



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



Robert Bertuzzi

18 – 19th May

Shotcrete Workshop

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 ?

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DBV, 2001 German Society for Concrete and Construction Technology (superseded)	Concrete	Guide to Good Practice – Steel Fibre Concrete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



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.

Surface	AS 5100.5	EuroCode 2	RILEM
External	B1, C	XC2, XC3	2
Internal	B1, B2	XC1	2



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:

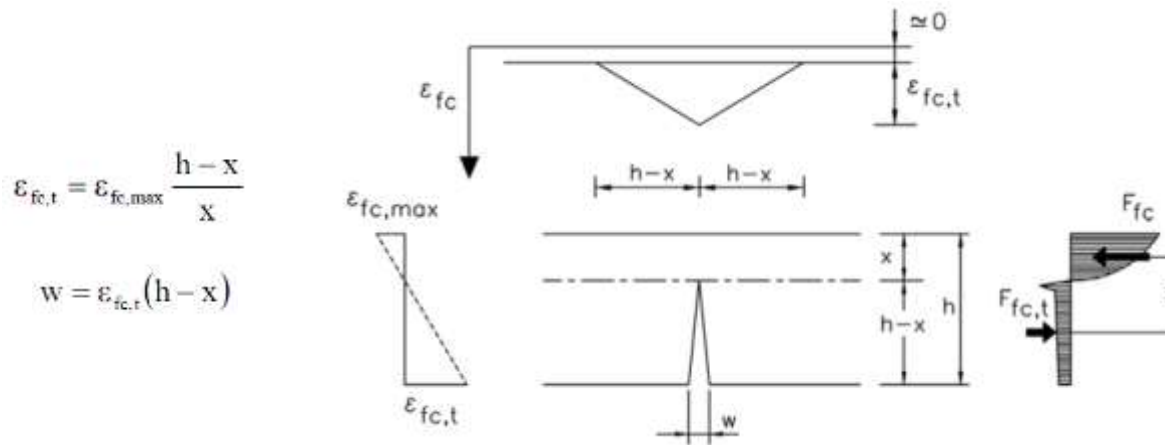
At the completion of the curing period the shotcrete must have no cracks of width greater than 0.15 mm.

- 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 σ - ϵ 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/m^3

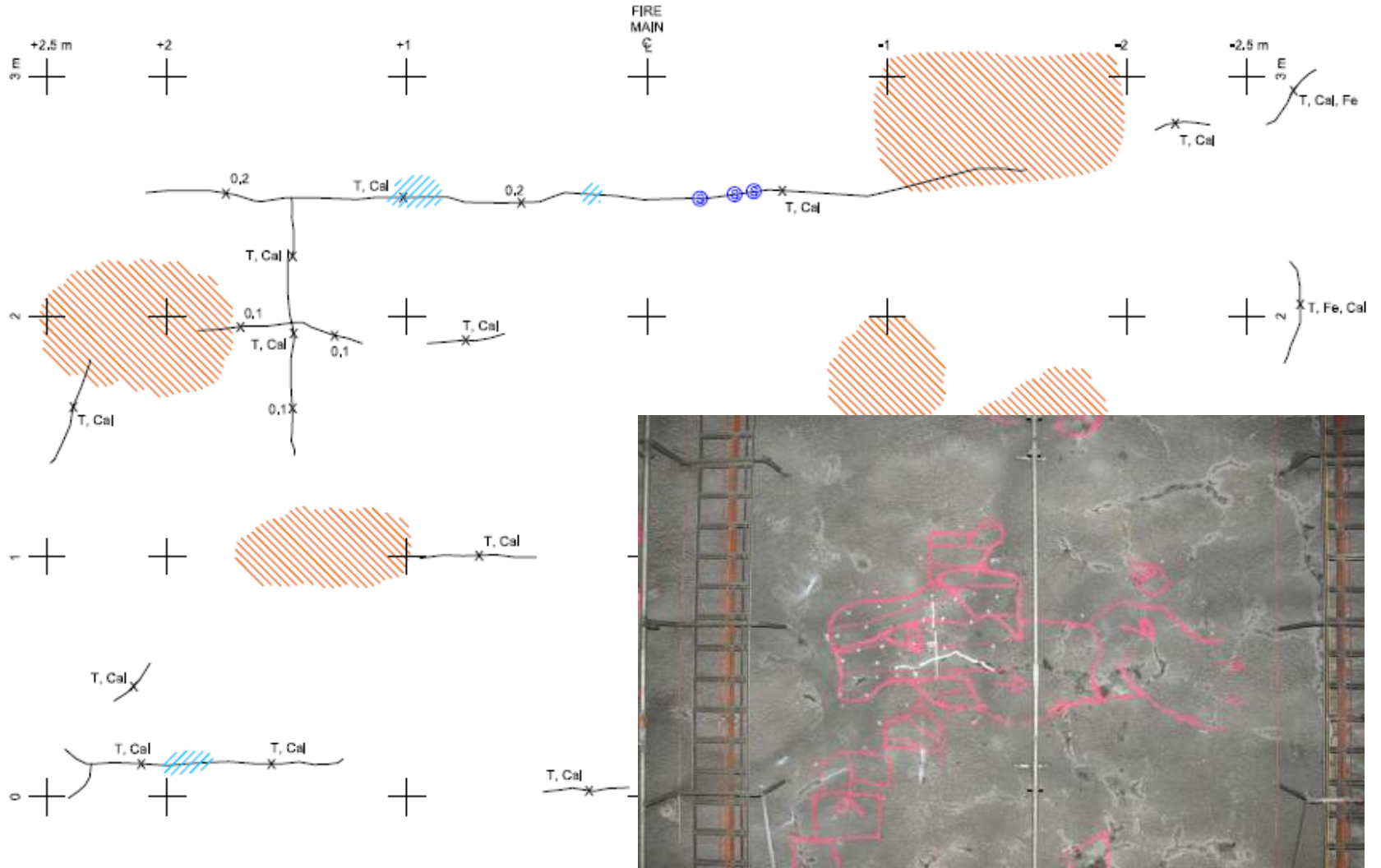


Cracking





Adhesion – difficult to assess



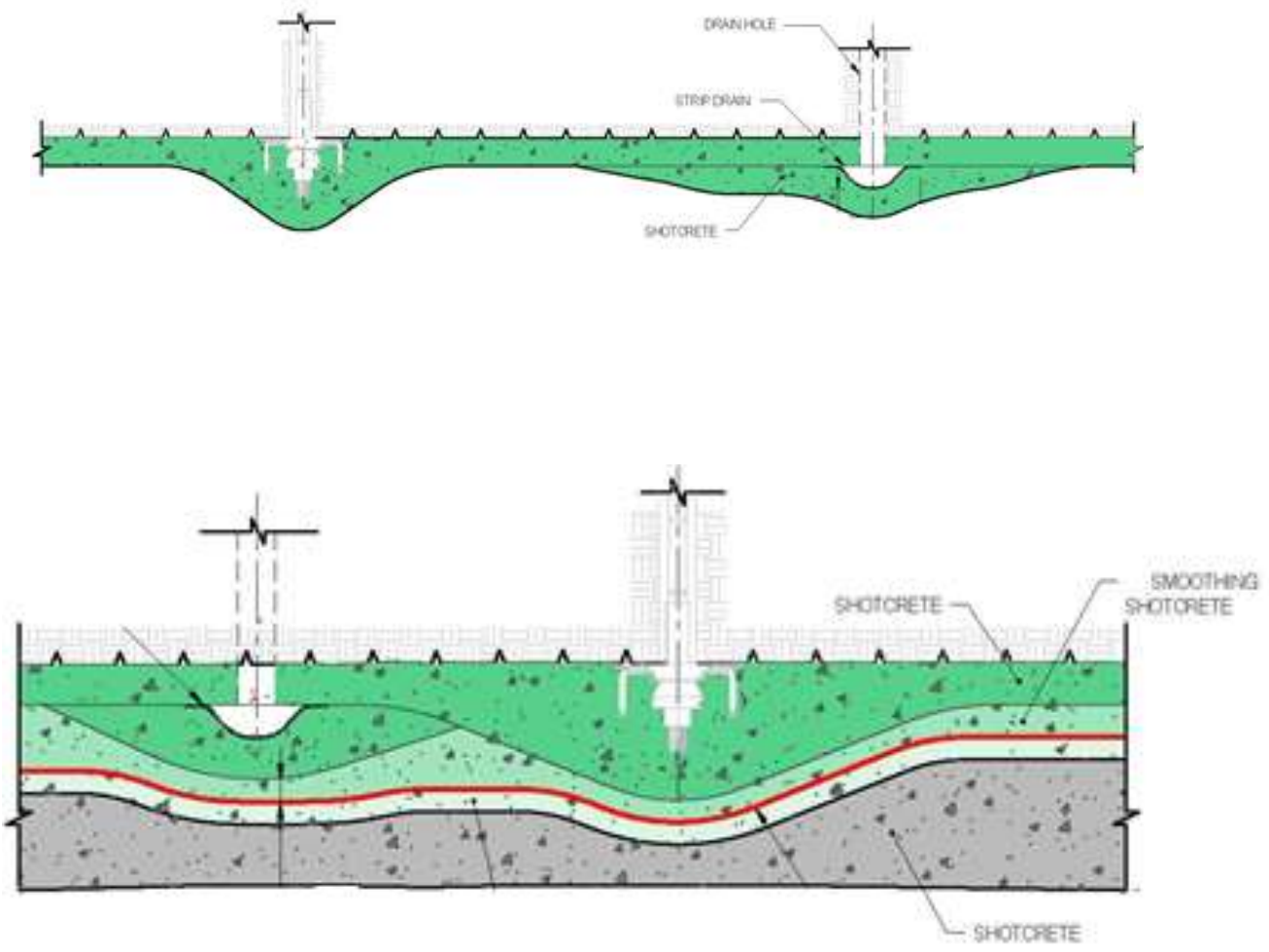


Water resistance

- 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



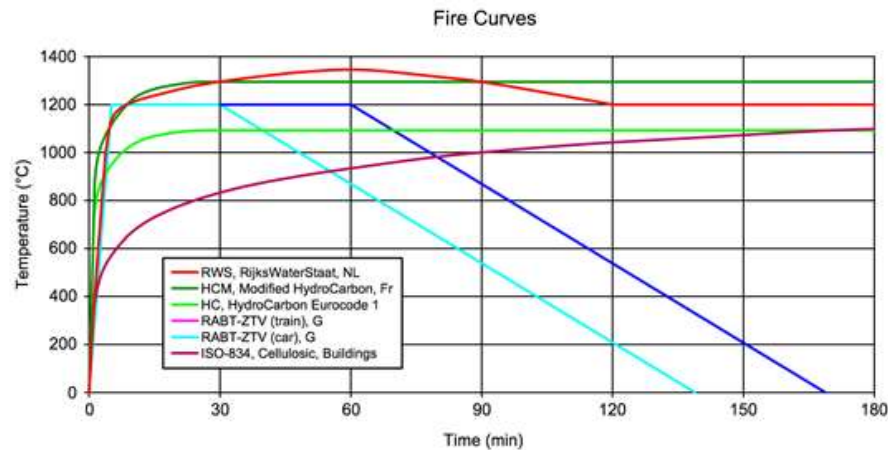
Addressing water resistance





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



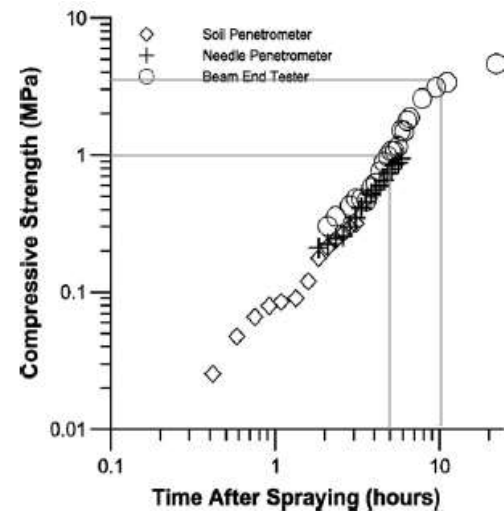
Addressing fire resistance

- 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 tunneled and lost than never to have tunneled 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 TUNNELLED WITH GOOD INTENTIONS • ETC.



Leunig