Steel Fiber Reinforced Concrete (SFRC) for TBM Tunnel Segmental Lining – Case Histories in the Middle East

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COWI BTM participates in some of the world’s landmark projects such as the largest offshore wind farms, deepest immersed tunnels, challenging metro-projects, longest bridges and most complex marine structures.
COWI SCFR Experiences

› Red Line North Underground, Doha QA
› Abu Hamour Sewer, Doha QA
› STEP Project, Abu Dhabi UAE
Why the SFRC should be used (or not) for segmental lining?

This presentation refers to tunnels in which 80% - 90% of the precast segments rings are reinforced with Steel Fibers and the remaining rings with traditional rebar cages.

› The SFRC is loved by Contractors.
› Corrosion and life service: The SFRC solved easily most of the corrosion issues within the design of precast segmental linings.
› The fibers reduces the local damages (corners), and severity of cracks in given conditions.
Why the SFRC should be used (or not) for segmental lining?

Fire protection: The expected spalling will be reduced
Stray current: is definitely solved
Sustainability: the steel reinforcement volume is significantly reduced
Why the SFRC should be used (or not) for segmental lining?

- The SFRC is not loved by some Agencies/Client. The technology is not fully known by the market. Difficult approval process.
- The design phase is critical, additional risk.
- The SFRC requires additional tests to define the SFRC strength.
- The SFRC requires the contractor capability for the concrete mix and the ring assembling.
- Some kind of cracks are critical with the fibers.
COWI designed 3 different SSFRC lining tunnels with diameters variable from 4 to 6m (check) in different type of soft rock to soils: STEP project in Abu Dhabi (UAE), Abu Hamour and Doha Metro projects in Doha (Qatar)

<table>
<thead>
<tr>
<th>Structural parts</th>
<th>Durability related design characteristics</th>
<th>Min/nom cover mm</th>
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</thead>
<tbody>
<tr>
<td>Typical tunnel segments</td>
<td>HDPE (internal) Epoxy coating (external)</td>
<td>N.A.</td>
</tr>
<tr>
<td>Special tunnel segments close to the adits</td>
<td>Traditional steel + steel fibre HDPE (internal) Epoxy coating (external)</td>
<td>60/65 (internal &amp; external)</td>
</tr>
<tr>
<td>Adits &amp; Shafts</td>
<td>Traditional steel Epoxy coating (internal)</td>
<td>75/85 (internal) 60/70 (external)</td>
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</table>
SSFRC Lining in Middle East Tunnels

The fibers: The solution for tunnel segments durability
Standard solution for high concentration of chloride and sulphate.
Damaged Segments

RC segments:
fragile material (RC) +
high concrete covers (Durability) =

Widespread failures of edges/corners/grooves
Several CMS of concrete are unprotected.
Damaged Segments

• **Assembling issues:**
  
  Greater ductility of the material
  
  +
  
  Greater impact resistance

  =

  Improved redistribution of the stresses in case of unforeseen loads

  less thick cracks
Damaged Segments

- **HIGH UNFORESEEN OVERSTRESS**
  (SEGMENTS MISALIGNMENTS IN THE ORDER OF CMS)

RC segments offer a greater margin of safety

Less margin of error during the installation of the segments!

There is no reinforcement limiting the diffusion of the cracks
SFRC is loved by the contractor

- No need of a dedicated plant for steel cages production

- Easy addition of the fibers to the concrete aggregates by means of a feeder

- Very simple equipment and no need of as high-qualified workmanship as opposed to steel cages production
Fire Protection – PPF Fibers

Steel fibers contribute to increase the fire protection against spalling, however,

the greater contribution is offered by PPF (average dosage 1-1.5 kg/mc)

PPF affects greatly the workability of the concrete mix

1 kg/m³  →  1 slump class down
Stray Current

No Steel Bars

No corrosion issues (environment and stray current)

No current dispersion system in the segments

No need to monitor the corrosion
Sustainability: Significantly Less Steel Reinforcement

• SAVING ON THE MATERIAL
  ($\approx - 60\% \text{ Steel }$)

RC segments: 70-120 kg/mc
SFRC segments: 25-50 kg/mc

Example:

1 km of metro tunnel with ordinary steel reinforcement $\Rightarrow$ 500-800 tons of steel

Economical and eco-friendly choice
Demanding Design and Approval Process

Some Clients/ Agencies may be reluctant to accept the full SFRC solution.

- Not fully known general standards.
- A few projects worldwide.
- Design focused in the segment details (borders, corners, holes) to minimize the tensile stress.
- Design focused in the detailed assessment of pushing rams phases and tensile stress.
SCFR – Lining Design

**REQUIREMENTS**
- CLIENT
- CONTRACTOR

**STUDY PHASE**
- THEORETICAL STUDY
- SFRC SPECIFICATION
- SPERIMENTAL STUDY

**PRODUCTION PHASE**
- TESTING
- ORDINARY PRODUCTION

**OPTIMIZATIONS**

NEED TO HAVE SOMEONE WITH A CLEAR PICTURE OF THE REPERCUSSIONS OF ANY CHANGE IN BOTH STUDY AND PRODUCTION PHASE.
SCFR - Design

- PRODUCTION ISSUES RELATED TO THE USE OF SF AND PPF
  WORKABILITY, AD-HOC MIX DESIGN, USE OF ADMIXTURES

A FINE TUNING OF THE CONCRETE MIX DESIGN COULD BE REQUIRED IN FUNCTION OF THE EQUIPMENT IN USE

- Cement
- Water
- Aggregates
- Steel Fibers
- PP Fibers
- Admixtures

CONCRETE MIX DESIGN

Moulds
Vibration system affects greatly the final results and mix design could be required to be optimized

EQUIPMENT

FINE TUNING
SFRC – Design of the details
Conclusions

**TREND :**
- The use of SCFR is the future of most of the TBM tunnels lining.

**ISSUES :**
- The operators may be skeptical about SCFR. A few projects worldwide.
- The technology requires very high level of contractor and designer.
- The project present major risks.

**SOLUTION :**
- Effective collaboration between involved parts (Client/contractor/designer)
- High skilled designer and contractor