POLITECNICO DI MILANO

SAIE, Bologna

Precast Concrete Technology (PCT - ITALY)

SESSION B - 19 ottobre 2016

FRC Precast Structures

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and Environmental Engineering
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Outline

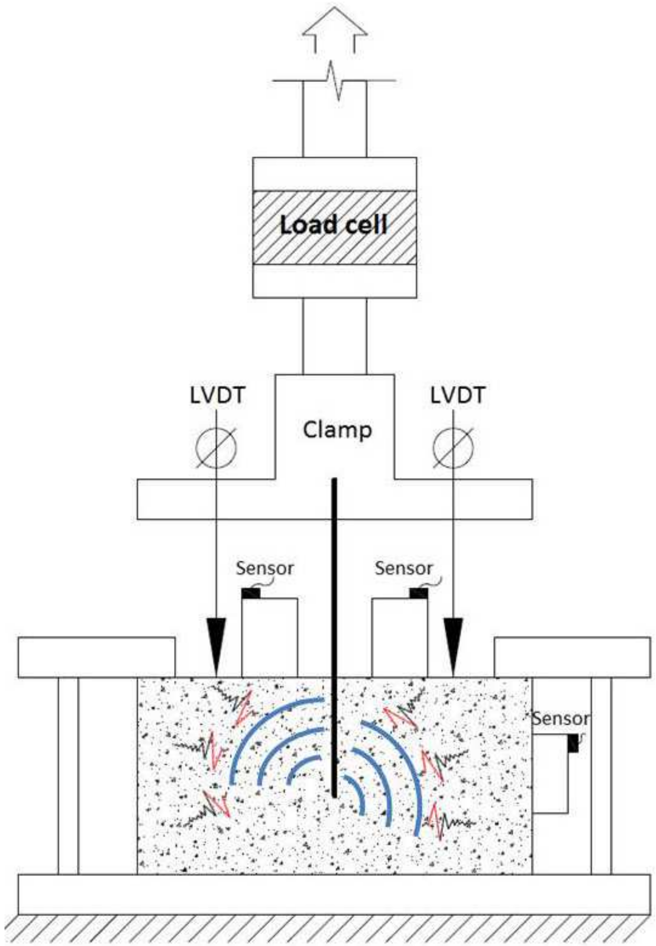
- comportamento strutturale del fibrorinforzato
- la classificazione
- esempi significativi di applicazioni strutturali in presenza di interazione suolo-struttura
- elementi lineari e strutture in parete sottile
- realizzazioni in HPFRC

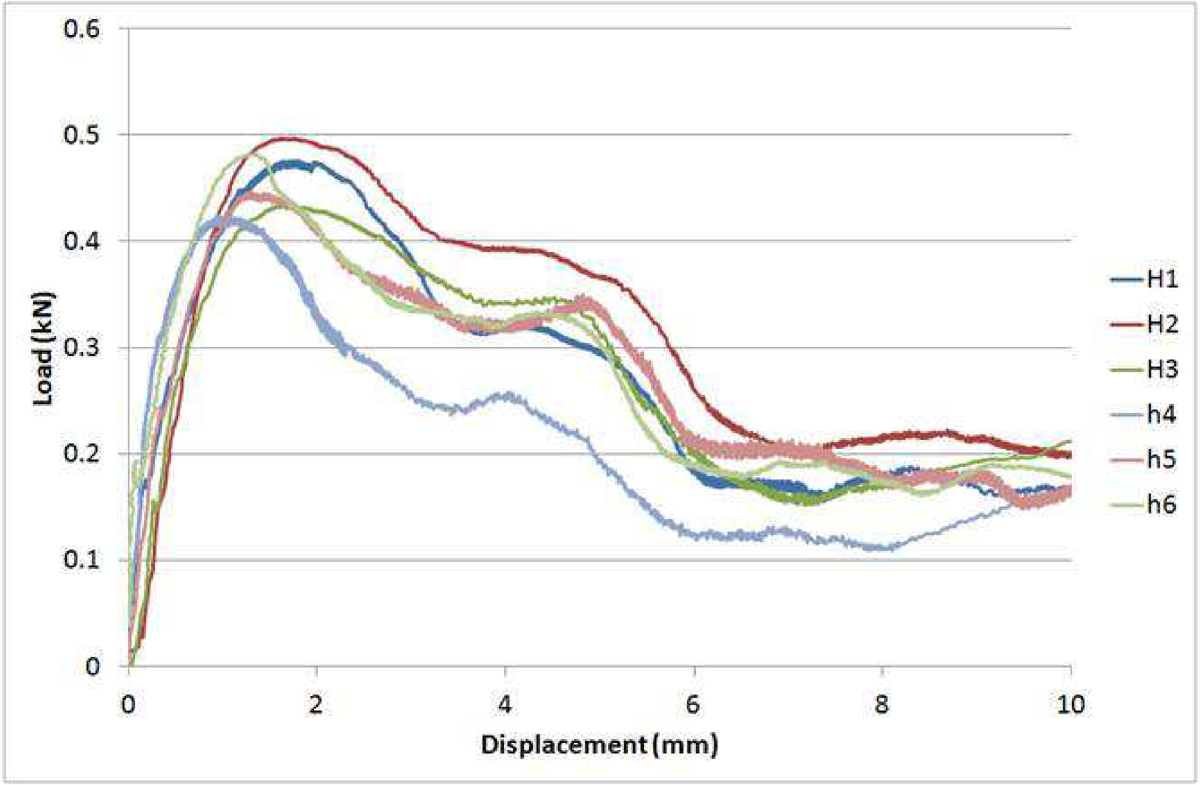
Hybrid concrete: a large number of variables!

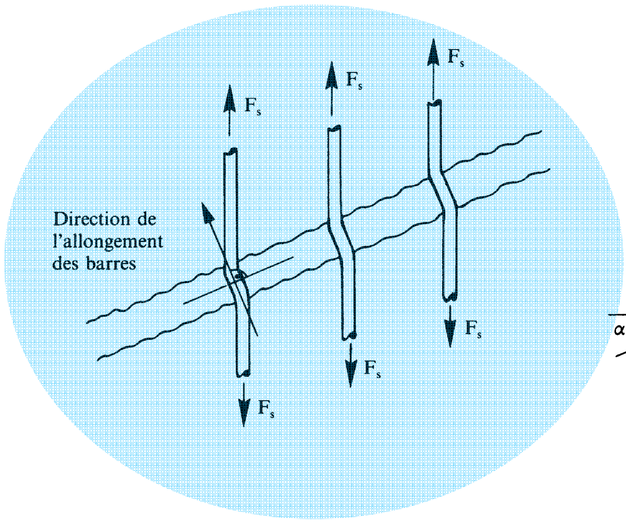


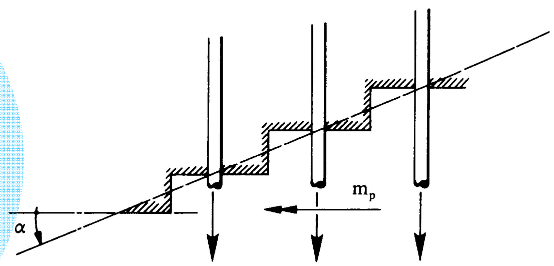


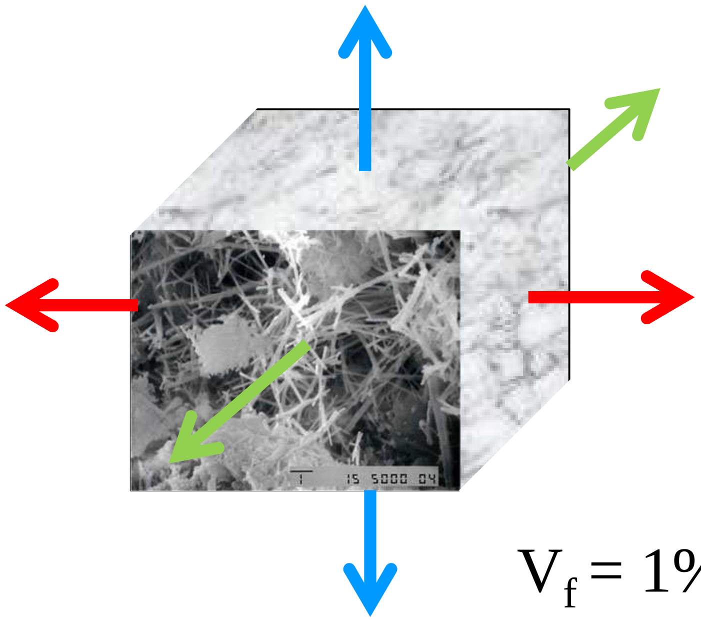

PULL-OUT as basic resistant mechanism

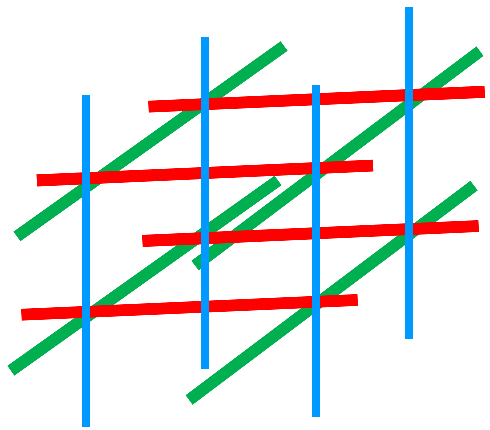










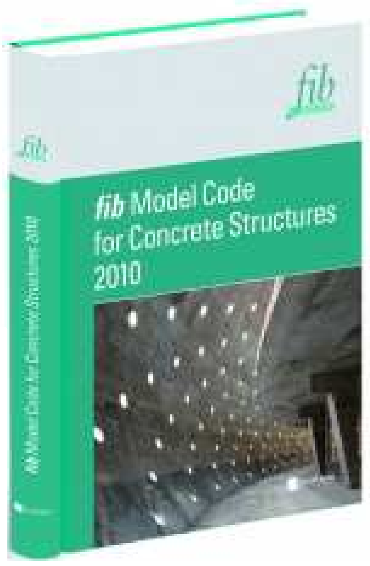


$V_f = 1\%$ $\cong$ $V_f = 3\%$

Model Code 2010

5.6 Fibre Reinforced Concrete

5.6.1 Introduction
5.6.2 Material properties
5.6.2.1 Behaviour in compression
5.6.2.2. Behaviour in tension
5.6.3 Classification
5.6.4 Constitutive laws
5.6.5 Stress-strain relationship for SLS
5.6.6. Partial safety factors
5.6.7 Orientation factor

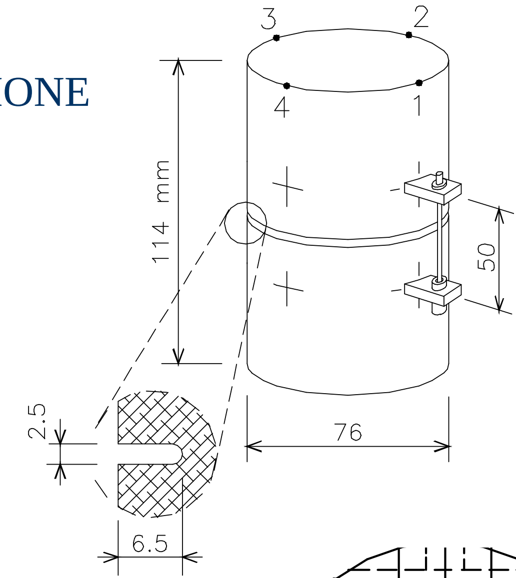


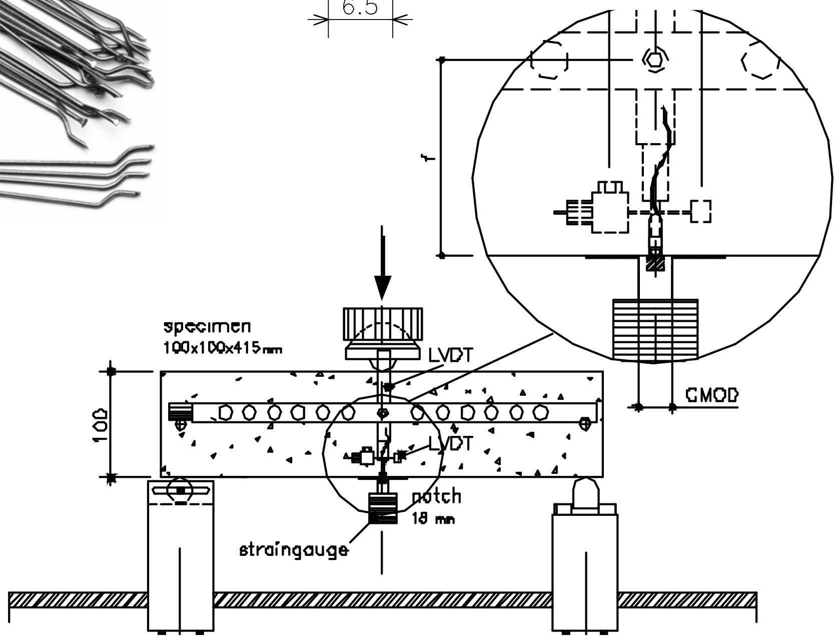
7.7 FRC structures

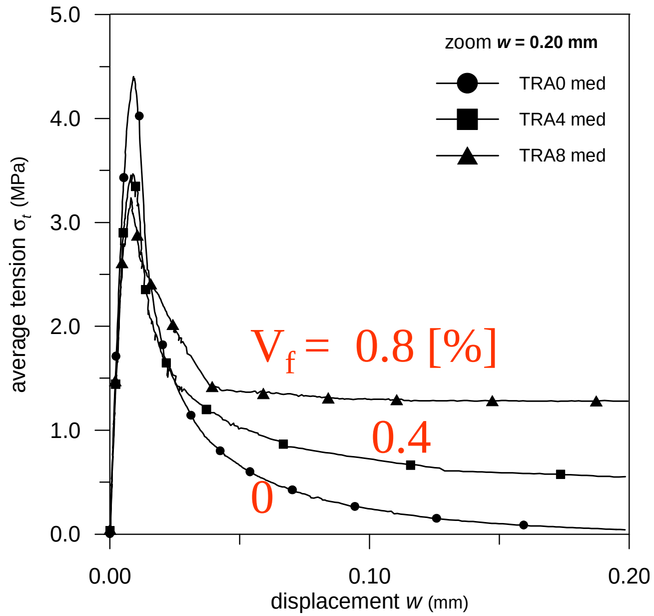
7.7.1 Classification
7.7.2 Design principles
7.7.3 Verification of safety (ULS)
7.7.3.1 Bending and/or axial compression in linear members
7.7.3.2 Shear in beams
7.7.3.2.1 Beams without longitudinal and shear reinforcement
7.7.3.2.2 Beams without shear reinforcement
7.7.3.2.3 Beams with shear and longitudinal reinforcement
7.7.3.2.4 Minimum shear reinforcement
7.7.3.3 Torsion in beams
7.7.3.3.1 Beams without longitudinal and transverse reinforcement
7.7.3.3.2 Beams with longitudinal and transverse reinforcement
7.7.3.4 Walls
7.7.3.4.1. Walls without conventional reinforcement
7.7.3.4.2. Walls with conventional reinforcement
7.7.3.5 Slabs
7.7.3.5.1 Members without reinforcement
7.7.3.5.2 Members with reinforcement
7.7.3.5.3. Punching
7.7.3.5.4. Shear in Slabs with longitudinal reinforcement
7.7.4 Serviceability Limit State (SLS)
7.7.4.1 Crack width in members with conventional
7.7.4.2 Minimum reinforcement for crack control

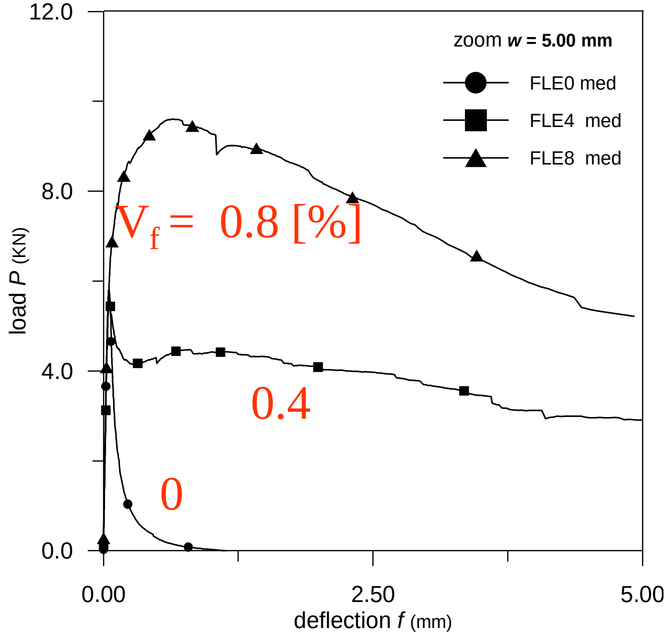
Peculiarità del materiale

COMPORTAMENTO SOFTENING IN TRAZIONE



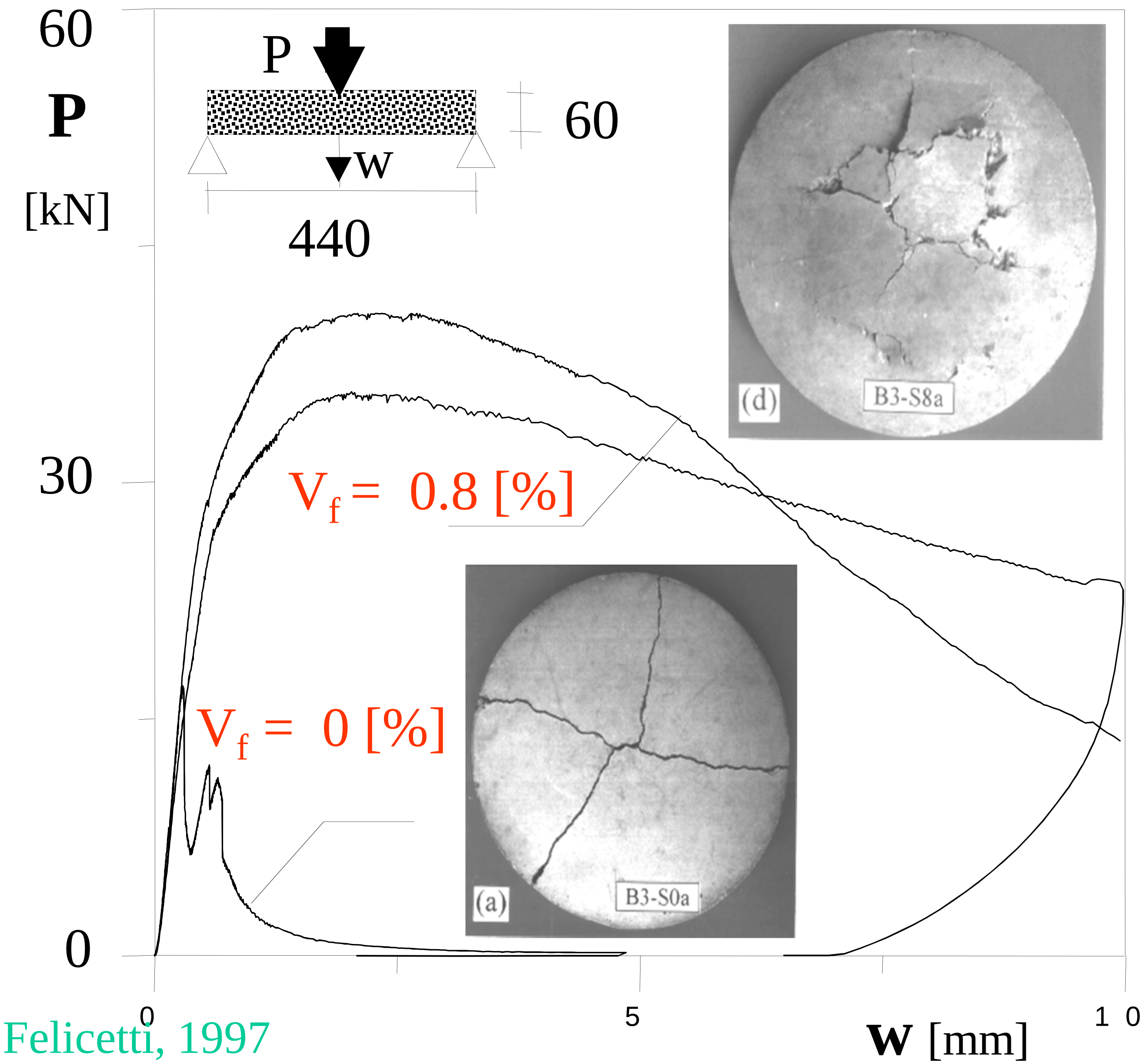






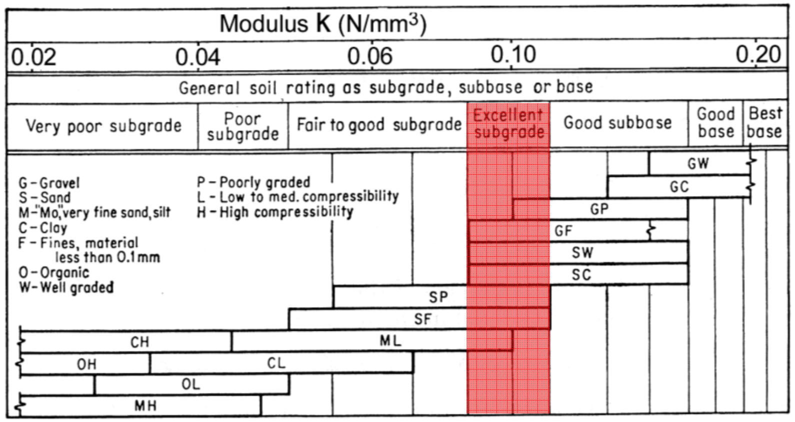
by di Prisco & Felicetti, 1997

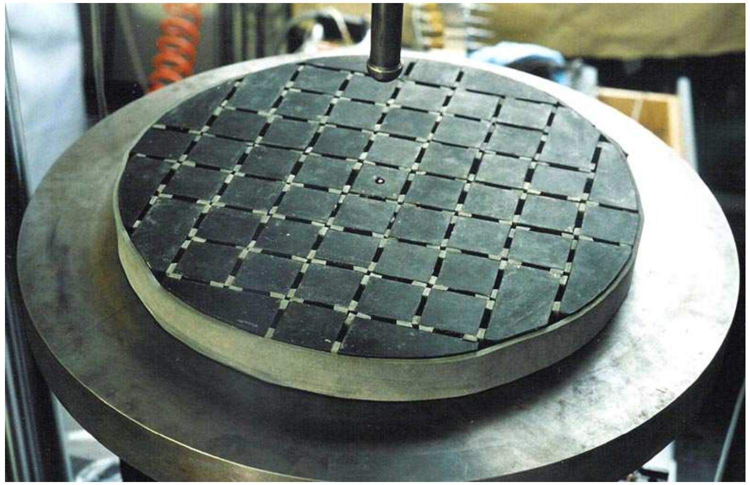
Comportamento della struttura iperstatica

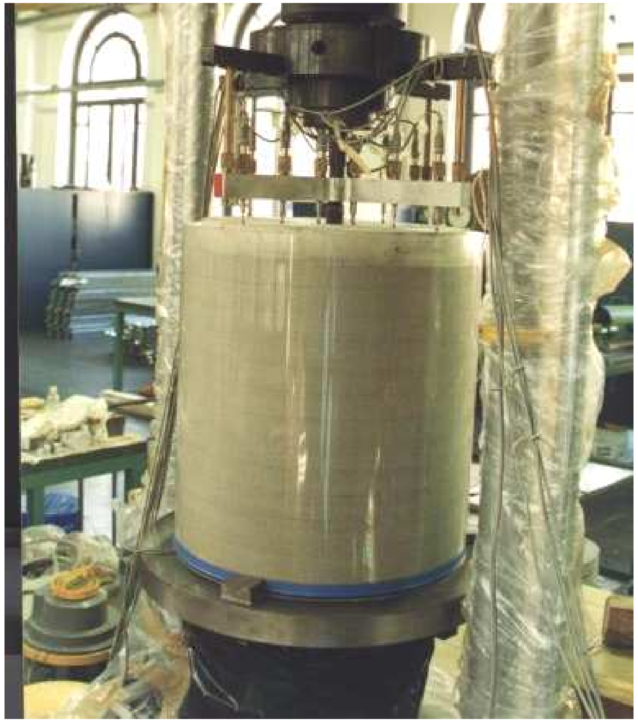


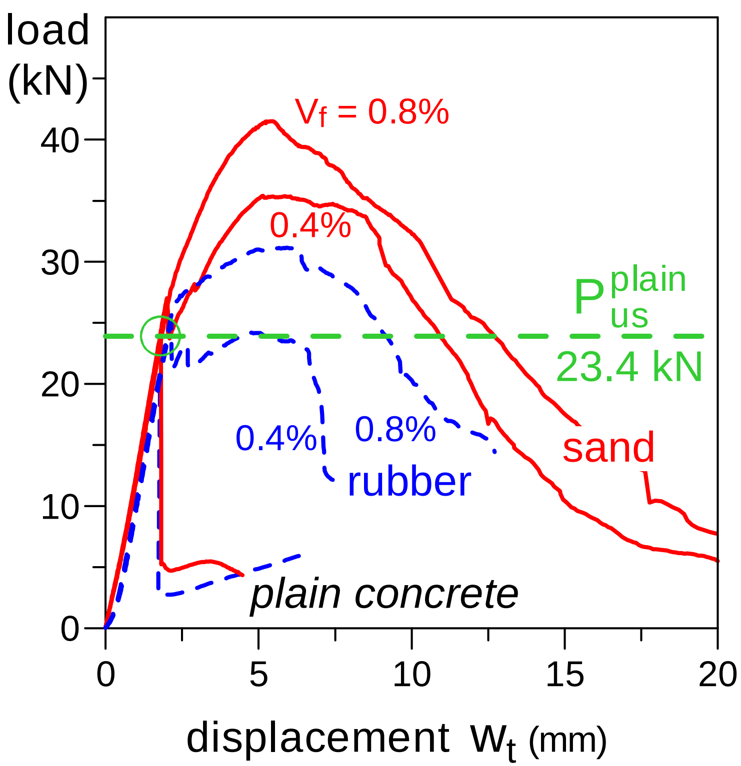
by di Prisco & Felicetti, 1997

Comportamento della struttura iperstatica



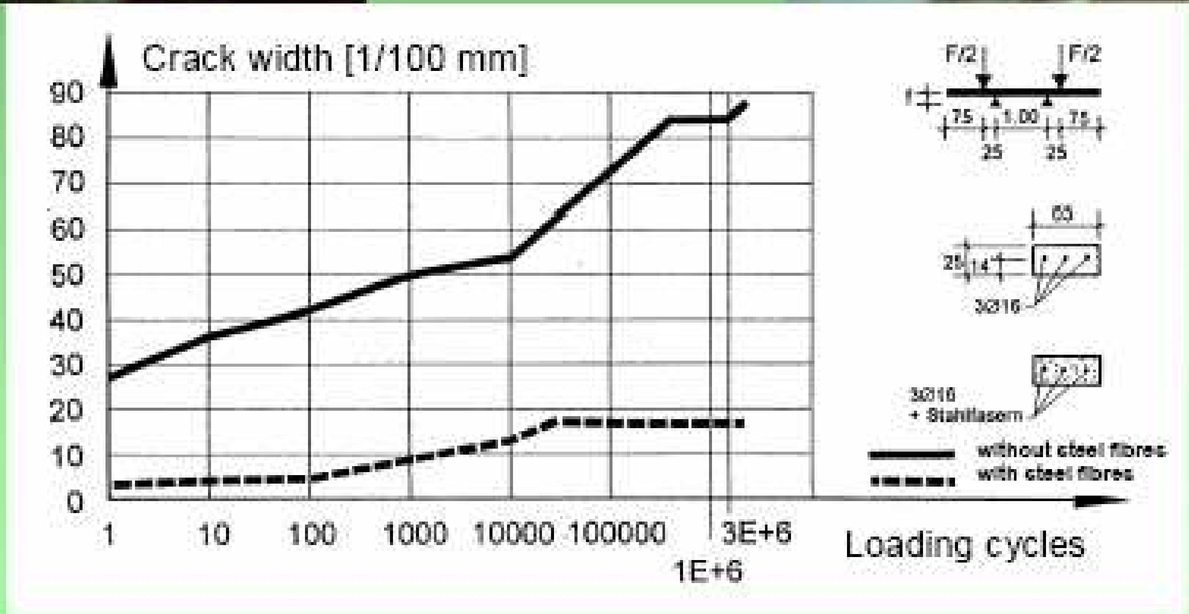






by di Prisco & Felicetti, 2004

Transrapid guideway

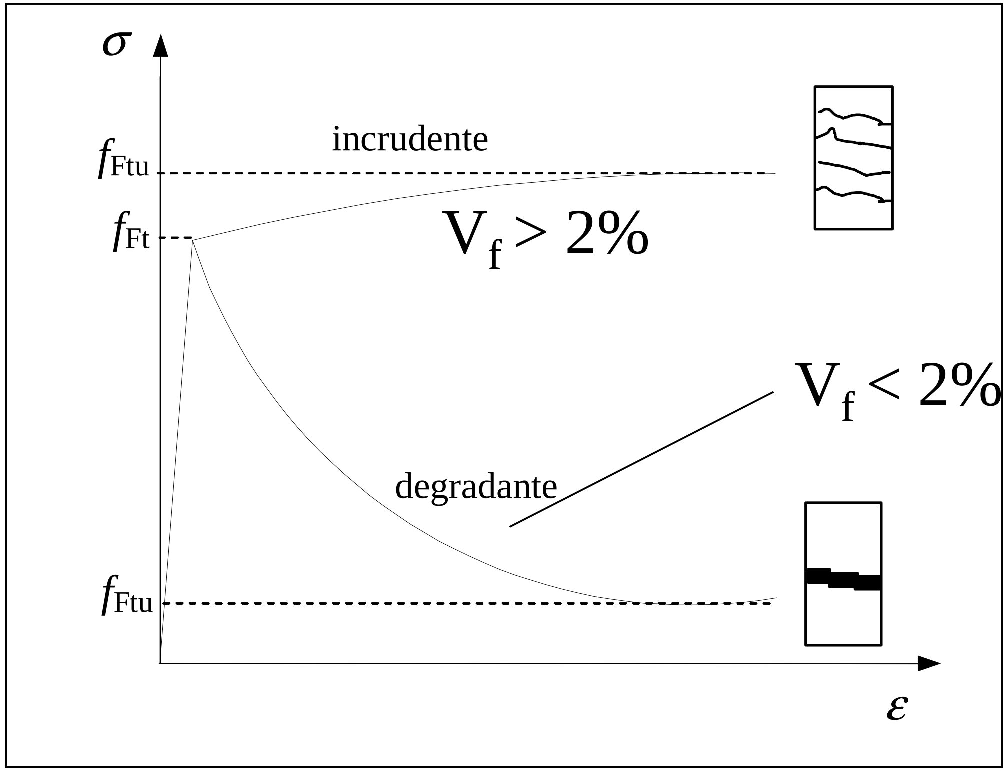


IBMB — TU - Braunschweig

by Falkner, 2006

Comportamento meccanico

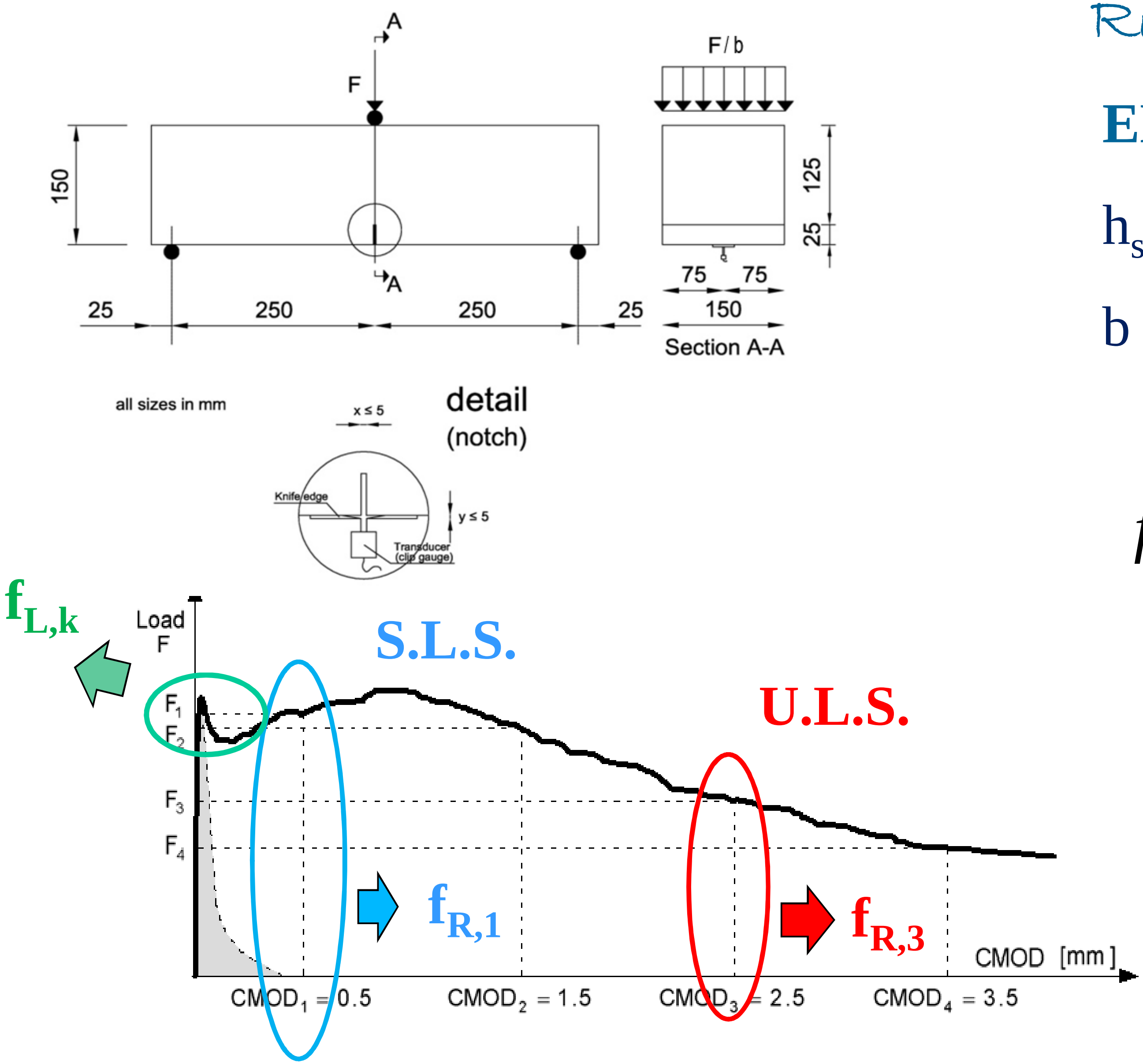
Trazione uniassiale



f_{FT} resistenza a trazione uniassiale di prima fessurazione

f_{FTu} resistenza a trazione uniassiale residua ultima

Classification for FRC market



Reference test

EN 14651

$h_{sp} = 125$ mm

$b = 150$ mm

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

Performance based design

cement 425: 472 kg
fly ash: 45 kg
water 200 l (w/b =0.39)
superplast. 1.3%

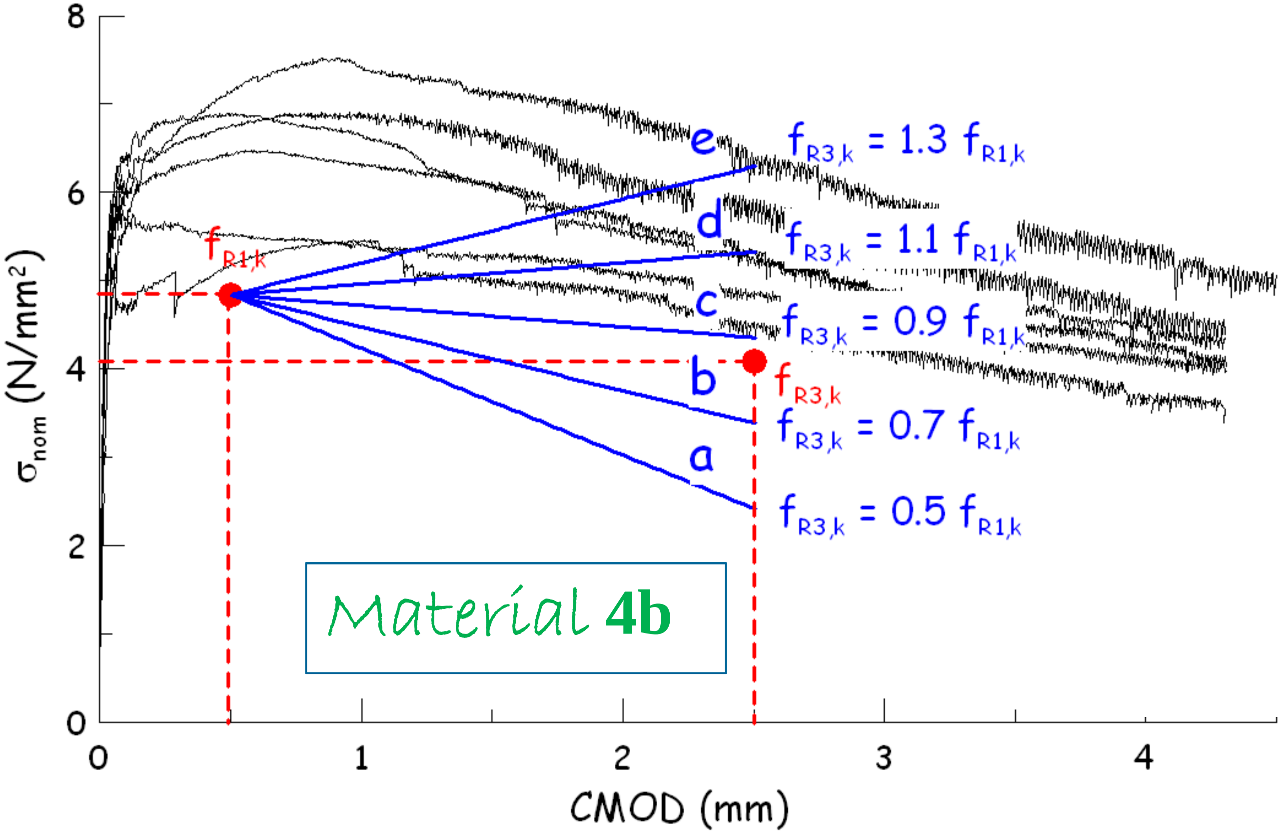
fine sand 0/4 850kg
coarse sand 4/8 886 kg

hooked-end fibres 65/35 50 kg

slump flow diameter: 690 mm
T50 2 sec
V-funnel time (0 min) 3.5 sec
V-funnel time (5 min) 4 sec
L-box (standard) h2/h1 = 1

Classification

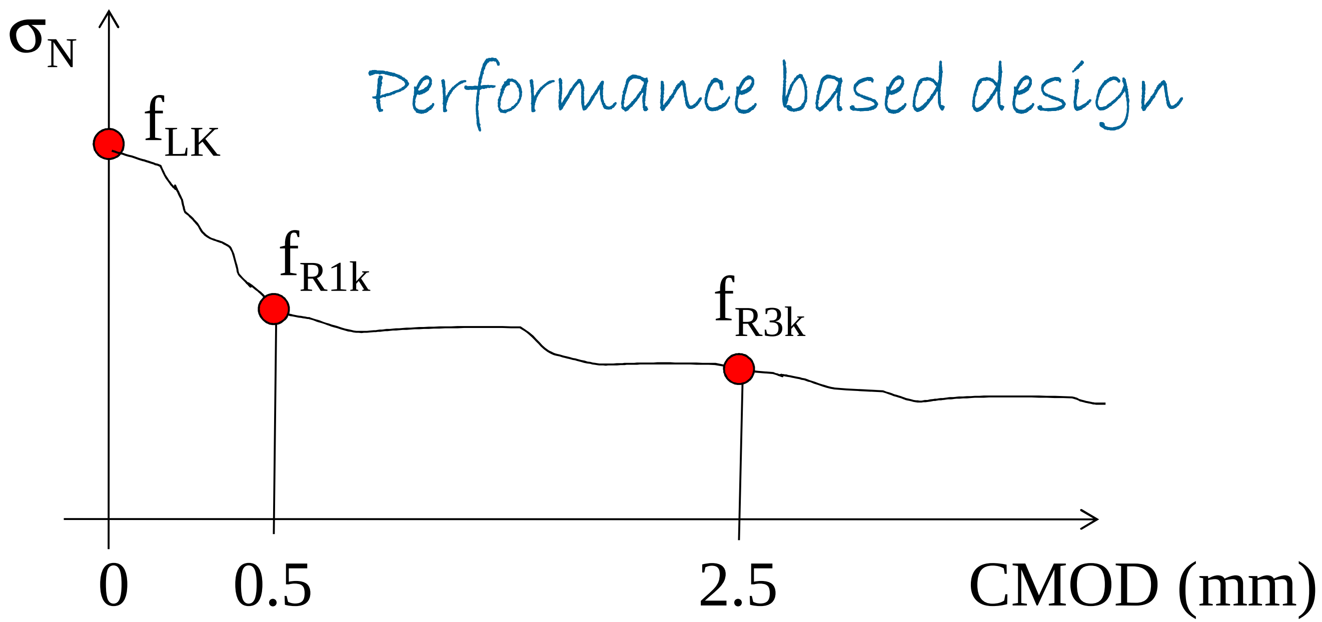
f_{R1k} 1.0; 1.5; 2.0; 2.5; 3.0; 4.0; 5.0; 6.0; 7.0; 8.0 [MPa]



$$f_{eq,k} = f_{eq,av} - ks$$
$$n = 6: \quad k = 1,87$$

	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**	

Minimum performance for a FRC



(5) **Fibre reinforcement can substitute (also partially) conventional reinforcement at ultimate limit state** if the following relationships are fulfilled:

$$f_{R1k}/f_{Lk} > 0.4; \qquad f_{R3k}/f_{R1k} > 0.5$$

Workability, passing and filling ability

Slump-flow

V-funnel

L-box

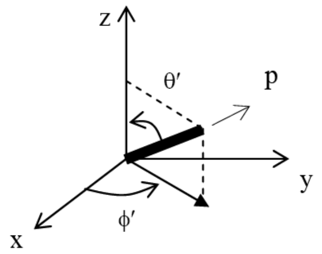
U-box

J-ring

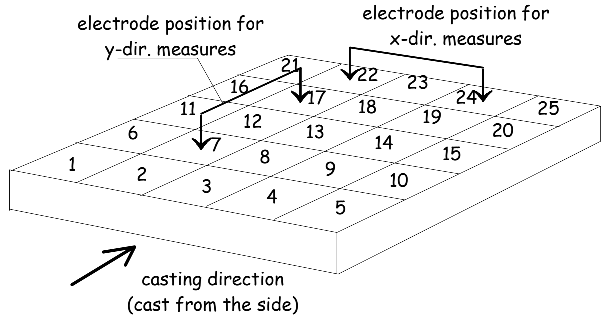
Conventional tests on fresh concrete to guarantee a homogeneous fibre distribution

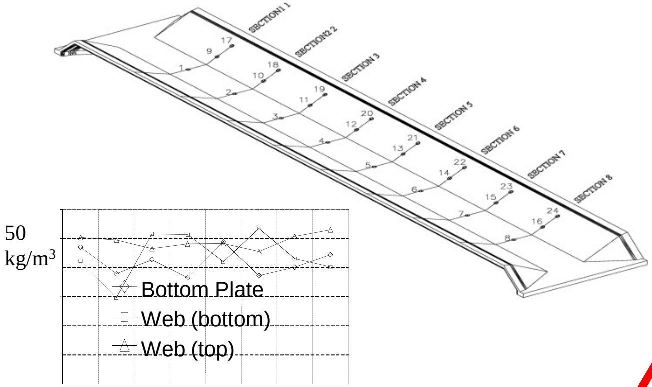
The real question remains: is the mix robust enough?

A “triangular” optimization



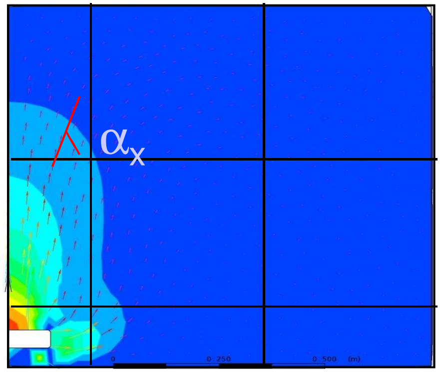
Fiber dispersion and orientation





SCSFRC

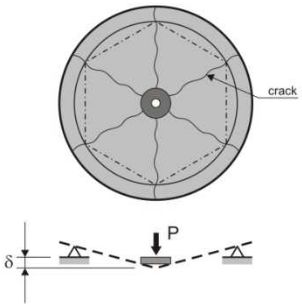
structural performance

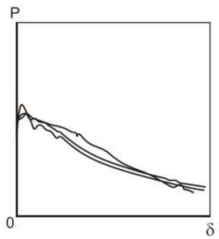


Fractional shear rate vector orientation

Mechanical properties

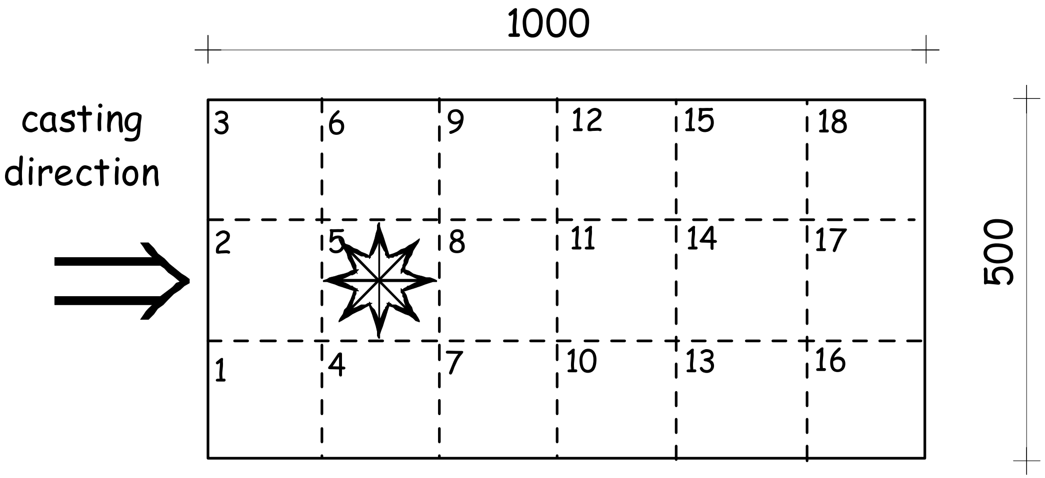
Fresh state behaviour

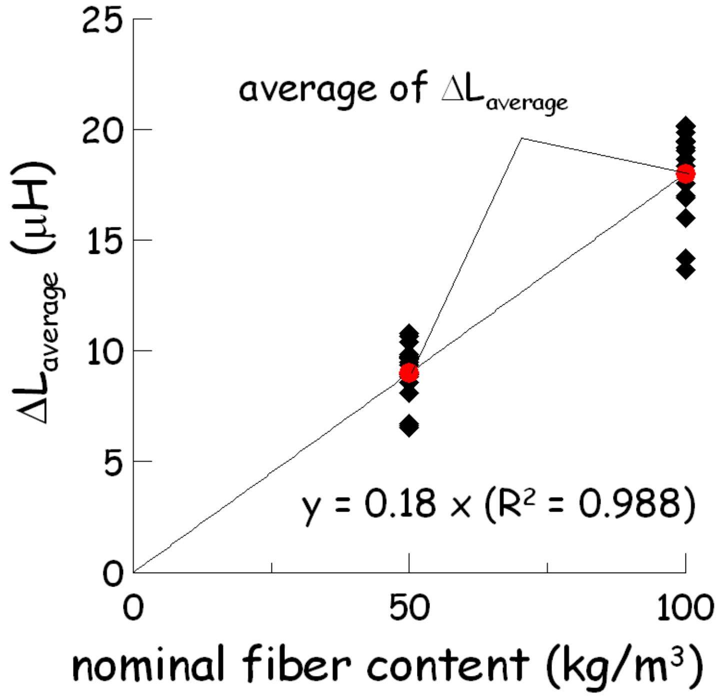


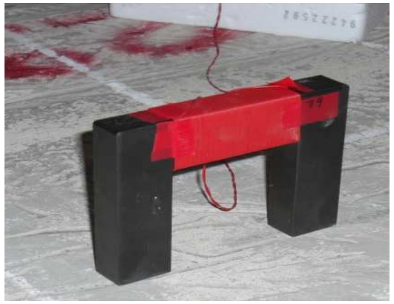


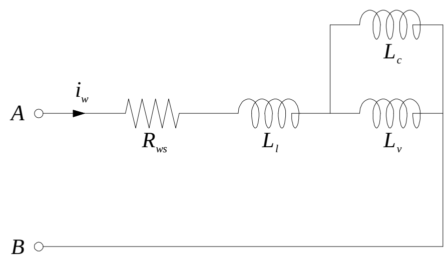
A non destructive test to identify fibre distribution

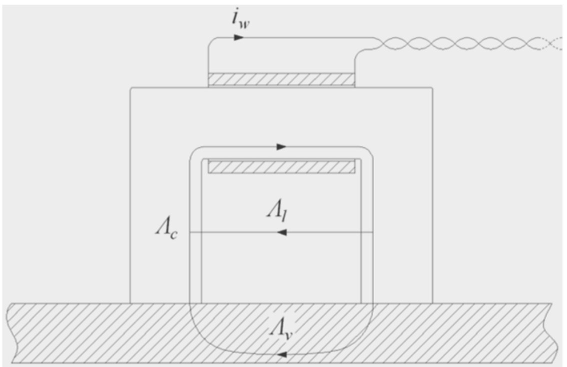
by Ferrara et al. 2010







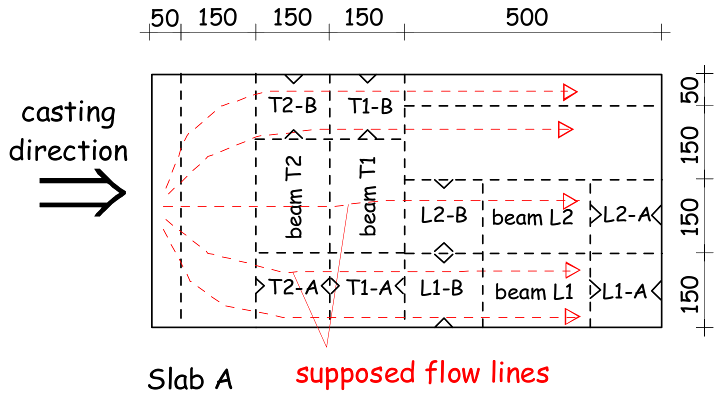


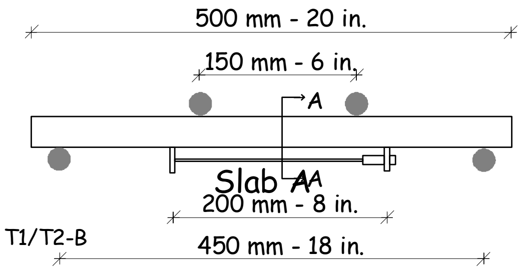


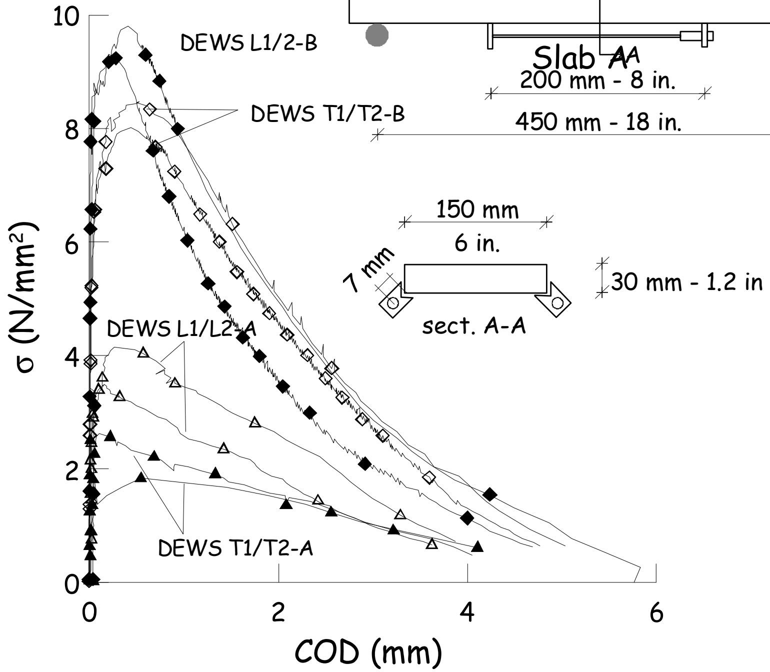
100 kg/m^3

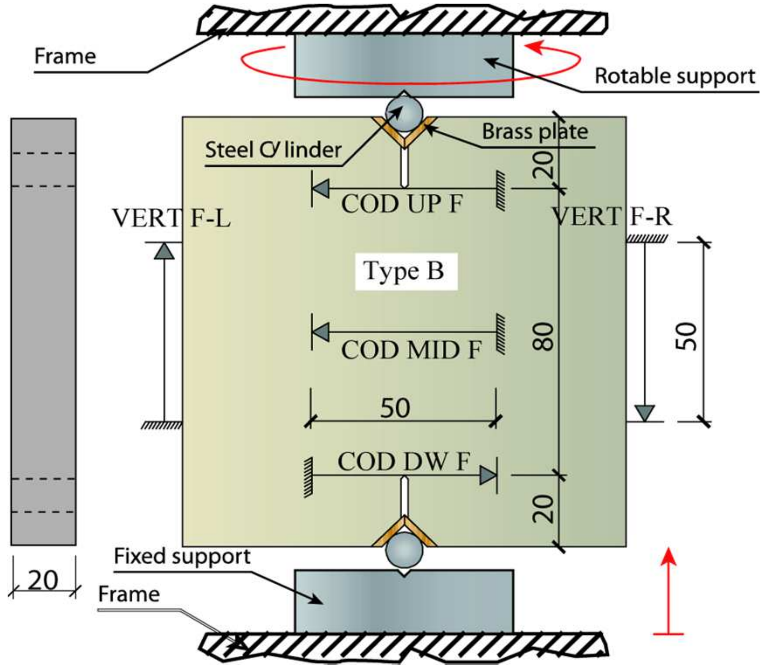
3 ND = 110.5	6 ND = 110.5	9 ND = 106.6 D = 109.9	12 ND = 103.6 D = 106.7	15 ND = 97.5	18 ND = 88.7
2 ND = 101.8 D = 119.1	5 ND = 108.7 D = 109.5	8 ND = 103.5 D = 107.8	11 ND = 100 D = 101.9	14 ND = 93.7 D = 98.2	17 ND = 79.4 D = 85
1 ND = 100.8	4 ND = 111.7	7 ND = 105.7 D = 105.6	10 ND = 99.5 D = 99.4	13 ND = 94.2	16 ND = 75.9

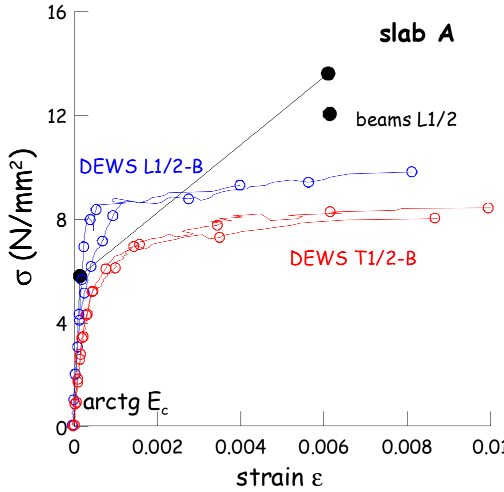
A destructive test to characterize FRC anisotropy

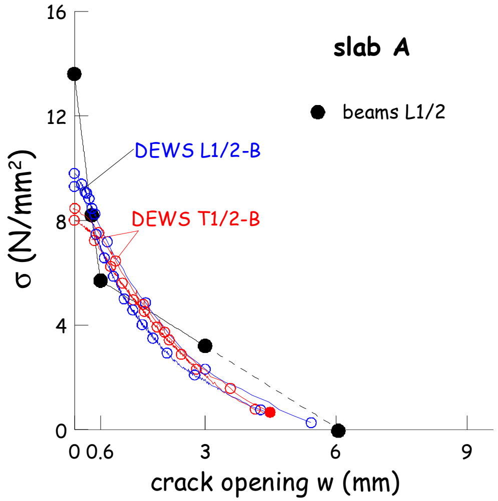












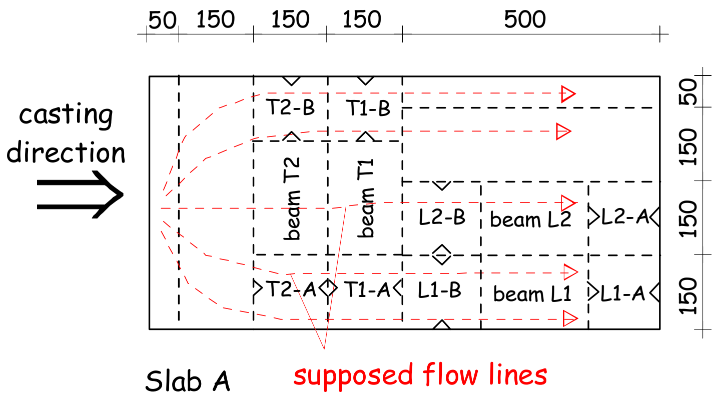
FRC is not homogeneous and not isotropic!

The inhomogeneity and anisotropic effects due to casting procedure can be taken into account by a special coefficient K that is at this time just empirical.

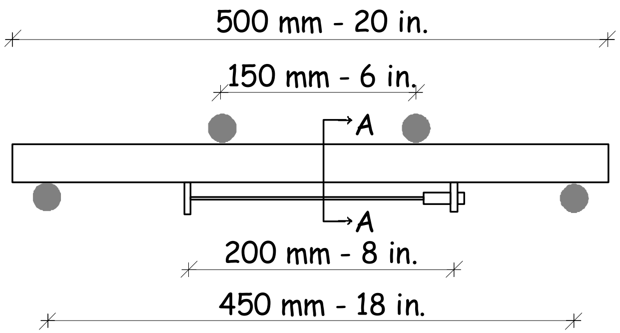
5.6.7 Orientation factor

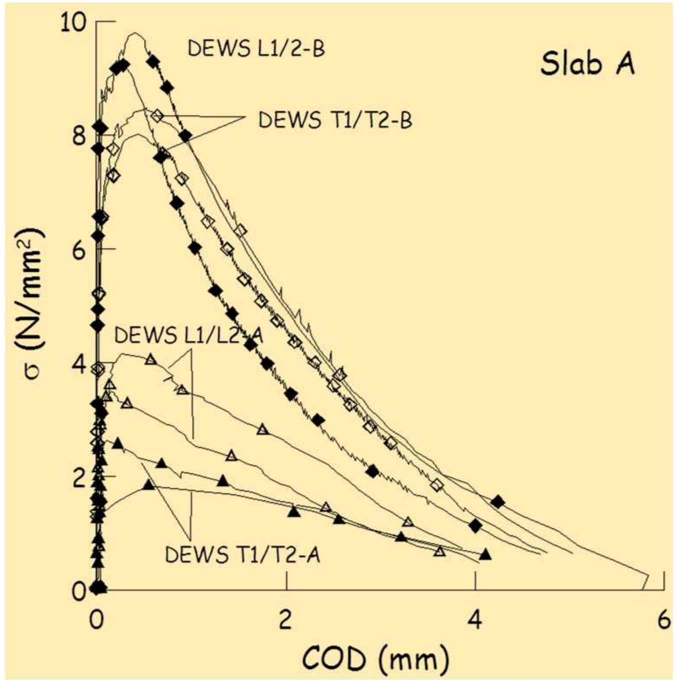
$$f_{Ftsd,mod} = \cdot f_{Ftsd}/K \qquad f_{Ftud,mod} = \cdot f_{Ftud}/K$$

Isotropic fibre distribution is assumed	$K = 1.0$
For favourable effects	$K < 1.0$
For unfavourable effects	$K > 1.0$

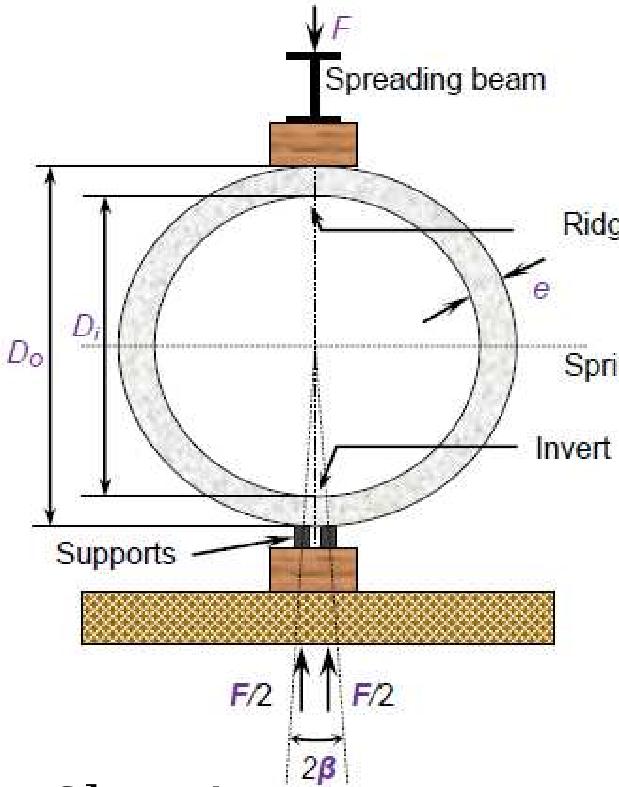


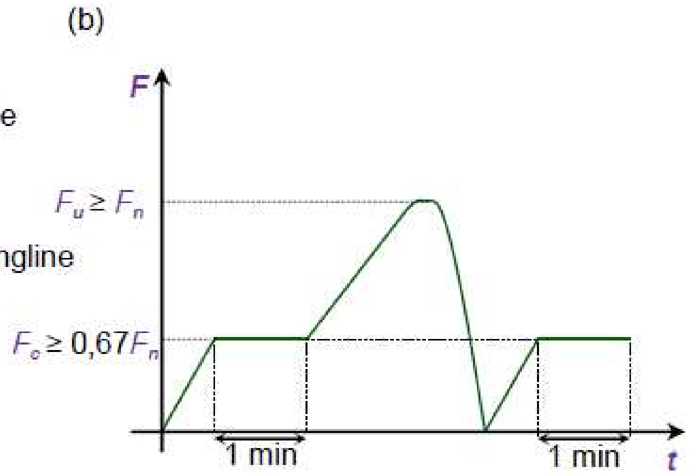
TG 8.3 FRC
TG 8.6 HPFRC





Precast elements interacting with the soil

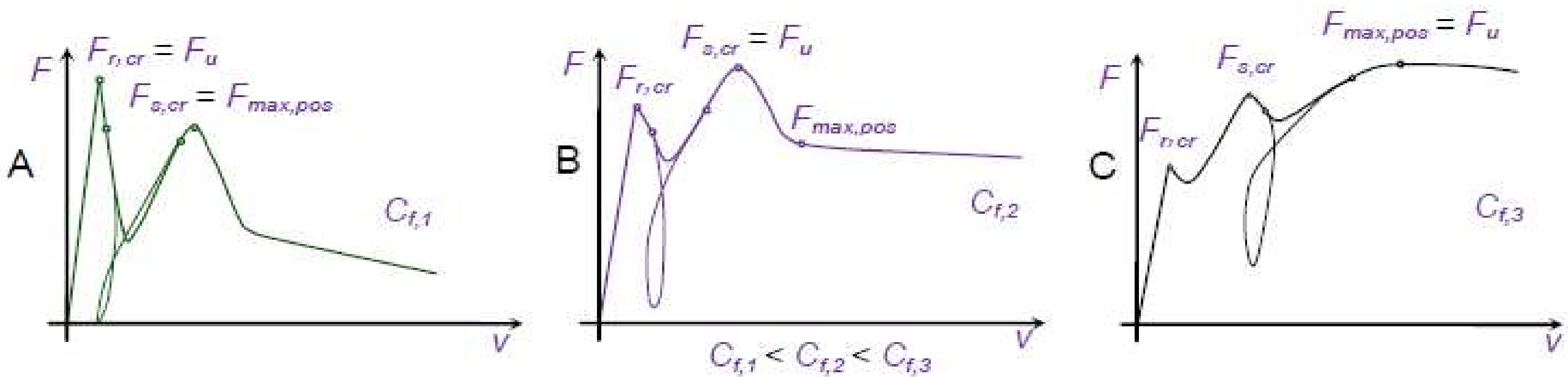




Class A

Class B

Class C



Typical ***F-v*** patterns obtained in FRCPs during the CT.

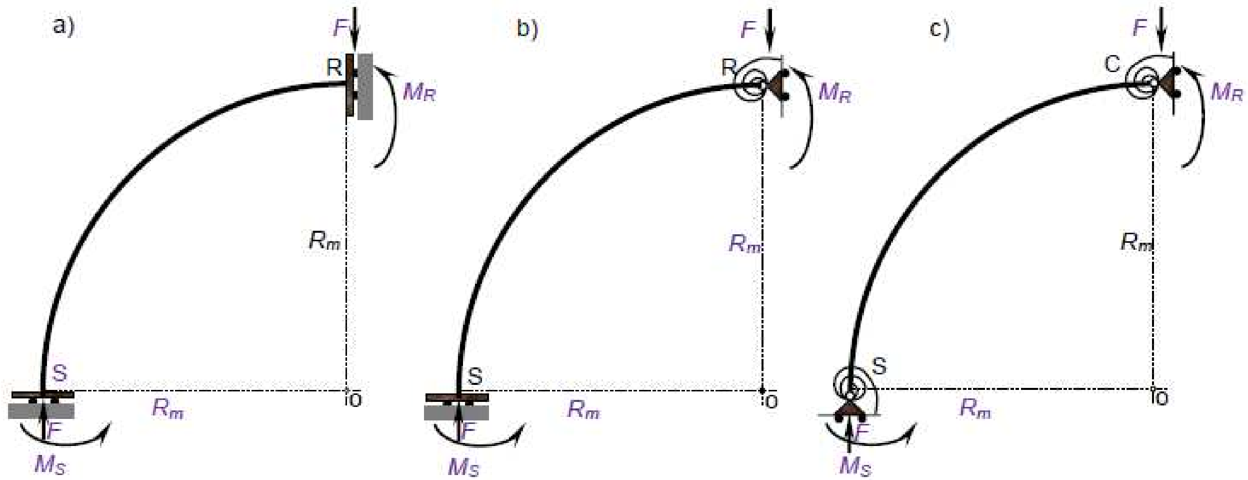
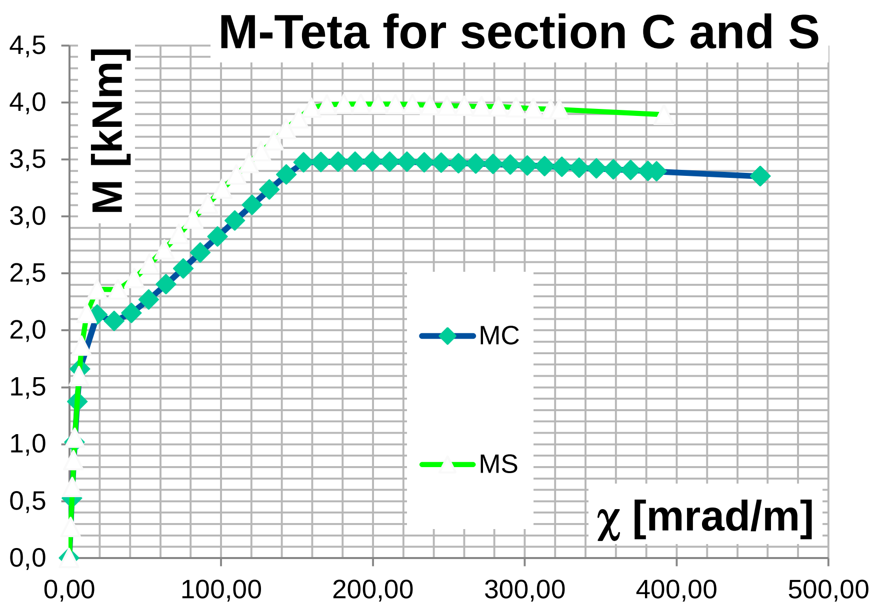
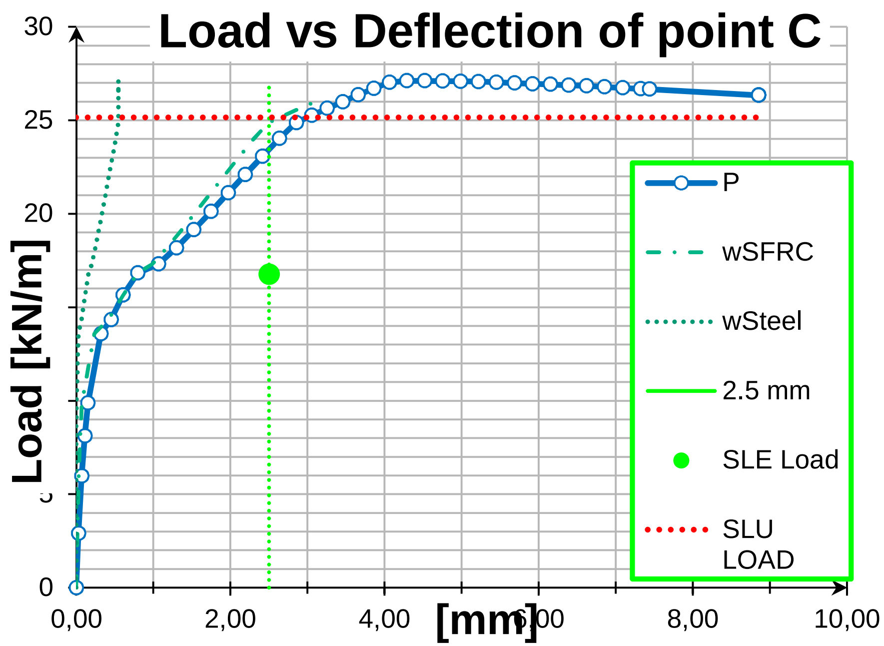


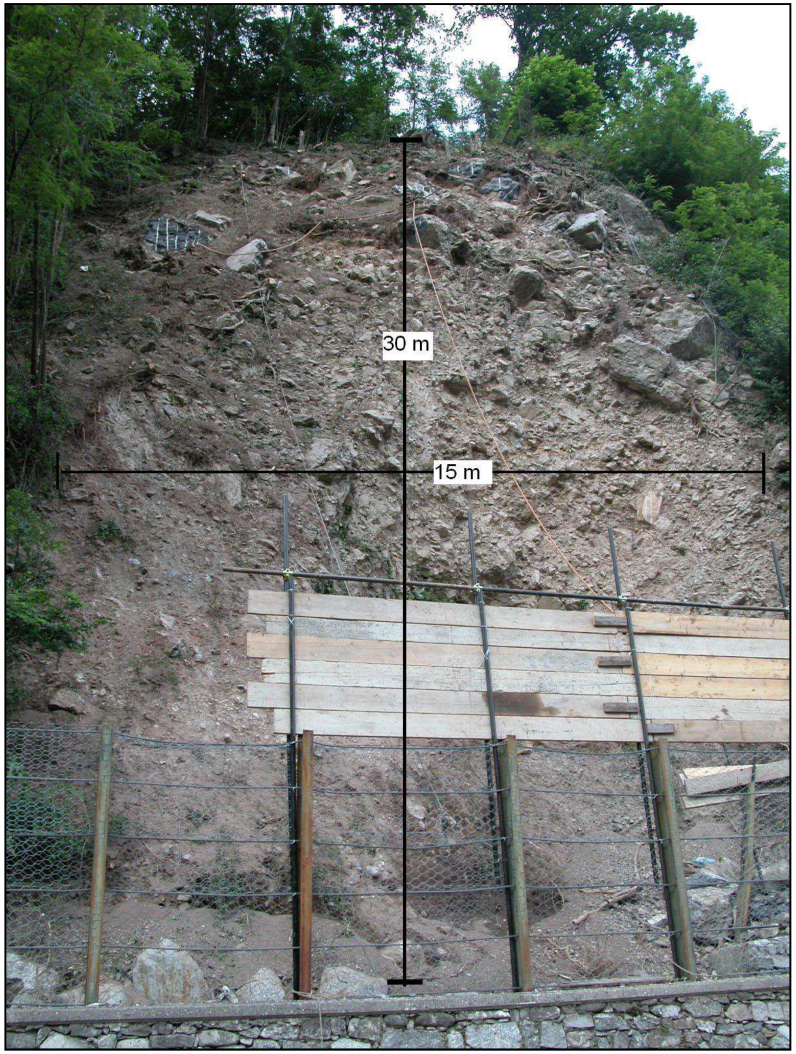
Figure 5. Structural model: (a) full linear regime, (b) linear regime with cracking in R and (c) also in S.





General framework

Ground slope

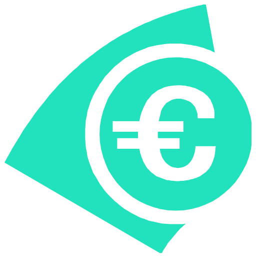


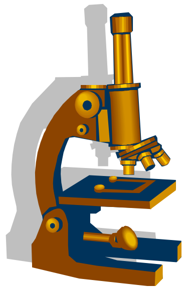
General framework

CASLINO

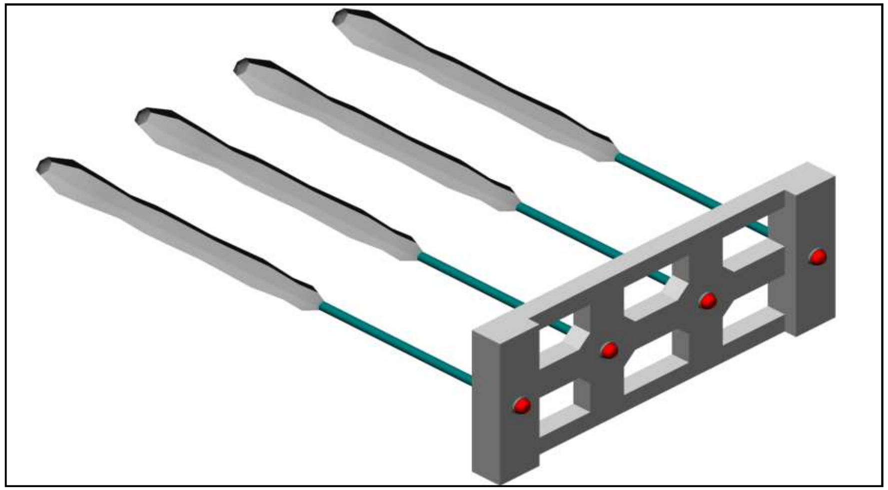
- ❑ Nailing
- ❑ Anchored bulkhead

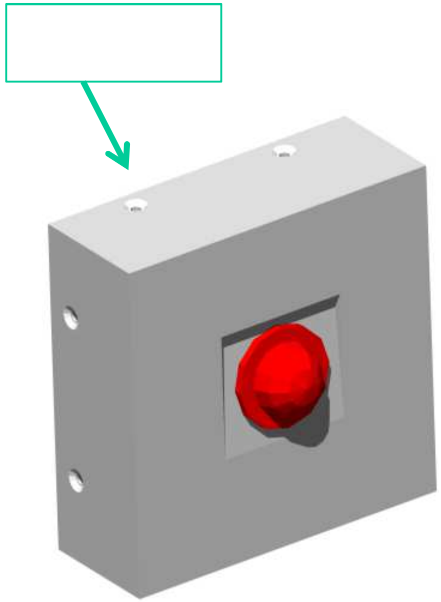
New design solution



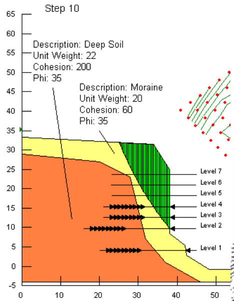


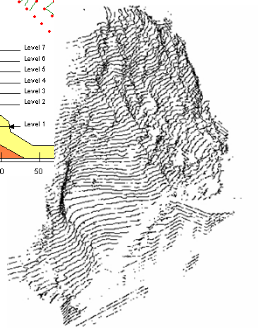
Laboratorio di Caslino d'Erba
struttura di protezione per la stabilità dei pendii

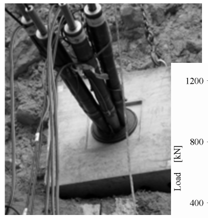


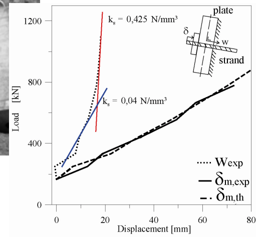


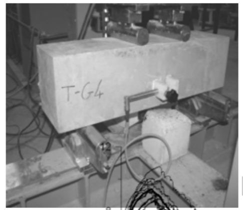
Chronology

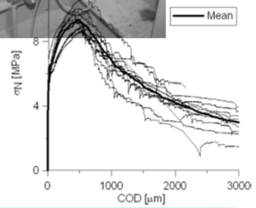






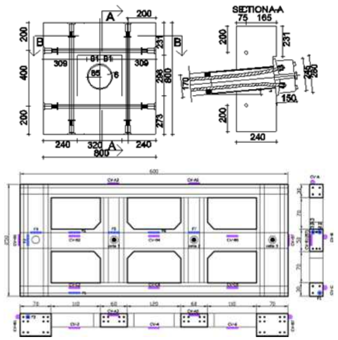


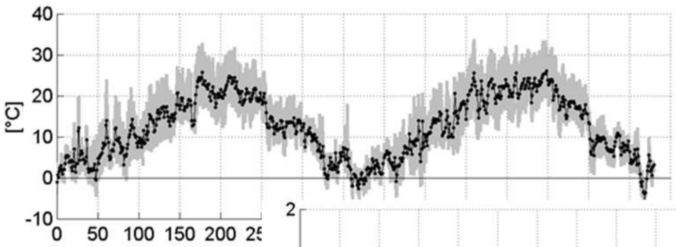


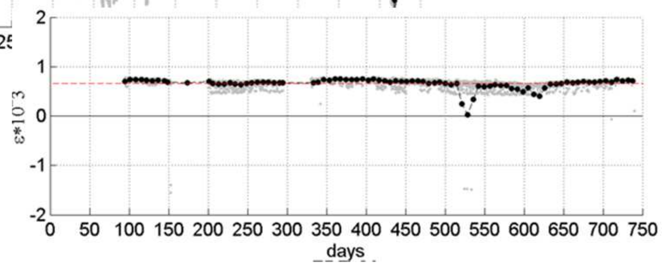


Design and casting elements

2003	2004	2005	2006

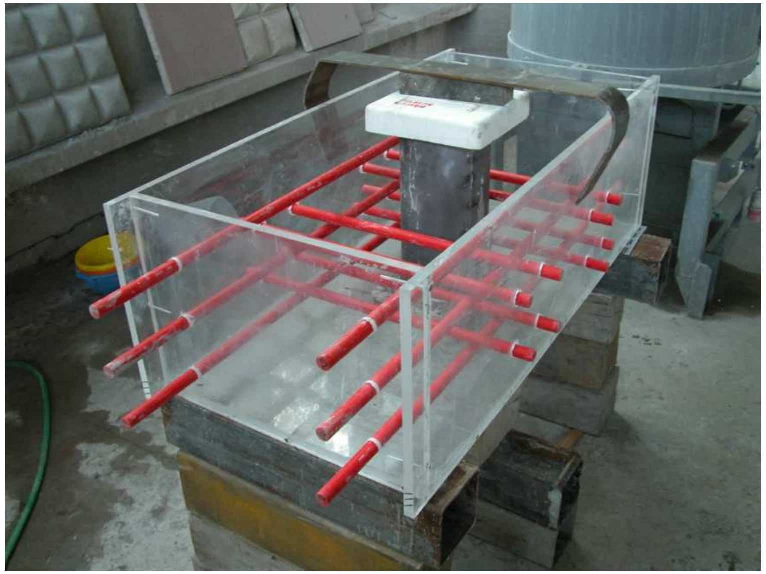


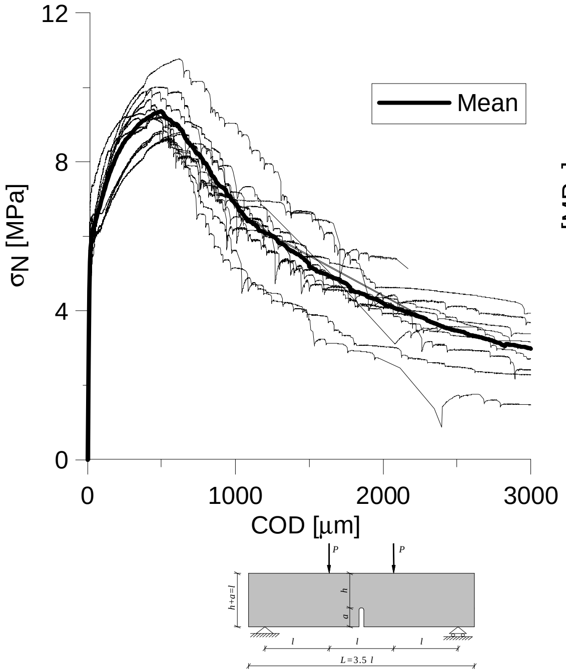




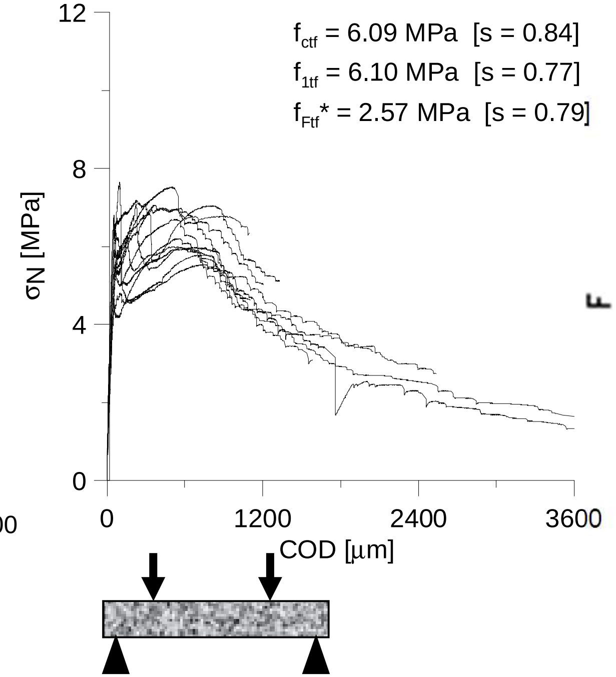
monitoring (full equipment) Monitoring (partial equipment)

2007	2008	2009	2010

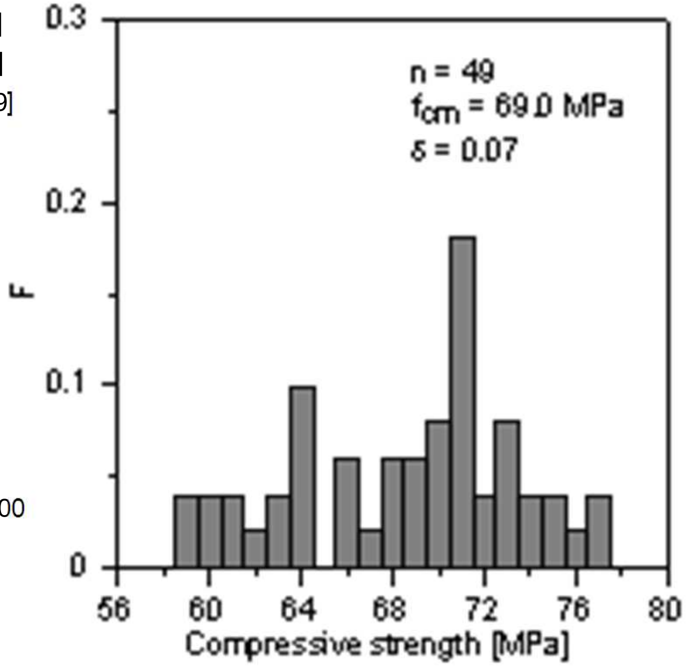




12
8
4
0
σN [MPa]
Mean
0
1000
2000
3000
COD [µm]
L=3.5 l



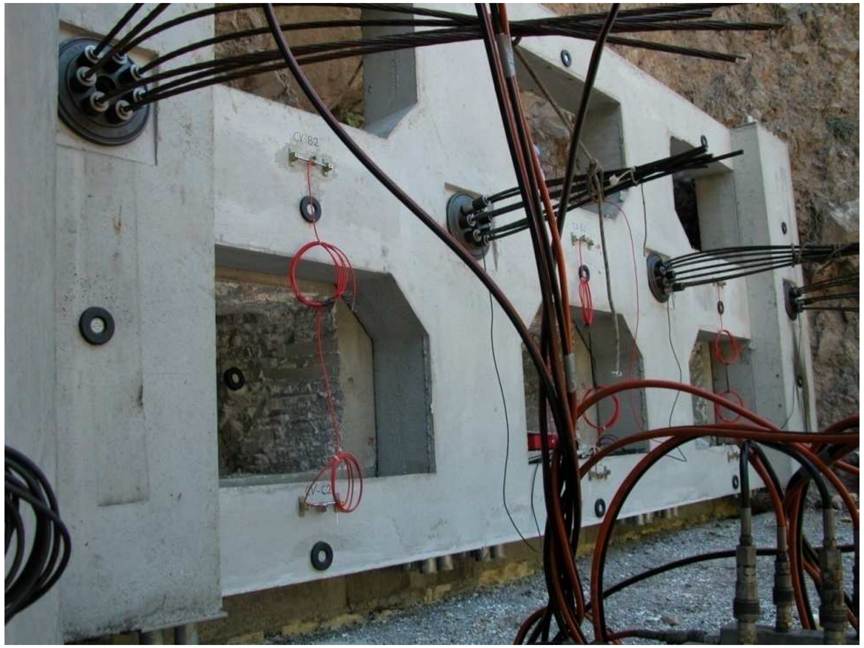
12
8
4
0
σN [MPa]
f_{ctf} = 6.09 MPa [s = 0.84]
f_{1tf} = 6.10 MPa [s = 0.77]
f_{Ftf}^* = 2.57 MPa [s = 0.79]
0
1200
2400
3600
COD [µm]



0.3
0.2
0.1
0
F
n = 49
f_{cm} = 69.0 MPa
δ = 0.07
56
60
64
68
72
76
80
Compressive strength [MPa]

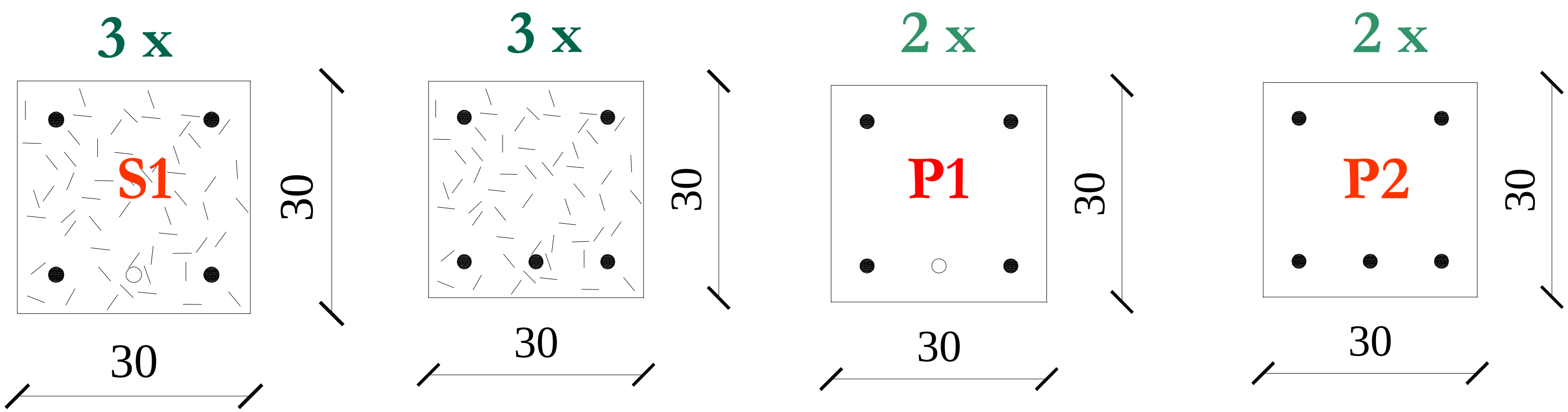

SOC. TRASPORTI BERGAMO
DEMAG
40


CV-B2

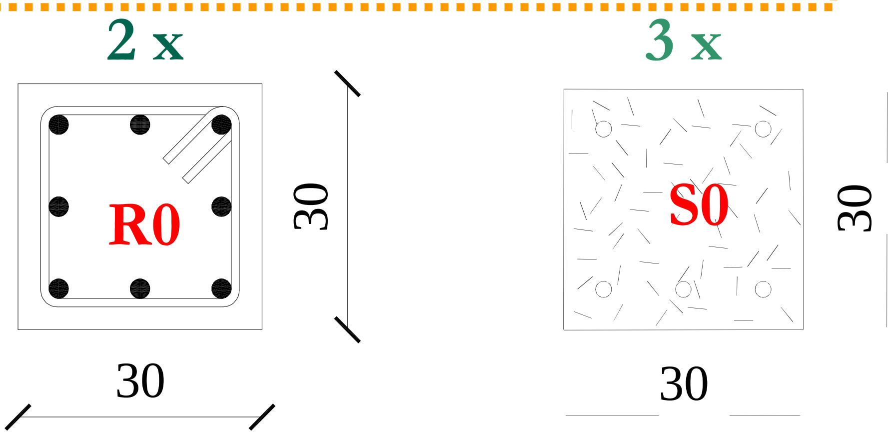


Experimental programme

Post-tensioned beams

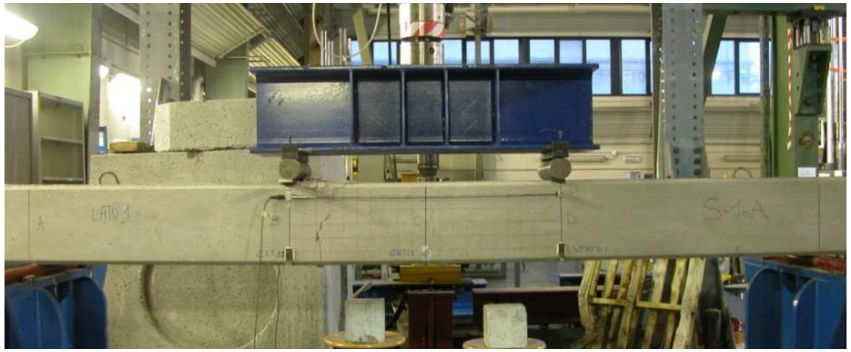


Not Post-tensioned beams

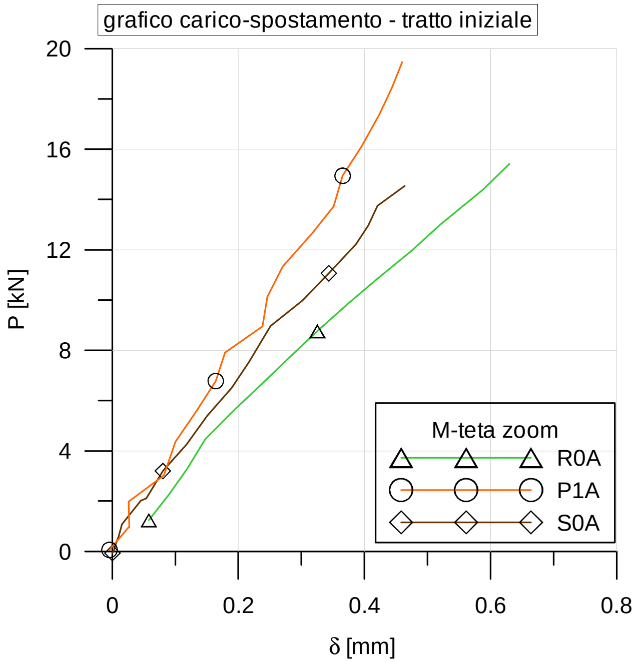


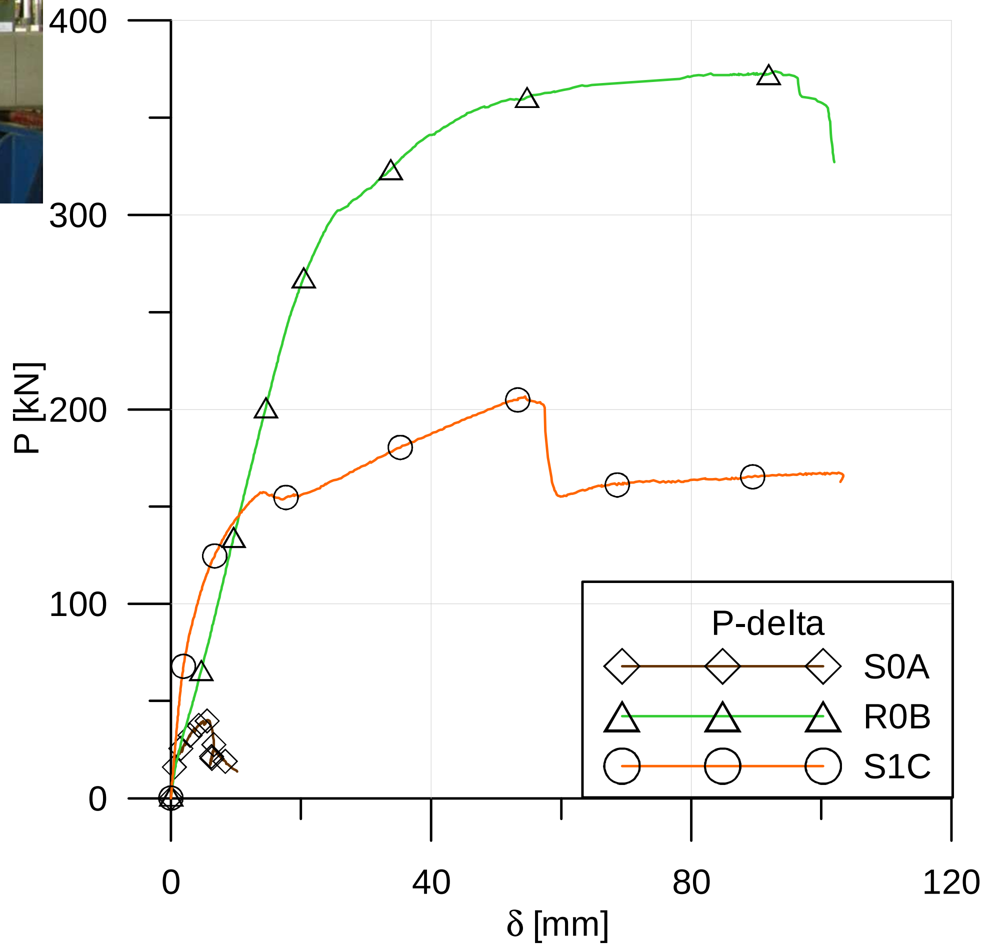
Total: 15 beams (6 typologies)

Experimental resuls



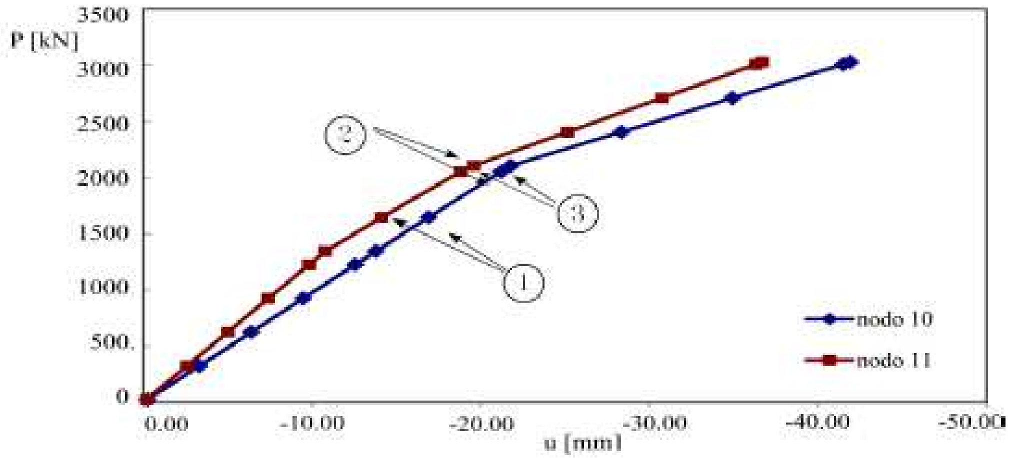
- In esercizio



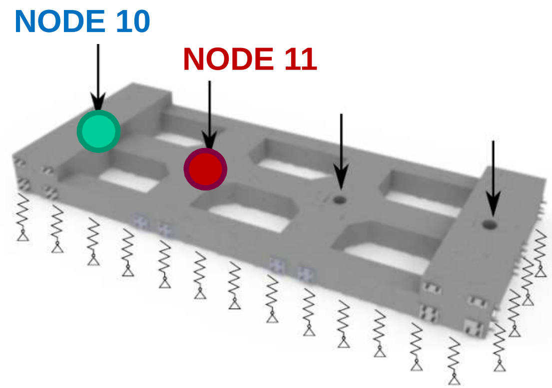


4 point load: activation of torsion hinges for low values of loads

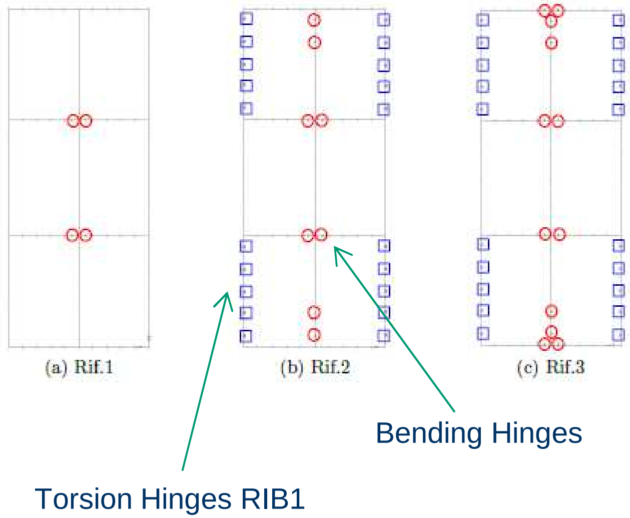
CASE 1: Indefinite Plastic hinges



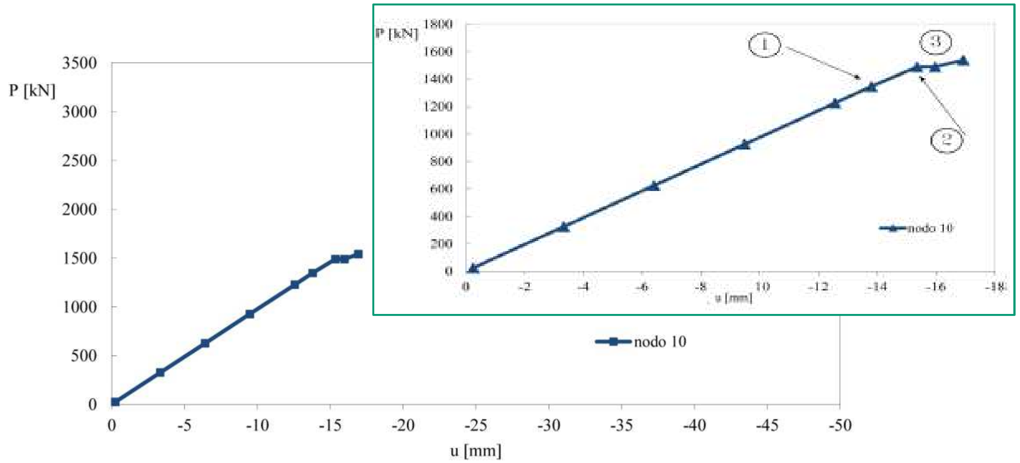
Anchor strand stretching vs . reference node displacement



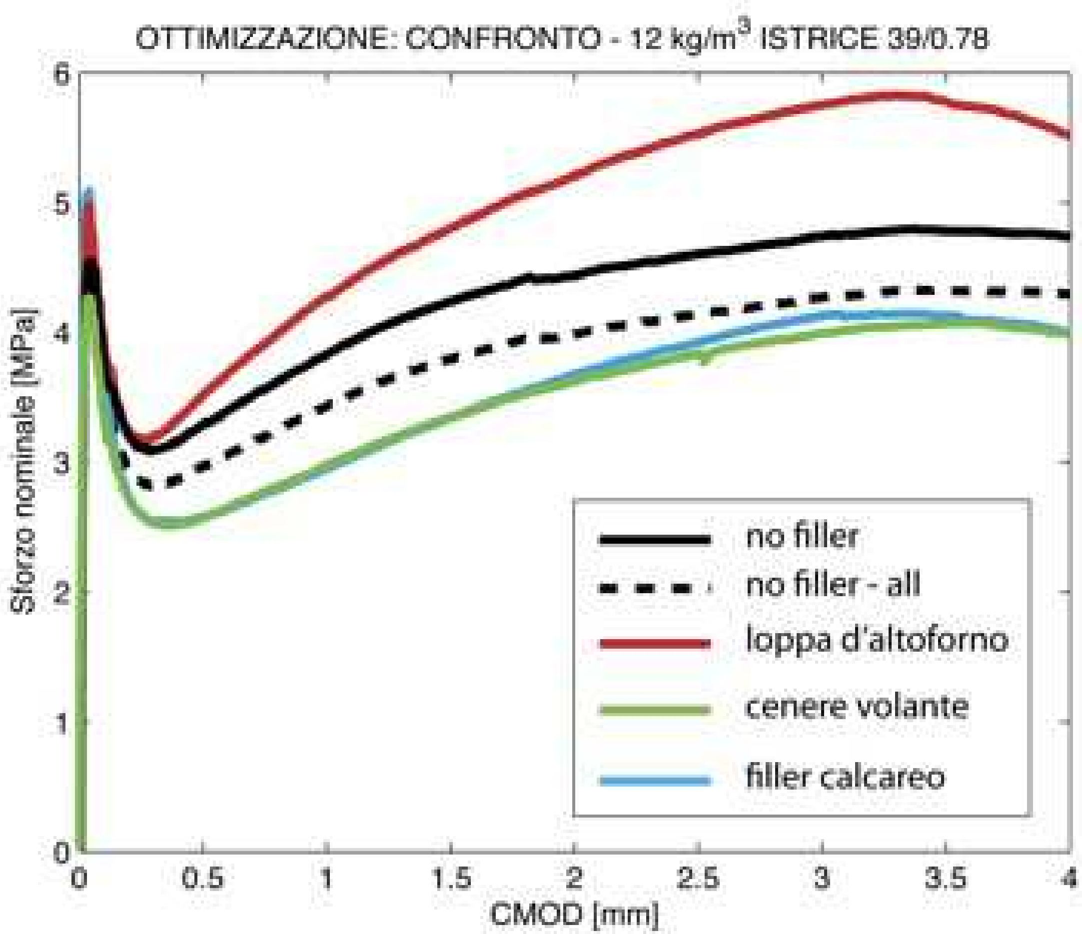
Kinematic mechanism



CASE 2: Plastic hinge with finite ductility

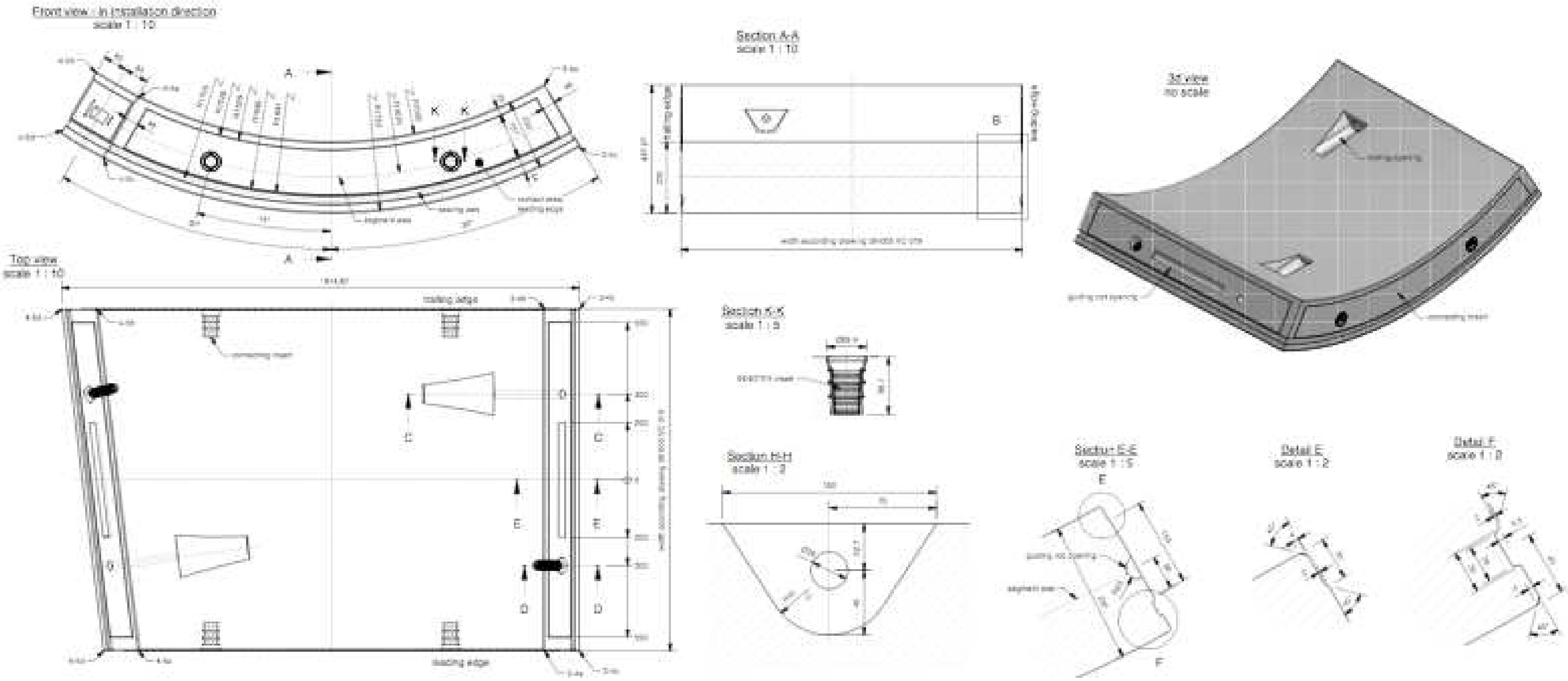


Polypropilene fibres



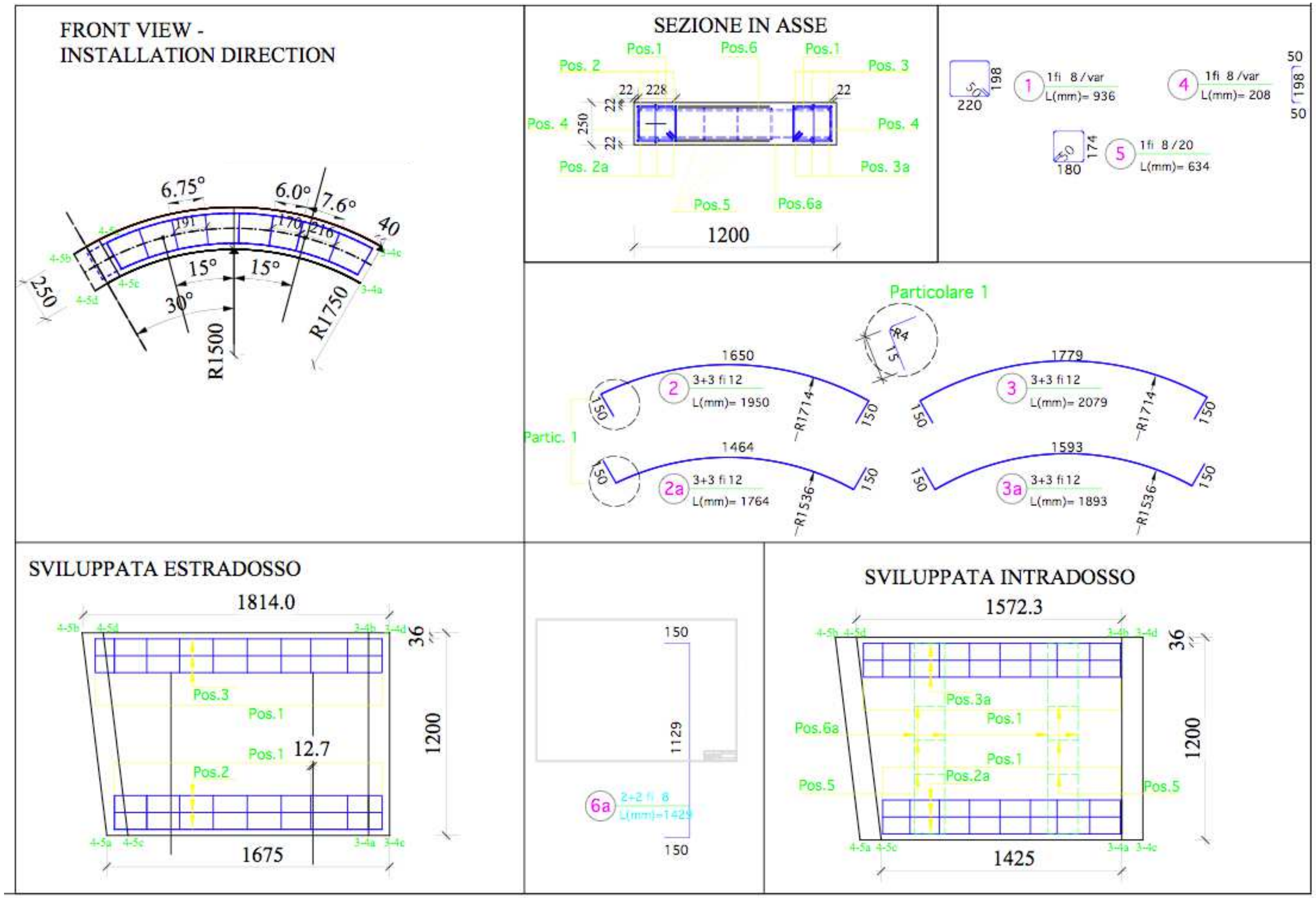
CARATTERIZZAZIONE STRUTTURALE

CONCIO DI TUNNEL



CARATTERIZZAZIONE STRUTTURALE

CONCIO DI TUNNEL



CARATTERIZZAZIONE STRUTTURALE

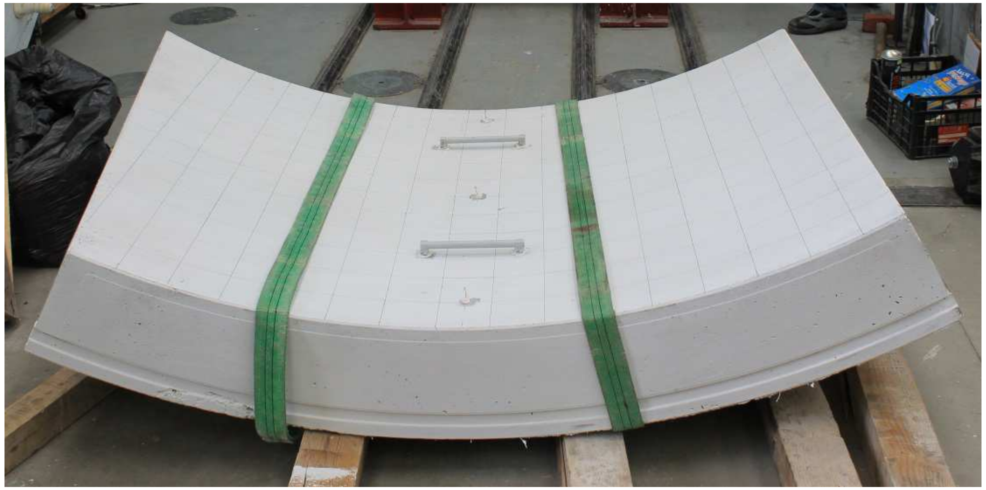
Fasi di getto

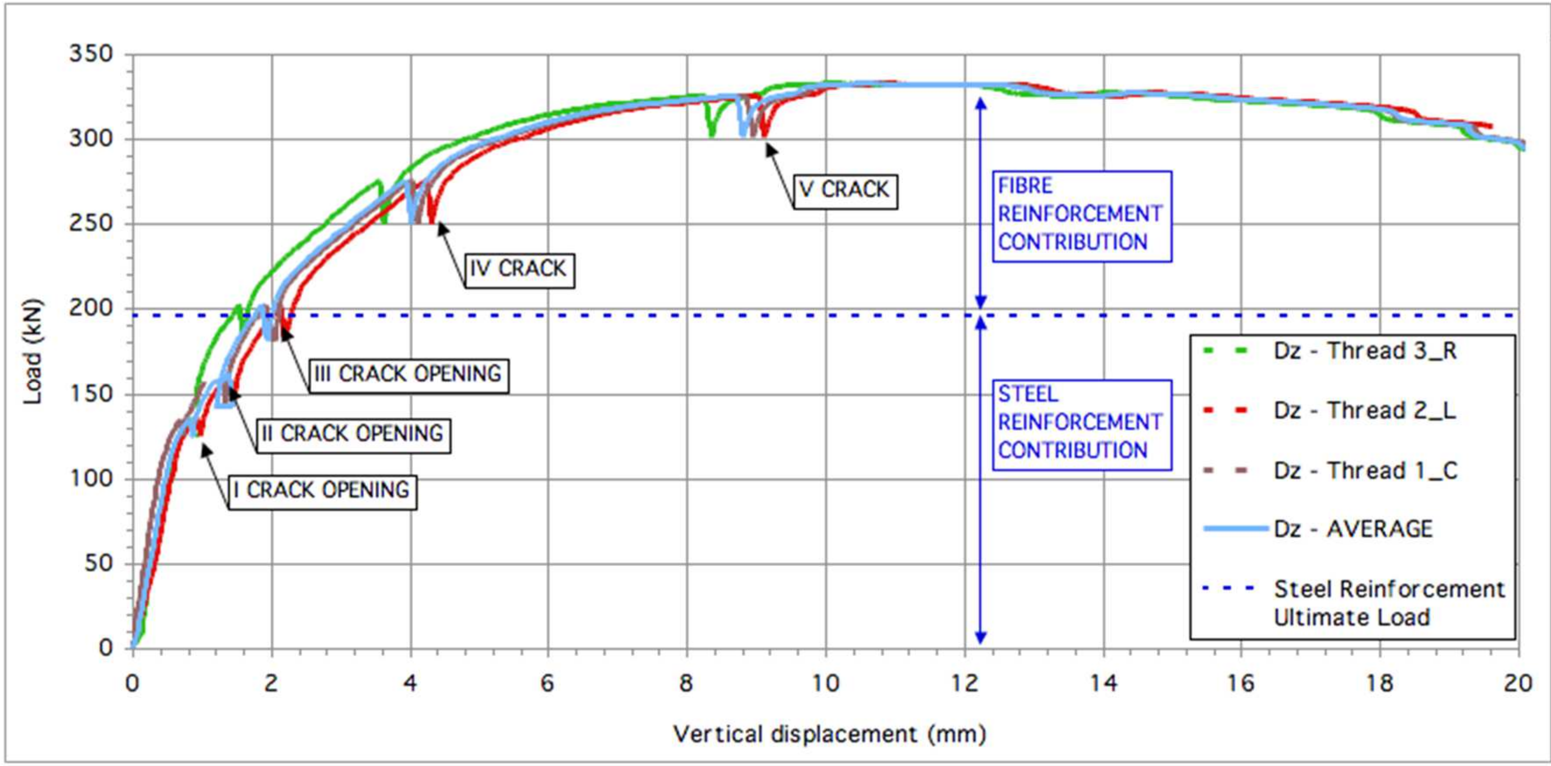
CARATTERIZZAZIONE STRUTTURALE

Fasi di getto

CARATTERIZZAZIONE STRUTTURALE

Set up prova

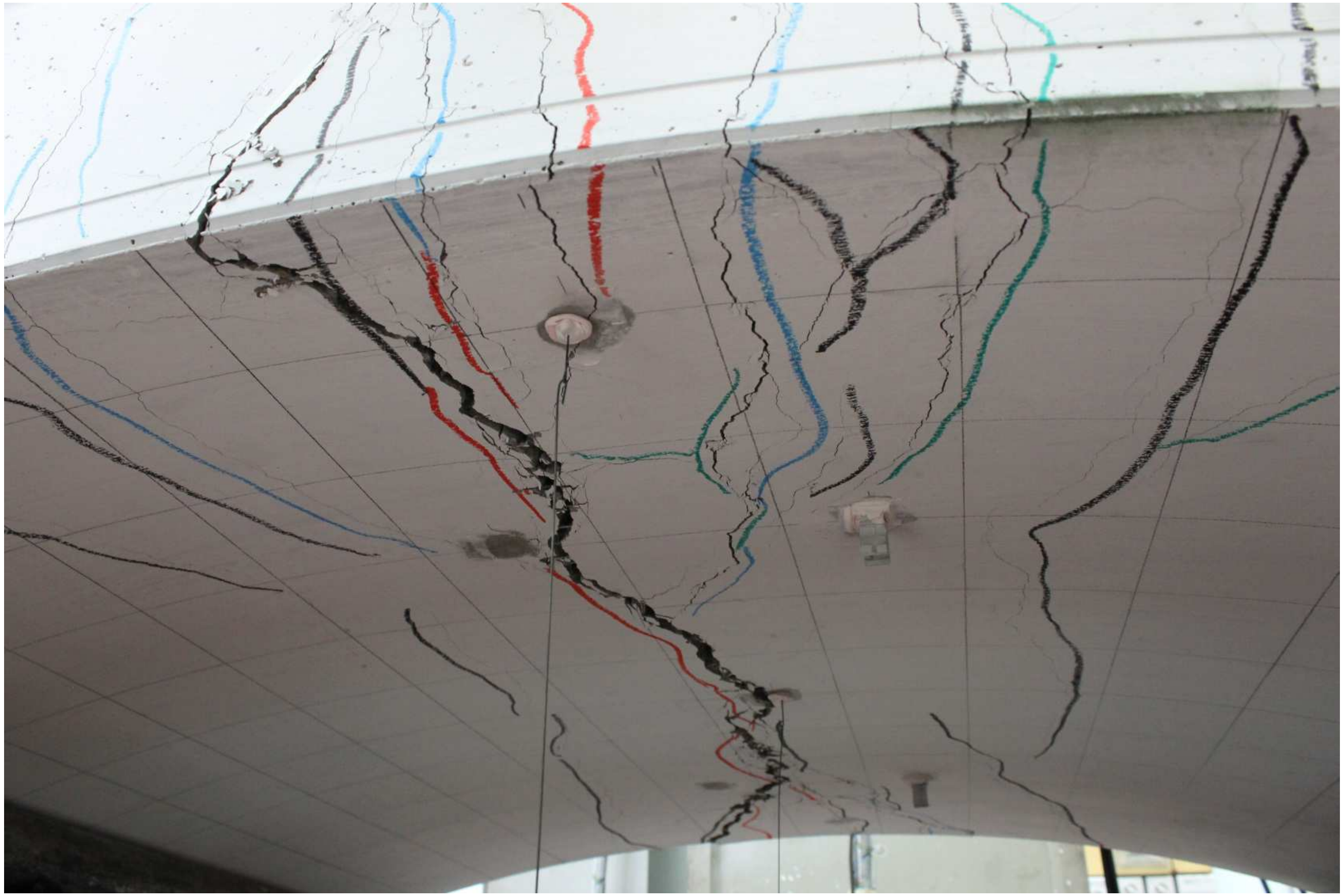



Load (kN)
Vertical displacement (mm)
I CRACK OPENING
II CRACK OPENING
III CRACK OPENING
IV CRACK
V CRACK
FIBRE REINFORCEMENT CONTRIBUTION
STEEL REINFORCEMENT CONTRIBUTION
Dz - Thread 3_R
Dz - Thread 2_L
Dz - Thread 1_C
Dz - AVERAGE
Steel Reinforcement Ultimate Load


149

CARATTERIZZAZIONE STRUTTURALE CONCIO DI TUNNEL

PROVA FLESSIONE ISOSTATICA



135 kN

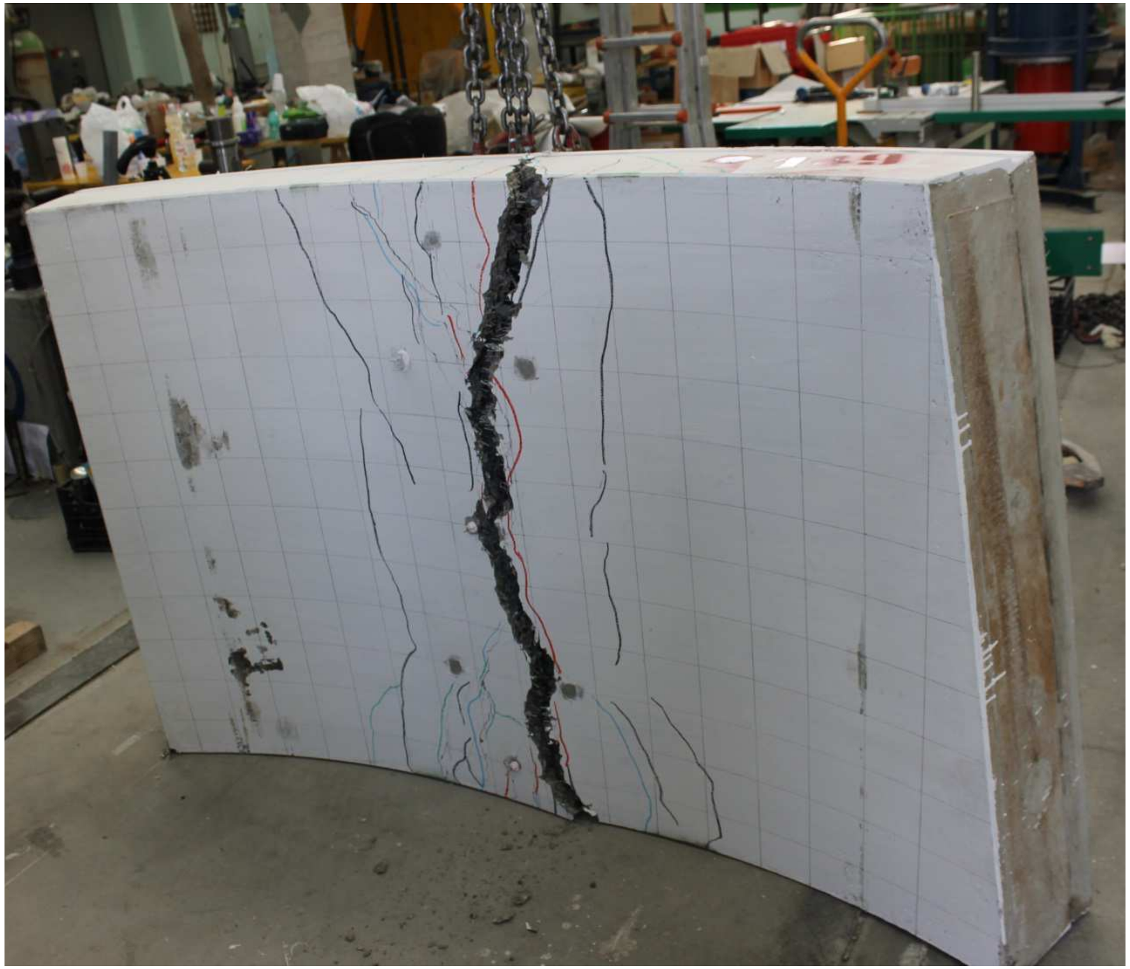
200 kN

260 kN

325 kN

CARATTERIZZAZIONE STRUTTURALE CONCIO DI TUNNEL

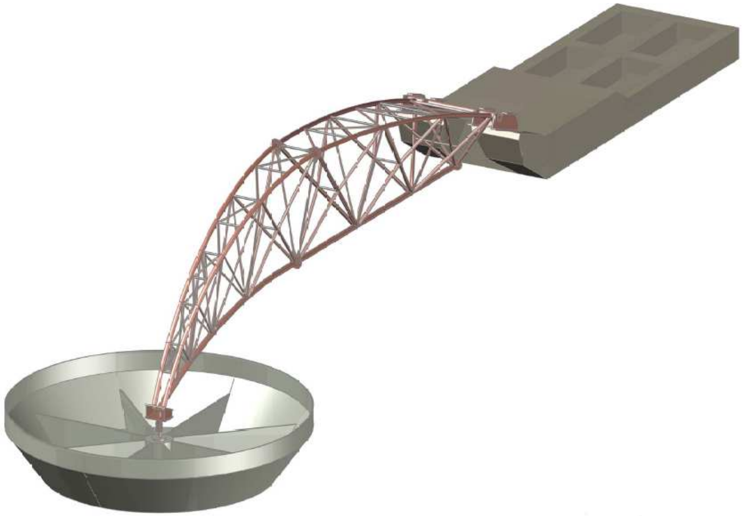
PROVA FLESSIONE ISOSTATICA



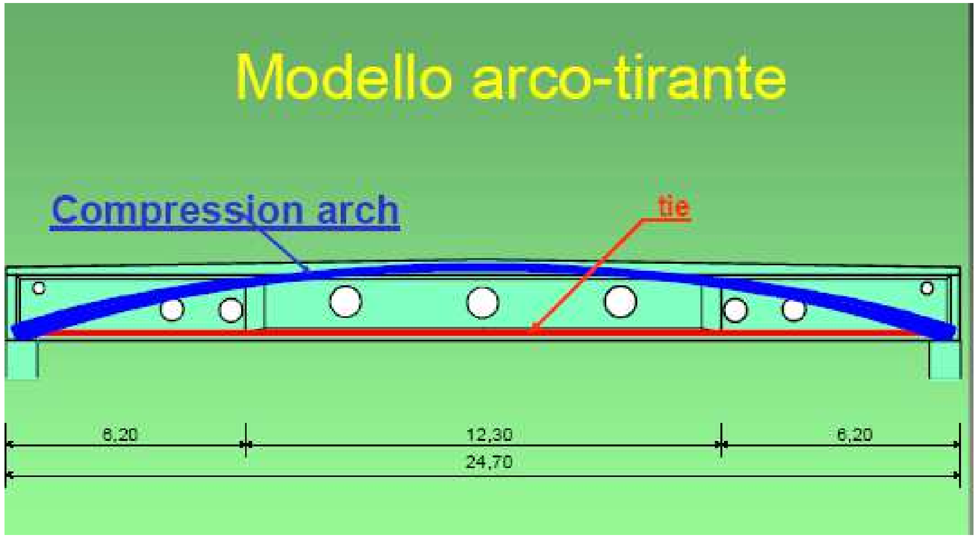
Conci di tunnel prefabbricati

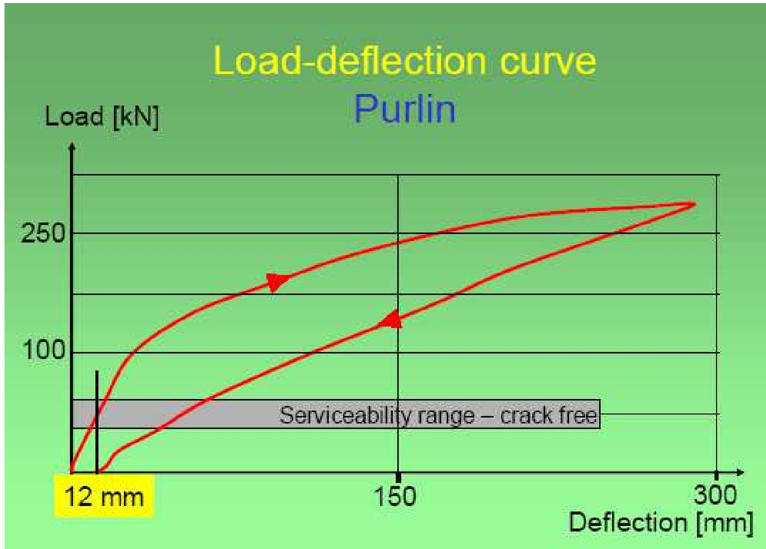
Università di Lipsia (by F. Dehn): aggiunta di fibre in polipropilene per evitare il fenomeno dello spalling esplosivo.

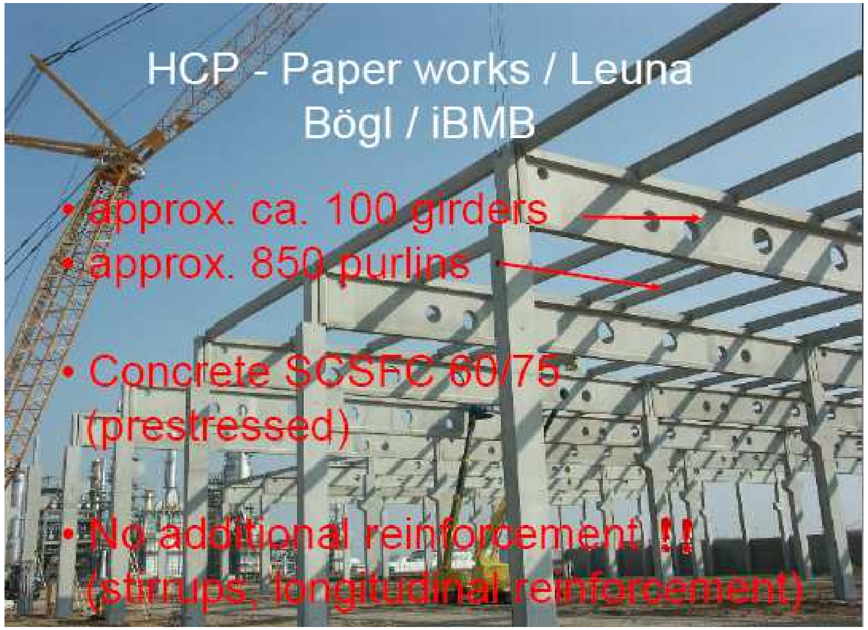
(by F. Dehn, 2005)



Linear precast elements for roofing







by Falkner, 2006

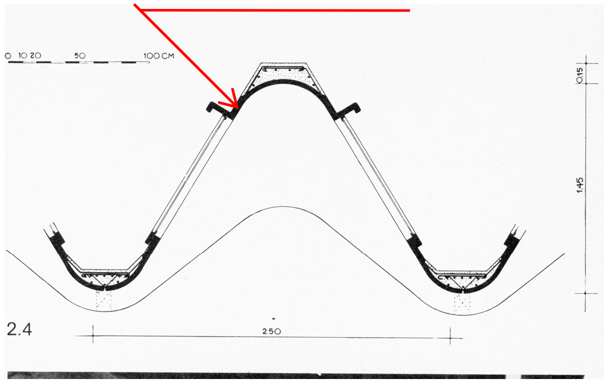

Pier Luigi Nervi
Architecture as challenge

✓A long history ... ***Ferrocement***

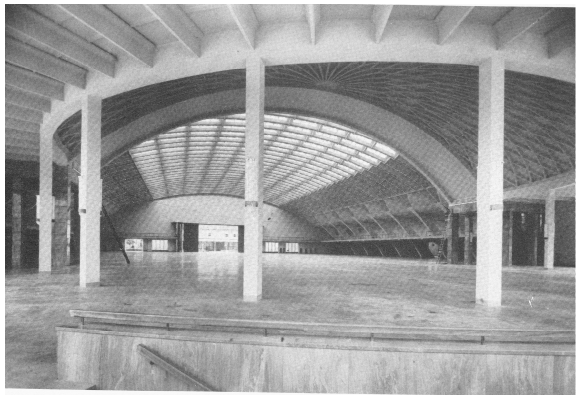
“We wondered if, increasing significantly the diffusion of the steel and its percentage (i.e. reinforcement ratio), it could not be possible to create a new material characterized by a higher strength and especially a larger elasticity and elongation ...”.

Pier Luigi Nervi, 1940

t = 38 mm!

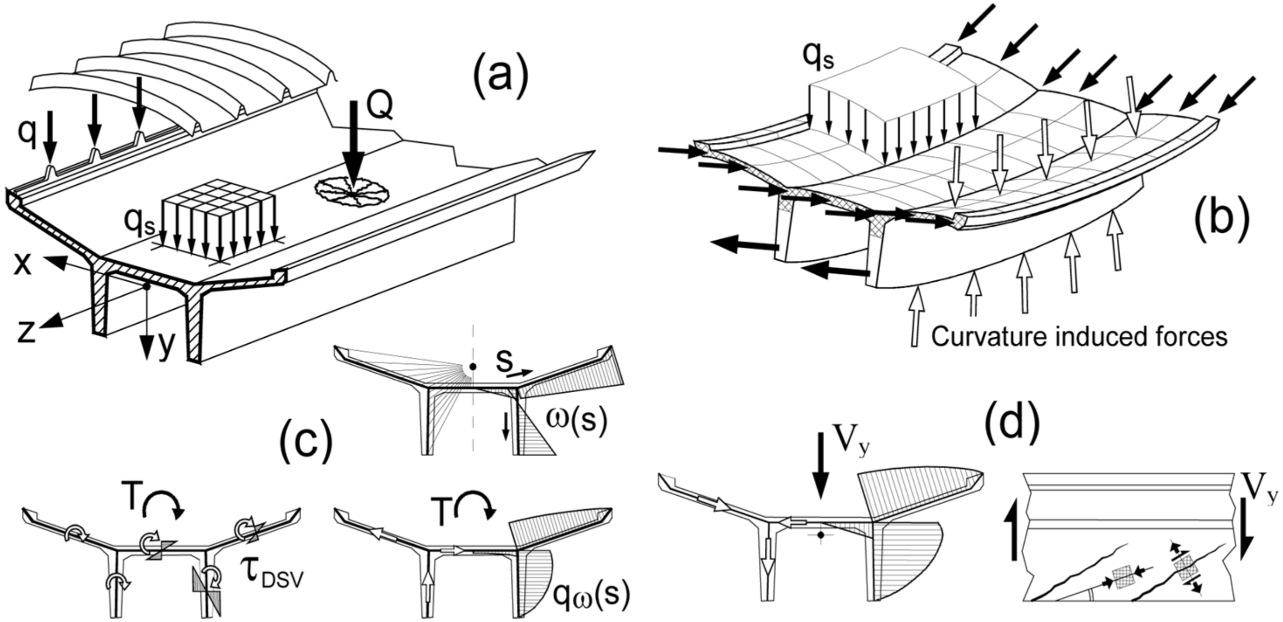


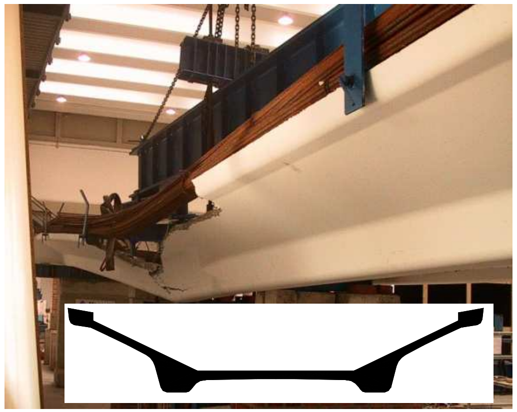
Vault span 94 m!

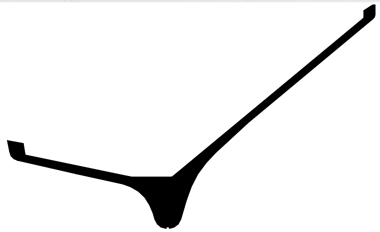


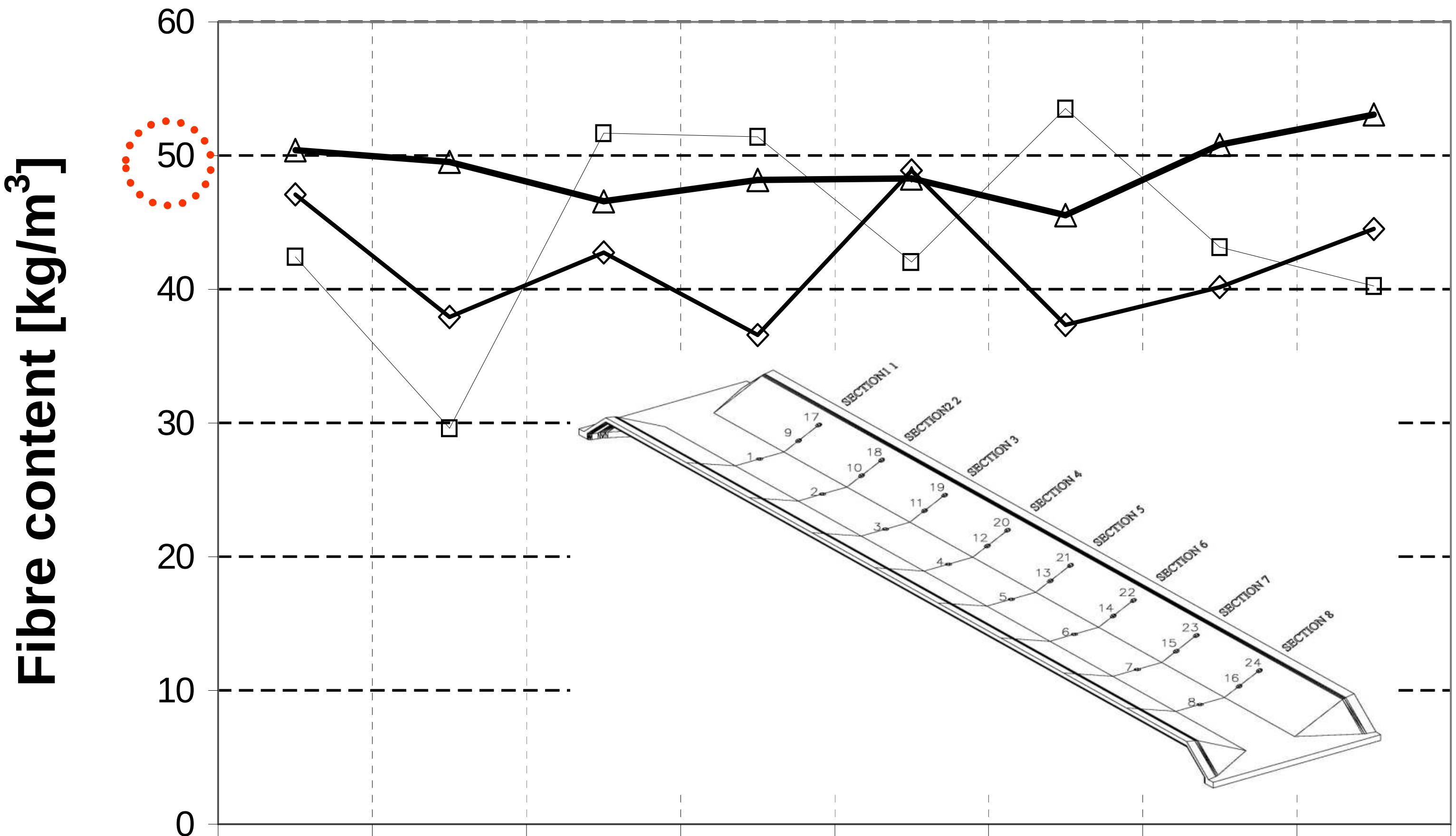
Exposition Palace: B Pavilion, Torino, 1949-50

FRC to substitute transverse reinforcement







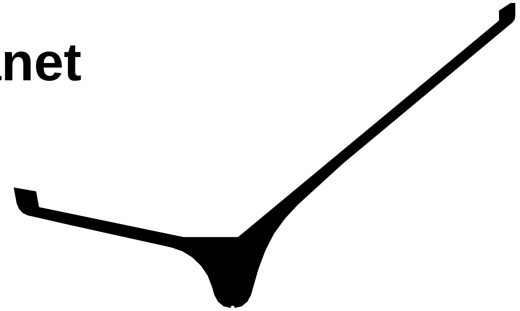


	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8
Bottom Plate	47,10	37,93	42,77	36,58	48,90	37,33	40,18	44,49
Web (bottom)	42,41	29,61	51,68	51,41	42,02	53,50	43,15	40,26
Web (top)	50,39	49,52	46,58	48,18	48,29	45,53	50,81	53,06

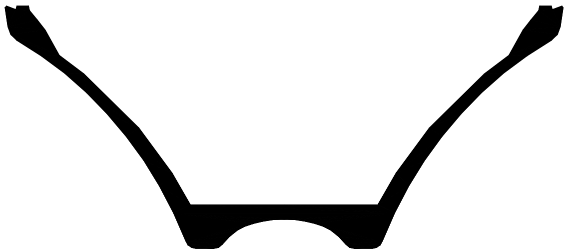
Thin webbed roof elements

NG-PL

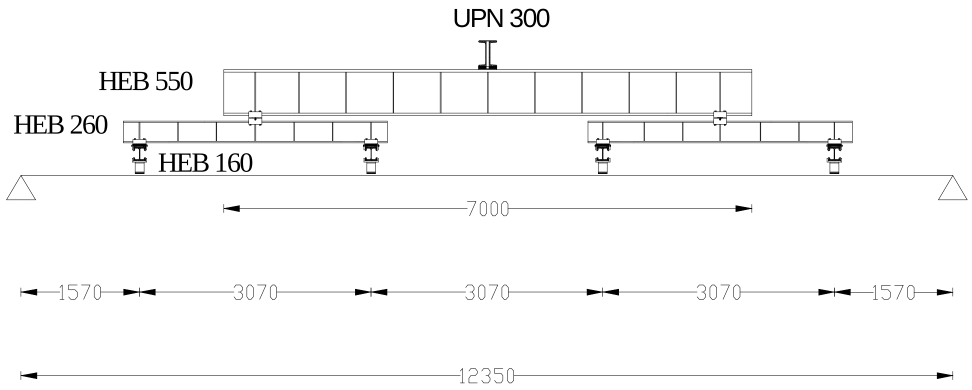
Planet

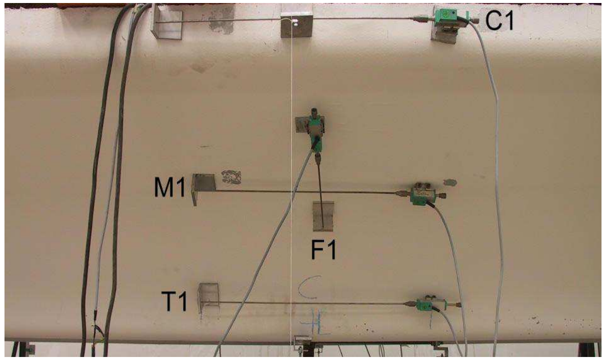


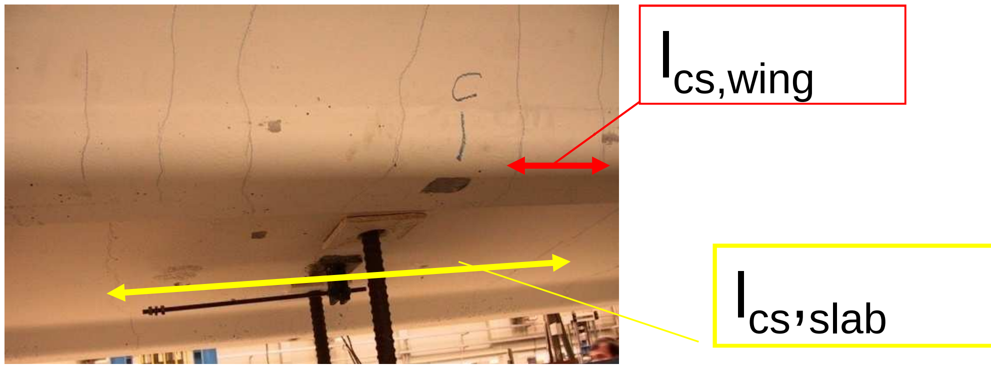
Tecnoplan



Bending tests on roof elements

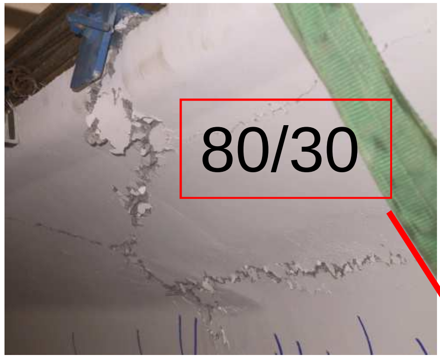




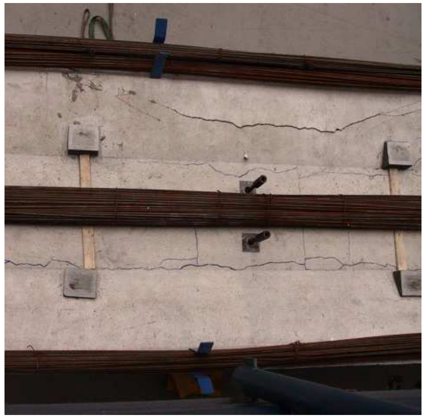


by di Prisco, Failla,Plizzari, 2003

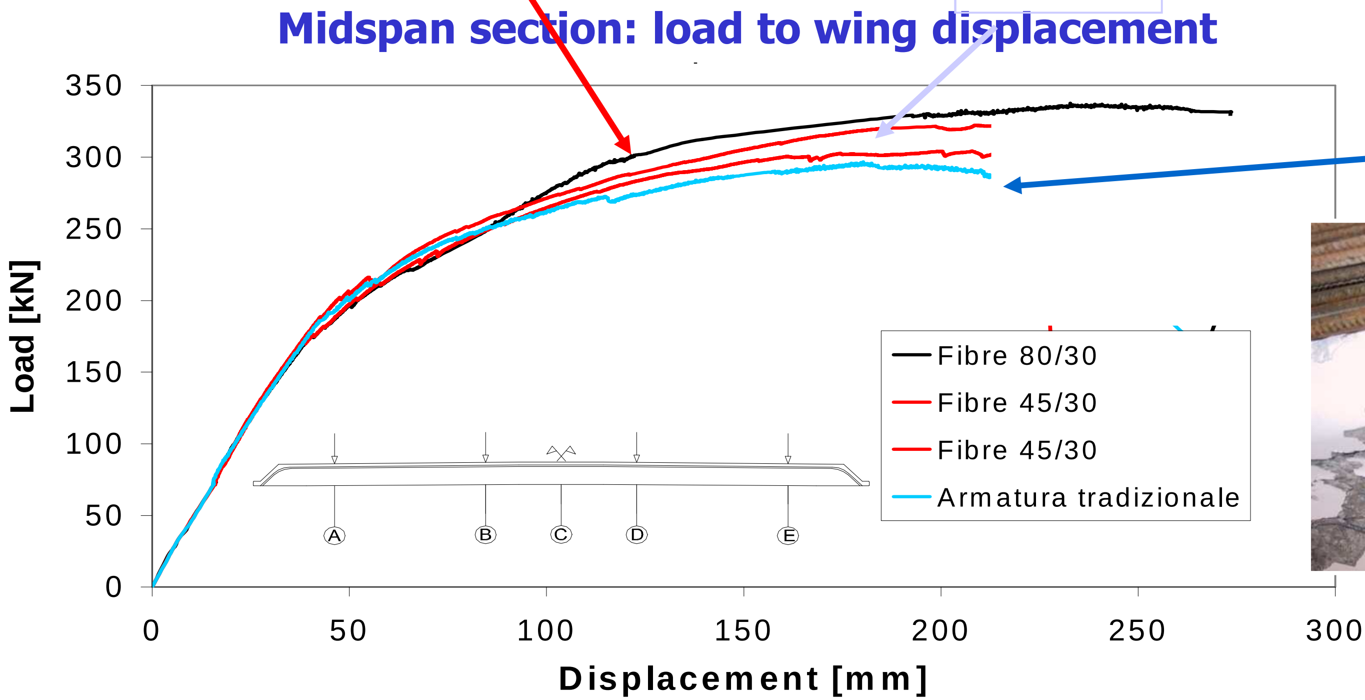
Test di flessione su elementi di copertura



45/30

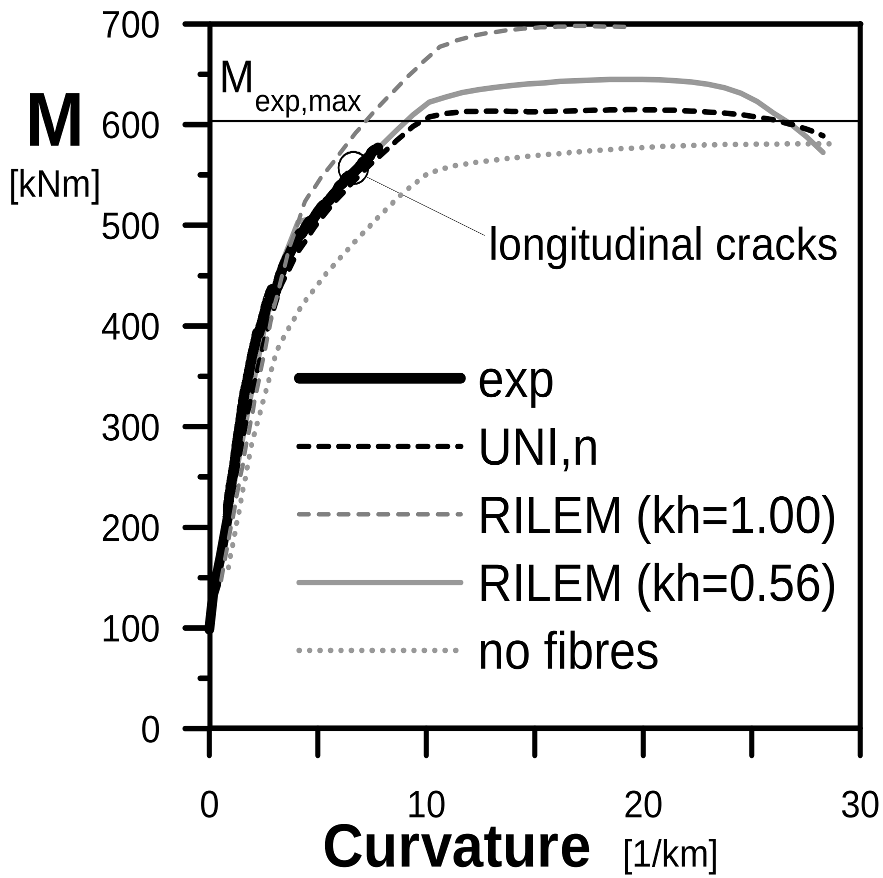


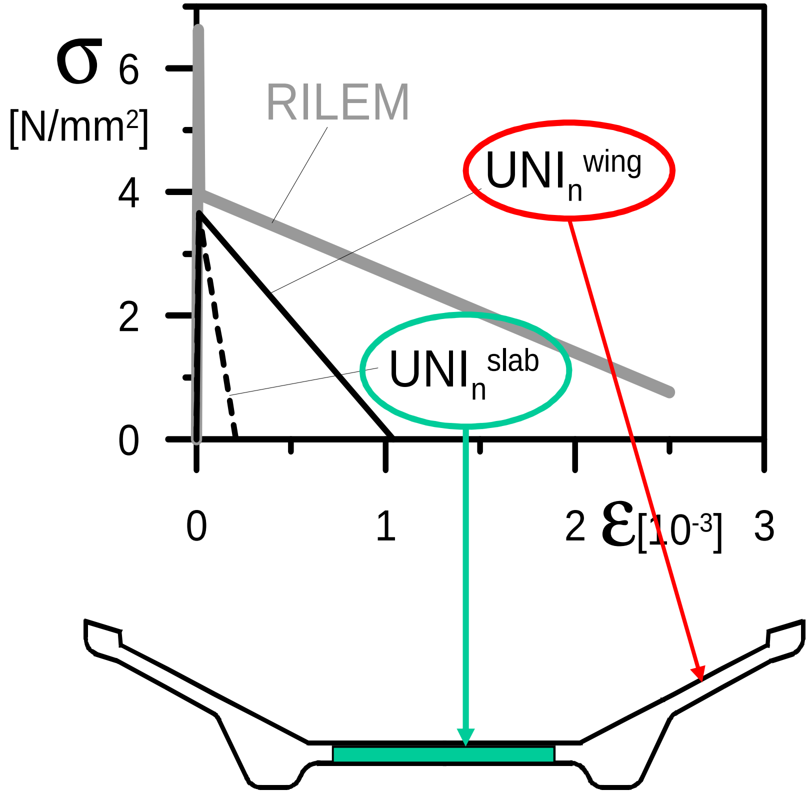
R/C



by di Prisco, Failla,Plizzari, 2003

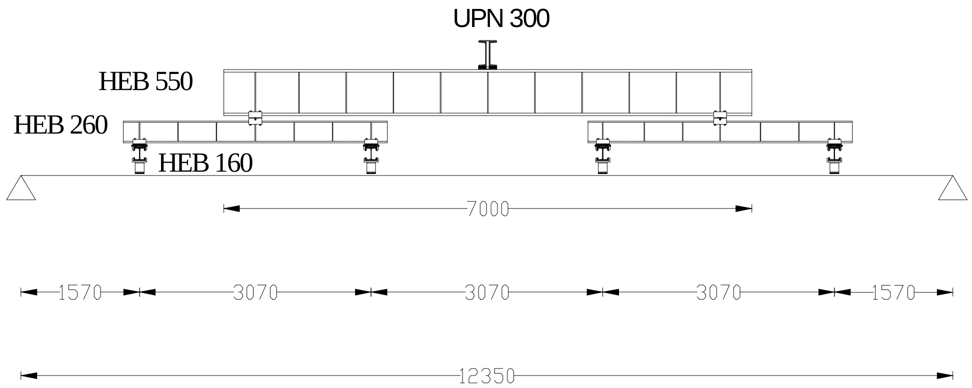
Test data	t_j [day]	f_{cm} [MPa]	fibre	C_f [kg/m^3]	$M_{R,CEB}$ [kNm]	$M_{R,EC2}$ [kNm]	$M_{R,sper}$ [kNm]	Weight [kg]	failure
25/07/02	69	72.05	45/30	50	614.8 (+1.9%)	567.7 (-5.9%)	603.4	6580	lb / wing
30/07/02	56	67.00	80/30	50	634.5 (+1.5%)	567.7 (-9.2%)	625.1	6500	lb / wing
06/09/02	35	74.07	-	-	582.3 (+5.9%)	567.7 (+3.3%)	549.6	5780	lb / wing

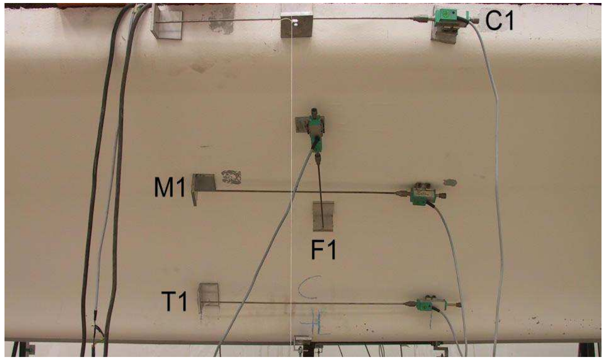




Bending tests on roof elements

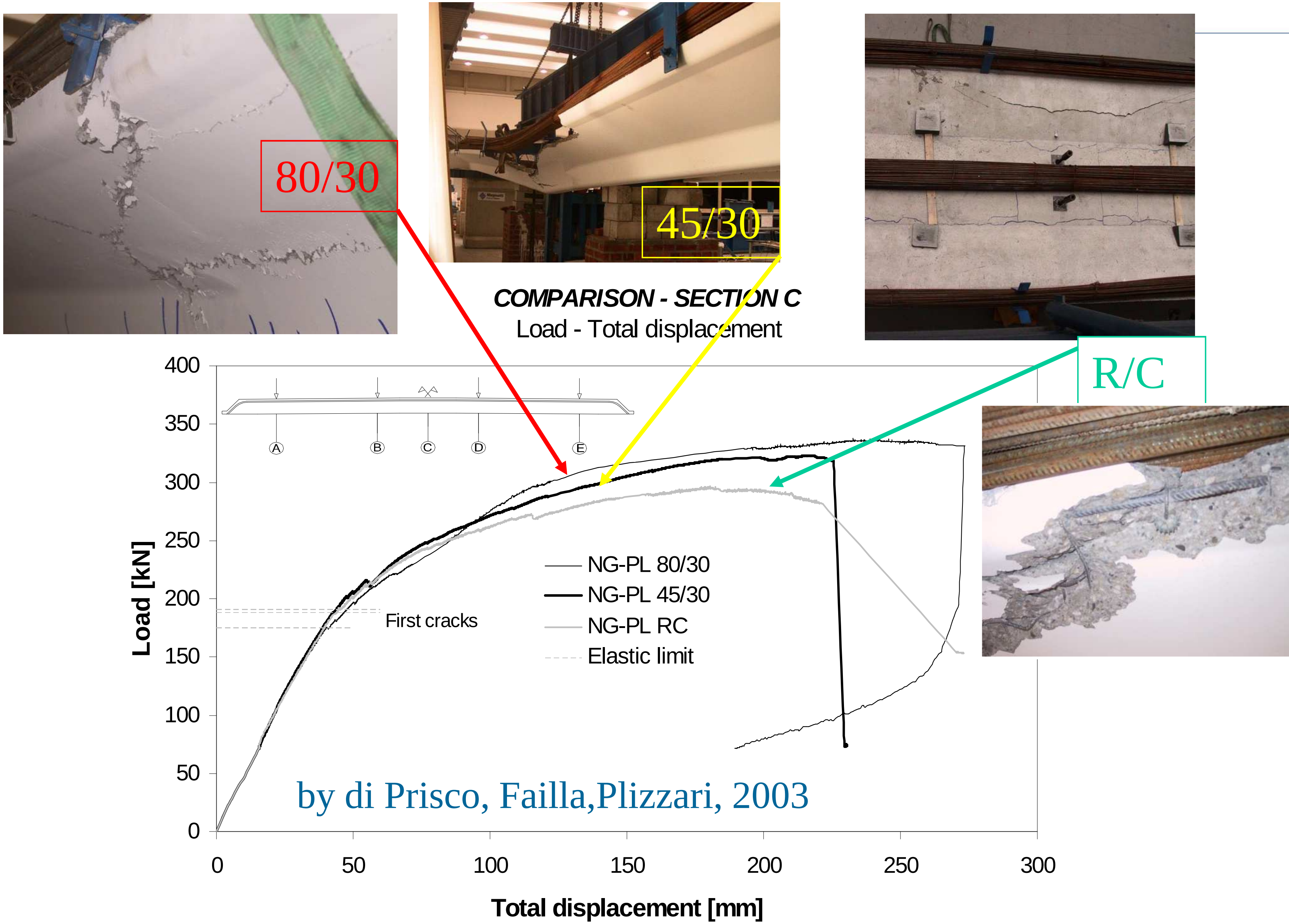
by di Prisco, Failla,Plizzari, 2003





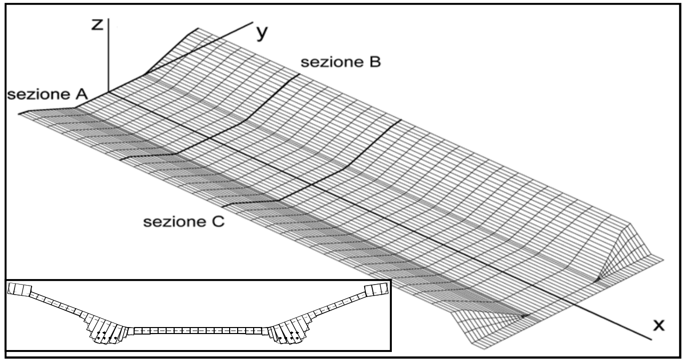
$l_{cs,wing}$

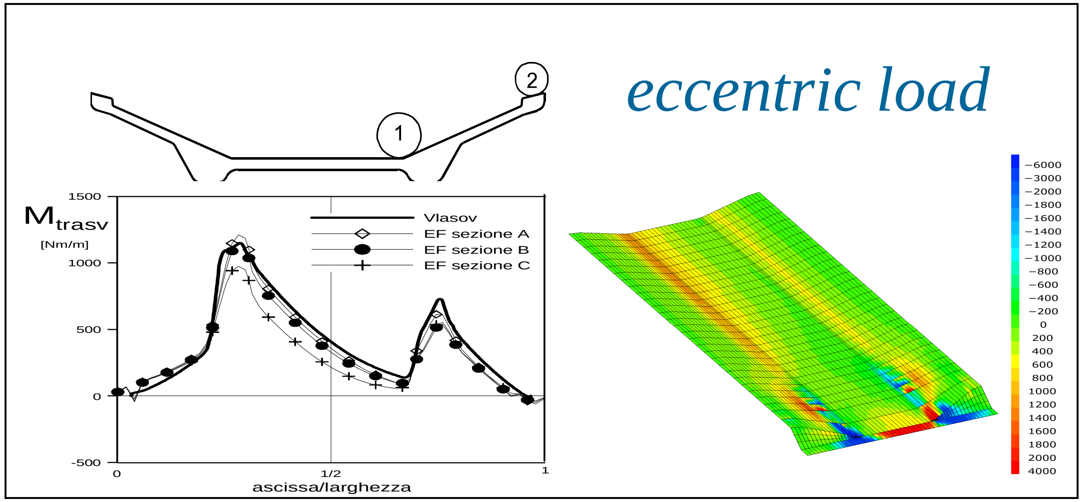
$l_{cs,slab}$

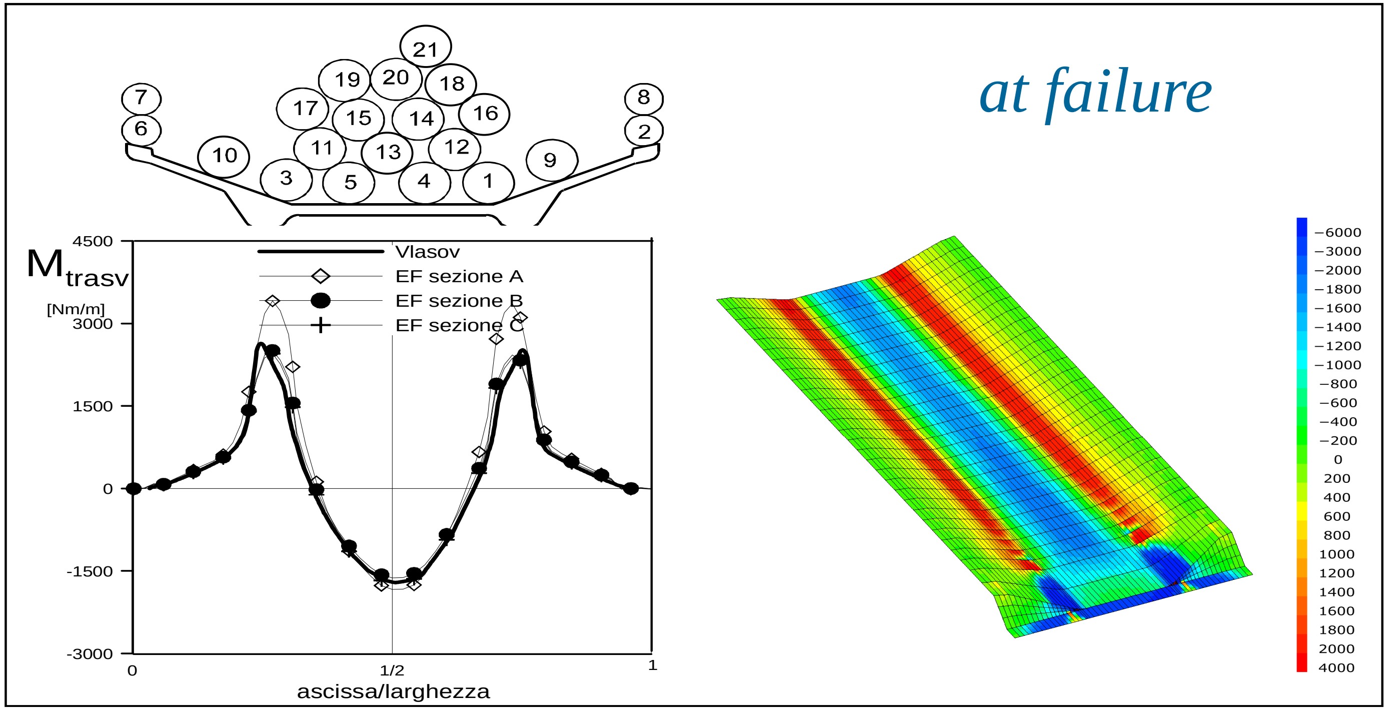


80/30
45/30
R/C
COMPARISON - SECTION C
Load - Total displacement
Load [kN]
Total displacement [mm]
0
50
100
150
200
250
300
350
400
0
50
100
150
200
250
300
A
B
C
D
E
First cracks
NG-PL 80/30
NG-PL 45/30
NG-PL RC
Elastic limit
by di Prisco, Failla,Plizzari, 2003

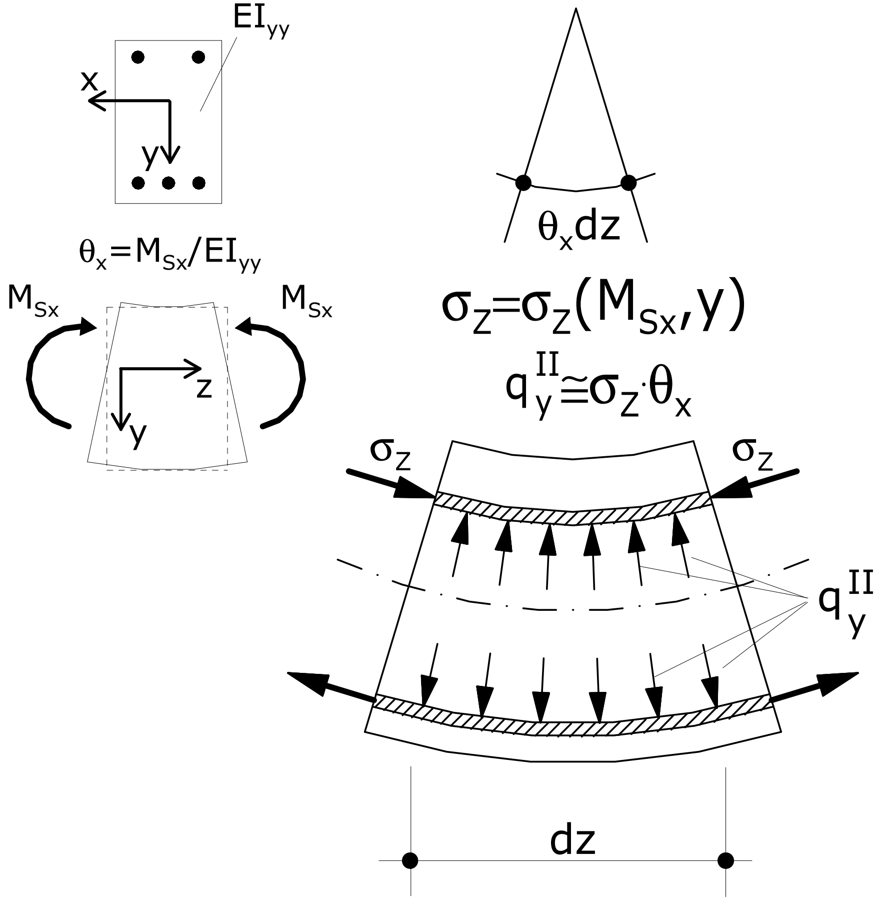
elastic check by FE



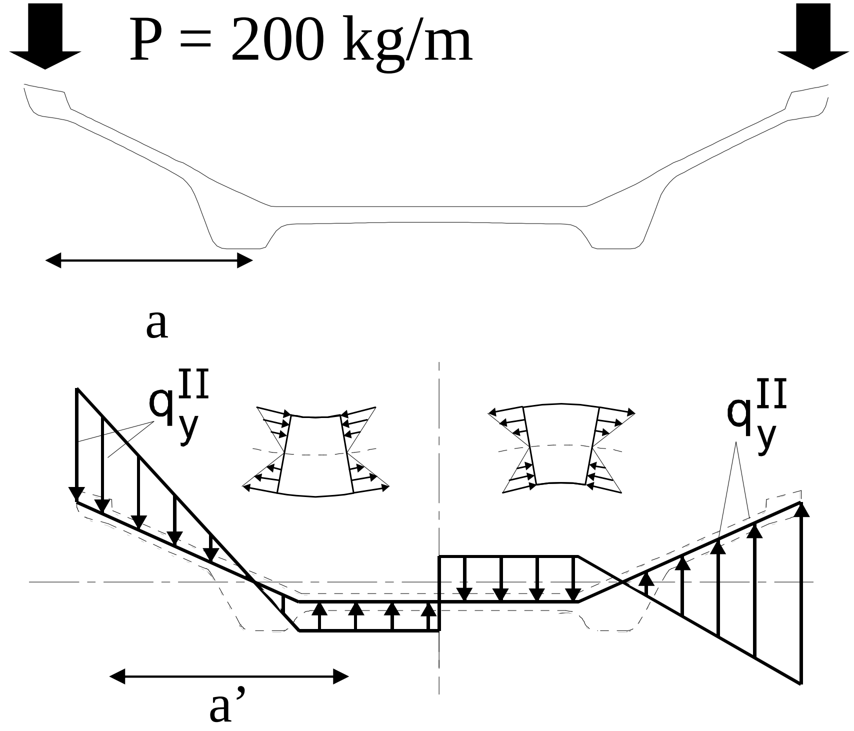




Simplified model



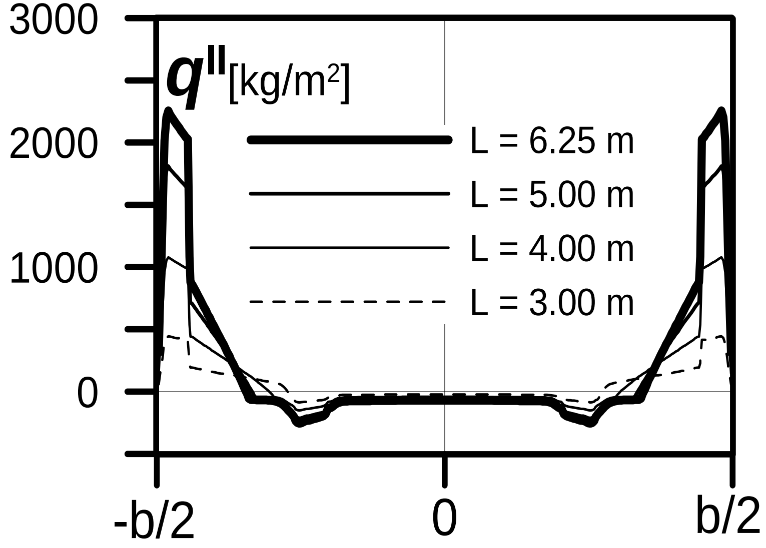
II order equilibrium

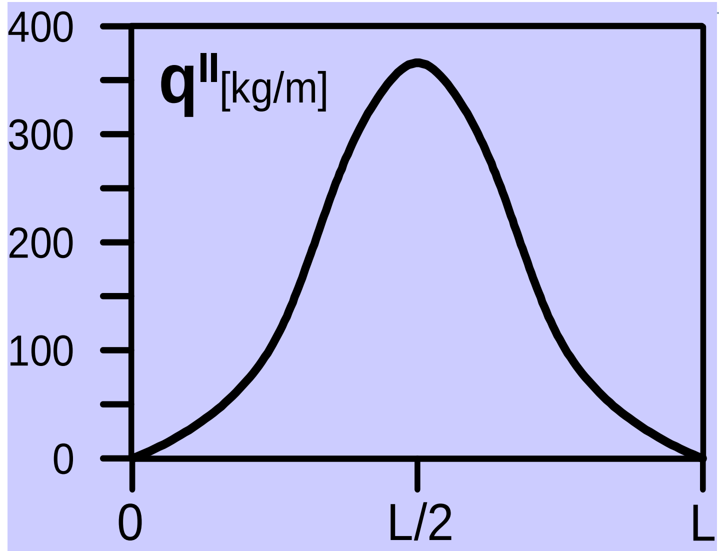


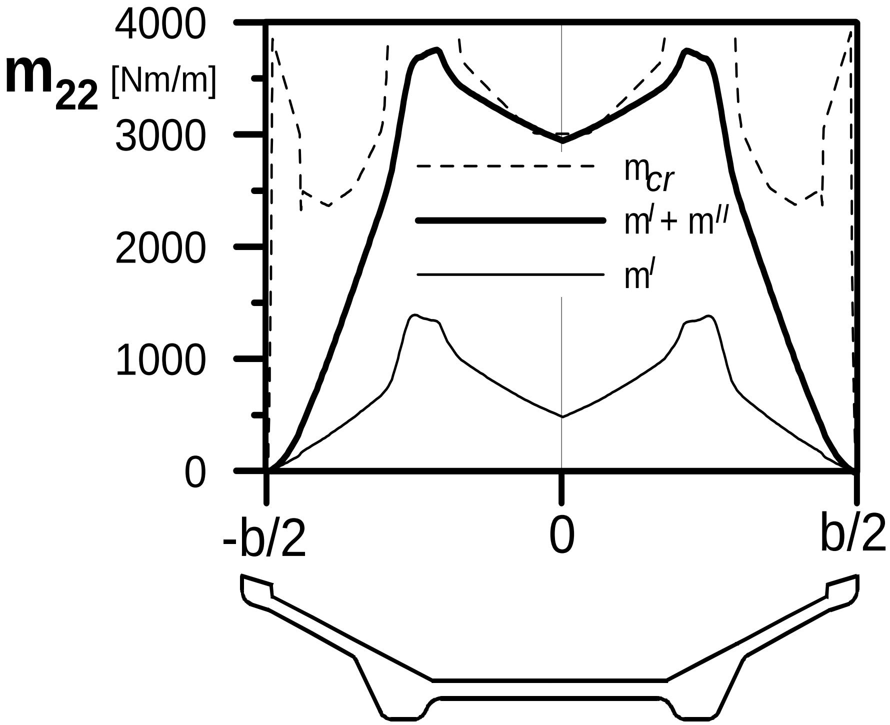
$M^{I} = Pa \approx 2$ N/mm*a

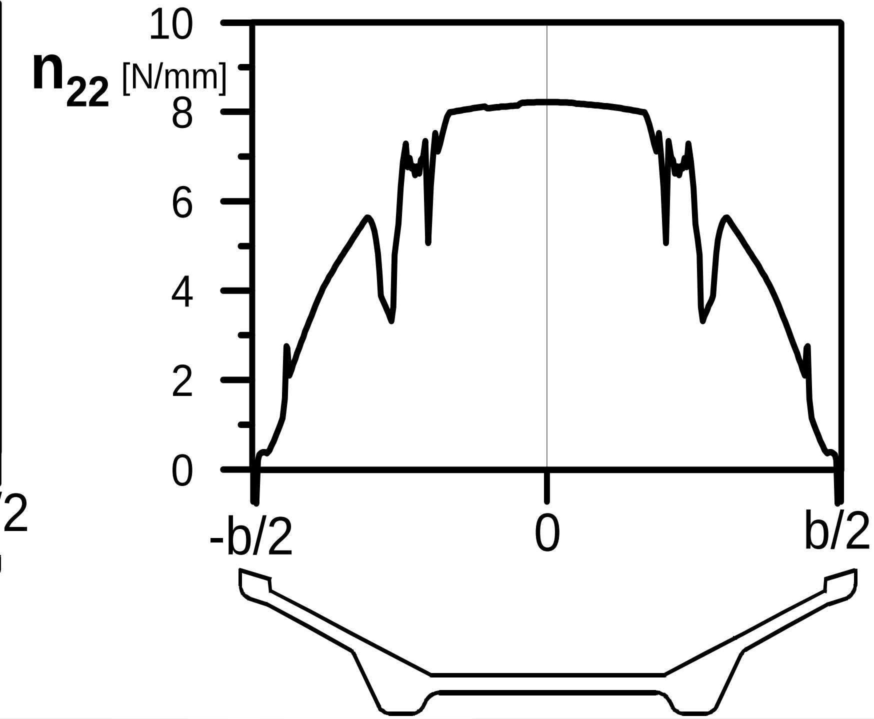
$M^{II} = \sigma_z*10^4 mm^2*10^{-5} mm^{-1}*a' =$

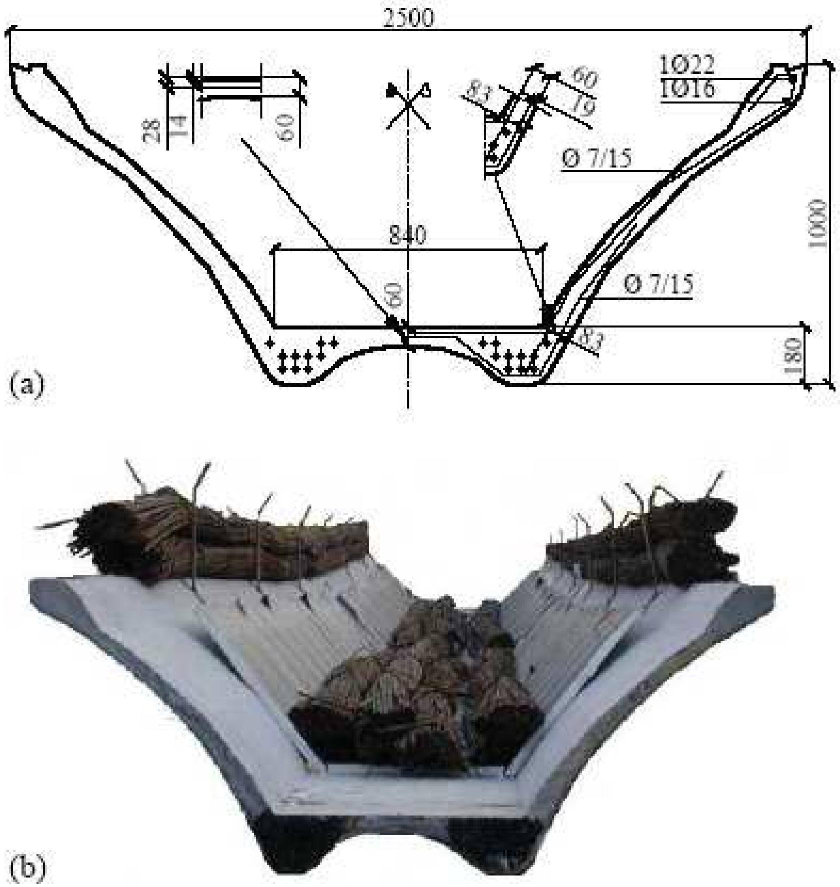
$= 40 N/mm^2*0.1mm*a'=4$ N/mm*a’


3000
2000
1000
0
q^II [kg/m²]
L = 6.25 m
L = 5.00 m
L = 4.00 m
L = 3.00 m
-b/2
0
b/2


400
300
200
100
0
q^II [kg/m]
0
L/2
L


4000
3000
2000
1000
0
m22 [Nm/m]
mcr
m/ + m//
m/
-b/2
0
b/2


10
8
6
4
2
0
n22 [N/mm]
-b/2
0
b/2



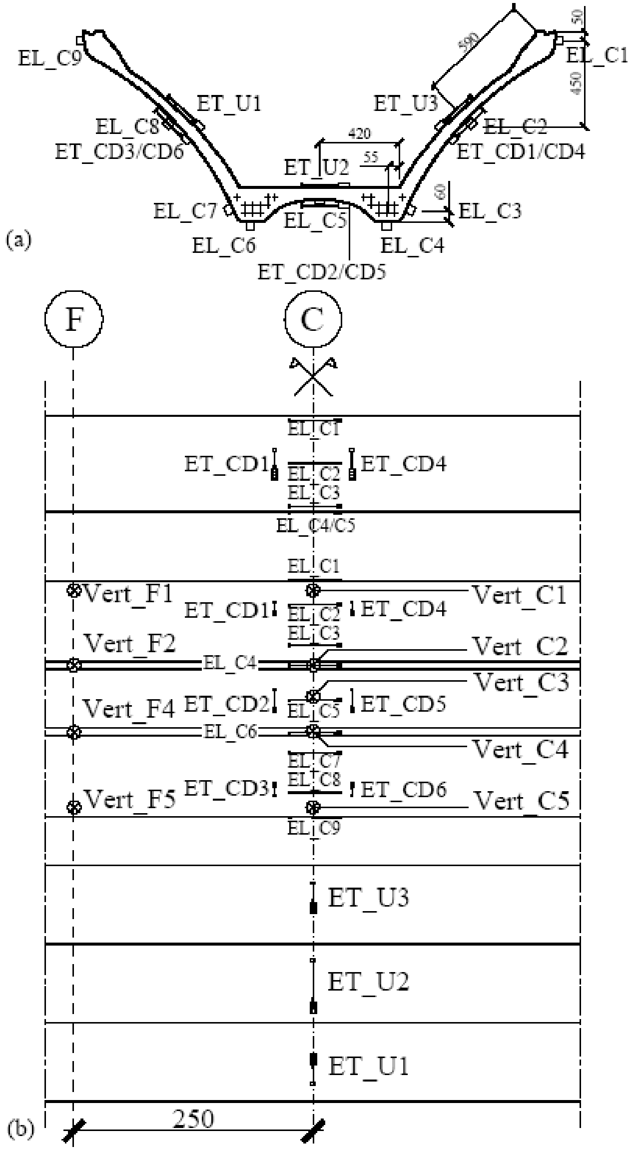


Figure 2. Instrumental equipment in the central segment: (a) cross section view; (b) longitudinal projections.

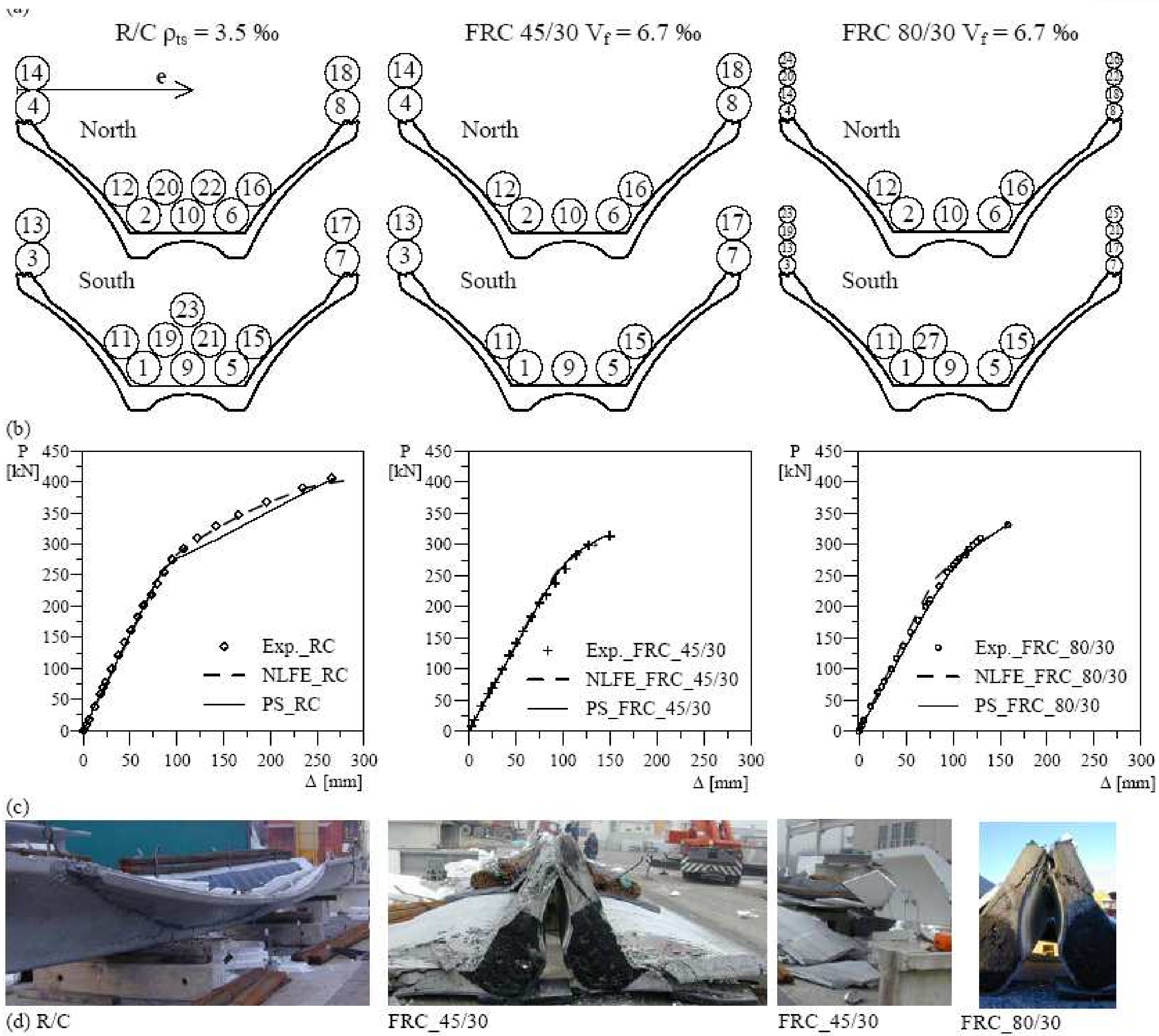
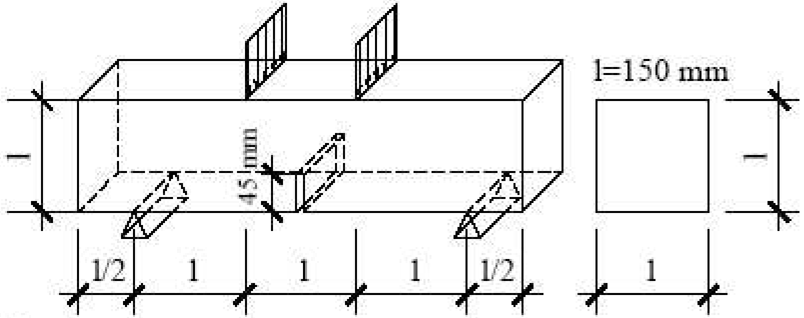


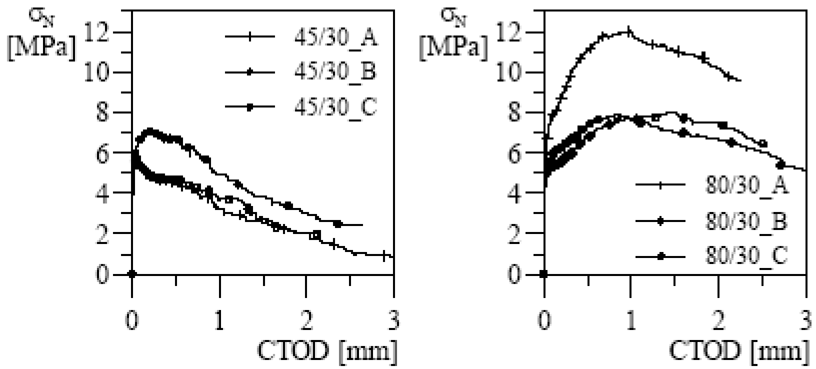
Figure 3. Structural tests: (a) typical loading situation view; (b) steel bundle location, (c) total load vs. midspan deflection measured with bottom LVDTs; (d) collapse views.



(a)

(b)

Figure 4. UNI test: (a) geometry and test set-up; (b) specimen image during testing.



(a) (b)

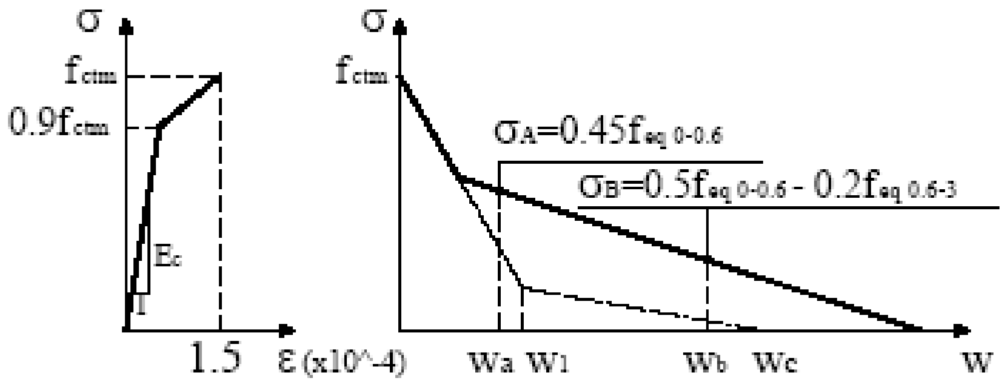
Figure 5. Load vs. CTOD for UNI tests: (a) 45/30; (b) 80/30

Table 1. Experimental mechanical characteristics of materials.

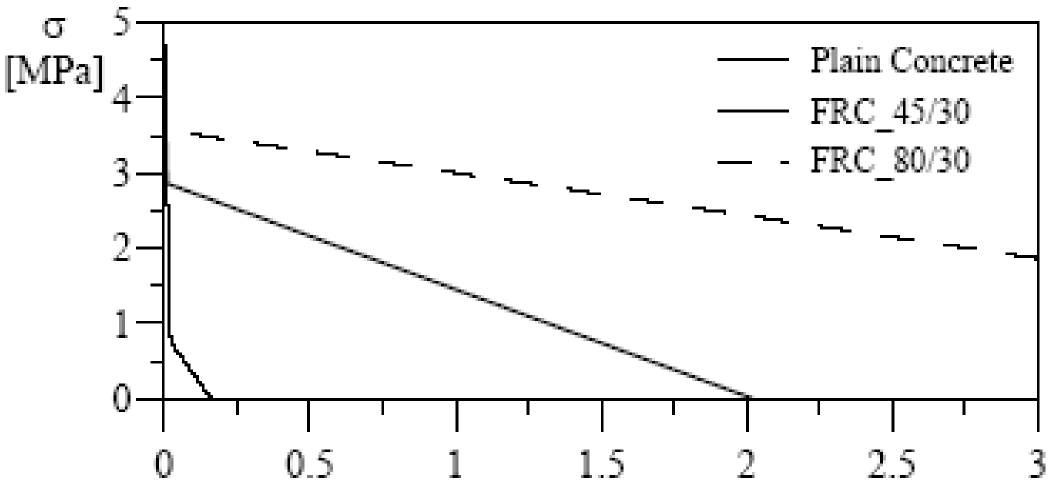
	R_{cm}	$f_{lf,m}$	$f_{eq0-0.6m}$	$f_{eq0.6-3m}$	f_{yk}	f_{ptk}
	MPa	MPa	MPa	MPa	MPa	MPa
R/C	82.58	-	-	-	500	1860
45/30	75.65	5.22	5.44	2.80	-	1860
80/30	73.20	5.22	7.56	8.12	-	1860

Table 2. Computed mechanical characteristics of materials.

	E_c	ν	f_c	f_{ct}	σ_a	w_a	σ_b	w_b
	MPa		MPa	MPa	MPa	mm	MPa	mm
R/C	39193	0.2	68.54	5.02	-	-	-	-
45/30	38176	0.2	62.79	4.70	2.45	0.3	0.31	1.8
80/30	37801	0.2	60.76	4.70	3.40	0.3	2.55	1.8

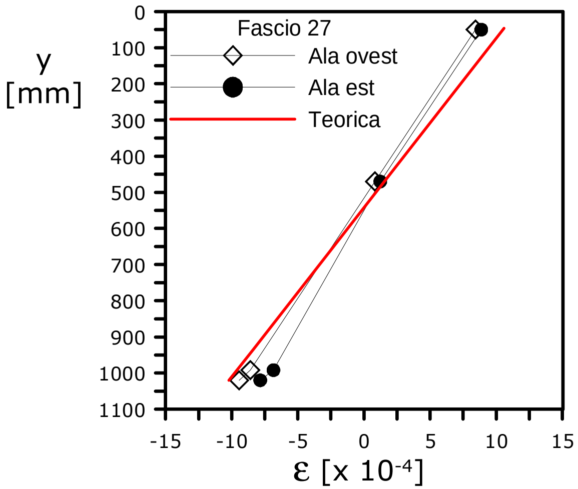

σ
f_ctm
0.9f_ctm
Ec
1
1.5
ε (x10^-4)
σ
f_ctm
σA=0.45f_eq 0-0.6
σB=0.5f_eq 0-0.6 - 0.2f_eq 0.6-3
Wa
W1
Wb
Wc
W

(a)

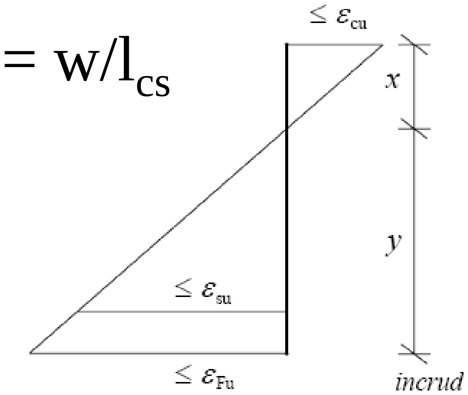

σ
[MPa]
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
3
Plain Concrete
FRC_45/30
FRC_80/30

Two theoretical approaches

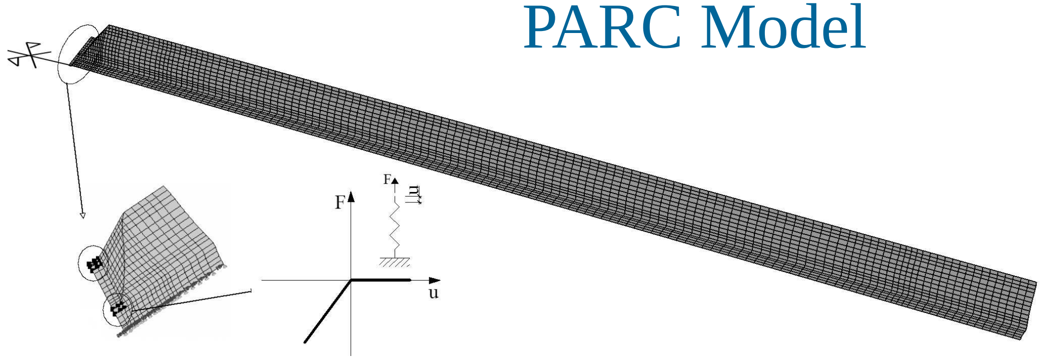
Plane Section

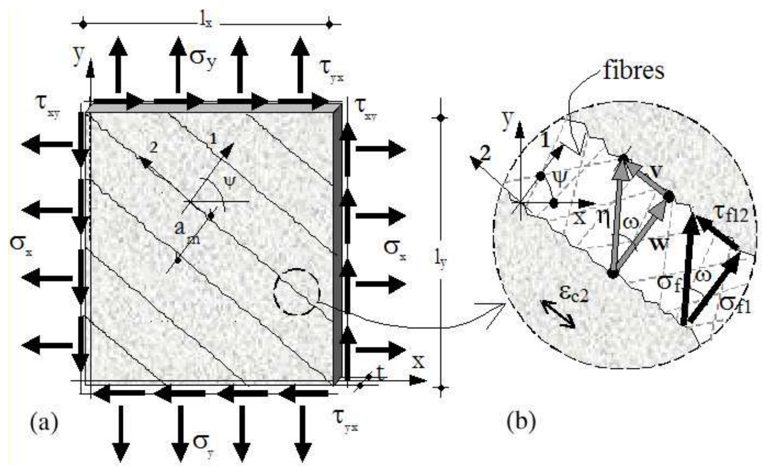


$$\varepsilon = w/l_{cs}$$

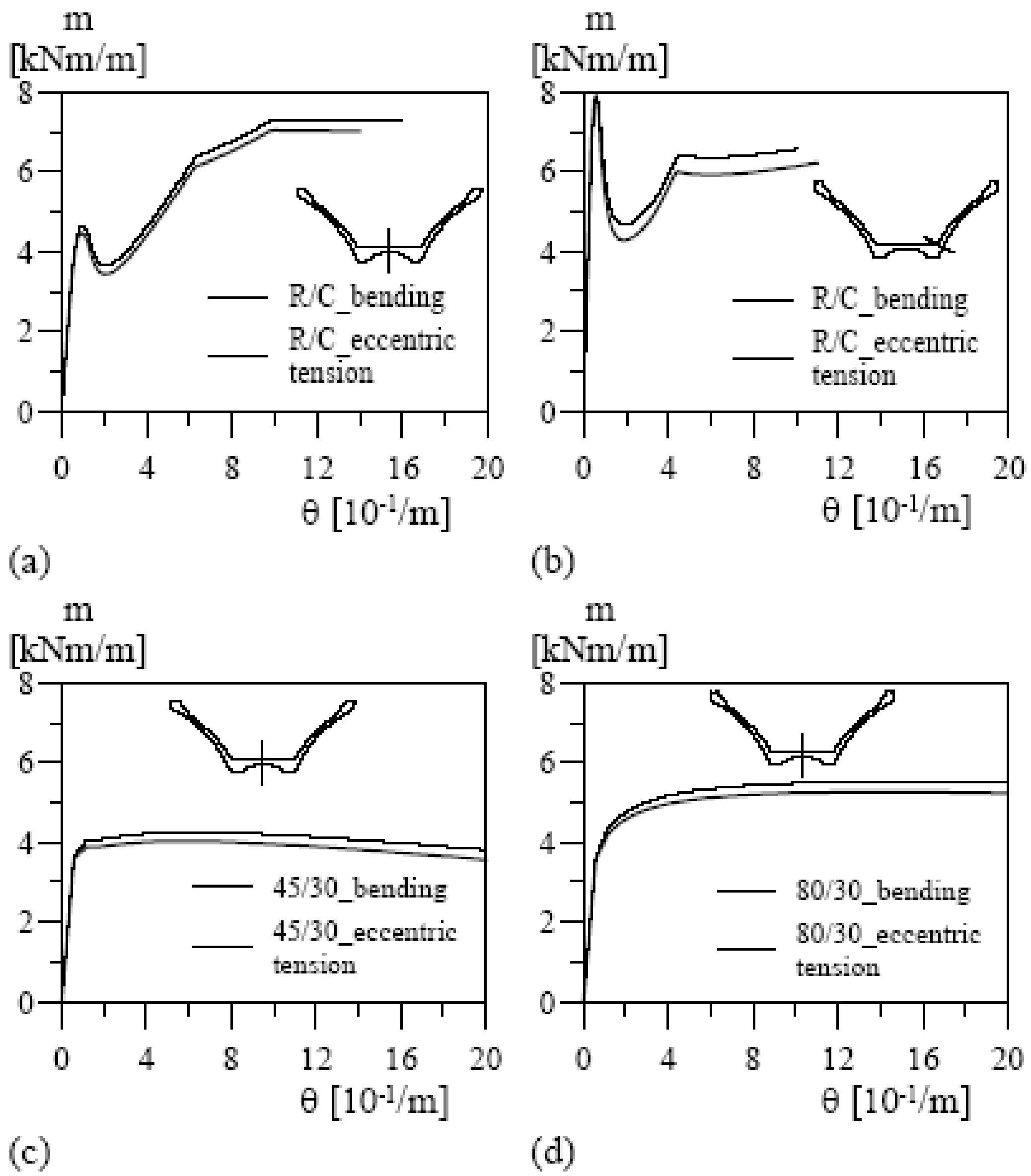


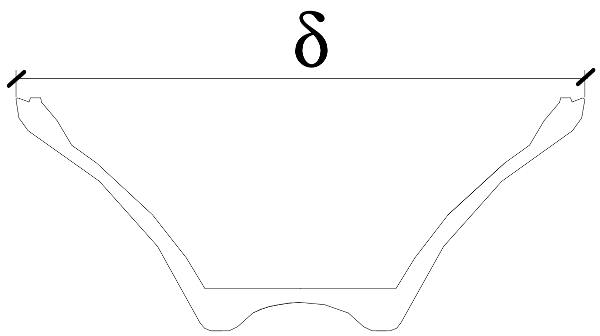
Finite Element & PARC Model

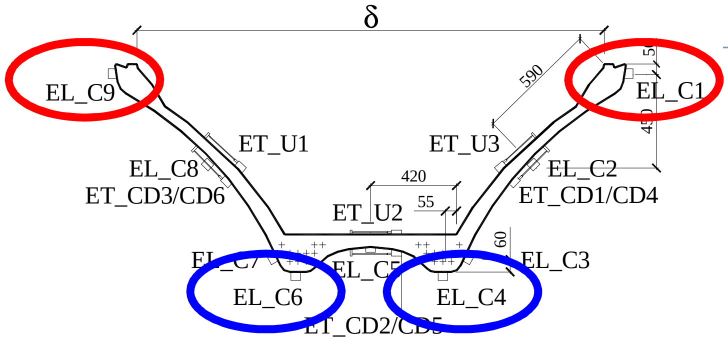


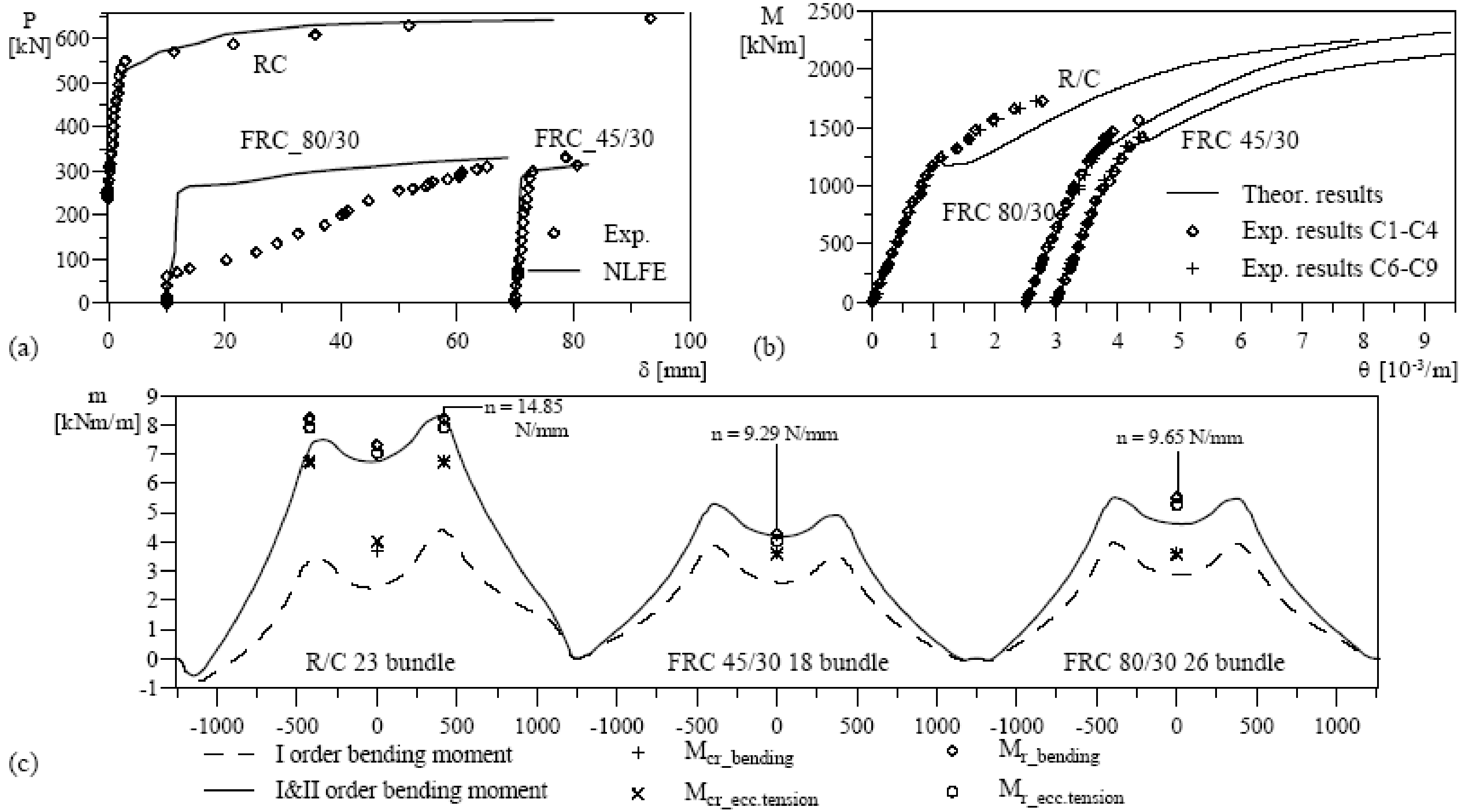


by Belletti,Cerioni, Iori, 2002

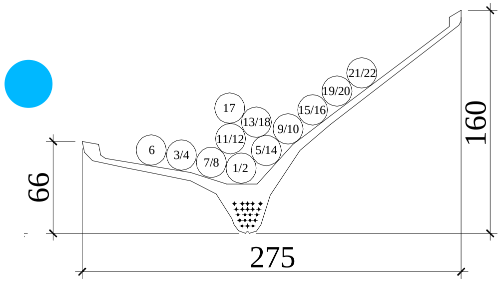

m
[kNm/m]
8
6
4
2
0
0
4
8
12
16
20
θ [10-1/m]
R/C_bending
R/C_eccentric
tension
(a)
m
[kNm/m]
R/C_bending
R/C_eccentric
tension
(b)
m
[kNm/m]
45/30_bending
45/30_eccentric
tension
(c)
m
[kNm/m]
80/30_bending
80/30_eccentric
tension
(d)


δ


δ
EL_C9
EL_C1
590
ET_U1
ET_U3
EL_C8
EL_C2
ET_CD3/CD6
ET_CD1/CD4
420
55
ET_U2
60
EL_C7
EL_C5
EL_C3
EL_C6
EL_C4
ET_CD2/CD5

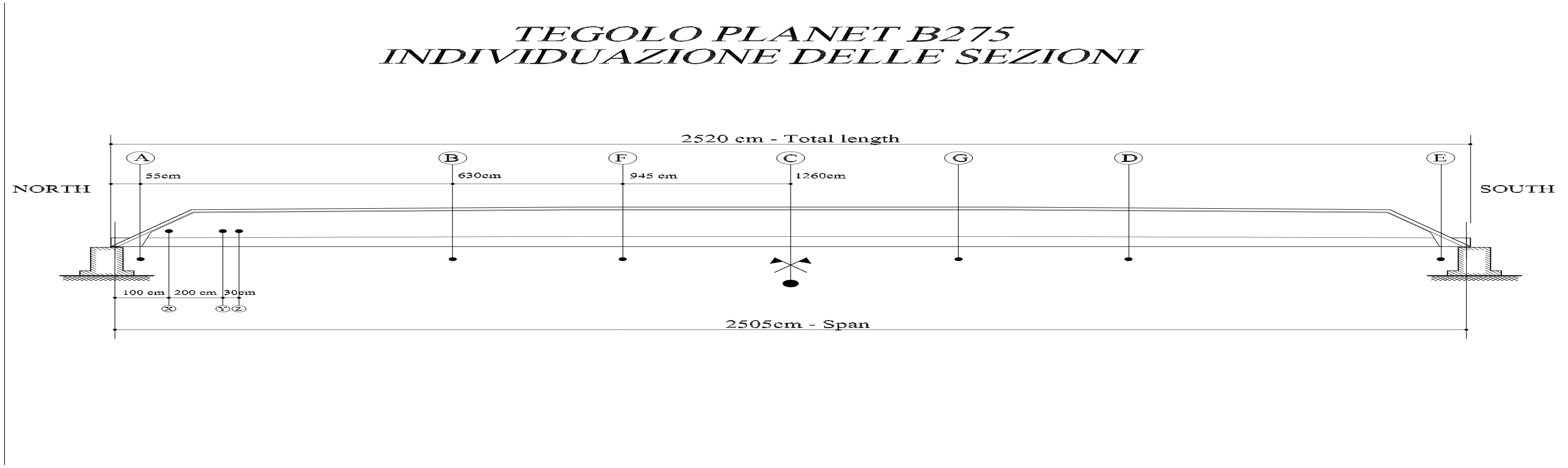

P [kN]
RC
FRC_80/30
FRC_45/30
Exp.
NLFE
(a)
δ [mm]
M [kNm]
R/C
FRC 45/30
FRC 80/30
Theor. results
Exp. results C1-C4
Exp. results C6-C9
(b)
θ [10^-3/m]
m [kNm/m]
n = 14.85 N/mm
n = 9.29 N/mm
n = 9.65 N/mm
R/C 23 bundle
FRC 45/30 18 bundle
FRC 80/30 26 bundle
(c)
I order bending moment
I&II order bending moment
M_cr_bending
M_cr_ecc.tension
M_r_bending
M_r_ecc.tension

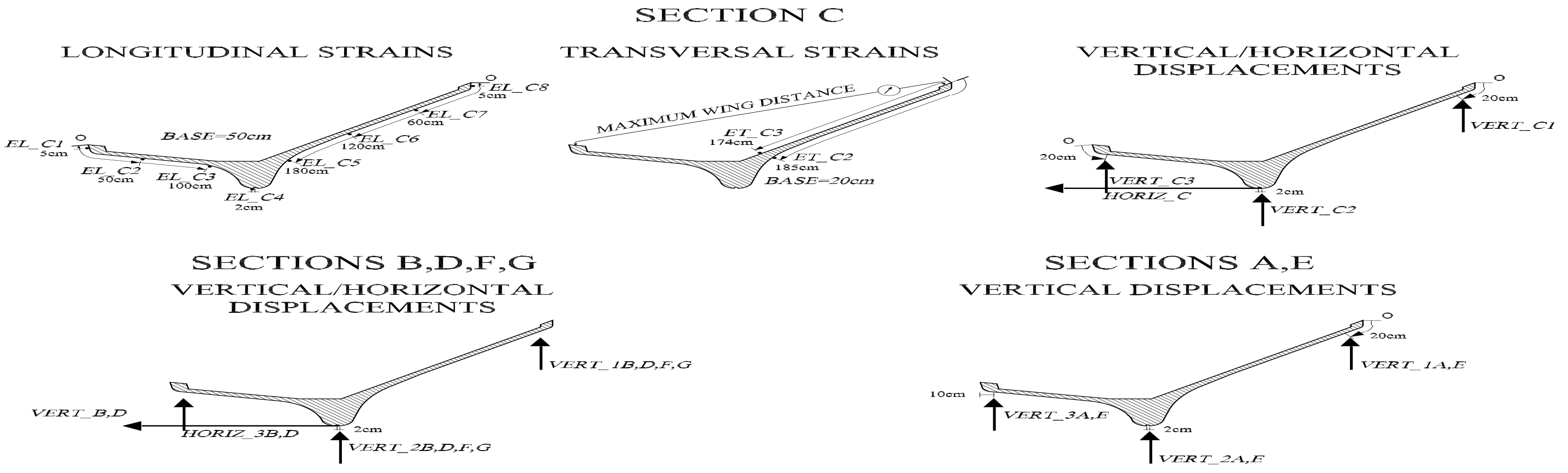
Real-size structures



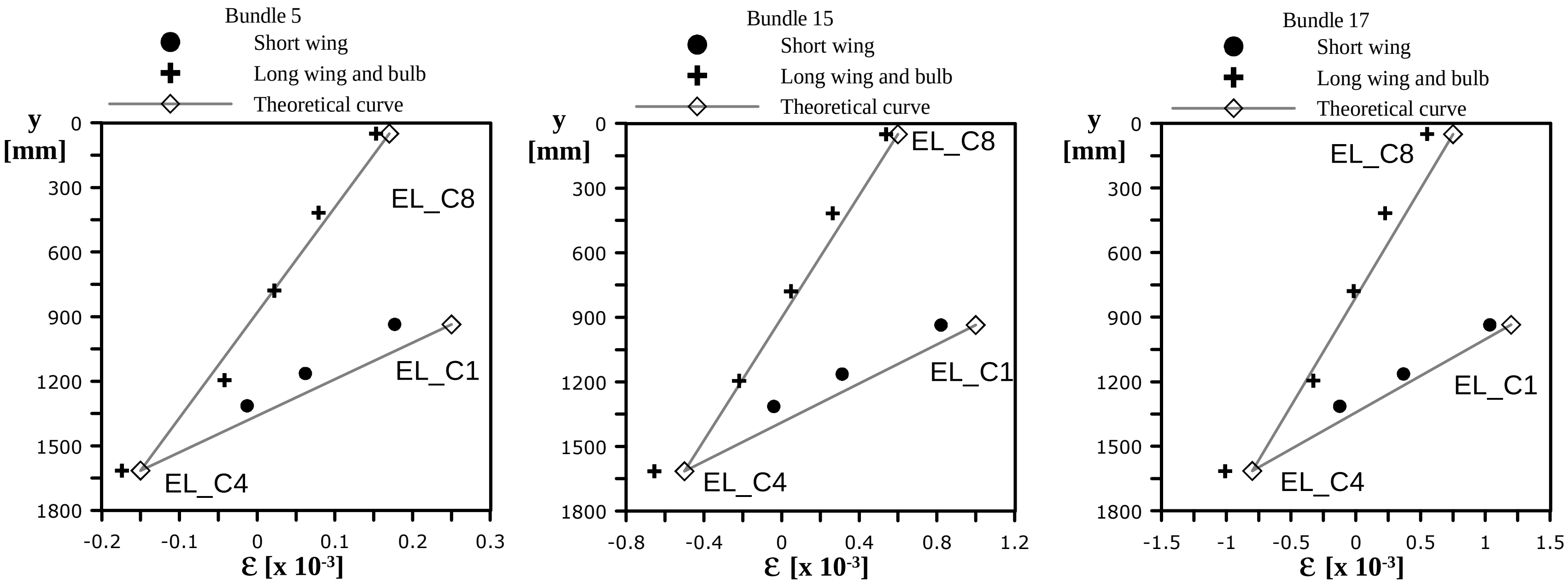
Element	Age [days]	Fibre	R_{cm} [MPa]	Element weight [kg]
P 70 00	17	-	71.20	22840
F 95 45	63	45/30	92.70	18740
F 60 45	45	45/30	62.25	18820
F 110 80	75	80/30	109.90	18480

Real-size structures





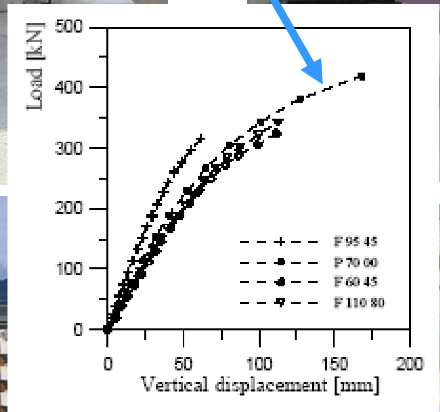
Real-size structures

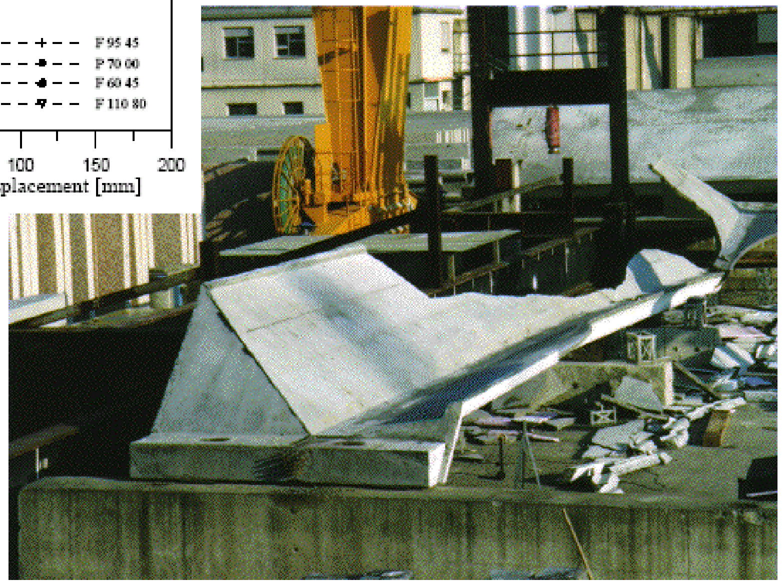


Precast Element	P [kN]	M_{CEB} [kNm]	M_{EC2} [kNm]	M_{EXP} [kNm]
P 70 00	418.80	2565 (+26.8%)	2461 (+20.3%)	2023
F 95 45	351.48	2383 (+40.4%)	2232 (+31.5%)	1697
F 60 45	343.01	2090 (+25.8%)	2042 (+22.9%)	1661
F 110 80	342.40	2530 (+53.4%)	2294 (+39.1%)	1649

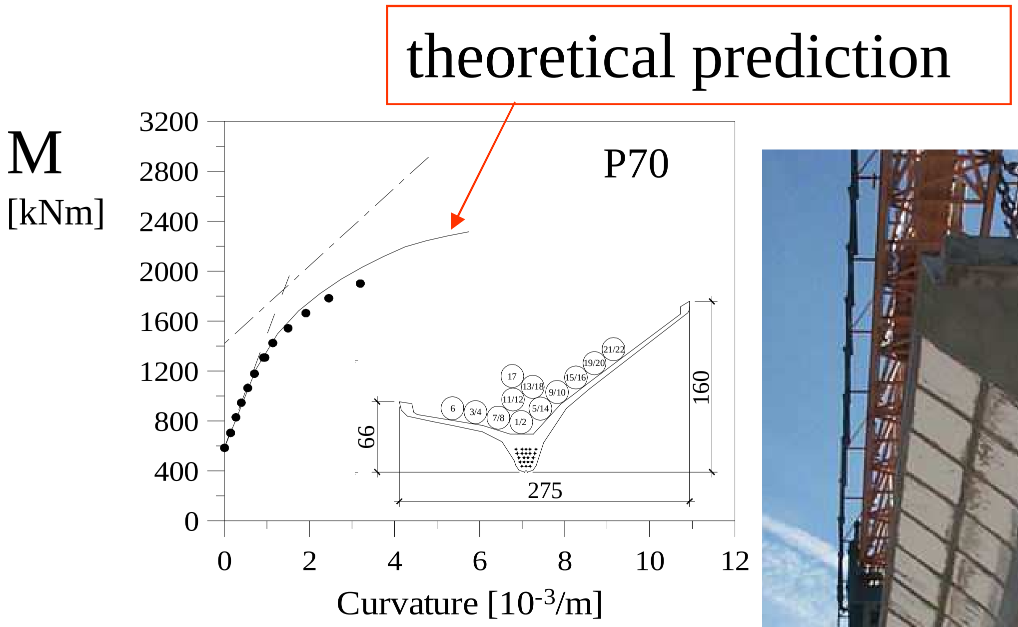
-35%

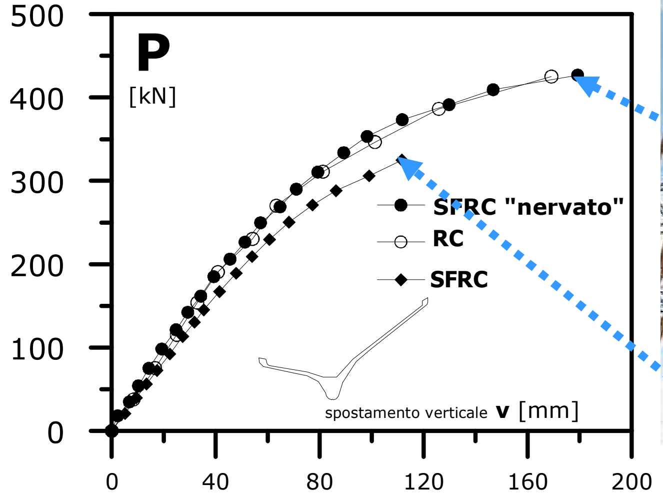
Full-size structures





Real-size structures

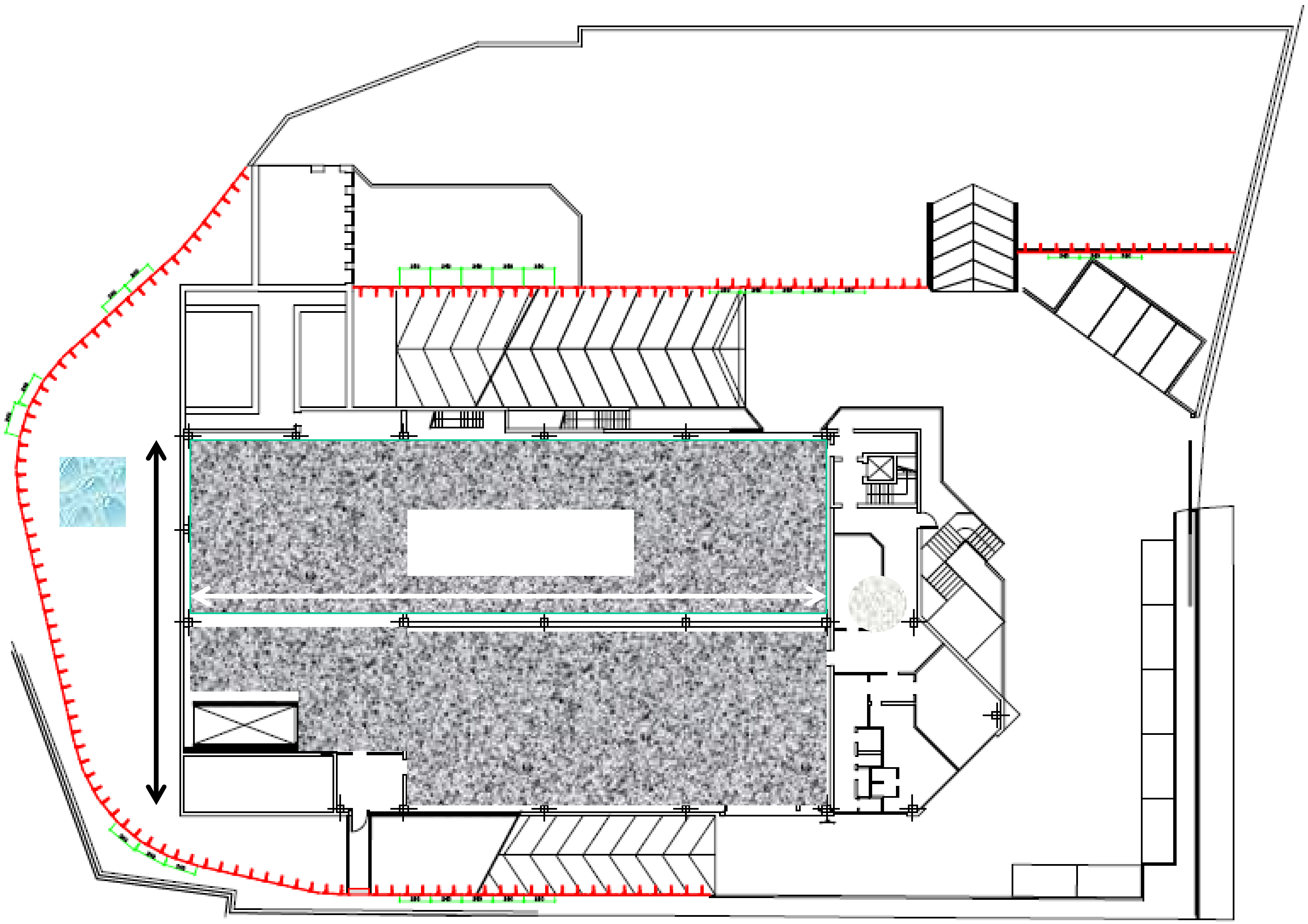


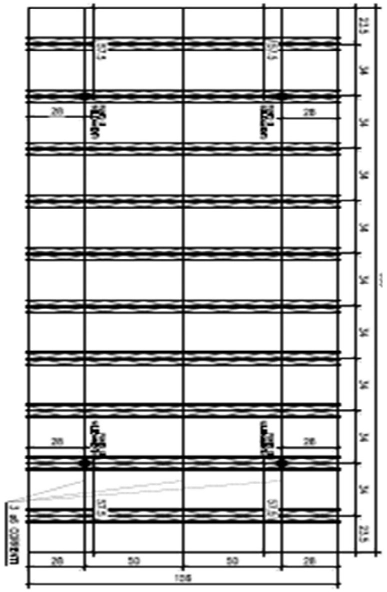


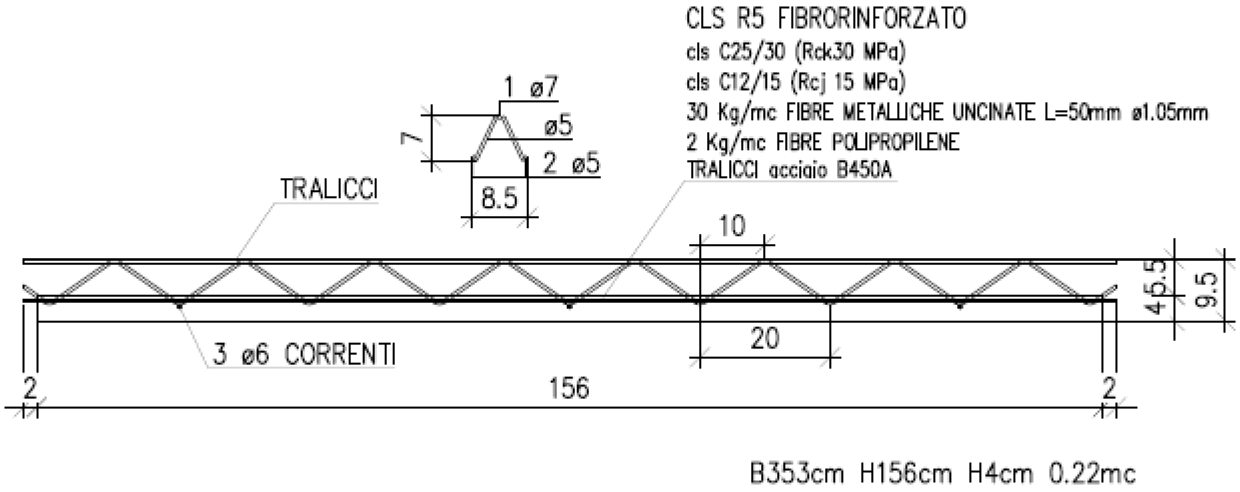
Precast elements
for partially precast elevated slabs

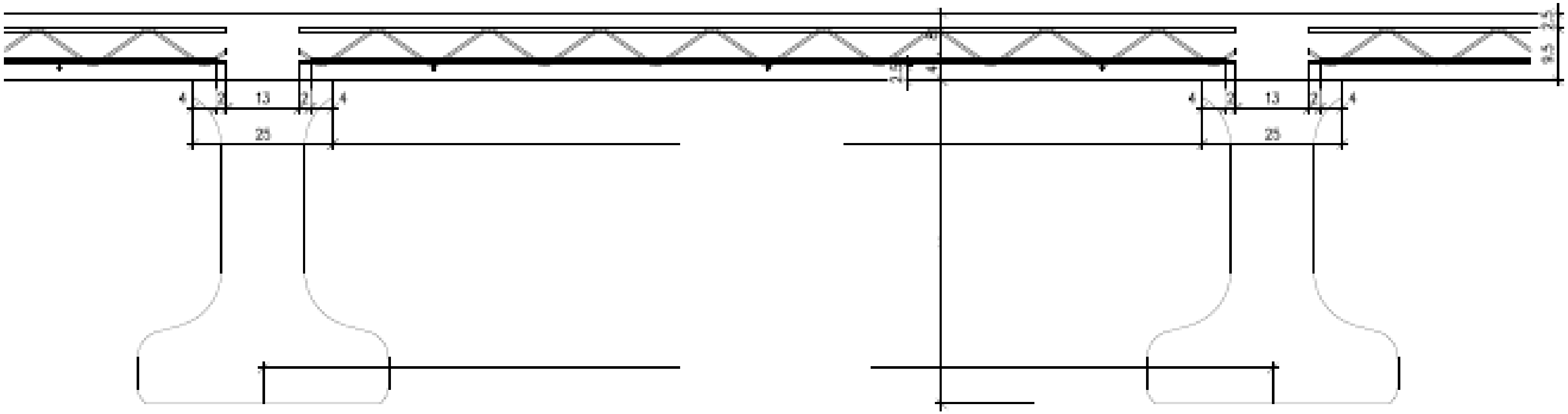
Outline

- engineering framework
- materials adopted
- characterization tests
- beam tests
- slab tests
- final deck test
- concluding remarks




26
50
50
26
156


CLS R5 FIBRORINFORZATO
cls C25/30 (Rck30 MPa)
cls C12/15 (Rcj 15 MPa)
30 Kg/mc FIBRE METALLICHE UNCINATE L=50mm ø1.05mm
2 Kg/mc FIBRE POLIPROPILENE
TRALICCI acciaio B450A
1 ø7
ø5
2 ø5
7
8.5
TRALICCI
10
4.5
5
9.5
20
3 ø6 CORRENTI
2
156
2
B353cm H156cm H4cm 0.22mc


4
2
13
2
4
25
4
2
13
2
4
25

Classes required by the designer for prefabricated elements and cast on site concrete

C45/55; 4c

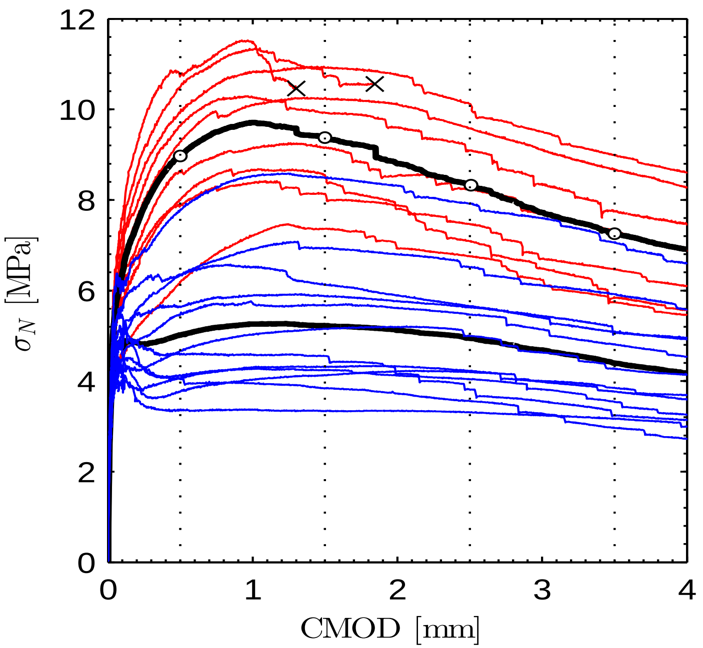
C28/35; 3c

Table 1 Concrete mix composition for: beams and predalles (Mixture 1) and top layer slab (Mixture 2)

Mixture 1	**Amount [kg/m³]**	**Mixture 2**	**Amount [kg/m³]**
Cement CEM I 52.5R	380	Cement CEM IV/A 42.5R LH	470
Limestone filler	100		
Water SSD	190	Water SSD	188
Sand 0/4	620	Sand 0/4	1008
Mixed sand 0/12	440	Mixed sand 0/8	504
Coarse aggregates 8/15	710	Coarse aggregates 8/14	171
Superplasticizer	5.5 (slab)	Superplasticer	7.6
	7.0 (beam)	Shrinkage reducer	4.0
Steel fibres (Dramix 3D 65-60)	40-60	Steel fibres (Dramix 4D 65-60)	30/50/35
Polypropylene fibers	1.5 (slab) - 1.0 (beam)		

Table 2 Identified material properties of Mixture 1 for various amounts of fibre content

Mixture	Parameter	Unit	$f_{ct,L}^{f}$	$f_{R,1}$	$f_{R,2}$	$f_{R,3}$	$f_{R,4}$
Mixture 1 – 40 kg/m³	*N*	[-]	12	12	12	12	12
	mean	[MPa]	4.62	5.02	5.22	4.95	4.40
	st. dev.	[MPa]	0.63	1.31	1.48	1.36	1.24
	COV	[%]	13.63	26.11	28.26	27.49	28.17
Mixture 1 – 60 kg/m³	*N*	[-]	9	9	8	7	7
	mean	[MPa]	5.56	8.97	9.38	8.33	7.25
	st. dev.	[MPa]	0.65	1.46	1.28	1.30	1.30
	COV	[%]	11.65	16.22	13.68	15.58	17.94



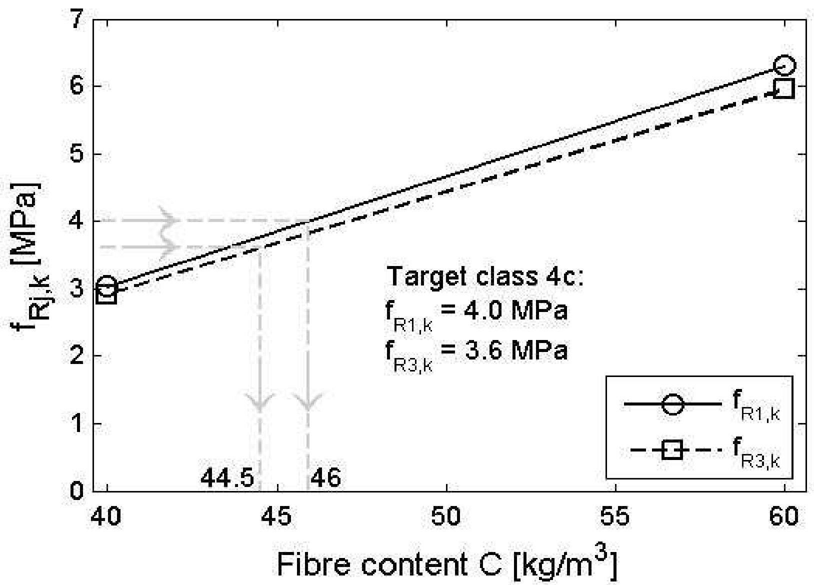
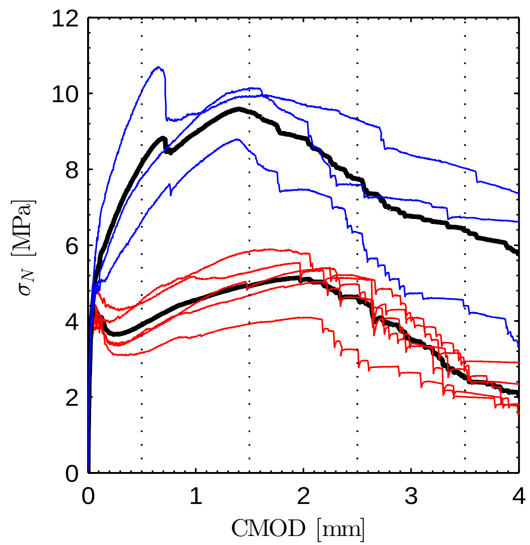
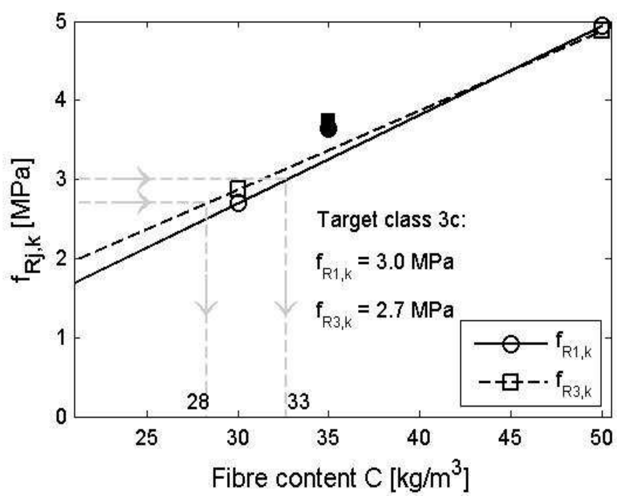
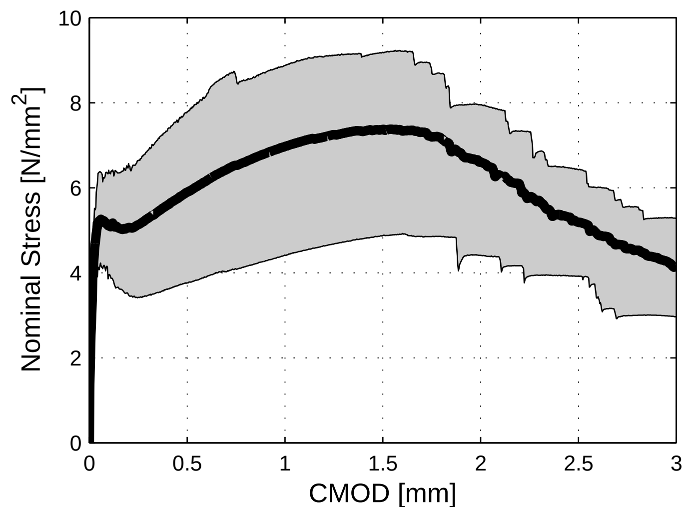


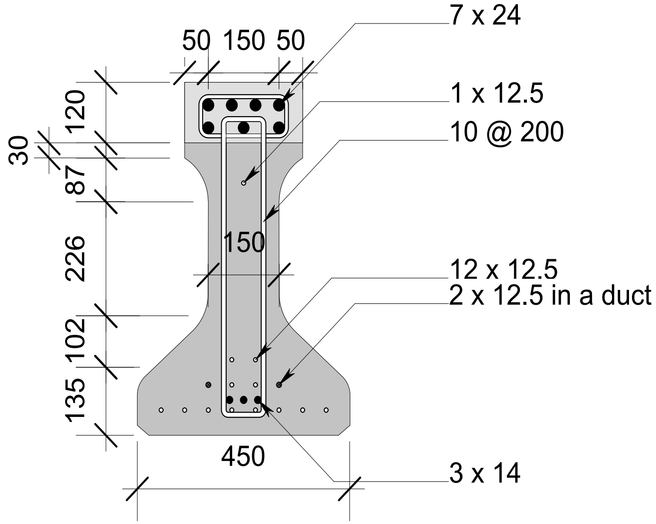
Table 3 Identified material properties of Mixture 2 for various amounts of fibre content

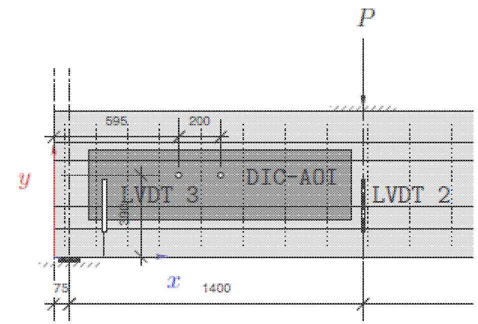
Mixture	Parameter	Unit	$f_{ct,L}^{f}$	$f_{R,1}$	$f_{R,2}$	$f_{R,3}$	$f_{R,4}$
Mixture 2 – 30 kg/m³	*N*	[-]	5	5	5	5	5
	mean	[MPa]	4.23	3.90	4.92	4.62	2.51
	st. dev.	[MPa]	0.34	0.59	0.71	0.81	0.41
	COV	[%]	8.04	15.18	14.42	17.55	16.51
Mixture 2 – 50 kg/m³	*N*	[-]	3	3	3	3	3
	mean	[MPa]	4.61	8.16	9.51	7.74	6.39
	st. dev.	[MPa]	0.28	1.73	0.89	1.49	1.84
	COV	[%]	6.15	21.22	9.39	19.27	28.74
Mixture 2 – 35 kg/m³	*N*	[-]	12	12	12	12	12
	mean	[MPa]	5.24	5.92	7.41	5.20	3.28
	st. dev.	[MPa]	0.62	1.20	1.29	0.77	0.75
	COV	[%]	13.03	20.32	17.43	14.86	22.93

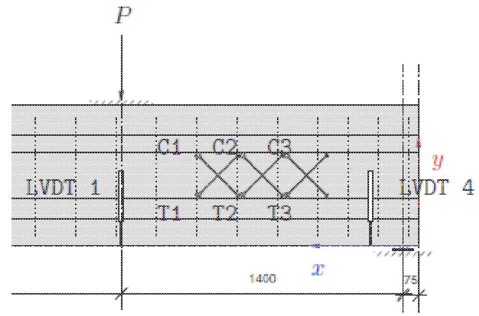


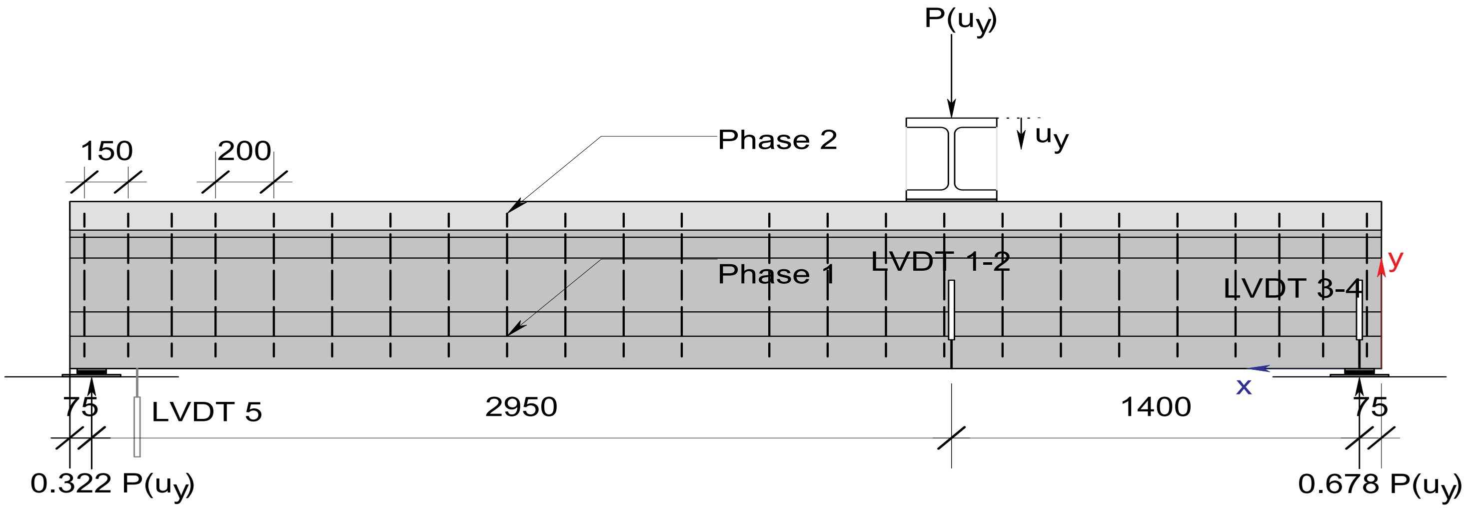


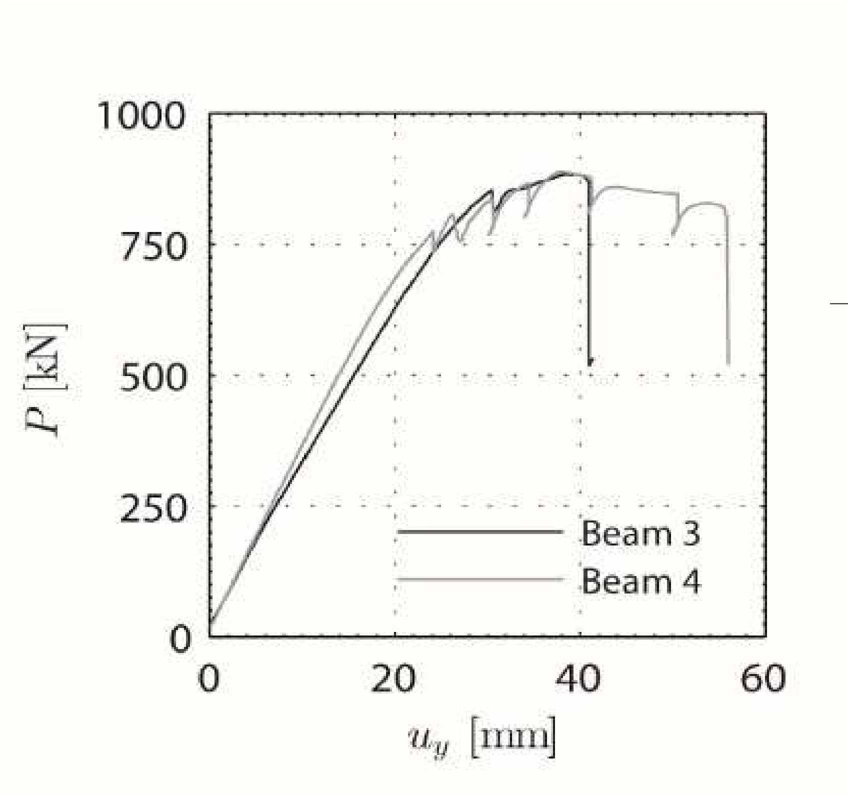


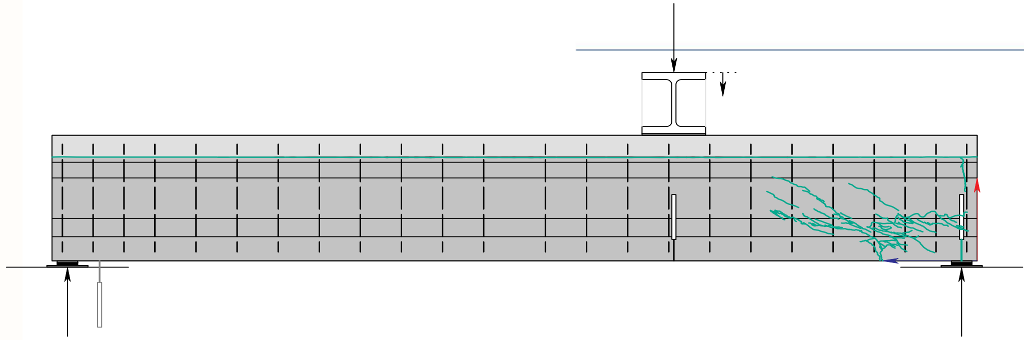

7 x 24
1 x 12.5
10 @ 200
12 x 12.5
2 x 12.5 in a duct
3 x 14
50 150 50
30
120
87
226
150
102
135
450

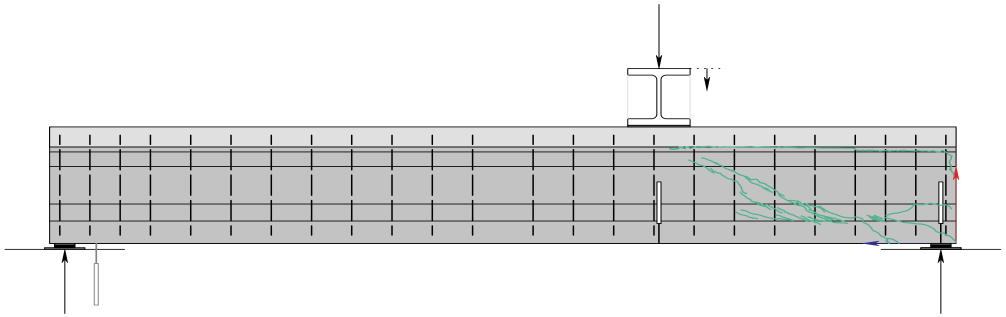

P
595
200
DIC-AOI
LVDT 3
LVDT 2
y
x
75
1400


P
C1 C2 C3
T1 T2 T3
LVDT 1
LVDT 4
y
x
1400
75


P(uy)
uy
Phase 2
Phase 1
150
200
LVDT 1-2
LVDT 3-4
y
x
LVDT 5
75
2950
1400
75
0.322 P(uy)
0.678 P(uy)








Beam 4


Beam 3


Beam 4

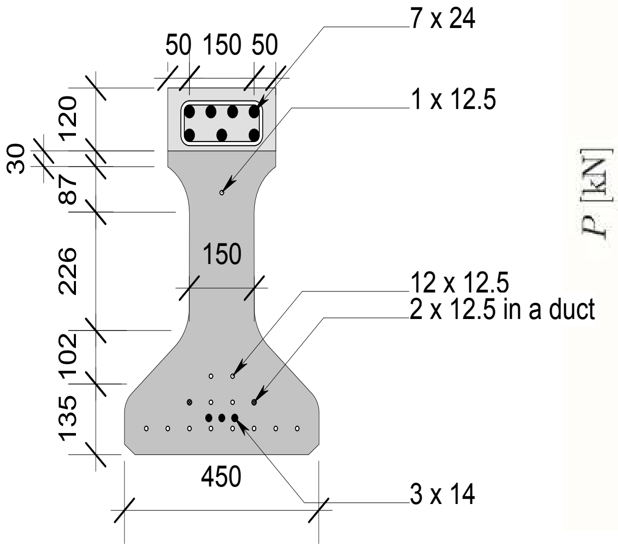
According to Model Code 2010

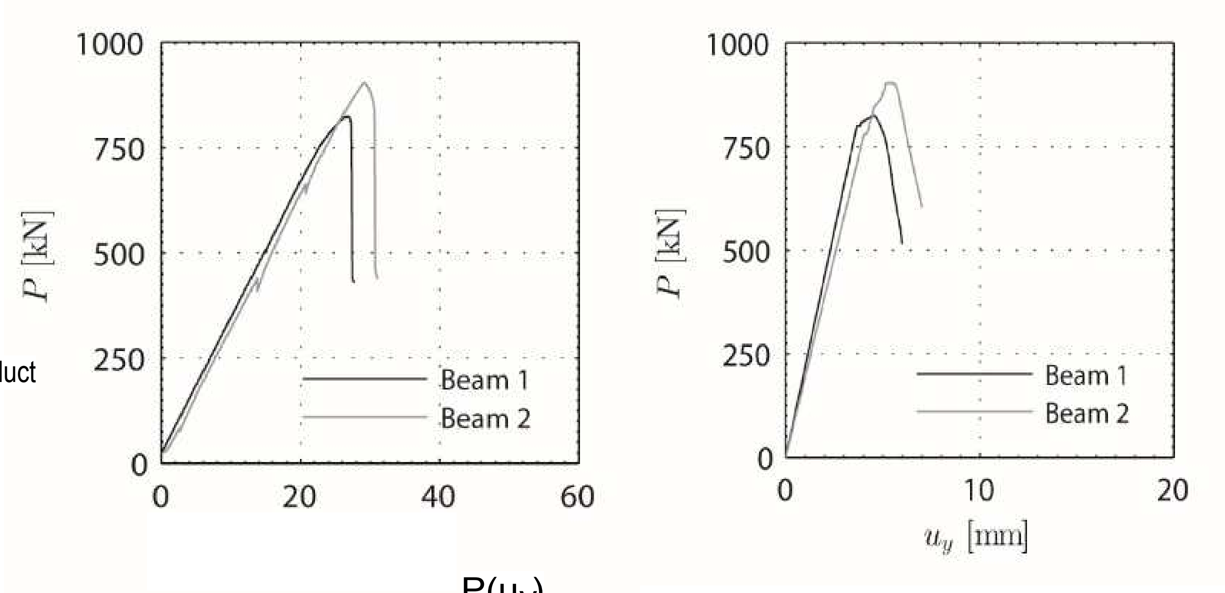
$$V_R = \frac{A_{sw}}{s} z f_{ywd} \cot\theta + \left[0.18 \left(1 + \sqrt{\frac{200}{d}} \right) \left[100 \rho_l \left(1 + 7.5 \frac{f_{Ftuk}}{f_{ctk}} \right) f_{ck} \right]^{\frac{1}{3}} + 0.15 \sigma_{cp} \right] b_w d$$

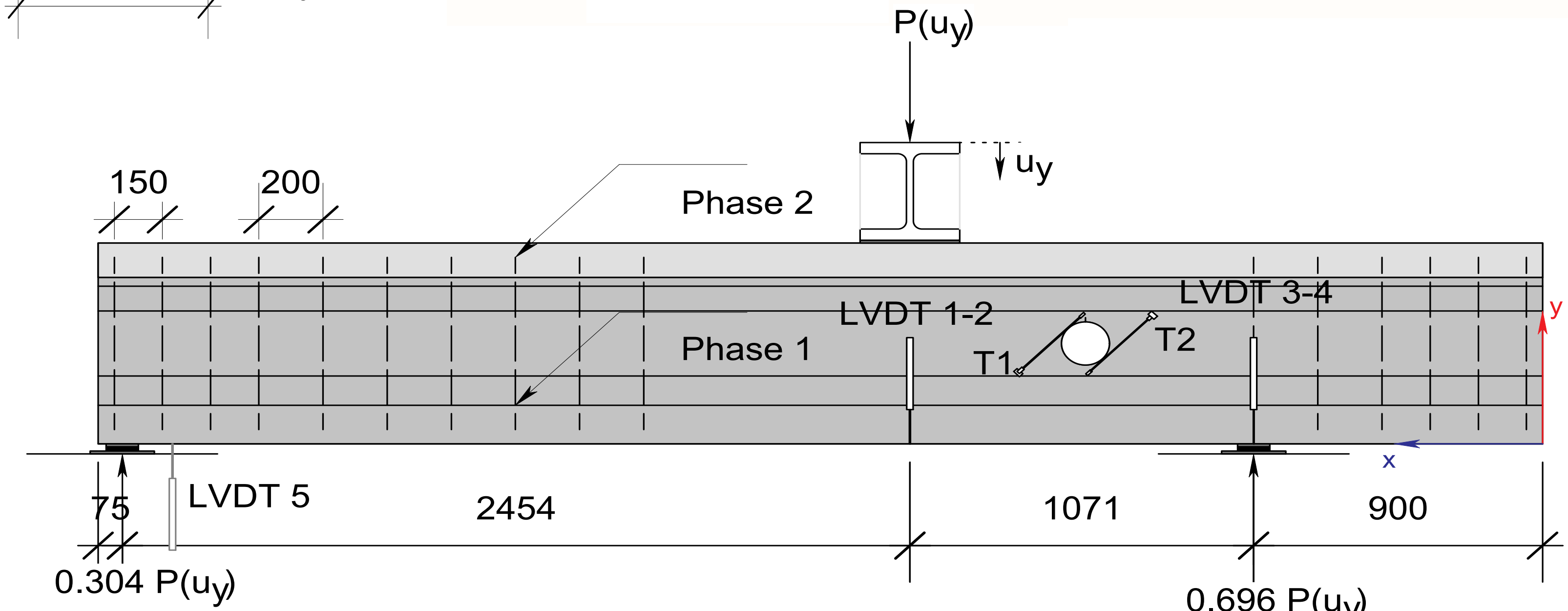
Table 4 Experimentally observed and theoretically calculated cracking and failure loads for Beams 3 and 4

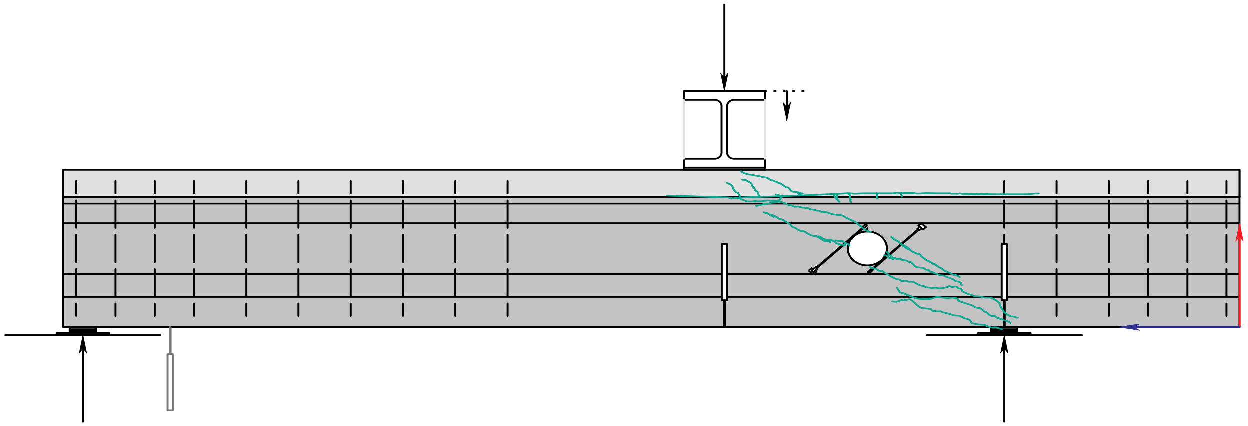
Specimen	$P_{cr,exp}$	$P_{cr,calc}$	$P_{cr,exp}/P_{cr,calc}$	$P_{u,exp}$	Failure	$P_{u,calc}$	$P_{u,exp}/P_{u,calc}$
	[kN]	[kN]	[-]	[kN]	mode	[kN]	[-]
Beam 3	847.1	818.7	1.03	884.6	S+A	724.0	1.22
Beam 4	764.8	818.7	0.93	888.7	S+A	724.0	1.23

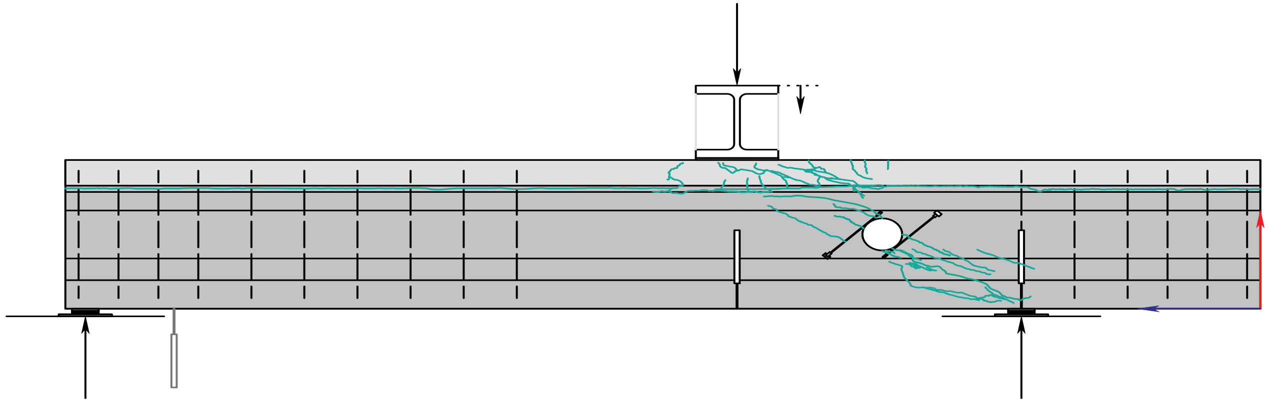
Note: S+A indicates combined shear failure with loss of Anchorage

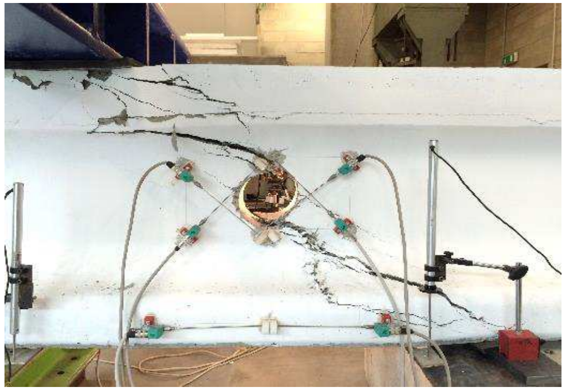

7 x 24
50 150 50
1 x 12.5
120
30
87
150
226
12 x 12.5
2 x 12.5 in a duct
102
135
450
3 x 14

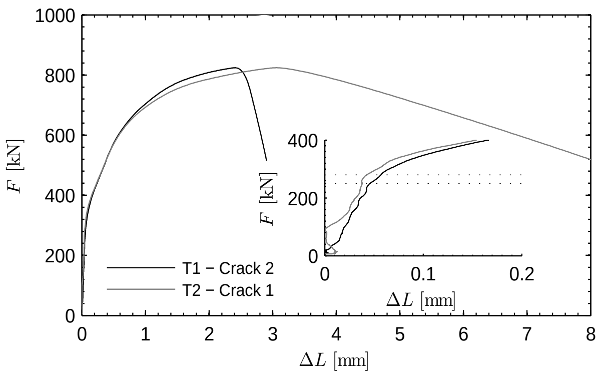

1000
750
500
250
0
P [kN]
0
20
40
60
Beam 1
Beam 2
1000
750
500
250
0
P [kN]
0
10
20
u_y [mm]
Beam 1
Beam 2


P(uy)
uy
150
200
Phase 2
LVDT 1-2
LVDT 3-4
Phase 1
T1
T2
y
x
75
LVDT 5
2454
1071
900
0.304 P(uy)
0.696 P(uy)

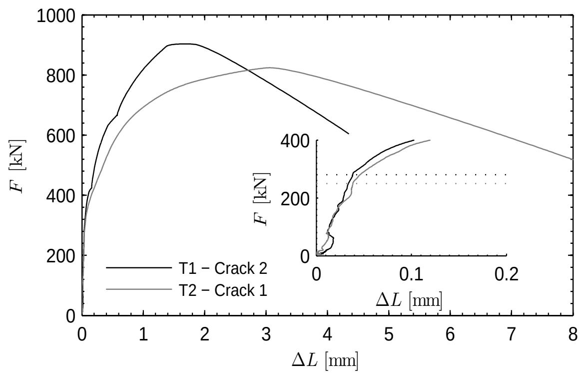




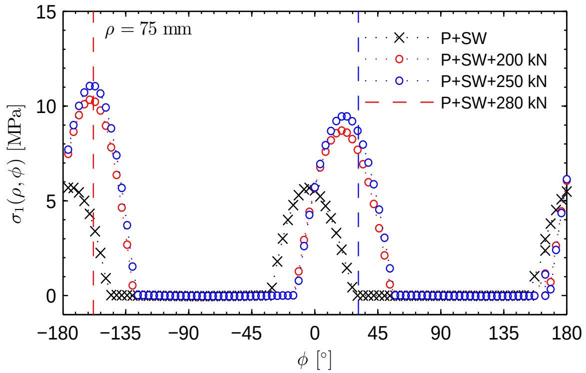




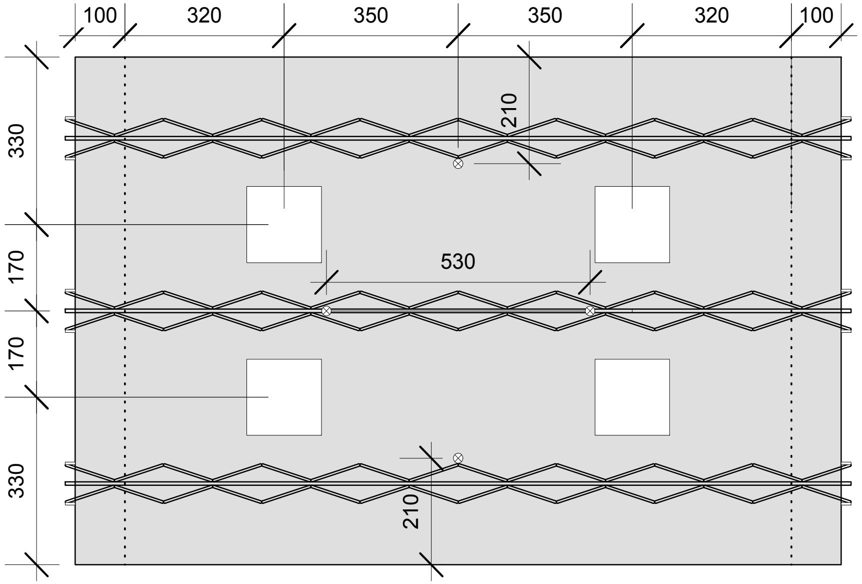
1000
800
600
400
200
0
F [kN]
0 1 2 3 4 5 6 7 8
ΔL [mm]
T1 − Crack 2
T2 − Crack 1
400
200
0
0 0.1 0.2
ΔL [mm]

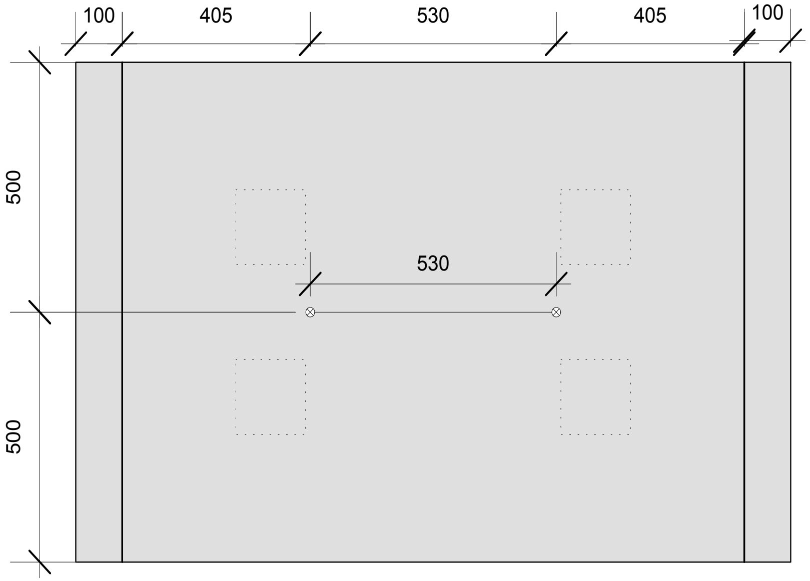


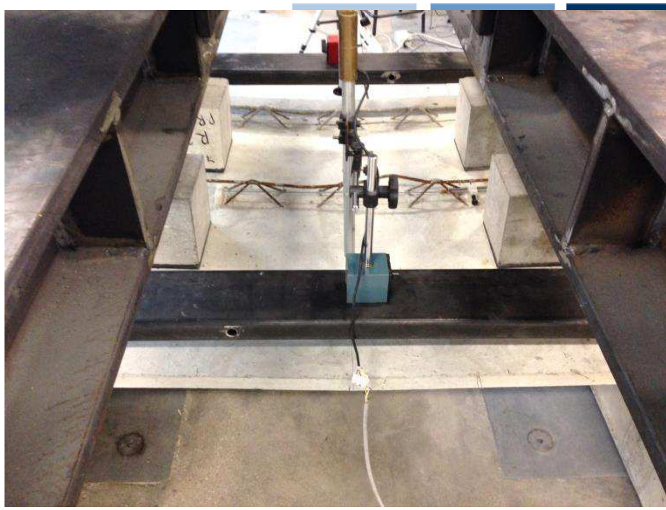
1000
800
600
400
200
0
F [kN]
0 1 2 3 4 5 6 7 8
ΔL [mm]
T1 − Crack 2
T2 − Crack 1
400
200
0
0 0.1 0.2
ΔL [mm]

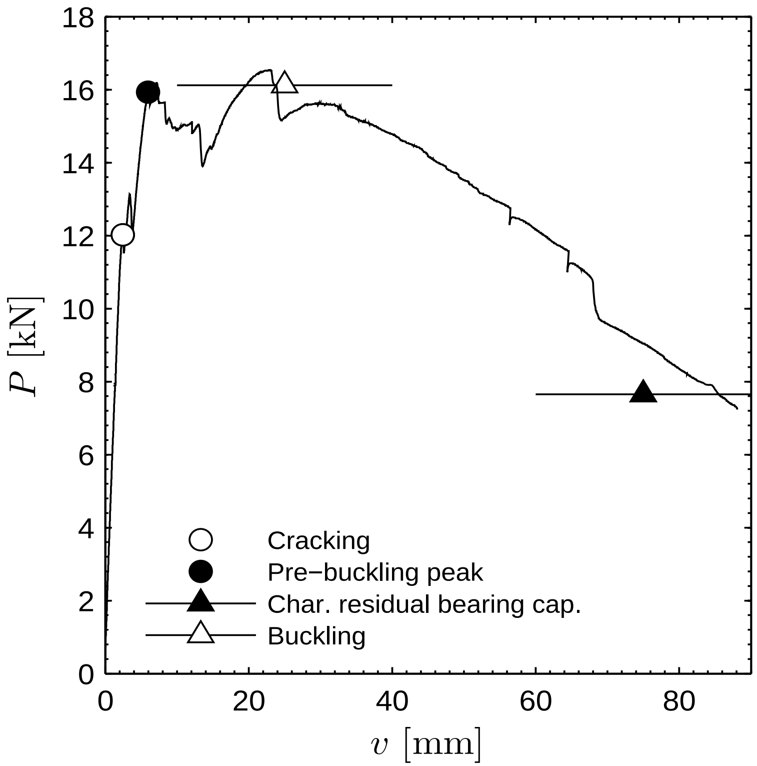


ρ = 75 mm
P+SW
P+SW+200 kN
P+SW+250 kN
P+SW+280 kN
15
10
5
0
σ1(ρ, φ) [MPa]
−180 −135 −90 −45 0 45 90 135 180
φ [°]

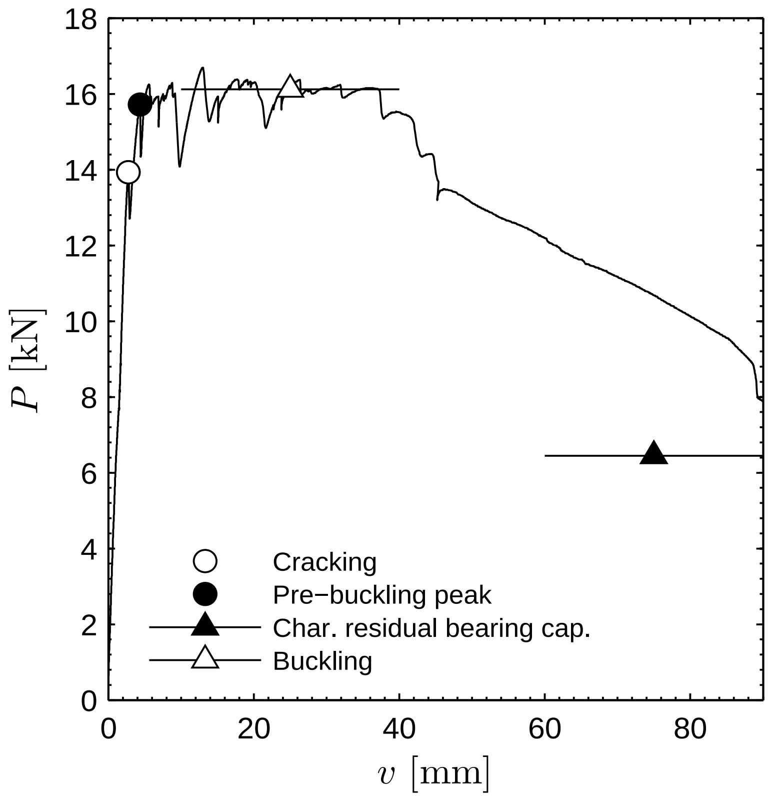

100
320
350
350
320
100
210
330
170
530
170
330
210


100
405
530
405
100
500
530
500

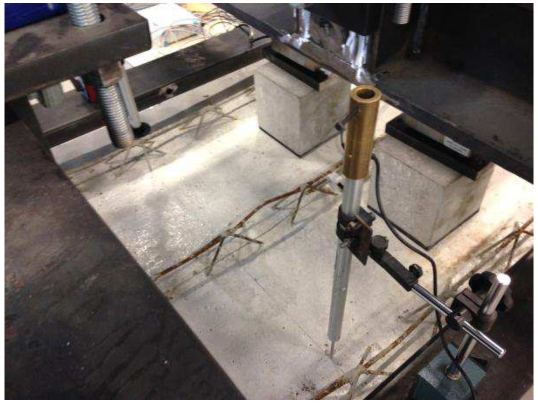




P [kN]
v [mm]
Cracking
Pre−buckling peak
Char. residual bearing cap.
Buckling



P [kN]
v [mm]
Cracking
Pre−buckling peak
Char. residual bearing cap.
Buckling

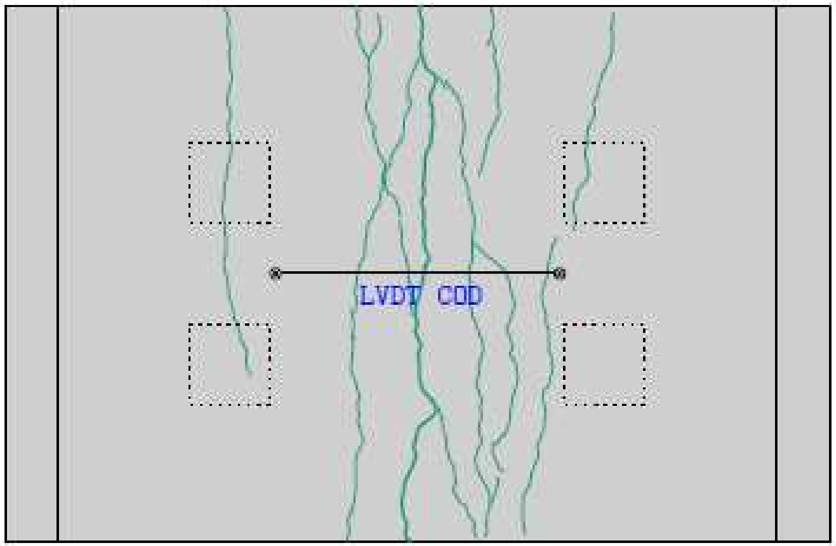


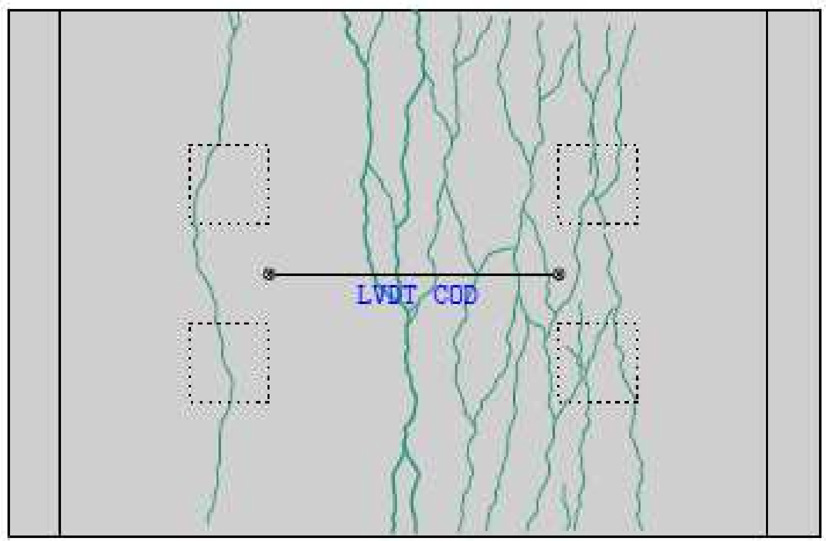
$$f_{ct,fl}^{40} = \alpha_{fl}^{-1} f_{ct} = \frac{1+0.06h^{0.7}}{0.06h^{0.7}} 0.9 f_{ct,L}^{f}$$

$$\alpha = \frac{1}{L}\sqrt{\frac{3\pi^2 EIz}{aP/2+M_{sw}}}$$

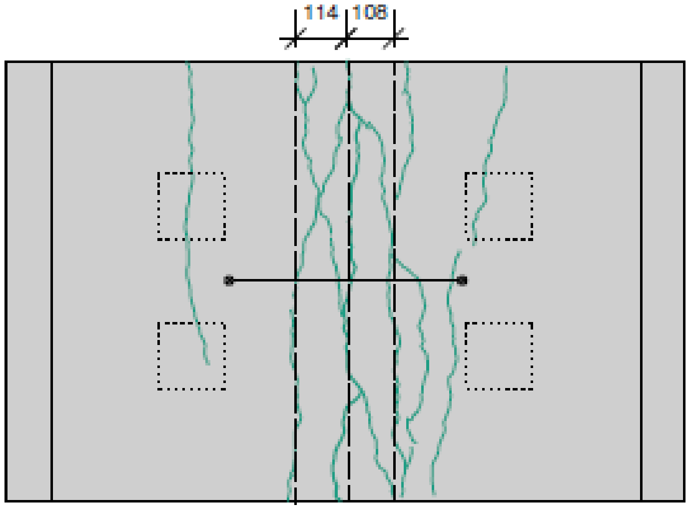
$$P_{cr,calc} = 2\frac{\frac{f_{ct,fl}^{40} I_0}{y_0} - M_{sw}}{a}$$

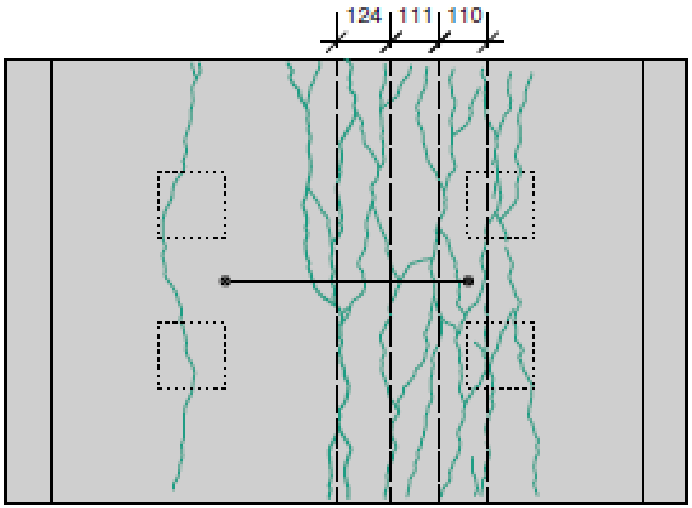
α equal to 0.61





Specimen	Cracking			Buckling
	$P_{cr,exp}$	$P_{cr,calc,k}$	$P_{cr,exp}/P_{cr,calc,k}$	$P_{buckl,exp}$
	[kN]	[kN]	[-]	[kN]
Slab 1	12.05	12.61	0.96	16.01
Slab 2	13.93	12.74	1.09	16.00





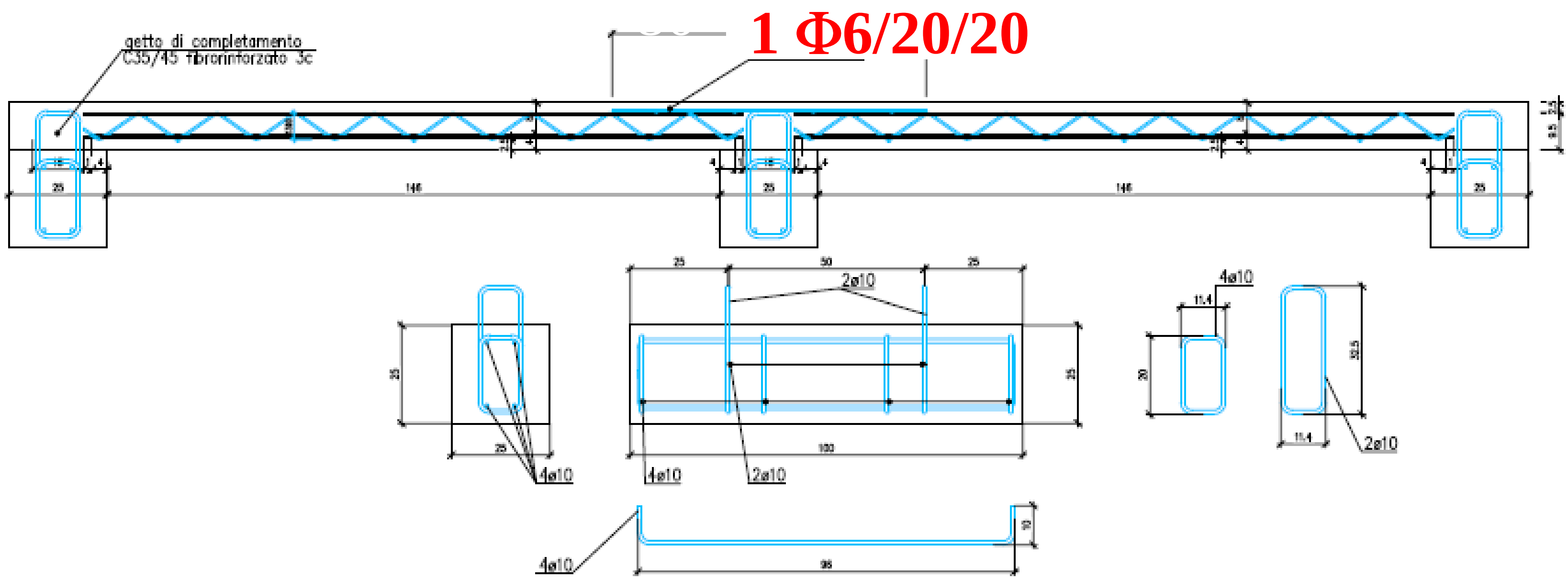
$$s_{r1} = \xi \left(50 + 0.25 k_1 k_2 \frac{\phi}{\rho_l} \right)$$

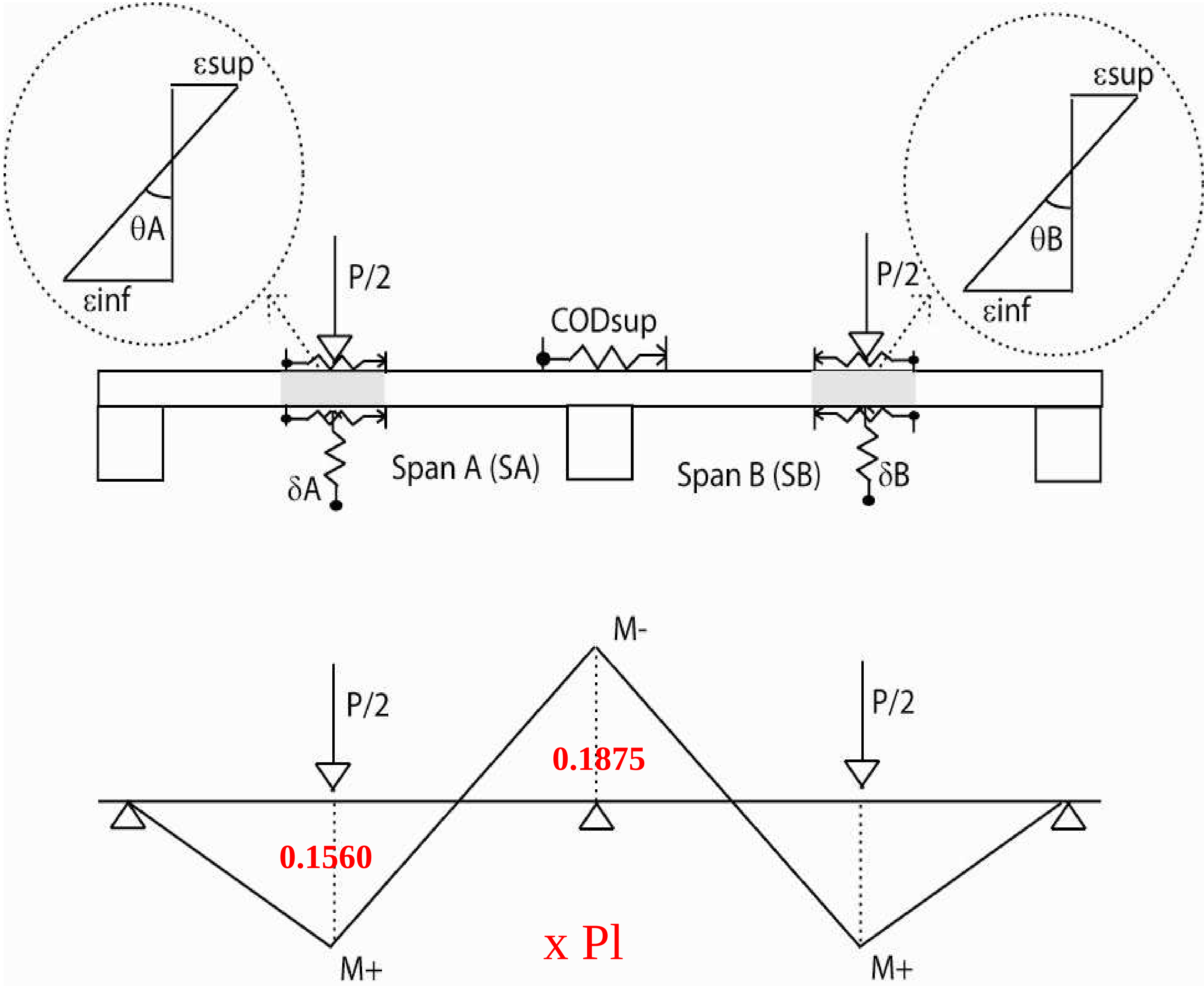
129,8 mm

- $\xi = 50 \frac{0.75}{60} = 0.625$
- $k_1 = 0.8$
- $k_2 = 0.5$
- $\phi = 5$
- $\rho = \frac{A_{sl}}{by} = \frac{6 \times \pi \times 2.5^2}{1000 \times 37.14} = 0.00317$

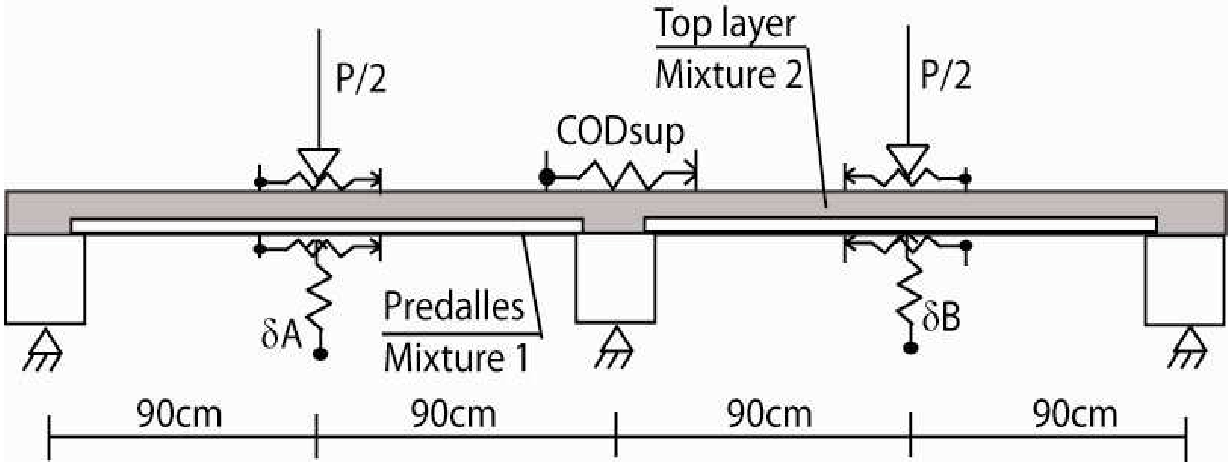
?

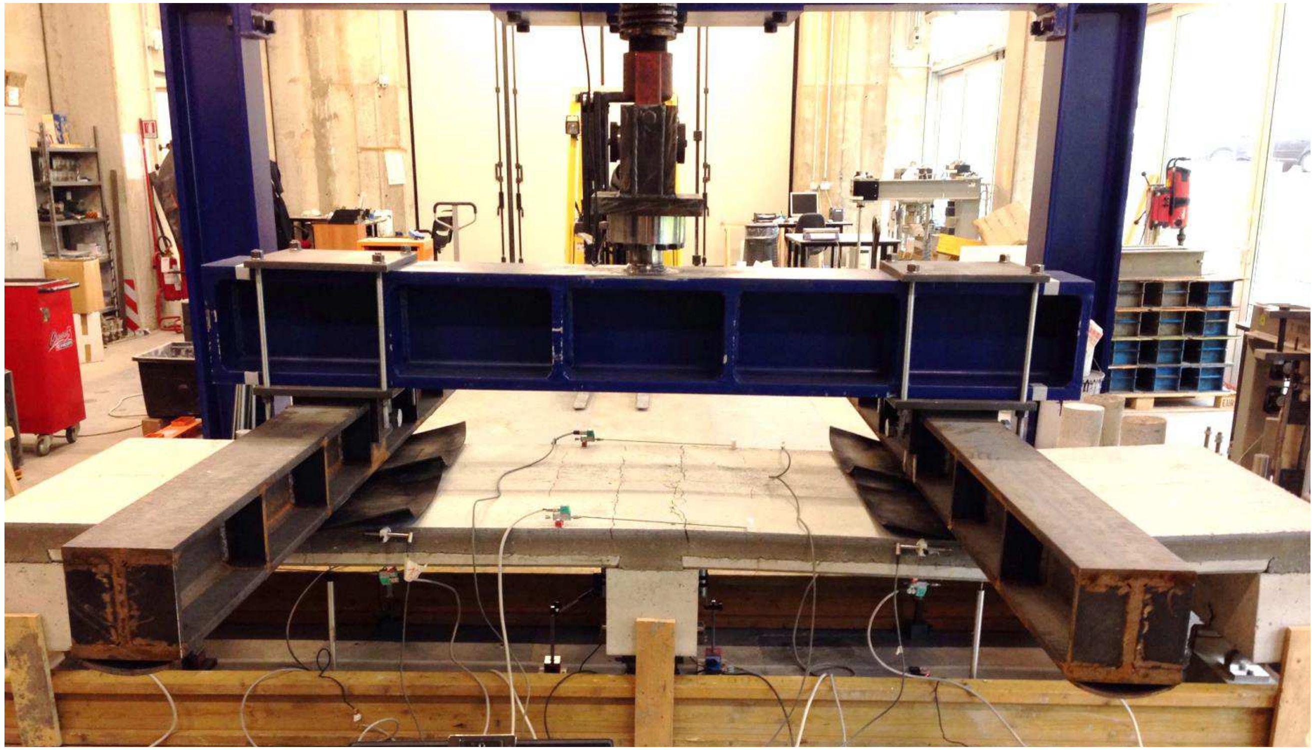
$$l_{cs} = \min\{s_{rm}, y\} = \min\{194.7, 37.14\} = 37.14 \text{ mm}$$

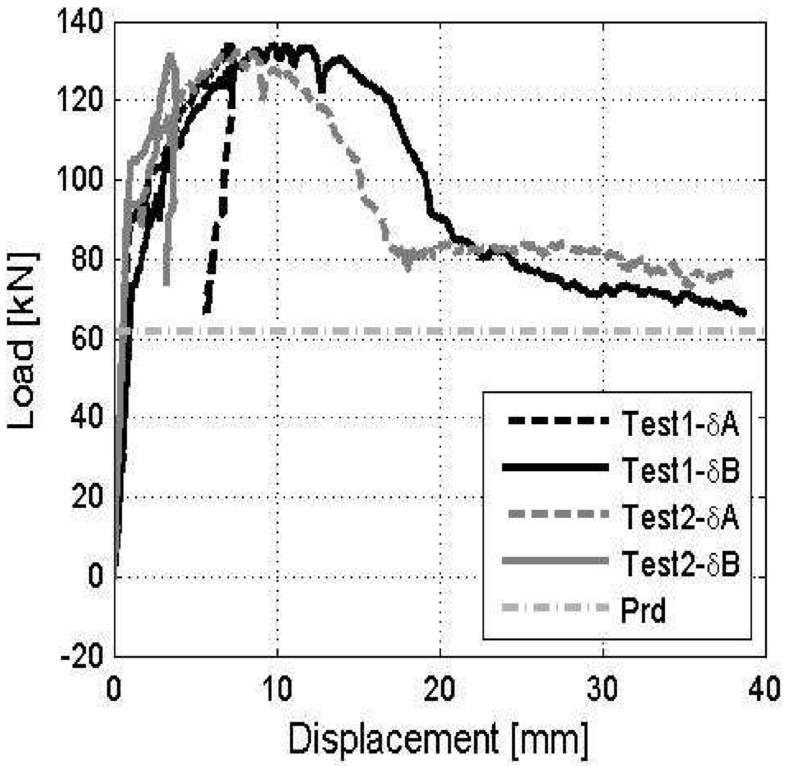

1 Φ6/20/20
getto di completamento
C35/45 fibrorinforzato 3c
2ø10
4ø10
4ø10
4ø10
2ø10
2ø10
4ø10

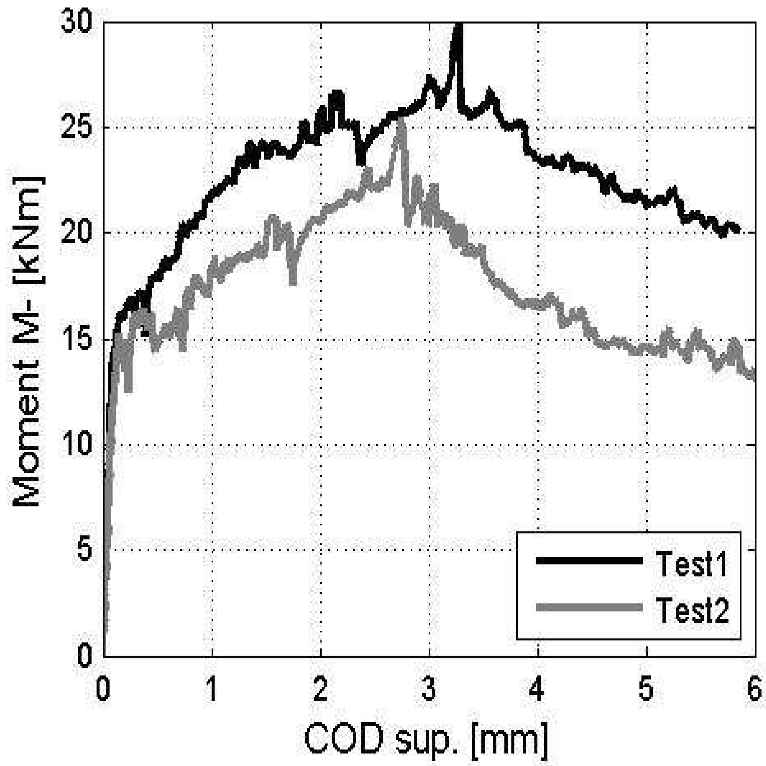


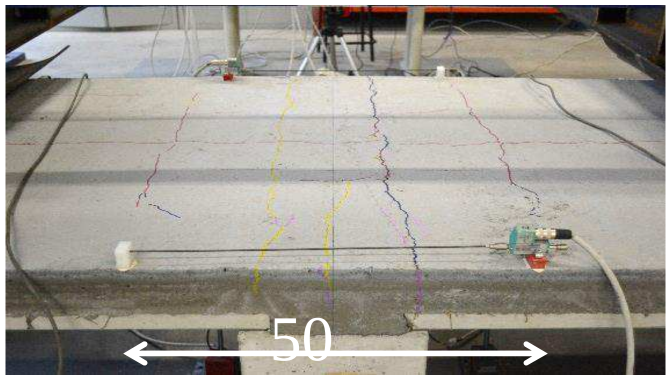
εsup
θA
εinf
P/2
CODsup
P/2
εsup
θB
εinf
δA
Span A (SA)
Span B (SB)
δB
M-
P/2
P/2
0.1875
0.1560
x Pl
M+
M+

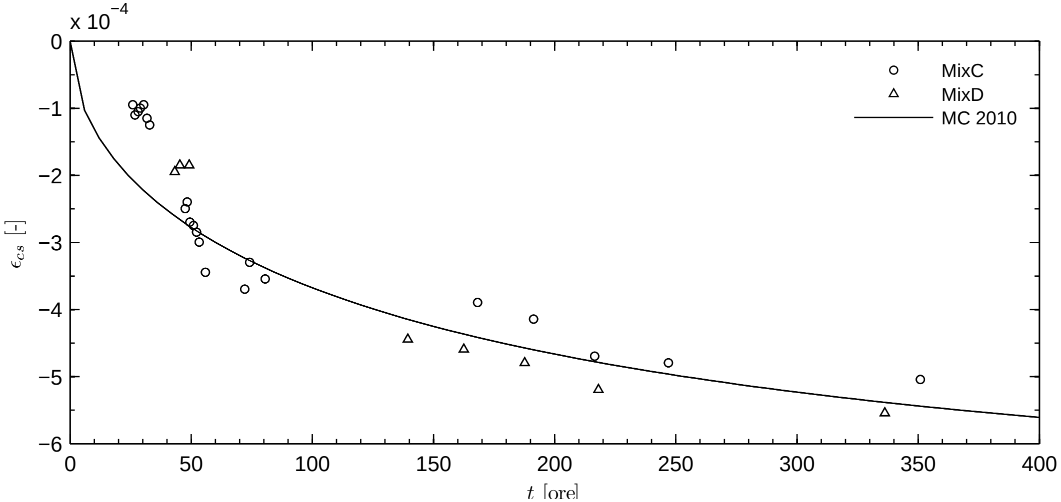

Top layer
Mixture 2
P/2
P/2
CODsup
Predalles
Mixture 1
δA
δB
90cm
90cm
90cm
90cm



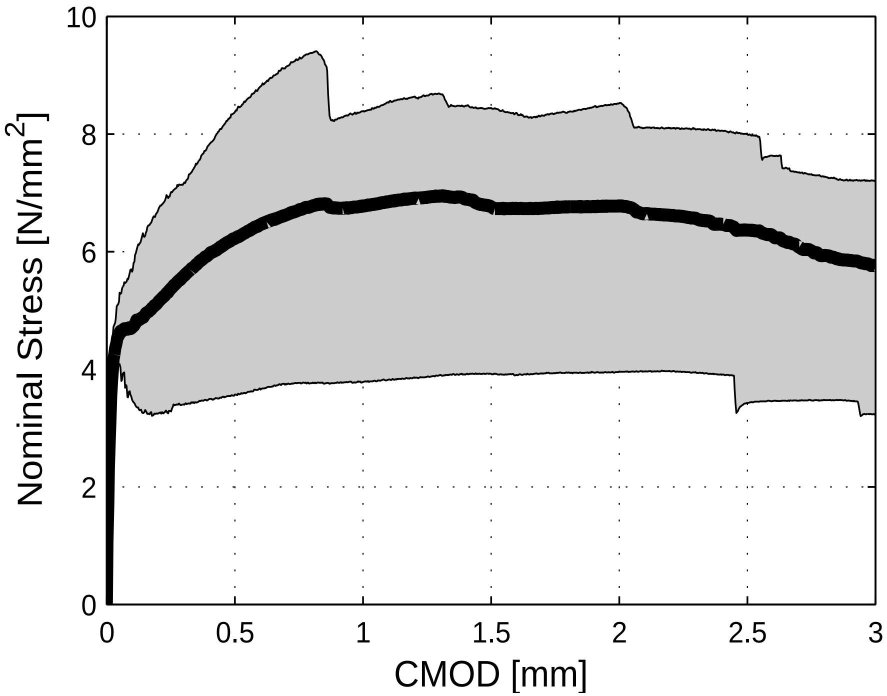

Load [kN]
Displacement [mm]
Test1-δA
Test1-δB
Test2-δA
Test2-δB
Prd


Moment M- [kNm]
COD sup. [mm]
Test1
Test2


50

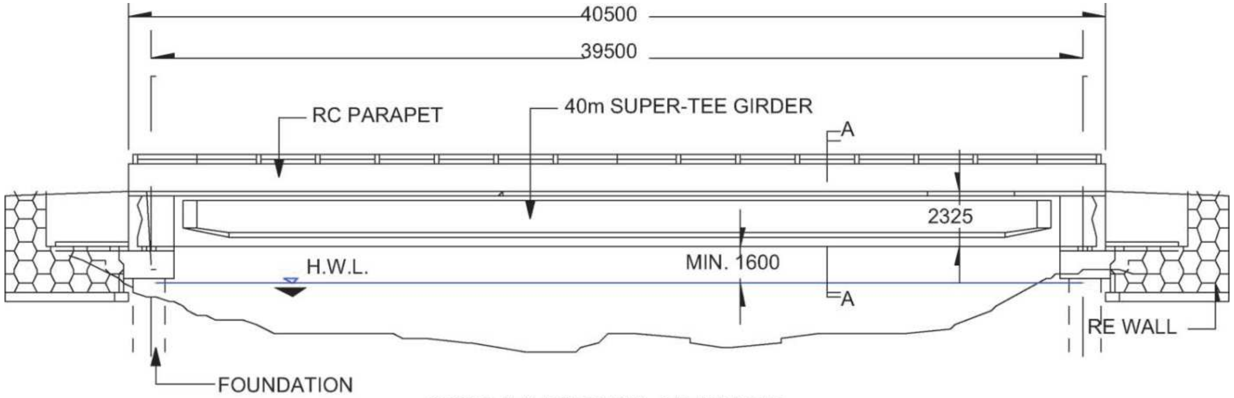


Componente	Mix E	**Mix F**
CEM IV/A 42.5R LH (kg/m3)	470.0	**380.0**
Filler Calcareo (kg/m3)	-	**100.0**
Acqua (kg/m3)	188.0	**160.0**
Superflux DYNAMON SR41 (kg/m3)	7.6	**7.6**
Antiritiro Mapei SRA 25 (kg/m3)	4.0	**6**
Sabbia 0/4 (kg/m3)	1008.0	**1008**
Mista 0/8 (kg/m3)	504.0	**504.0**
Ghiaia 4/14 (kg/m3)	171.0	**171.0**
Fibre (kg/m3)	35.0	**35.0**

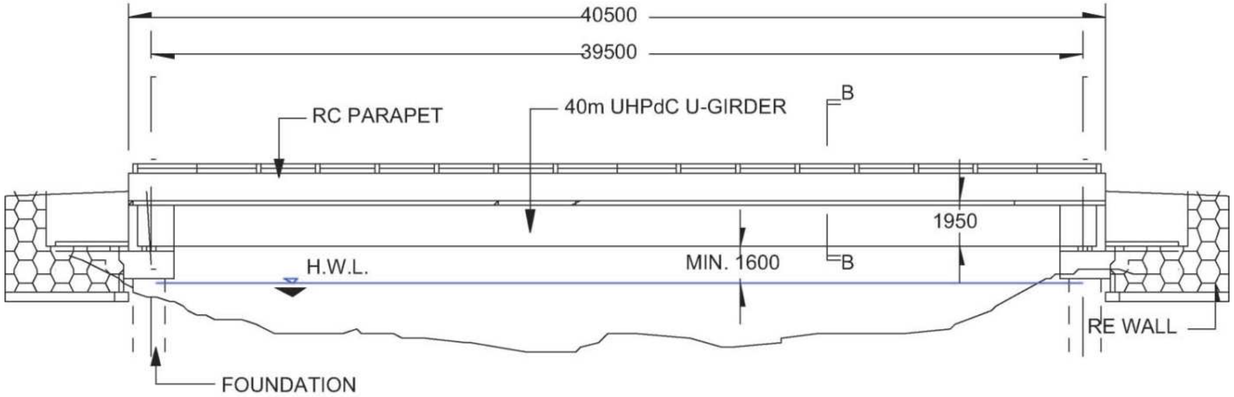


HPFRC precast elements

Comparison of two bridges (Voo/Foster, 2010)

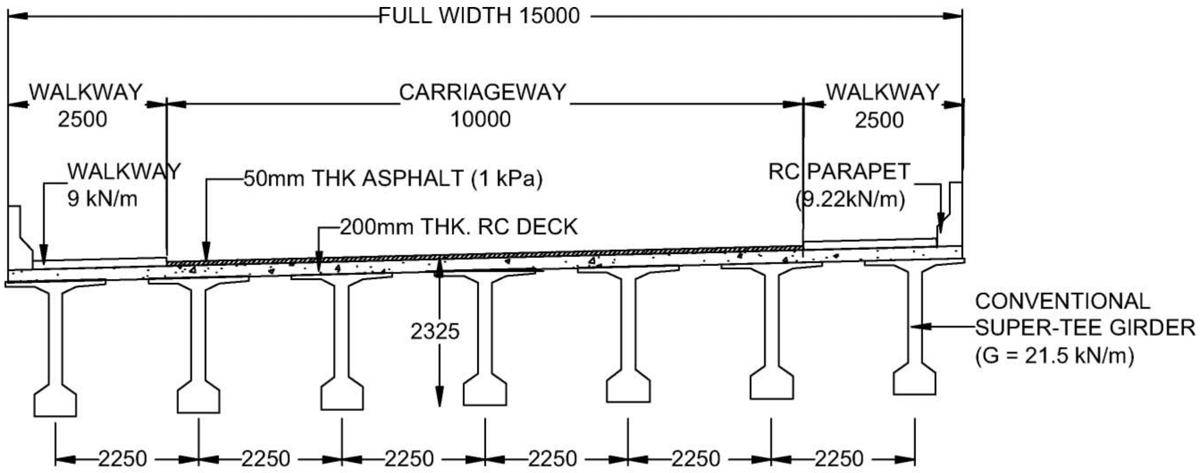


CONVENTIONAL METHOD

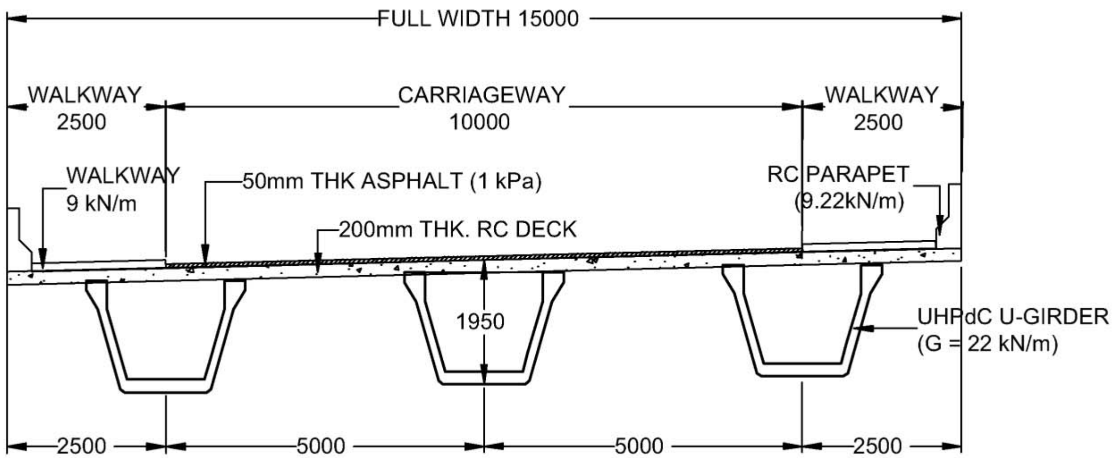


UHPdC METHOD

Comparison of two bridges

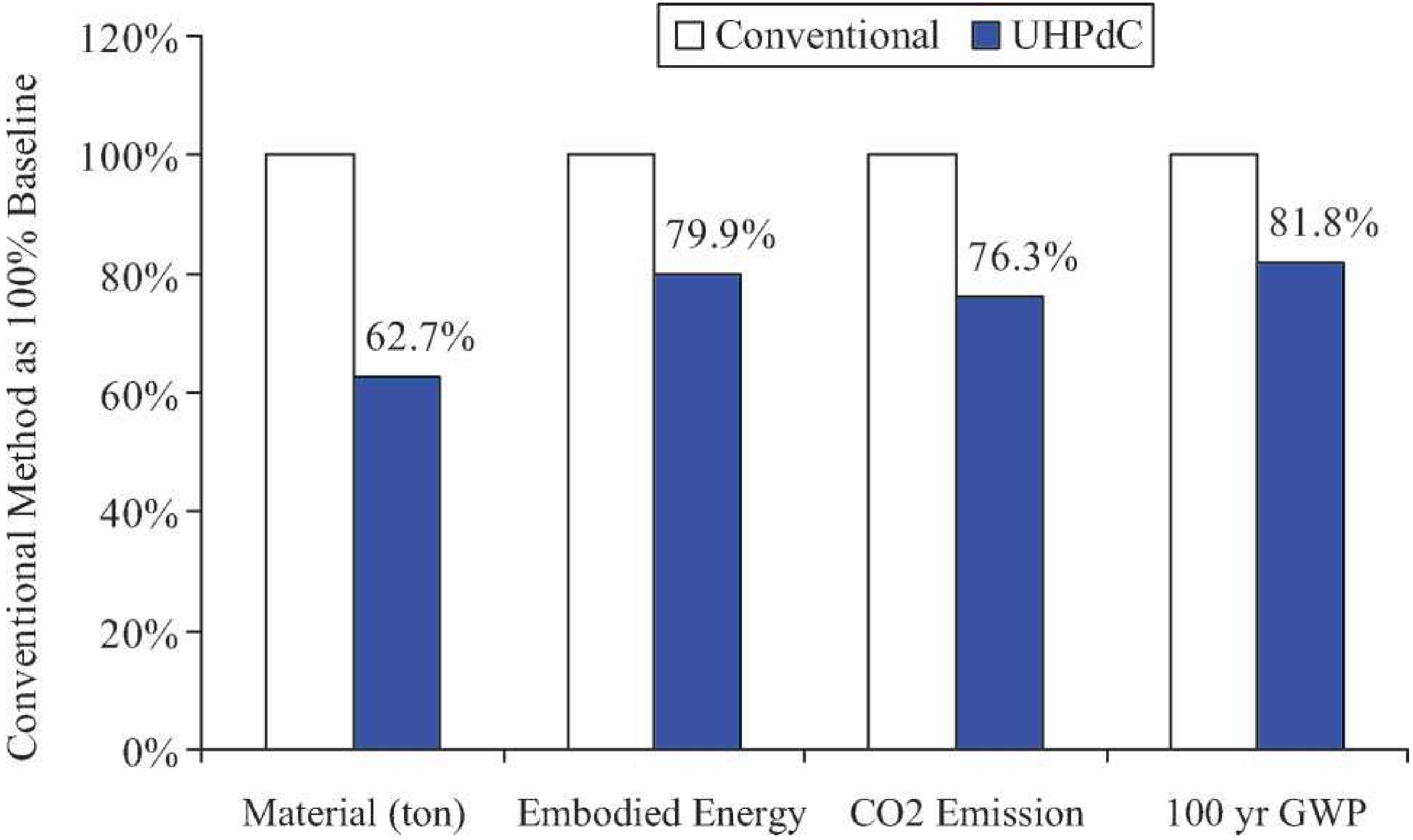


CONVENTIONAL METHOD (VIEW A-A)



UHPdC METHOD (VIEW B-B)

Comparison of two bridges (Voo/Foster 2010)



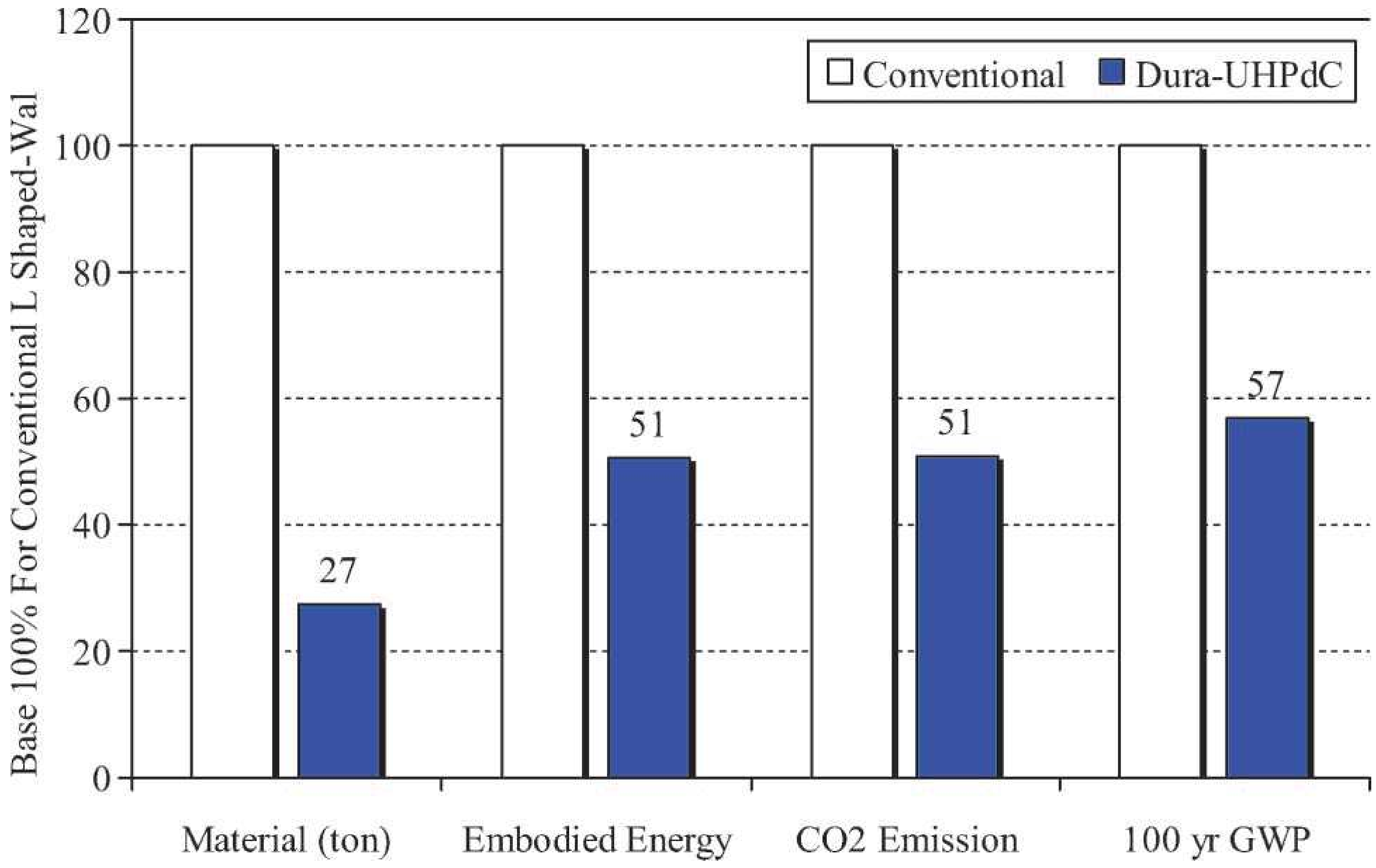
Courtesy Joost Walraven

Two solutions for a 180 m long retaining wall (Voo/Foster, 2010)

Construction of retaining wall for drain channel in Ipoh, Malaysia,

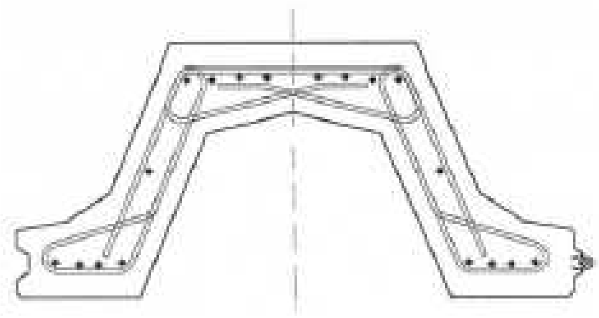
Solution in conventional concrete and UHPFRC (f_{cm} =160 N/mm^2)

Results of EIC for retaining walls



Sheet piles

by Jansze et al. 2005



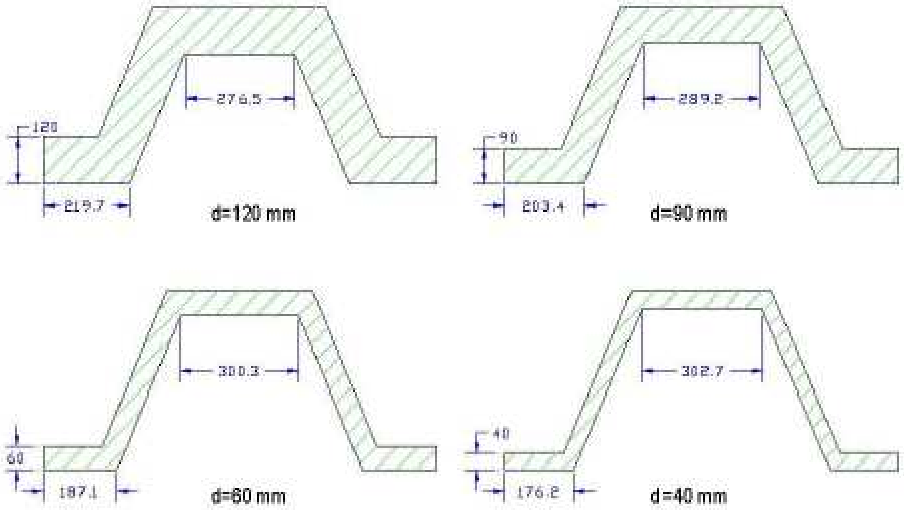


Fig. 3 Sheet pile geometries as a variable in the optimisation study (all 450 mm in height)

Fig. 10 Mould with strands for pile production

MATERIALS

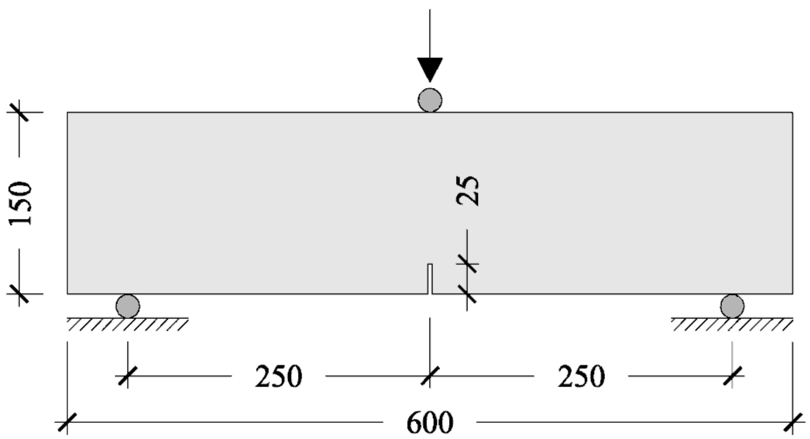
HPFRCC

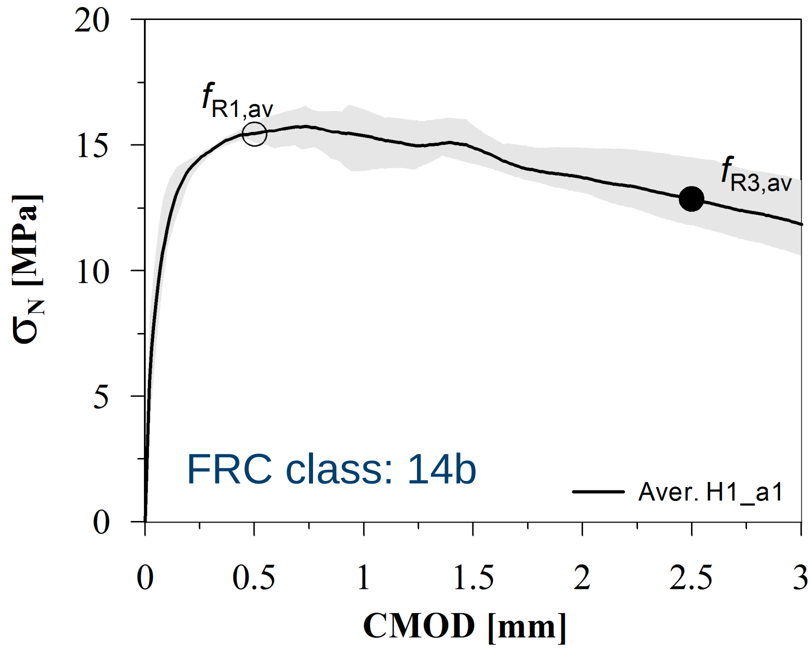
w/b=0.19 and SP/c=5.5%.

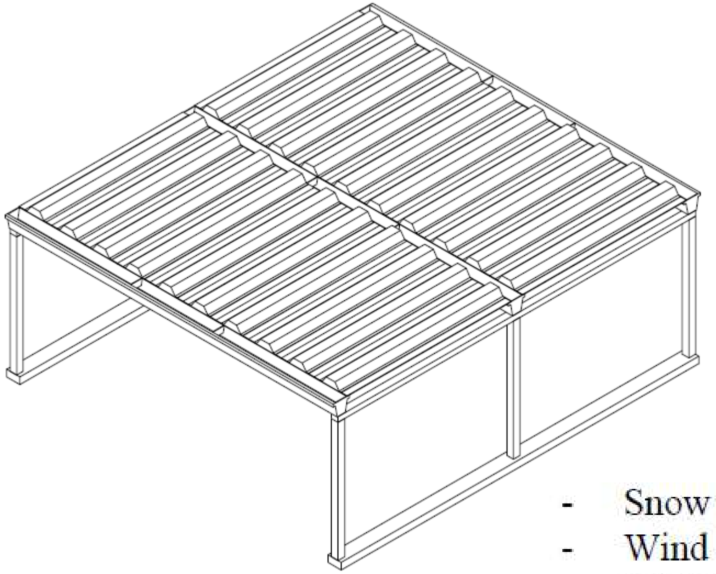
Component	Content
Cement I 52.5	600 kg/m^3
Sand 0 ÷ 2 mm	977 kg/m^3
Water	200 l/m^3
Superplasticizer	33 l/m^3
Slag	500 kg/m^3
Steel fibers	100 kg/m^3

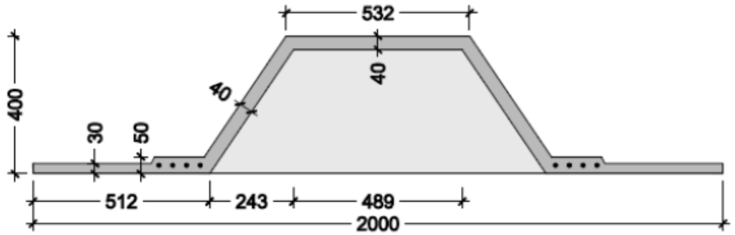
Flexural residual strengths.

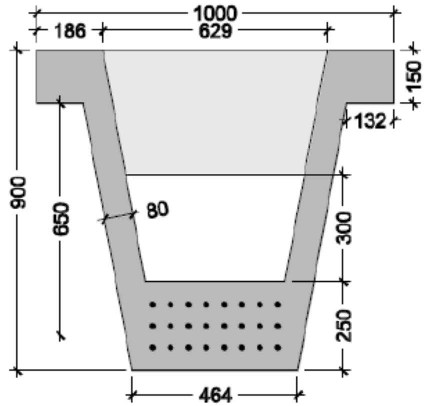
Specimen	f_{R1} [MPa]	$f_{R1,av}$ [MPa] (std)	f_{R3} [MPa]	$f_{R3,av}$ [MPa] (std)
H1_a1_1	15.90	15.46	14.51	12.87
H1_a1_2	15.11	(0.40)	12.27	(1.44)
H1_a1_3	15.38		11.82	











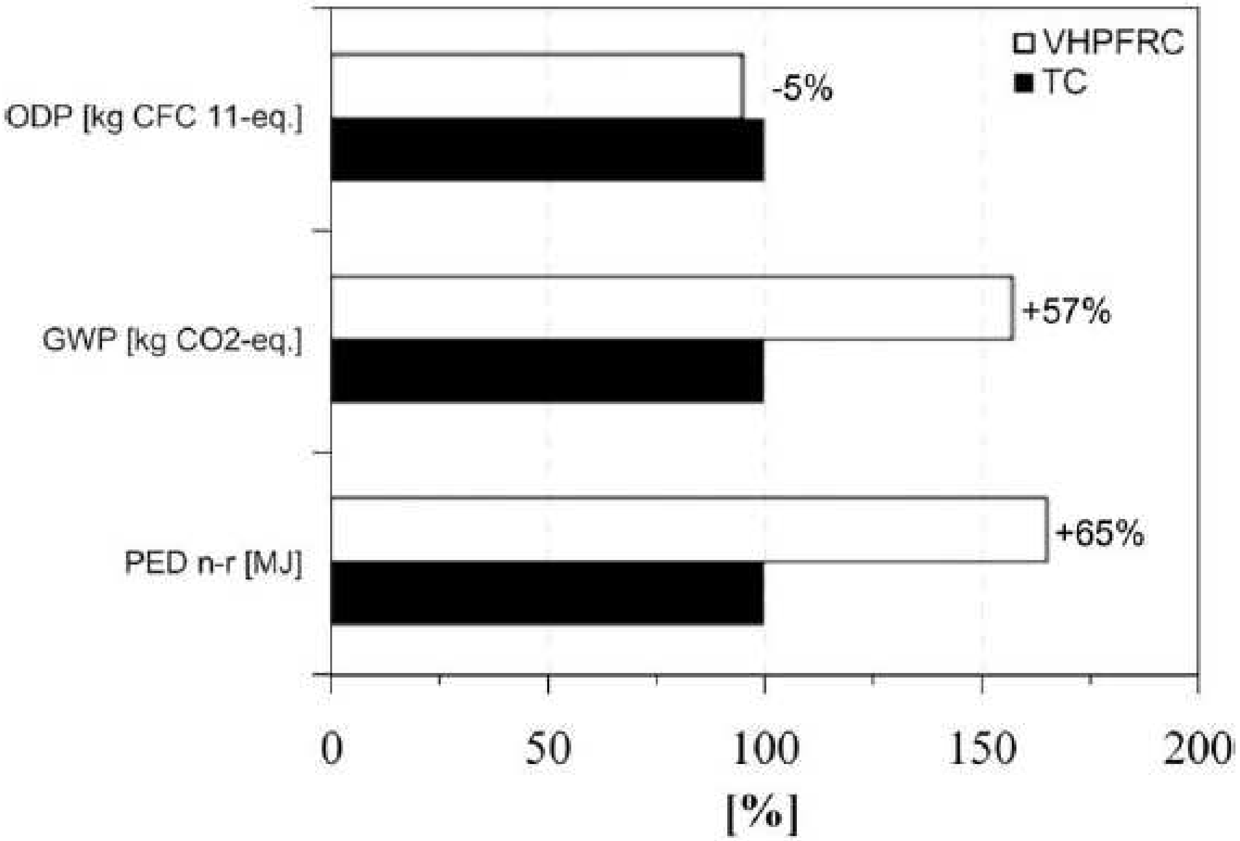
- Snow load: 1.2 kN/m^2
- Wind load: 0.64 kN/m^2
- Distributed maintenance load: 0.5 kN/m^2
- Seismic acceleration: S_d = 0,07 g

Table 3. Materials costs

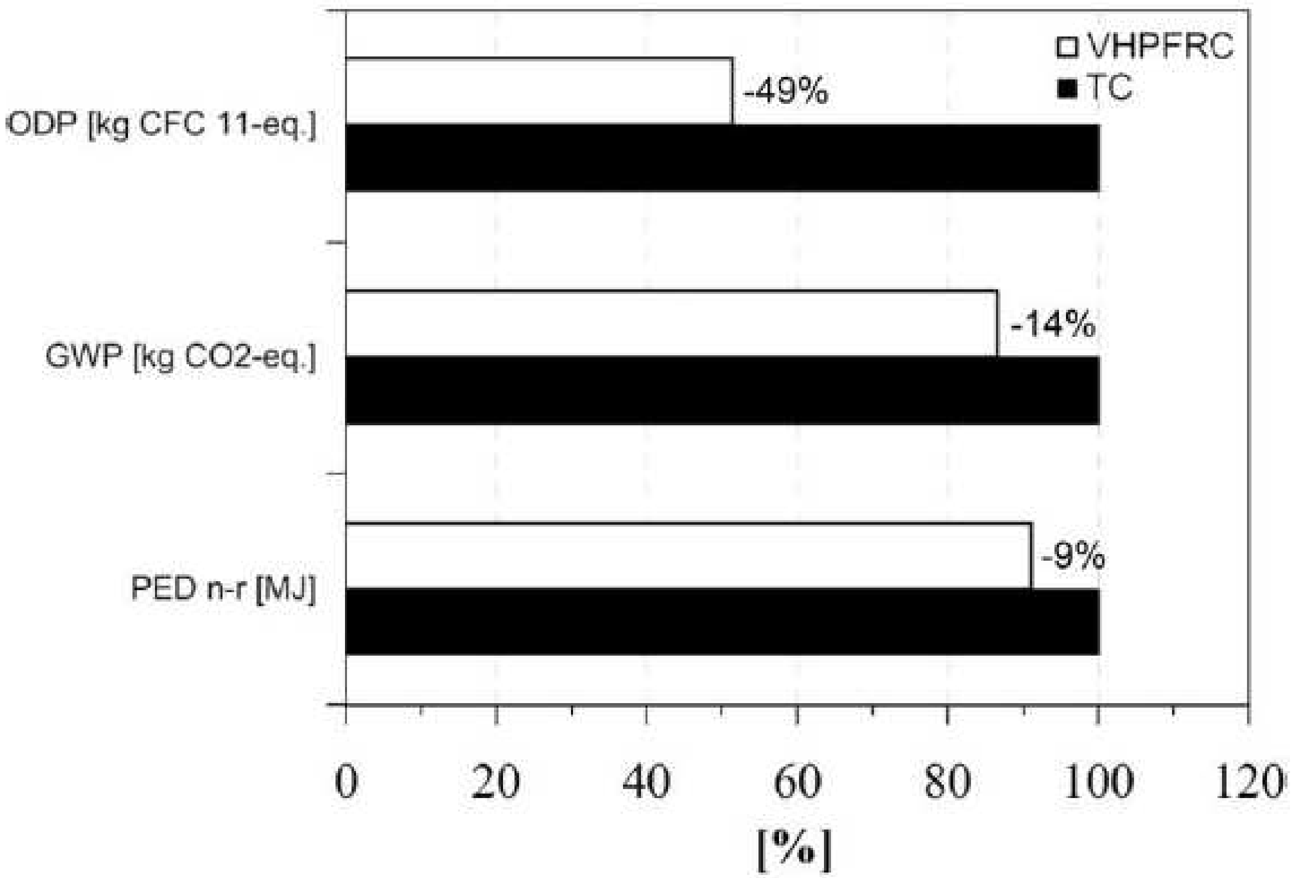
Conventional Concrete C50/60 (€/m^3)	VHPFRC (fibers incl.) (€/m^3)	Steel Bars (€/kg)	Prestressed Tendons (€/kg)	Fiber Reinforced Concrete (€/m^3)
50	440	0.65	1.00	150

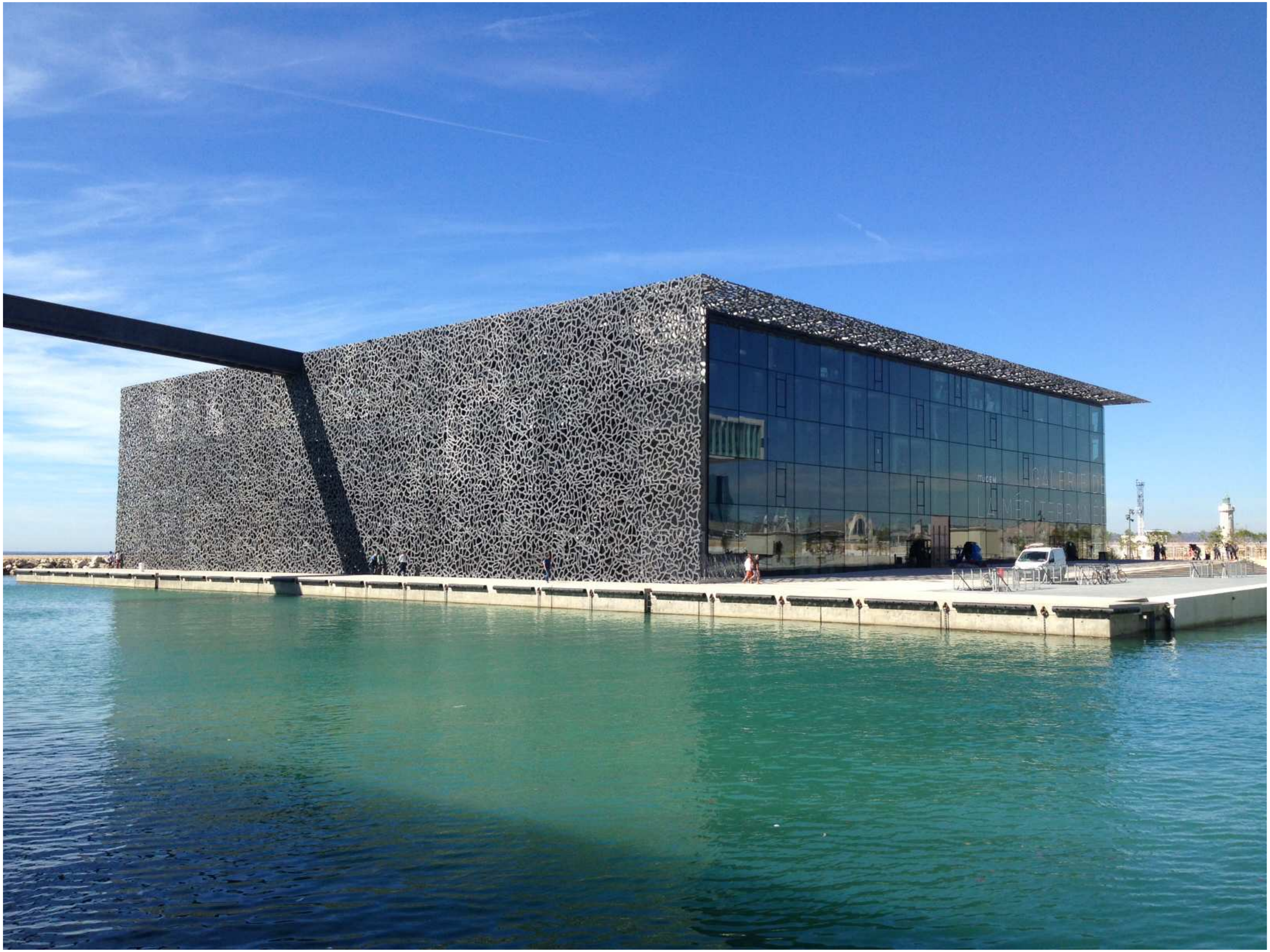
Table 7 – Structure costs

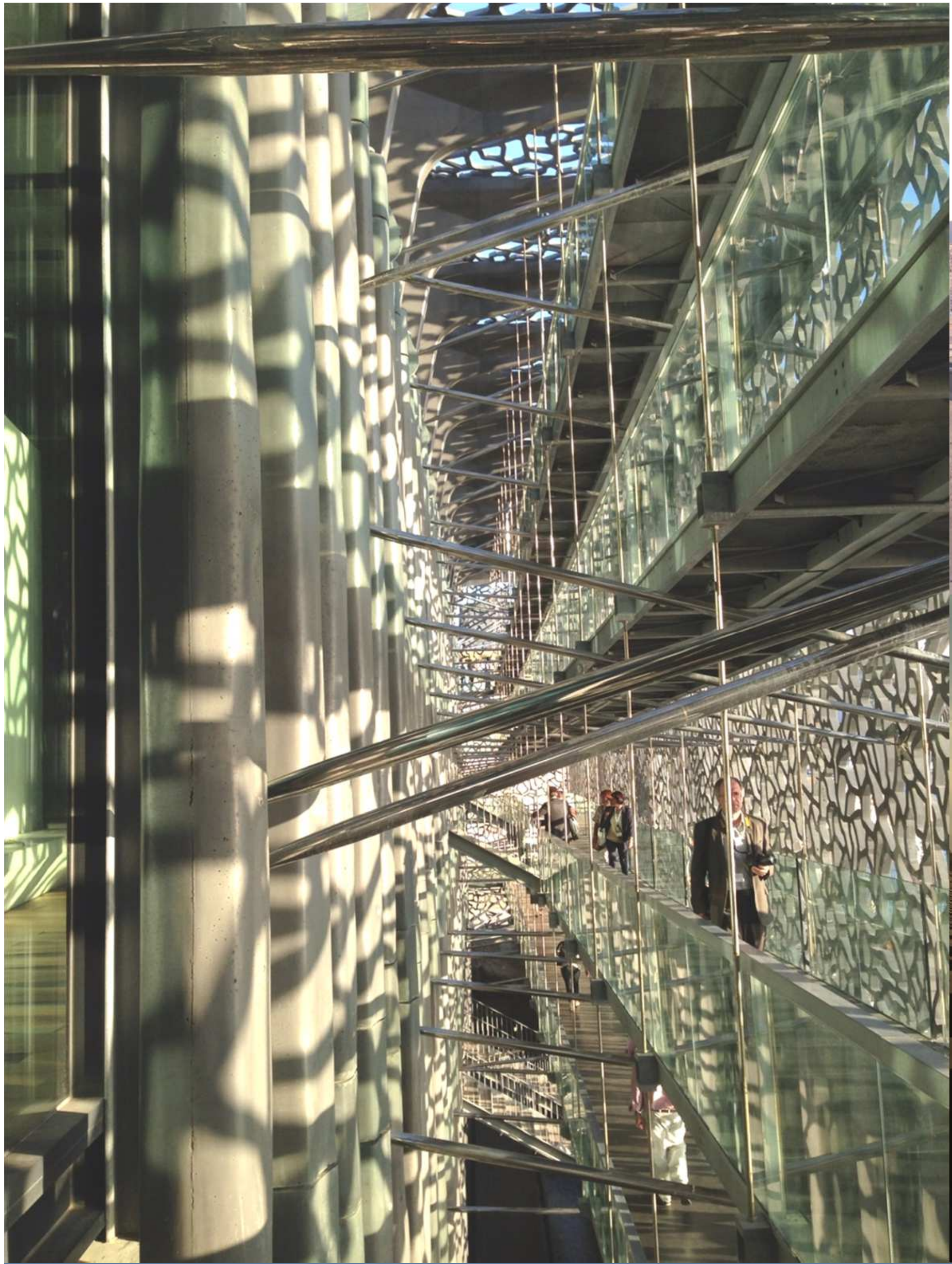
	Material Cost (€)	Labor Cost (€)	Transport Cost (€)	Storage Cost (€)	Assembly Cost (€)	**Structure Cost (€)**
Traditional	22.401	21.728	5.601	6.301	7.002	**63.033**
New Solution	24.037	8.175	3.075	3.459	7.002	**45.748**



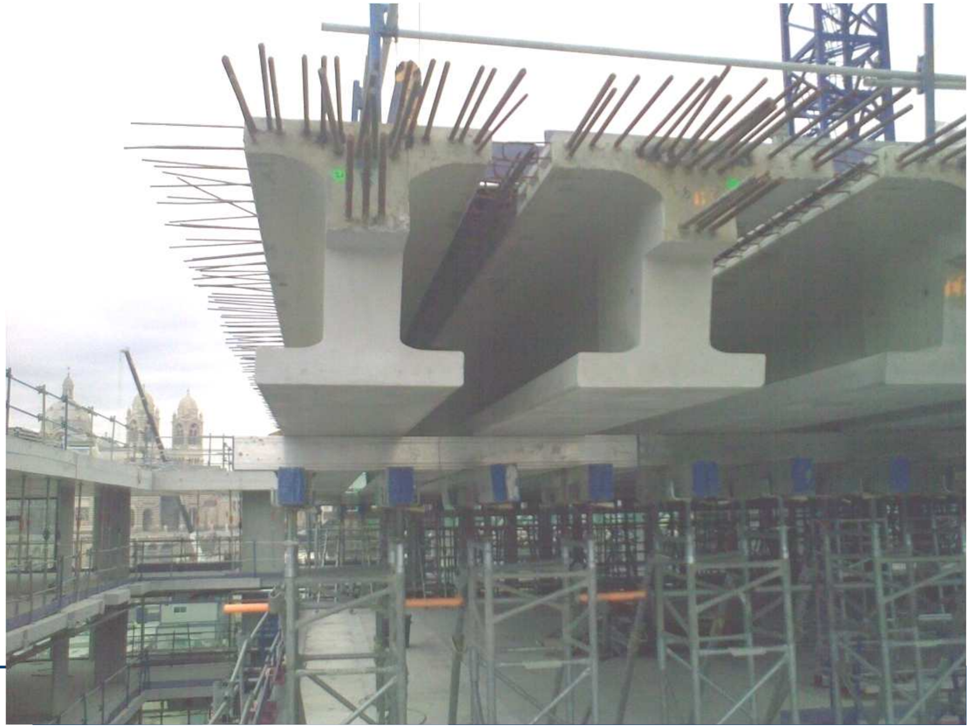
VHPFRC
TC
ODP [kg CFC 11-eq.]
-5%
GWP [kg CO2-eq.]
+57%
PED n-r [MJ]
+65%
0
50
100
150
200
[%]

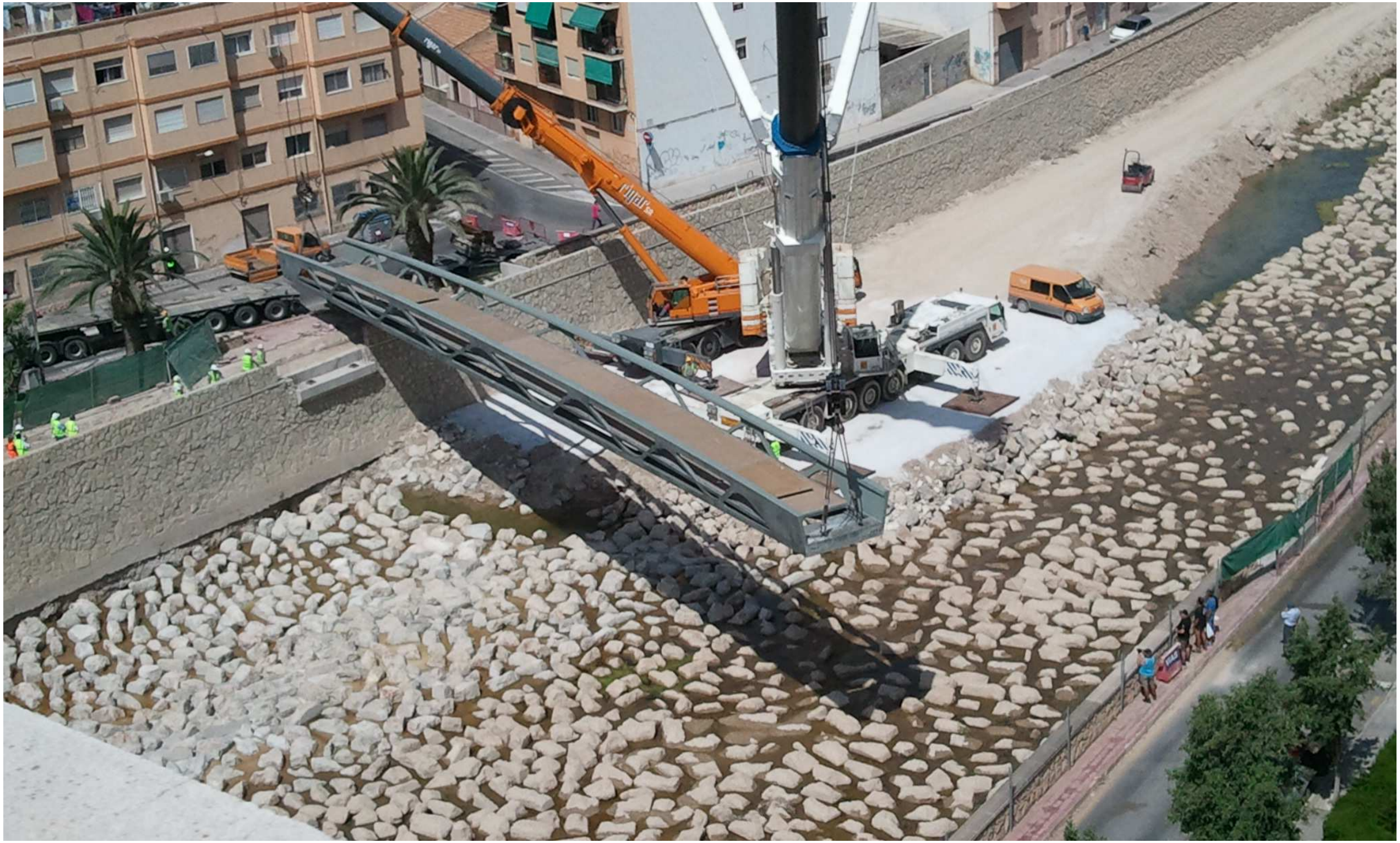

VHPFRC
TC
ODP [kg CFC 11-eq.]
-49%
GWP [kg CO2-eq.]
-14%
PED n-r [MJ]
-9%
0
20
40
60
80
100
120
[%]



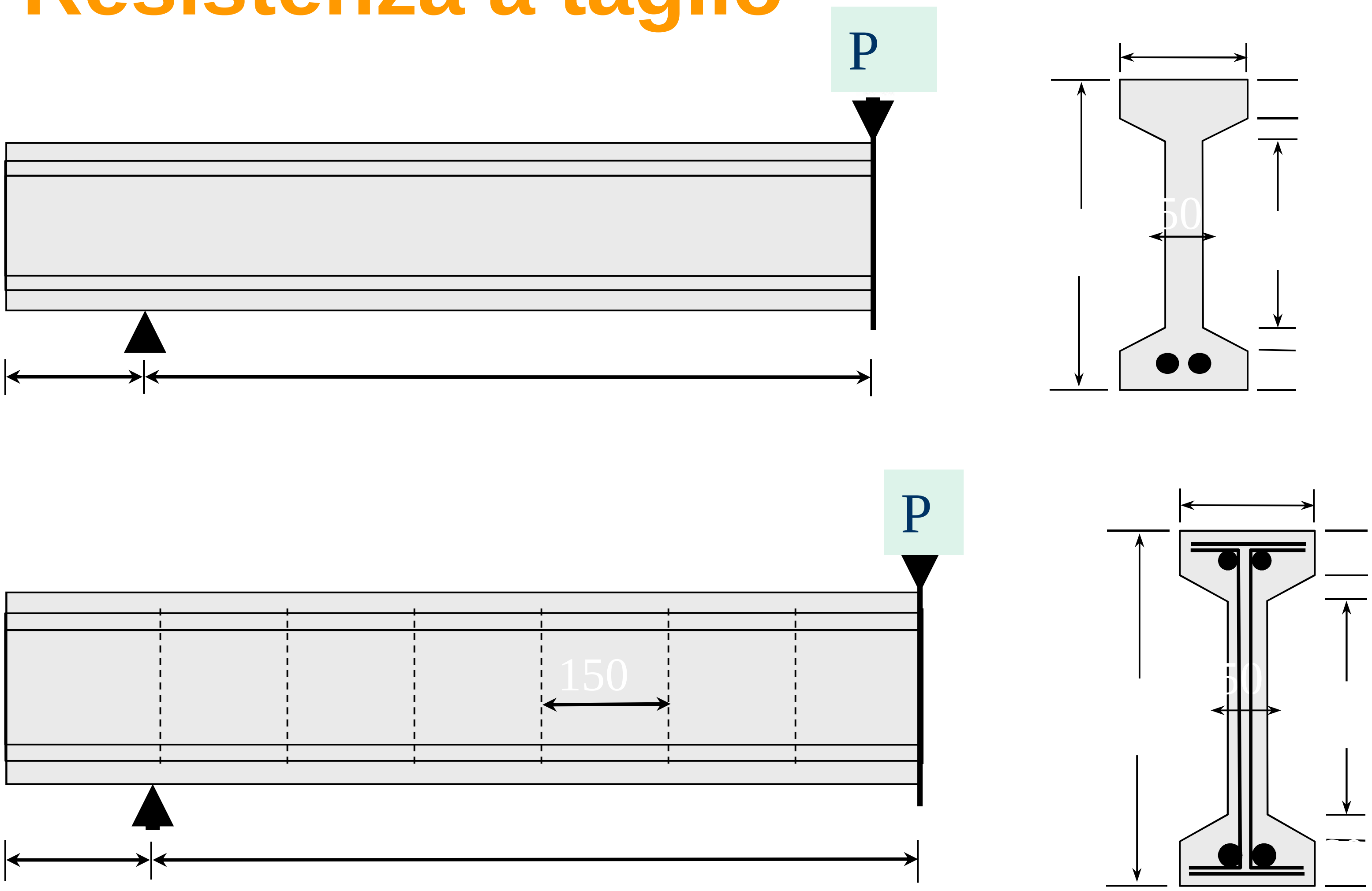






Resistenza a taglio

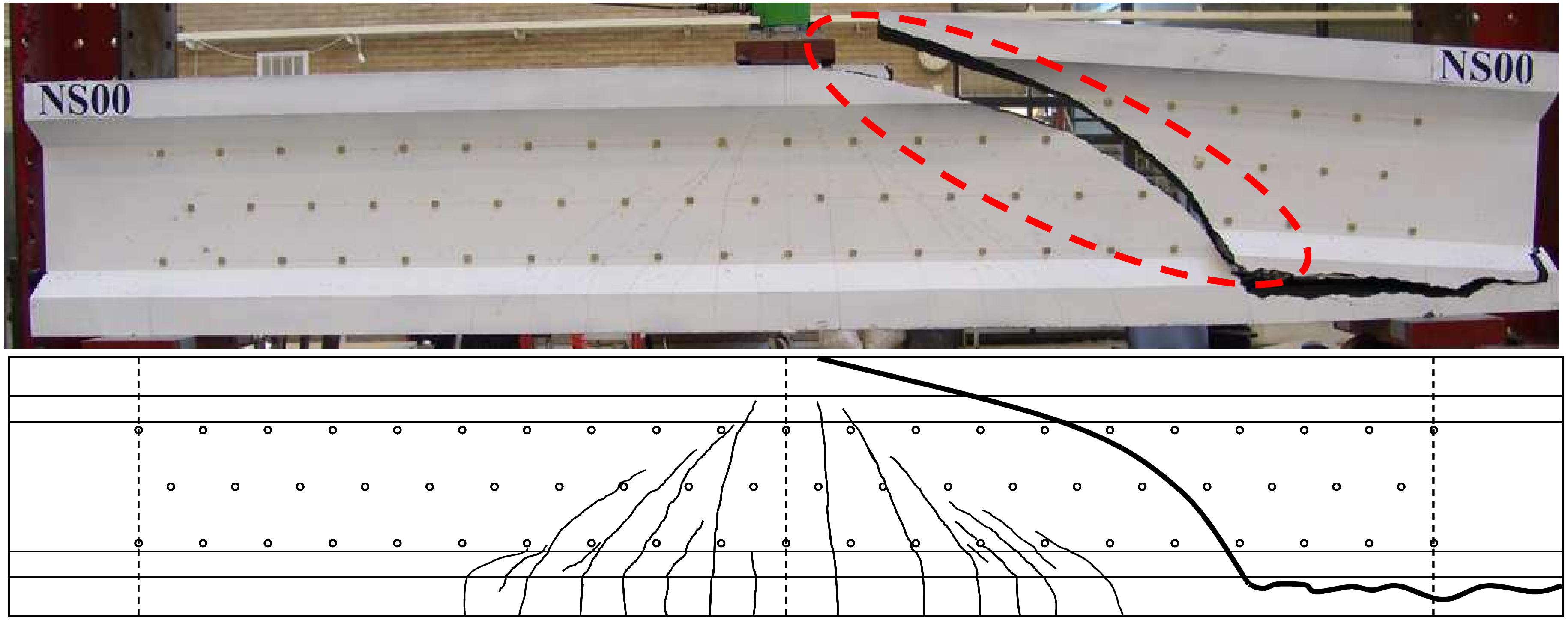


by Pansuk & Walraven (2007)

Mix design

Composition (kg/m³)	*0% fibres*	*0.8% fibres*	*1.6% fibres*
CEM I 52.5 R	*390*	*390*	*390*
CEM III/A 52.5 N	*558*	*558*	*558*
Silica fume (50%)	*102*	*102*	*102*
Sand (0-2 mm)	*1140*	*1118*	*1097*
Steel fibres [OL13/0.16]	*0*	*63*	*125*
Superplasticizer	*33*	*33*	*33*
Free water	*138*	*138*	*138*

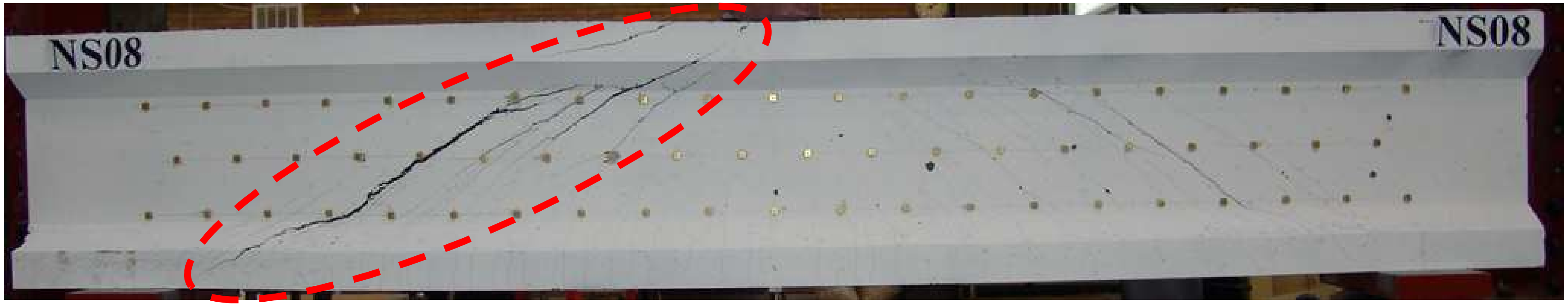
$R_c = 140$ MPa

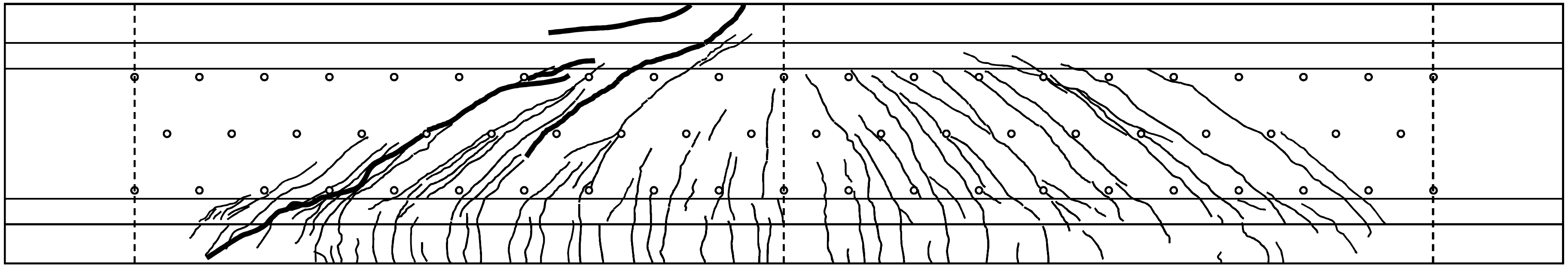


Ultimate load: 91 kN Current load: 52 kN 70 kN75 kN 82 kN 91 kN

Clacestruzzo bianco

by Pansuk & Walraven (2007)

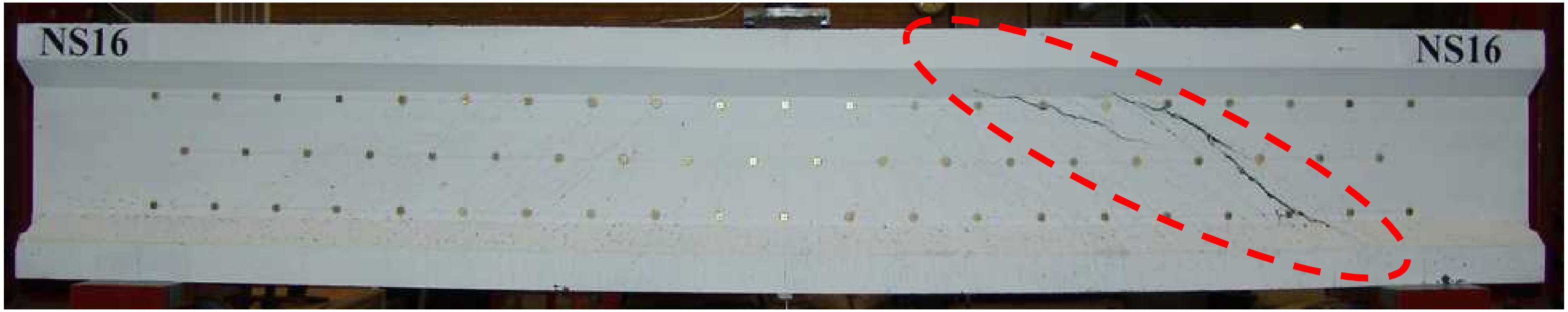


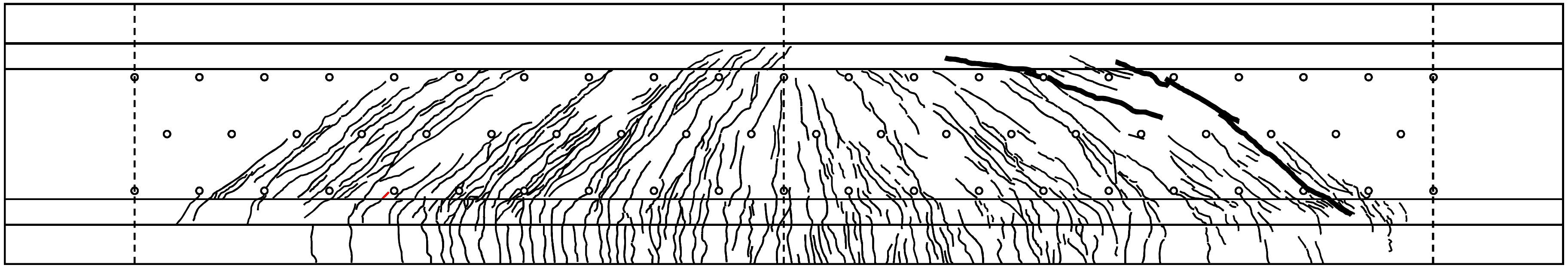


Ultimate load: 340 kN Current load:150 kN200 kN250 kN300 kN340 kN

No stirrups, 0,8% fibres

by Pansuk & Walraven (2007)





Ultimate load: 531 kN Current load: 200 kN300 kN400 kN531 kN

No stirrups, 1,6% fibers

by Pansuk & Walraven (2007)

SCC material

	Dosage (kg/m^3)
Cement type I 52.5	600
Slag	500
Water	200
Superplasticizer	33 (l/m^3)
Sand 0-2 mm	983
Fibers (l_f = 13mm; d_f = 0.16mm)	100

$\gamma = 2450 – 2530\ kg/m^3$

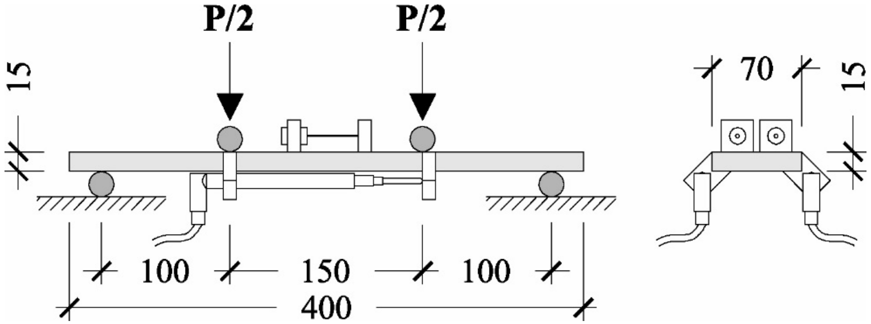
$R_{cm,\ 24h}$ = 66.3 Mpa
$R_{cm,\ 7d}$ = 99.1 Mpa
$R_{cm,\ 28d}$ = 116.5 Mpa
E_{sm} = 45249 Mpa

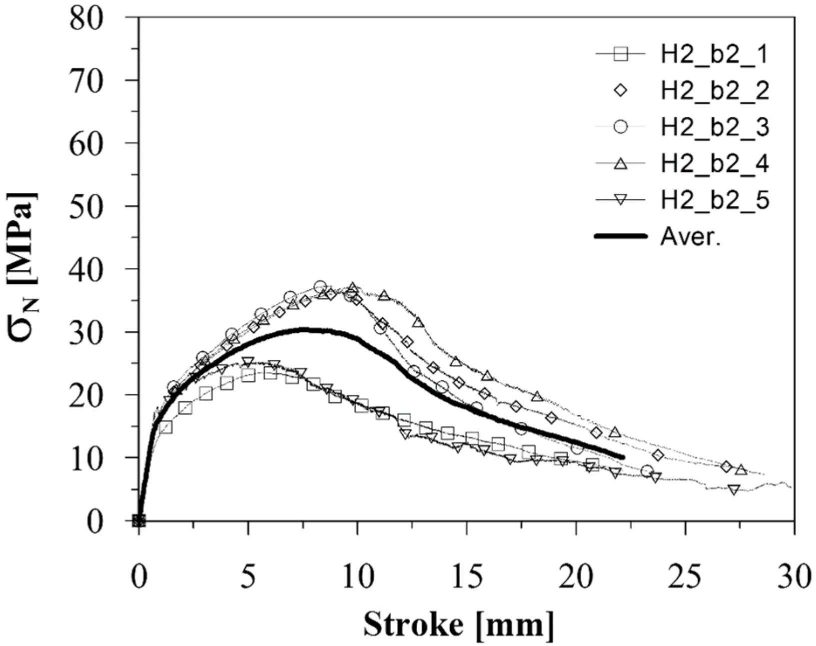
> 750 mm

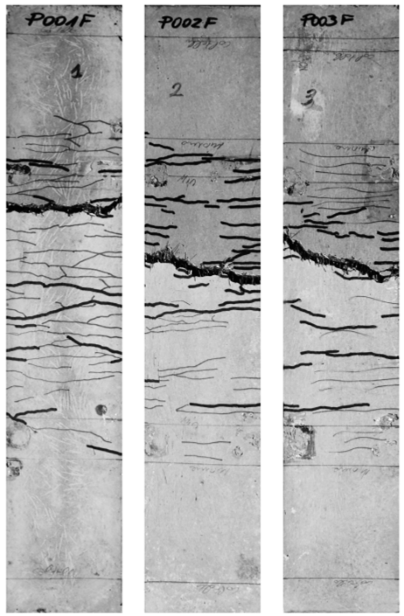
730-800 mm

4PB tests on ‘structural’ unnotched specimens

HPFRCC - Randomly oriented fibers

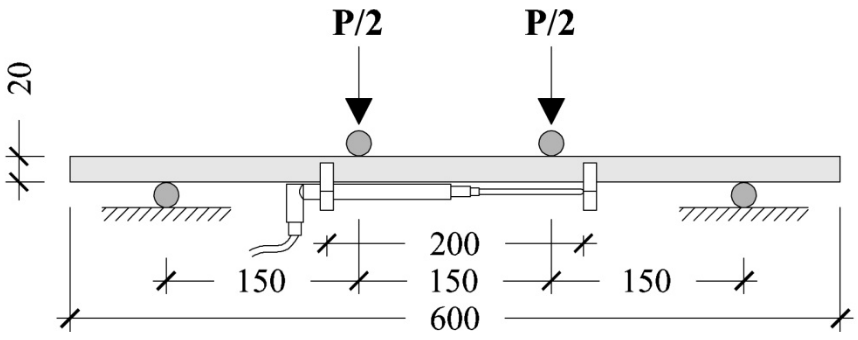


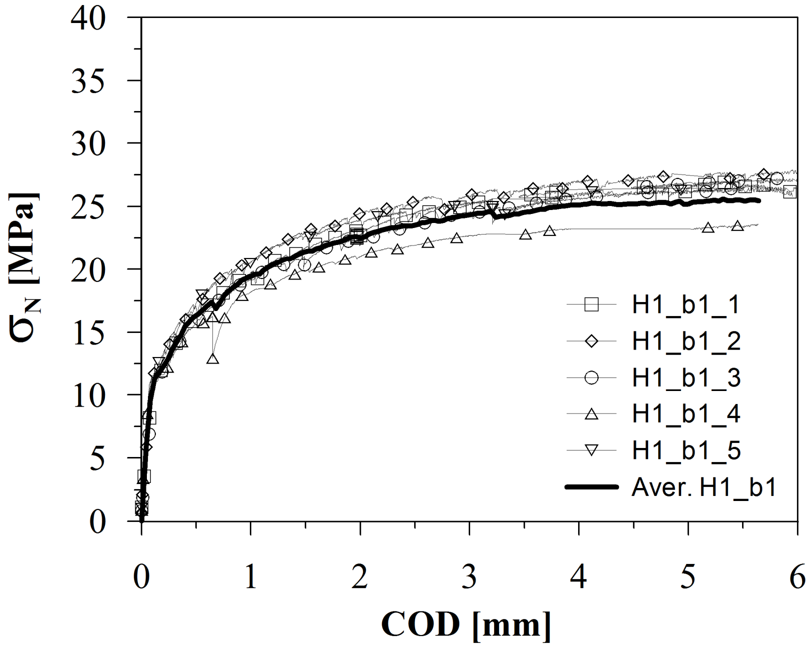


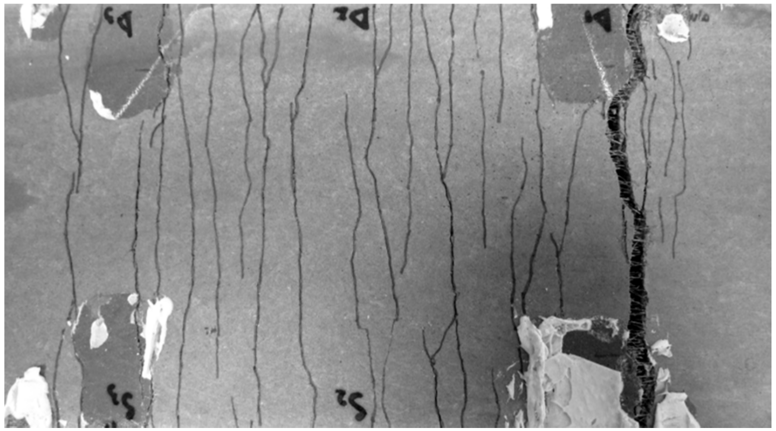


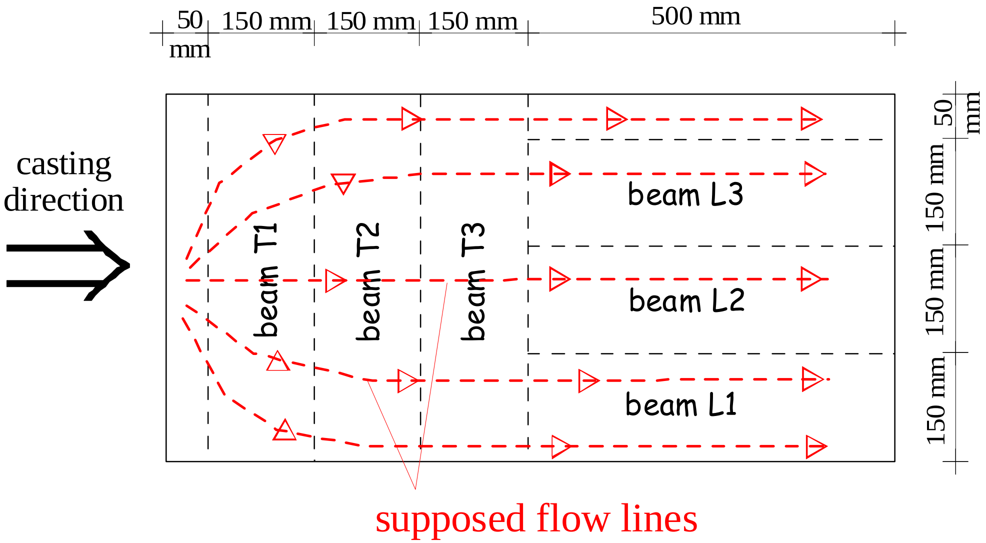
4PB tests on ‘structural’ unnotched specimens

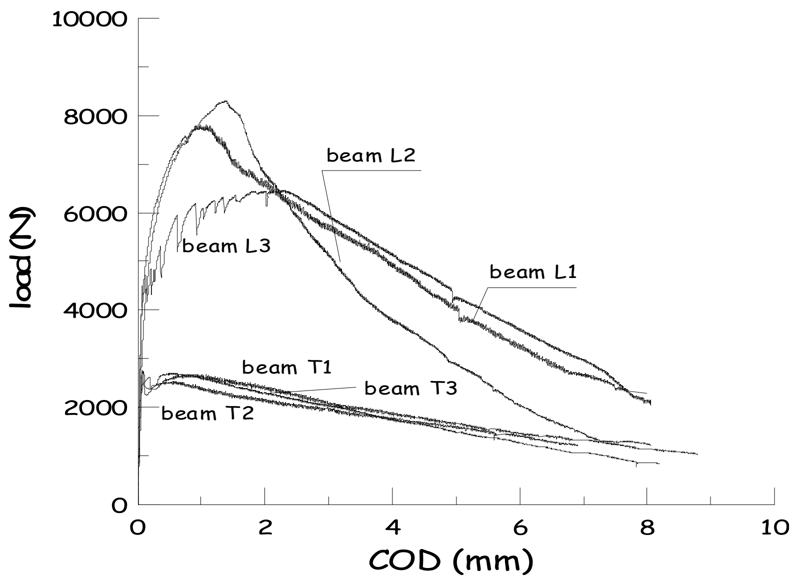
HPFRCC - Oriented fibers



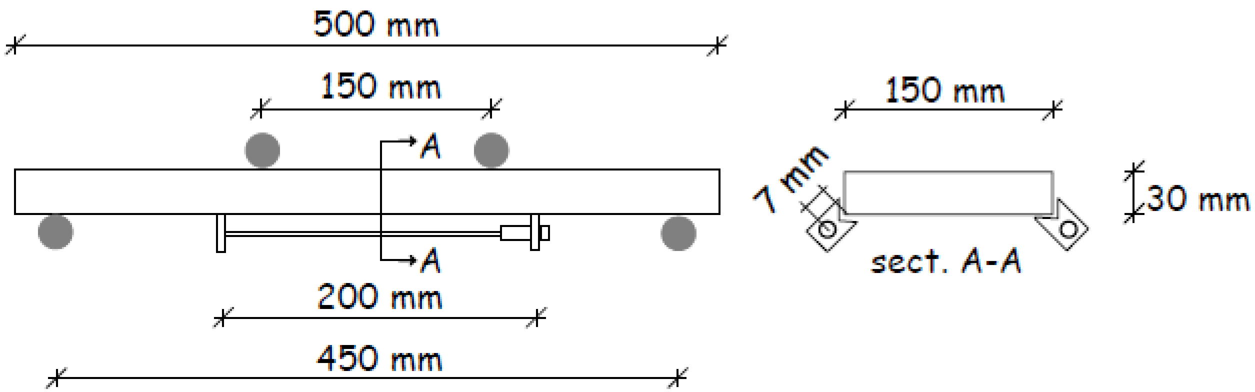






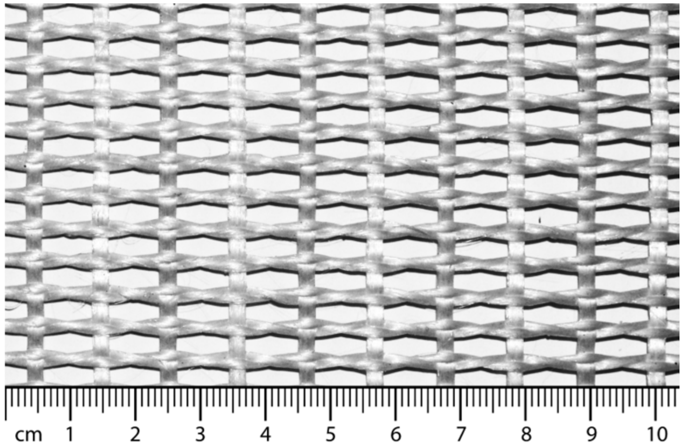


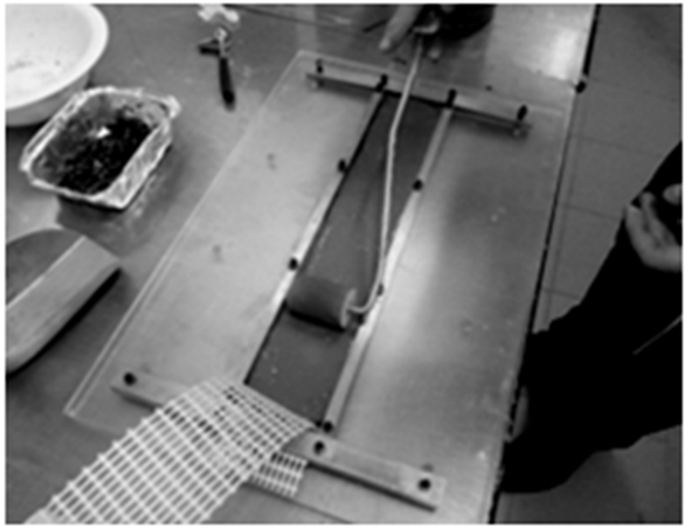
by Ferrara et al., 2009



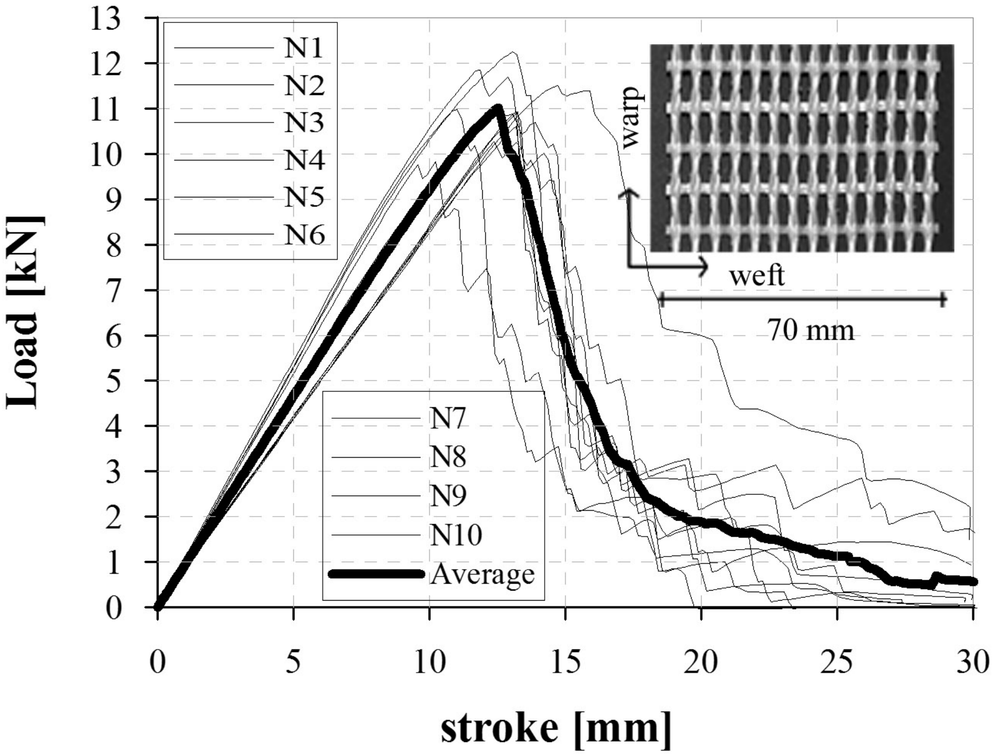
MATERIALS

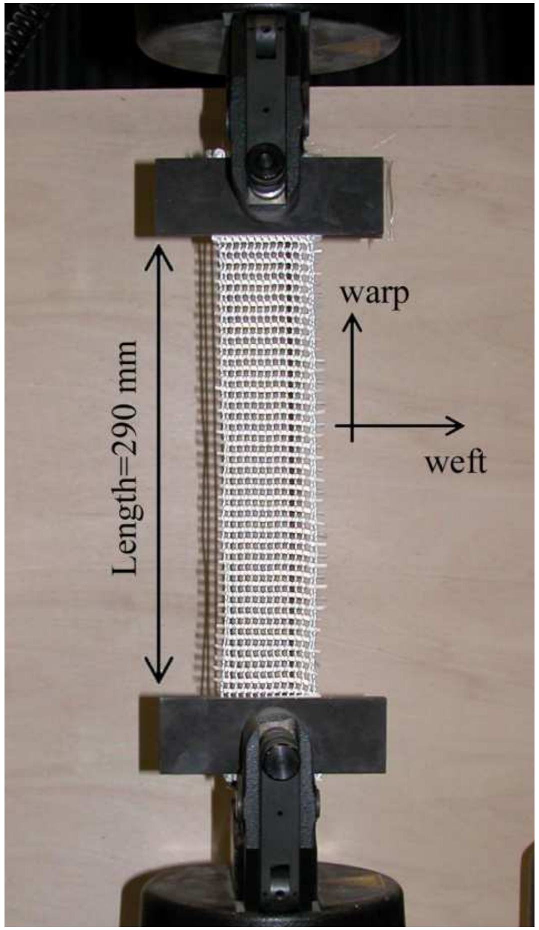
AR glass textiles



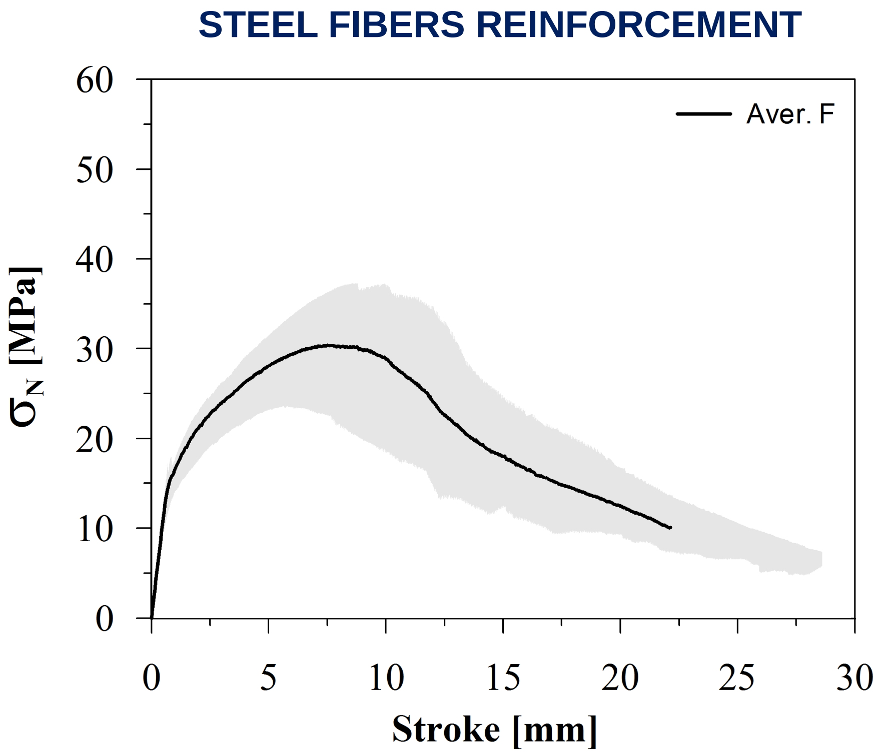


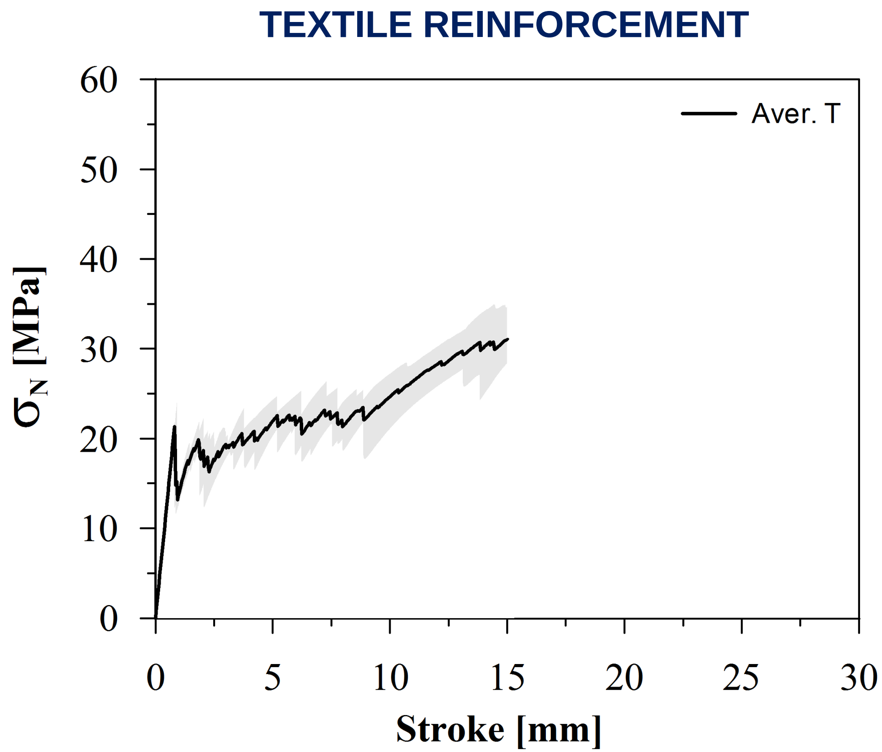
Characteristic	
Material	AR-glass
Fabrication technique	Leno weave
Warp wire spacing [mm]	4.9
Weft wire spacing [mm]	10.1
Warp fineness [Tex]	2 x 1200
Weft fineness [Tex]	1200
Warp filament [μm]	19
Weft filament [μm]	19
Maximum tensile load on 70 mm [kN]	11.02


Load [kN]
stroke [mm]
N1
N2
N3
N4
N5
N6
N7
N8
N9
N10
Average
warp
weft
70 mm


Length=290 mm
warp
weft

Experimental results

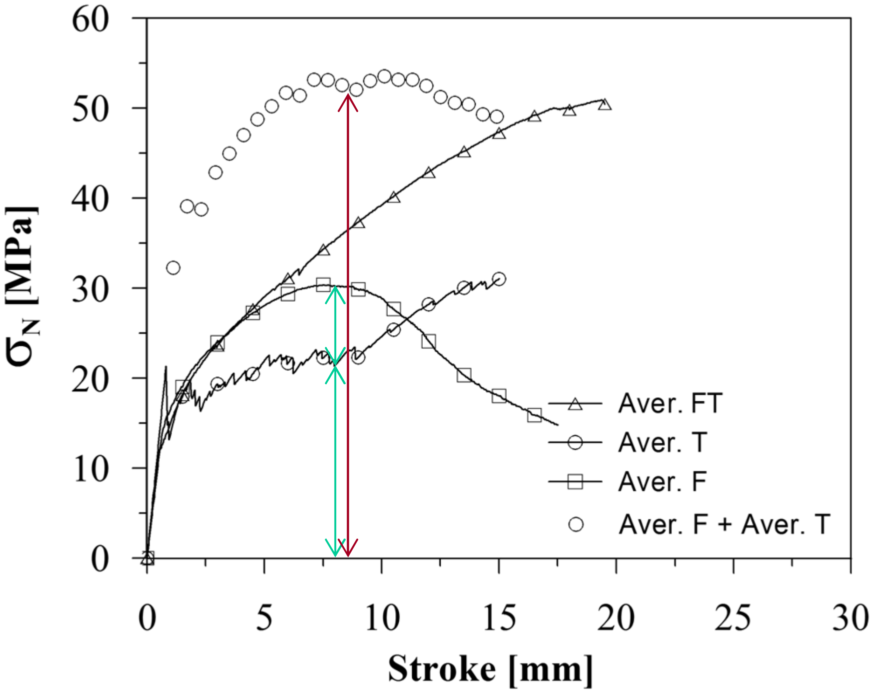




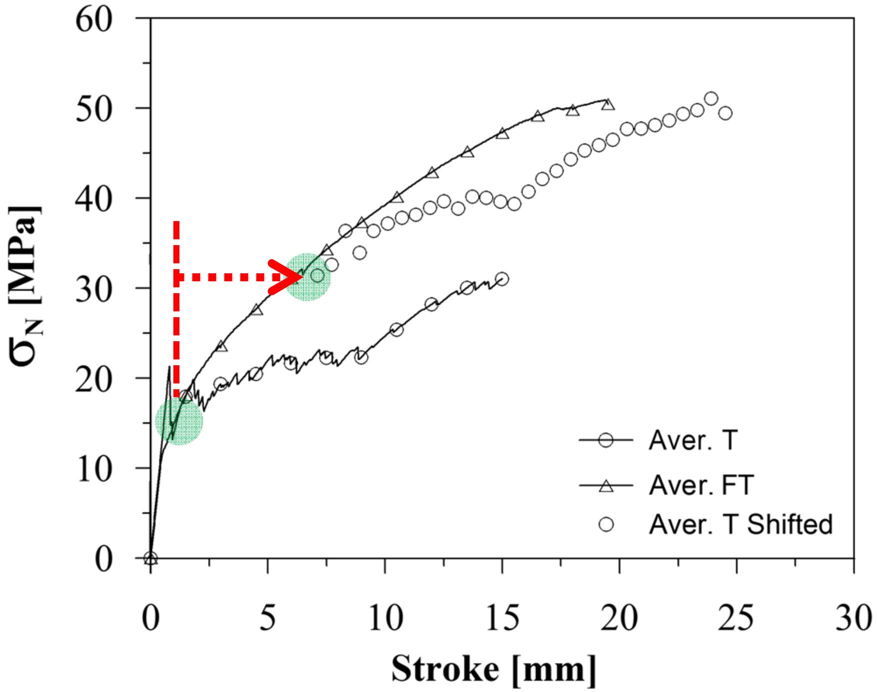
Nominal Stress vs. Stroke curves

Experimental results

CUMULATIVE AVERAGE CURVE (F+T)



SHIFTED T CURVE



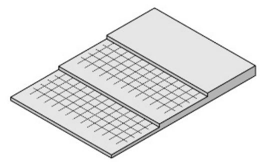
No clear synergic effects (as the ones highlighted in direct tension)

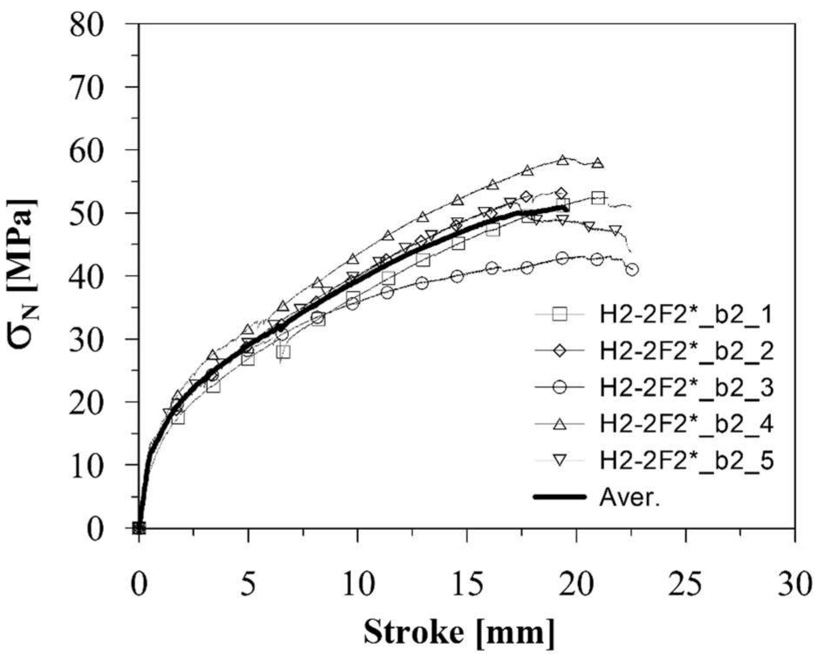
The response of the lower glass fabric took place after the onset of a diffuse micro-cracking, that was found to be close to an equivalent strain ε* of about 2.7%.

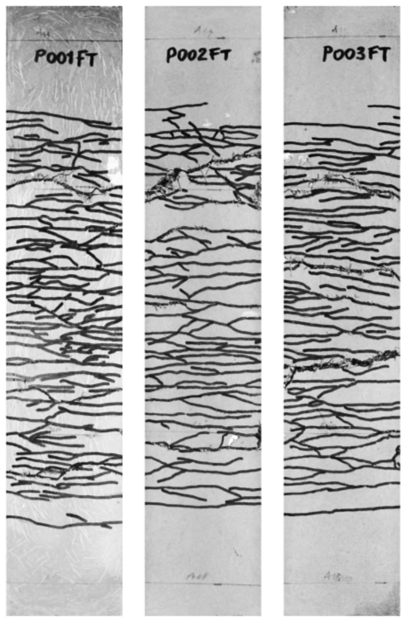
4PB tests on ‘structural’ unnotched specimens

HyFRCC: HPFRCC + 2 layers of AR glass fabrics - Randomly oriented fibers

2 layers

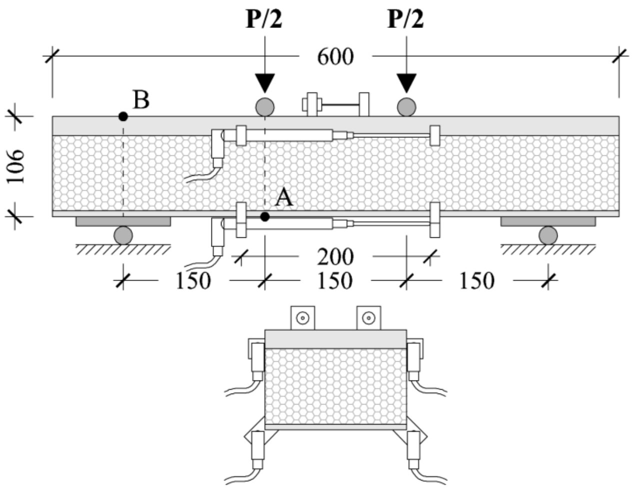




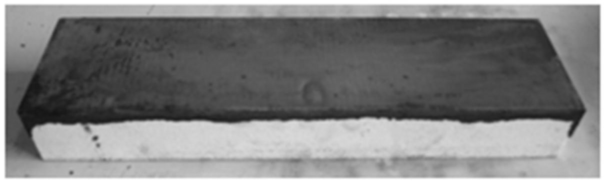


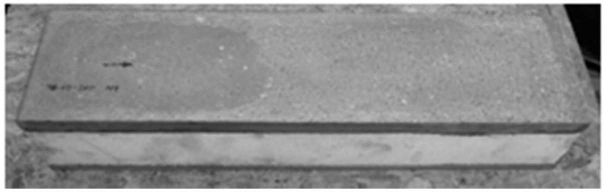
CASE STUDY: ROOFING ELEMENT

Specimen	Core material	Interface material
H1-P-T1-2F1*_b1_1	EPS150	-
H1-P-T1-2F1*_b1_2	EPS150	-
H1-P-T1-2F1*_b1_3	EPS150	-
H1-F-N-T1-2F1*_b1_1	FoamglasS3	NorphenPU
H1-F-N-T1-2F1*_b1_2	FoamglasS3	NorphenPU
H1-F-N-T1-2F1*_b1_3	FoamglasS3	NorphenPU
H1-F-A-T1-2F1*_b1_1	FoamglasS3	AdesilexPG1
H1-F-A-T1-2F1*_b1_2	FoamglasS3	AdesilexPG1
H1-F-A-T1-2F1*_b1_3	FoamglasS3	AdesilexPG1



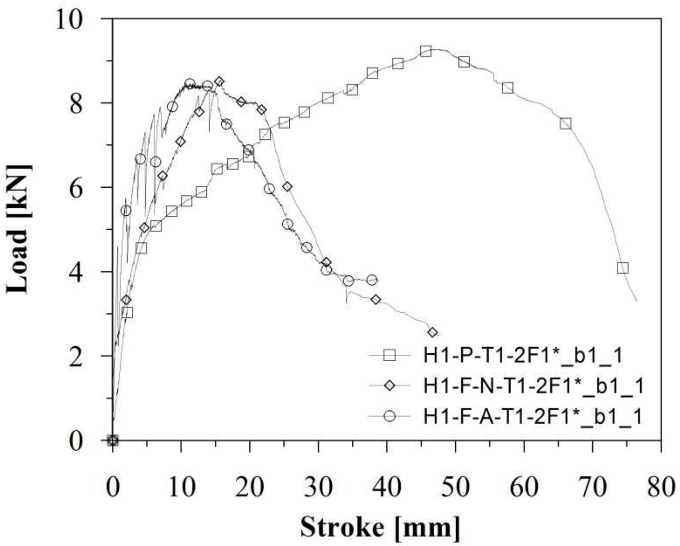
POLYSTYRENE CORE

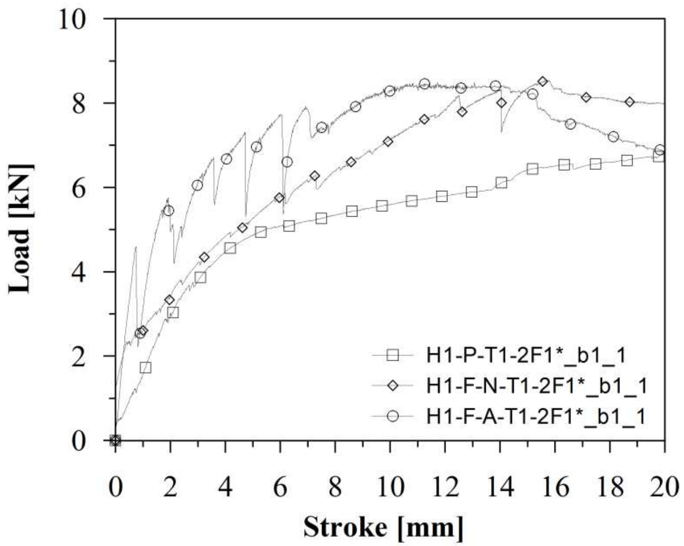


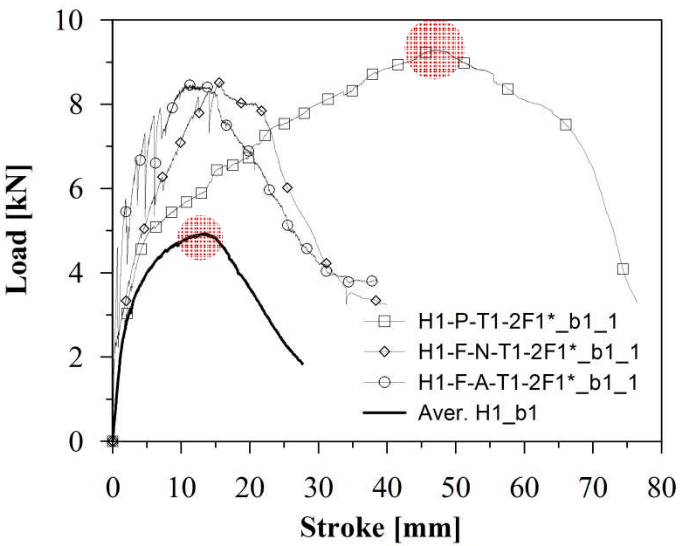


GLASS FOAM CORE

CASE STUDY: ROOFING ELEMENT





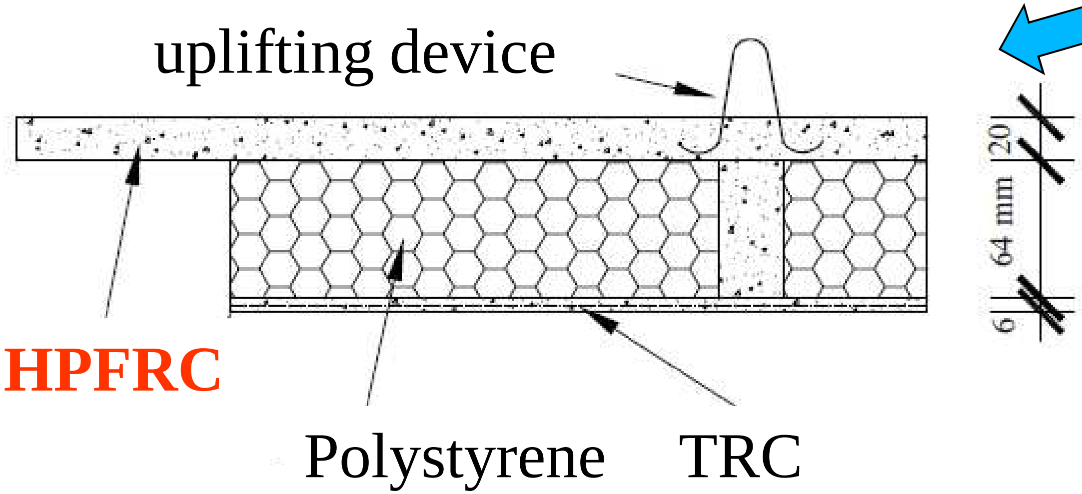


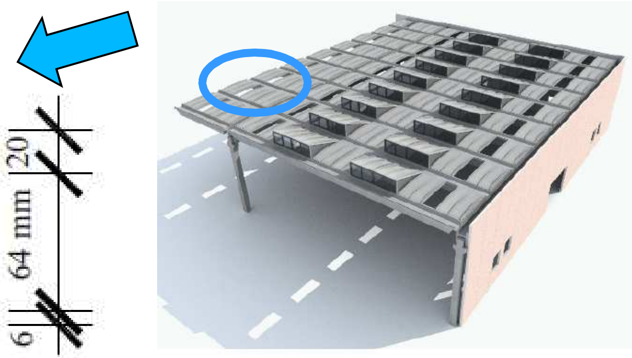
Comparison between the sandwich composites and the HPFRC "structural" plate:

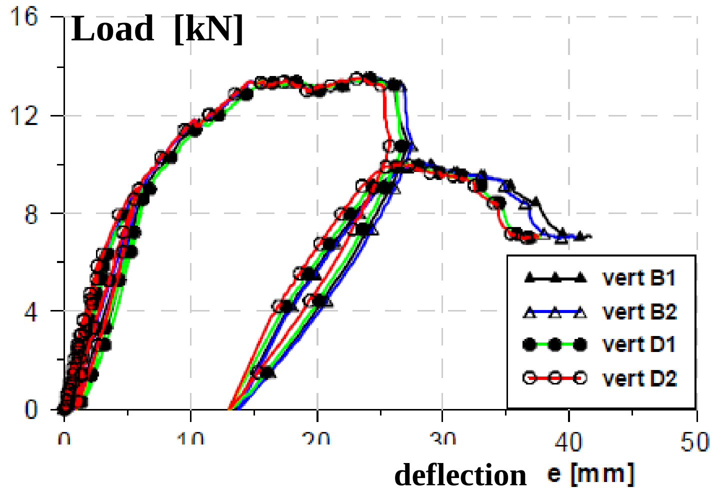
+ 90% of the peak load

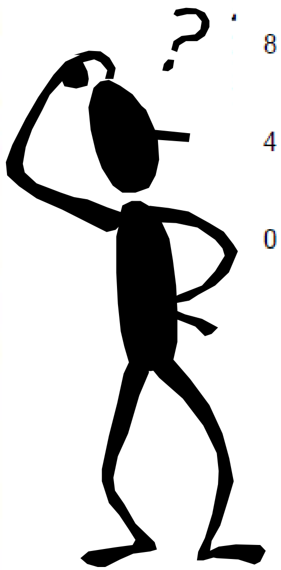
+ 250% of the peak displacement

New solutions for sustainable roofing





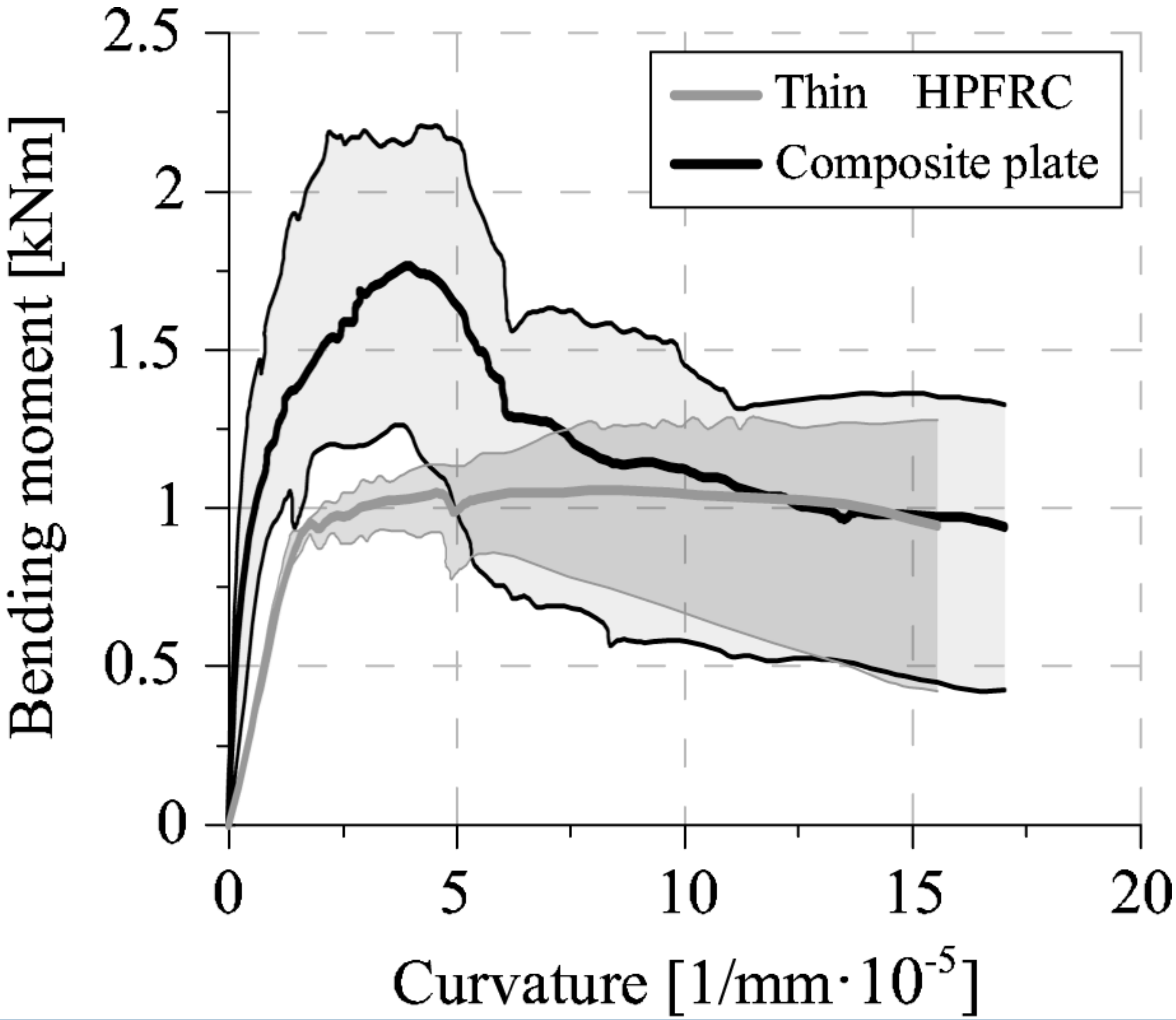




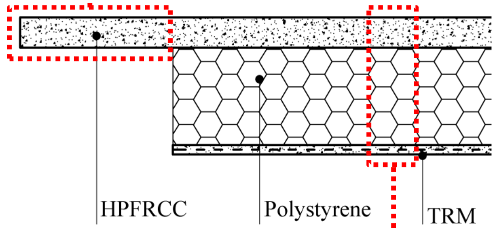
Precast roof elements: casting in the plant

Precast roof elements: real scale test

Precast roof elements: experimental results



Thin HPFRC



Composite plate

CASE STUDY: ROOFING ELEMENT

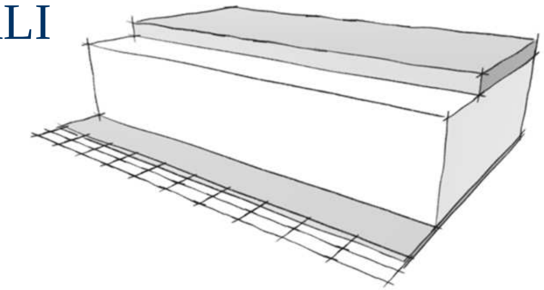
Roof systems are in important component of the building envelope, since they are specifically designed to separate the living spaces from the natural environment. They should ensure:

- adequate mechanical performances;
- energy efficiency;
- sound insulation;
- durability;
- aesthetics.

HOW CAN WE MEET THE REQUIREMENTS OF THE REVISED NATIONAL CODES?

S.IN.E.RG.I.E ATTI.V.E.

SISTEMA INTEGRATO SOSTENIBILE ENERGETICAMENTE ATTIVO PER IL RINNOVO DEGLI EDIFICI INDUSTRIALI ATTRAVERSO COPERTURE COMPOSITE



UNIONE EUROPEA

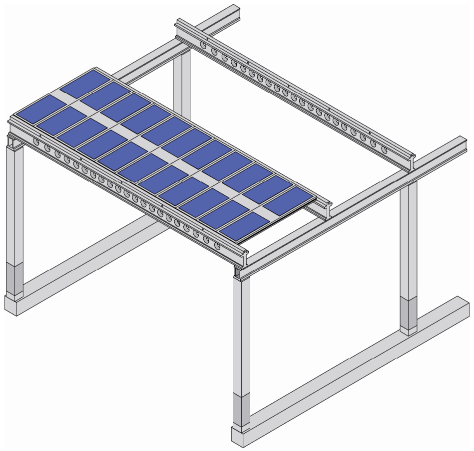
Ministero dell'Istruzione dell'Università e della Ricerca

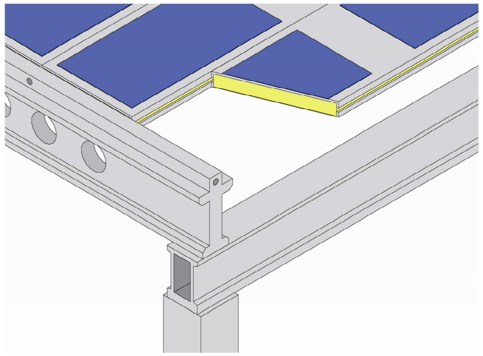
RegioneLombardia

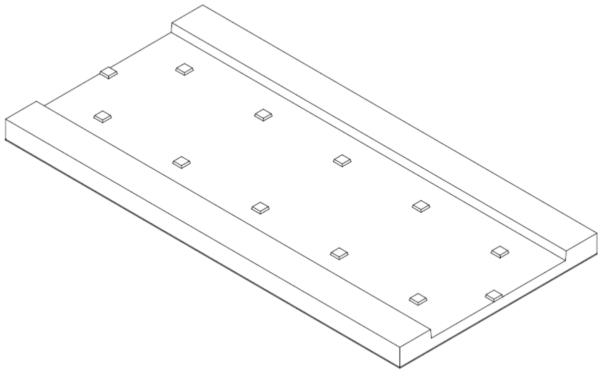
POR COMPETITIVITÀ 2007-2013

HPFRC + INSULATING CORE + TRC

• self-weight reduction to solve seismic requirements;
• fire safety improvement;
• environmental sustainability, relying both on the improvement of the thermal performances and on the design of Building-Integrated Photovoltaics (BIPV) and the use of recycled fibres;
• global cost reduction: no need of waterproofing layer

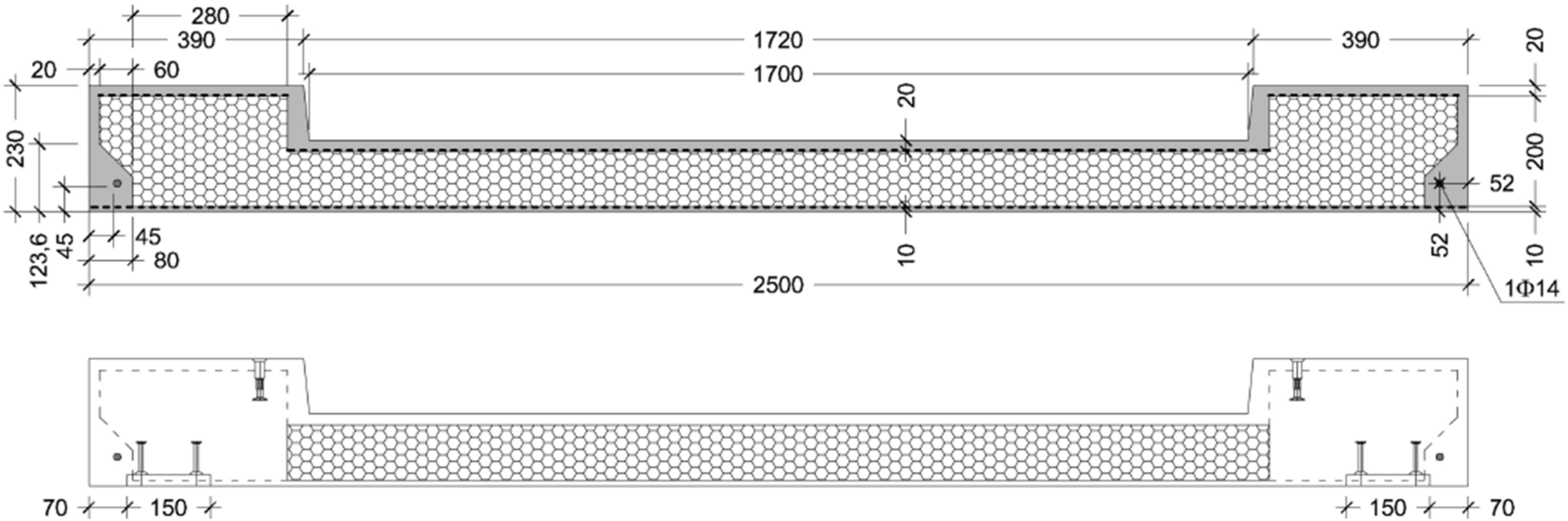






The proposal

- 2.5 m wide and 5 m long secondary prefabricated elements.
- Main features: **lightness** (self-weight of about 1.2 kN/m^2); remarkable **thermal insulation** (U = 0.42 W/m^{2}K), **waterproof quality**, **ease of assembly**, **fire safety** (> R30) and effective **integration of photovoltaic systems**.



HPFRCC - material characterization

Table 1. HPFRCC mix design.

Component	Dosage
Cement I 52.5	600 kg/m^3
Sand 0-2 mm	847 kg/m^3
Water	225 l/m^3
Superplasticizer	28 kg/m^3
Slag	500 kg/m^3
Steel fibers	100 kg/m^3

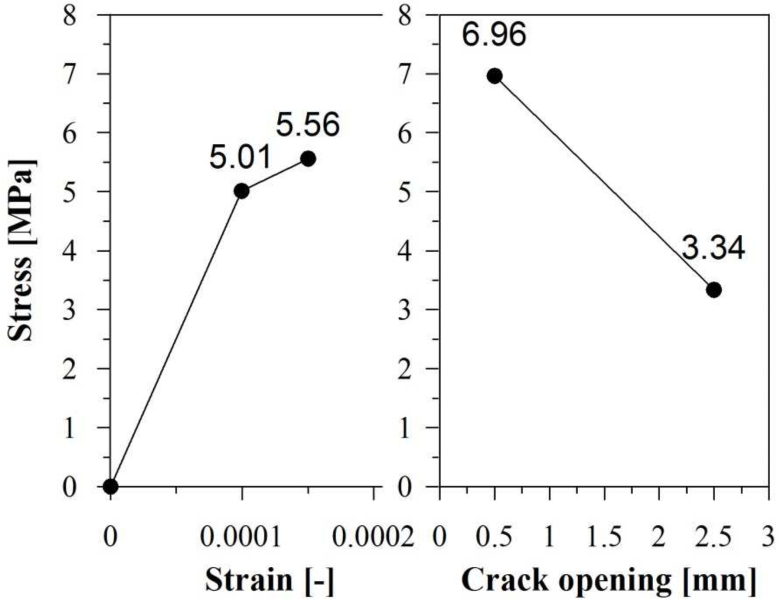
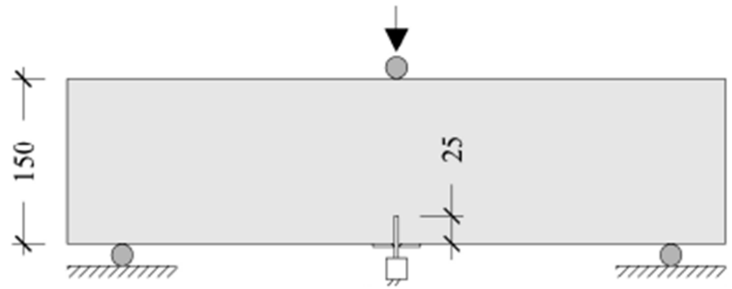
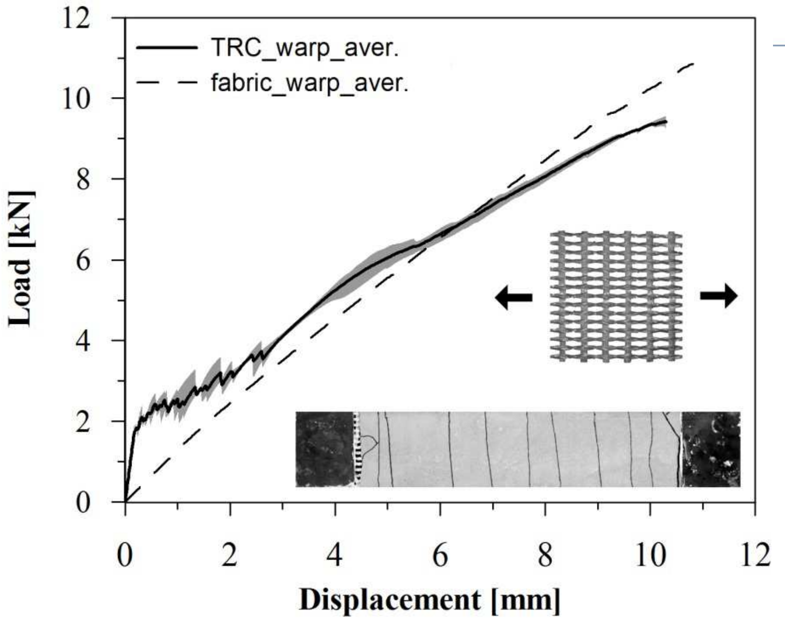


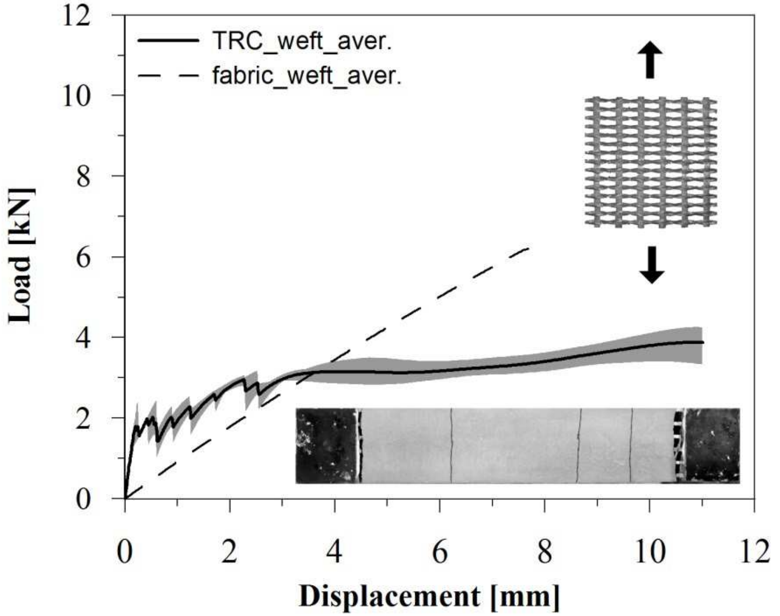
Table 2. HPFRCC reference tensile strengths.

	Stress [MPa]	Crack opening w [mm]
f_{Ftsk} (SLS)	6.96	0.5
f_{Ftuk} (ULS)	3.34	2.5



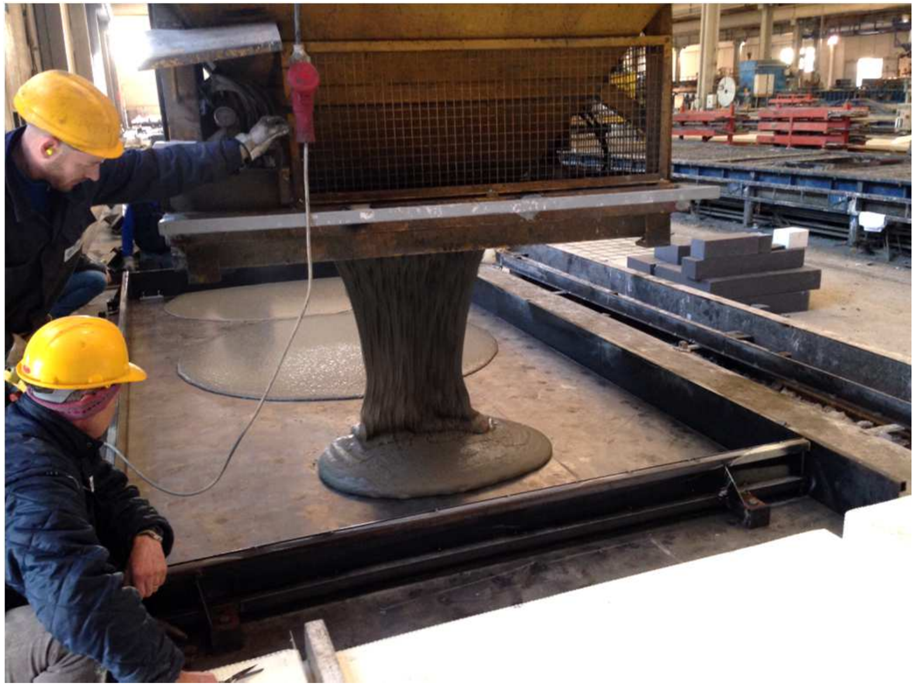
TRC - material characterization





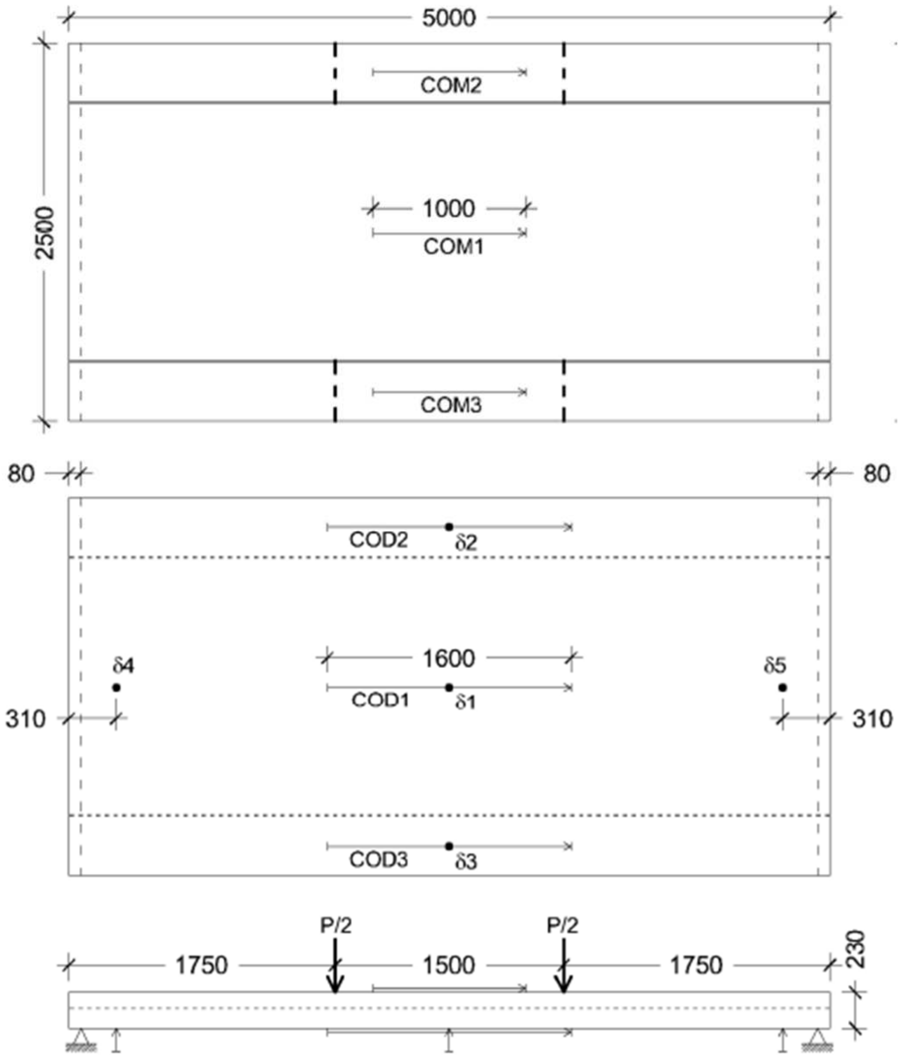
CASE STUDY: ROOFING ELEMENT

CASE STUDY: ROOFING ELEMENT



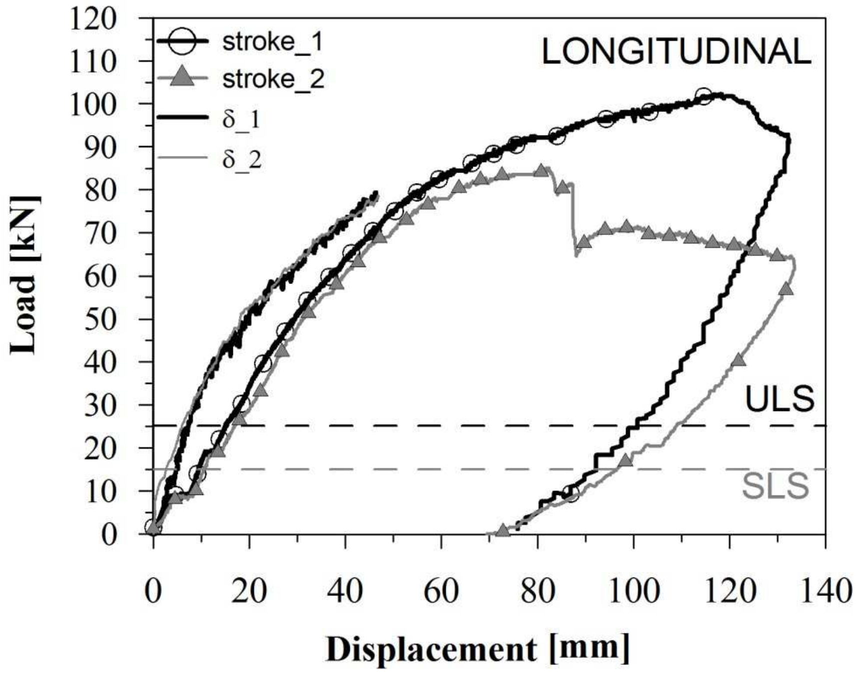
CASE STUDY: ROOFING ELEMENT

Longitudinal bending tests - setup

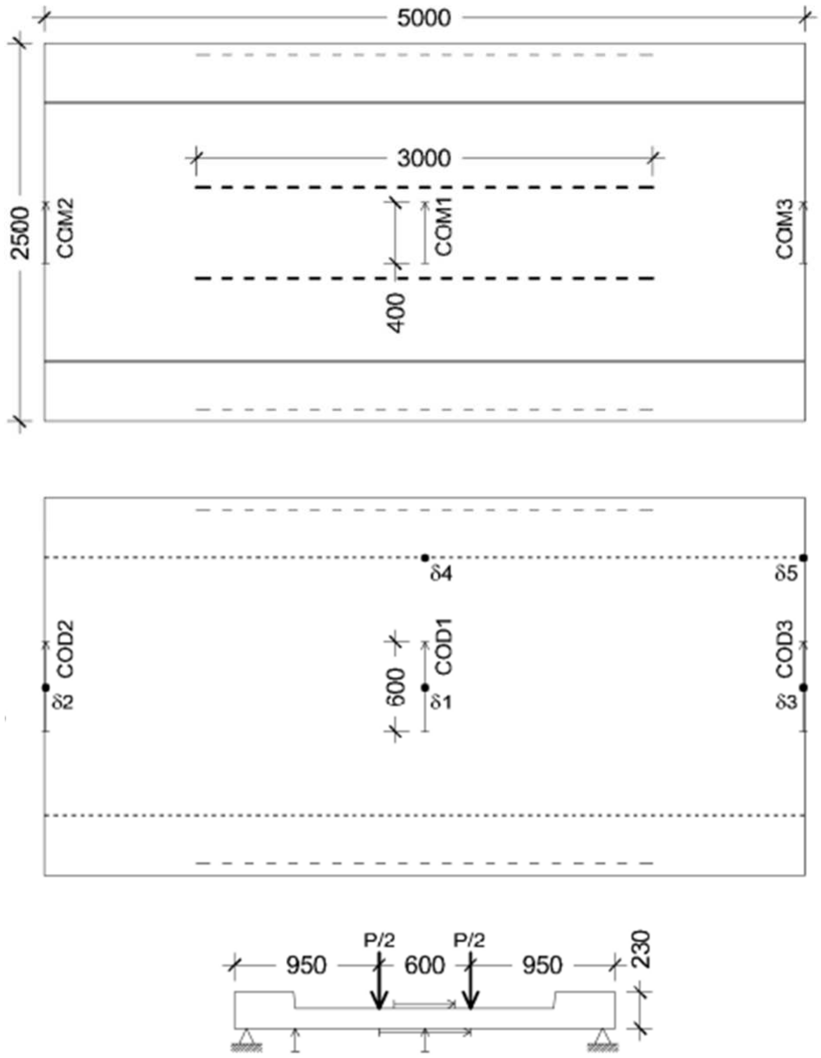


Longitudinal bending tests

- **- Remarkable strength and ductility levels:** peak loads were about **3.5 to 4 times higher** than the one associated to the Ultimate Limit State (ULS).
- - Test number 2 was halted right after the widening of some shear cracks, originally developed on an HPFRCC web, probably due to a poor control of the wall thickness and an uneven distribution of the fibrous reinforcement.

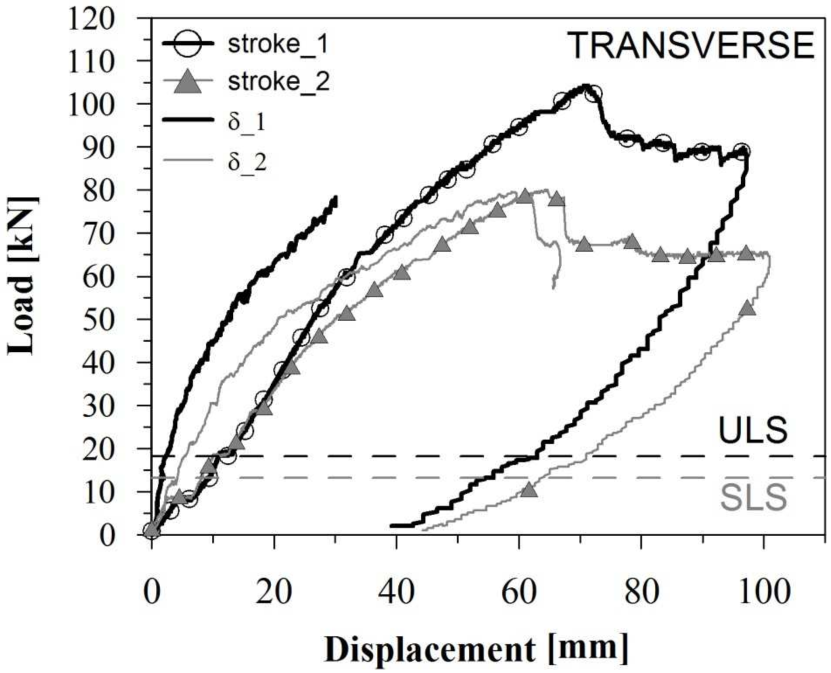


Transverse bending tests - setup

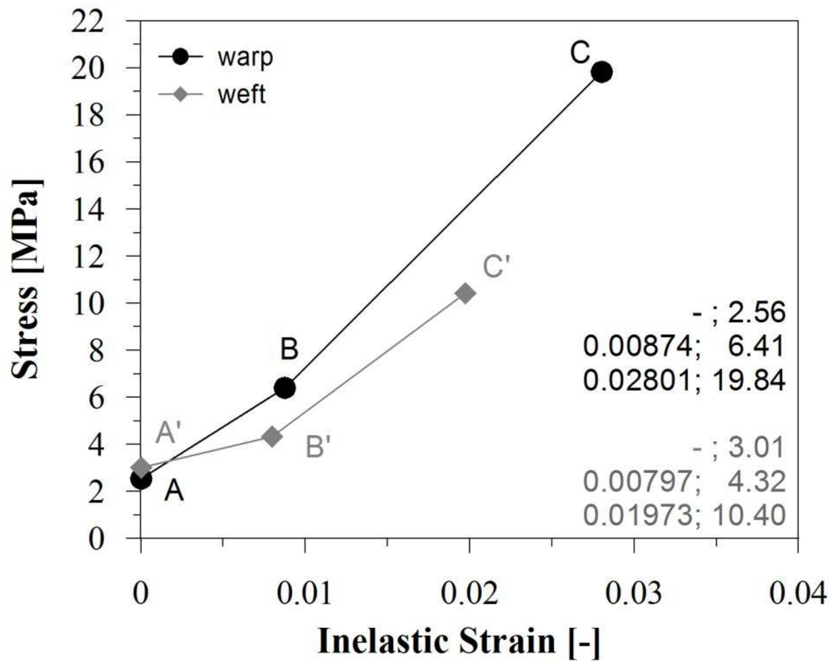


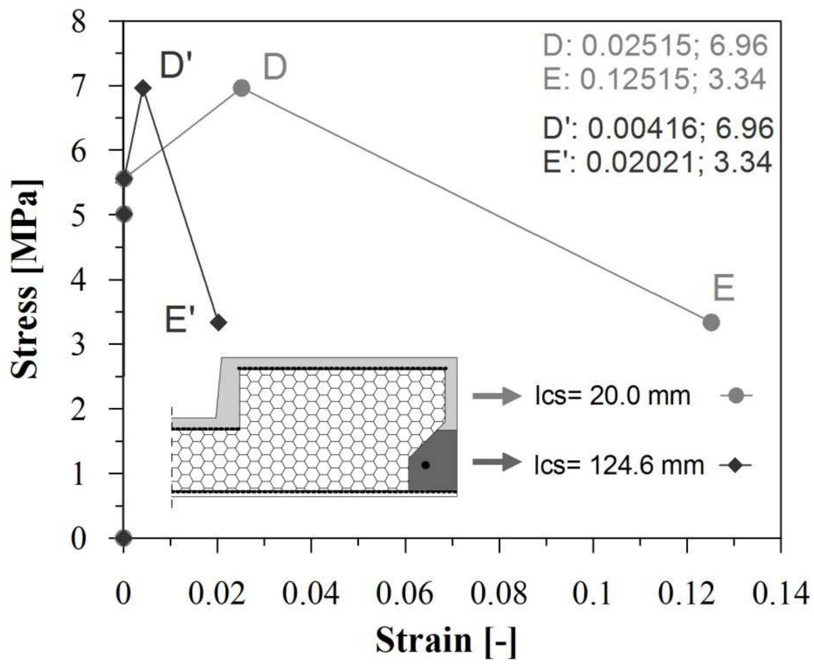
Transverse bending tests

- ✓ Ultimate loads about **4 to 4.5 times higher** than the ULS design one.
- ✓ Peak load of test number 1 corresponded to the localization of a flexural crack,
- ✓ Test number 2 an early failure occurred due to the delamination of the TRC bottom layer (caused by the introduction of an alternative production procedure).

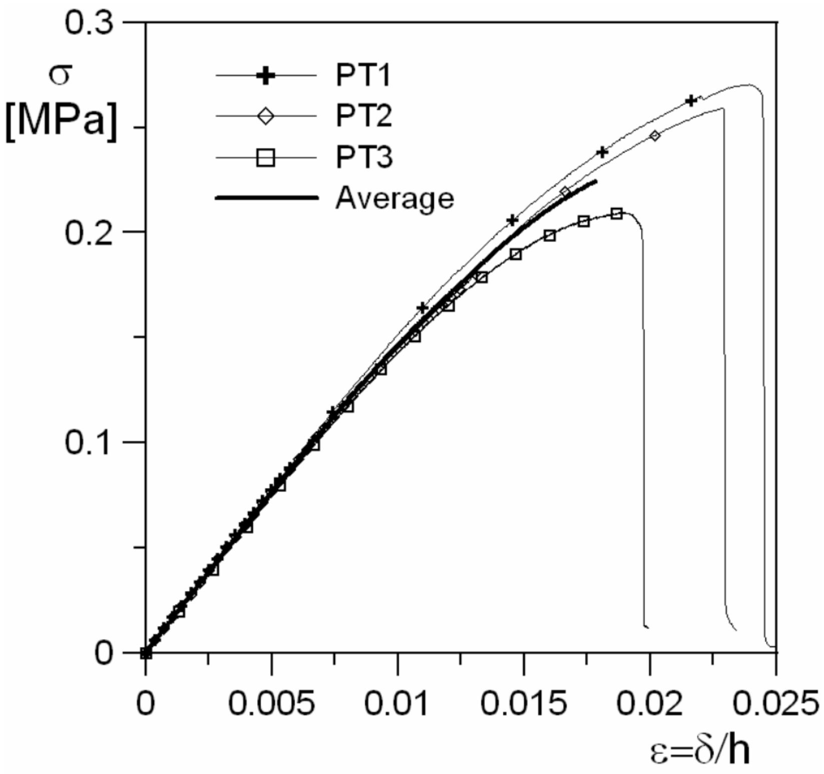


Constitutive laws for the cement-based materials

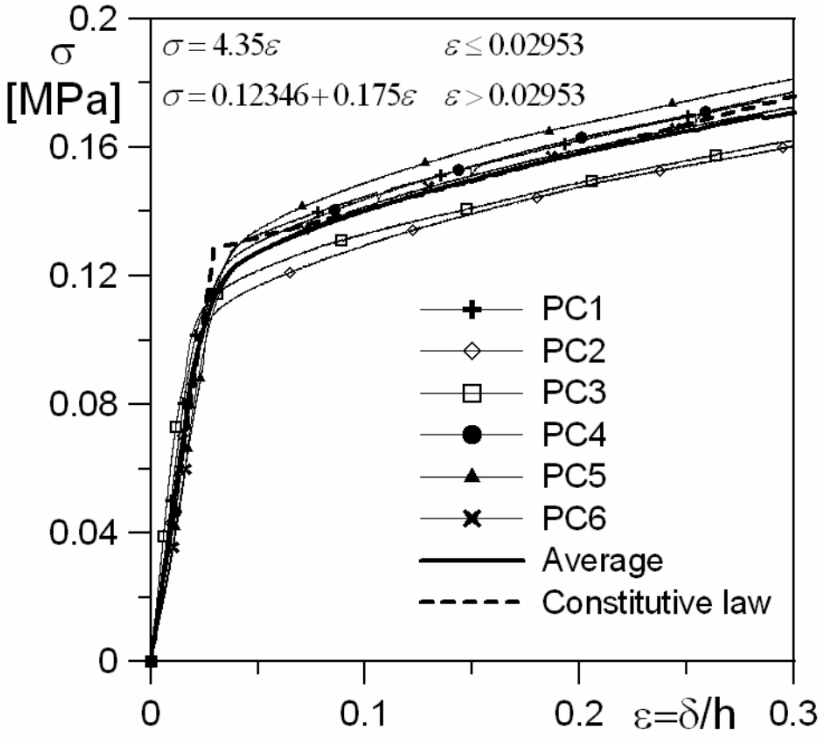




Mechanical characteristics of polystyrene

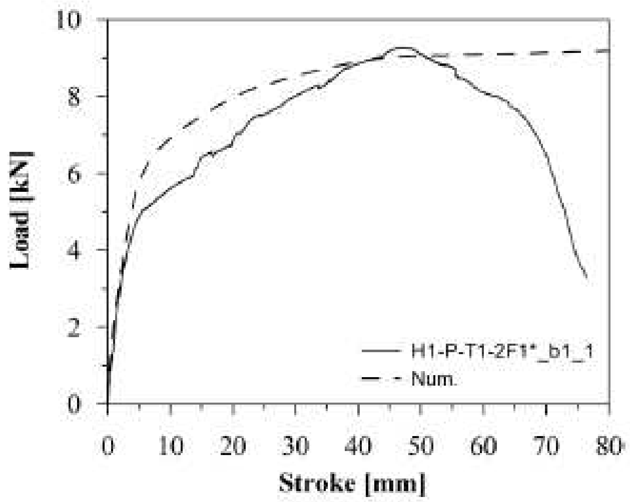


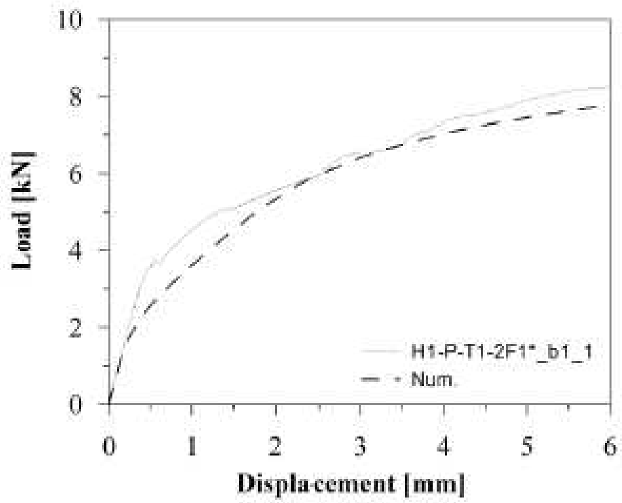
Uniaxial tension

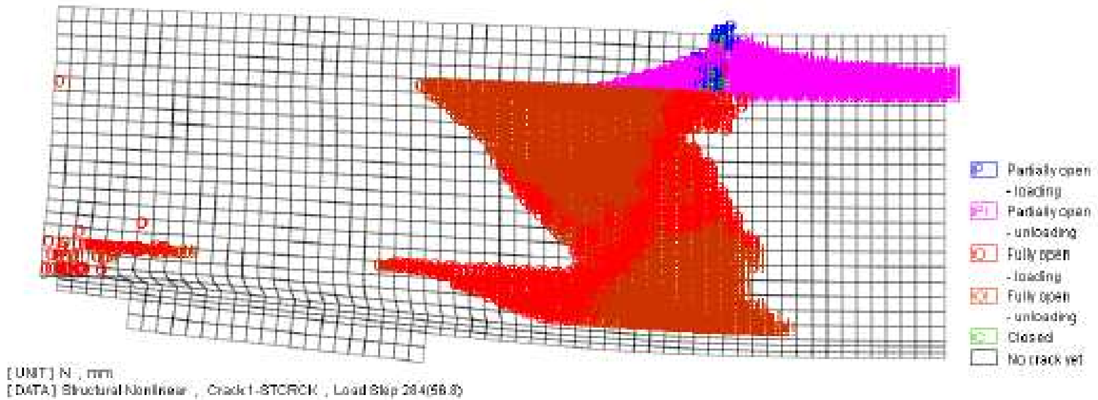


Uniaxial compression

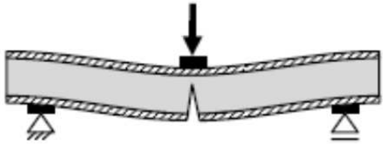
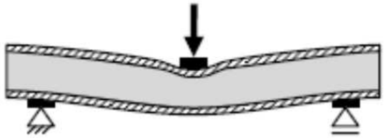
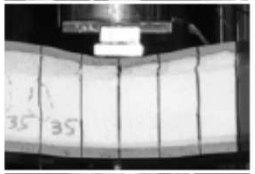
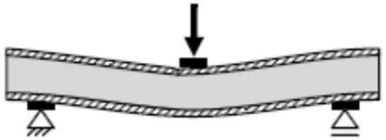
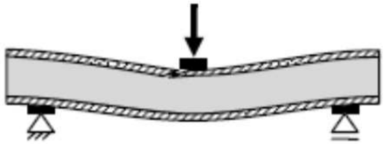
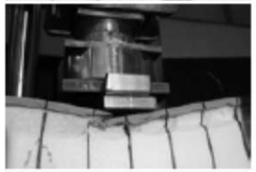
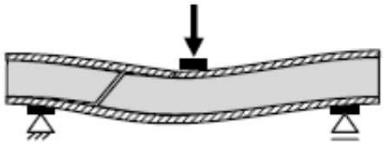
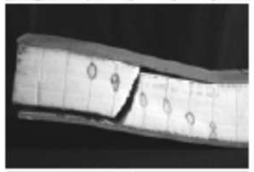
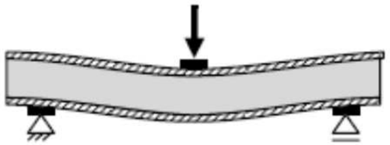
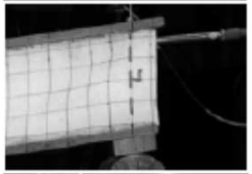
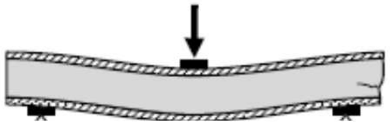
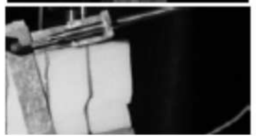
NUMERICAL SIMULATIONS: HPFRC “structural” plates and sandwich composites



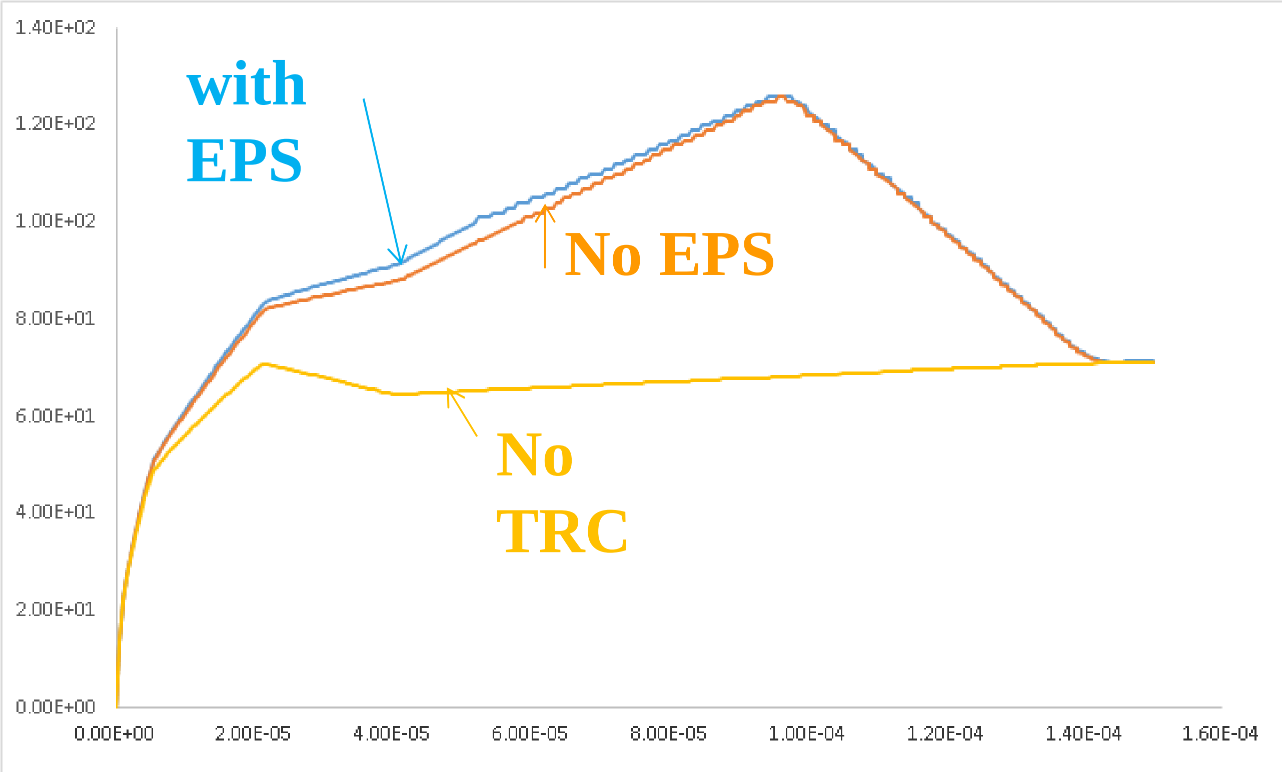




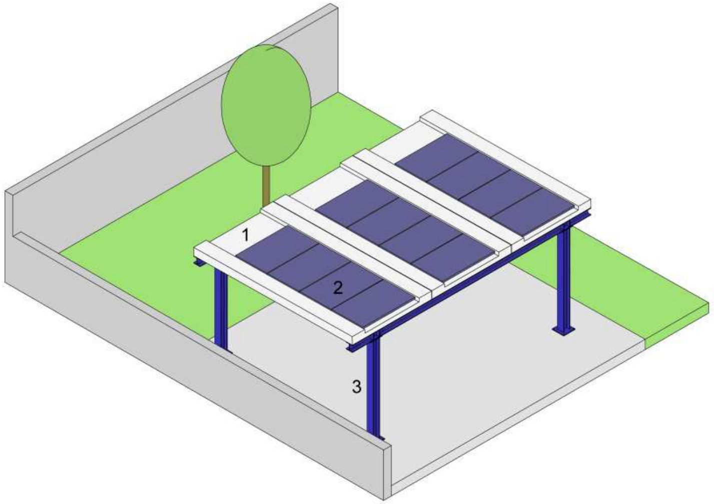
by F. Müller, C. Kohlmeyer, J. Schnell, 2012

No.	Failure mode		
A	tension failure of the reinforcement		
B	compression failure of the core at the point of load application		
C	local bending failure of the upper facing		
D	local shear failure of the upper facing		
E	shear failure of the core and delamination of core and facings		
F	longitudinal shear failure of the bond between the core and the upper facing (at one or both ends)		
G	compression failure of the core at the supports (at one or both ends)		

M
[kNm]



Curvature
[1/mm]


1
2
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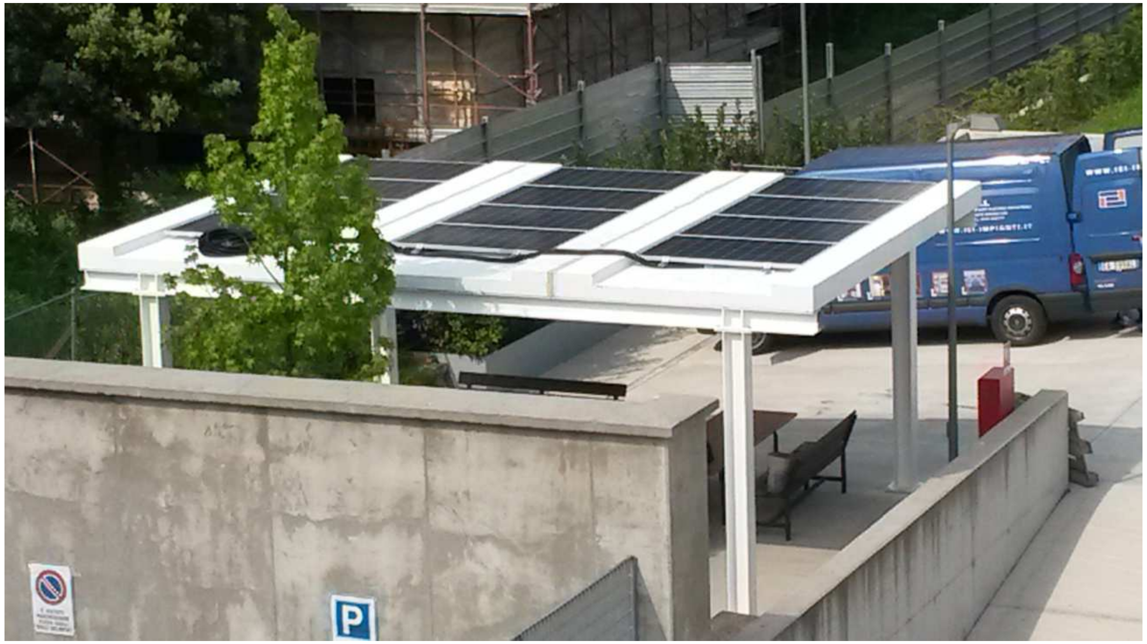


RESEARCH FRAMEWORK

POLITECNICO MILANO

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

Funded by INTERREG

INTERREG ITALIA–SVIZZERA ITALIE–SUISSE ITALIEN–SCHWEIZ

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

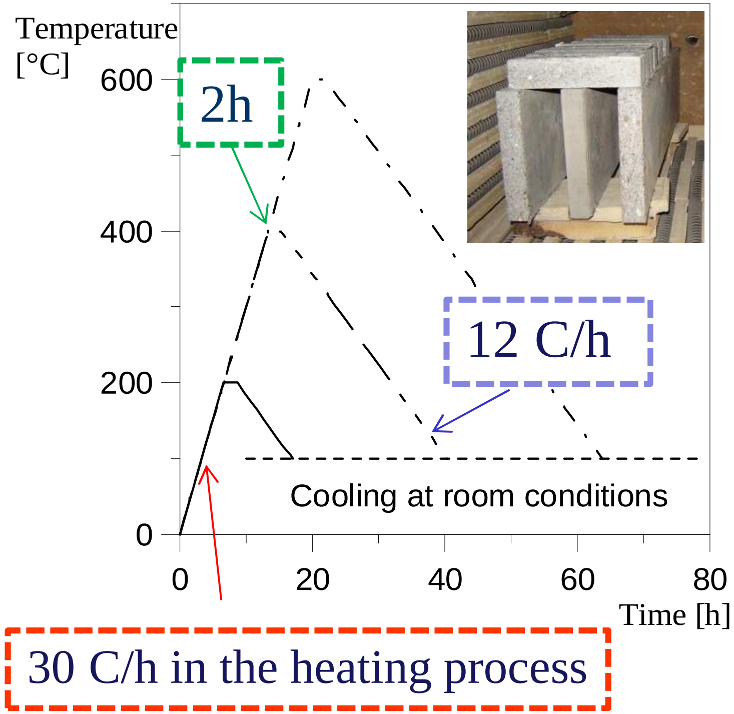
III Level

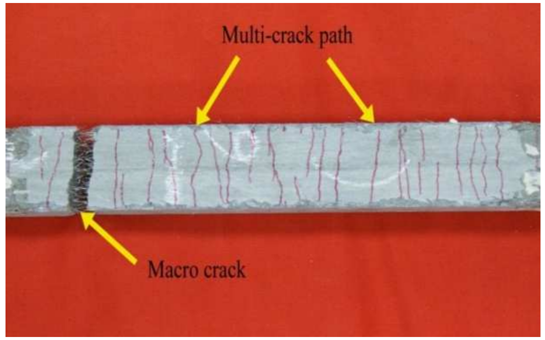
Structure

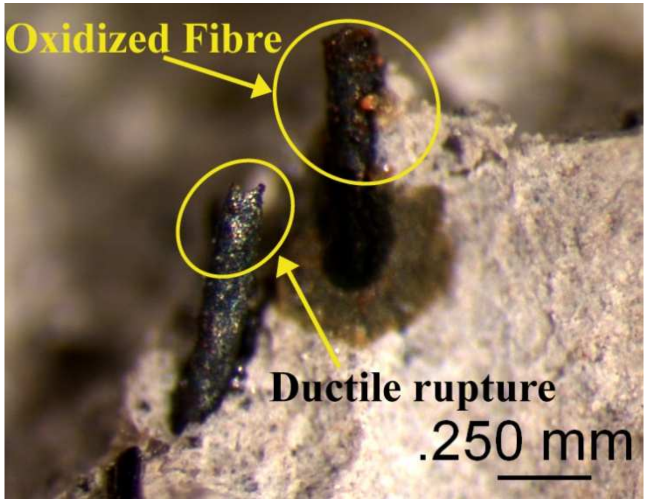
Structural targets

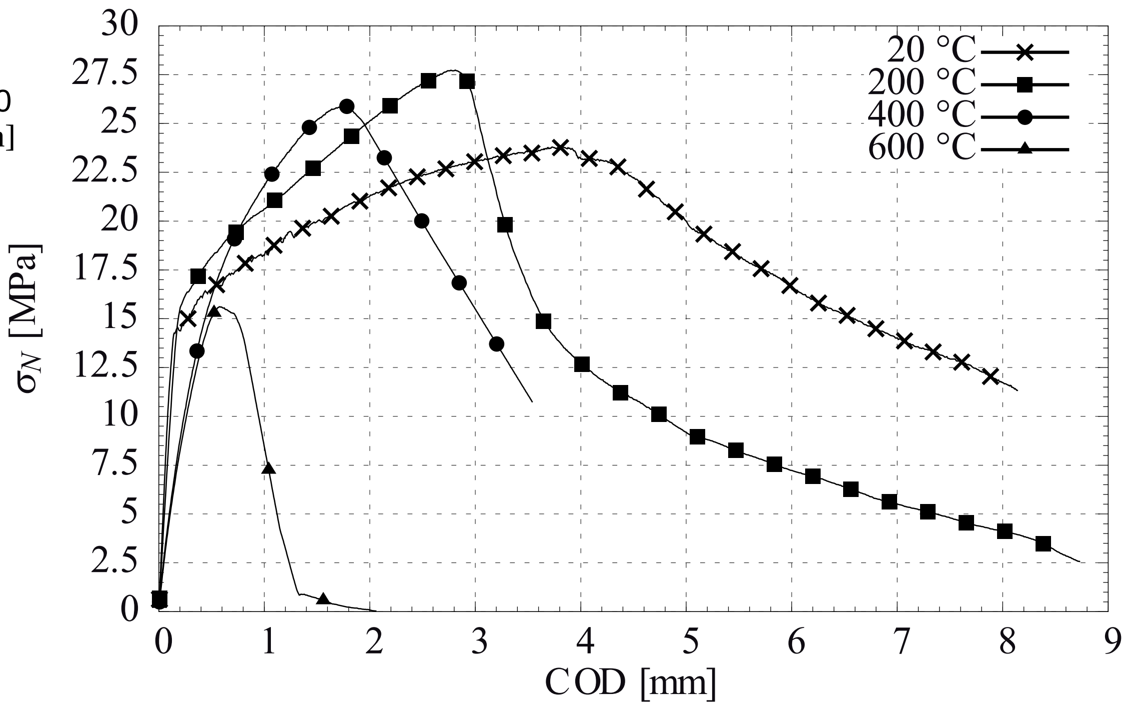
- ✓ Internal explosion with detonation: tunnel segment resisting to a blast wave caused by a terroristic attack with **25 kg of TNT**
- ✓ Fire: acceptable damage (no interruption for serviceability conditions) in case of **T = 600°C** for about 2 hours on the segment surface
- ✓ Serviceability and Ultimate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

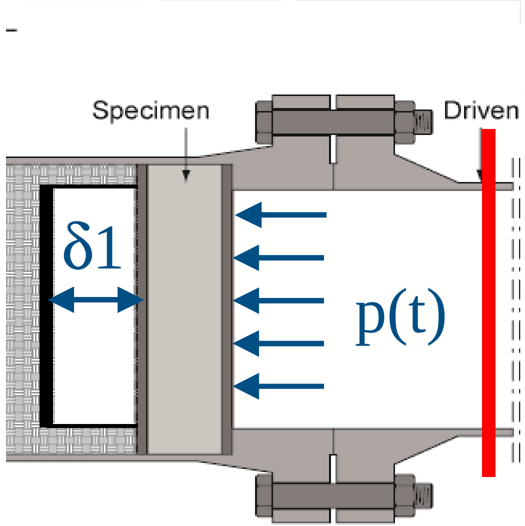
UHPFRC: fire resistant advanced material



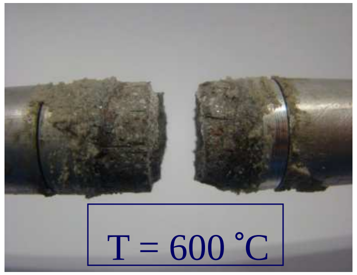


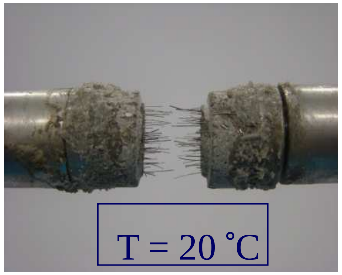


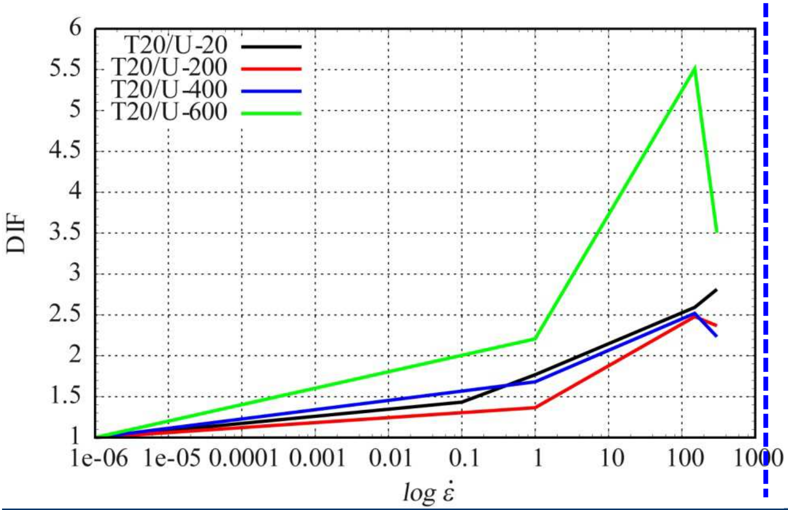


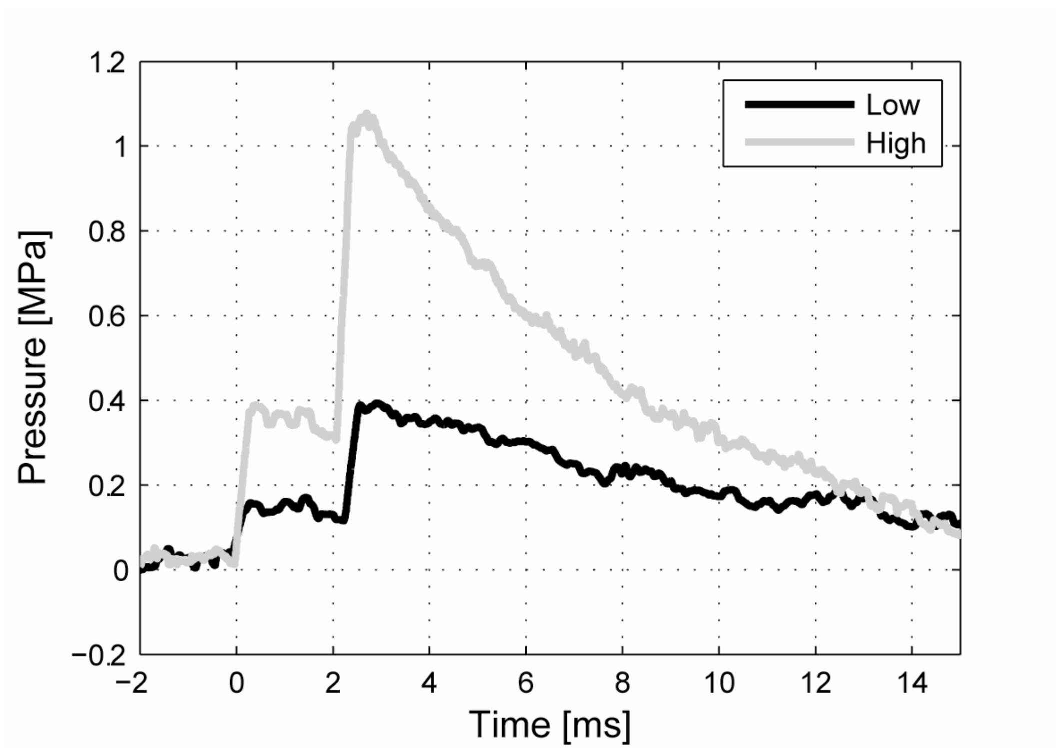


Pressure measurement cross section









D.M. 14/01/2008: Classification and required performance

Tabella 3.5.IV – *Livelli di prestazione in caso di incendi*

Livello I	Nessun requisito specifico di resistenza al fuoco dove le conseguenze del collasso delle strutture siano accettabili o dove il rischio di incendio sia trascurabile;
Livello II	Mantenimento dei requisiti di resistenza al fuoco delle strutture per un periodo sufficiente a garantire l'evacuazione degli occupanti in luogo sicuro all'esterno della costruzione;
Livello III	Mantenimento dei requisiti di resistenza al fuoco delle strutture per un periodo congruo con la gestione dell'emergenza;
Livello IV	Requisiti di resistenza al fuoco delle strutture per garantire, dopo la fine dell'incendio, un limitato danneggiamento delle strutture stesse;
Livello V	Requisiti di resistenza al fuoco delle strutture per garantire, dopo la fine dell'incendio, il mantenimento della totale funzionalità delle strutture stesse.

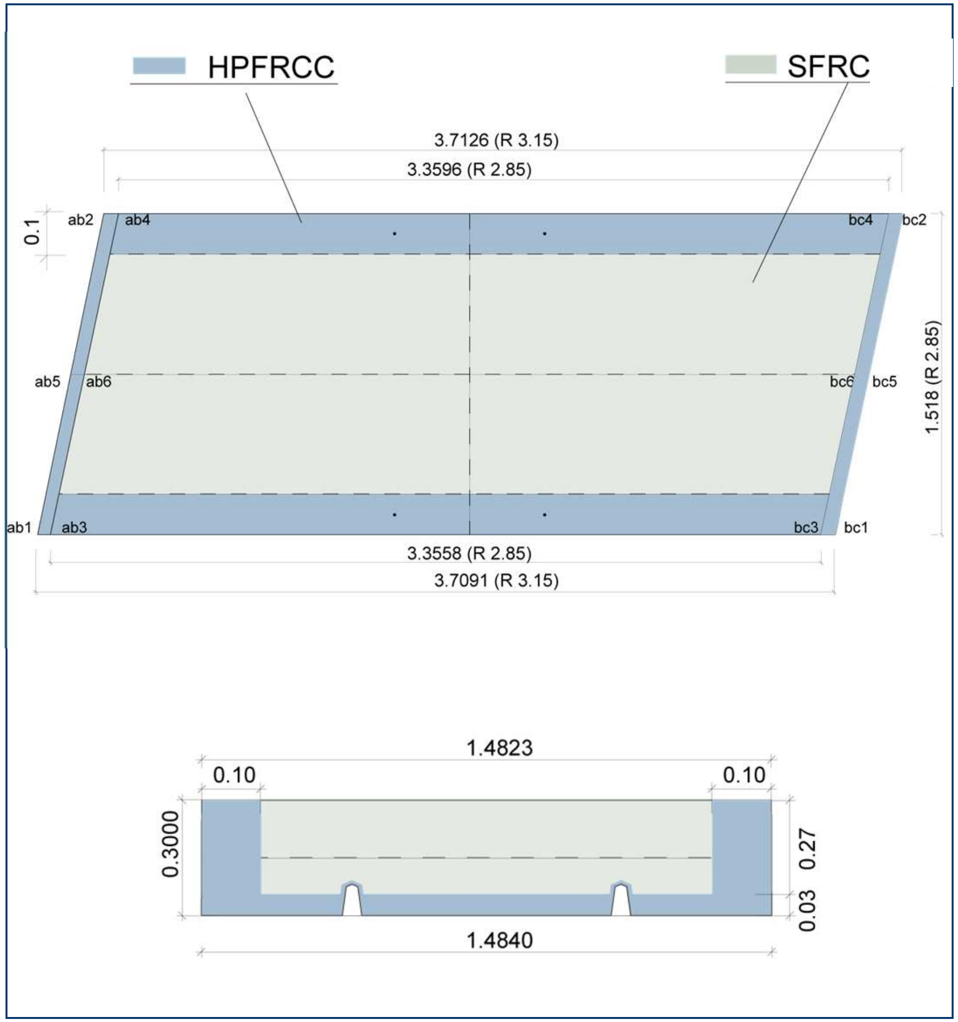
Tabella 3.6.I – *Categorie di azione dovute alle esplosioni*

Categoria di azione	Possibili effetti
1	Effetti trascurabili sulle strutture
2	Effetti localizzati su parte delle strutture
3	Effetti generalizzati sulle strutture

Segment: Materials

Concrete:	SFRC	HPFRCC	
E_c	40000	45000	
✓ ρ	$24\ 10^{-10}$	$25\ 10^{-10}$	——
✓ $f_{c,peak}$	**-71**	**-115**	
✓ $\varepsilon_{c,peak}$	-0.0035	-0.003	
✓ $f_{ct,peak}$	**4.55**	**7**	
✓ $\varepsilon_{ct,peak}$	0.0001	0.005	
✓ f_{R1} (COD1 = 0.5 mm)	**4.84**	12	
✓ f_{R2} (COD2 = 2.5 mm)	4.08	8.4	
✓ $f_{I,peak}$	-	5	
✓ $\varepsilon_{I,peak}$	-	0.00011	

Prototype Tunnel Segment



Structural design model

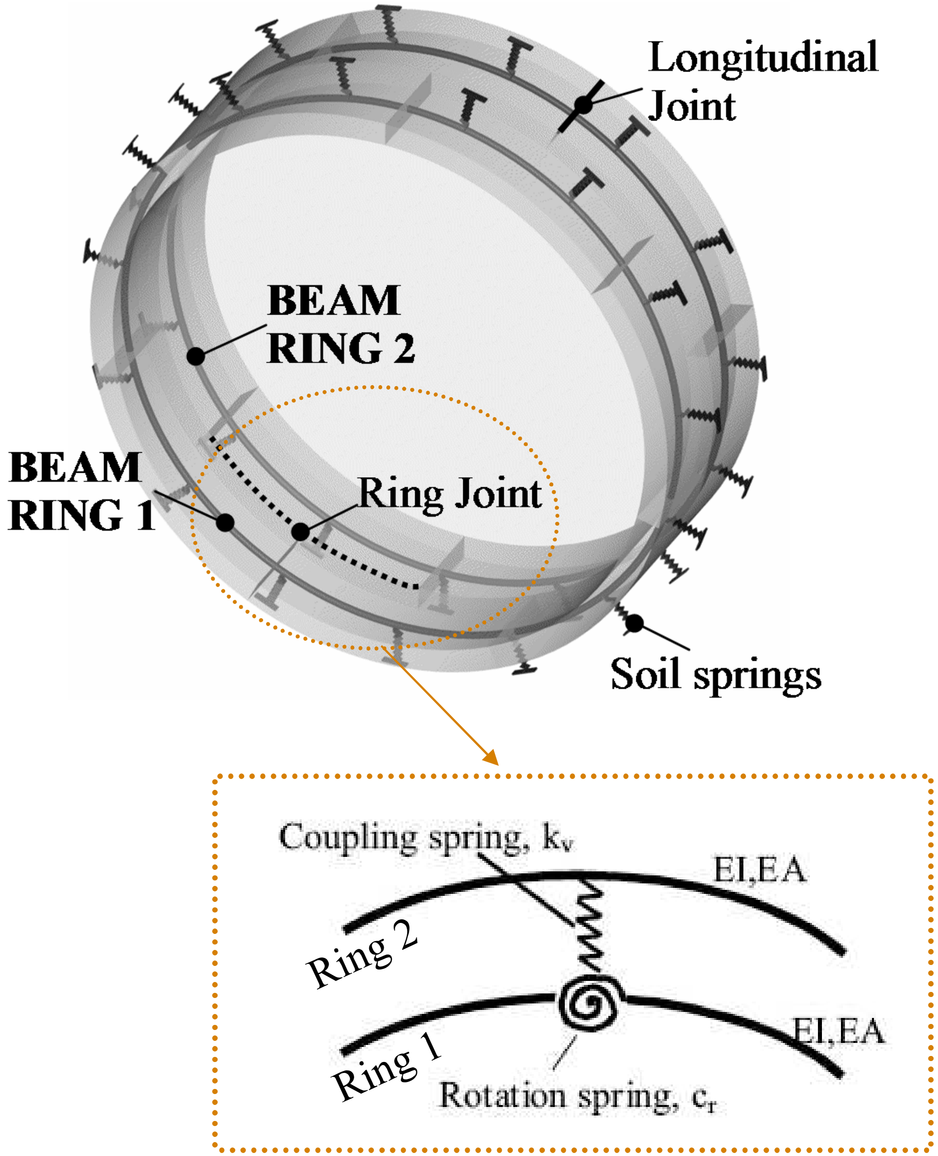
MODEL ASSUMPTIONS

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

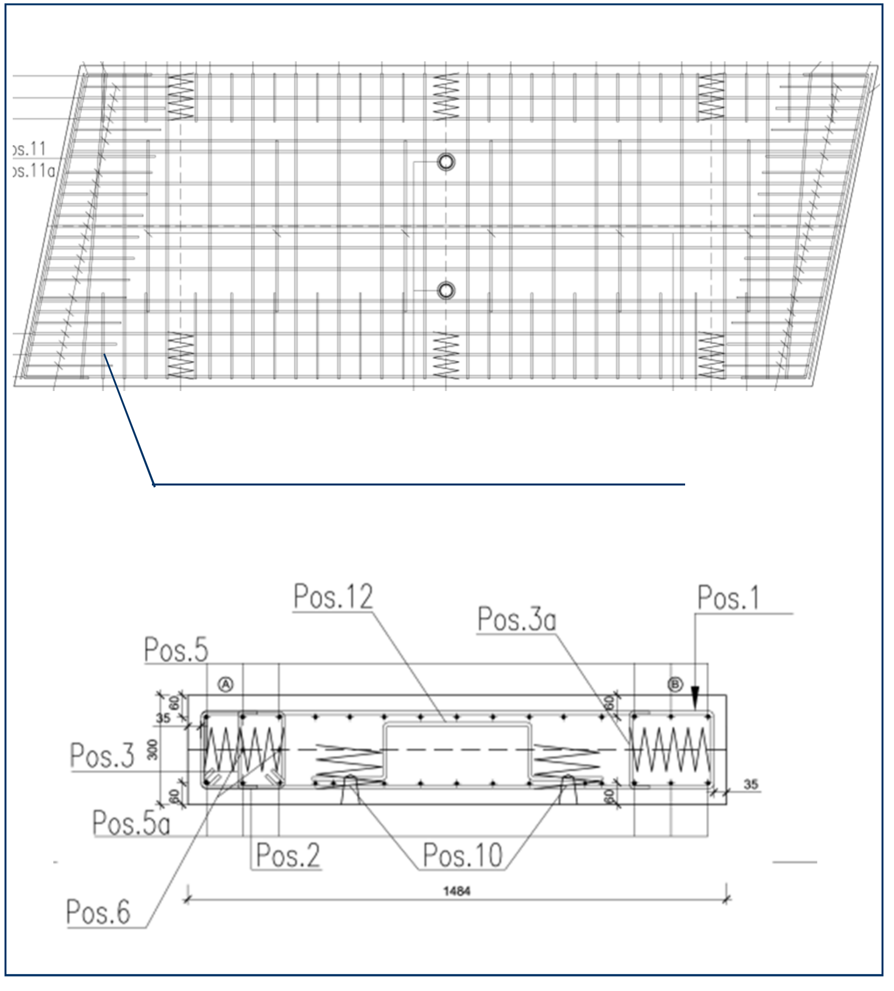
- ✓ N. of **element per segment**: 12
- ✓ N. of **element per k-segment**: 4
- ✓ **Length** of beam element: 0.2945 m
- ✓ **Total N.** of elements: 128



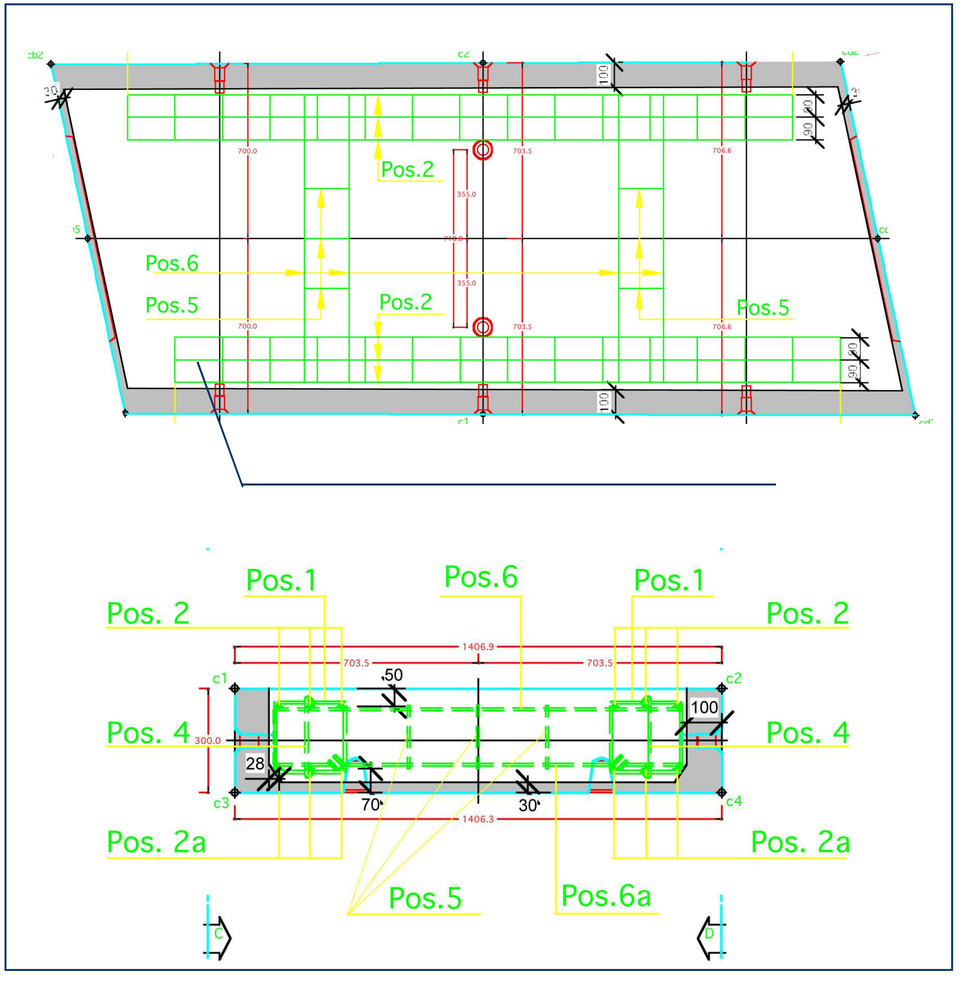
Target?

Segment: Reference geometry and steel reinforcement

Traditional Solution



Innovative Solution

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Thanks for your kind attention!