World Tunnel Congress & Exhibition

WTC 2019

ITA - AITES General Assembly and World Tunnel Congress

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

MAY 3-9

NAPLES 2019

Società Italiana Gallerie
Italian Tunnelling Society
HYBRID SOLUTION WITH FIBER REINFORCED CONCRETE AND GLASS FIBER REINFORCED POLYMER REBARS FOR PRECAST TUNNEL SEGMENTS

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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

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

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

Emerging Technology Series

Precast tunnel segments in fibre-reinforced concrete

State-of-the-art report
FRC in TBM tunnels

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

- 2011-2017
- 2006-2010
- 2000-2005
- '90s
- '80s

Legend:
- Hybrid RC/FRC
- FRC
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
GFRP Rebars

COMPOSKE PROJECT:
DESIGN AND TESTING OF PRECAST TUNNEL SEGMENT


FRC + GFRP Rebars

Section A-A

Lateral view

Intrados view

1.42 m

0.30 m

06.40 m

05.80 m
FRC + GFRP Rebars

40kg/m³ 4D 80/60BG steel fibers

\( f_{cm} \quad 62 \text{ MPa} \)

18 mm diameter

40 GPa Young’s Modulus

1000 MPa tensile strength
FRC + GFRP Rebars

BENDING TESTS

TBM TESTS
BENDING TEST RESULTS

\[ P_{\text{max}_{\text{SFRC+GFRP}}} = 367 \text{ kN} \]

\[ P_{\text{max}_{\text{SFRC}}} = 225 \text{ kN} \]

\[ \Delta P +63\% \]

Load [kN] vs. Displacement [mm] chart with SFRC and SFRC+GFRP curves.
BENDING TEST RESULTS

**SFRC segment**

<table>
<thead>
<tr>
<th>Load step</th>
<th>125 kN</th>
<th>160 kN</th>
<th>180 kN</th>
<th>210 kN</th>
<th>222 kN</th>
<th>250 kN</th>
<th>270 kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFRC</td>
<td>&lt;0.05</td>
<td>0.25</td>
<td>0.35</td>
<td>0.60</td>
<td>1.00</td>
<td>n/a**</td>
<td>n/a**</td>
</tr>
<tr>
<td>SFRC-GFRP</td>
<td>&lt;0.05</td>
<td>0.10</td>
<td>0.15</td>
<td>n/a**</td>
<td>0.35</td>
<td>0.45</td>
<td>0.70</td>
</tr>
</tbody>
</table>

**SFRC+GFRP segment**

<table>
<thead>
<tr>
<th>Load step</th>
<th>145 kN</th>
<th>160 kN</th>
<th>180 kN</th>
<th>250 kN</th>
<th>270 kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFRC+GFRP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: n/a** indicates not applicable or not measurable.
TBM TEST RESULTS
### TBM TEST RESULTS

**SFRC segment**
- **1st crack [kN]**: 1250
- **Service load [kN]**: 1580
- **Unblocking thrust* [kN]**: 2670
- **Unload [kN]**: 0
- **Maximum crack width [mm]**: SFRC - 0.05, SFRC + GFRP - <0.05

**SFRC + GFRP segment**
- **1st crack [kN]**: 0.05
- **Service load [kN]**: 0.10
- **Unblocking thrust* [kN]**: 0.40
- **Unload [kN]**: 0.15

<table>
<thead>
<tr>
<th>Load</th>
<th>SFRC</th>
<th>SFRC + GFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st crack [kN]</td>
<td>1250</td>
<td>0.05</td>
</tr>
<tr>
<td>Service load [kN]</td>
<td>1580</td>
<td>0.10</td>
</tr>
<tr>
<td>Unblocking thrust* [kN]</td>
<td>2670</td>
<td>0.40</td>
</tr>
<tr>
<td>Unload [kN]</td>
<td>0</td>
<td>0.15</td>
</tr>
</tbody>
</table>
APPLICATIONS?
TEST WITH GAP

INTRADOS VIEW

F1 LOAD  F2 LOAD  F3 LOAD

Pot 1  Pot 3  LVDT1  Pot 5  LVDT2  Pot 7

2 mm
TEST WITH GAP
TEST WITH GAP

SFRC+GFRP Segment

INTRADOS VIEW

LOAD STEP
- Cycle I: 500 kN
- Cycle II: 600 kN
- Cycle III: 780 kN
- Cycle IV: 1000 kN
TEST WITH GAP

<table>
<thead>
<tr>
<th>Load [kN]</th>
<th>Crack width [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>250</td>
<td>0.35</td>
</tr>
<tr>
<td>500</td>
<td>0.60</td>
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<tr>
<td>600</td>
<td>0.80</td>
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<tr>
<td>750</td>
<td>0.70</td>
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<tr>
<td>1000</td>
<td>0.90</td>
</tr>
<tr>
<td>1250</td>
<td>1.20</td>
</tr>
</tbody>
</table>

* n/a = not available

Crack n. 6

<table>
<thead>
<tr>
<th>1st Cycle</th>
<th>2nd Cycle</th>
<th>3rd Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load [kN]</td>
<td>Crack width [mm]</td>
<td>Load [kN]</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>250</td>
<td>0</td>
<td>400</td>
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<tr>
<td>500</td>
<td>0</td>
<td>600</td>
</tr>
<tr>
<td>600</td>
<td>0.40</td>
<td>780</td>
</tr>
<tr>
<td>600</td>
<td>0.40</td>
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</tr>
<tr>
<td>0</td>
<td>0.25</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0.20</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0.20</td>
<td>0</td>
</tr>
<tr>
<td>750</td>
<td>0.90</td>
<td>750</td>
</tr>
<tr>
<td>500</td>
<td>0.80</td>
<td>500</td>
</tr>
<tr>
<td>250</td>
<td>0.50</td>
<td>250</td>
</tr>
<tr>
<td>0</td>
<td>0.25</td>
<td>0</td>
</tr>
</tbody>
</table>
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