World Tunnel Congress & Exhibition

WTC 2019

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NAPLES 2019

ITA - AITES General Assembly and World Tunnel Congress

TUNNELS AND UNDERGROUND CITIES: ENGINEERING AND INNOVATIONMEET ARCHAEOLOGY, ARCHITECTURE AND ART

Società Italiana Gallerie
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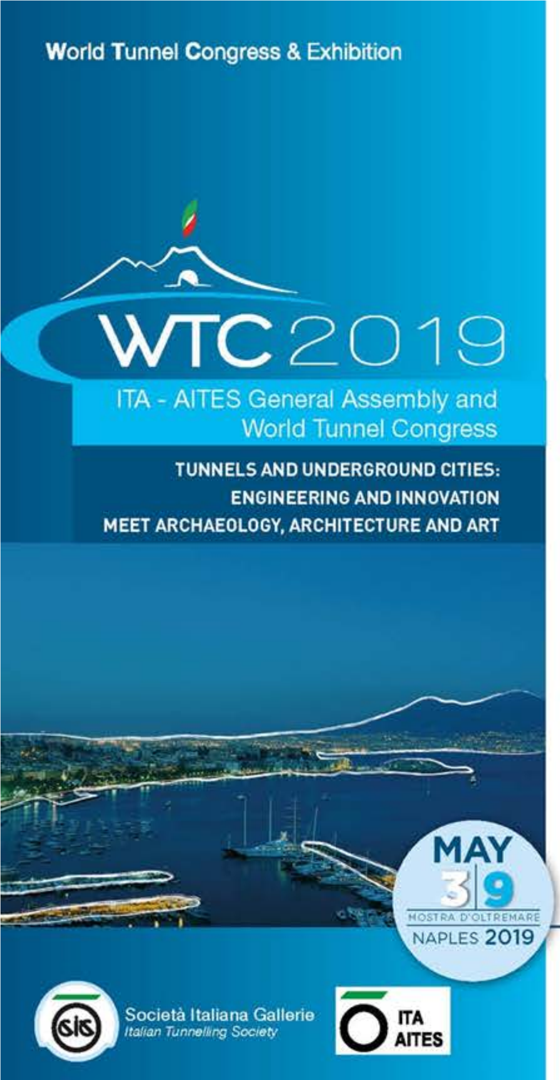


Innovation in underground engineering, materials and equipment Segment Linings and Shotcrete

HYBRID SOLUTION WITH FIBER REINFORCED CONCRETE AND GLASS FIBER REINFORCED POLYMER REBARS FOR PRECAST TUNNEL SEGMENTS

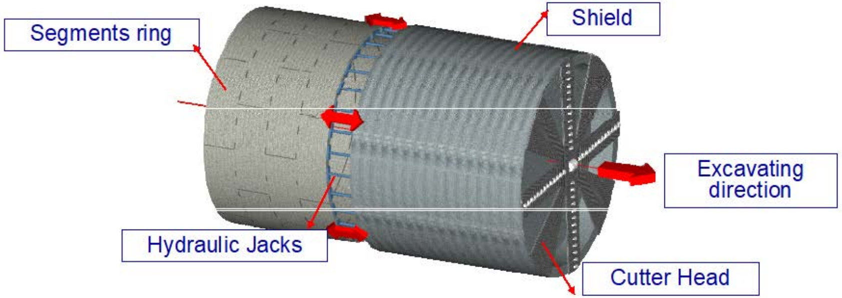
B. De Rivaz, N. Giamundo, A. Meda, Z. Rinaldi, S. Spagnuolo
Presenting Author A. Meda

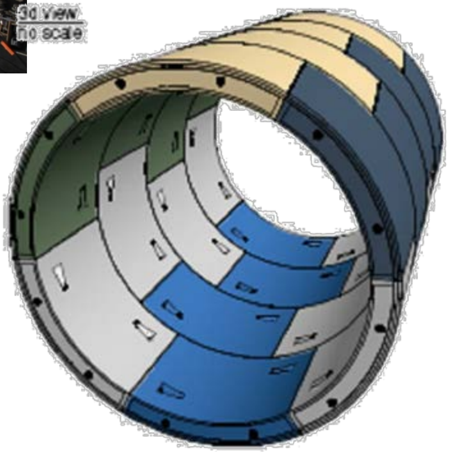
ATP construction composites

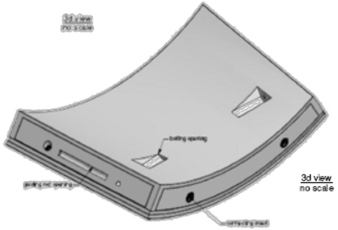
BEKAERT MACCAFERRI UNDERGROUND SOLUTIONS

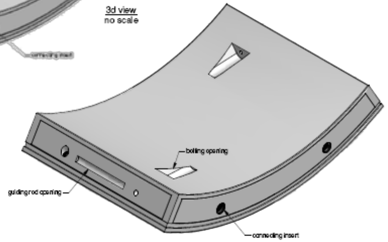
Università di Roma Tor Vergata

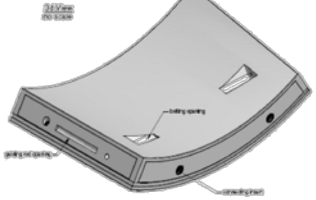
Fiber reinforced concrete in tunneling in segmental lining tunnels

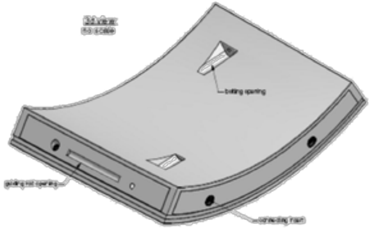












Doha metro

Adoption of FRC only solution for durability problems

120 years of service life

Very high chloride exposure

Problems related to stray currents

Documents for FRC precast segment


RECOMMENDATION OF AFTES N°GT38R1A1

Design, dimensioning and execution of precast steel fibre reinforced concrete arch segments

AFTES welcomes all suggestions relating to this text.


544.7R-16

Emerging Technology Series

Report on Design and Construction of Fiber-Reinforced Precast Concrete Tunnel Segments

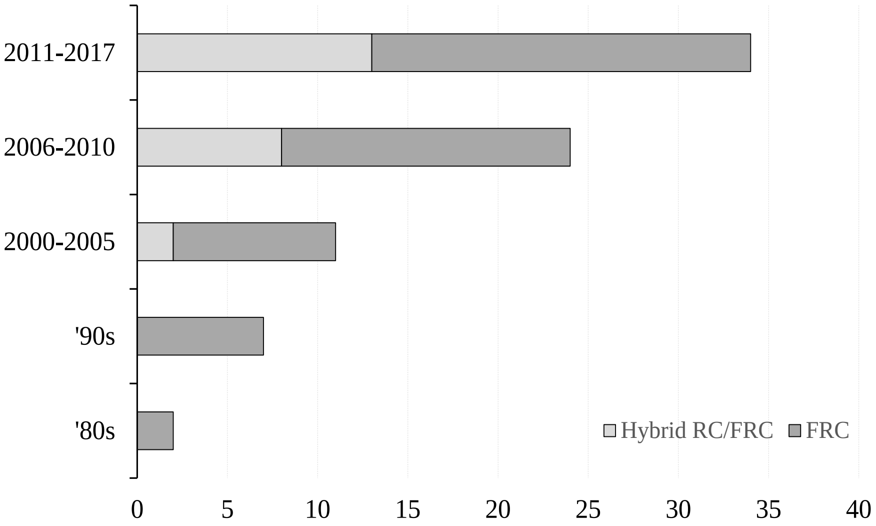
Reported by ACI Committee 544

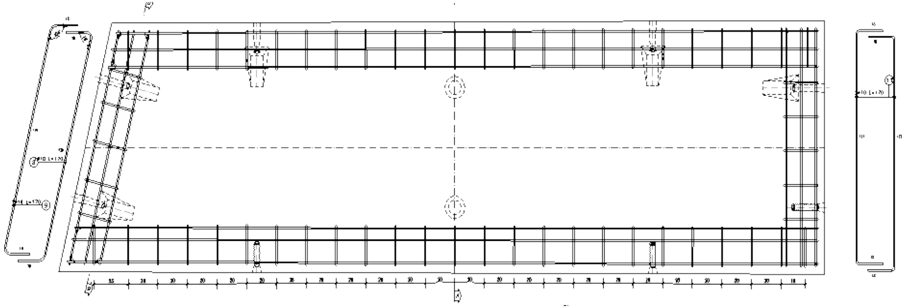
CONTENTS

CHAPTER 1—INTRODUCTION AND SCOPE, p. 2

FRC in TBM tunnels

FRC & RC/FRC precast tunnel segments: case studies over the years





Hybrid vs FRC only solution

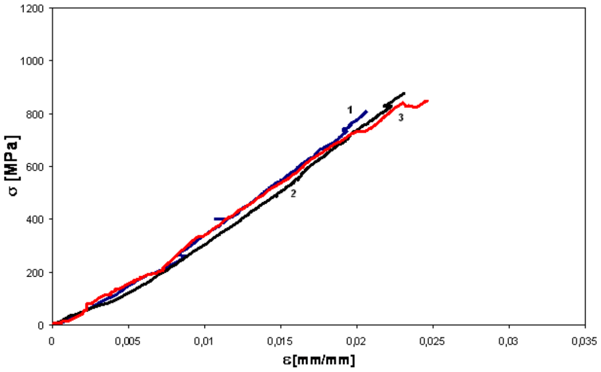
Tunnels could have different geotechnical conditions along their development.

Even if a FRC only solution is proposed, in some parts of the tunnel, the use of a hybrid solution can be convenient (e.g. cross passage, shallow tunnels….) instead to increase the FRC performance.

In general it is convenient do define a FRC that can cover the great part of the tunnel and adopt and hybrid solution in the remaining part.

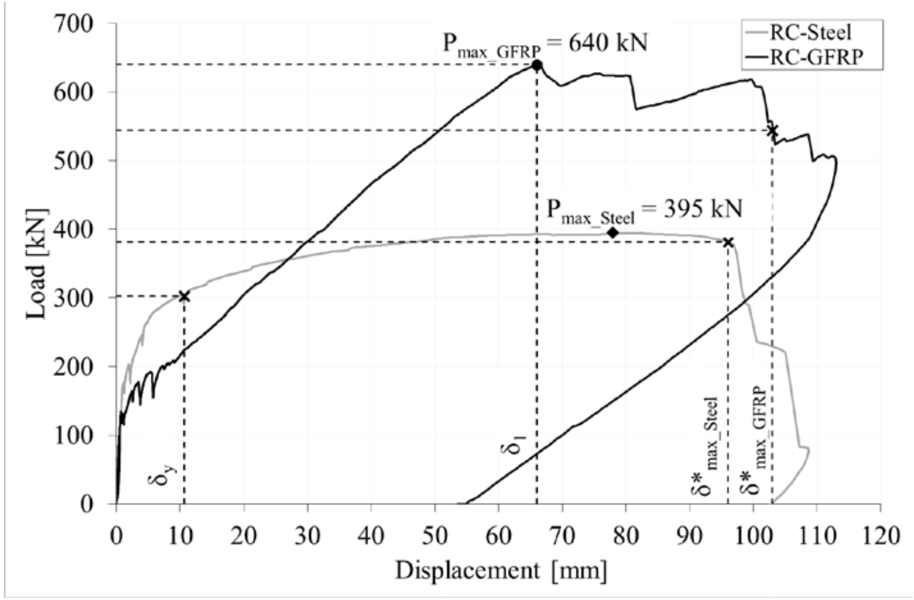
Durability problems in hybrid solution with black steel cages

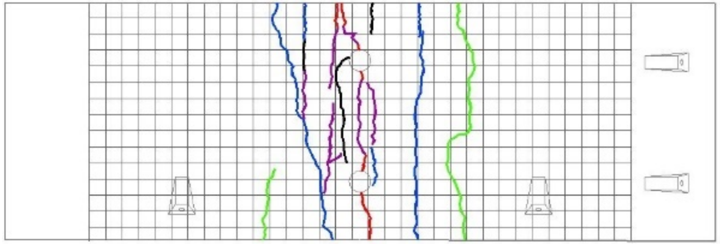
GFRP Rebars



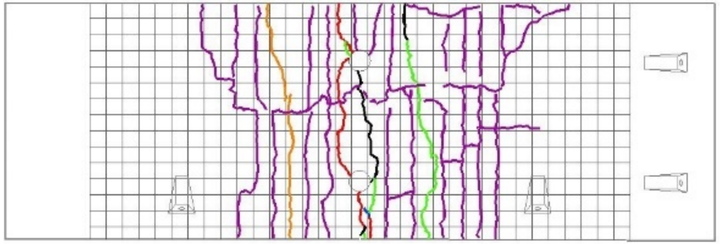
1200
1000
800
600
400
200
0
σ [MPa]
0
0,005
0,01
0,015
0,02
0,025
0,03
0,035
ε[mm/mm]
1
2
3

GFRP Rebars





Steel



GFRP

GFRP Rebars

COMPOSKE Project:
Design and Testing of Precast Tunnel Segment

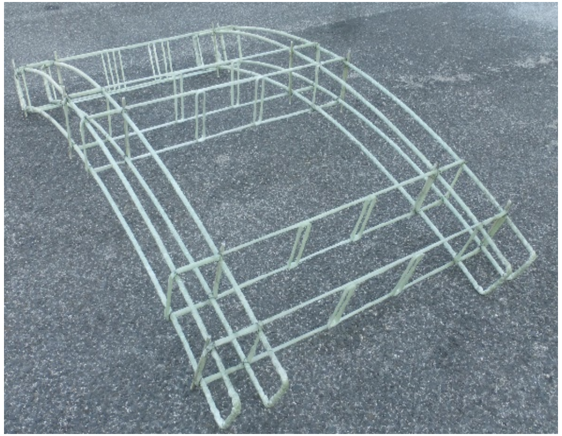
Caratelli, A., Meda, A., Rinaldi, Z., Spagnuolo S. (2016). “Precast tunnel segments with GFRP reinforcement”. Tunnelling and Underground Space Technology vol. 60 (Nov. 2016) pp. 10–20.

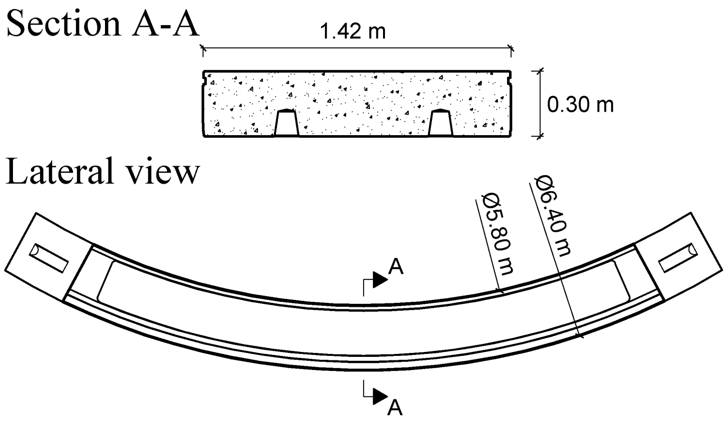
Spagnuolo, S., Meda, A., Rinaldi, Z., Nanni, A. (2017). Precast Concrete Tunnel Segments with GFRP Reinforcement. Journal of Composites for Construction. ASCE.

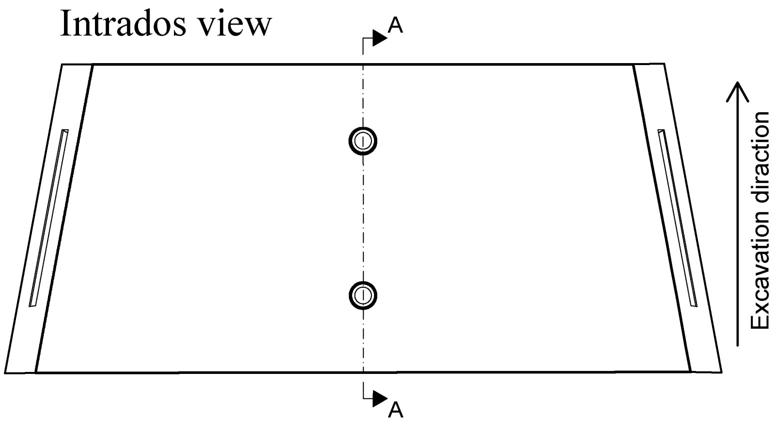
Spagnuolo, S., Meda, A., Rinaldi, Z., Nanni, A. (2018). Curvilinear GFRP bars for tunnel segments applications. Composites Part B, 141, pp. 137–147.

Caratelli, A., Meda, A, Rinaldi, Z., Spagnuolo, S., Giona Maddaluno. (2017). Optimization of GFRP reinforcement in precast segments for metro tunnel lining. Composite Structures 181, pp. 336–346

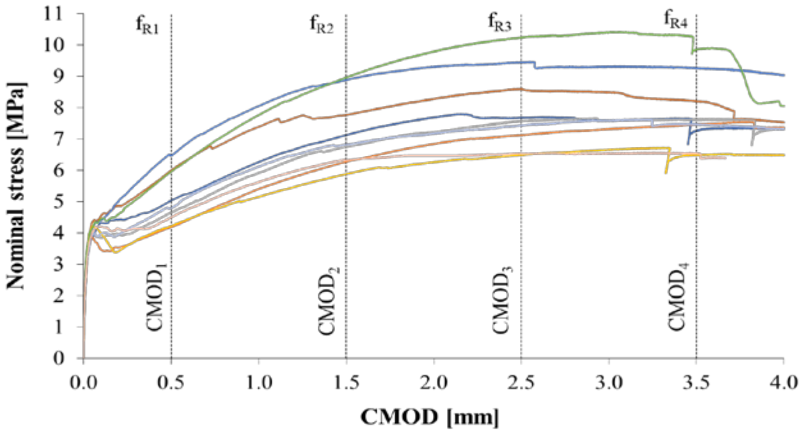
FRC + GFRP Rebars

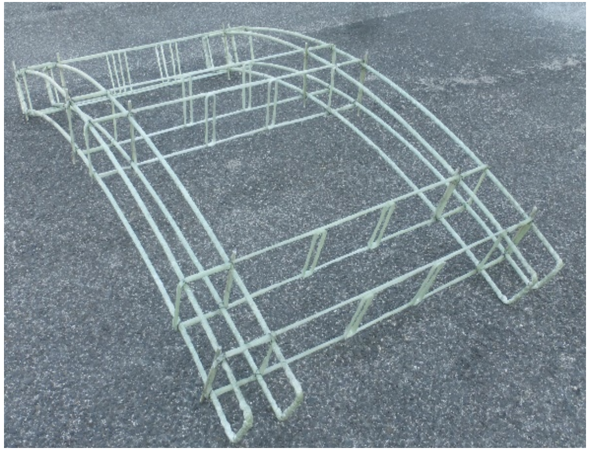






FRC + GFRP Rebars

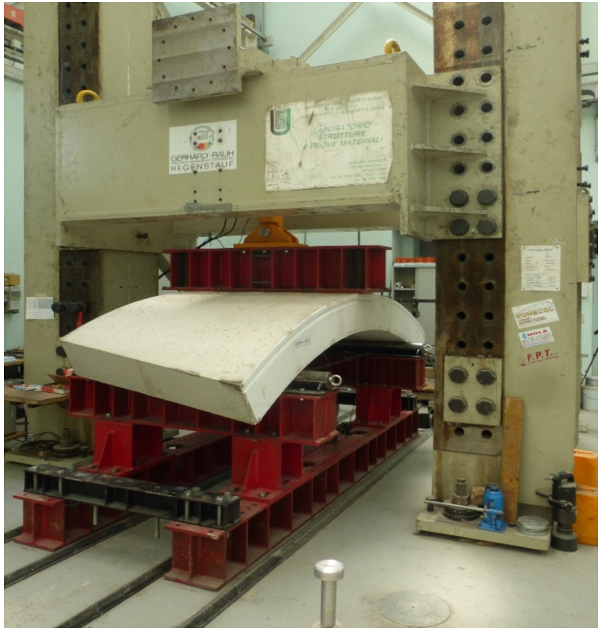




40kg/m^3 4D 80/60BG steel fibers
f_{cm} 62 MPa

18 mm diameter
40 GPa Young's Modulus
1000 MPa tensile strength

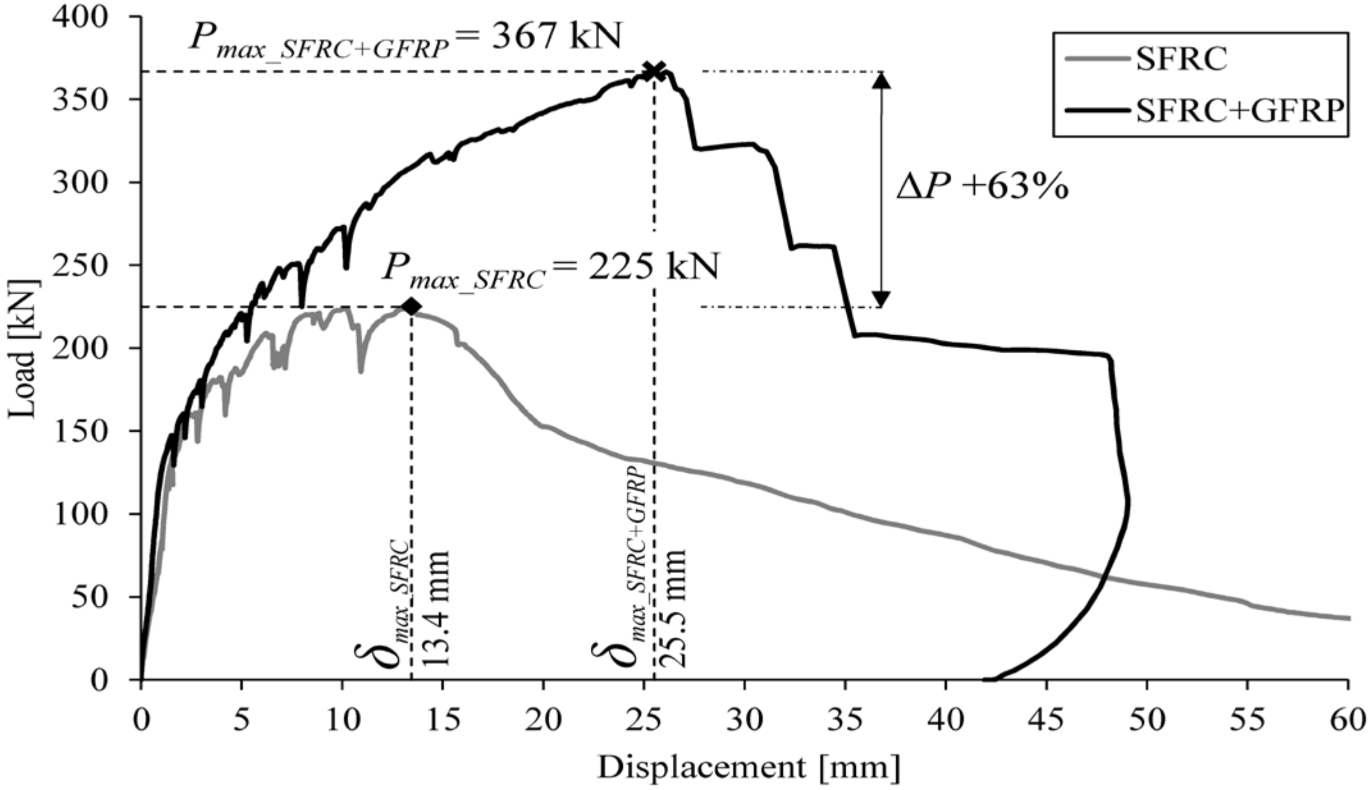
FRC + GFRP Rebars



BENDING TESTS

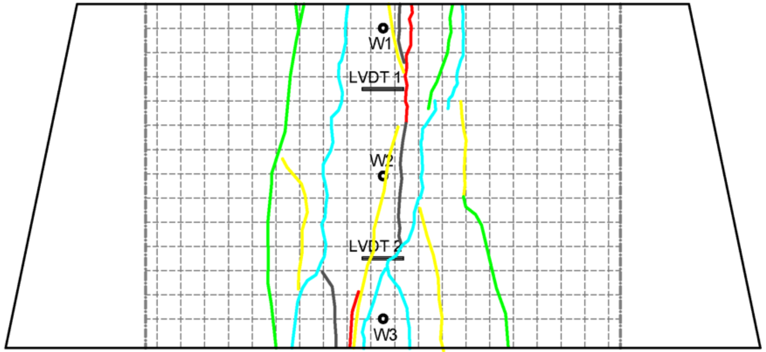
TBM TESTS

BENDING TEST RESULTS



BENDING TEST RESULTS

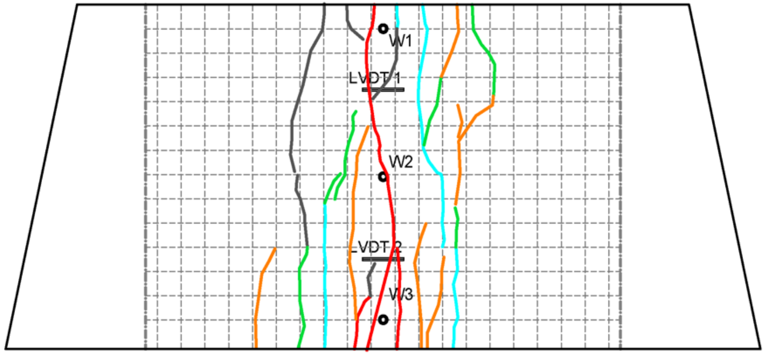
SFRC segment



Load step

- 125 kN
- 160 kN
- 180 kN
- 210 kN
- 222 kN
- Failure 225 kN

SFRC+GFRP segment

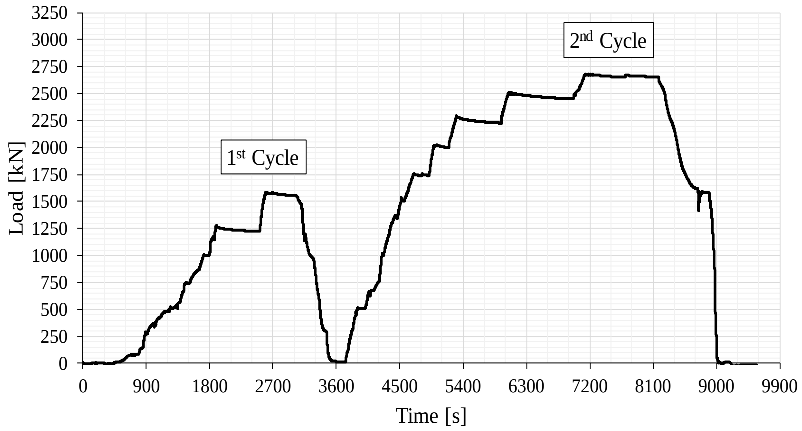


Load step

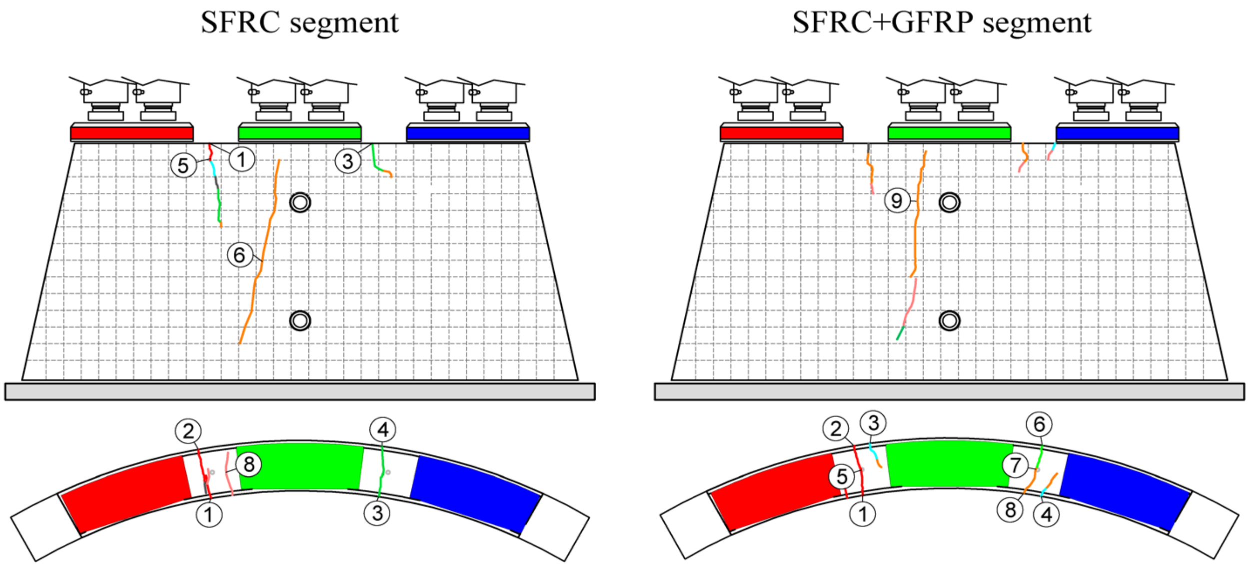
- 145 kN
- 160 kN
- 180 kN
- 220 kN
- 250 kN
- 270 kN
- Failure 367 kN

Loading							
Load [kN]	125	160	180	210	222	250	270
Crack width							
SFRC	<0.05	0.25	0.35	0.60	1.00	n/a**	n/a**
SFRC-GFRP	<0.05	0.10	0.15	n/a**	0.35	0.45	0.70

TBM TEST RESULTS



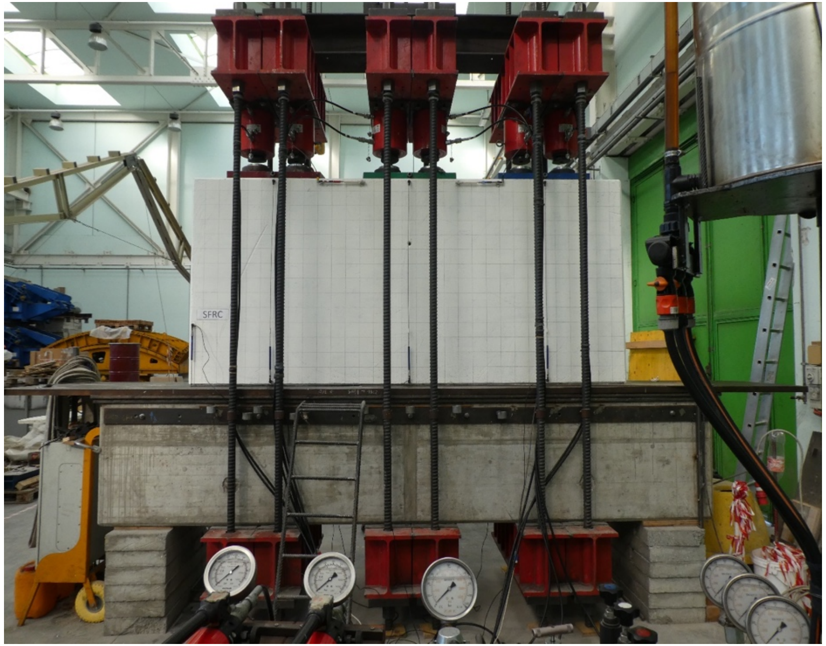
TBM TEST RESULTS

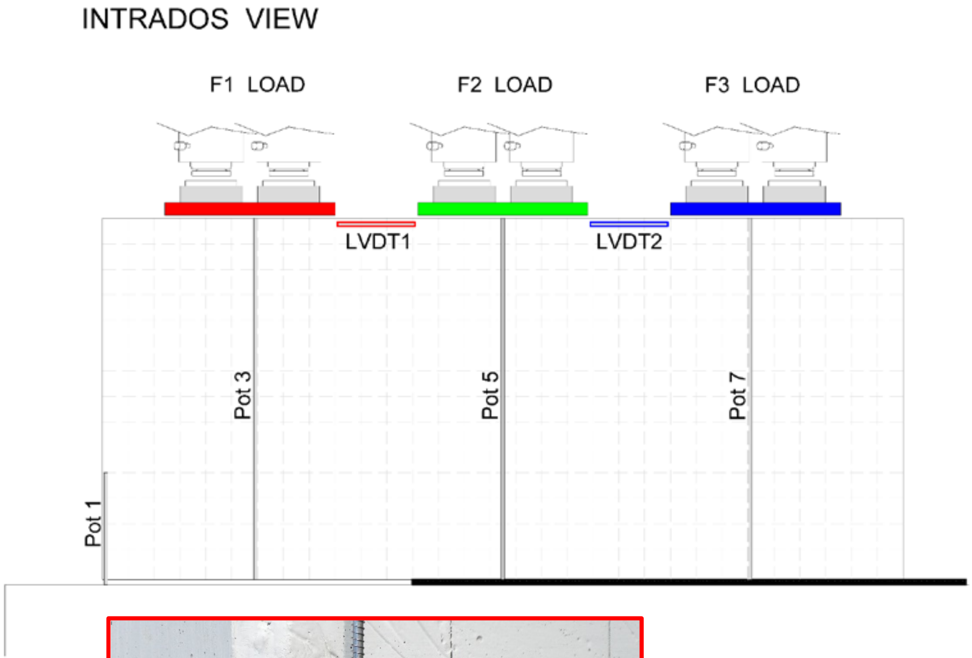


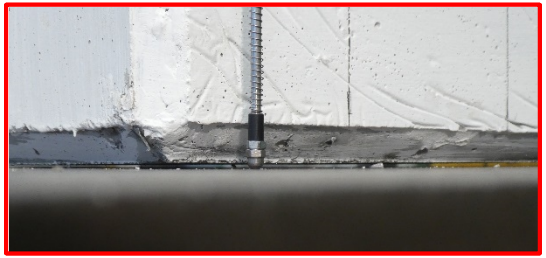
Load		Maximum crack width [mm]	
		SFRC	SFRC -GFRP
1st crack [kN]	1250	0.05	<0.05
Service load [kN]	1580	0.10	0.05
Unblocking thrust*[kN]	2670	0.40	0.25
Unload [kN]	0	0.15	0.10

APPLICATIONS?

TEST WITH GAP



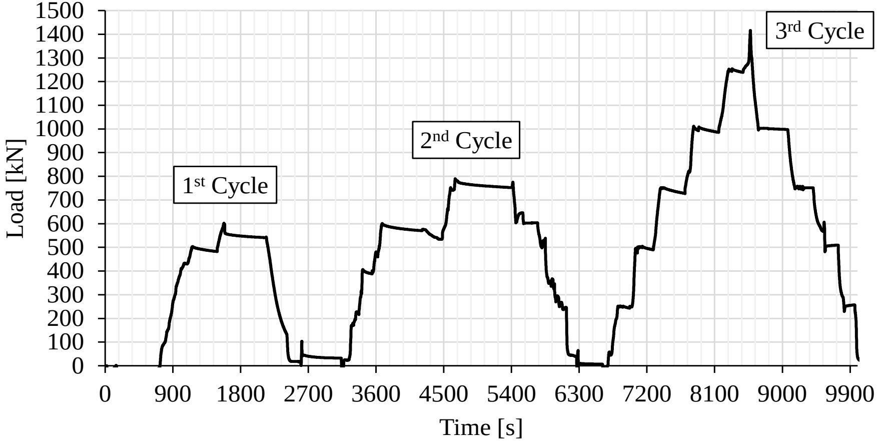


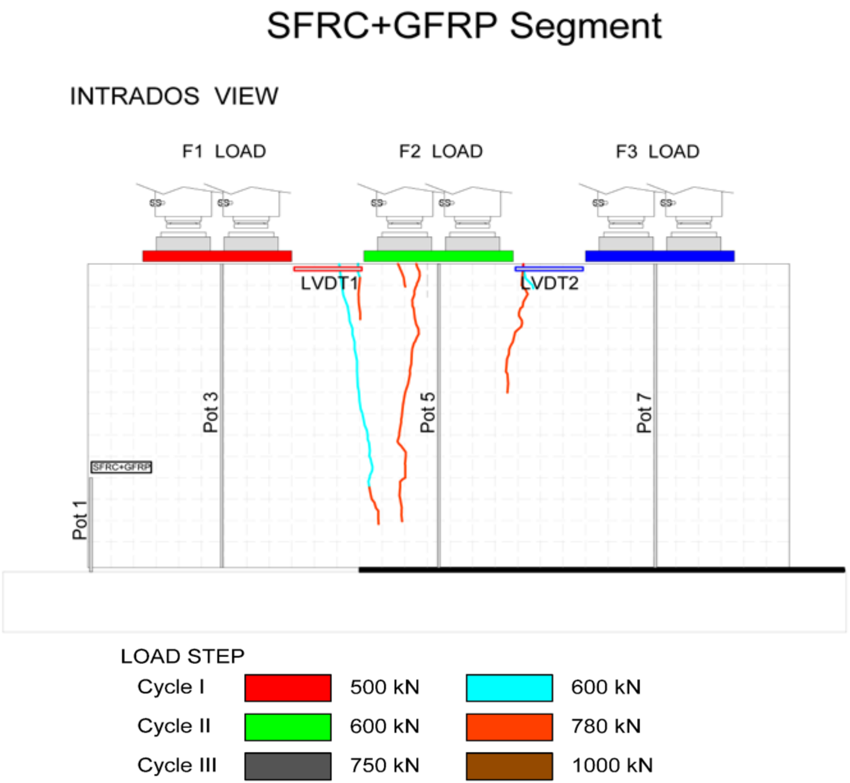


2 mm

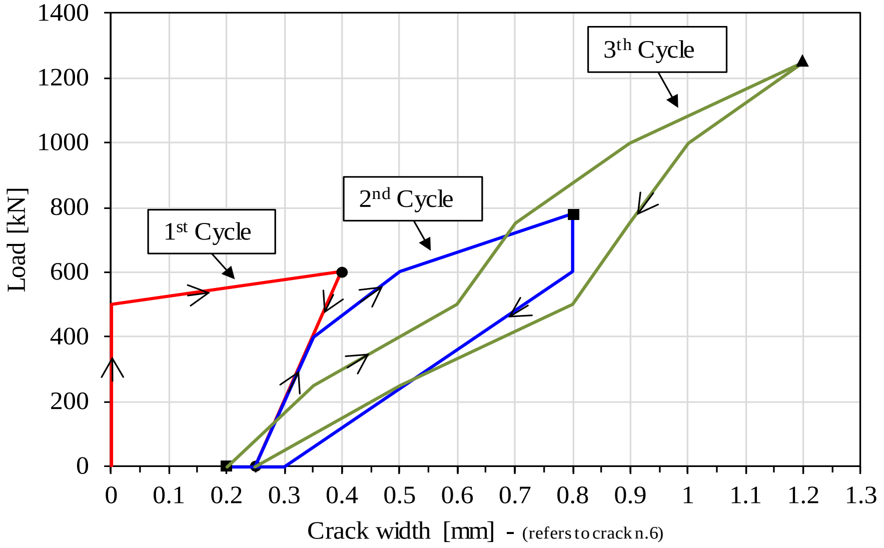
TEST WITH GAP

TEST WITH GAP





TEST WITH GAP



	Crack n. 6					
	1st Cycle		2nd Cycle		3th Cycle	
	Load	Crack width	Load	Crack width	Load	Crack width
	kN	mm	kN	mm	kN	mm
	0	0	0	0.25	0	0.20
	250	0	400	0.35	250	0.35
	500	0	600	0.50	500	0.60
	600	0.40	**780**	**0.80**	750	0.70
	0	**0.25**	600	0.80	1000	0.90
			0	0.30	**1250**	**1.20**
after 15' (2nd Cycle)			0	0.20	1415	n/a*
after 30' (2nd Cycle)			**0**	**0.20**	1000	1.00
					750	0.90
					500	0.80
					250	0.50
					0	0.25
after 15' (3th Cycle)					**0**	**0.25**

* n/a= not available

CONCLUSIONS

The results of bending tests, clearly show the synergic effects of the two materials (fibers and GFRP reinforcement) by increasing the peak load and reducing the crack width.

The results of the point load test confirm the effectiveness of the solution, since the addition of the perimetric cage led to halve the crack width under the service load, and to reduce it under the unblocking thrust force, and at the complete unloading, respectively.

GFRP reinforcement can enhance the crack re-closure capacity when gaps are present