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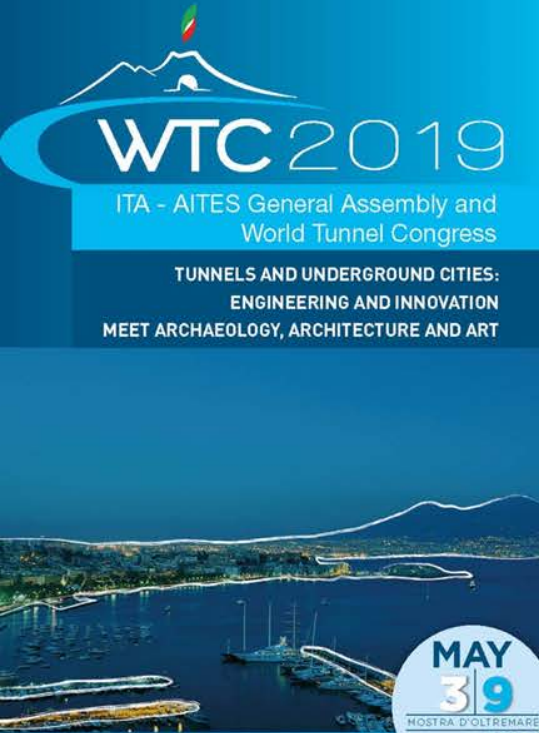
**TUNNELS AND UNDERGROUND CITIES: ENGINEERING
AND INNOVATION MEET ARCHAEOLOGY, ARCHITECTURE AND ART**

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MOSTRA D'OLTREMARE
NAPLES 2019



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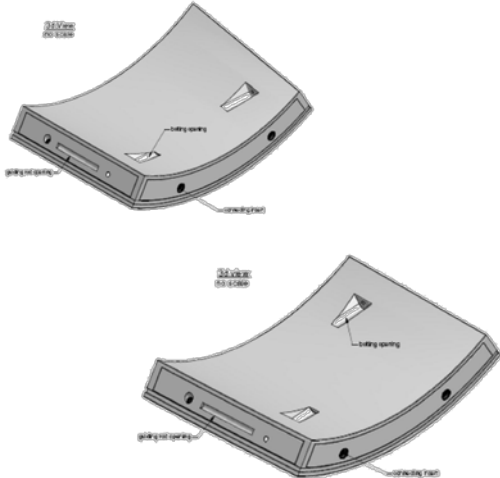
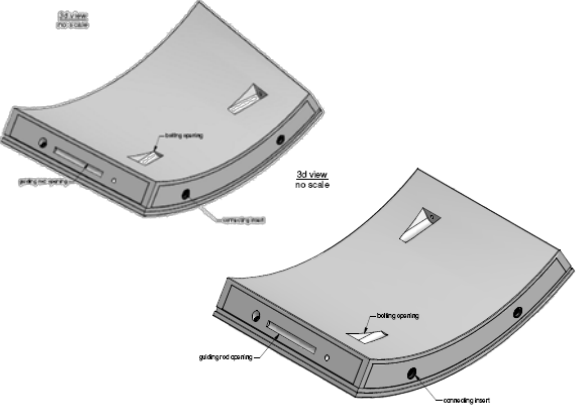
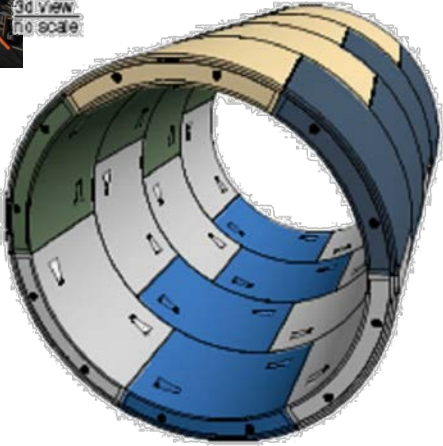
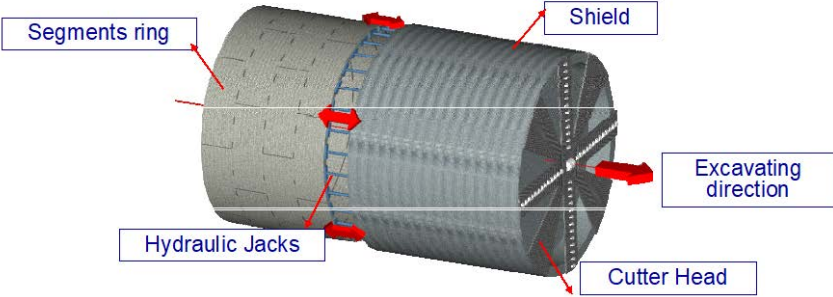




HYBRID SOLUTION WITH FIBER REINFORCED CONCRETE AND GLASS FIBER REINFORCED POLYMER REBARS FOR PRECAST TUNNEL SEGMENTS

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

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 witnesses 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

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ACI encourages the development and application of new and emerging technologies through the publication of the Emerging Technology Series. This series presents preliminary and experimental data on new materials, methods, and techniques, and provides a platform for discussion and debate. The series is intended to provide a forum for the exchange of ideas and information, and to stimulate research and development in the field of emerging technologies. The report should contain a clear and concise summary of the work, and a discussion of the results. The publication of this document should not be construed as an endorsement or approval of the technology, or as a guarantee of its performance or safety.

These recommendations have emerged as an alternative to traditional reinforcing bars and welded wire mesh reinforcement for precast concrete tunnel segments. They are significantly improved post-cracking behavior and crack control characteristics, fiber-reinforced concrete (FRC) segments offer advantages over traditional

ally reinforced concrete segments such as saving cost and reducing production time, while developing a more robust product with improved handling and long-term durability. Specific guidelines on the design of fiber-reinforced precast concrete tunnel segments is needed for their emerging technology. This document offers general information on the history of FRC precast segments from inventory projects throughout the world, a procedure for structural analysis and design based on governing load cases, and a description of the material properties, mix, and analysis required for the design. The proposed guidelines are based on the knowledge gained from experimental research, analytical work, and the experience gained in numerous FRC precast segment projects.

Keywords: crack width, work process, fiber, fiber-reinforced concrete, precast concrete, tunnel segments, lining, tunnel segment, segment, cast-in-place, tunnel, tunnel lining

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Bulletin

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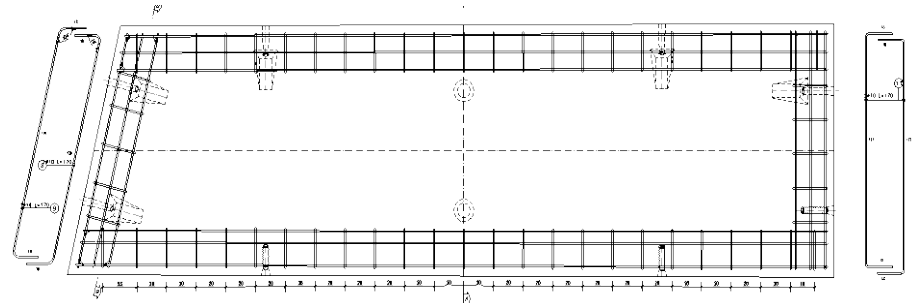
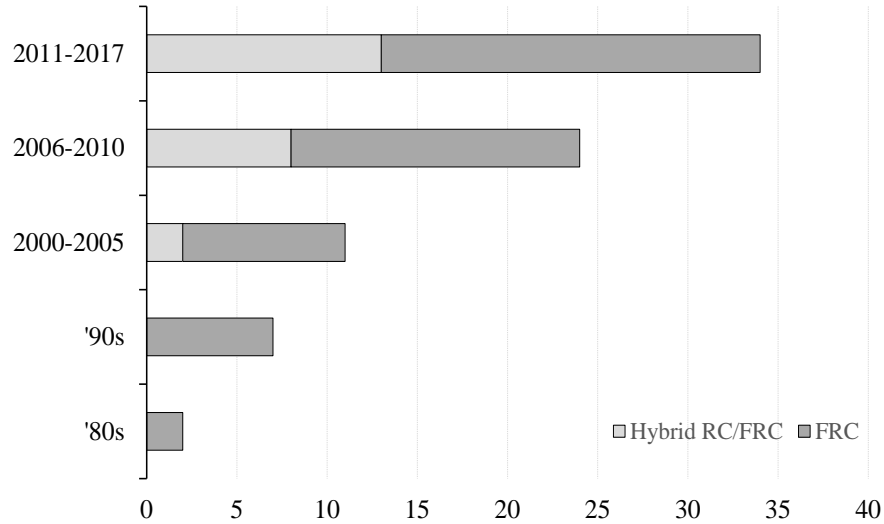
Precast tunnel segments in fibre-reinforced concrete

fib

State-of-the-art report

FRC in TBM tunnels

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



Hybrid vs FRC only solution

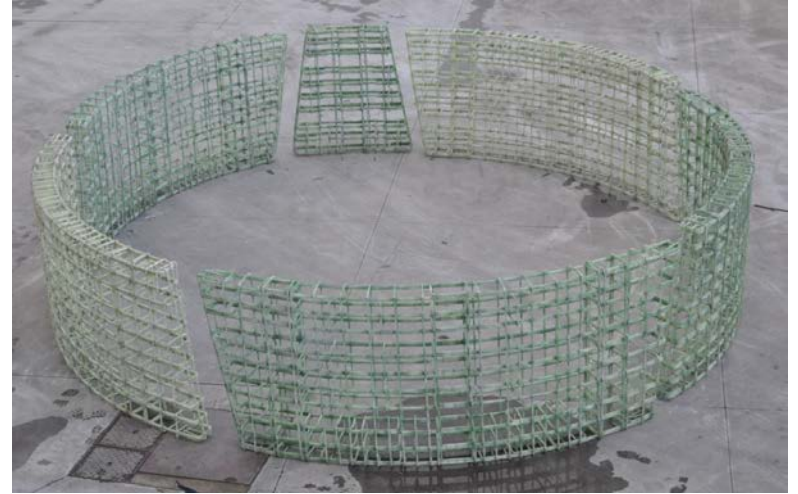
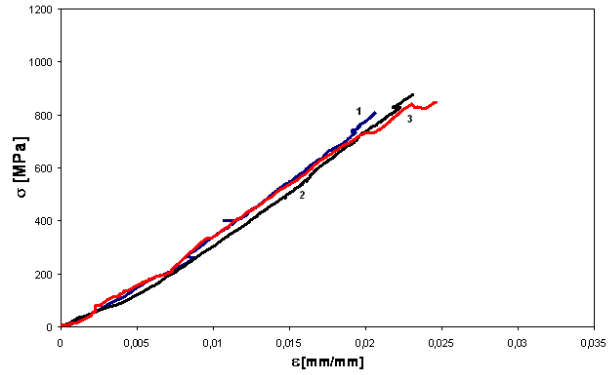
Tunnels could have different geotechnical conditions along their development.

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.

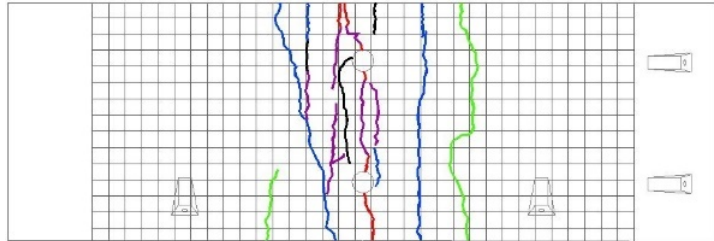
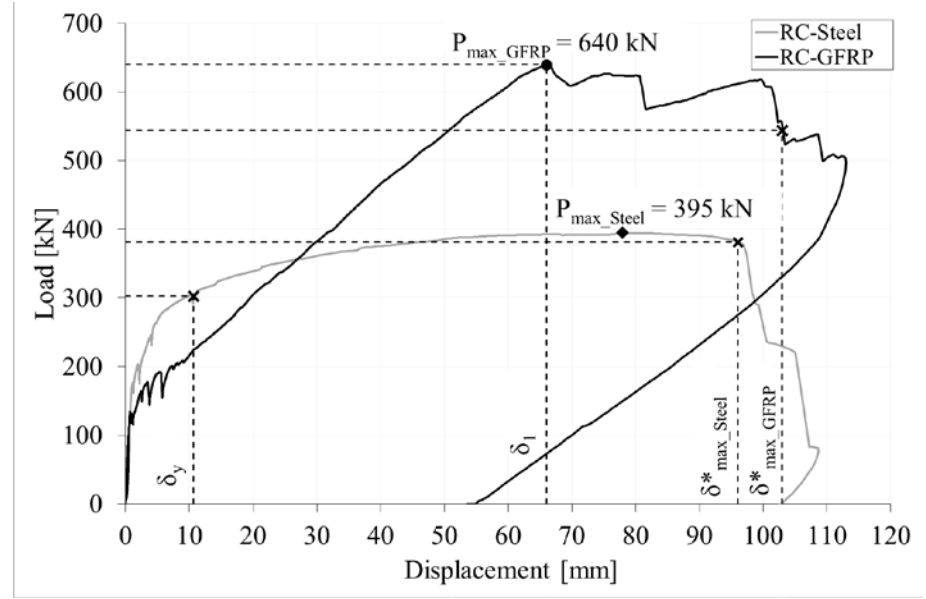
In general it is convenient to define a FRC that can cover the great part of the tunnel and adopt a hybrid solution in the remaining part.

Durability problems in hybrid solution with black steel cages

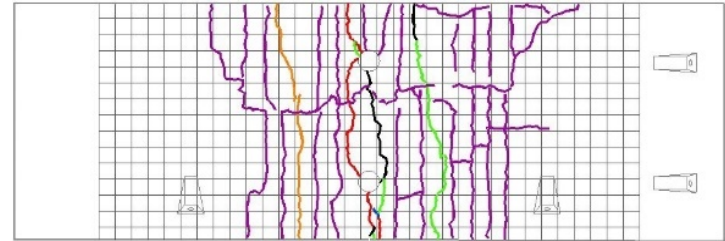
GFRP Rebars



GFRP Rebars



Steel



GFRP



GFRP Rebars

COMPOSKE PROJECT: DESIGN AND TESTING OF PRECAST TUNNEL SEGMENT

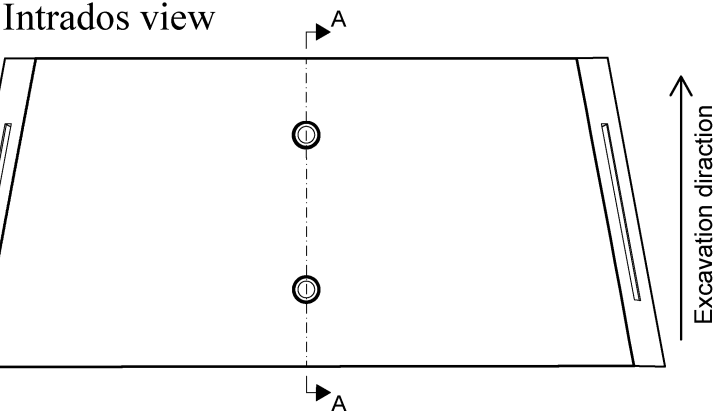
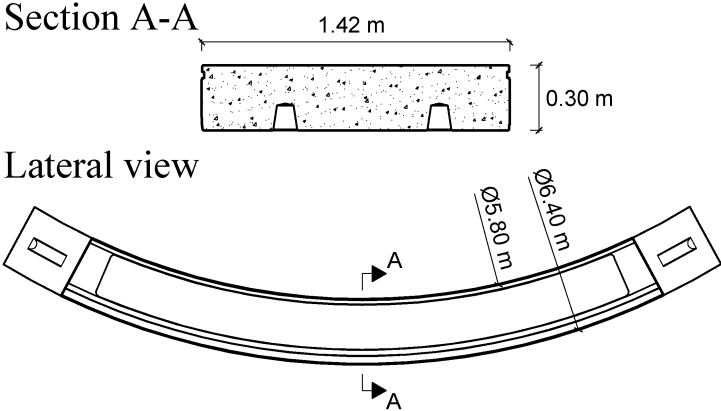
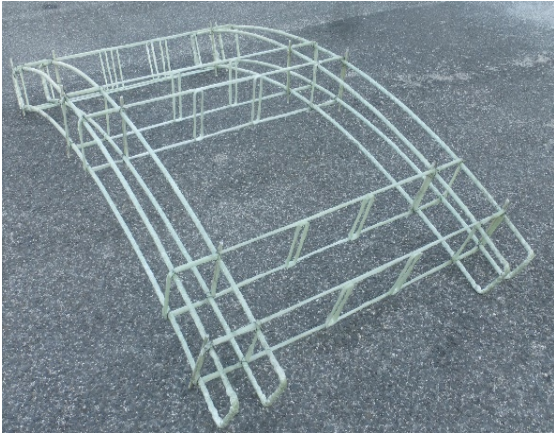
Caratelli, A., Meda, A., Rinaldi, Z., Spagnuolo S. (2016). “Precast tunnel segments with GFRP reinforcement”. *Tunnelling and Underground Space Technology* vol. 60 (Nov. 2016) pp. 10–20.

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

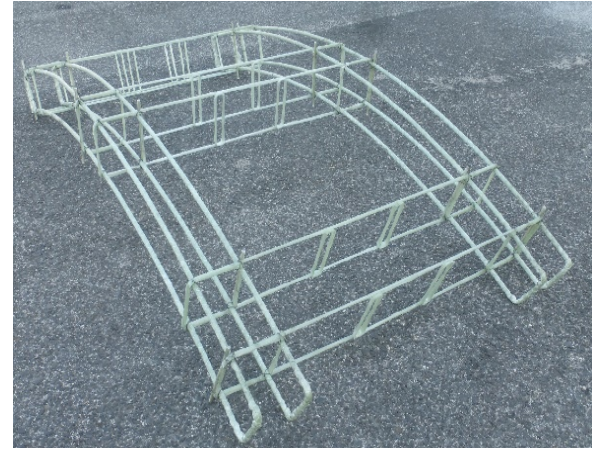
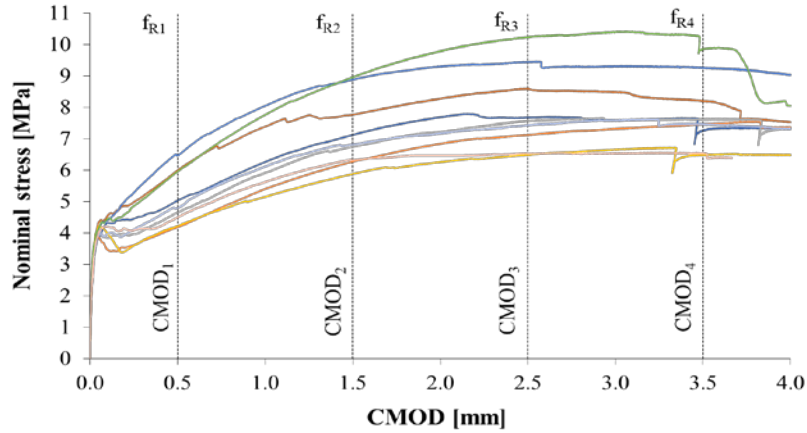
Spagnuolo, S., Meda, A., Rinaldi, Z., Nanni, A. (2018). *Curvilinear GFRP bars for tunnel segments applications*. *Composites Part B*, 141, pp. 137–147.

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/m³ 4D 80/60BG steel fibers

f_{cm} 62 MPa

18 mm diameter

40 GPa Young's Modulus

1000 MPa tensile strength

FRC + GFRP Rebars

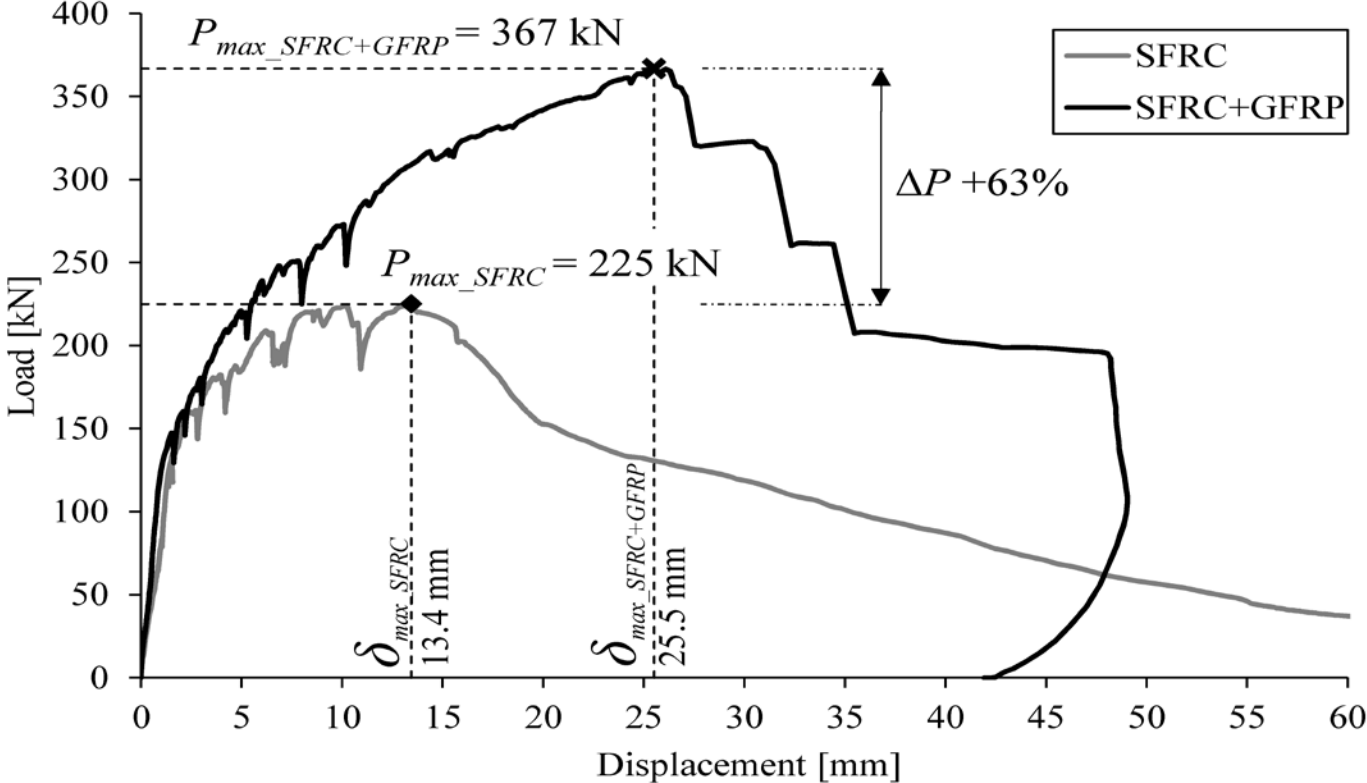


BENDING TESTS



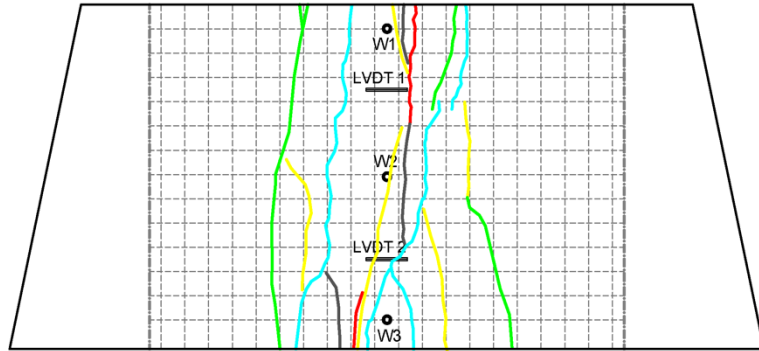
TBM TESTS

BENDING TEST RESULTS

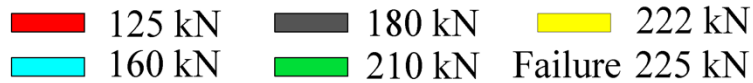


BENDING TEST RESULTS

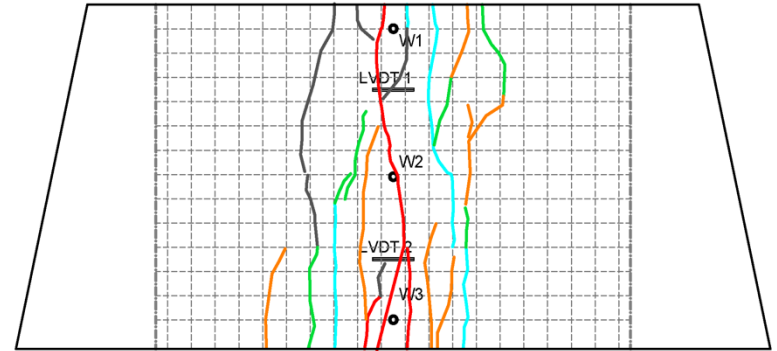
SFRC segment



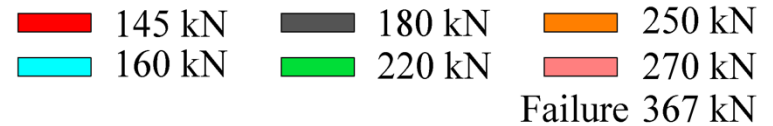
Load step



SFRC+GFRP segment

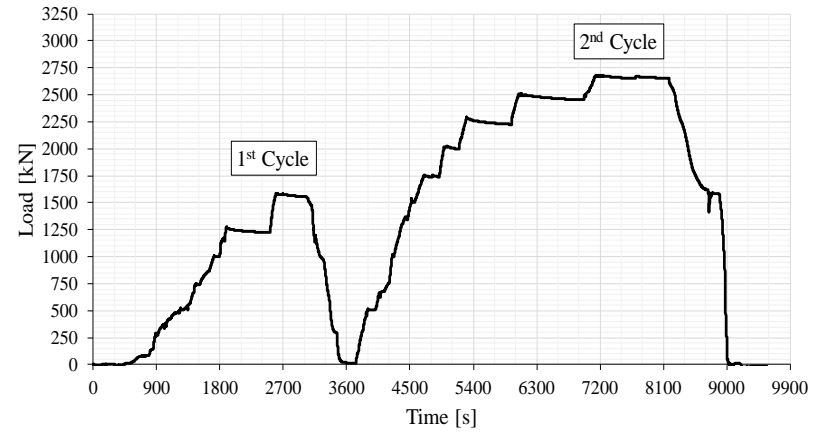


Load step



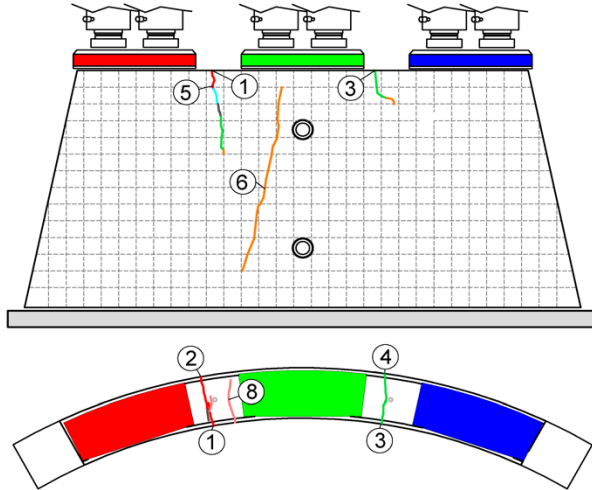
Loading							
Load [kN]	125	160	180	210	222	250	270
Crack width							
SFRC	<0.05	0.25	0.35	0.60	1.00	n/a**	n/a**
SFRC-GFRP	<0.05	0.10	0.15	n/a**	0.35	0.45	0.70

TBM TEST RESULTS

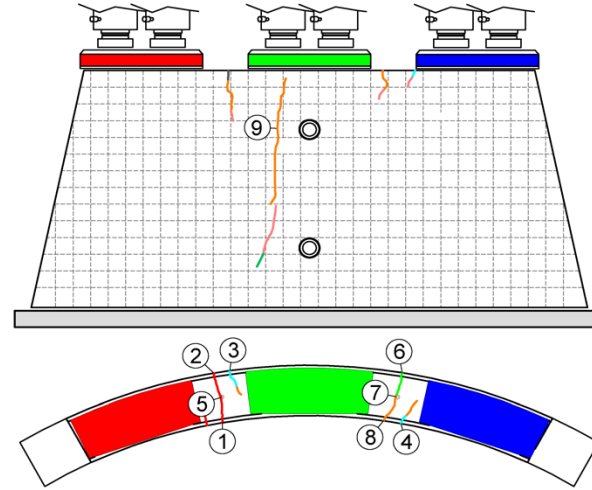


TBM TEST RESULTS

SFRC segment



SFRC+GFRP segment



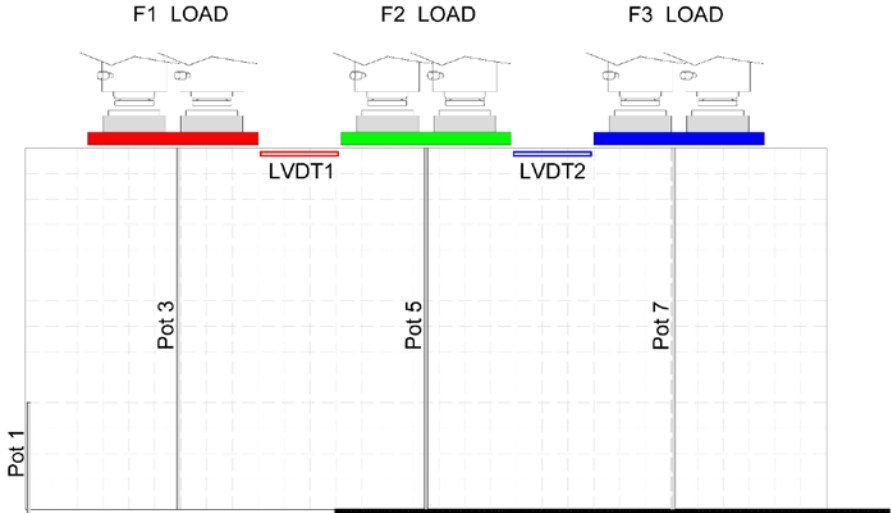
Load		Maximum crack width [mm]	
		SFRC	SFRC -GFRP
1 st crack [kN]	1250	0.05	<0.05
Service load [kN]	1580	0.10	0.05
Unblocking thrust*[kN]	2670	0.40	0.25
Unload [kN]	0	0.15	0.10

APPLICATIONS?

TEST WITH GAP



INTRADOS VIEW

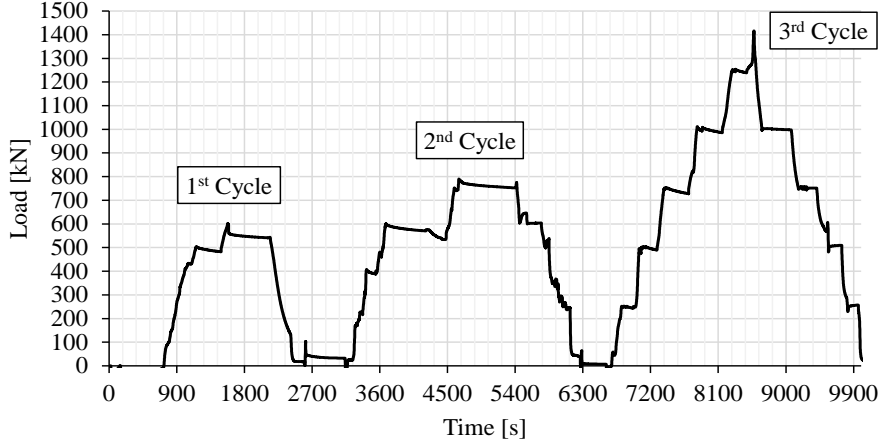


2 mm

TEST WITH GAP

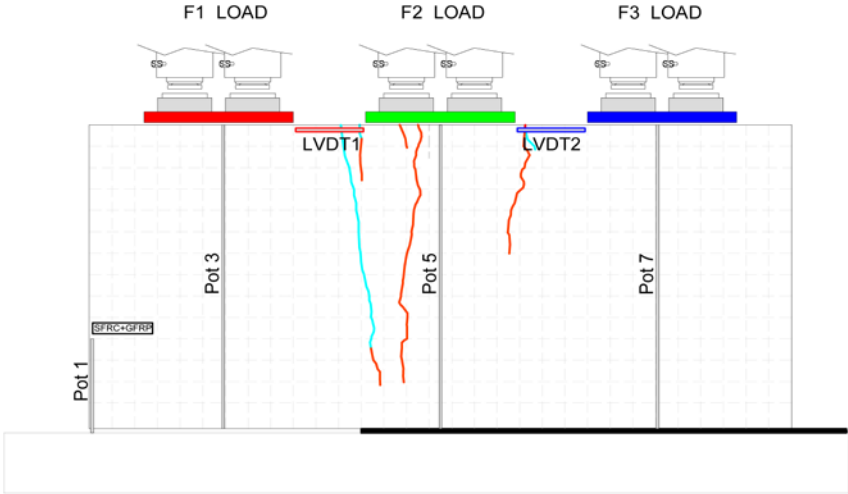


TEST WITH GAP



SFRC+GFRP Segment

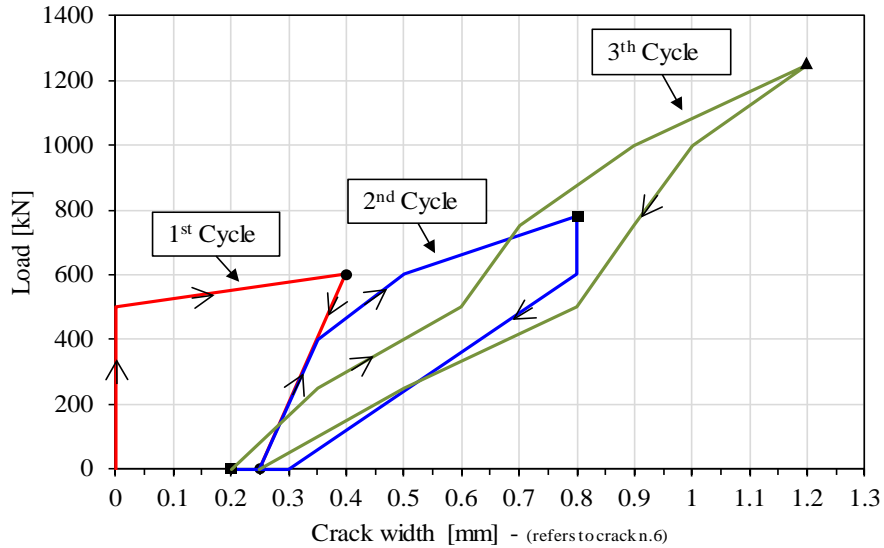
INTRADOS VIEW



LOAD STEP

Cycle I	500 kN	600 kN
Cycle II	600 kN	780 kN
Cycle III	750 kN	1000 kN

TEST WITH GAP



Crack n. 6						
1 st Cycle		2 nd Cycle		3 th 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'	0	1415	n/a*	
		after 30'	0	0.20	1000	1.00
				750	0.90	
				500	0.80	
				250	0.50	
				0	0.25	
				0	0.25	

after 15'

* 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