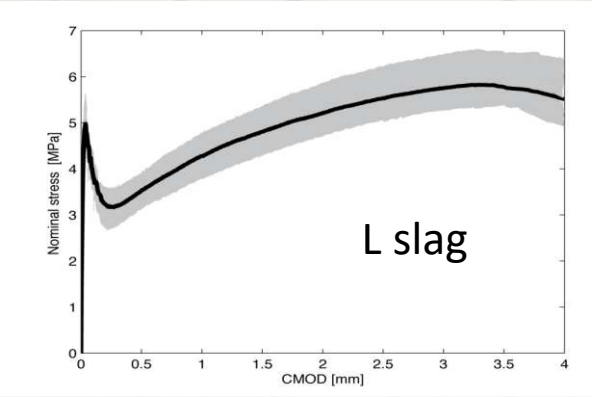
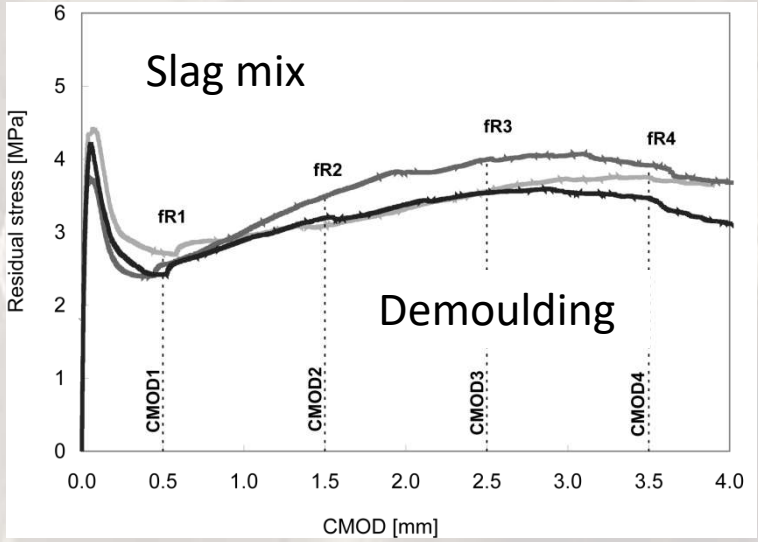
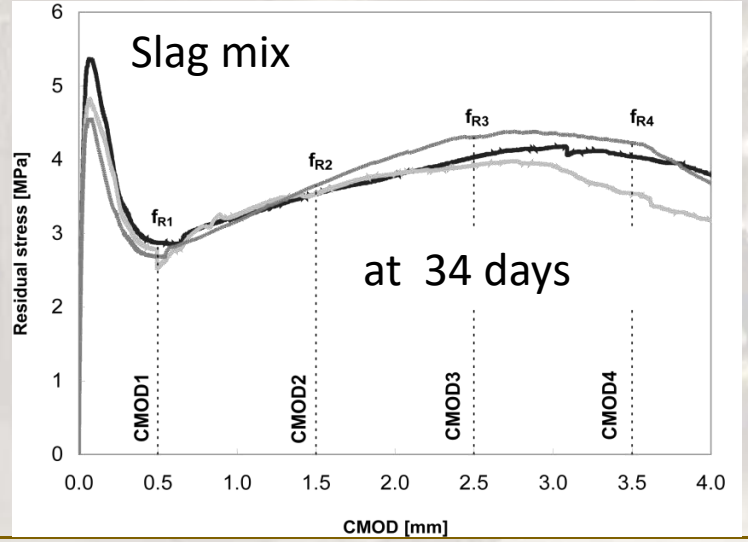


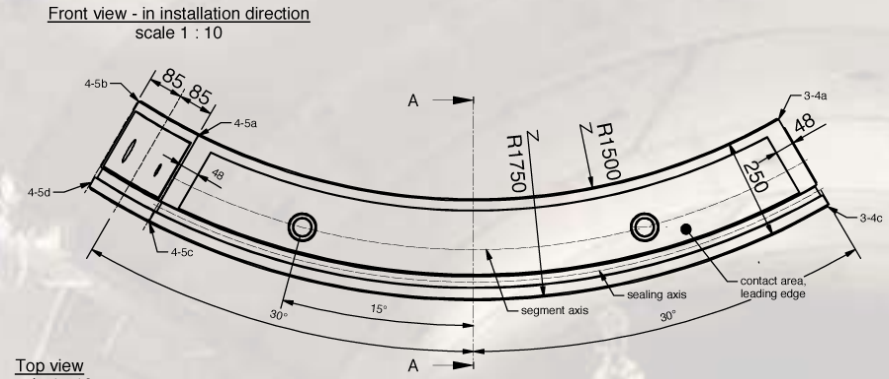
Table 1 – Fibre IST

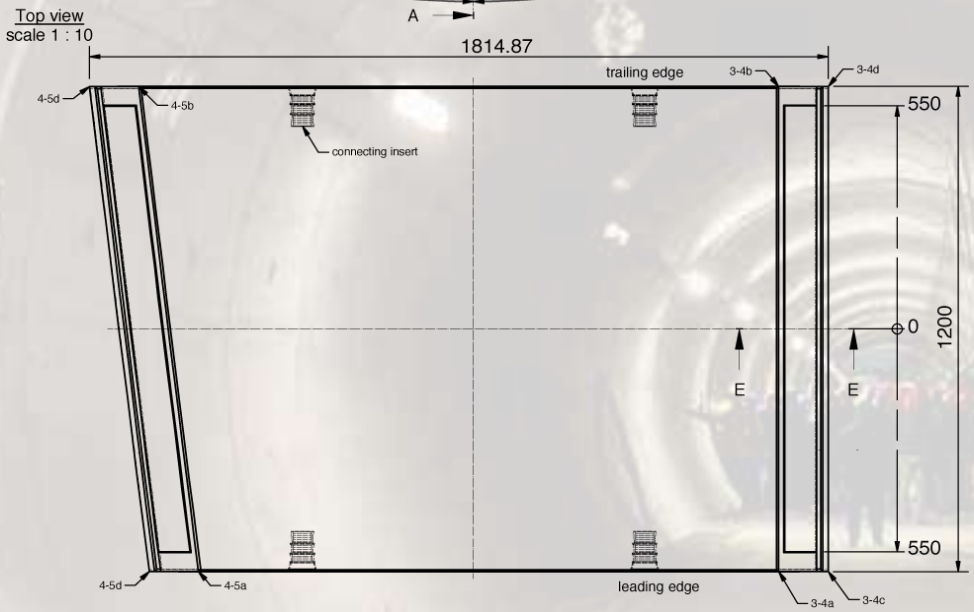
Type	Polymeric fibres for structural use
Composition	Polymeric compound with high density
Kind	Monofilament
Diameter [mm]	0.78
Length [mm]	39
Specific weight [kg/dm³]	1
Ultimate tensile strength [MPa]	470
Elastic modulus [MPa]	3.6
Water absorption	None
Acid resistance	Total
Superficial treatment	None

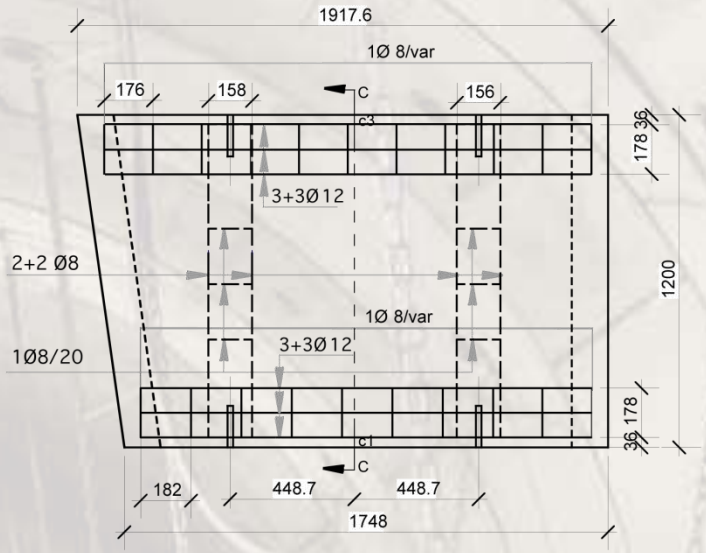
W/c ratio	0.47
Cement CEM I 52.5 [kg/m³]	340
For F: Limestone filler [kg/m³]	*60*
For L: Blast furnace slag [kg/m³]	*60*
Sieve sand 0/3 [kg/m³]	620
Natural sand 0/12 [kg/m³]	440
Round gravel 8/15 [kg/m³]	710

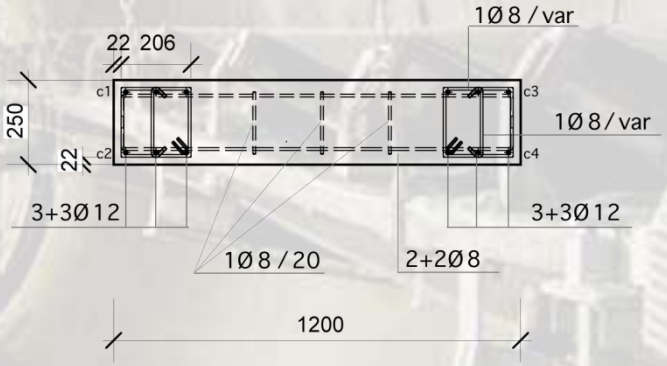

Slag mix
Demoulding
Residual stress [MPa]
CMOD [mm]
fR1
fR2
fR3
fR4
CMOD1
CMOD2
CMOD3
CMOD4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
1
2
3
4
5
6


Slag mix
at 34 days
Residual stress [MPa]
CMOD [mm]
fR1
fR2
fR3
fR4
CMOD1
CMOD2
CMOD3
CMOD4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
1
2
3
4
5
6

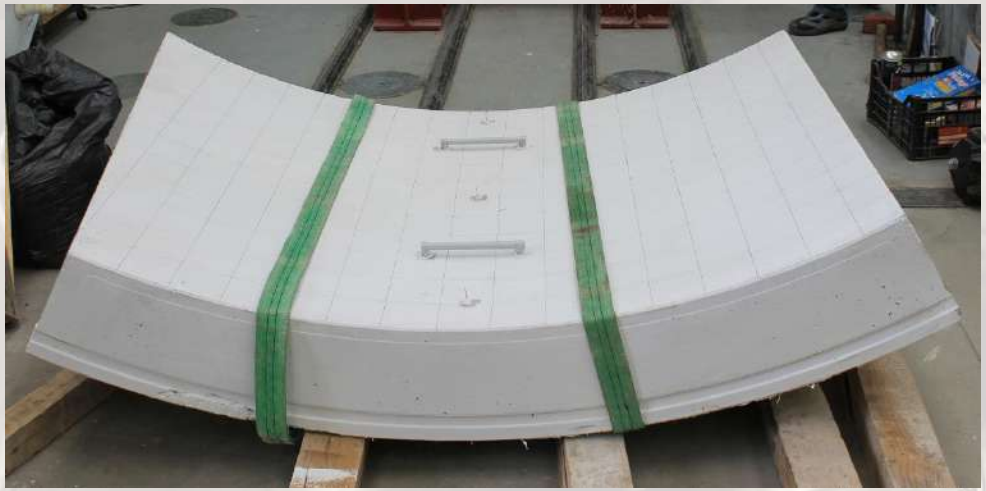

Front view - in installation direction
scale 1 : 10
4-5b
85
85
4-5a
A
R1750
R1500
3-4a
48
250
4-5d
48
4-5c
3-4c
contact area, leading edge
sealing axis
segment axis
30°
15°
30°
A

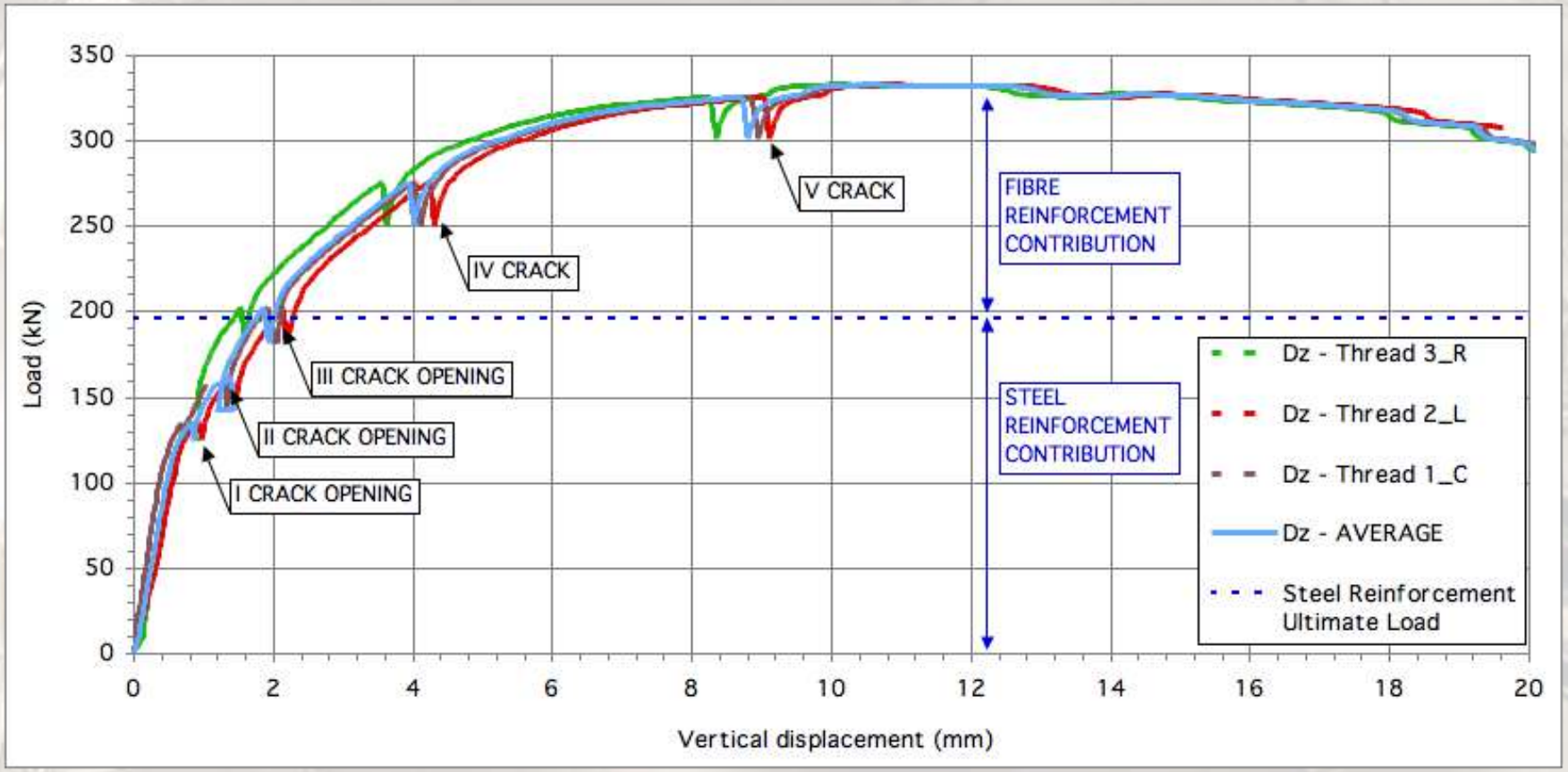

Top view
scale 1 : 10
1814.87
trailing edge
3-4b
3-4d
4-5d
4-5b
connecting insert
550
0
1200
E
E
550
4-5d
4-5a
leading edge
3-4a
3-4c


1917.6
1Ø 8/var
176
158
C
156
c3
178
36
3+3Ø12
2+2 Ø8
1200
1Ø 8/var
1Ø8/20
3+3Ø12
36
178
c1
C
182
448.7
448.7
1748

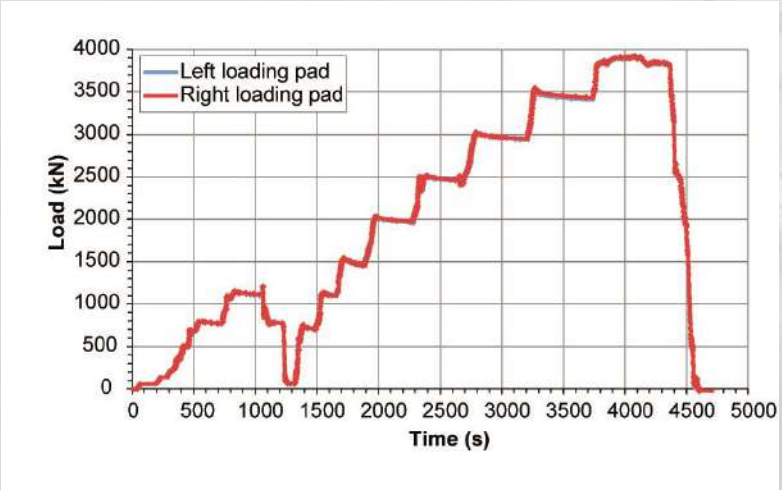

1Ø 8 / var
22
206
c1
c3
250
1Ø 8 / var
22
c2
c4
3+3Ø12
3+3Ø12
1Ø 8 / 20
2+2Ø8
1200

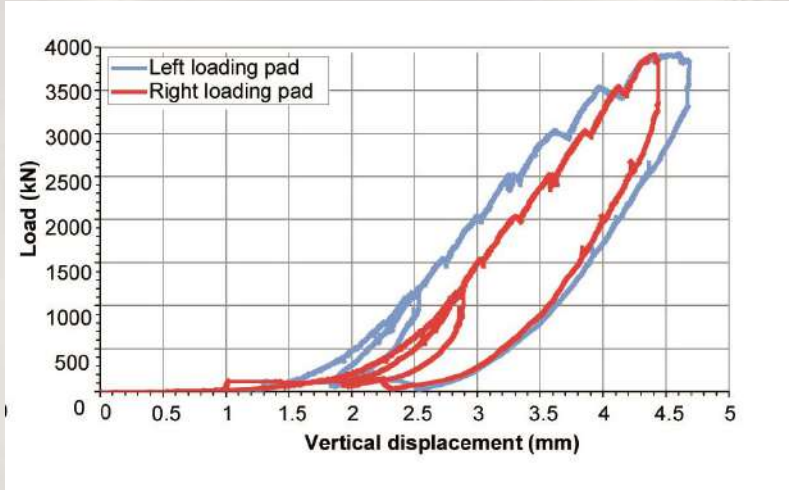
Set up prova

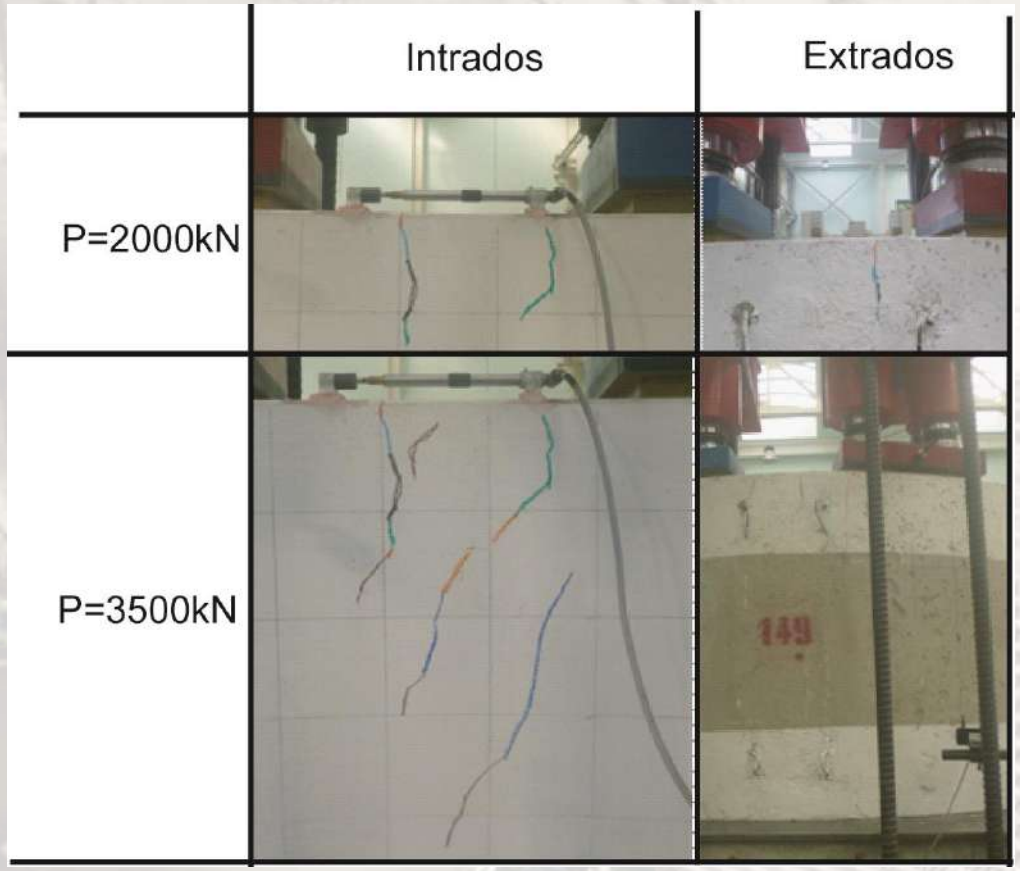



Load (kN)
Vertical displacement (mm)
V CRACK
IV CRACK
III CRACK OPENING
II CRACK OPENING
I CRACK OPENING
FIBRE REINFORCEMENT CONTRIBUTION
STEEL REINFORCEMENT CONTRIBUTION
Dz - Thread 3_R
Dz - Thread 2_L
Dz - Thread 1_C
Dz - AVERAGE
Steel Reinforcement Ultimate Load

149


Left loading pad
Right loading pad
Load (kN)
Time (s)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000


Left loading pad
Right loading pad
Load (kN)
Vertical displacement (mm)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Intrados
Extrados
P=2000kN
P=3500kN

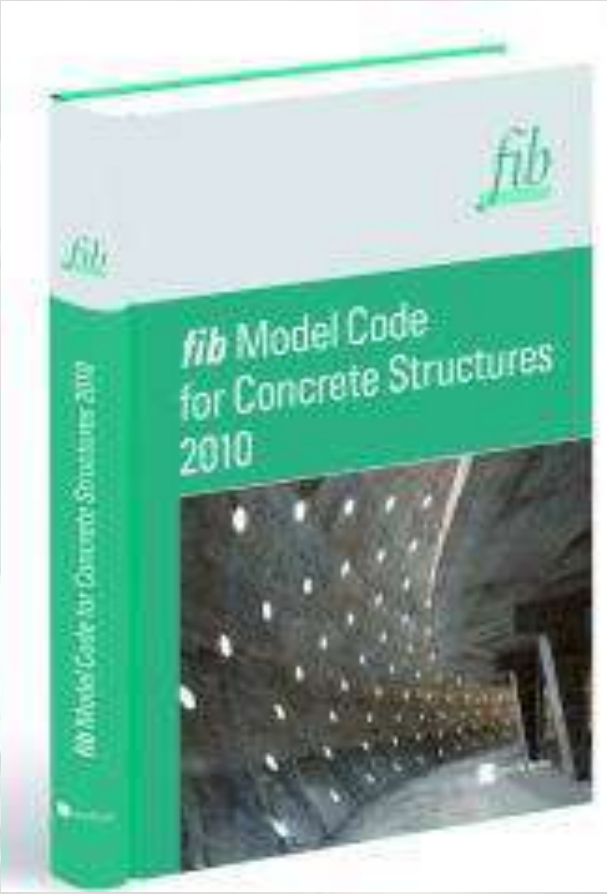
Tested fibre cocktails - amount of fibres [V%]

Mix	0	S 0.3	S 0.5	S 1.0	P 0.1	Ce 0.1	S 1.0 +P 0.1	S 1.0 +P 0.2	S 1.0 +Ce 0.1	S 1.0 +Ce 0.2
Steel (short)	-	0.3	0.5	1.0	-	-	1.0	1.0	1.0	1.0
Polymer	-	-	-	-	0.1	-	0.1	0.2	-	-
Cellulose	-	-	-	-	-	0.1	-	-	0.1	0.2

Balázs – Czoboly: Fibre Cocktails to improve Fire Resistance, CONSEC2016 - 13 Sept 2016, Lecco

Fibres	Post cracking residual flexural strength	Explosive spalling
Short Steel Fibres (ℓ=13 mm)	↑	in range of 0.5 to 1.0 V%
Cellulose Fibres or Micro Polymer Fibres	No effect	Explosive spalling **avoided**
Fibre Cocktails	↑	Explosive spalling **avoided**

Balázs – Czoboly: Fibre Cocktails to improve Fire Resistance, CONSEC2016 - 13 Sept 2016, Lecco



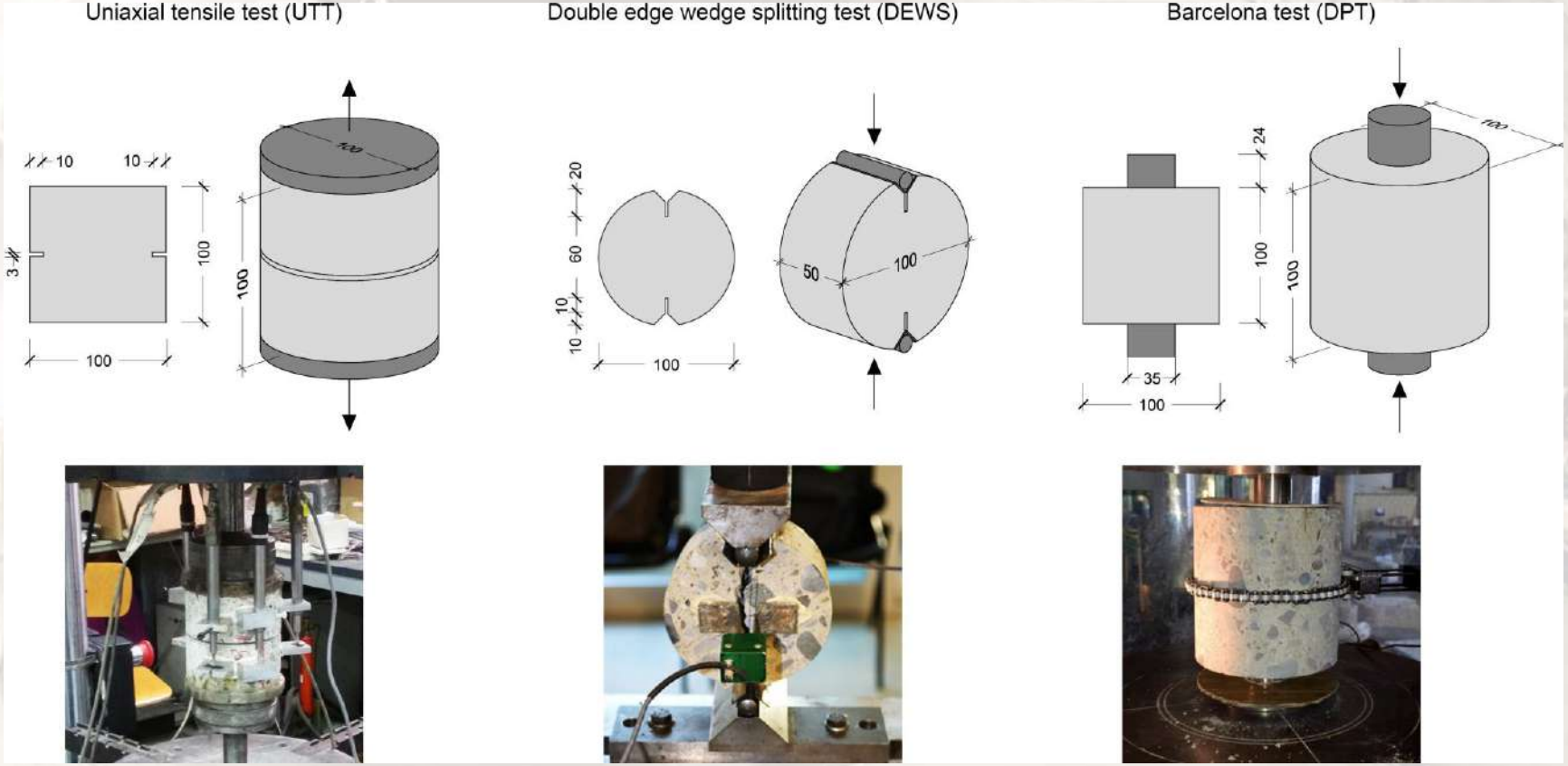
(1) Fibre-Reinforced Concrete (FRC) is a composite material characterized by a cement matrix and discrete fibres (discontinuous). The matrix is made of either concrete or mortar. **Fibres can be made of steel, polymers, carbon, glass or natural materials**.

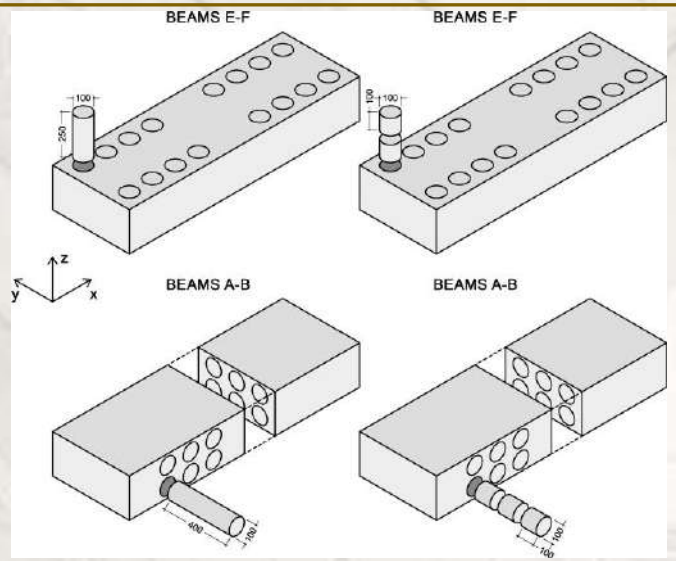
(2) Fibre materials with a Young's Modulus which is significantly affected by time and/or thermo-hygrometrical phenomenon are not covered by this Model Code **for the structural use**.

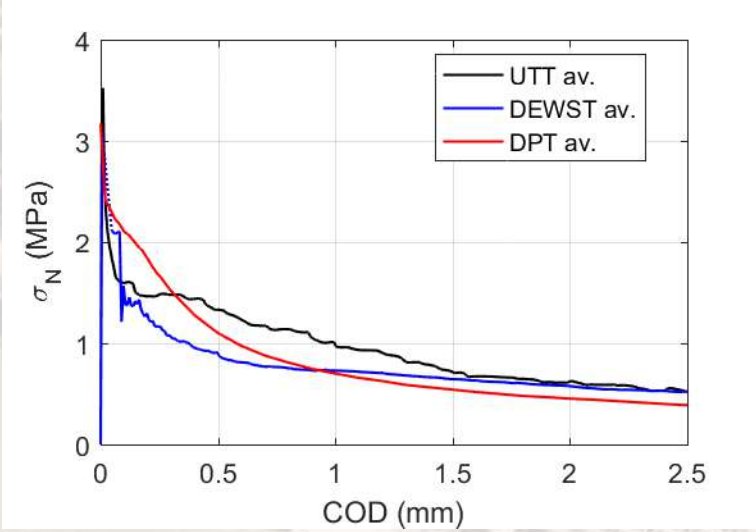
(3) Mixtures of different types and/or sizes of fibres can also be used (called **hybrid fibre reinforced concrete**).

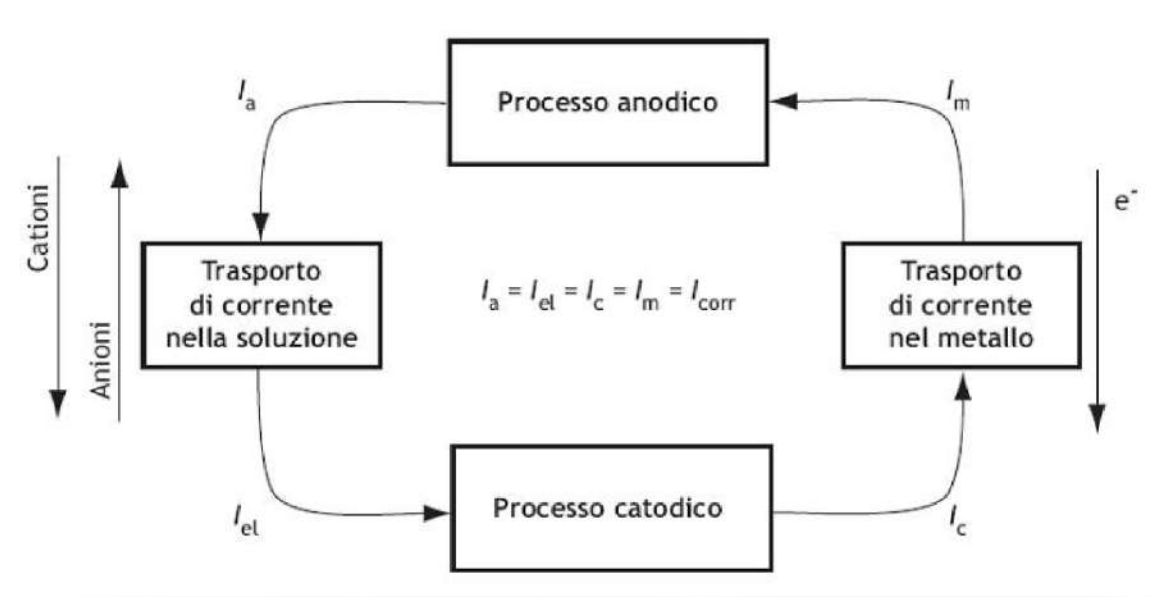
Other tests for quality control

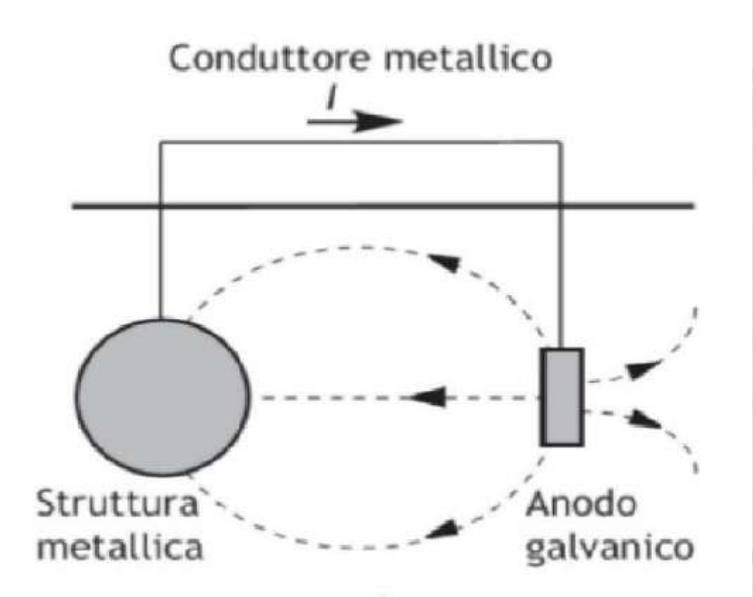
Martinelli, P., Colombo, M., Pujadas, P., de la Fuente, A., Cavalaro, S., di Prisco, M.,
Characterization tests for predicting the mechanical performance of SFRC floors: identification of fibre distribution and orientation effects, (2021) Materials and Structures/Materiaux et Constructions, 54 (1), art. no. 3 .





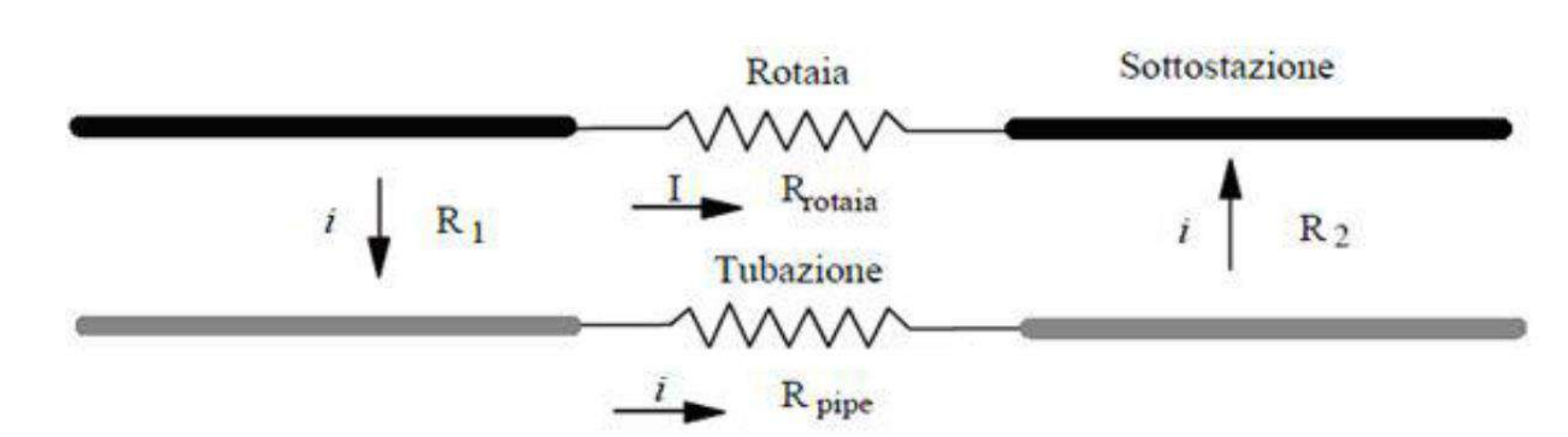




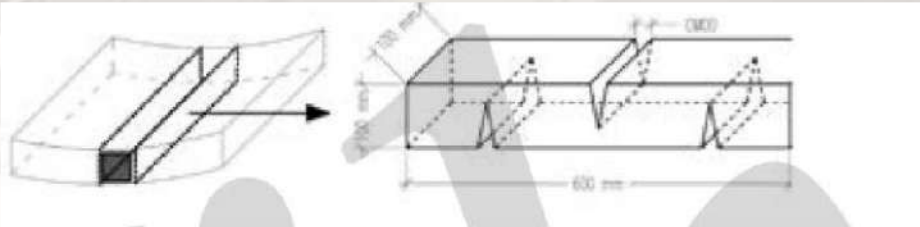


Interferenza stazionaria

Correnti vaganti



Interferenza non stazionaria



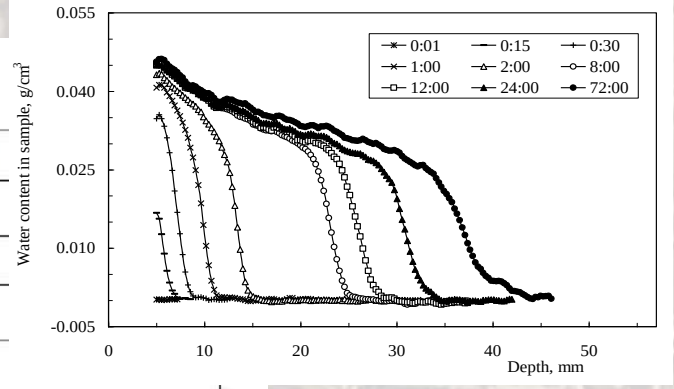
: Specimen extraction, sketch and crack positioning. Adapted from (S. Abbas, 2014)

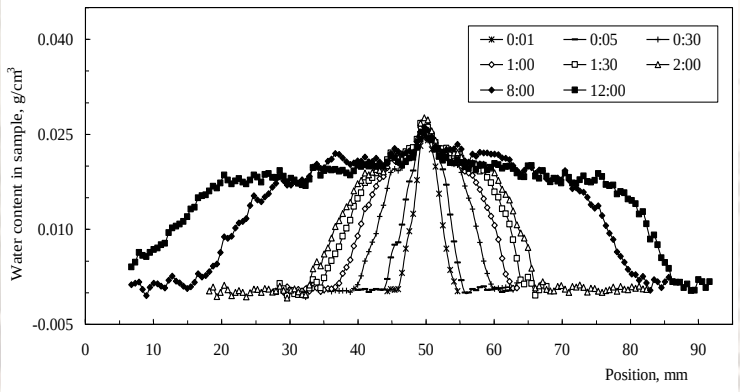
Water penetrates into a normal concrete (W/C=0.45) within 72 hours up to 37 mm.
Chloride penetrates in this period not deeper than 5 to 7 mm.

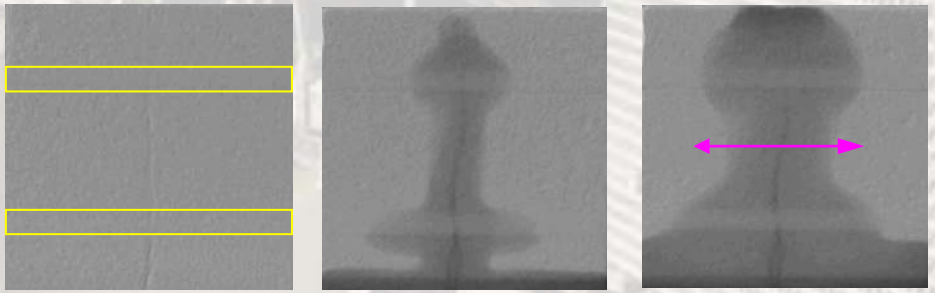
Suction time: 0 2 72 hours

Table 8-1: Crack width limits obtained from literature study

Reference	Crack width limit
D. C. Morse and G. R. Williamson, 1977	0.25 mm
J.-L. Granju and S. U. Balouch, 2005	0.10 mm
E. Nordström, 2005	0.10 mm
E. J. de P. Hansen, T. Ekman, and K. K. Hansen, 1999	0.15 mm
D. J. Hannant and J. Edgington, 1975	0.40 mm
R. Weydert and P. Schiessl, 1998	0.00 mm (no cracks allowed)
D. Nemegeer, J. Vanbrabant, and H. Stang, 2000	0.50 mm







Suction time: 0 .5 2 hours

Crack widths allowed for SFRC (Bull. 83)

Annex L – EC2

(1) For SFRC, the concrete cover due to durability requirements $c_{\mathrm{min,dur}}$ according to 6.5.2.2 shall only apply to the embedded reinforcement, not to the steel fibres.

(2) To avoid fibre accumulation, a minimum cover of c_{min} = 20 mm to embedded reinforcement shall be used for all SFRC members.

(3) For ULS design of SFRC in exposure classes XC2-XC4, XD1-XD3, and XS1-XS3, designed to be uncracked at SLS, the tensile strength in the outer most tension fibres shall be disregarded within a layer of $c_{\mathrm{f,dur}}$ = 10 mm from the exposed surface.

(4) For ULS and SLS design of SFRC in exposure classes XC2-XC4, XD1-XD3, and XS1-XS3 designed to be cracked at SLS, the residual tensile strength in the outer most tension fibres shall be disregarded with a distance of $c_{\mathrm{f,dur}}=k_{\mathrm{dur}}\cdot c_{\mathrm{min,dur}}$ from the exposed surface, unless provisions (5) or (6) are satisfied.

If the characteristic crack width calculated in accordance with 9.2 is less than the crack width limit $w_{\mathrm{lim,cal}}$ stated in Table 9.2(NDP) and L.9, the values of $c_{\mathrm{f,dur}}$ may be reduced as follows:

$$c_{\mathrm{f,dur}} = k_{dur}\, c_{\mathrm{min,dur}} \frac{w_{\mathrm{k,cal}}}{w_{\mathrm{lim,cal}}} \geq 10 \text{ mm} \qquad \text{(L. 15)}$$

NOTE The value of k_{dur}·is 0,50 unless a National Annex gives a different value for use in a Country.

(5) If stainless steel fibres are used, the residual tensile strength of the outermost tension fibres within depth $c_{\mathrm{f,dur}}$ may be used.

(6) The residual tensile strength of fibres in the layer $c_{\mathrm{f,dur}}$ may be used during the construction phase.

A.C.C.I.DE.N.T

Funded by INTERREG

Advanced Cementitious Composites In DEsign and coNstruction of safe Tunnel

SUPSI
University of Applied Sciences of Southern Switzerland

I Level

Material

II Level

Meso-structure

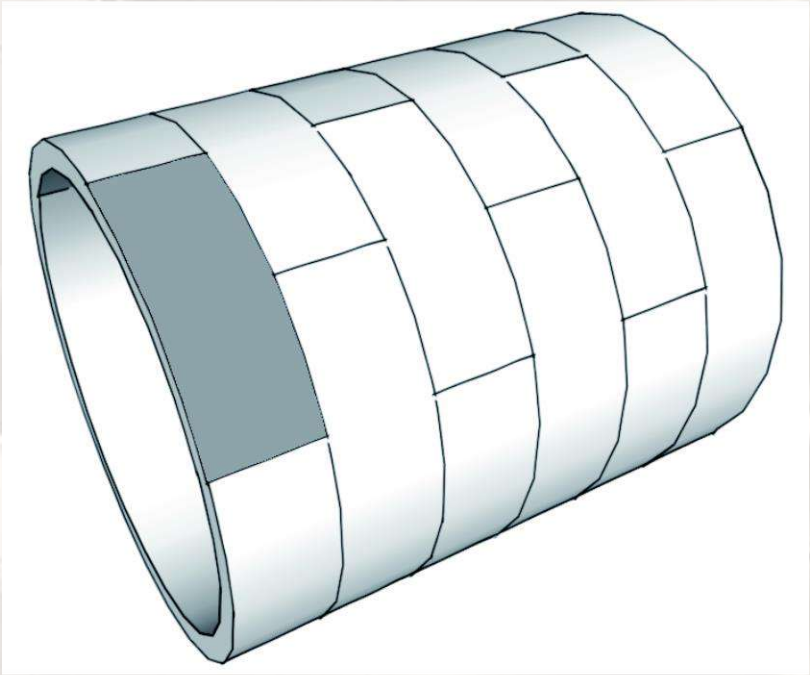
III Level

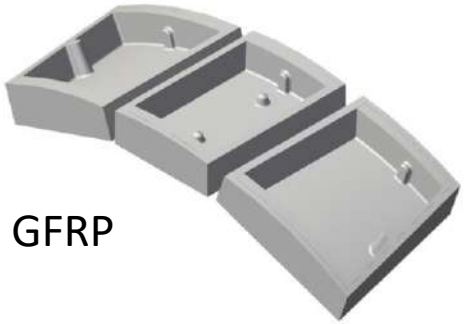
Structure

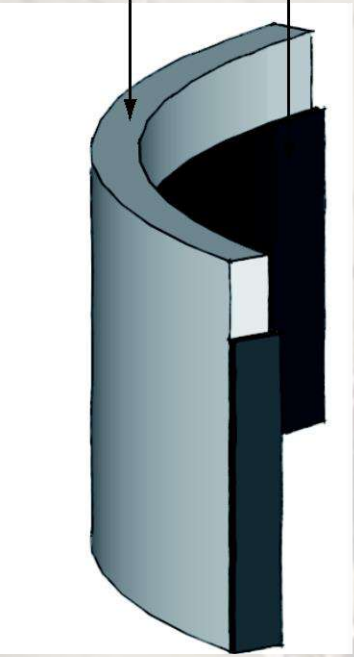
Structural targets,

- ✓ Internal explosion with detonation: tunnel segment resisting to a blast wave caused by a terroristic attack with **25 kg of TNT**
- ✓ Fire: limited damage (no interruption for serviceability conditions) in case of **T = 600°C** for about 2 hours on the segment surface
- ✓ Serviceability and Ultimate loads considered in the consolidated **construction experience**.

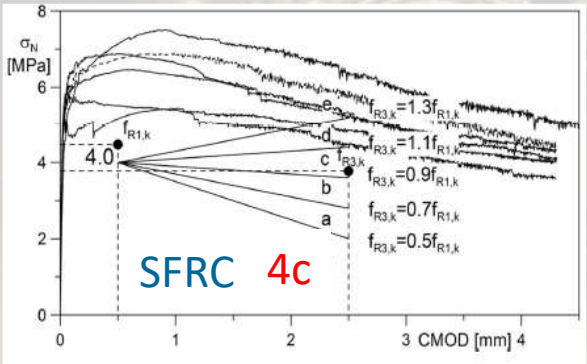
Production procedure

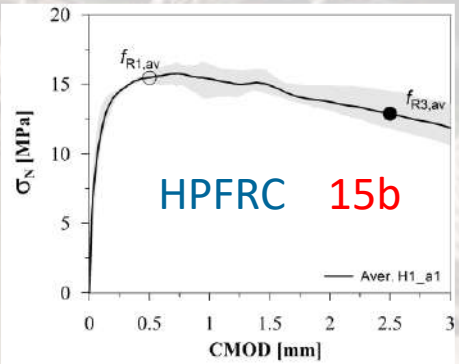


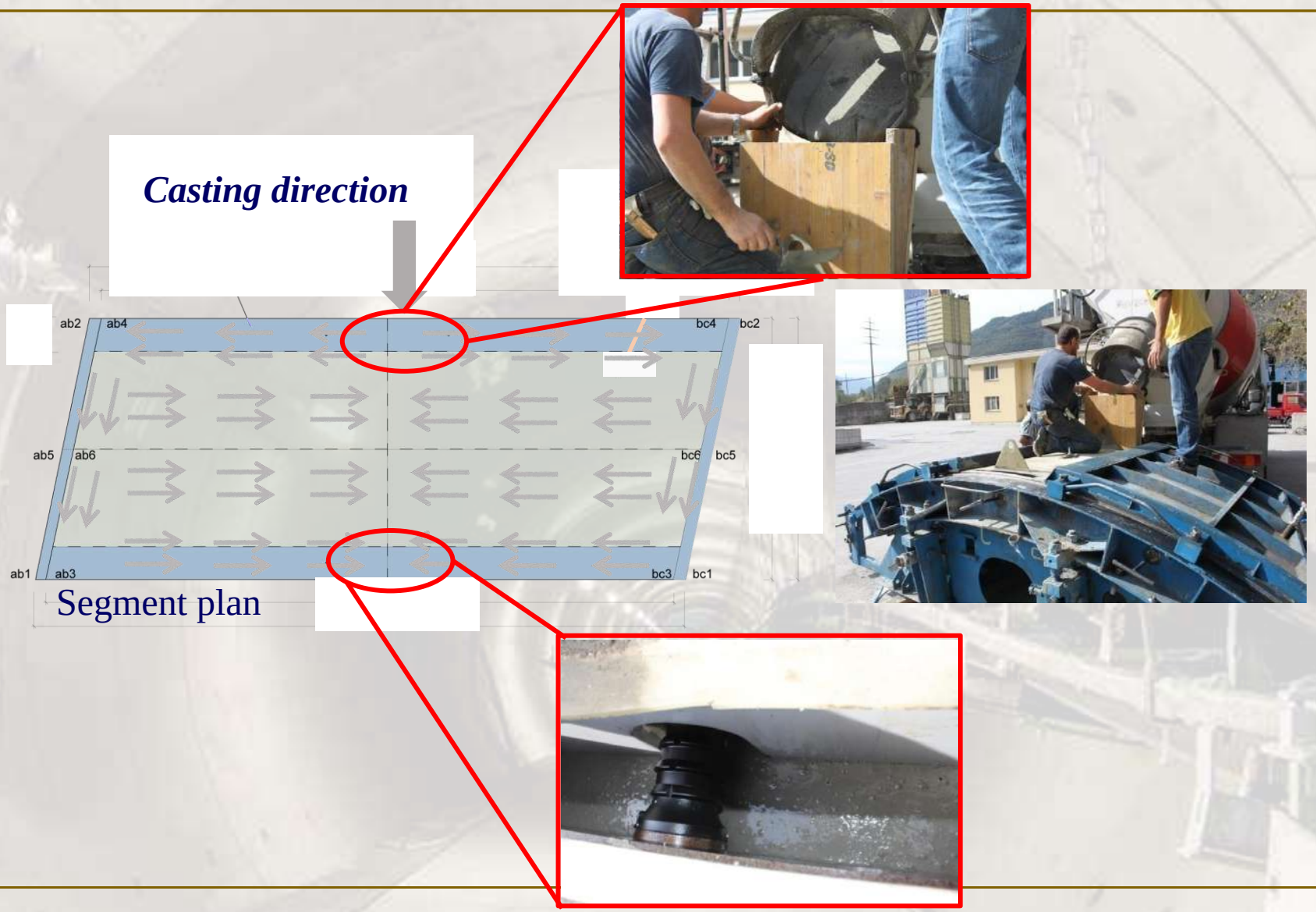




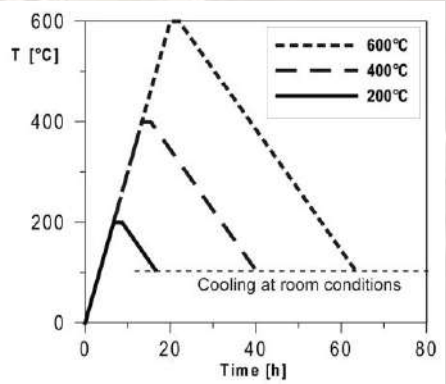
			SFRC				HPFRC			
Properties at 28 days			C60/75		Class 5c		C110/130		Class 15d	
			f_{cd}	f_{ctd}	f_{Ftsd}	f_{Ftud}	f_{cd}	f_{ctd}	f_{Ftsd}	f_{Ftud}
	Condition	Duration	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
ULS	perm. transient	Short	41.33	2.19	1.50	1.88	72.00	3.17	4.50	3.50
		Long	35.13				61.20			
	Accident	Short	51.67	2.74	1.50	1.04	90.00	3.97	5.63	4.38
		Long	43.92				76.50			
SLS	Characteristic	$f_{ck}/f_{ctk0.05}$	62.00	3.29	2.25	1.25	108.00	4.76	6.75	5.25

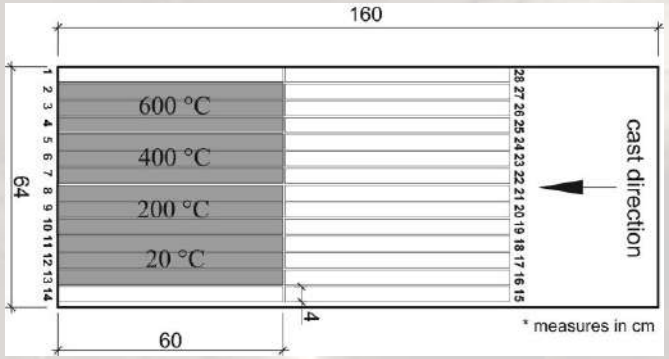


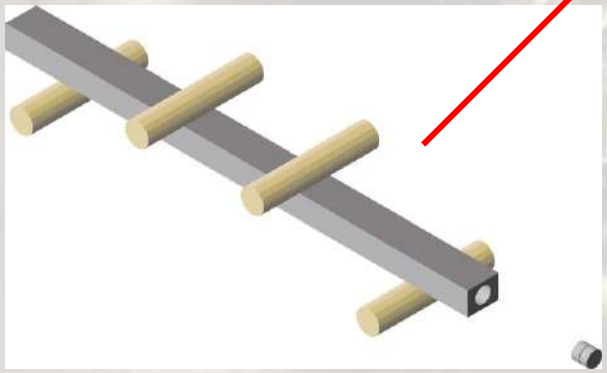


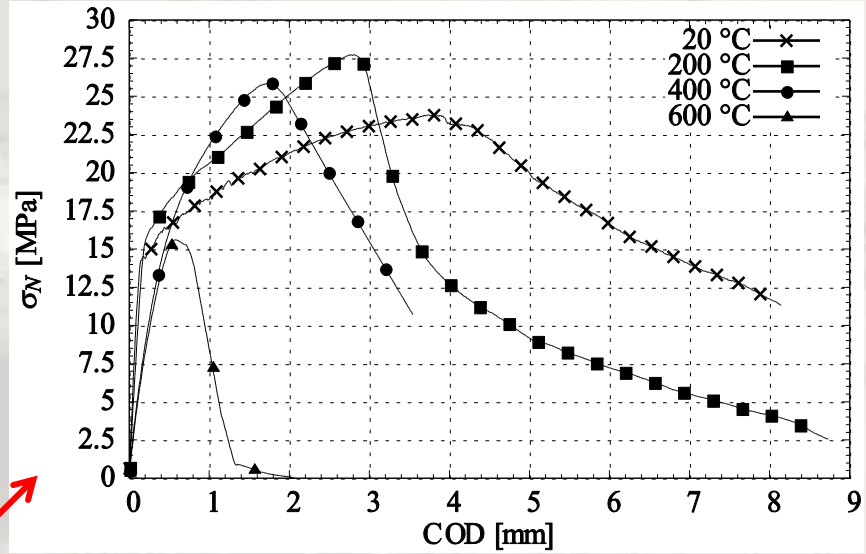

Casting direction
ab2
ab4
bc4
bc2
ab5
ab6
bc6
bc5
ab1
ab3
bc3
bc1
Segment plan

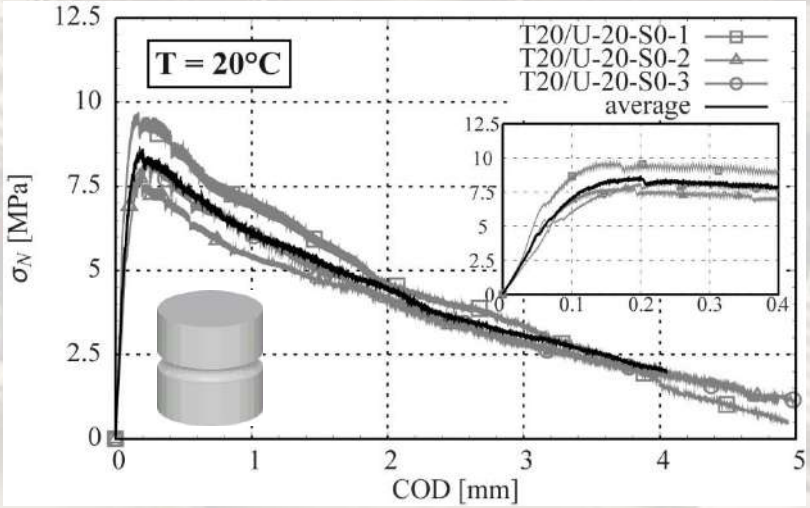
Caverzan, A., Colombo, M., di Prisco, M., Rivolta, B., High performance steel fibre reinforced concrete: residual behaviour at high temperature (2015), Materials and Structures/Materiaux et Constructions, 48 (10), pp. 3317-3329.



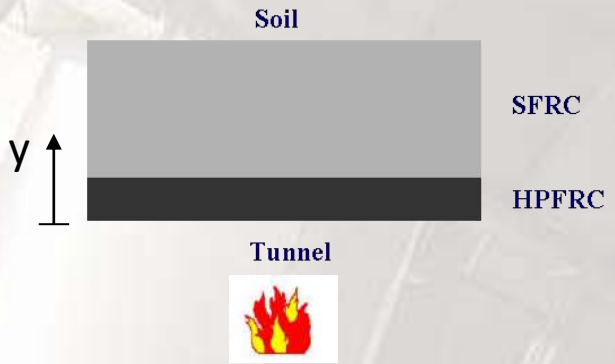


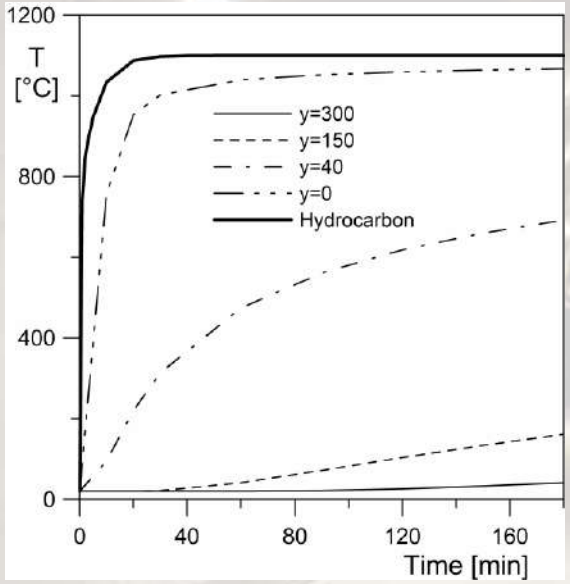


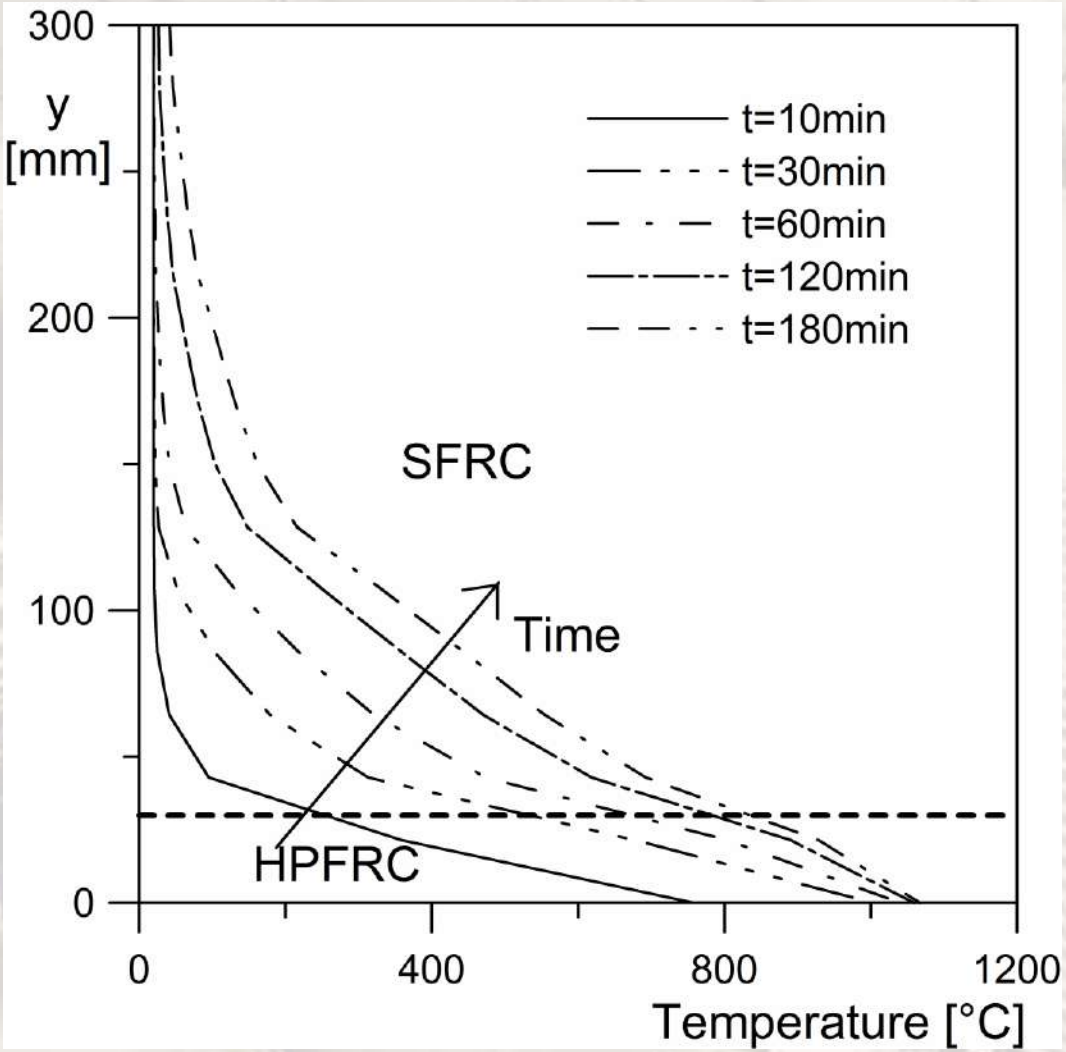




Fire behaviour of the cross section





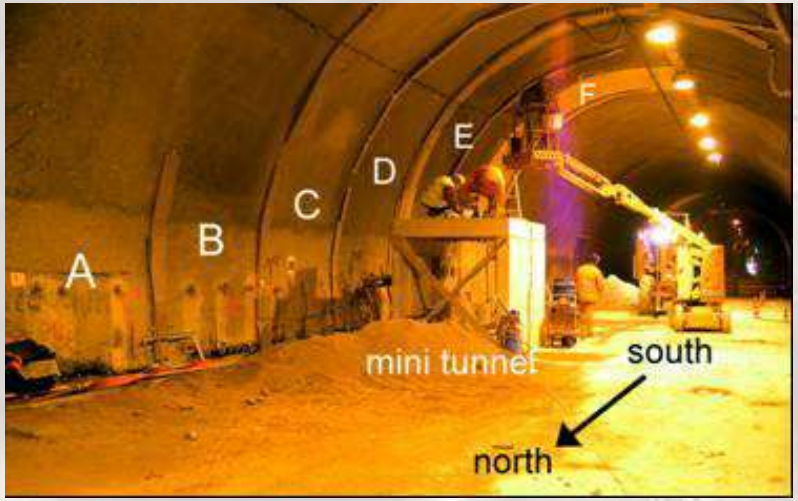


Incendi in galleria

le prove nel tunnel del Virgolo – Bolzano, 2005

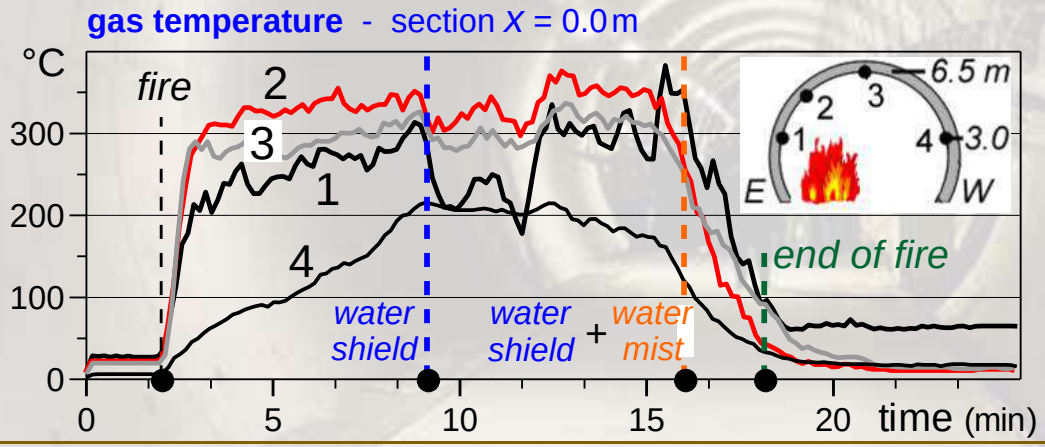
progetto UPTUN - Work Package 6

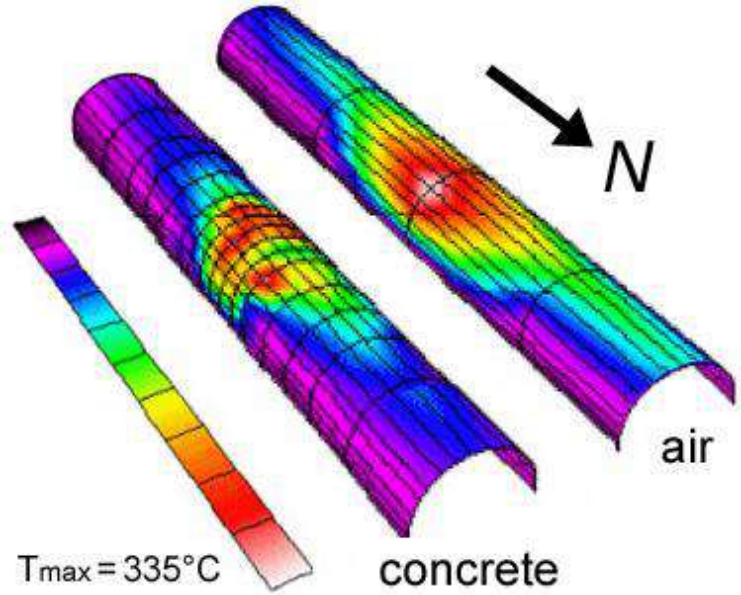
Bamonte, P., Felicetti, R., Gambarova, P.G., Nafarieh, A., On the fire scenario in road tunnels: A comparison between zone and field models, (2011) Applied Mechanics and Materials, 82, pp. 764-769

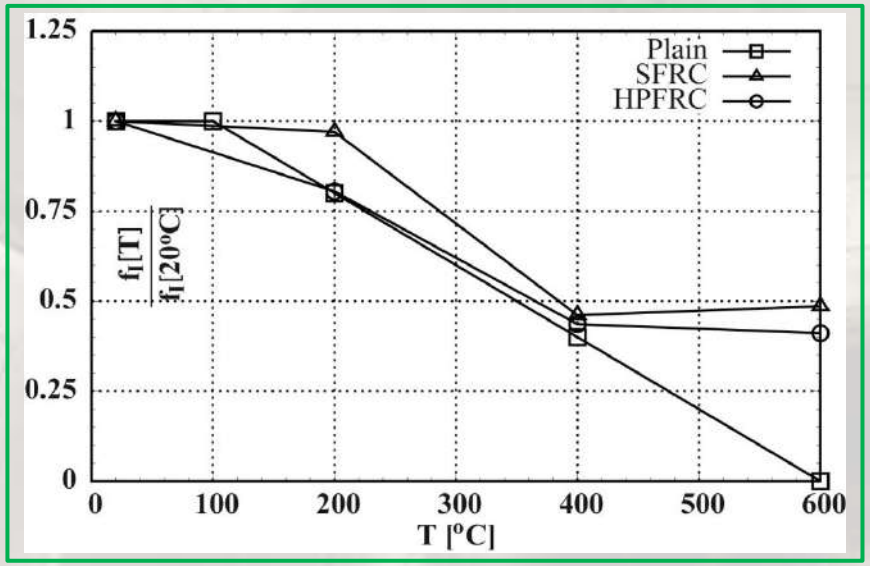


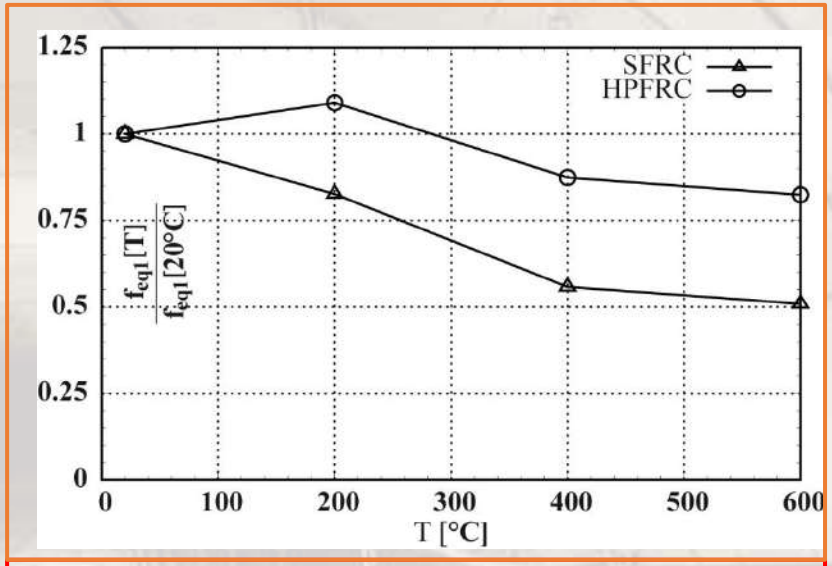
- 6 diversi rivestimenti in calcestruzzo proiettato
- potenza termica fino a 30 MW
- accurata misurazione della temperature

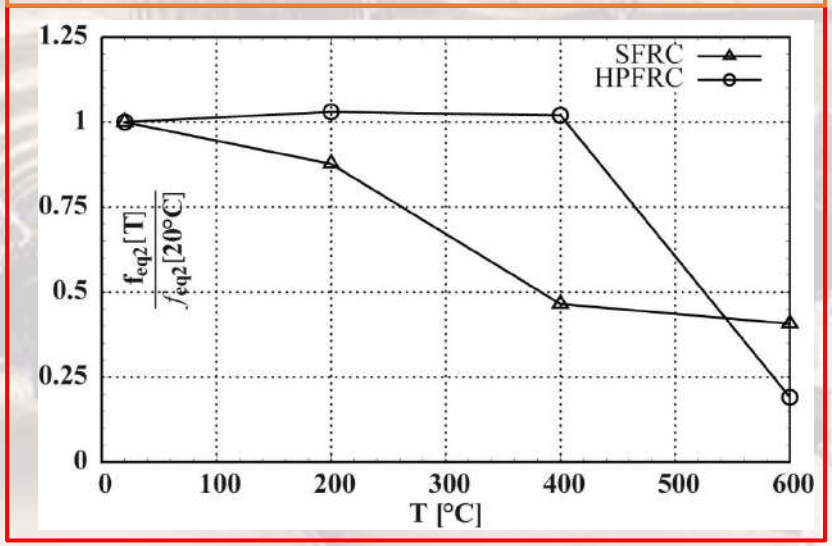
gas: 28 punti
calcestruzzo: 94 punti

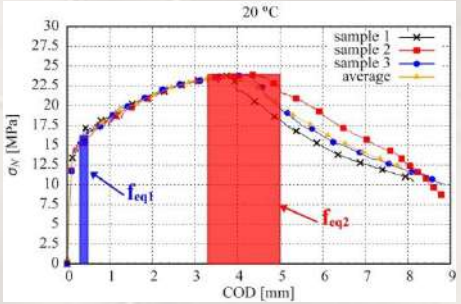


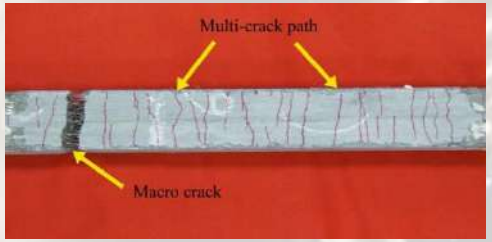




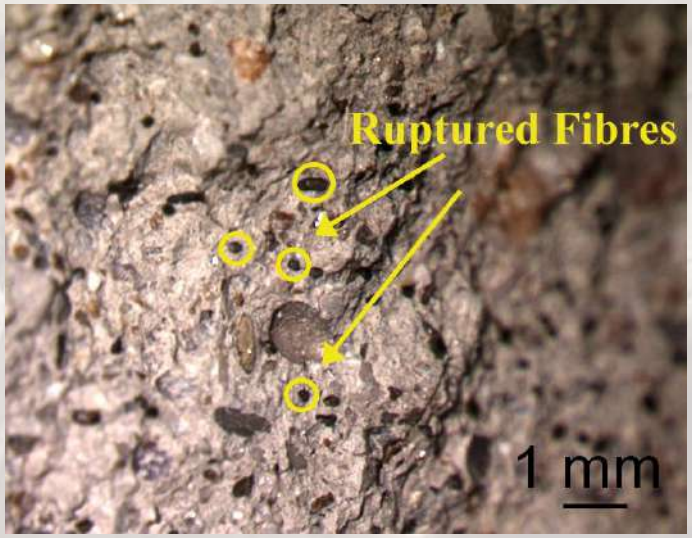


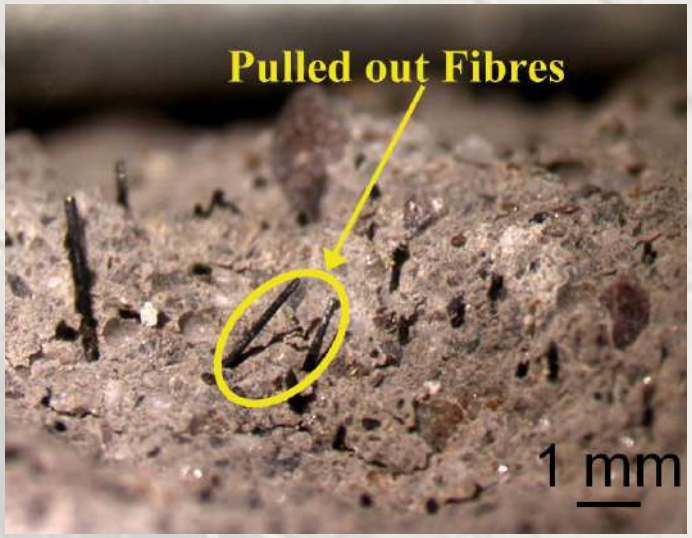


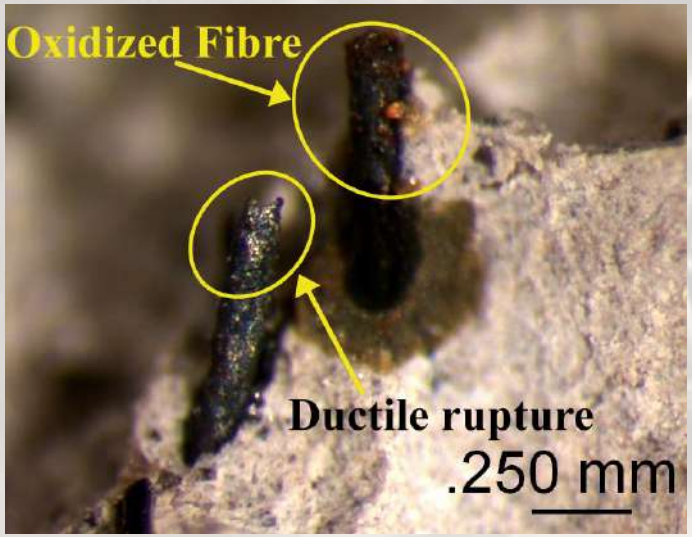


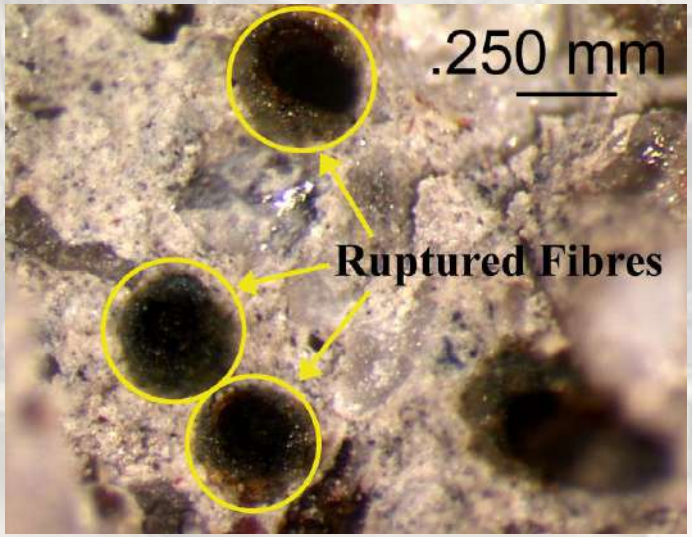


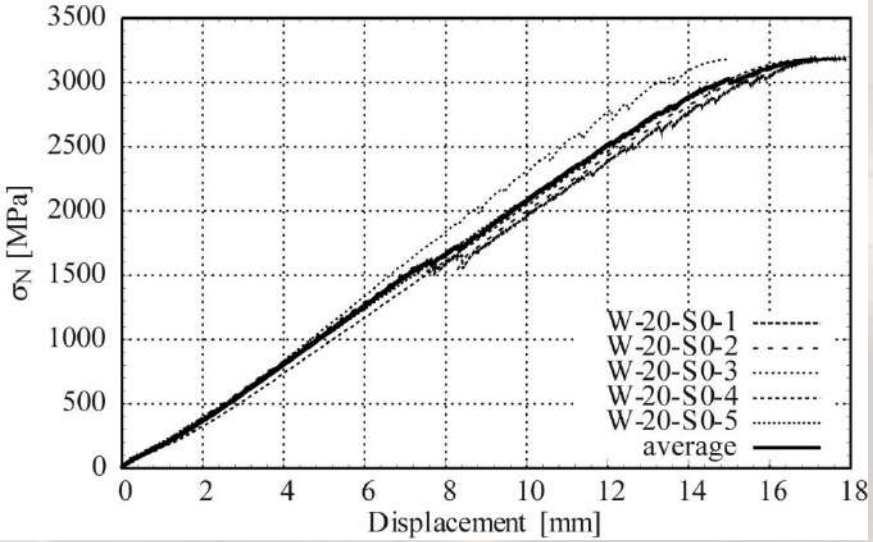
Caverzan, A., Colombo, M., di Prisco, M., Rivolta, B., High performance steel fibre reinforced concrete: residual behaviour at high temperature (2015), Materials and Structures/Materiaux et Constructions, 48 (10), pp. 3317-3329.

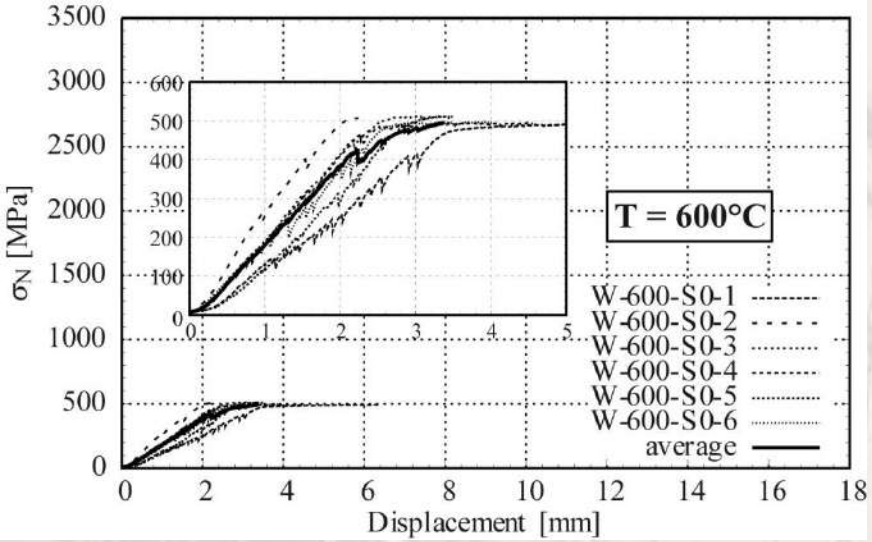

Ruptured Fibres
1 mm


Pulled out Fibres
1 mm


Oxidized Fibre
Ductile rupture
.250 mm


.250 mm
Ruptured Fibres

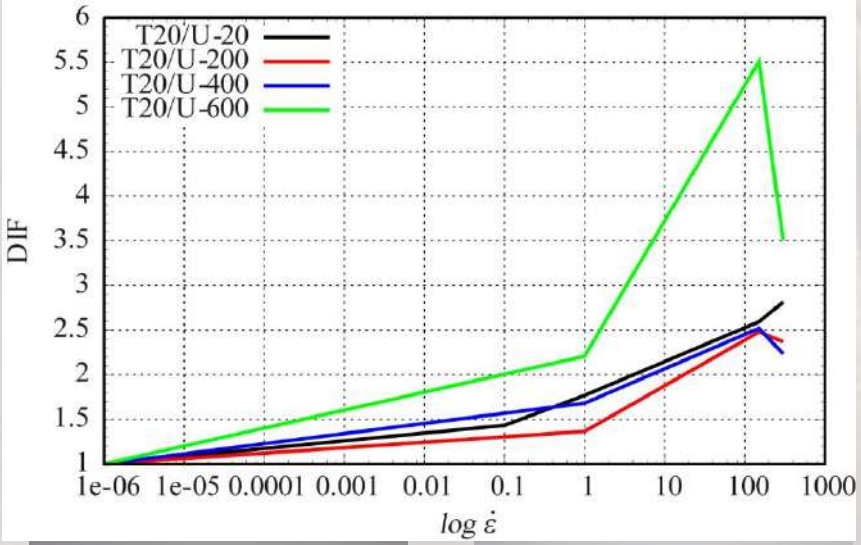

σN [MPa]
Displacement [mm]
W-20-S0-1
W-20-S0-2
W-20-S0-3
W-20-S0-4
W-20-S0-5
average

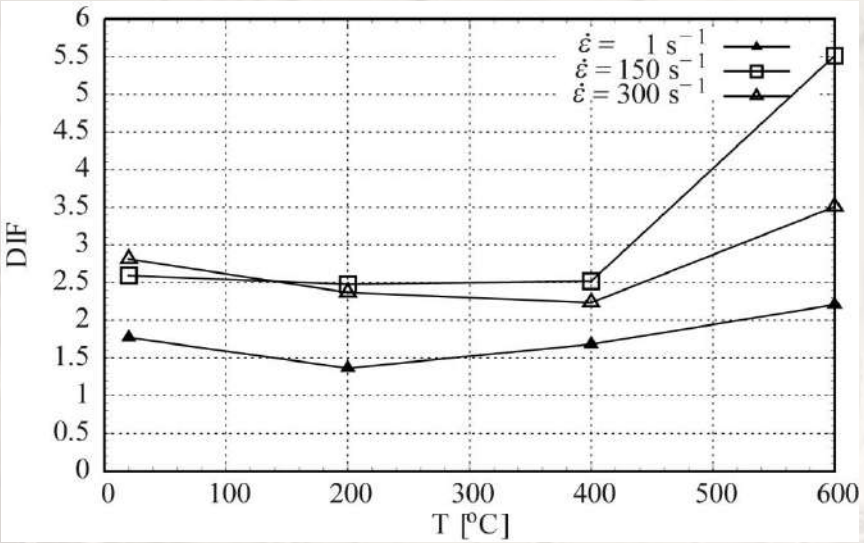

σN [MPa]
Displacement [mm]
T = 600°C
W-600-S0-1
W-600-S0-2
W-600-S0-3
W-600-S0-4
W-600-S0-5
W-600-S0-6
average

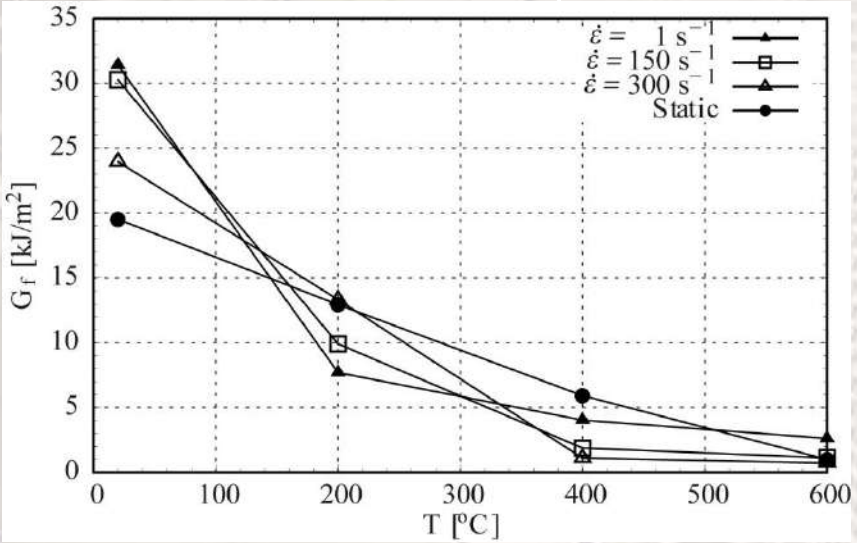
10 µm

10 µm

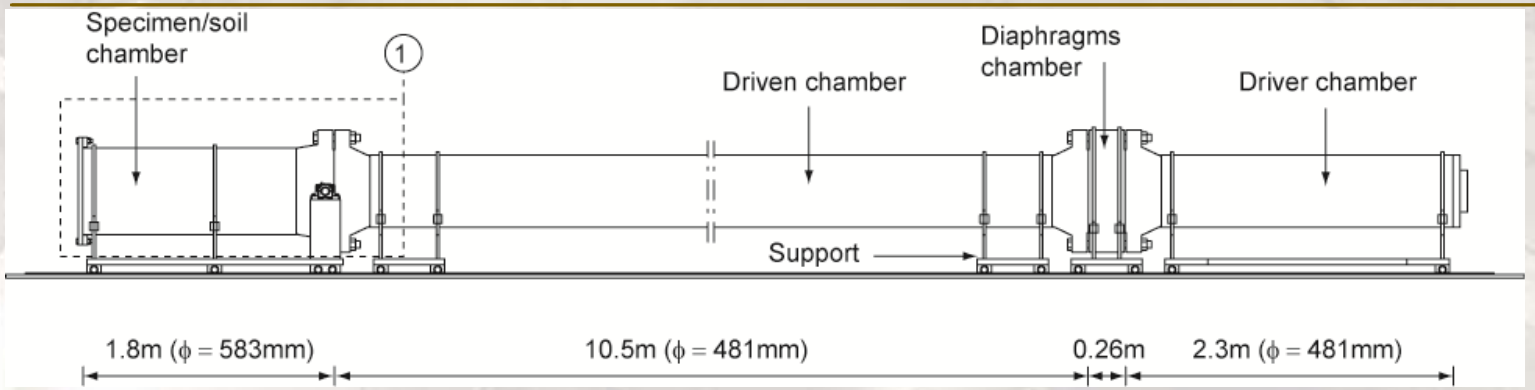
Caverzan, A., Cadoni, E., di Prisco, M..
Dynamic tensile behaviour of high performance fibre reinforced cementitious composites after high temperature exposure
(2013), Mechanics of Materials, 59, pp. 87-109.



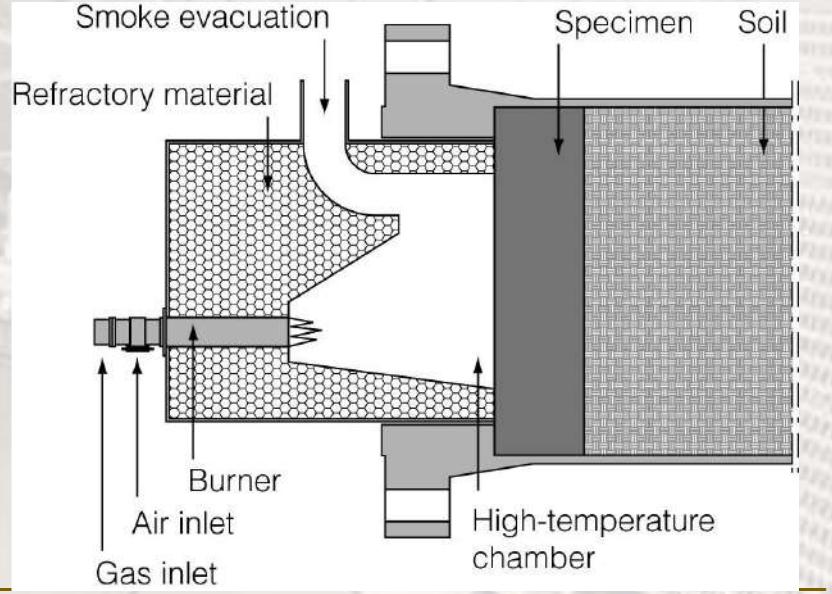


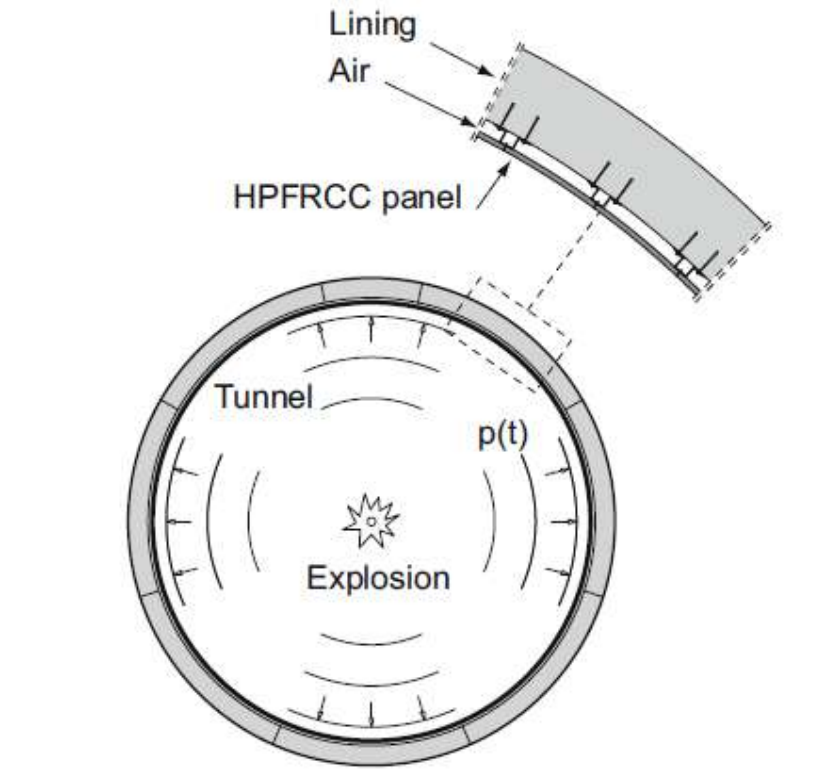


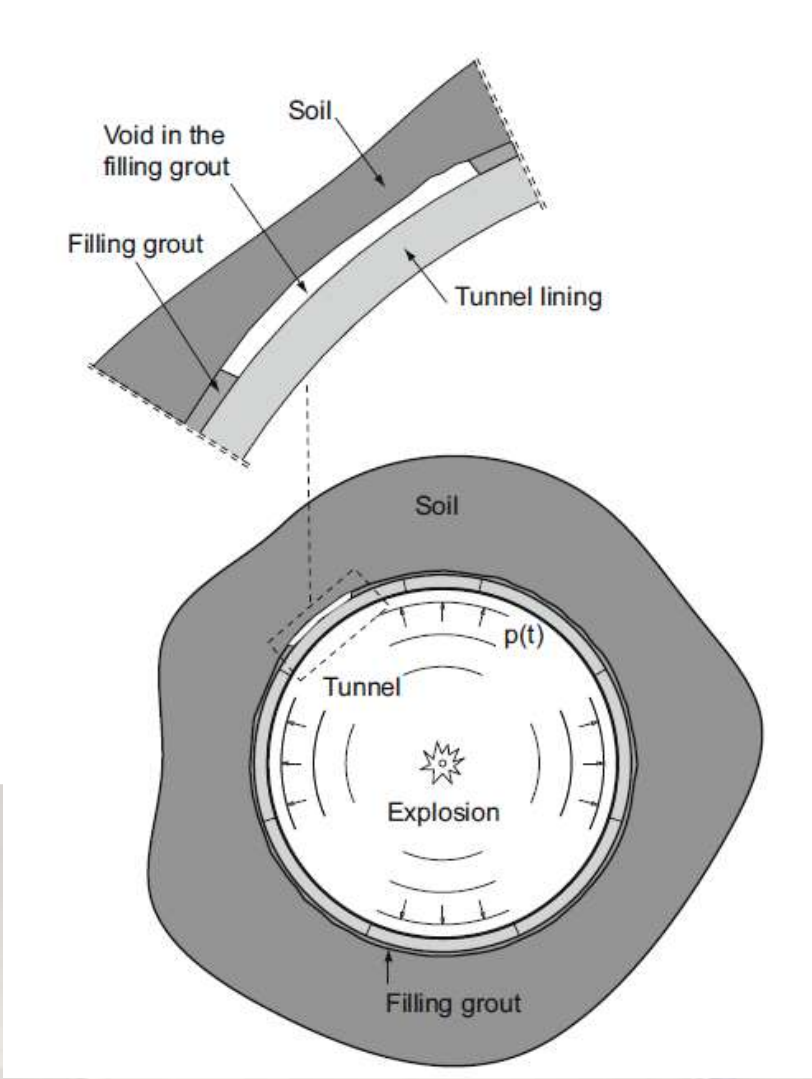
• Shock-Tube lateral view

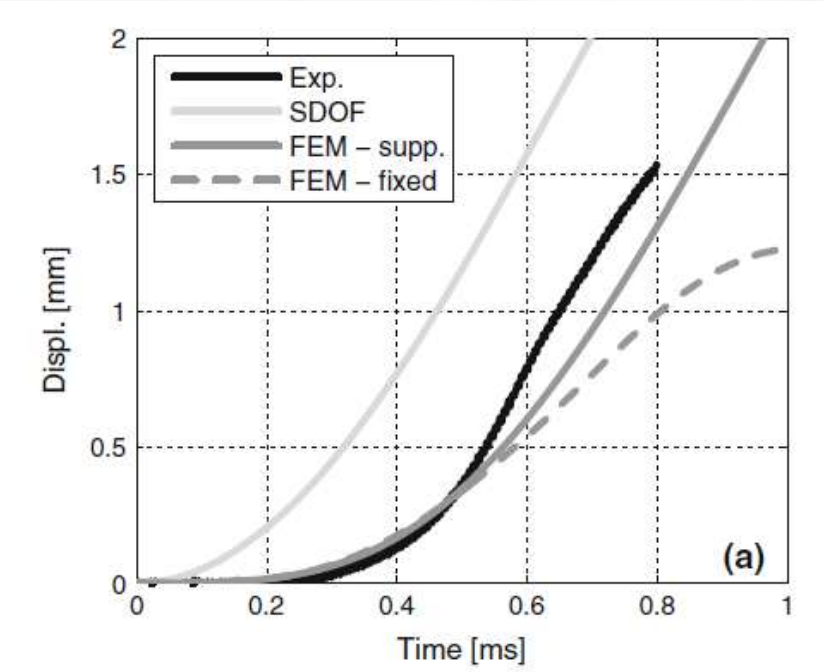


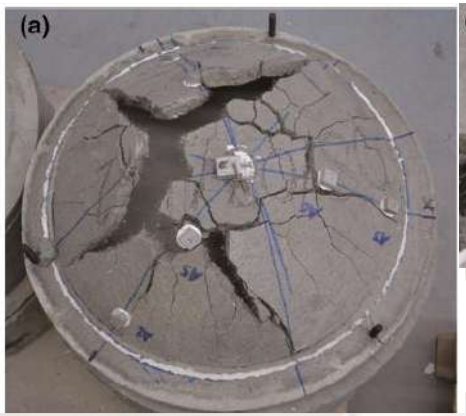
Andreotti, R., Colombo, M., Guardone, A., Martinelli, P., Riganti, G., di Prisco, M..
Performance of a shock tube facility for impact response of structures (2015), International Journal of Non-Linear Mechanics, 72, pp. 53-66.

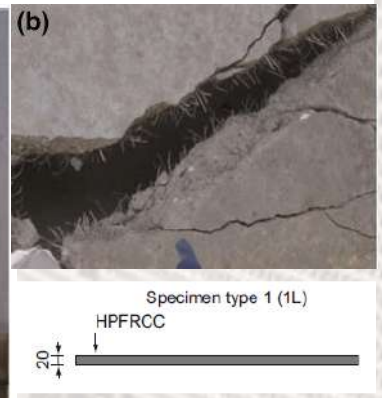




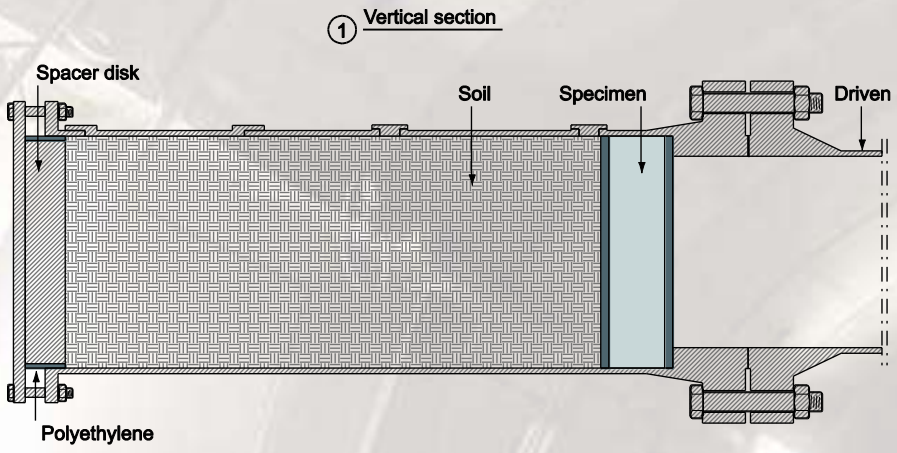


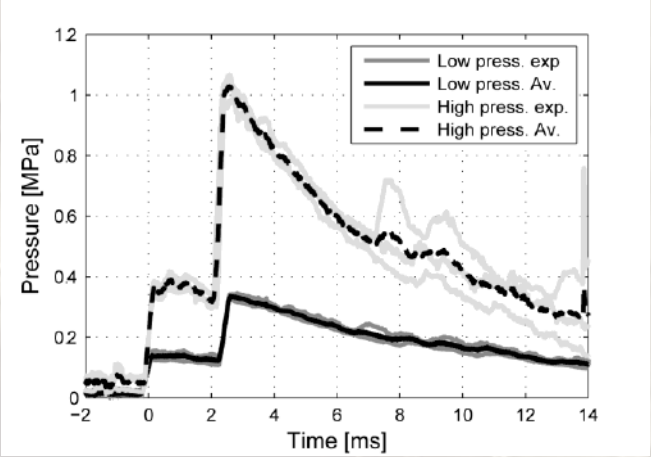


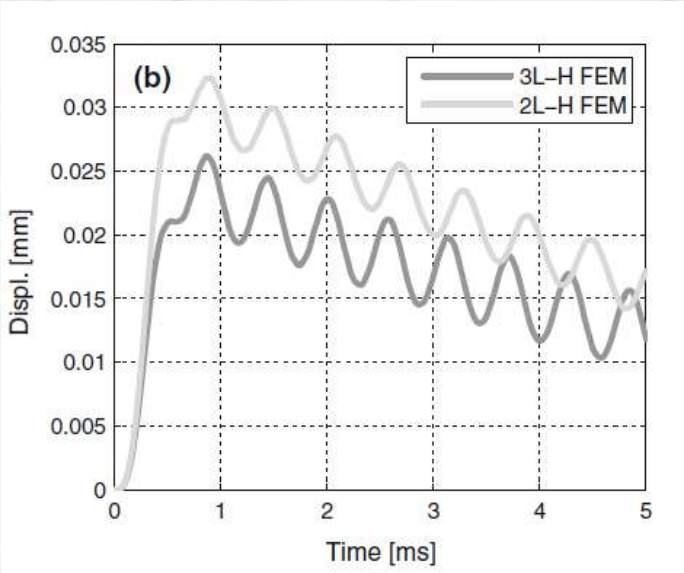


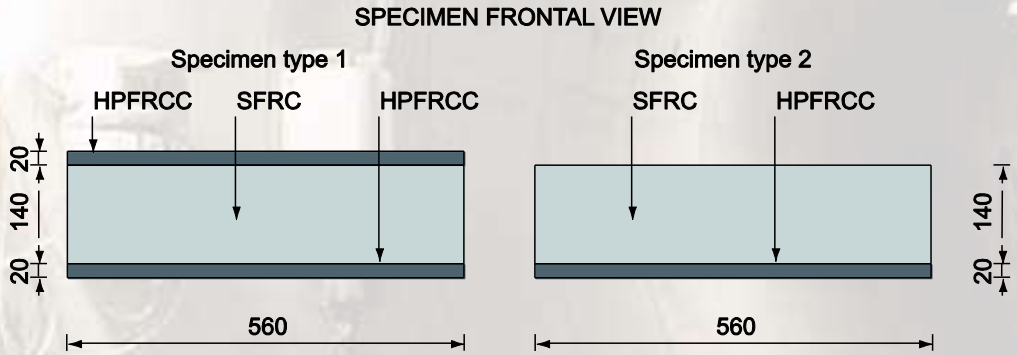


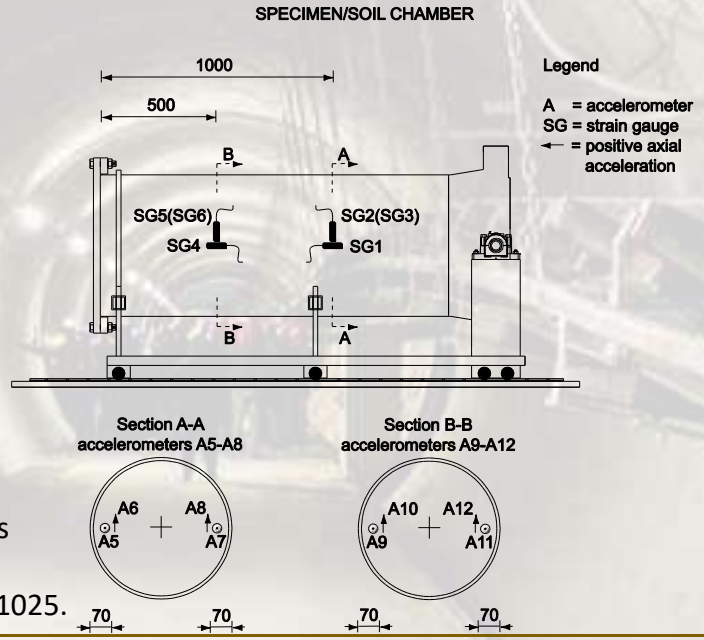
Colombo, M., Martinelli, P., Di Prisco, M., Layered high-performance concrete plates
interacting with granular soil under blast loads: An experimental investigation.
(2013) European Journal of Environmental and Civil Engineering, 17 (10), pp. 1002-1025.









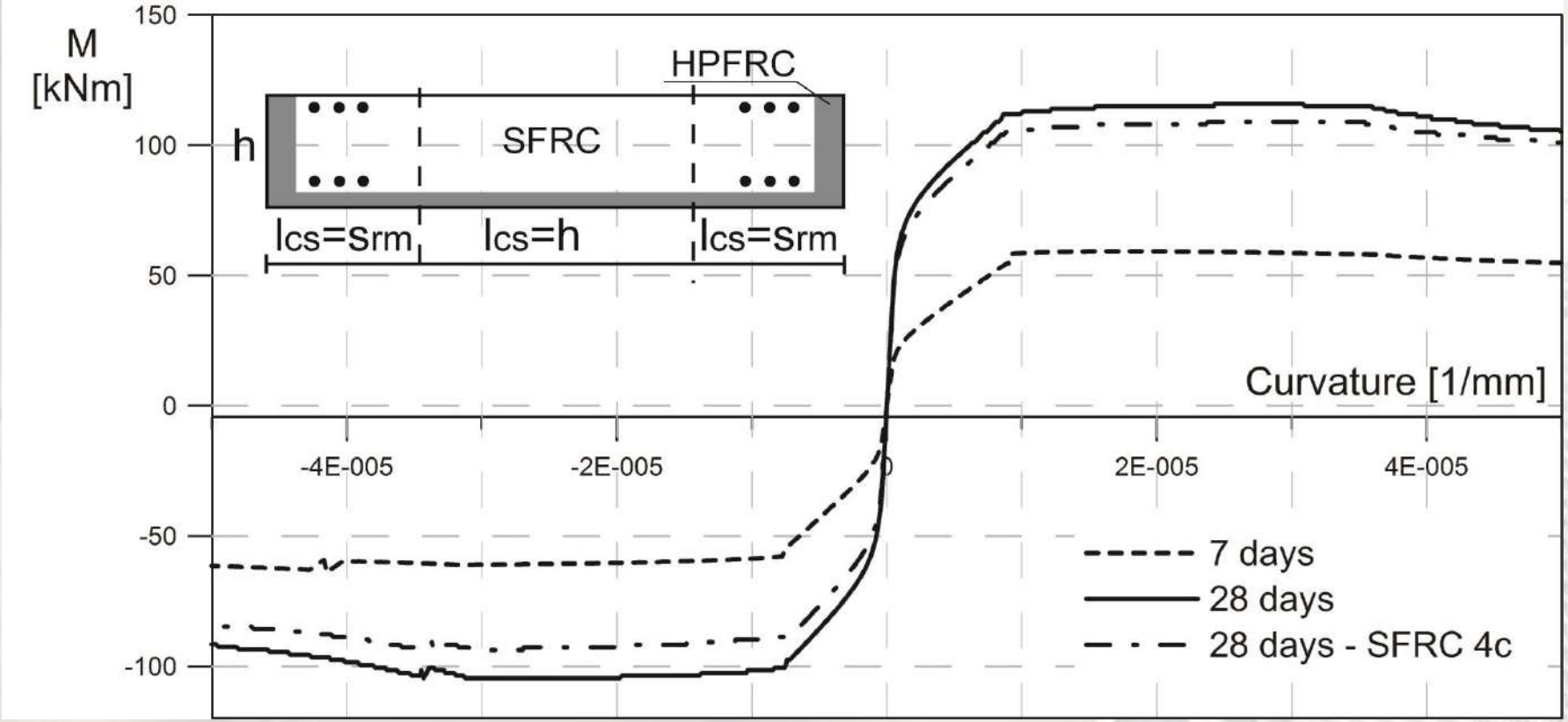


No failure
No delamination

Colombo, M., Martinelli, P., Di Prisco, M., Layered high-performance concrete plates interacting with granular soil under blast loads: An experimental investigation. (2013) European Journal of Environmental and Civil Engineering, 17 (10), pp. 1002-1025.

Colombo, M., Martinelli, P., di Prisco, M., A design approach for tunnels exposed to blast and fire (2015), Structural Concrete, 16 (2), pp. 262-272.

Colombo, M., Martinelli, P., di Prisco, M., Underground tunnels exposed to internal blast: Effect of the explosive source position (2016) Key Engineering Materials, 711, pp. 852-859.



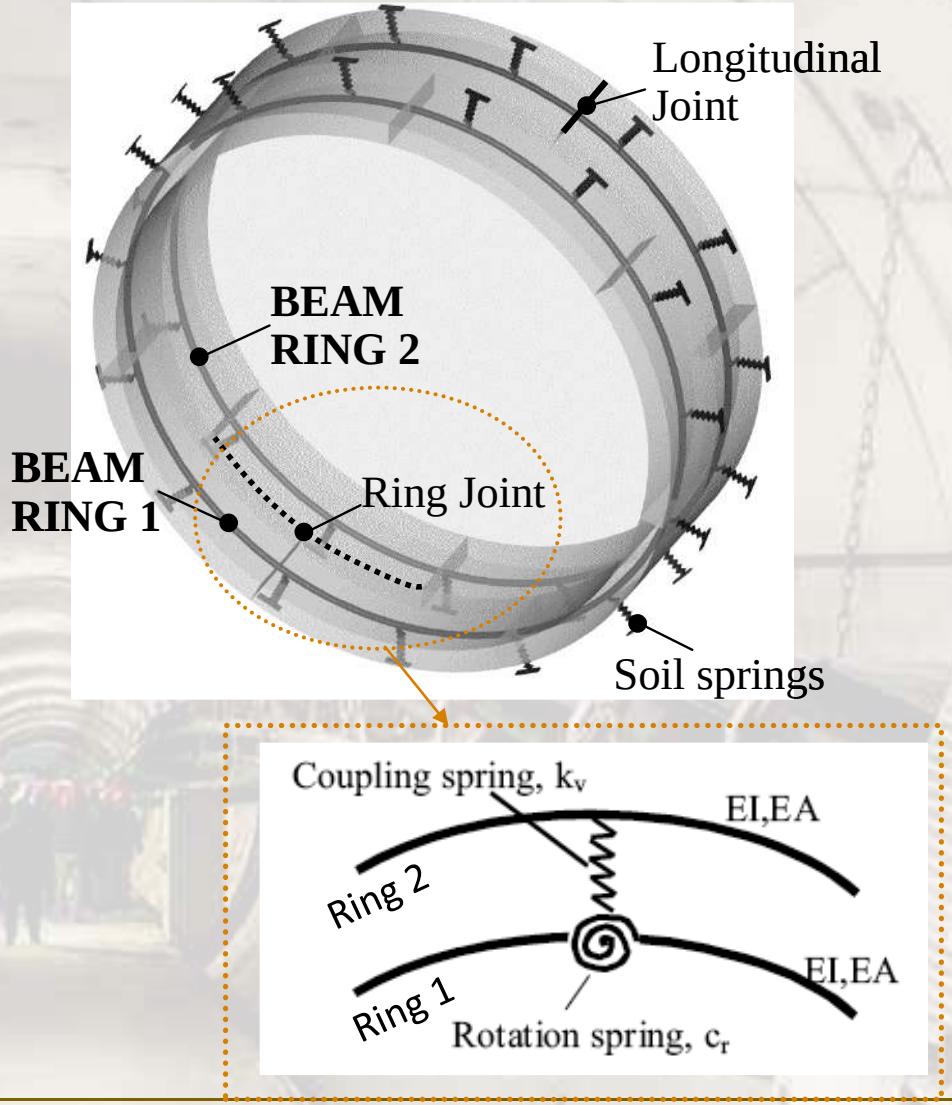
Structural design model

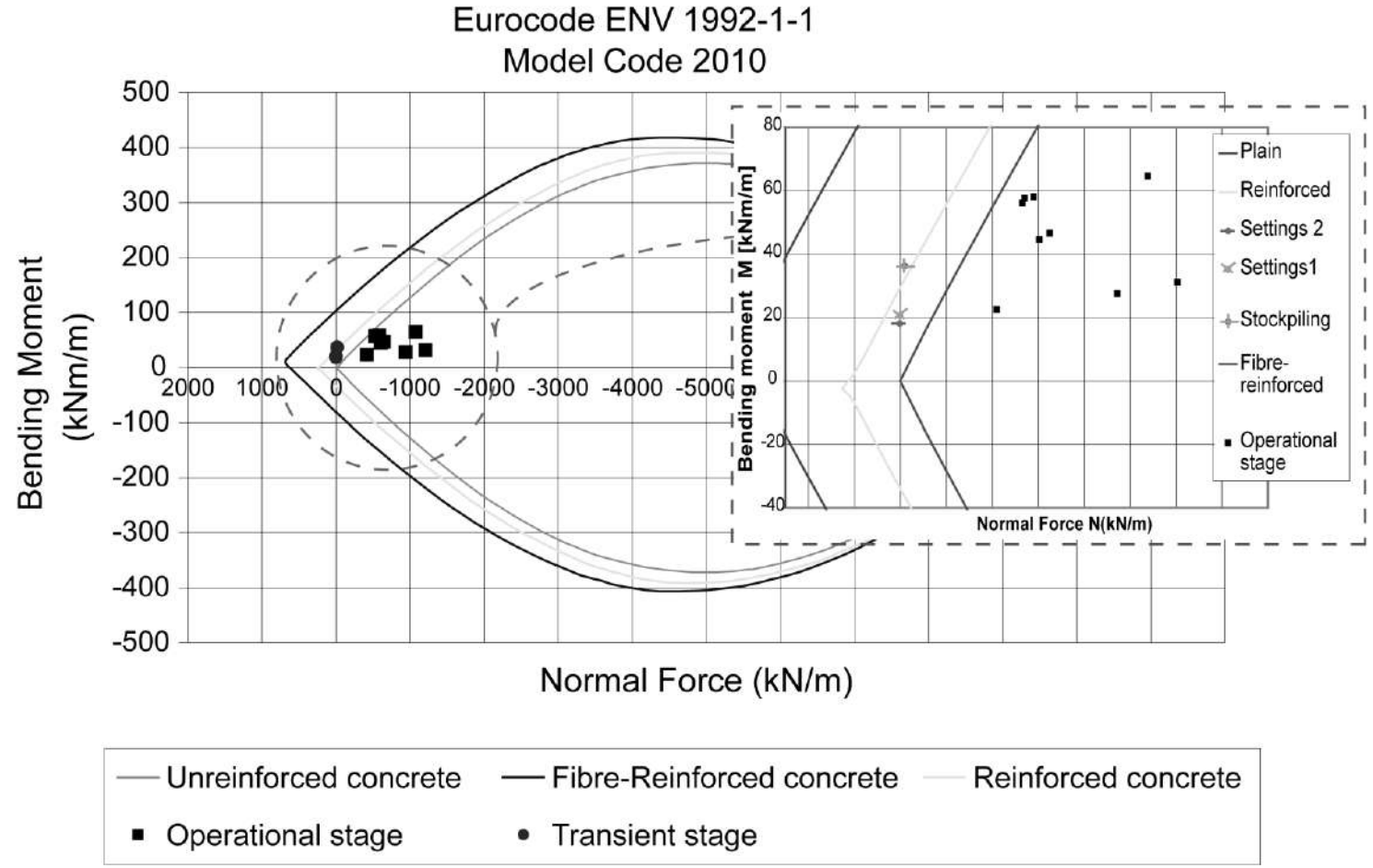
MODEL ASSUMPTIONS

- ✓ **Two half rings** with **masonry layout**
- ✓ **Hinged beam** to represent segment
- ✓ **Rotational spring** for longitudinal joints
- ✓ **Shear spring** for circumferential joint
- ✓ **Radial and tangential springs** for soil

MODEL PARAMETERS

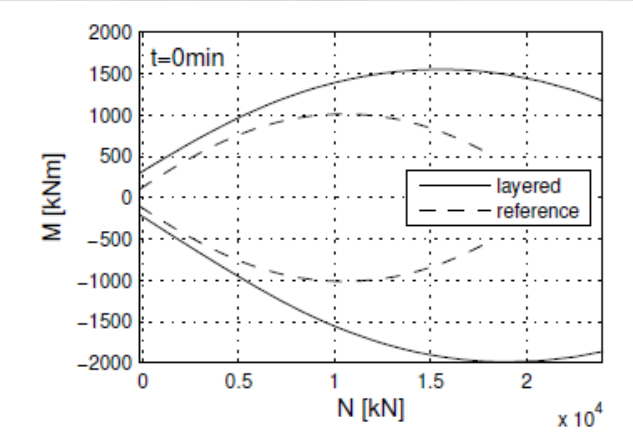
- ✓ N. of **element per segment**: 12
- ✓ N. of **element per k-segment**: 4
- ✓ **Length** of beam element: 0.2945 m
- ✓ **Total N**. of elements: 128

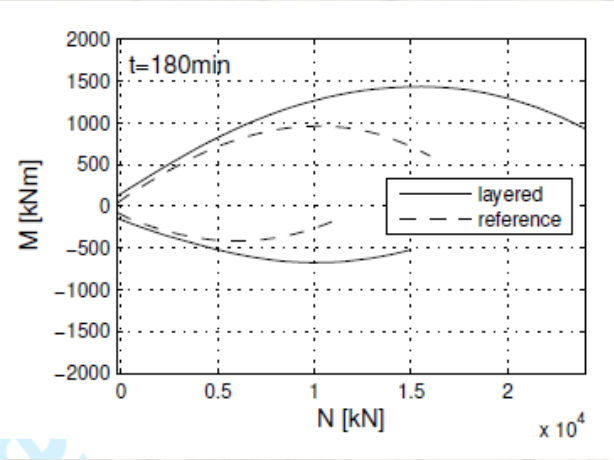


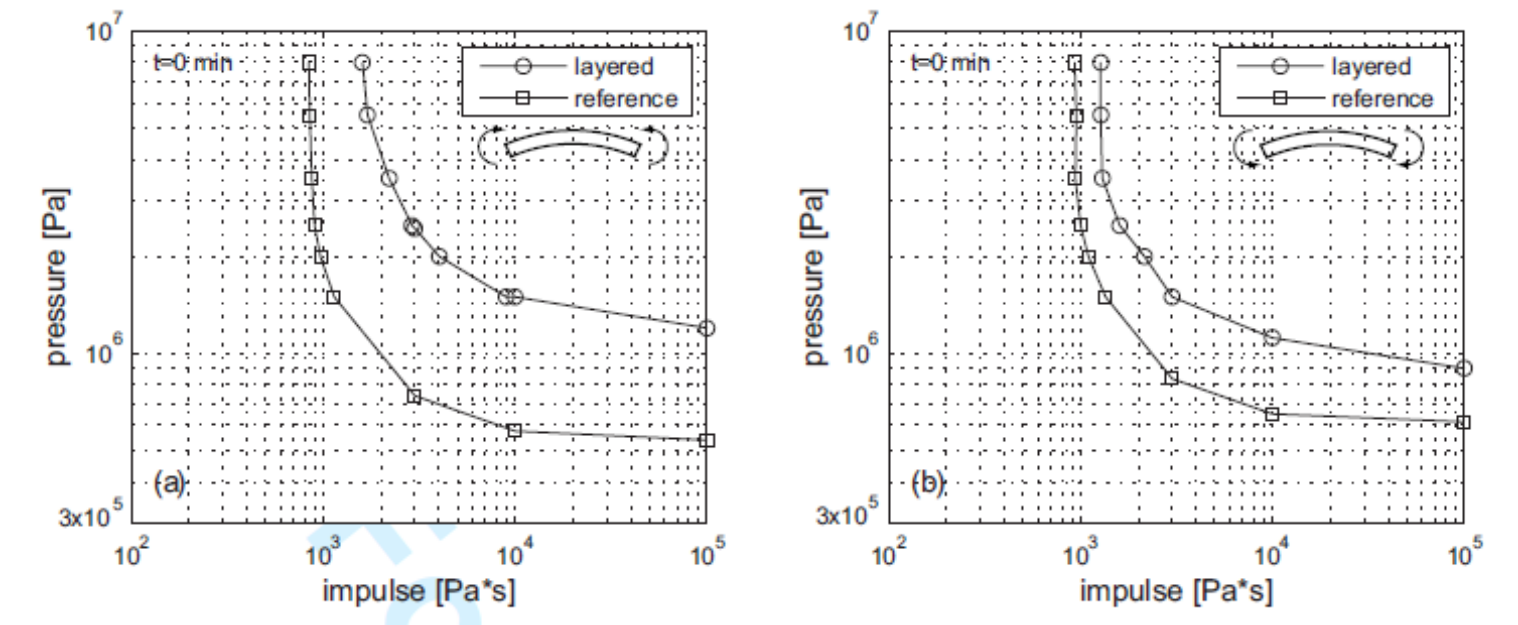

Eurocode ENV 1992-1-1
Model Code 2010
Bending Moment (kNm/m)
Normal Force (kN/m)
500
400
300
200
100
0
-100
-200
-300
-400
-500
2000
1000
0
-1000
-2000
-3000
-4000
-5000
Bending moment M [kNm/m]
Normal Force N(kN/m)
80
60
40
20
0
-20
-40
Plain
Reinforced
Settings 2
Settings1
Stockpiling
Fibre-reinforced
Operational stage
Unreinforced concrete
Fibre-Reinforced concrete
Reinforced concrete
Operational stage
Transient stage

Colombo, M., Martinelli, P., di Prisco, M., A design approach for tunnels exposed to blast and fire (2015), Structural Concrete, 16 (2), pp. 262-272.

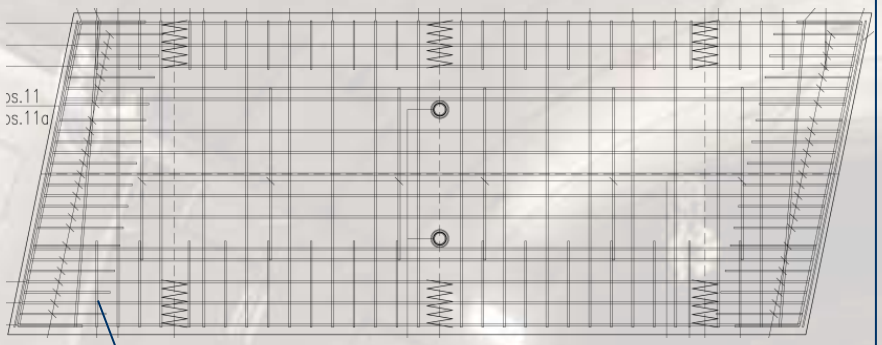
Colombo, M., Martinelli, P., di Prisco, M., Underground tunnels exposed to internal blast: Effect of the explosive source position (2016) Key Engineering Materials, 711, pp. 852-859.



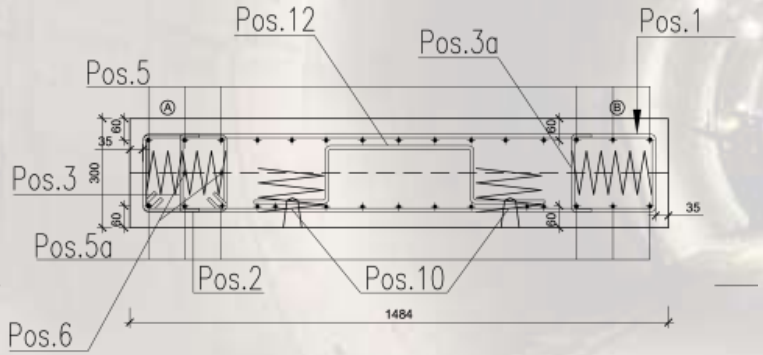




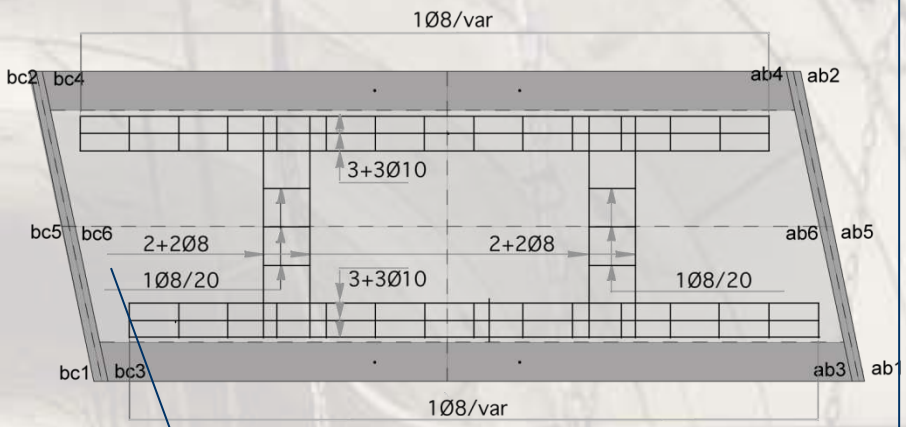
Traditional Solution



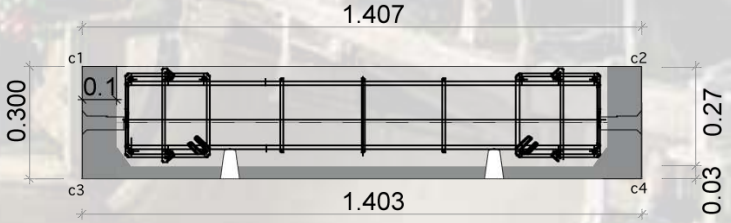
Steel Reinforcement: 110 kg/m³



Innovative Solution



Steel Reinforcement: 35 kg/m³



MATERIAL	UNIT COST	VOLUME	TOTAL
CONCRETE C40/50	100 €/m^3	1.34 m^3	134 €
STEEL REINFORCEMENT	0.9 €/kg	120 kg/ m^3	145 €
			279 €
MANUFACTURE	25 %	-	70 €

MATERIAL	UNIT COST	VOLUME	TOTAL
HPFRCC (borders)	430 €/m^3	0.29 m^3	125 €
SFRC	150 €/m^3	1.05 m^3	158 €
TRM	3 €/m^2	4.48 m^2	13 €
STEEL REINFORCEMENT	0.9 €/kg	35 kg/m^3	43 €
			339 €
MANUFACTURE	15 %	-	50 €

TRADITIONAL SOLUTION **350 €**

Segment cost

+ 17% TOTAL COST

- 71% steel reinforcement

- 10% of trad. material cost for manufacture

INNOVATIVE SOLUTION **390 €**

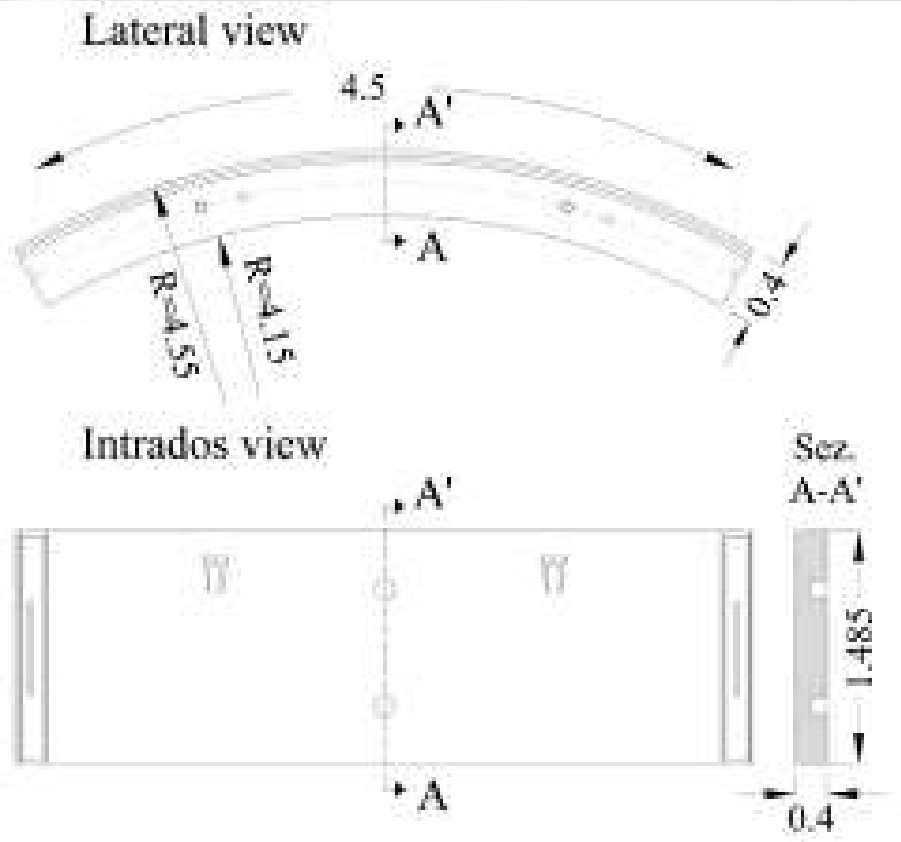
Three possible uses of GFRP bars

A. Meda, M. Moja, E.M. Pizzarotti, G. Vago, GFRP reinforcement for segmental linings of mechanized tunnels, ICC 2018

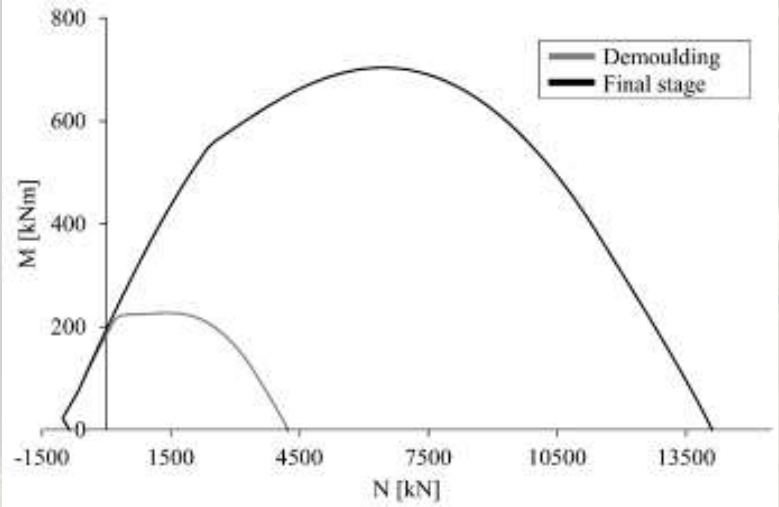
$$f_f = E_f \varepsilon$$

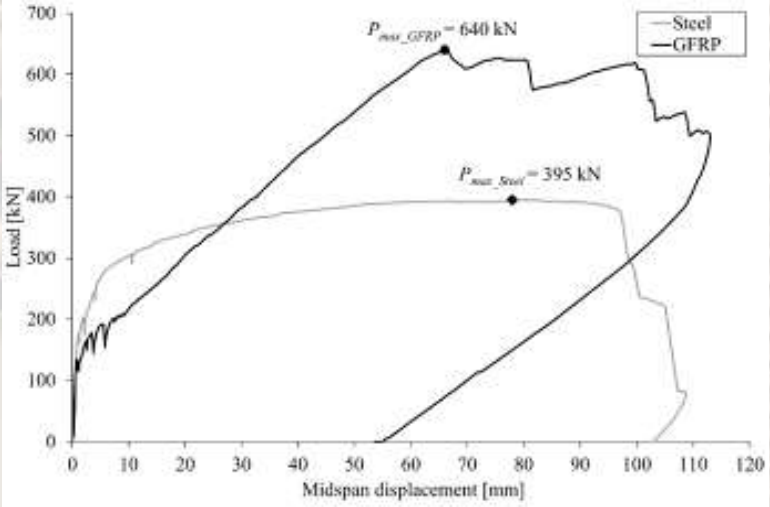
$$f_{fd} = \eta_a \eta_l \frac{f_{fk}}{\gamma_f} \qquad \varepsilon_{fd} = 0.9\eta_a \frac{\varepsilon_{fk}}{\gamma_f}$$

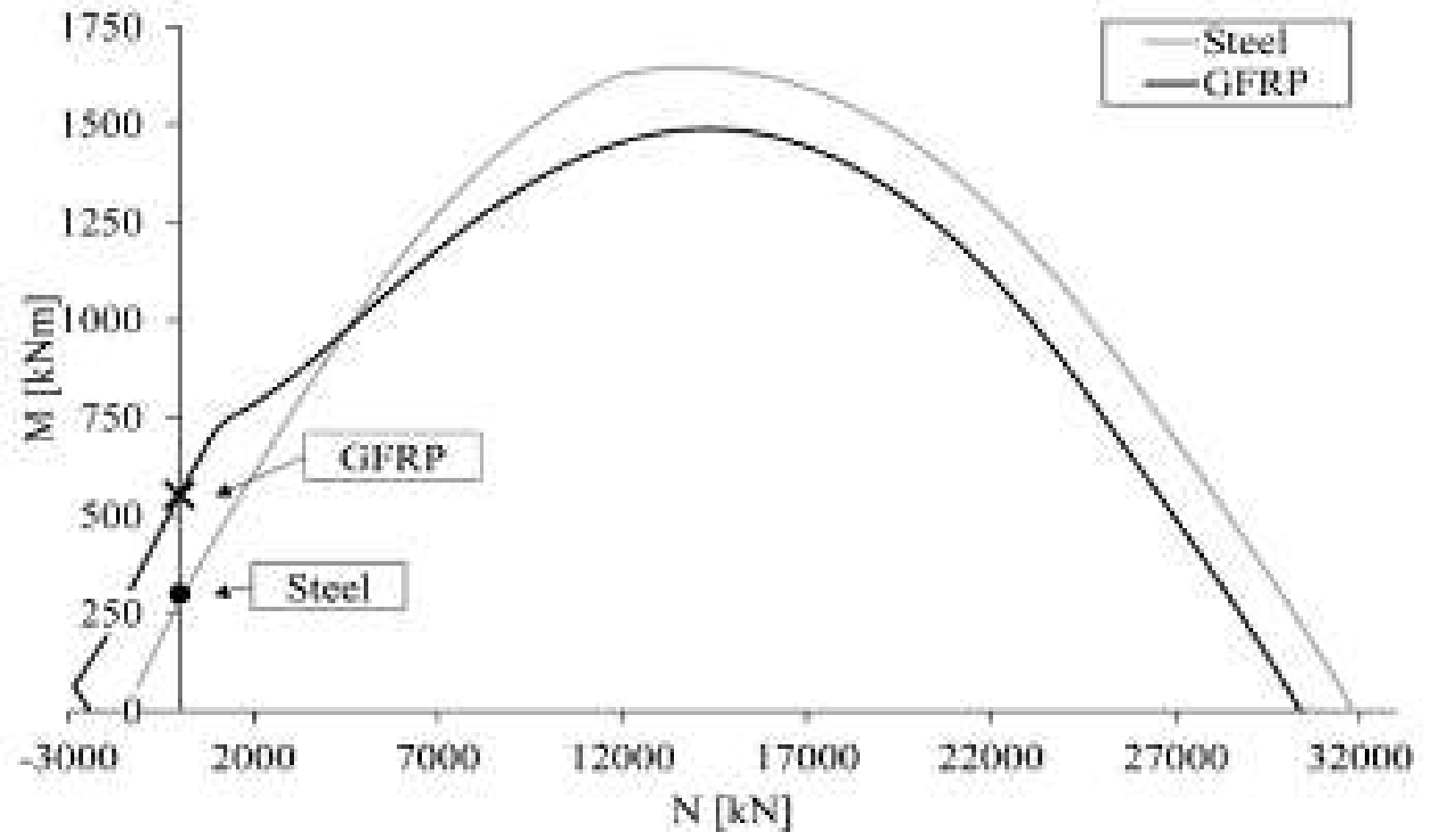
η_a, η_l e γ_f are the environmental reduction factors (η_a=0.7 for wet environment and η_a=0.8 for dry environment), the long-term loading coefficient (η_l=1 for provisional structures) and the partial safety factor for GFRP (γ_f = 1.5). Furthermore, no resistance of GFRP rebar in compression is considered.

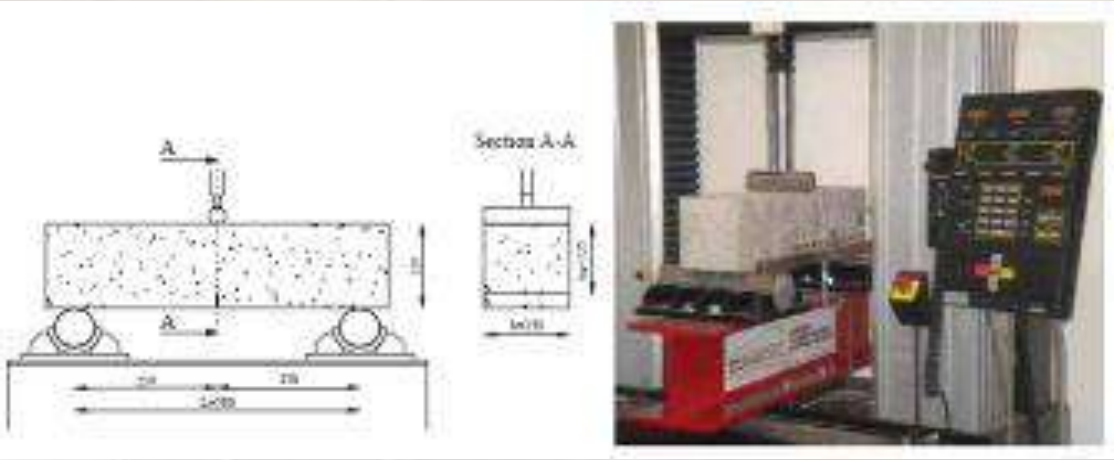


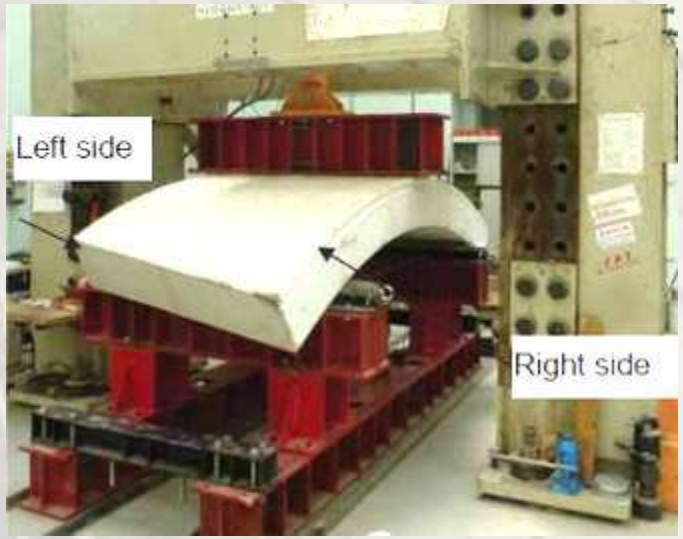
Concrete cylindrical strength at demoulding	$f_{ck,\,6h}$	12 MPa
Concrete cylindrical strength final stage	$f_{ck,\,28d}$	40 MPa
Concrete partial safety coefficient	γ_c	1.5
GFRP strength	f_{fk}	755 MPa
Young's modulus	E_f	40 GPA
Ultimate deformation	ε_{fk}	0.019
Environmental reduction factor	η_a	0.7
Long-term loading coefficient	η_l	1
Concrete partial safety coefficient	γ_f	1.5

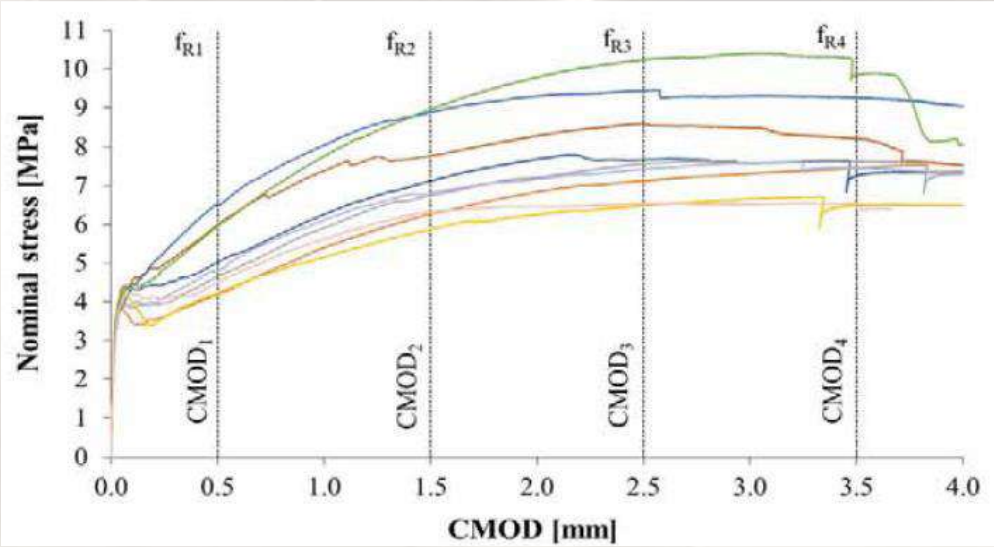


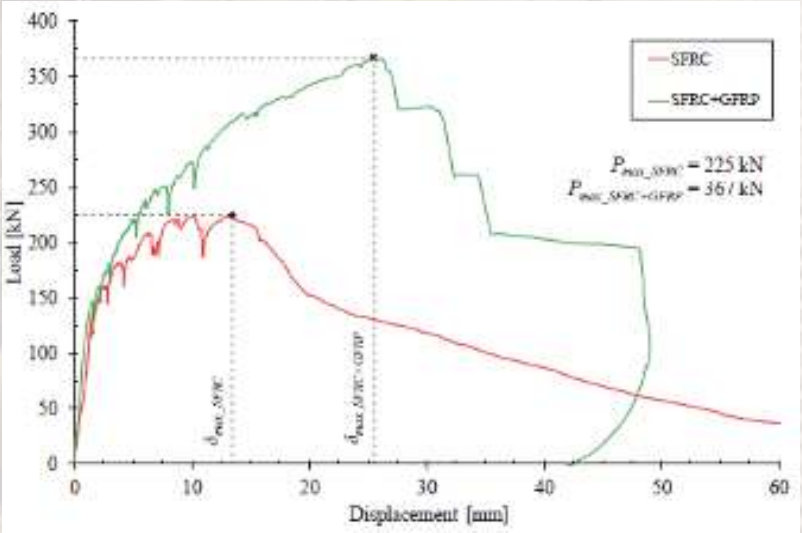


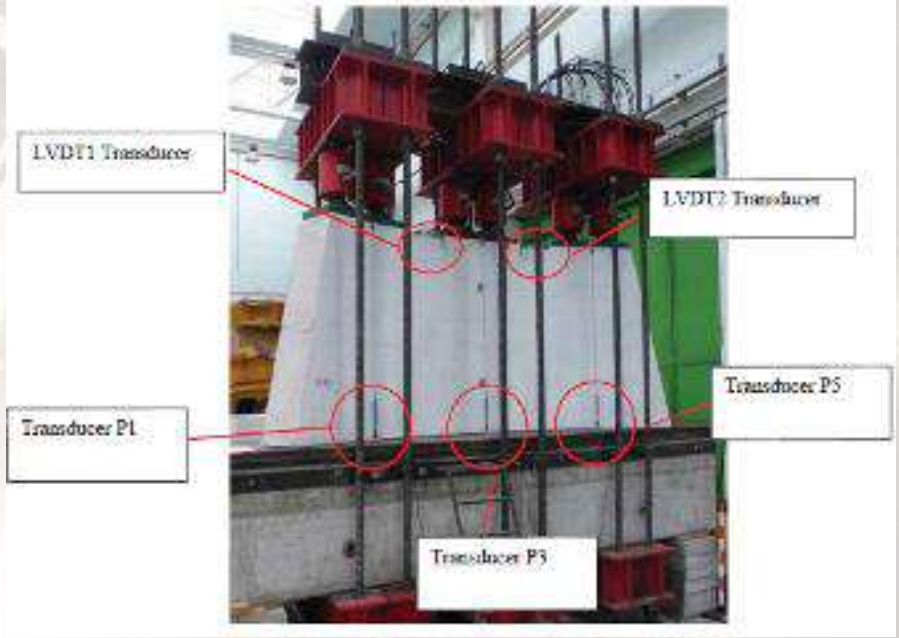

Steel
GFRP
GFRP
Steel
M [kNm]
N [kN]
1750
1500
1250
1000
750
500
250
0
-3000
2000
7000
12000
17000
22000
27000
32000


A
A
Section A-A


Left side
Right side


Nominal stress [MPa]
CMOD [mm]
f_{R1}
f_{R2}
f_{R3}
f_{R4}
$CMOD_1$
$CMOD_2$
$CMOD_3$
$CMOD_4$

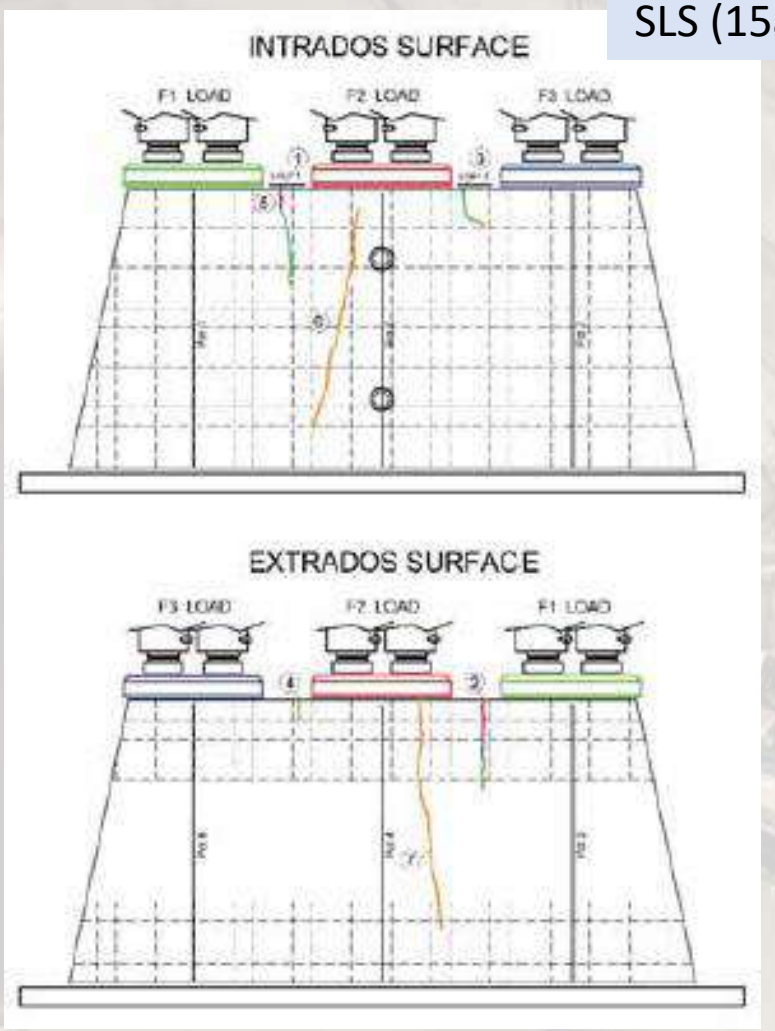

Load [kN]
Displacement [mm]
SFRC
SFRC+GFRP
P_{max_SFRC} = 225 kN
$P_{max_SFRC+GFRP}$ = 367 kN



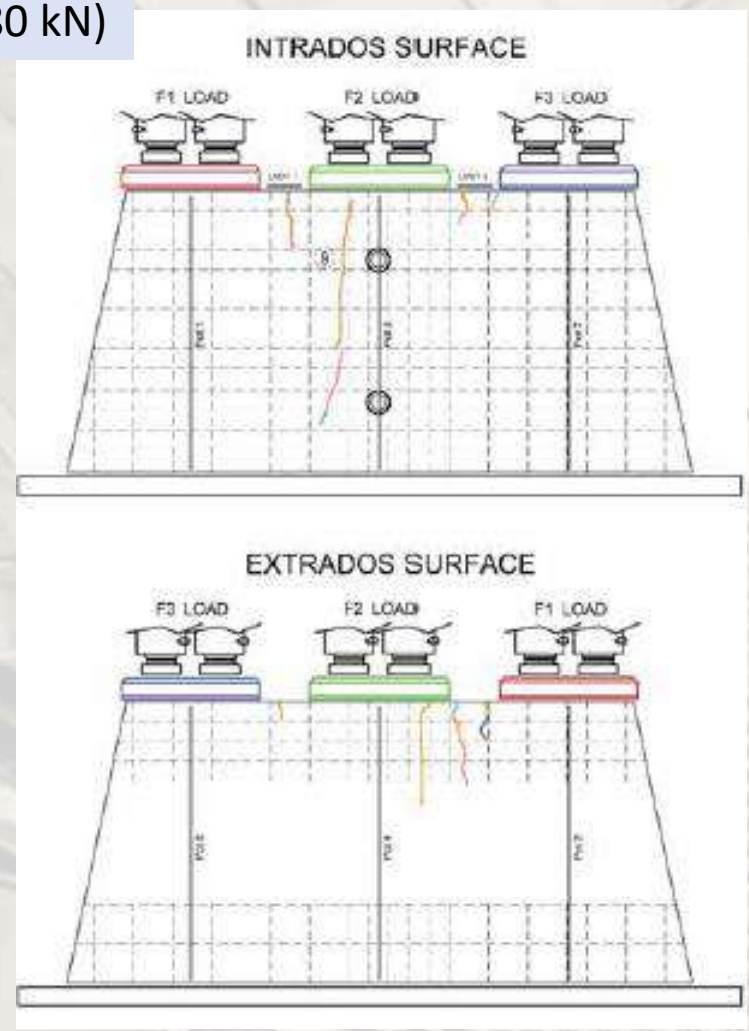
	Load [kN]			Unload [kN]
	1st crack	Service load	Unblocking thrust*	
Reinforcement	1250	1580	2670	0
	Maximum crack width [mm]			
SFRC	0.05	0.10	0.40	0.15
SFRC+GFRP	<0.05	0.05	0.25	0.10

Note: * For metro tunnel, TBM pushing capacity coincides with unblocking thrust

SLS (1580 kN)

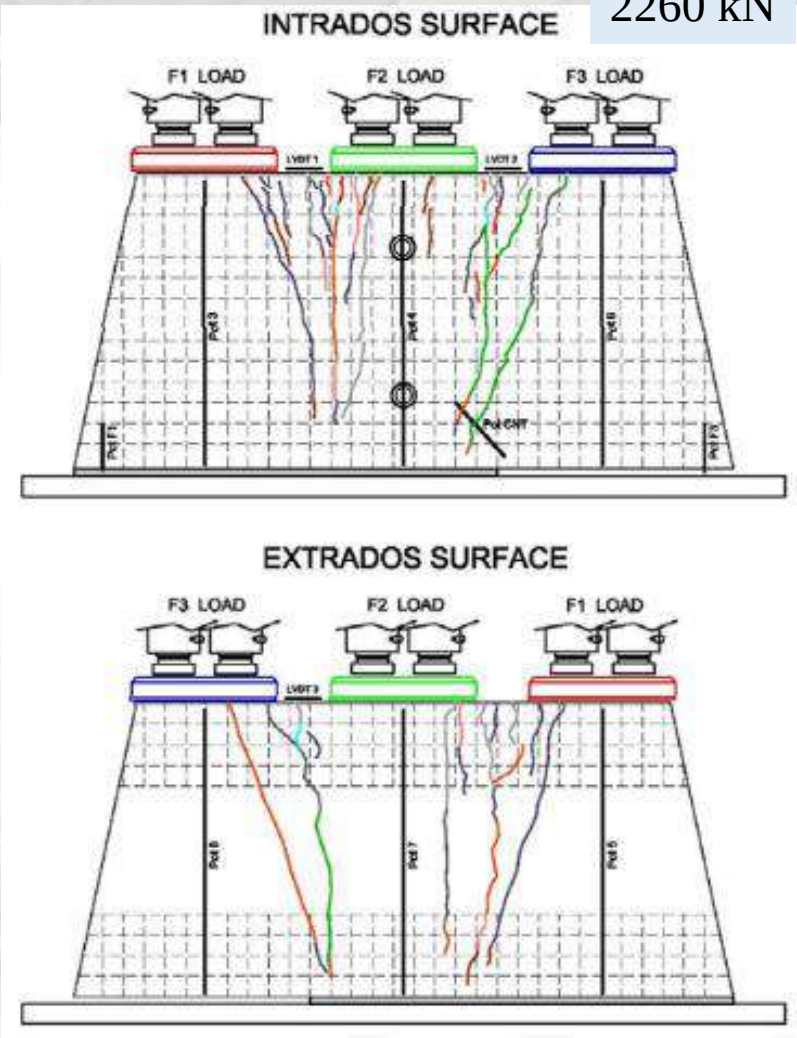


SFRC only

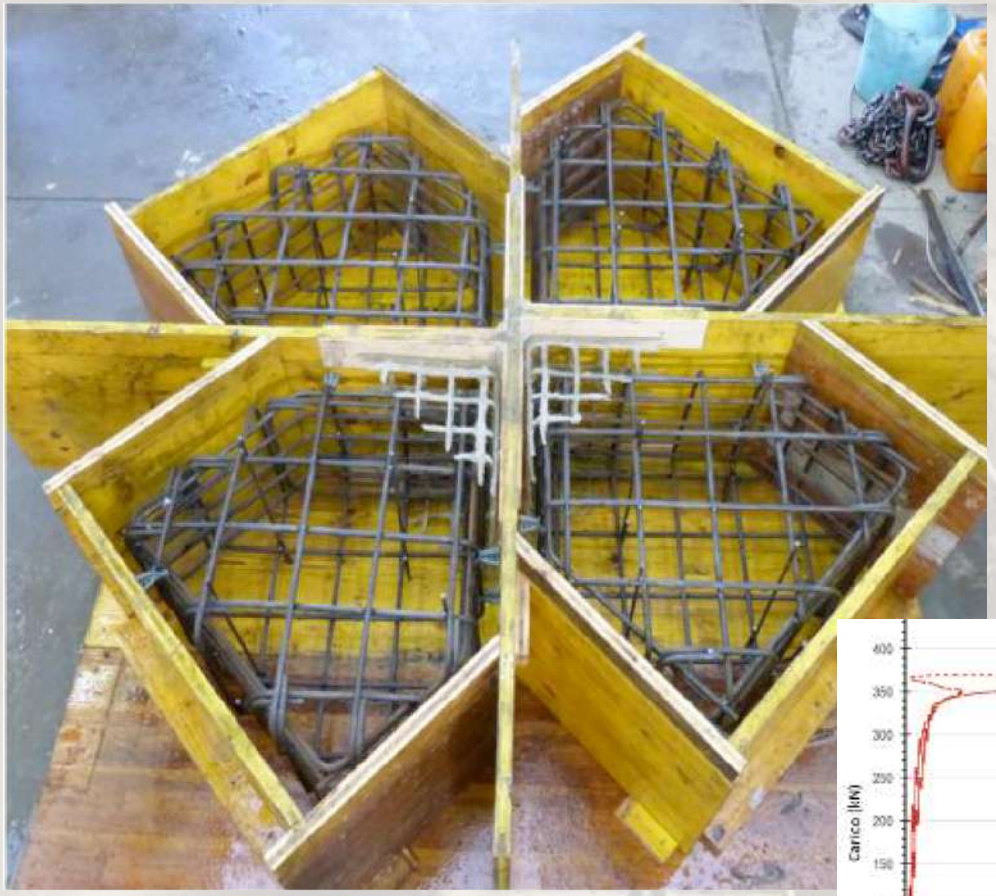


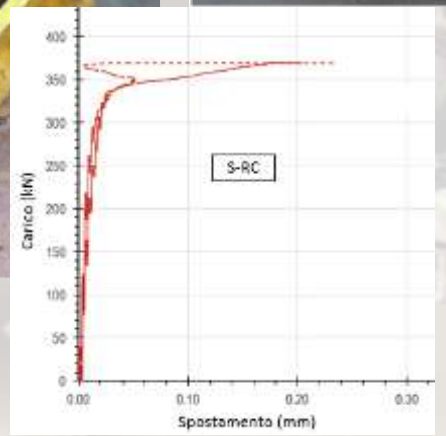
SFRC+GFRP

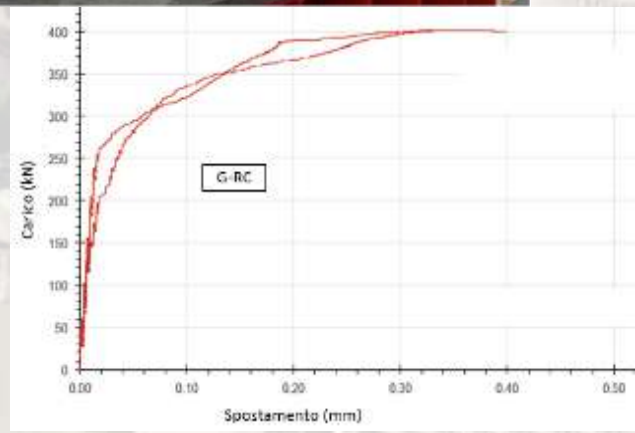
2260 kN



from 225 kN up to 367 kN (63%) and reduces the crack width of more than 50%.




S-RC
Carico (kN)
Spostamento (mm)
0
50
100
150
200
250
300
350
400
0.00
0.10
0.20
0.30


G-RC
Carico (kN)
Spostamento (mm)
0
50
100
150
200
250
300
350
400
0.00
0.10
0.20
0.30
0.40
0.50

Linea Guida per la identificazione, la qualificazione ed il controllo di accettazione di compositi fibrorinforzati a matrice polimerica (FRP) da utilizzarsi per il consolidamento strutturale di costruzioni esistenti

CNR – Commissione di studio per la predisposizione e l'analisi di norme tecniche relative alle costruzioni

CONSIGLIO NAZIONALE DELLE RICERCHE

COMMISSIONE DI STUDIO PER LA PREDISPOSIZIONE E L'ANALISI DI NORME TECNICHE RELATIVE ALLE COSTRUZIONI

EN 13706-1/-2/-3 2002

Istruzioni
per la Progettazione, l'Esecuzione ed il Controllo
di Strutture
di Calcestruzzo Armato
con Barre di Materiale Composito Fibrorinforzato

+

CNR-DT 203/2006

ROMA – CNR 18 Giugno 2007

CNR – Commissione di Studio per la Predisposizione e l'Analisi di Norme Tecniche relative alle costruzioni

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di Interventi di Consolidamento Statico
mediante l'utilizzo di
Compositi Fibrorinforzati a Matrice Inorganica

CNR-DT 215/2018

ROMA – CNR 06.02.2019

Consiglio Superiore dei Lavori Pubblici
Servizio Tecnico Centrale

Linea guida per l'identificazione, la qualificazione, la certificazione di valutazione tecnica ed il controllo di accettazione dei calcestruzzi fibrorinforzati FRC (Fiber Reinforced Concrete)

Aggiornamento Novembre 2021

Consiglio Superiore dei Lavori Pubblici
Prima Sezione

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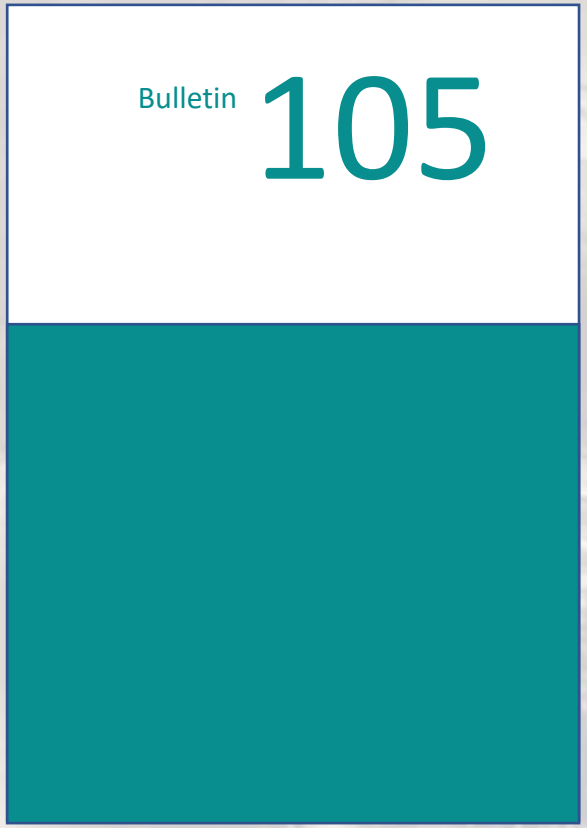
Oggetto: Affare 56_2022 - Revisione da parte del STC delle "Linee guida per la progettazione, messa in opera, controllo e collaudo di elementi strutturali in calcestruzzo fibrorinforzato con fibre di acciaio o polimeriche". **Nomina Commissione relatrice.**

Per poter riferire in una prossima adunanza di Prima Sezione, le SS.LL. sono nominate quali componenti della Commissione relatrice per predisporre la proposta di parere dell'Affare in oggetto. Con funzioni di supporto tecnico-specialistico e di assistenza alla Commissione stessa è indicato il nominativo dell'ing. Claudio GILBO (Sogesid SpA).



Thank you for your attention!