Design issues to construct shotcrete for a tunnel with a 100 year design life

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Eastern Australia Ground Control Group
Shotcrete in Tunnels

• Behaviour
  – Loading
  – Failure mechanism

• Design standards
  – AS 5100 (Bridge Code)
  – European (EuroCode, RILEM, UK Concrete Society)

• Performance requirements
  – Durability, groundwater, fire

• Construction
  – multiple layers, dust, re-entry
Australian standards

• AS 5100.5:2017 Concrete

  – Section 16 SFRC applies
    “where steel fibres are used to improve the performance and capacity of reinforced and prestressed concrete structures.”

    “Hardening SFRC and the use of synthetic fibres is beyond the scope of this Standard.”

    “The minimum concrete grade and cover for SFRC in exposure classifications A, B1 and B2 shall be as for concrete without fibres and shall apply to the steel reinforcement only. SFR shall not be used in exposure classification C1 or C2.”

  – Does AS5100.5 apply to a tunnel lining?

  – A solution is to look further afield to international codes
# International standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>Title</th>
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<tbody>
<tr>
<td>DBV, 2001 German Society for Concrete and Construction Technology (superseded)</td>
<td>Guide to Good Practice – Steel Fibre Concrete</td>
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<tr>
<td>BS EN 14889-1, 2006 British Standards Institution, EuroCode</td>
<td>Fibres for Concrete. Steel Fibres. Definition, specifications and conformity</td>
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<tr>
<td>DAfStb, 2015 German Committee for Structural Concrete</td>
<td>Commentary on the DAfStb Guideline Steel fibre reinforced concrete</td>
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<tr>
<td>ASTM A820, 2016 American Society for Testing and Materials</td>
<td>Specification for Steel Fibres for Fibre-Reinforced Concrete</td>
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<tr>
<td>CS, 2007 UK Concrete Society</td>
<td>TR No. 63: Guidance for the Design of Steel-Fibre-Reinforced Concrete</td>
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Performance requirements

• Durability (structural)

• Water resistance

• Fire resistance
Durability

- Typically a 100-year design life is required
  - Exposure classification
  - Crack control
Exposure classification

• Tunnel lining is exposed to different environments.
• The outside surface may be in contact with
  – ground and groundwater
  – water resisting membrane
• The inside surface is exposed to atmosphere, vehicle emissions, and possible elevated temperatures.

<table>
<thead>
<tr>
<th>Surface</th>
<th>AS 5100.5</th>
<th>EuroCode 2</th>
<th>RILEM</th>
</tr>
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<tbody>
<tr>
<td>External</td>
<td>B1, C</td>
<td>XC2, XC3</td>
<td>2</td>
</tr>
<tr>
<td>Internal</td>
<td>B1, B2</td>
<td>XC1</td>
<td>2</td>
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</tbody>
</table>
Exposure classification

- The exposure class defines
  - Cover required to bar reinforcement
  - Maximum crack width in international codes
Maximum crack width

- **AS 5100.4 Cl. 4.15**
  
  *Cracking of concrete is a complex process with numerous variables. Consequently the design process to control cracking is simplified. The prediction of cracking is, therefore, not precise and it is reasonable to expect the need for limited crack repair in some structures with a design life of 100 years.*

- **RMS Specification B82 requires:**
  
  *At the completion of the curing period the shotcrete must have no cracks of width greater than 0.15 mm.*

- **European guidelines**
  
  *Max. crack widths of 0.2, 0.3 and 0.4 mm for exposure classes*
Crack width

- TR63 Guidance for the design of SFRC (2007)
  - Although there is no suitable design approach for estimating crack widths in structures reinforced with fibres only
  - Crack widths can be estimated using the method given in the RILEM $\sigma$-$\varepsilon$ design guideline (2003)
Addressing cracks

• Approaches taken include
  – Relying on adhesion between the shotcrete and rock
  – Allowing for a loss of section
  – Repairing cracks > 0.3 mm

• Macro-synthetic fibres
  – are not covered in AS, RMS or Eurocodes
  – Detailed specification, testing regime and trial results required to obtain RMS approval
  – North Strathfield rail underpass 6 kg/m³
Adhesion – difficult to assess
Water resistance

• Typical requirements for road tunnels are:
  – < 1 drip per 30 seconds onto road pavement
  – No drips or flow onto walkways
  – 1 l/s/km

• Tighter limits are typically required for rail tunnels
Addressing water resistance
Fire Resistance

- Typical requirement is for tunnel structures to have a fire resistance level (FRL) of not less than 240/-/- (*) under a specified temperature curve or fire load

(*) Structural/integrity/insulation
Addressing fire resistance

- Adding 1 kg/m³ of polypropylene fibres

- Including an allowance of for section loss due to shotcrete spalling (typically, 25 mm)
Supported ground

- All long-term goals while still providing early strength
- Min compressive strengths 1 to 4 MPa
- Re-entry based either on
  - Accepted strength versus age relationship
  - Beam end tests
Spraying rigs
The Tunnel Wisdoms

• A DRIPPING TUNNEL OR A CROWING HEN IS NEITHER GOOD TO GOD NOR MEN • Drip Happens • BETTER LATE THAN TUNNEL • Better to have tunnelled and lost than never to have tunnelled at all • BREVITY IS THE SOUL OF TUNNEL • If it aint broke, don’t tunnel it • FOOLS TUNNEL IN WHERE ANGELS FEAR TO GO • TUNNEL IN HASTE, REPENT AT LEISURE • You can’t have too much of a good tunnel • TUNNEL, HEAL THYSELF • SPARE THE ROD AND SPOIL THE TUNNEL • TOMORROW IS ANOTHER TUNNEL • Don’t change horses in mid-tunnel • THE ROAD TO HELL IS TUNNELLLED WITH GOOD INTENTIONS • ETC.

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