European Shotcrete Tech

AN OVERVIEW OF PERMANENT SHOTCRETE LINING CODES AND STANDARDS FROM DIFFERENT JURISDICTIONS

By Andy Thompson

This article examines the range of codes and standards applicable to the design of permanent shotcrete (sprayed concrete) linings, for underground construction. The relevance of these codes and standards to the designer will be dictated to some degree by the location of the project. There is no single approach to the design of such linings, as the final use of the underground facility will be a primary driver (in conjunction with the ground that the facility is being constructed in). For the purposes of this paper, the codes and standards in Europe, the UK, North America, Australia, and Turkey (for seismic design) have been reviewed.

DESIGN APPROACH

EUROPE

As the use of shotcrete placement for permanent tunnel linings (especially for transportation projects) has become more commonplace, Europe has developed an integrated chain of standards from material specification through testing and structural design. This has created a standardized set of documents that can be utilized across multiple countries and jurisdictions, providing a consistent approach to the design and construction of such linings. Local annexes are developed for specific cases, such as the seismic design elements in Turkey.

While this provides a consistent framework for the design and construction of permanent shotcrete linings, it can introduce complexity and can in some cases be over-prescriptive. The "standard" suite of standards for permanent shotcrete linings is outlined below:

- EN 14487 defines sprayed concrete requirements
- EN 14488 defines testing methods
- EN 14651 establishes residual flexural strength testing
- EN 14889 governs the use of fibers
- Eurocodes provide structural and geotechnical design rules

In addition to the documents identified above, the EFNARC guidelines are used for testing and certification processes for shotcrete operators, together with the ITA guidelines.

UNITED KINGDOM

The UK generally follows a very similar approach to Europe, using the EN standards supplemented with UK-specific annexes. Given the extensive use of shotcrete placement on projects such as Crossrail and HS2, plus the analysis of the shotcreted designs and performance from the Crossrail project, there is an additional solid library of information that can also be deployed to inform the design process. The recently issued "Sprayed Concrete Linings in Soft Ground" guidelines from the British Tunnelling Society have attempted to provide additional clarity on certain areas of the design process, including:

- Lack of sprayed concrete lining (SCL) specific design standards or codes

Fig. 1: Shotcreter education in full swing

- Ground structure interaction using numerical modelling (clarity on use of load and material factors)
- Residual flexural tensile capacity and ductility of sprayed fiber-reinforced concrete
- Tensile capacity of plain and fiber-reinforced concrete
- Composite linings (SCL/membrane/SCL)
- Analysis of radial joints in SCL
- Permanent and temporary nature of SCL
- Advance rates in relation to strength gain

TURKEY

The country has largely adopted the European sprayed concrete framework, with the main difference being the use of country-specific concrete and seismic specifications: Reinforced Concrete TS 500 and Turkish Earthquake Building Code (TBEC 2018), respectively. With Turkey being in an active seismic zone, older tunnels have been retrofitted where possible to provide enhanced seismic protection, and newer tunnels are designed to allow for it. In addition, the recommendations of the ITA and EFNARC are typically also adopted.

NORTH AMERICA

Unlike Europe, in North America there is no clearly established suite of standards that are directly comparable to the European approach. ACI 506 documents are primarily related to concrete application standards, construction specifications, and quality control guidance. Structural design is typically performed in accordance with ACI 318 or CSA A 23.3 in the US and Canada, respectively. There is no dedicated shotcrete structural design code for SCL. Supplementing these codes and standards are Federal Highway Administration (FHWA) guidance documents and position/best practice papers published by the American Shotcrete Association (ASA).

The North American approach to SCL is heavily based on empirical and practical considerations and is well suited to contractor-driven delivery of shotcrete linings. As a less-integrated approach than that which has evolved in Europe, however, it can lead to a fragmented methodology for specifying and design (despite the best efforts of ASA). It can also lead to one-off project requirements that, while valid for a single project, are not contributing to the development of a standardized approach.

AUSTRALIA

The approach to specifying and design of permanent shotcrete linings in Australia appears to be a hybrid of the North American and European approaches. There is no comprehensive design code dedicated to permanent SCL, and the approach on recent major projects has been to supplement Australian standards with international guidance. For example, AS 3600 structural concrete design is used alongside CIA Z5 Shotcrete Recommended Practice and owner-developed specifications that may be supplemented with ITA and EFNARC guidelines. This provides a flexible approach to develop project-specific solutions, but that flexibility can lead to bespoke specifications and designs.

Region	Design Philosophy
Europe	Code-driven, performance-based, highly standardized
UK	European approach with project-specific owner enhancements
Turkey	European-style framework with enhanced seismic requirements
USA/Canada	Construction-specification driven; structural design separated from shotcrete placement standards
Australia	Structural code plus owner specification and industry guidance

Table 1

As outlined in Table 1, there appear to be two different approaches to codes and standards related to permanent shotcrete linings specifically for transportation tunnels:

1. **European System (Europe, UK, Turkey)**
   a. Eurocodes or Eurocode-derived national standards
   b. EN 14487 and EN 14488 for sprayed concrete
   c. Extensive use of EFNARC and ITA guidance
2. **North American / Australian System**
   a. Structural concrete codes (ACI 318, CSA A23.3, AS 3600)
   b. Shotcrete-specific guidance (ACI 506 or CIA Z5)
   c. Increasing use of performance-based design for fiber-reinforced shotcrete employing residual strength and energy absorption testing

In summary, the structural design of permanent shotcrete linings is almost always supplemented by ITA recommendations, EFNARC guidance, and project-specific owner requirements. This is primarily because the primary concrete design codes do not fully address ground-support interaction and tunnel lining behavior.

The European framework approach provides a comprehensive standardized approach that can be adopted for the design and construction of permanent shotcrete linings, as it covers the entire lifecycle of the process from material requirements to structural design integration, construction, and testing requirements. The approach adopted in Australia and North America will result in similar engineering outcomes but tend to rely more heavily on projects' specifications, owner requirements, and

Topic	Europe	United Kingdom	Turkey	North America (USA/Canada)	Australia
Primary concrete design code	Eurocode 2 (EN 1992) and Eurocode 7 (EN 1997)	BS EN 1992 and BS EN 1997 (Eurocodes with UK National Annexes)	TS 500 Reinforced Concrete Code	ACI 318 (USA), CSA A23.3 (Canada)	AS 3600 and often AS 5100 for transport infrastructure
Shotcrete-specific standard	EN 14487-1 and EN 14487-2	BS EN 14487	TS EN 14487-1 (Turkish adoption of EN 14487)	ACI 506R and ACI 506.2	Austroads ATS 5328, TfNSW B82, CIA guidance
Testing standards	EN 14488 series	BS EN 14488 series	TS EN 14488 series	ASTM C1550, C1609, C1604 and ACI testing methods	AS 1012 plus project-specific shotcrete testing
Fiber-reinforced shotcrete design	EN 14651 and EN 14889	BS EN 14651 and BS EN 14889	EN 14651 and EN 14889 adopted through European standards	ASTM performance tests and ACI 544 guidance	Predominantly performance-based using residual strengths and CIA guidance
Tunnel design methodology	ITA and EFNARC	BTS/ICE, ITA and EFNARC	ITA and EFNARC	FHWA, ACI, ITA	ITA, EFNARC and Australian Shotcrete Society guidance
Seismic design	Eurocode 8	Eurocode 8	TBEC 2018 (TBDY 2018)	ASCE 7 (USA), NBCC (Canada)	AS/NZS 1170

Table 2: Comparison of Codes and Standards

engineering judgement compared to the single integrated shotcrete design standard approach adopted in Europe.

OVERVIEW OF EUROPEAN CODES AND STANDARDS

The discussion below is not intended to be a side-by-side comparison of the various standards used in the US and Europe: It is intended to be a high-level summary of what each code or standard covers.

Structural Design Standards

EUROCODE 2 (EN 1992)

EN 1992-1-1: Eurocode 2 – Design of Concrete Structures

This is the principal structural design code used for reinforced concrete and fiber-reinforced shotcreted structures in Europe. It provides requirements for Ultimate Limit State (ULS) design, Serviceability Limit State (SLS) design, durability, crack control, reinforcement design, and structural concrete material properties.

When designing permanent shotcrete linings, Eurocode 2 would typically be used in conjunction with EN 14487-1 and 2.

When compared to ACI 318, Eurocode 2 requires a more detailed approach to serviceability, durability, long-term behavior, and crack control. This will require more explicit verification of crack widths and long-term deformation.

Eurocode 7 (EN 1997): Geotechnical Design

This is used for tunnel and ground-support applications because shotcrete placement is often part of the ground-support system, especially in SEM/NATM applications. This code covers the following areas, ground-structure interaction, partial safety factors, geotechnical load cases, and excavation support systems.

Shotcrete Material Standards

EN 14487-1

Sprayed Concrete – Definitions, Specifications, and Conformity

This is the primary European shotcrete standard and covers wet- and dry-mix shotcrete, material requirements, exposure classes, early-age strength classes, fiber-reinforced shotcrete, conformity, and quality control.

The current EN version is 2022/2023, but this can vary by country depending on national adoption of the EN.

EN 14487-2

Execution of Sprayed Concrete

This standard provides requirements for spraying operations, equipment, shotcreter qualifications, production control, and site execution procedures, and is the key standard used by contractors on European tunnel projects.

The North American equivalent for the above would be ACI 506.

Shotcrete Testing Standards

EN 14488 SERIES

Testing Sprayed Concrete

The EN 14488 series specifies test methods for shotcrete and includes the major elements listed in Table 3, which may also be specified for QA/QC and acceptance criteria:

Standard	Purpose
EN 14488-1	Sampling fresh and hardened concrete
EN 14488-2	Early-age compressive strength
EN 14488-3	Flexural strengths of fiber-reinforced beams
EN 14488-4	Bond strength
EN 14488-5	Energy absorption of fiber-reinforced shotcrete panels
EN 14488-6	Thickness determination
EN 14488-7	Fiber content determination

Table 3

Fiber-reinforced Shotcrete

EN14889 – FIBERS FOR CONCRETE

With the increasing use of fiber-reinforced concrete, EN14889 (Fibers for Concrete) has been developed and includes requirements for steel fibers, polymer fibers, conformity assessments, and material properties.

EN14651 – FLEXURAL TENSILE STRENGTH TESTING

Provides the residual flexural strength test used to characterize structural fiber-reinforced concrete and shotcrete.

EFNARC GUIDELINES

The European Federation of Producers and Applicators of Specialist Products for Structures (EFNARC) publishes guidance documents that are used extensively in European tunneling practice. These documents cover the following areas: Execution of spraying, shotcreter testing, test panel execution, etc. Although not a statuary guideline, these documents are treated as a best practice manual and will typically be specified as part of the construction specifications.

CONCLUSION

While there are differences in philosophy and approach between North America, Australia and Europe, it is doubtful if a permanent shotcrete lining designed for similar ground conditions and end-use will be significantly different. The process to reach that final design may be different, however, as will be the certification, testing, and QA/QC process during construction.

FURTHER READING

1. Sprayed Concrete Linings in Soft Ground, British Tunnelling Society, 2025
2. Permanent Sprayed Concrete Linings, ITA WG 12, 2020.

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