

**ITAtch DESIGN GUIDANCE FOR SPRAY APPLIED
WATERPROOFING MEMBRANES**

ITAtch Activity Group
Lining and Waterproofing

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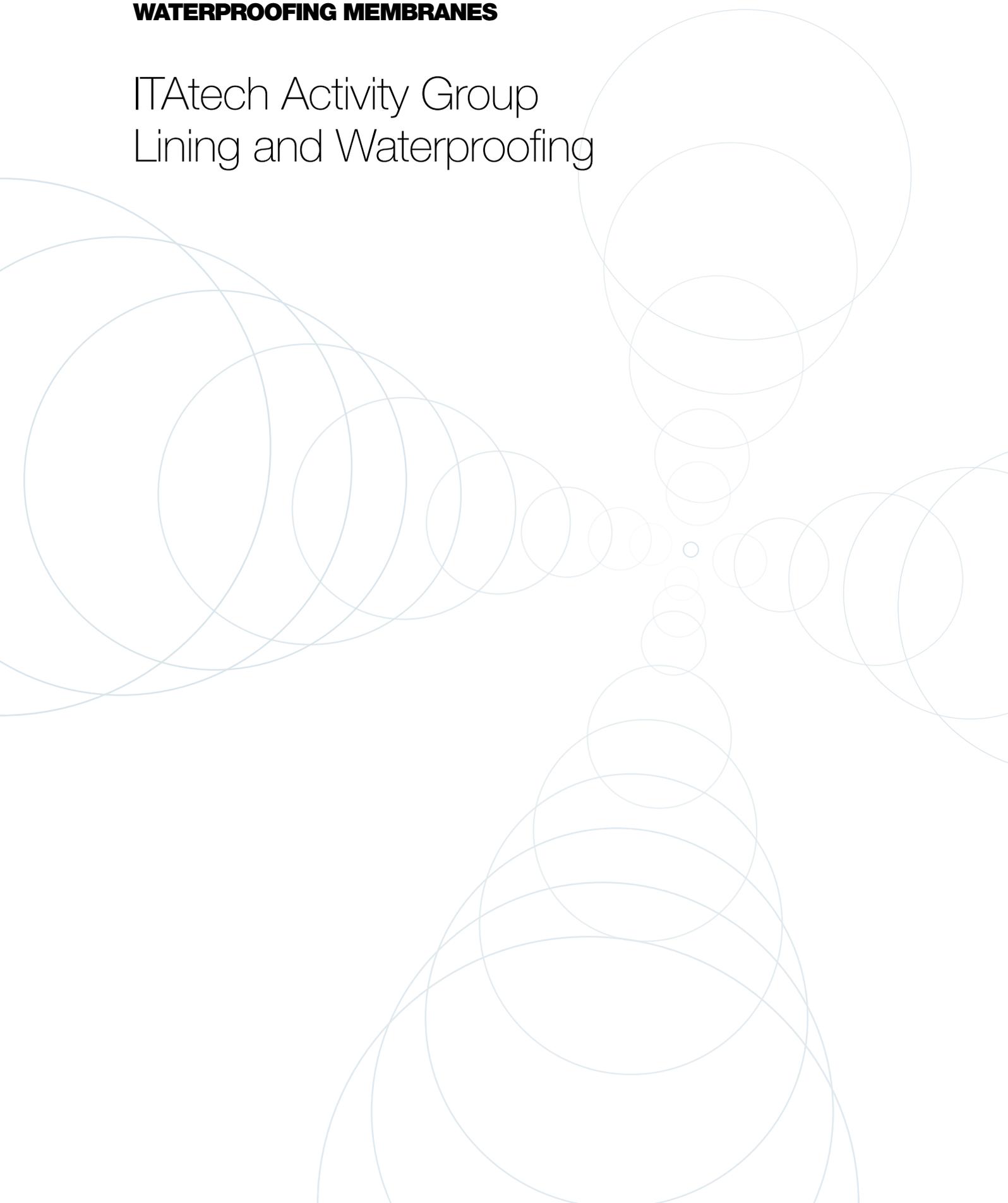
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This guidance document has been written to assist tunnel designers, contractors and owners in understanding the benefits of and limitations in the use of spray applied waterproofing membranes in excavated tunnels and shafts, and to provide guidance in drawing-up specifications and design details.

Spray applied waterproofing membranes for tunnels are proprietary construction materials that are applied to the primary lining surface with spray equipment, in order to form a coating that is bonded to the concrete that can provide an effective barrier to the ingress of liquid water into the structure. These materials are most commonly formulations of reactive or water-based polymers, some of which may incorporate cement compounds, and are sprayed either by hand or robotically. To tunnel owners, designers and contractors they can offer potentially greater flexibility over membranes that are installed as pre-formed sheets, a waterproofing method that has been used for many years. These spray applied waterproofing membranes and concrete lining materials are commonly used together, and when the membrane and lining are correctly specified and designed, may provide a fast and economic alternative solution to preventing water ingress into tunnels.

A sprayed concrete lined tunnel typically comprises a sprayed concrete primary (often considered and referred to as a temporary) lining, a waterproofing membrane, and a (sprayed or cast-in-situ) concrete secondary lining (often also called the final or permanent lining). The purpose of the primary lining is to stabilise a freshly-exposed excavation and so prevent any rock or soil collapse. It is sprayed with concrete following excavation, using rapid-setting concrete applied by a spraying machine controlled by a “Nozzleman”, who directs the jet of concrete onto the substrate and can stand in a safe location some distance away from the application surface. The primary lining also provides a firm substrate onto which a waterproofing membrane can be applied. Using sprayed waterproofing membranes facilitates the use of sprayed concrete for secondary linings.

BACKGROUND

Many tunnel owners and constructors have become accustomed to expecting leaks in tunnels, particularly when built in wet ground or below the water table, with the issue being not whether the tunnel will leak but by how much, and as a result whether it will be fit for purpose throughout its design life. Excessive leakage leads to excessive costs and programme delays during construction, and leaves the tunnel owner with maintenance costs and disruption throughout the working life of the tunnel for which he had not planned, together potentially with a reduced tunnel service life. Once a tunnel is leaking it is exceptionally difficult to stop the leaks entirely.

Since the 1970's, many sectors of the civil and structural engineering industry have been moving increasingly towards the use of spray applied waterproofing membranes as an effective alternative way to waterproof below-ground structures and critical infrastructures such as cut-and-cover tunnels, immersed tube tunnels, bridges et alia.

OBJECTIVE OF THE GUIDANCE DOCUMENT

This guidance document should provide designers, contractors and owners with a comprehensive set of information that will enable the inclusion of spray-applied waterproofing membranes for use in tunnel linings. This information is split into the following sections:

- Assessment of specific project situation and the potential benefits from the unique properties of a spray applied membrane as the chosen waterproofing system
- Current limitations of spray applied waterproofing system
- The potential impact on the tunnel lining design; composite shell action
- Guidance on technical specifications

This guide includes an Example Specification (Appendix A), Training Certification (Appendix B), Generic Detail Drawings (Appendix C) and Case Studies for each of the principle materials currently available on the market (Appendix D).

1 >> WHY IS WATERPROOFING REQUIRED?



Figure 1: Example of water ingress through a sprayed concrete lining

Robust waterproofing of underground structures is one of the most cost effective ways to enhance safety and function as well as to increase the useful design life of new and existing structures. Special maintenance due to deterioration of the structure can be eliminated or minimised and, more importantly, the structure is able to function for the duration of its design life.

As shown in Figure 1, water ingress through a sprayed concrete lining is possible through cracks and flaws; areas where the concrete may have a greater permeability than the surrounding, well installed concrete. Cracks on the sprayed concrete lining are mainly located in the vicinity of lattice girders and construction joints, e.g. in the interface top heading-bench or bench-invert, in part due to the increased likelihood of shadowing or poorly compacted concrete in these zones. They are mostly caused by external loads, temperature changes, shrinkage, and placement of sprayed concrete.

Watertightness is directly related to the durability and serviceability of the sprayed concrete lining. Sprayed concrete can be produced to be watertight in small scale samples. However, building a large watertight sprayed concrete surface, as required for tunnel linings, can most practicably be done by means of additional measures. The waterproofing system should also protect the final permanent lining against aggressive environment (e.g. aggressive groundwater or soil).

The example specification in Appendix A includes a table characterising the watertightness classes that a project might require. In general a client will be looking to achieve a completely dry tunnel (waterproofing class 1), but in practice a largely dry tunnel (waterproofing class 2) will achieve their goals with a lower cost. The impact of water ingress and also any drainage and cleaning costs over the full lifetime of the project should be considered when defining the watertightness class in the specification.

2 >> INTRODUCTION TO SPRAY APPLIED WATERPROOFING MEMBRANES

There are different types of spray applied waterproofing membranes. They may be produced by means of non-reactive systems (curing by hydration or air-drying), or reactive systems (curing by polymer reaction). They are all thin elements, typically with a total final thickness of 3 or 4 mm.

Spray applied waterproofing membranes are produced and installed in situ against the primary tunnel lining and typically covered later on by a secondary tunnel lining or a non-structural protective layer (e.g. mortar or sprayed concrete) according to the design requirements.

Generally the membrane can be applied in one stage directly onto the concrete lining or substrate. Some membranes require first the application of a primer layer onto the substrate before application of the membrane in one or two consecutive layers.

When installed between the primary and secondary concrete linings, spray applied membranes may bond to both primary and secondary linings (double-bonding) or only to one lining (single-bonding), depending on the design requirements and the product chosen. In the case of a spray applied membrane with double bonding properties, the resulting sandwich-structure (concrete-membrane-concrete) may act as a quasi-monolithic structure, depending on the bonding characteristics and properties of the membrane.

A number of tunnels, cross-passages, stations and shafts have been successfully completed using spray applied waterproofing systems over the last years, under quite different conditions and design requirements. The use of spray applied waterproofing membranes is not the panacea for all waterproofing requirements for sprayed concrete tunnels, but it does offer a viable solution for a specific window of ground and hydrological conditions that are quite regularly found on tunnelling projects.

2.1. FEATURES

Spray applied waterproofing can offer benefits in geometrically complex areas such as lay-by niches, cross passages, rail tunnel turn-outs and crossover caverns, where installation of conventional waterproofing membranes is inherently difficult and testing or locating of possible leaks can be challenging.

Spray applied membranes lend themselves to the use of sprayed concrete secondary linings, as they negate the need for customised

shutters traditionally used for cast in-situ linings to line these complex shapes and junctions. They also do not require mesh to allow the build-up of sprayed concrete on a non-rigid substrate such as with the use of a sheet waterproofing membrane.

A key feature of spray applied waterproofing membranes is their simple application by means of equipment often already available on site for sprayed concrete application, thus freeing up time and space for other activities. Typically 50 – 100m²/h can be manually sprayed by 3 operators. Robotic spraying can reach application rates up to 180m²/h.

Spray-applied membranes can be applied to limited sections to provide isolated waterproofing, such as in the crown sections of tunnels, or as a continuous waterproofing system.

Further features of spray-applied waterproofing membranes are:

- Continuity without discrete joints; confinement measures (injection, tubes, weld links, compartmentalisation with waterstops etc.) are not required as the bond between the membrane and the substrate prevents waterpaths developing between layers.
- Spray applied membranes do not have any welded seams, and are simply connected by spraying a short overlap zone onto the previously applied membrane section
- Easier and quicker location and repair of leaks. A seepage point through the membrane can be easily resolved locally precisely where the seepage occurs since this point corresponds to the seepage channel in the concrete behind the membrane
- They can be combined with other waterproofing systems. Standard joint details between spray applied and sheet membranes are available, making the system totally flexible
- They are compatible with all concrete placement techniques, allowing placement of a sprayed concrete inner lining, and reinforcement types (mesh, rebars and fibers) on either side of the membrane. The membrane can be sprayed straight onto many types of penetrating items (e.g. anchored reinforcement)
- There is no folding and stretching of the spray applied membrane during the casting or spraying of the secondary/permanent lining as it is in intimate contact and fully bonded to the primary lining

2 >> INTRODUCTION TO SPRAY APPLIED WATERPROOFING MEMBRANES

2.2. INSTALLATION CONSIDERATIONS

During the application period in the tunnel, spray applied membranes are exposed to the local environmental conditions, such as temperature and humidity, which, depending on the chosen product, can interfere with the curing process of the membrane. The membrane is also vulnerable to poor workmanship, as with all waterproofing systems, therefore proper training and accreditation of applicators is crucial for successful application. Close and systematic quality control of the in-situ produced membrane is required at all stages of the lining construction process to ensure correct thickness and coverage.

Some membrane systems may require additional surface preparation, see section 6.2.

Spray applied membranes may not be practical to install when high levels of water ingress through the substrate are expected. The waterproofing system approach based on anticipated water ingress through the primary sprayed concrete lining is summarised in Figure 2 below. The chart shows water ingress ranging from completely dry through to extensive water ingress throughout much of the tunnel primary lining surface. Spray applied membranes are deemed suitable for water ingress up to isolated areas with trickling or running water, or for tunnels treated with de-watering or pre-injection methods to control water ingress to manageable levels during construction. Tunnels that are substantially wet are ideally waterproofed with sheet membranes for example.

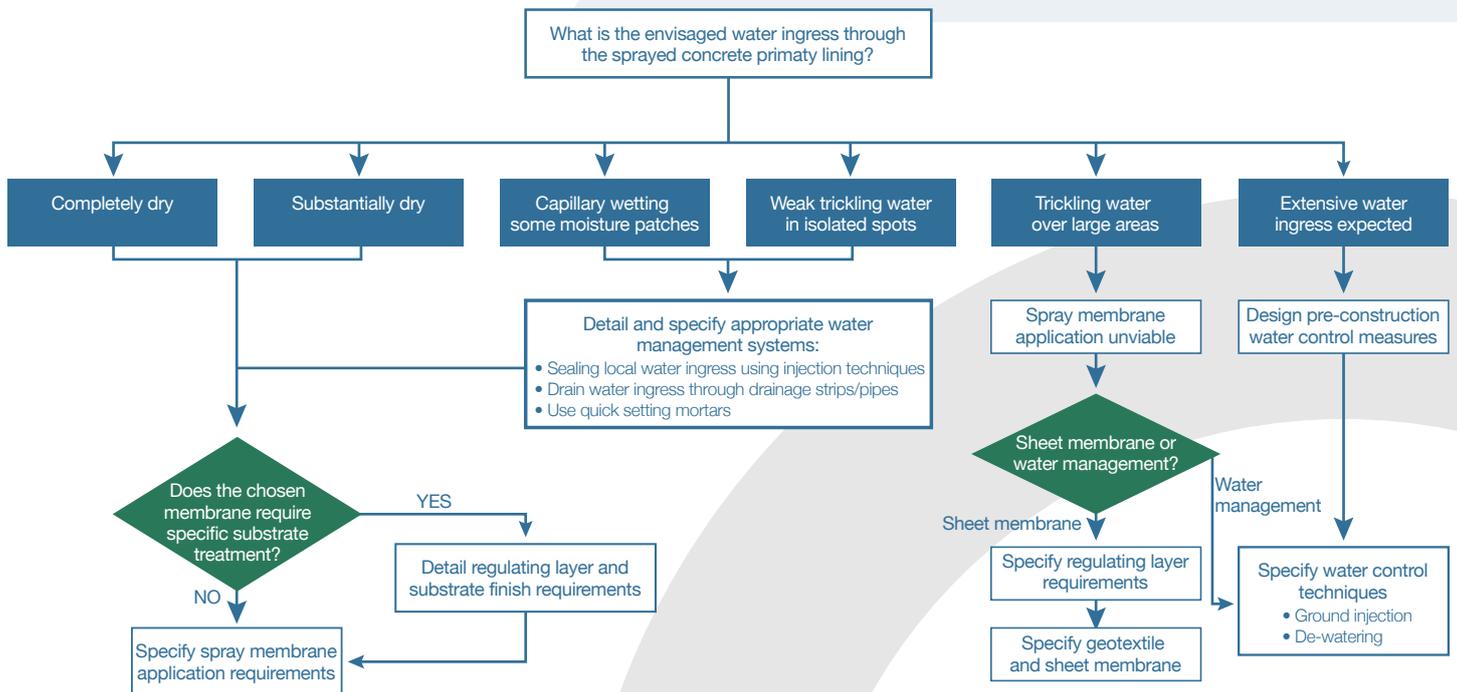


Figure 2: Flow chart describing waterproofing approach based on anticipated water ingress through the primary sprayed concrete lining

3 >> THE USE OF SPRAY APPLIED WATERPROOFING MEMBRANES

In general the waterproofing systems of underground structures are designed to either:

- Withstand full water pressure, with a full round waterproofing system and without groundwater drainage (displacement concept),
- Withstand limited water pressure with a partially drained system for partial stress relief (partial displacement concept),
- Relieve full water pressure through managed drained systems, i.e. a fully drained waterproofing system with non-pressurised water drainage (drained concept).

The choice of the system depends on different factors, for example, the water pressure, anticipated groundwater conditions, maintenance regime, and environmental impacts (e.g. risk of settlement).

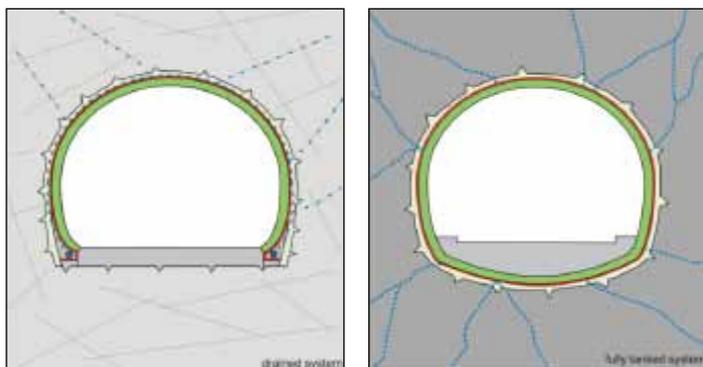


Figure 3: Drained system (on the left) and undrained or fully tanked system (on the right)

Spray applied waterproofing membranes are suitable to design and build undrained, systematically drained, locally drained, and mixed waterproofing systems as described in the following section. Spray applied membranes are not seen as a practicable solution for full surface water pressure relief (fully drained) designs due to the bonded nature of the membrane restricting the movement of water within the system.

3.1. USE OF SPRAY APPLIED MEMBRANES TO BUILD UNDRAINED WATERPROOFING SYSTEMS (DISPLACEMENT CONCEPT)

Typically undrained waterproofing systems are required to build underground structures in urban areas, such as metro running tunnels and stations, where permanent drainage of groundwater into the tunnel may cause settlement on the surface and lead to distress of existing buildings or facilities, but also to reduce the long term maintenance issues associated with drainage systems and pumps. Other underground structures which may require a undrained waterproofing system include:

- Water transfer tunnels and shafts, incl. sewage tunnels and pump storage shafts
- Power intake tunnels, headrace tunnels and surge shafts of hydropower plants
- Tunnels passing through drinking water aquifers, and
- Tunnels passing below sites of scientific interest and natural lakes, nature reserves etc.

Due to their bonding properties, spray applied membranes do not allow water migration along the concrete-membrane interface, reducing considerably the risk of water inflows/losses through the tunnel concrete lining.

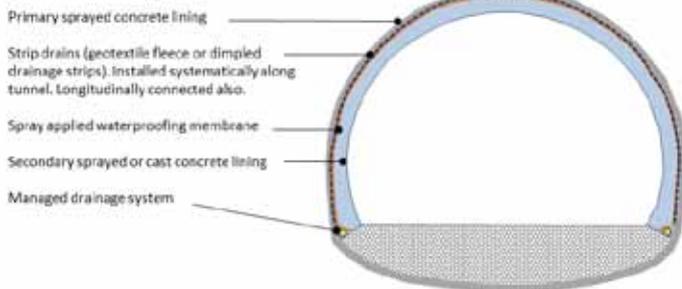
3 >> THE USE OF SPRAY APPLIED WATERPROOFING MEMBRANES

3.2. SYSTEMATIC DRAINAGE SYSTEM

In this case a drained system is installed at regular intervals (e.g. every 5 or 10 m) along the tunnel profile to permanently avoid build-up of groundwater pressure behind the concrete lining. This can be achieved, for example, with the installation of dimpled sheets strips onto the primary concrete lining which are connected to the drainage system at the invert level. The dimpled drainage sheets should be closely fitting to the primary concrete lining and have a regulating layer of sprayed concrete applied prior to application of the waterproofing membrane.

Increased security against potential water pressure build up is offered by connecting the systematic circumferential drainage strips with longitudinal drainage strips, typically installed in the crown and sidewalls of the underground structure.

Systematic drainage system

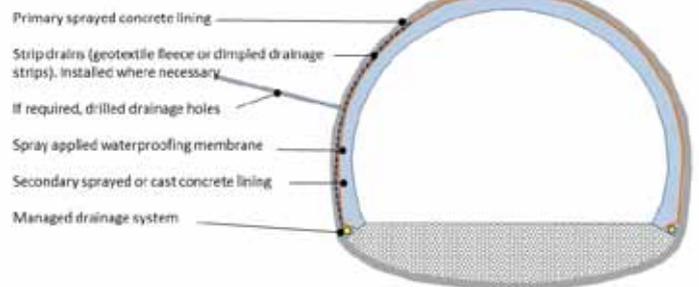


3.3. LOCALISED DRAINAGE SYSTEMS

This type of drained system may be used, for example, in the case of tunnel construction in an impermeable rock mass with groundwater circulating through some cracks in the rock, and, consequently, with localised water ingress through the tunnel primary lining.

Waterproofing with a spray applied waterproofing membrane can be effectively done after local seepage water has been collected and drained, for example, by means of short drill holes, packers and hoses which are installed in seepage spots, or dimpled drainage strips connected to the tunnel drainage system.

Localised drainage system



3 >> THE USE OF SPRAY APPLIED WATERPROOFING MEMBRANES

3.4. MIXED SYSTEMS

In this approach the waterproofing membrane is applied only in the crown of the tunnel, forming a watertight “umbrella” in the crown of the tunnel. The rest of the tunnel cross section does not receive any waterproofing membrane and can be considered as free draining, allowing the groundwater to percolate along the interface between concrete lining and ground, or through the sidewalls, into the tunnel drainage at the invert or sidewall footing level and be drained towards the tunnel portal. The span of the membrane “umbrella” normally is designed to protect the users or services installed referred to as the “operational envelope” in the tunnel from dripping water.

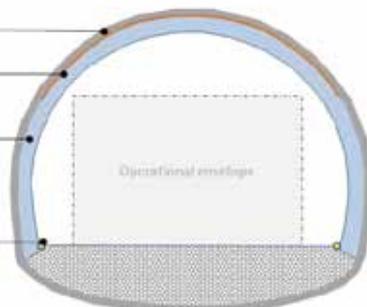
Mixed drainage system

Primary sprayed concrete lining

Spray applied waterproofing membrane applied to tunnel profile to prevent drips into operational envelope

Secondary sprayed or cast concrete lining

Groundwater allowed to percolate into tunnel in zone outside structural envelope, and drain into managed drainage system or gulleys



3.5. COMBINATION WITH OTHER WATERPROOFING SYSTEMS

Spray applied membranes can be installed in combination with other waterproofing systems, i.e. plastic sheet membranes (see Generic Drawings in Appendix C). In such overlapping areas the following is recommended:

- (1) Overlapping should be installed at dry areas
- (2) The surface of the substrate should be treated properly (e.g. with a mortar bed) to provide a flat surface for installation of the sheet membrane
- (3) The sheet membrane should be properly fixed. Screws and bolts may be required depending on the existing groundwater pressure
- (4) The sheet membrane should be well stretched, and should not present undulation or folds along its end
- (5) Proper overlapping with the spray applied membrane should be done according to supplier's instructions (minimum width of approx. 40 cm)
- (6) Material compatibility between components should be tested and documented.
- (7) System compatibility should be provided (for example, from a drained to undrained system). Care has to be taken to not align structural concrete joints with waterproofing system transition zones.

3.6. USE OF SPRAY APPLIED MEMBRANES TO WATERPROOF RETAINING WALLS

Spray applied membranes have also been used to waterproof retaining walls, such as diaphragm walls, bored piled walls etc., for example, to build metro stations. For these types of structures a regulating layer of sprayed concrete is applied to the retaining walls, followed by membrane application. The covering layer can either be sprayed or cast in-place concrete.

4 >> TYPICAL MEMBRANE PROPERTIES

In the following sections some typical properties of spray applied waterproofing membranes are summarised, which in combination contribute to the watertightness of the lining system. The required minimum thickness of the applied membrane influences watertightness as well as quality assurance and durability issues.

4.1. SYSTEM WATERTIGHTNESS

4.1.1. In the completed structure state

System watertightness comes from two key characteristics, the membrane watertightness and its bonding properties.

In a bonded solution, migration of groundwater along membrane-concrete interfaces cannot occur, because potential groundwater paths can be eliminated, mitigating considerably the risk of water ingress into the tunnel. Additionally, a bond between the membrane and the secondary (inner) lining can provide a further barrier against water ingress into the tunnel.

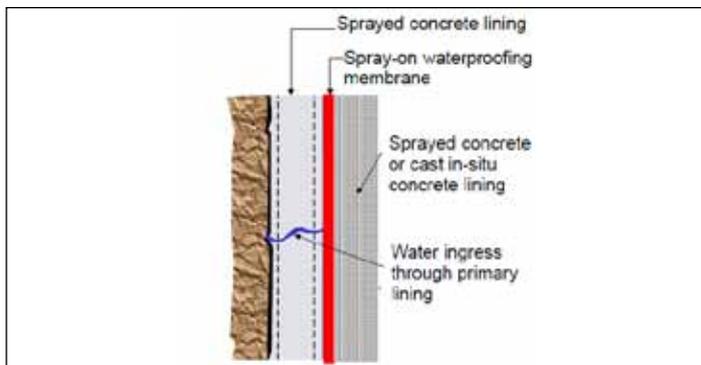


Figure 4: Schematic section of final tunnel concrete lining with spray applied waterproofing membrane between primary and secondary lining.

The membrane should present a minimum thickness according to the supplier's instructions, in order to be watertight. Typically spray-applied membranes can only withstand active water pressure when they are completely cured and normally embedded between two concrete linings.

As shown on Figure 4, in the case of a double bonded spray-applied membrane (the membrane is bonded to both the primary and overlying secondary lining), water has to find a path through three failure zones. Firstly a crack in the primary lining, then a tear in the membrane followed by a second crack in the secondary lining. All of these failure zones need to occur in the same spot as water cannot migrate along the membrane-concrete interface surface.

In the worst case, where defects in all the linings and membrane do align, minor water ingress may migrate through this point into the tunnel. However, since a point of water ingress into the tunnel must correspond directly to the defect in the spray applied membrane and primary lining; it is easy to treat the source locally.

Remedial measures to treat secondary lining water ingress involve the use of standard leak sealing injection techniques, targeted at repairing the defect in the spray applied membrane. This typically involves the following process:

- Leak identification
- Drilling a small diameter hole (approx. 18 to 25mm) in the centre of the source of the damp patch, to a depth that is approx. 50mm into the primary lining
- Install packers and Inject acrylic resin to permanently seal water ingress
- Observe water ingress and repeat injection if necessary
- Remove all packers and repair concrete surface.

4 >> TYPICAL MEMBRANE PROPERTIES

4.1.2. Dealing with water pressure during the construction phase

Quite often during the installation of the tunnel linings, active water pressure is present in the construction phases between the primary lining being completed, the membrane applied and the final step of installing the secondary lining. It is vital the design also considers these “temporary” stages of construction and present guidelines and details to manage any present water ingress.

Current best practice is to address water ingress prior to the application of the spray applied waterproofing membrane. The most common options are:

- Option 1: Fix to the primary lining a strip of dimpled drainage sheet approximately 300 mm wide and lead water ingress to invert for temporary or permanent drainage. The dimpled drainage strip is over coated in regulating sprayed concrete as per normal substrate preparation for spray applied membranes. All surfaces are covered in spray applied membrane and active water ingress is allowed to drain freely to drainage system in tunnel.
- Option 2: Insert packers and attach drainage tubes in area of water ingress. As above option, take drainage tubes to temporary or permanent drainage system in tunnel invert. Spray membrane to all surfaces, remove drainage tubes and inject through packers to seal, or allow drainage to continue in permanent case through tubes.
- Option 3: Spray apply membranes to all surfaces other than the area of ingress, allow membranes to cure fully, inject water sealing resins in area of water ingress, and finally complete spray membrane spraying once area is sealed.

Consideration by the designer must be given to the period of time between completing the spray applied membrane application and installing the secondary lining, particularly if solutions to seal against active water ingress are adopted rather than allowing relief of water pressure. In such cases where active water pressure will act on the membrane, the installation of the spray applied waterproofing membrane and the secondary lining should be carefully sequenced. For solutions allowing relief of water pressure, such as temporary drainage sheets and tubes, then the timing of the secondary lining is less of concern. Finally, the curing characteristics of spray applied membranes may vary from product to product and guidance should be sought from the manufacturers.

4.2. BOND STRENGTH

A distinctive feature of a spray-applied membrane is its bond strength. Membranes with sufficient bond strength provide the lining system with unique mechanical properties and waterproofing features that contribute to the durability of the lining system.

The provision of sufficient bond between the primary lining and the spray applied waterproofing membrane, as per Table 2 “Spray Applied Waterproofing Membrane Properties” in Appendix A (Example Specification), shall prevent delamination of the membrane and the consequent movement of groundwater immediately behind the waterproof membrane.

The bonding characteristic of the membrane, i.e. double-bonded or single-bonded is of fundamental importance in the lining design. While single-bonded membranes usually adhere only to the primary (outer) lining, double-bonded ones adhere equally to both primary and secondary linings.

The minimum specified bond strength of spray applied membranes to both the primary and/or secondary concrete linings and other lining components must be 0.5 MPa or greater.

If the primary concrete lining should be designed for permanent purposes and be integrated in the final tunnel lining, double bonded membranes may be used to enable design optimisations, e.g. reduction of the thickness of the secondary lining.

The watertightness properties attributed to double bond properties are not always facilitated by all spray applied waterproofing membranes. In all cases the designer must evaluate the bonding characteristics of the chosen membrane system both to the substrate, but also to the overlying concrete lining. Should there be limited or no bond to the overlying concrete the membrane will require more detailed inspection to ensure complete coverage, and/or methods to compartmentalise should be considered, such as with the adoption of re-injectable tubes or hydrophilic strips at a standardised frequency along the tunnel.

4.3. TENSILE STRENGTH, ELONGATION AND CRACK BRIDGING

The crack bridging performance of spray applied membranes is a function of their tensile strength and elongation. Currently available spray applied membranes can bridge cracks of at least 2.5 mm. If the designed structure requires greater crack bridging performance, this may be achieved with increasing membrane thickness, but this must be subject to the agreement of the manufacturer.

Double-bonded membrane systems are usually able to bridge over cracks in both primary and secondary concrete linings.

4.4. DURABILITY

The ingredients of most widely available spray applied membranes are based on established chemistries with proven track record.

The manufacturer of all products for the waterproofing works shall provide documentation to demonstrate the products are durable for the given groundwater conditions and anticipated ground contaminations at each site, as specified in the project. Groundwater and ground conditions that may potentially harm the membrane need to be considered. The final product is formulated to be stable chemically and to be resistant to water containing pollutants that make the environment aggressive to the membrane, mostly acidic or alkaline. It should be noted that chemicals with similar compositions, such as other hydrocarbons, may negatively affect the membrane.

4.5. FLAMMABILITY

Despite recommendations that the membrane is covered with secondary lining concrete not long after it is cured to prevent damage, during construction the membrane may be exposed in the tunnel environment for several weeks. It is therefore important that the membrane does not pose a significant risk in the case of fire both during the spraying process and as a cured exposed membrane. This is important in order to ensure safety and health of operatives and tunnel structural safety, and it complies with the specifications of the project (see Appendix A).

5. TRIALS AND TESTING

For many projects it will be necessary to demonstrate the membrane being applied in a site trial. Certificates of Compliance to the ITAttech Example Specification (see Appendix A) shall be provided, together with other requirements requested by the designer.

Based on an in-situ application process to reflect the actual application condition, these trials shall demonstrate the suitability of materials (including equipment, membranes, injections tubes, grouts and fixings) for use in an underground environment. Evidence of compatibility (for example bonding) with the construction of secondary linings shall also be demonstrated.

Any changes in materials or supplier shall require new Certificates of Compliance, which shall also be submitted for acceptance.

Samples shall be taken from the trial area and tested fully in accordance with the Specification and additional designer requirements.

6 >> APPLICATION REQUIREMENTS

The application equipment and skills for different spray applied membranes are quite different, but the following issues are valid for most systems:

- The spraying equipment shall be capable of feeding materials at a regular rate and spraying the product from the nozzle at velocities which promote adherence of the membrane to the surface with minimum rebound and maximum adhesion and coverage.
- The equipment used should be capable of supplying the product components at the required pressures, volumes and ratios recommended by the manufacturer of the waterproofing membrane.
- The Contractor should ensure that all his nominated spraying operatives will have gained certified training in accordance with the ITAttech spray membrane scheme (see Appendix B) prior to any application in the permanent works.
- Regular equipment maintenance and cleanliness are vital to ensure correct membrane applications.
- An approved Quality Audit System is in place before trials and permanent works.

Correct preparation of the surface before membrane application is necessary for achieving a continuous membrane and avoiding material overconsumption.

6.1. MANAGEMENT OF WATER INGRESS

The ease of application of a waterproofing membrane depends upon the level of water ingress through the substrate before membrane application. The following table provides guidance in the preparation that may be required before the installation of a spray-applied membrane.

Level of water ingress	Preparation prior to membrane application
<p>Dry: No moisture is detectable on the inside</p> <p>Substantially dry: such moisture is found that there is no impact on the internal surface; e.g. if a piece of blotting paper or newspaper is placed on a patch, it does not become discoloured as a result of absorbing moisture.</p> <p>Capillary wetting. There may be slightly moist patches but no active running water ingress.</p>	<p>Membrane can be installed directly onto substrate once it is cleaned of loose dust, grease and/or debris. Some membranes require the surface to be dampened before the membrane is applied.</p>
<p>Weak trickling water in isolated spots</p>	<p>Management of active water inflow is required prior to membrane application, including:</p> <ol style="list-style-type: none"> Installation of local drainage strips Sealing of local water inflow using quick setting mortar Local injection Temporary drainage using pipes <p>In drained tunnels, pipes/drainage strips can be incorporated into a long term drainage solution or locked off once the waterproofing membrane has cured.</p>
<p>Trickling/flowing water in isolated spots</p>	<p>Source of water should be channelled or treated prior to membrane installation.</p> <p>Treatment options will be determined by the flow of water.</p> <p>Solutions that prevent water travelling through the substrate (grouting in or behind the lining) may be more effective than quick setting materials on the surface.</p>
<p>Trickling/flowing water in many locations</p>	<p>Extensive management of water ingress, as described above, is usually required prior to membrane application. Careful evaluation of the spray-applied waterproofing approach is required.</p>

Table 1: Substrate preparation before membrane application

6 >> APPLICATION REQUIREMENTS

6.2. SUBSTRATE SURFACE QUALITY AND PREPARATION

Spray applied membranes can accommodate irregularities (changes in section and shape) in the substrate surface, but the surface texture / roughness must be closed, in order to prevent trapped air in the surface matrix from expanding under the membrane, creating pinholes.

There are typically three levels of substrate roughness for application:

- As-sprayed concrete with or without fibres or as excavated rock
- Sprayed smoothing layer or gunite (typically 4 mm aggregates)
- Smooth or float finished

The encountered substrate roughness and quality do influence the time needed for the substrate preparation works, the consumption of material and the speed of application. It is recommended that very rough surfaces are regulated in order to maximise the efficiency of the waterproofing membrane, using a finer aggregate sprayed concrete or specific surface regulating material.

	<p>As-shot sprayed concrete primary lining.</p> <p>Spray applied waterproofing membranes can be sprayed directly onto this surface, but pinholing, membrane thickness and material consumption will be difficult to control.</p>
	<p>Using a regulating / smoothing layer of finer aggregate materials will facilitate installation of a high quality membrane, reduce material consumption, and enable quicker application.</p>
	<p>A completely smooth finish requires additional labour, but will permit the highest level of quality control of membrane application, depending on the requirements of manufacturers.</p>

Table 2: Substrate surface finishes

If a regulating layer is used, a typical thickness of 1 to 3 cm with a maximum aggregate size of 4 mm shall be applied to the primary lining prior to membrane application. It is important to ensure a proper application of the regulating layer (e.g. surface preparation, correct accelerator dosage that allows proper setting time, correct spraying angle, correct air content and pressure), in order to avoid pitting and large craters on the surface, and achieve minimum bonding requirement of 0.5 MPa.

6.3. POTENTIAL CAUSES OF LOCAL FAILURES

Potential causes of local failures with spray membranes include:

- Poor application due to poor workmanship, lack of training, quality control procedures and equipment.
- Damage by construction teams before installation of final linings. For membrane installed in inverts at a protective sprayed or cast concrete layer of similar quality to the final lining is used. The thickness of the protection concrete shall be determined by the designer to meet all anticipated loads. For walls and crowns of tunnels some membrane are applied in two coloured layers that act as a signal coat if damaged (the underlying colour is made visible and easily identified). Unlike sheet membranes, spray membrane are bonded to and therefore supported by the substrate and so are less prone to damage by subsequent construction activities.
- Exceptionally rough primary sprayed concrete lining substrates that cannot be effectively sealed.
- Excessively wet tunnel surfaces without adequate water management (tunnel surface having running water).
- Extended exposure to extreme environmental conditions, such as heat, freezing, UV.

All the above conditions can be prevented by addressing each issue in the Specification and maintaining sufficient quality control. In all cases the spray applied membranes must be QC checked and signed off by all parties prior to secondary lining works as per the Specification requirements.

7 >> QUALITY CONTROL

Quality control is required throughout the membrane application process, and shall include final checking of the membrane to ensure full compliance with project specifications, manufacturer's instructions or recommendations in this guidance document.

7.1. COVERAGE

A visual inspection of the spray applied waterproof membrane should be carried out on every defined application area. Areas in which the substrate is still visible, the sprayed membrane is not suitably opaque or where the spray applied waterproof membrane is damaged, should be marked up with a compatible spray paint and an additional layer of spray applied waterproof membrane shall be applied with a minimum lap of 200 mm on the adjacent membrane, or according to manufacturer's recommendations.

For all spray membrane systems, visual inspection or non-destructive testing assist detection of defective areas. These are simply spray painted and marked on the surface ready for repair (Figure 5).



Figure 5: Quality assurance of sprayed membranes: visual identification of defects

7.2. THICKNESS

The routine testing of spray membrane coverage and thickness must be undertaken, monitored and recorded on site quality inspection check sheets. There are a number of methods normally used to measure spray membrane thickness and are summarised below:

- The most effective and useful guide during application is for the team to take wet film thickness measurements using a simple depth gauge as shown in Figure 6. Measurement should be carried out at the frequencies required by the specification or manufacturer. For each test the thickness and location of the test are recorded on a Quality Control Sheet. Under-thicknesses can be remedied immediately or later.



Figure 6: Thickness control: wet film thickness testing

- Thickness by measuring quantities in trials. The applied thickness can be assessed by measuring the quantity of spray membrane used for the area over which it has been applied. A simple calculation gives the average thickness of the membrane in the applied area. Under consumption will indicate the need for an additional coat.
- Two coat application. Applying the membrane in two coats can offer better control of thickness and coverage than a single thick layer (Figure 7). This is often adopted with the reactive membrane systems and is even further improved with different colour 1st and 2nd coats to assist the nozzleman.



Figure 7: Two colour application of waterproofing membrane (1st coat orange, 2nd coat white)



Figure 8: Optional method with cut-out inspection patches to establish the applied membrane thickness

- Cut-out inspection patches, typically 50x50mm, are an optional method to establish the applied membrane thickness. These patch tests should be taken randomly from all sections of the tunnel profile, and the patches are easily repaired by over-spraying.

7.3. BOND TO SUBSTRATE

The bond strength of the membrane to the substrate should be 0.5 MPa or greater within 28 days to maintain the integral bond to eliminate water paths between membrane and sprayed concrete. Depending on the product selected, during membrane curing and development of the bonding strength temporary drainage measures may be required to drain any water inflow and to avoid build-up of water pressure, which would retard the curing process of the membrane and lead to water



Figure 9: Tensile bond test of horizontal substrate with elcometer. Dolly before and after testing (on the right)

paths in the interface between membrane and substrate.

Testing should be in accordance with the example specification in Appendix A. The bond should have reached a sufficient value to permit the safe application of the secondary sprayed concrete without risk of material delamination, in accordance with the manufacturer's recommendation.

7.4. INTEGRITY TESTING

Holiday Detection, also known as Continuity Verification and Spark Testing, is a test procedure that enables the detection and repair of pinholes, voids and other defects in membranes and coatings. Such defects are often termed as holidays or discontinuities.



Figure 10 : Example of integrity testing to detect and repair pinholes, voids and other defects in membranes

The test method is non-destructive, i.e. the material under test is not damaged by the test, and is effective on non-conductive materials, where the membrane or coating of sufficient dielectric strength acts as an insulator. The test requires a high voltage DC power source, to one terminal of which is attached an exploring wire connected typically to a copper wire brush, and to the other terminal a return wire fixed to a sound ground point in the concrete substrate. The voltage is set according to the thickness of the coating, such that if a full depth coating defect is located in the membrane a spark from the will pass through the air gap/defect, forming a circuit and triggering a visual and audible alarm. When testing the installed material the wire brush/conductive strip is passed across 100% of the surface under test; any defects identified are then immediately marked up and the indicated area locally repaired by hand with the same membrane system. The membrane in that area is then re-tested, and when it is found to be defect free is signed off.

8.1. LINING CONFIGURATIONS

Typical tunnel lining configurations include double-shell lining (DSL), single shell lining (SSL) and composite shell lining (CSL), as shown on Figure .

Sprayed concrete single shell linings (SSL) have been built for decades, e.g. for the construction of water tunnels, caverns, and transportation tunnels. It is a permanent sprayed concrete lining consisting of a single layer or several layers placed at different times, without a waterproofing membrane. The main design issues of SSL are related to the structural interaction between primary (outer) lining and secondary (inner) lining, which are usually built at different times and thus submitted to different stresses and strains, as well as to watertightness of the sprayed concrete lining.

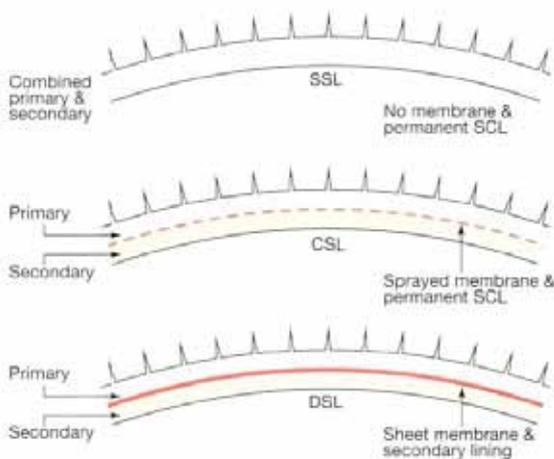


Figure11: Typical tunnel lining configurations (Thomas, 2009)

Traditionally, the lining of tunnels and other underground structures excavated by conventional methods has been designed and built based on the double-shell lining (DSL) approach. According to this approach, initially a temporary (and low quality) sprayed concrete lining is constructed to stabilise the opening after excavation and to contain only short to medium-term loads (primary lining). Later on a permanent cast in situ concrete lining is installed to contain long-term loads, and attend the requirements of serviceability and durability (secondary lining). Watertightness is achieved by the installation of a waterproof sheet membrane between primary and secondary linings, which acts additionally as a separation / sliding layer, reducing the potential of shrinkage cracking on the secondary lining. Under some project conditions, e.g. deep tunnels with anticipated high water pressure and required fully drained conditions, the DSL approach is the only possible approach to build the underground structure.

During the last two decades, significant progress was made in concrete technology (mix-design), with advanced admixtures (e.g. water reduction, alkali-free accelerators), as well as in the application of sprayed concrete, with sophisticated spraying robots, and in waterproofing of tunnel linings (spray applied membranes). All these factors have enabled designers to use sprayed concrete linings increasingly for long term service life.

8.2. THE COMPOSITE SHELL LINING SYSTEM

Composite shell lining (CSL) systems are based on the single shell lining approach and consist of two concrete linings, which are usually installed at different stages, with a double-bonded spray-applied waterproofing membrane embedded between them. The secondary (inner) lining may consist of sprayed concrete (often fibre reinforced) or cast in-situ concrete. Both concrete and waterproofing membrane are vital functional parts of this system. The following picture shows schematically an example of a composite shell lining with an embedded double-bonded spray-applied waterproofing membrane between primary and secondary linings.

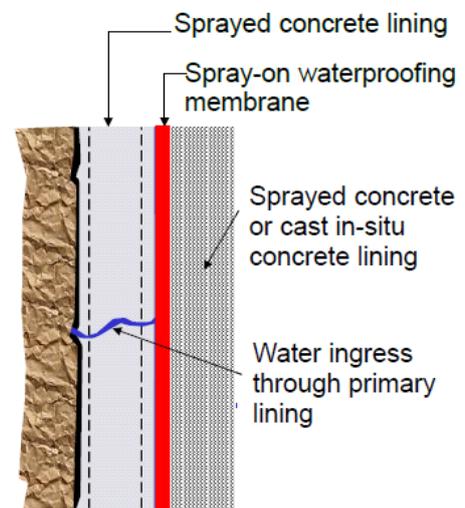


Figure 12: Example of a composite shell lining with a double-bonded spray-applied waterproofing membrane

After application the membrane adheres to the primary lining and starts developing its bonding strength and curing. When curing of the membrane has finished, a secondary concrete lining (sprayed or cast insitu concrete) or a protective concrete layer can be installed against the membrane.

After installation of the secondary lining / protective layer onto the cured membrane, bonding between the two layers develops and provides additional safety to the composite lining system.

8.2.1. The principle of composite action

The principle of composite action can be demonstrated by comparing the action of two joists placed one on top of the other. If these are simply placed one on top of the other and loaded as a beam there will be some relative movement between the two. However, if these are physically connected, the bending strength and stiffness are significantly improved as the two will act together as a single unit with double the thickness.

8.2.2. Improvement in performance

Primary and secondary linings installed without a waterproofing membrane are often thought as acting as a single shell thanks to the influences of geometry, bond and shear connection through surface roughness. In many cases however, this solution does not offer a suitable watertightness in the long term. Spray applied waterproofing membranes allow the benefits of both options by connecting the primary concrete lining to the secondary concrete lining by means of a fully bonded (double-bonded) membrane that can transfer some of the shear forces, allowing the linings to work together. Aside from the obvious waterproofing advantages the fully bonded membrane is also structurally advantageous.

Testing at SINTEF Material Laboratory, Norway has suggested that energy absorption post-initial cracking has increased in the case of a composite lining made of fibre reinforced sprayed concrete, with a sprayed membrane in-between two layers, subjected to central loading in comparison to the same concrete sample without membrane.

If the primary lining is designed for permanent purposes, and suitable load transfer through the spray applied membrane to the secondary lining occurs, designers have the opportunity to significantly reduce the lining thickness in comparison to the assumption that the whole final load is acting on the secondary lining only.

Research at the University of Southampton (Su, Bloodworth & Haig, 2013) is exploring the influence of membrane thickness and interface conditions on the degree of transfer between the primary and secondary linings through the membrane. Such data can give further confidence in the degree of composite action allowable in the design as well as provide input parameters for numerical modelling.

8.2.3. Typical failure mode

The adhesive tensile strength of the membrane is a significant parameter for the creation of an effective bond. It should be high enough to prevent membrane delamination and to avoid migration of water in the interface between membrane and concrete lining as described in Section 4.1.1.

The following types of tensile failure can occur within the composite shell lining, depending on the part of the bonded lining system which fails under stress:

- Tensile failure due to cohesion break in the concrete
- Tensile failure due to adhesion break between concrete and membrane
- Tensile failure due to cohesion break within the membrane layer

In the design of composite lining systems the shear stress in the joint concrete-membrane must be limited to the admissible shear stress according to Design Standards, to avoid any tensile failure, as it is usually required for the design of single shell linings with two distinct sprayed concrete linings.

8.2.4. Waterproofing approaches

CSL can usually be designed as a undrained (fully tanked) structure against limited water pressure or as a systematically or locally drained structure (see also chapter 3), depending on the requirements of the project.

8.2.5. Introduction to numerical modelling of CSL systems

The composite lining must be able to withstand all potential loading conditions from the ground, ground water and surface loads throughout the design life of the tunnel. The lining structure should be watertight, durable, as well as capable of accommodating the loads of internal structures such as lighting canopies and ventilation fans and have a surface finish to achieve the required reflectance and aesthetic appearance.

To achieve composite behaviour and guarantee the structural effectiveness of the system, a bond needs to be achieved between the concrete layers and the sprayed membrane to permit the transfer of normal and shear forces between the primary and secondary layers.

The bond strength required at the interface between the primary and secondary lining to permit the composite action must be evaluated for each project. The prevailing load conditions must be considered before coming to a judgment on whether or not a composite lining solution is achievable.

The properties of the interfaces between the concrete and the waterproofing membrane are required for numerical simulation of the structural CSL. These properties are usually taken from back-analysis of shear test data. Shear test curves can be replaced with curves derived from numeric simulations of the shear tests.

Typical interface parameters used in numerical models are the angle of interface friction, the interface cohesion, as well as the Interface shear and normal stiffness.

The exact parameters for the interface elements may vary depending on the theory implemented in each numerical modelling program. Therefore, it is recommended that the input parameters for the model are derived by first back-analysing test data and calibrating the numerical model.

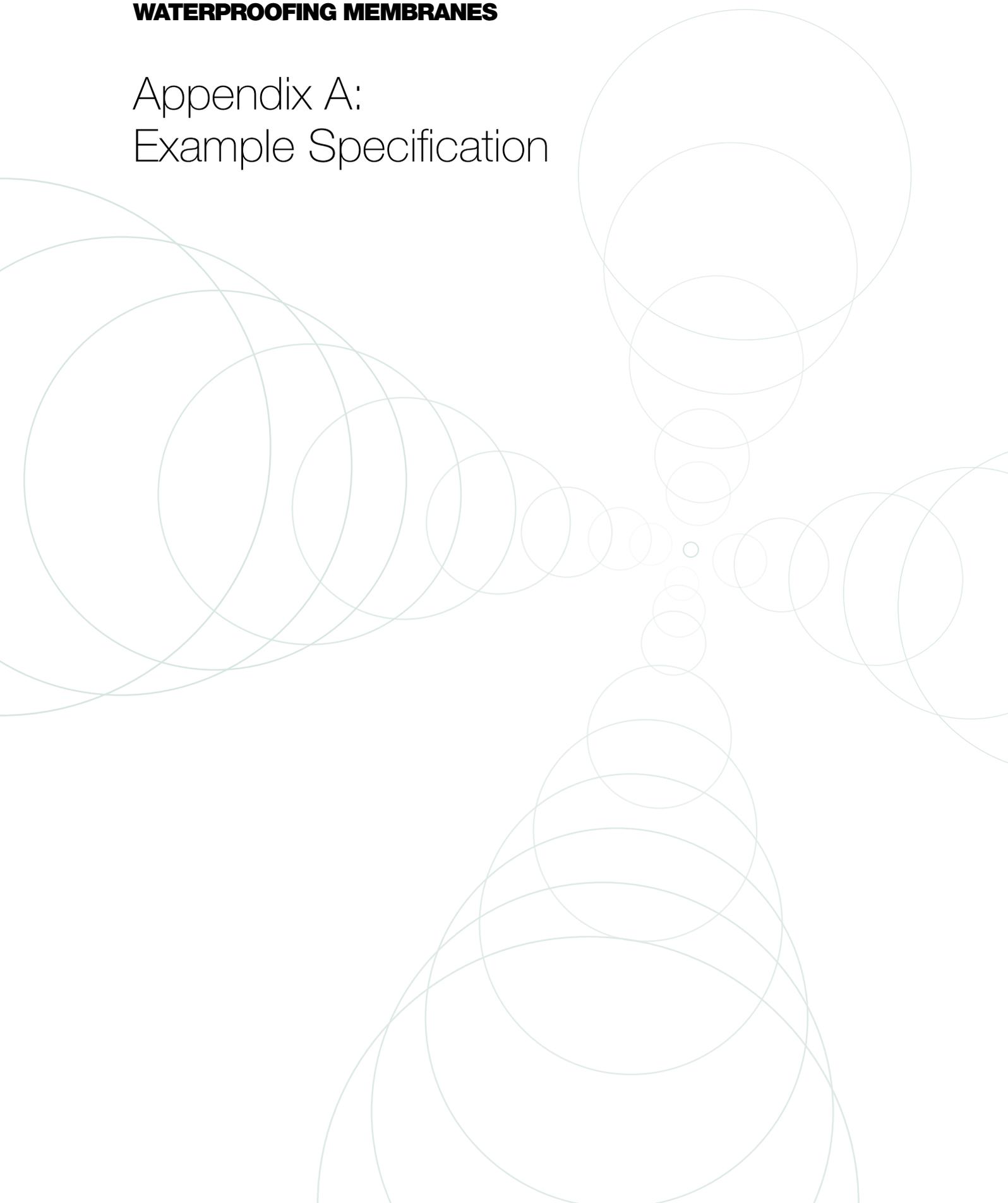
Holter, K. G., & Nermoen, B. (2011). Permanent Waterproof Tunnel Lining Based on Sprayed Concrete and Spray-Applied Double- Bonded Membrane. Proceeding of the World Tunnel Congress 2011, Underground Space in the Service of a Sustainable Society (pp. 330-340). Helsinki: ITA-AITES.

Su, J., Bloodworth, A. & Haig, B. (2013). Experimental Investigation into the Interface Properties of Composite Concrete Lined Structures. Proceedings of the World Tunnelling Congress 2013. Geneva: ITAAITES.

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**ITAtch DESIGN GUIDANCE FOR SPRAY APPLIED
WATERPROOFING MEMBRANES**

Appendix A:
Example Specification



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1 >> PERFORMANCE REQUIREMENTS ON WATERPROOFING

(1) The tunnels shall incorporate a waterproof membrane in order to achieve the waterproofing class as defined in Table 1 below:

Waterproofing Class	Definition for impermeability on the inner soffit	Characteristic of the waterproofed inner soffit General
1	Completely dry	The inner soffit shall not show any moisture areas. Acceptable amount of water in the tunnel: no water.
2	Largely dry	On the inner soffit, weak moisture penetration shall only appear on max. 10% of each section surface (visible as a dark colour change on the concrete surface). On dry hands contacting weak moisture areas no evident marks of water shall be visible afterwards. Disposed blotting paper or absorbent newsprint shall not change in colour due to moisture absorption. Acceptable amount of water in the tunnel: any quantity less than the acceptable amount of waterproofing class 3.
3	Slightly wet	On the inner soffit, weak moisture penetration shall only appear on max. 10% of each structure's section surface (visible as a dark colour change on the concrete surface). Acceptable amount of water in the tunnel: general 0.02 litre/m ² /d, for less than 50 m of tunnel length 0.1 litre/m ² /d.

Table 1: Water- tightness Classes (Based On Ril853)

- (2) The waterproofing system used shall be suitable for the Works and the local conditions of ground and groundwater. Any expected movement of the structural elements caused by shrinkage, temperature changes and settlements, should not result in the waterproofing system losing its waterproofing properties.
- (3) All the materials to be used for waterproofing shall be compatible with each other, as well as with any bordering materials such as concrete. Any harmful chemical influences shall be prevented.

2 >> MEMBRANE PROPERTIES AND TESTING STANDARDS

- (1) The spray applied waterproofing membrane product shall be demonstrated to conform to the properties identified in.
- (2) Table 2 based on laboratory based samples and standard preparation techniques. Independent test certificates to demonstrate conformity shall be submitted.
- (3) The designer should assess the environmental conditions of the project and define additional relevant test methods and requirements.
- (4) Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)

Property	Test Method	Minimum Requirement
Bond to substrate	ASTM 1583/C 1583M (Pull-off Method) or EN ISO 4624 (but using a 50mm dolly) or EN 1542	0.5 MPa within 28 days after membrane application
Double bond (to substrate and inner lining). Only in the case of double-bonded membranes.	ASTM 1583/C 1583M (Pull-off Method)	0.5 MPa within 28 days after application of final concrete layer
Watertightness	Based on EN 12390-8, with adaptation for inclusion of a spray applied membrane (see Figure 1 below and Appendix A-2 of this document); Based on EN 14891, Part A7, for the concrete mix design	Zero penetration of water through the membrane
Crack Bridging	EN 1062-7 Method A: C1 Static Tensile Test - Measured at 20°C	Class A5 Min. 2.5 mm
Flammability	EN ISO 11925-2	Class E, as defined in EN 13501-2+A1
Chemical resistance	According to EN 14414, Method A (acid solutions) and Method B (alkali solutions). Resistance against chloride (at 10% chloride concentration). Testing based on EN 14414 Method A or B shall be according to the groundwater chemistry of the project as specified by the designer.	a) There shall be no visual sign of degradation; b) Comparison of the tensile properties (tensile strength and elongation at break) of the tested specimen with those of a control sample. The acceptance criteria shall be a maximum change of 25% compared to the control sample tensile strength and elongation at break of the membrane.
Resistance to leaching	According to EN 14415, in hot water (Method A), and aqueous alkaline liquids (Method B).	a) There shall be no visual sign of degradation; b) Comparison of the tensile properties (tensile strength and elongation at break) of the tested specimen with those of a control sample. The acceptance criteria shall be a maximum change of 25% compared to the control sample tensile strength and elongation at break of the membrane. c) The loss in mass of the sample shall not be greater than 5 % compared to the control sample.

Table 2: Essential properties of the spray applied waterproofing membrane

2 >> MEMBRANE PROPERTIES AND TESTING STANDARDS

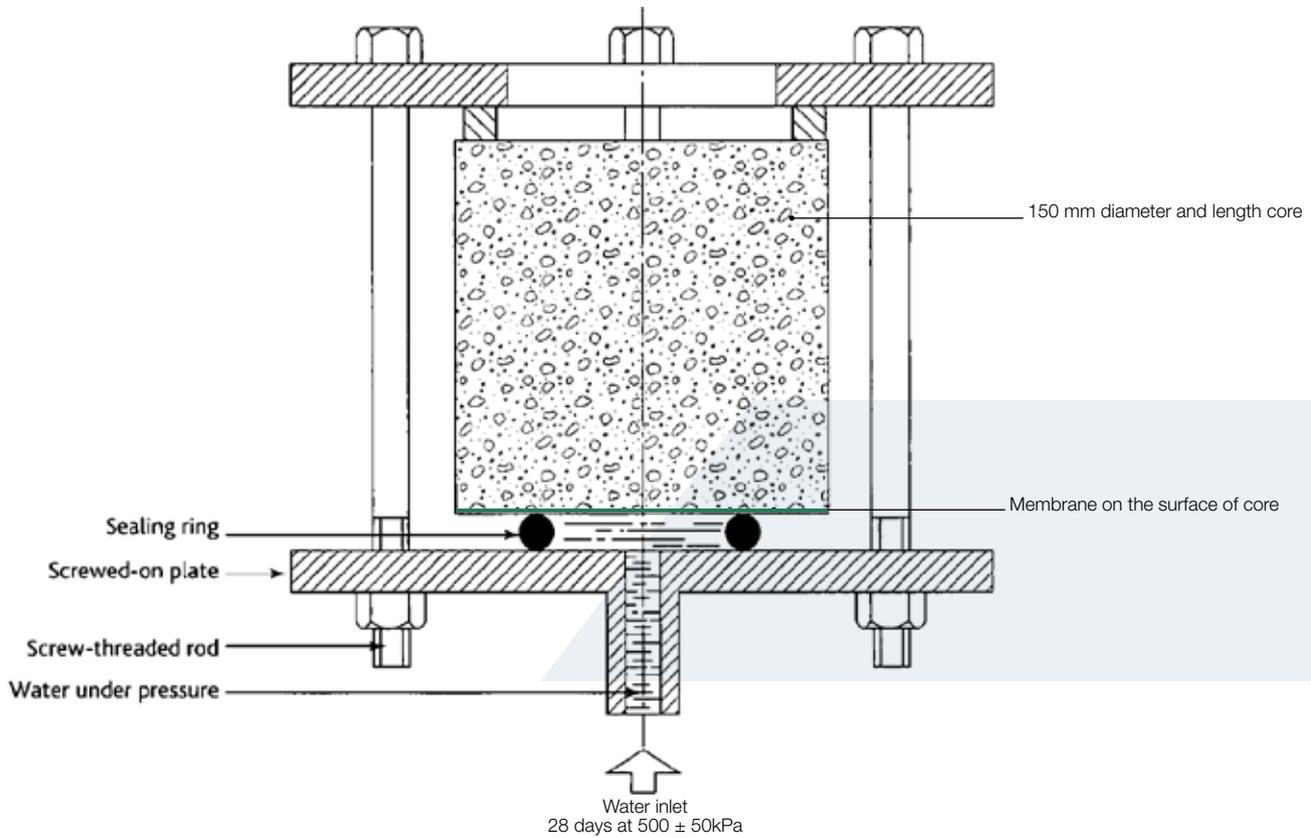


Figure 1: EN 12390-8 test method altered for inclusion of a spray applied waterproofing membrane

- (5) All material suppliers shall have certification to show compliance with ISO 9001 and provide the certificate of the FPC (Factory production control) of the product.
- (6) Materials shall not contain either substances classified as carcinogens, mutagens or teratogens (substances toxic to reproduction) or substances classified as respiratory hazards in accordance with local or national regulations.
- (7) All waterproofing system components shall be designed for the minimum design life of the structure.

3 >> PRE-SELECTION TRIAL

- (1) A pre-construction trial may be required for the proposed membrane system.
- (2) The Contractor shall submit for acceptance prior to the trial a method statement and quality plan. These documents shall be prepared in conjunction with the applicator and endorsed by the manufacturer of the material, describing the details of the waterproofing works including protective measures, at all stages. As part of the trial the Contractor shall demonstrate the temporary water management techniques they wish to adopt. If, during trials, adjustments to these documents must be made, these shall be submitted for acceptance before commencement of the full waterproofing works.
- (3) During trials, the Contractor shall demonstrate compliance with material requirements and testing criteria outlined in this Specification. This should be done with the minimum thickness of membrane to be accepted.
- (4) The trial shall, where possible, be representative of the conditions to be encountered during the full project installation. The spray applied waterproofing membrane product shall be demonstrated to conform to the performance properties shown in Table 2. If a real tunnel substrate is not available, tested sections shall be taken from test panels, at least 1000 mm by 1000 mm, by 150 mm thickness (to allow water penetration cores to be taken)
- (5) The trial shall be used by the Contractor to demonstrate the suitability of the materials, equipment and construction methodology and the competence of operatives. As a minimum the trial shall include the following items:
 - Installation of water management techniques,
 - Application of smoothing or regulating layer (if required),
 - Application (including equipment and skills of the application team) of the spray applied membrane and bond to the substrate,
 - Quality control systems and testing methodologies for ensuring coverage and thickness, including the required testing regime,
 - Demonstration of the methods used to test the in-situ membrane to ensure that complete water tightness has been achieved prior to the secondary lining be installed
 - Repair techniques for any defects detected in the spray applied waterproofing membrane,
 - Demonstration that a sprayed concrete lining can be applied inside the fully cured spray applied waterproofing membrane (including the main tunnel crown) with no observed instability, such as sagging or sprayed concrete fallout.
 - Demonstration of repair techniques applied when a leakage is detected after installation of the secondary lining.
 - Demonstration of how an overlap joint is prepared and installed.
 - Demonstrate how to apply the membrane in zones with construction joints
 - Demonstrate double-bonded test method in table 3 for composite shell linings.
- (6) The trial shall be subject to an approvals process and additional waterproofing and secondary lining works may not proceed until both the Contractor and Project Manager are satisfied and the Project Manager has accepted all aspects of the trial.

4 >> APPLICATION REQUIREMENTS

- (1) All waterproofing membranes shall be installed and tested in accordance with the manufacturer's instructions or recommendations as described in the method statement and materials shall be mixed in accordance with the manufacturer's instructions, using recommended equipment.
- (2) Testing shall be undertaken as necessary to ensure satisfactory functioning of the membrane at each stage of the installation.
- (3) Defective waterproofing membranes shall be repaired in accordance with the manufacturer's instructions or replaced.
- (4) All waterproofing applicators will have undergone application training determined by the manufacturer of the membrane and be experienced and certified (by the manufacturer) in the installation and testing of the waterproofing system.

4.1. MANAGEMENT OF WATER INGRESS

- (1) Where water ingress through the primary lining is such that it may affect the successful installation of the spray applied waterproofing membrane, the Contractor shall use water management techniques. This water management shall be maintained throughout the membrane placing process, and shall be so arranged that water pressure behind the membrane cannot develop during construction of the tunnel secondary lining.
- (2) Temporary drainage (e.g. dimple sheet stripes, drainage channels) shall have sufficient capacity for the encountered inflow of water, they should be resistant to damage from spraying and they should be flexible to achieve a close fit to the surface.
- (3) In case of using dimple sheets, they shall be a minimum of 500 mm in width and shall have dimples or surface relief features such that water is directed along the strip to a collection point. Drainage strips shall be adequately fixed by a method proposed by the contractor, for example, via shot fired nails, with rubber (e.g. self-sealing) washers/collars, on either side at minimum 250 mm centres.
- (4) Where leak remediation measures are to be through grouting, the methodology shall be submitted for acceptance prior to the application in the works. Supporting documentation and evidence shall include:

Grout plan procedure and sample of grouting materials including data sheets and evidence of performance in similar conditions.

On-site demonstration of injection pressure. The structural capacity of the structure shall not be exceeded.

4.2. PREPARATION OF SUBSTRATE, ROUGHNESS AND SURFACE FEATURES

- (1) The final requirements for the surface that will receive the waterproofing system shall be in accordance with the guidance given by the supplier of the sprayed membrane.
- (2) Where the required surface finish cannot be achieved with the primary sprayed concrete layer, a finer aggregate sprayed concrete layer shall be applied to regulate the substrate.
- (3) No further waterproofing application stages shall be carried out until the surface finish standard to be achieved has been agreed as satisfactory to the waterproofing supplier and Contractor.
- (4) The substrate shall be suitably dry for the 24 hours prior to membrane application.
- (5) Bars used for the purpose of providing support to secondary lining reinforcement shall be drilled and inserted prior to the application of the waterproofing membrane. The bars shall be cleaned so as to allow adequate bond with the spray applied waterproofing membrane.
- (6) Pull-off tests to verify if substrate surface strength is sufficient to comply with membrane bonding requirements (see table 3).

4.3. SUBSTRATE CLEANLINESS

- (1) Before applying the spray applied waterproofing membrane, the sprayed concrete surface shall be thoroughly cleaned and pre-wetted (as required by membrane manufacturer) using compressed air and/or water (without oil contamination) in accordance with guidance given by the membrane supplier.
- (2) High pressure water and/or air cleaning should be used in the case that the substrate has surface contaminations of old soot, soil, debris, dust, oil, grease, loose particles hardened dust, deteriorated concrete or any remains of an external surface curing agent.

4 >> APPLICATION REQUIREMENTS

4.4. TUNNEL CONDITIONS DURING APPLICATION OF MEMBRANE

- (1) The substrate temperature during application should be between +5°C and +40°C.
- (2) Ventilation shall be as required by the manufacturer and all local/national regulations.
- (3) When installing the spray applied waterproofing membrane, no other works shall be carried out in the vicinity which may cause personnel or equipment to come into contact with the spray applied waterproofing membrane before it has cured. If it is likely that excessive dust may be generated in the vicinity of the works (vehicle movements etc.) then dust suppression measures shall be put in place until the membrane has cured.
- (4) Lighting shall be sufficient to allow efficient installation and inspection of the spray applied waterproofing membrane.
- (5) If the application of the spray applied waterproofing membrane products present fire, occupational health and/or environment related hazards, notably in respect to the confined space environment, then measures shall be identified and put in place to control these hazards. Appropriate measures shall include, but not be limited to:
 - Ventilation requirements and air quality monitoring
 - Fire detection and suppression
 - Personal Protective Equipment
 - Exclusion zones
 - Eye wash and first aid facilities.

4.5. DEFECTS AND REPAIR OF LOCAL MEMBRANE

- (1) Areas in which the substrate is still visible, or where the spray applied waterproofing membrane's integrity is impaired, shall be marked up, e.g. with surveyor paint, and an additional layer of spray applied waterproofing membrane applied with a minimum lap according to manufacturer's recommendations around the area.
- (2) If, after repairs, any section of spray applied waterproof membrane still does not meet specified requirements it shall be removed and replaced. The cause of the problem shall be identified and remedial action taken before placing any further spray applied waterproofing membrane.
- (3) Adjacent sections of spray applied waterproofing membrane shall overlap by a minimum as defined by the manufacturer. Spray applied waterproofing membrane shall only overlap an existing section of membrane if the surface is clean of dust and contaminants.

5 >> QUALITY CONTROL

5.1. QUALITY CONTROL TESTING DURING CONSTRUCTION

- (1) The spray applied waterproofing membrane shall be tested in accordance with Table 3 below throughout the application process with the results recorded and monitored.
- (2) All defects and variations from the requirements as identified by the testing methods in Table 3 shall be repaired and retested.

Parameter	Test Method	Frequency	Pass/Fail Criteria
Quality of substrate	According to supplier's instructions and design of concrete	All surfaces	According to chapter 4.2 and 4.3
Quality of substrate (strength of surface)	EN ISO 4624	Every 500 m ² or as required by the manufacturer	Min. 0.5 MPa
Coverage/Continuity	Visual	A visual inspection to be carried out continuously while the membrane is applied and following application.	Full coverage
Coverage /Continuity	In-situ post application non-destructive test as identified by manufacturer (if available); e.g. Holiday testing with methacrylate membranes (ASTM D 4787)	All surfaces	No holes identified
Thickness	Wet film thickness by means of depth gauge	Minimum 10 tests per 100m ² (evenly spread across the full area, not localised)	Minimum thickness as per manufacturer's recommendations and design requirements achieved in all tests.
	Application quantity measurement	Per day	Minimum kg/m ² to match quantity identified during trials to achieve thickness as required
	Cured thickness 50 mm by 50 mm patches	On request of the Project Manager	The average of five spot measurements shall not be less than the specified dry film thickness. No single spot measurement shall be less than 90% of the specified dry film thickness.
Bond to substrate (for single bonded membranes)	ASTM D7234 Pull-off adhesion strength of coatings on concrete using portable pull-off adhesion testers	Min. 3 tests per day	Min. 0.5 MPa within 28 days after membrane application according to supplier's recommendations
Double bond (to substrate and inner lining). Mandatory for composite shell linings (with double-bonded membrane).	Based on ASTM D7234, Pull-off adhesion strength of coatings on concrete using portable pull-off adhesion testers, considering additional adhesive failure modes due to the secondary (inner) concrete lining.	Preliminary tests with min. 5 samples from each trial area at the project beginning. On request of the Project Manager from then on.	Min. 0.5 MPa 28 days after application of final concrete layer

Table 3: Construction Testing for spray applied waterproofing membranes

5.2. SUPERVISION

- (1) Dedicated waterproofing supervision (independent of the applicator) with suitable experience of and training (with certification from the manufacturer) in the installation of similar systems shall be present on site for all periods of waterproofing application.

5.3. RECORDS

- (1) The Contractor shall keep records, during both the pre-construction trials and the main works, of the following items on a standardised approved check-sheet, as per examples included in this specification (see Appendix A-1 for quality records):
 - The inspection of the substrate prior to installing the waterproofing membrane.
 - The location of any water management measures which are undertaken, such as drainage strips and injection tubes, their terminal units and expansion sealant.
 - All quality control tests, identifying the section of work to which they relate.
 - Records of any repairs and retesting carried out.
 - The inspection and testing of the waterproofing membrane, prior to installation of the secondary lining.
 - The delivery tickets for each consignment of each material as retained by the Contractor.

6. SECONDARY CONCRETE LININGS

- (1) Secondary concrete linings which are installed against the spray applied waterproofing membrane layer shall be installed in such a way that there is no damage to the integrity of the spray applied waterproofing membrane.
- (2) The secondary concrete lining shall be installed as soon as possible following a period of time (as identified in Manufacturer's Information and detailed in the method statement) that allows complete curing of the spray applied waterproofing membrane. The spray applied waterproofing membrane shall not be without a secondary concrete lining for a period of time that results in a build-up of water pressure behind the membrane.
- (3) Installation of secondary lining reinforcement shall where practical negate the need for protrusions or penetrations of the waterproofing membrane. The contractor shall demonstrate his proposed methodology for reinforcement installation.
- (4) Starter bars, where used, shall have been encapsulated by spray applied waterproofing membrane, as specified by the membrane manufacturer, prior to installation of secondary concrete layers.
- (5) Concreting and other tunnelling activities associated with the secondary lining works shall not result in contamination of the waterproofing works. Where required, protection shall be provided to the spray applied waterproofing membrane when adjacent sections of concrete lining installation are underway.
- (6) If a break of greater than 24 hours is anticipated, any un-compacted concrete overspray that has adhered to the membrane shall be cleaned off before curing: leaving a clean surface of membrane to receive the secondary lining.
- (7) Curing compounds/agents (such as acrylics or waxes) applied to the secondary lining shall not come into contact with the spray applied waterproofing membrane.
- (8) Before a section of secondary lining is installed the waterproofing membrane shall be checked for defects by a suitable and proven non-destructive test method. Installation of the secondary lining cannot take place until the area is signed off by the independent waterproofing supervisor; two days prior concreting works is recommended.

7 >> REFERENCES AND STANDARDS

- ASTM International. (2004). ASTM C1583/C 1583M
Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull- off Method). USA: ASTM International.
- ASTM International. (2008, June). ASTM D 4787
Standard Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates. USA: ASTM International.
- ASTM International. (2012, July). ASTM D7234
Standard Test Method for Pull- Off Adhesion Strength of Coatings on Concrete using Portable Pull- Off Adhesion Testers. USA: ASTM International.
- European Committee for Standardization (CEN). (1999, April). European Standard EN 1542
Products and systems for the protection and repair of concrete structures. Test methods - Measurement of bond strength by pull- off. Belgium: CEN.
- European Committee for Standardization (CEN). (2003, May). European Standard EN ISO 4624
Paints, varnishes and plastics. Pull- off test for adhesion. Belgium: CEN.
- European Committee for Standardization (CEN). (2004, May). European Standard EN 1062- 7
Paints and varnishes - Coating materials and coating systems for exterior masonry and concrete - Part 7: Determination of crack bridging properties. Belgium: CEN.
- European Committee for Standardization (CEN). (2004, May). European Standard EN 14414
Geosynthetics - Screening test method for determining chemical resistance for landfill applications. Belgium: CEN.
- European Committee for Standardization (CEN). (2004, May). European Standard EN 14415
Geosynthetic barriers - Test method for determining the resistance to leaching. Belgium: CEN.
- European Committee for Standardization (CEN). (2009, February). European Standard EN 12390- 8 EN
Testing hardened concrete - Part 8: Depth of penetration of water under pressure. Belgium: CEN.
- European Committee for Standardization (CEN). (2009, September). European Standard EN 13501- 2+A1
Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services. Belgium: CEN.
- European Committee for Standardization (CEN). (2010, November). European Standard EN ISO 11925- 2
Reaction to fire tests - Ignitability of products subjected to direct impingement of flame - Part 2: Single- flame source test. Belgium: CEN.
- ISO. (2008). International Standard ISO 9001
Quality management systems — Requirements. Switzerland: ISO.

APPENDIX A-1 >> EXAMPLE QUALITY CONTROL CHECK SHEET

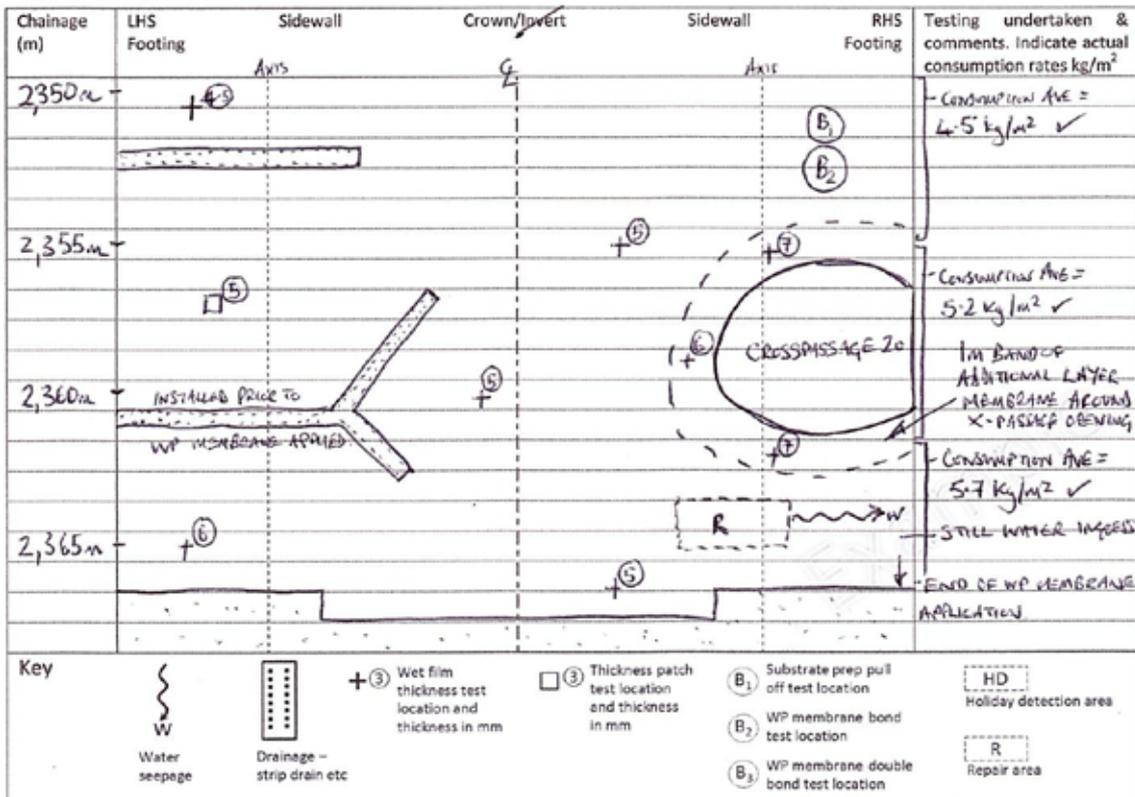
Spray Applied Waterproofing Membrane – Quality Control Check Sheet



Project: Metrosub 10, UK

Tunnel/Structure	SOUTHBOUND RUNNING TUNNEL		Date/Time	10/01/12 14:30	
Regulating Layer	<input type="checkbox"/>	Required thickness		Shift/Team	SHIFT B
Waterproofing membrane	<input checked="" type="checkbox"/>	Required thickness	4 mm	Approved Applicator Name	A. N. O'THER
		Req'd consump' rate	4 kg/m ²	Certificate No.	98765
Secondary lining	<input type="checkbox"/>	Required thickness		Ambient Temp.	17°C
				Substrate Temp.	15°C
				Rel. Humidity %	75%

Plan of structure



Inspection & Approvals

<input checked="" type="checkbox"/>	Regulating layer approved
<input checked="" type="checkbox"/>	Spray wp membrane approved CH 2350 to CH 2363m
<input type="checkbox"/>	Secondary lining approved
<input checked="" type="checkbox"/>	Section not approved CH 2363 - CH 2367m
Re-inspection date/time: 11/01/12 @ 14:00	

Representative	Name	Signature	Date	Time
Contractor Representative	T. EYBLEN		10/01/12	14:30
Supervisor Representative	R. KOMMIS		10/01/12	14:38
Client Representative	B. GINH		10/01/12	14:40
Details of re-work to permit approval: WATER INGRESS AT CH 2364 NEEDS ADDRESSING.				

APPENDIX A-2 >> ALTERED PROCEDURE FOR THE WATERTIGHTNESS TEST

SAMPLE PREPARATION:

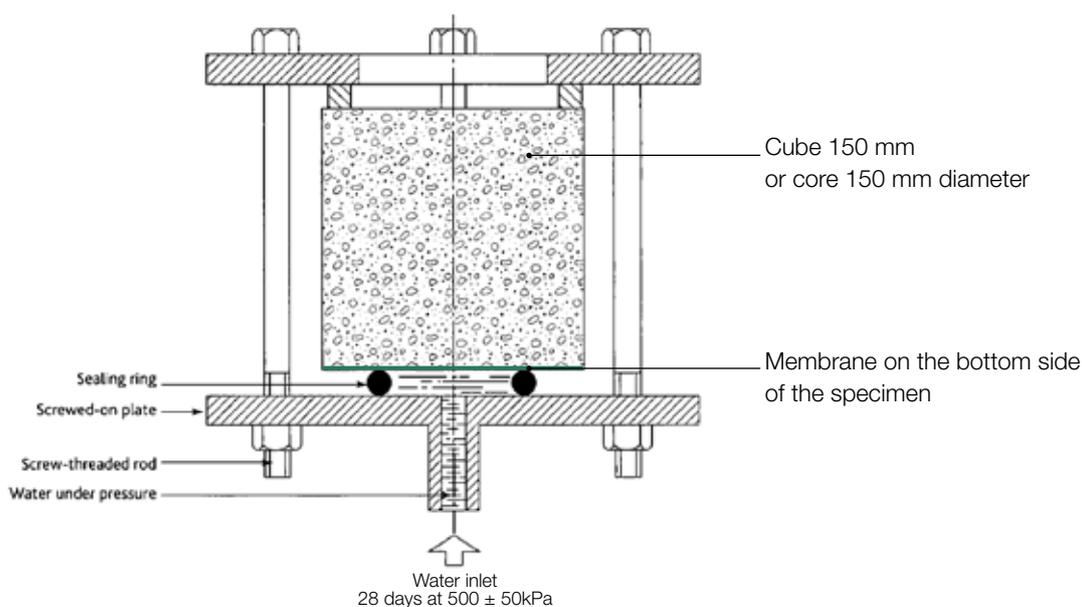
- Specimens according to EN 12390-8 in terms of shape, dimensions, curing and storage produced of porous concrete
- Concrete mix design according to EN 14891 - A7 (water – cement ratio ≥ 1.0 ; max. grain size 16 mm)
- Surface preparation of one of the previously moulded faces according to EN 12390-8. Alternatively the specimen surface can be grinded flat prior to the membrane application.
- 3 specimens shall be prepared and tested in parallel.

MEMBRANE APPLICATION:

- The concrete substrate surface shall be clean and comply with the supplier's requirements.
- The membrane material shall be applied according to the supplier's instructions in order to achieve required membrane thickness.
- The membrane material shall be cured according to the membrane supplier's instructions.

TEST PROCEDURE:

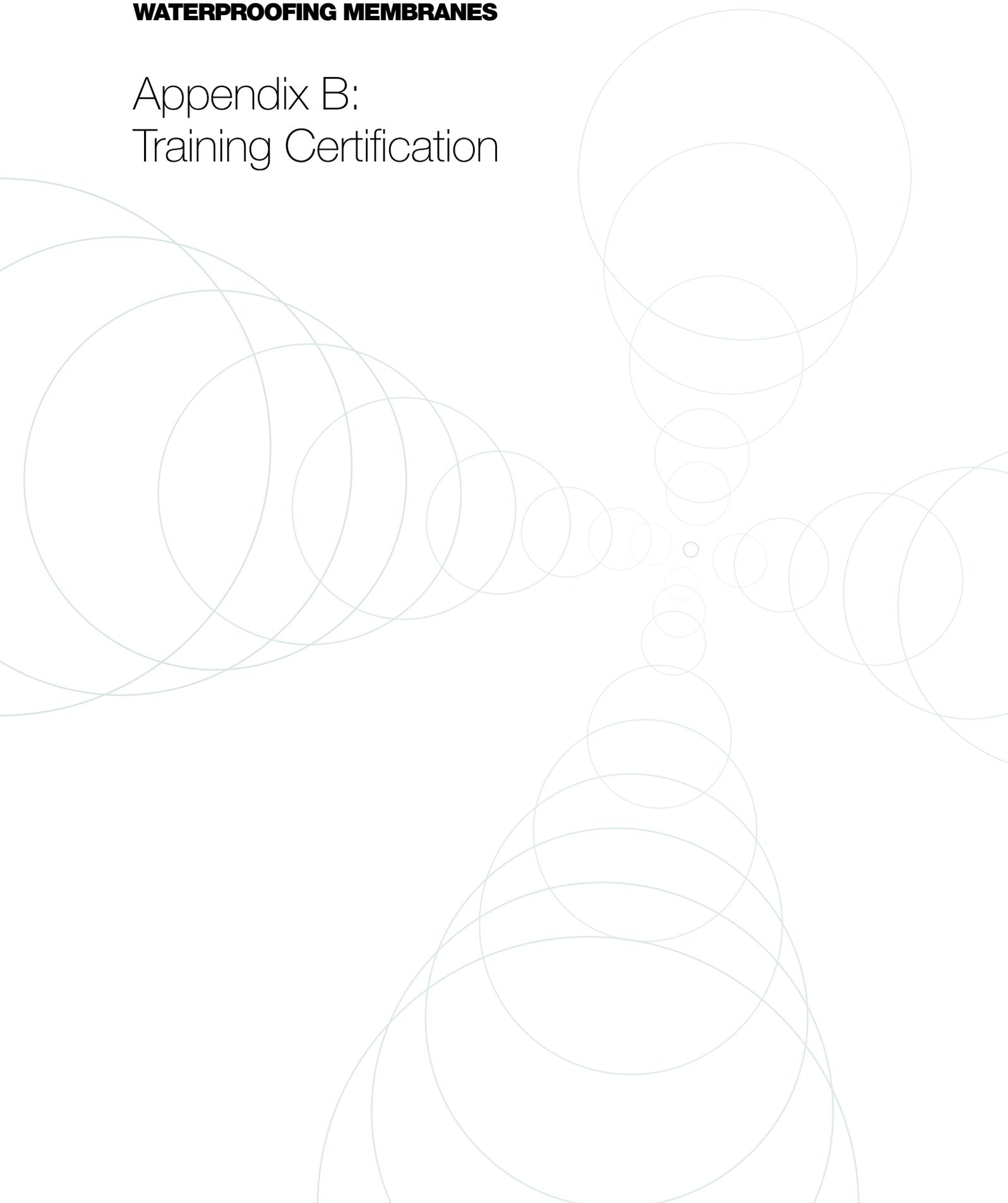
- 3 test specimens shall be tested in parallel in a test stand according to EN 12390-8.
- Water pressure of (500 ± 50) kPa shall be applied for 28 days.
- After 28 days the specimens are removed from the test stand and broken according to EN 12390-8
- A failure of the membrane may result in water outlet from the specimen surface prior 28 days or a moisture horizon at the fracture face which shall be marked e.g. with a pencil
- Water outlet from the specimen surface before 28 days shall be recorded. The test of this specimen shall be cancelled.
- The thickness of the membrane shall be measured after braking the specimen and cutting it off the surface



EN 12390-8 test method altered for inclusion of a spray applied waterproofing membrane

**ITAtch DESIGN GUIDANCE FOR SPRAY APPLIED
WATERPROOFING MEMBRANES**

Appendix B:
Training Certification



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1 >> INTRODUCTION

Durable, robust engineering solutions require the combination of high quality products and competent, skilled applicators working in accordance with thorough methodologies. Products are controlled by strict quality systems and their applicability is defined by performance requirements given in national and/or project targeted specifications. It is essential that methods for establishing competence of applicators is available to those specifying these products for projects, to ensure the material potential is met.

Training and certification is available for sprayed concrete application through the EFNARC and ACI nozzle-man schemes, but at this point, no equivalent international standard has been set for those applying spray applied waterproofing membranes.

This Spray Applied Membrane Training and Certification Scheme (SAMTaCS) is an answer to the construction industry's need to have a neutral and objective procedure for assessing and certifying spray applied waterproofing membrane applicators.

The aim of the Spray Applied Membrane Training and Certification Scheme is to improve the overall quality of application of spray applied membranes by providing an independent course for recognition of competent operators and their working methods.

The scheme consists of the following elements:

- Education and training courses for applicators
- Education courses for supervisors and engineers
- Certification of applicators who have already gained the necessary experience and can demonstrate their technical knowledge and practical ability.

ITAtch (AG Waterproofing) will provide guidelines for the course content for both levels of education courses.

The certification scheme operates through examiners who assess experienced applicators for their theoretical and practical skills at their workplace. The examiner himself has a wide experience in underground construction and waterproofing applications, particularly in spray applied membranes, and has been independently accredited by an independent body (e.g. CUC) through attendance at an Examiner Assessment Course.

The certification scheme is not a training scheme for neither the applicator nor the examiner as both are expected to have a high level of competence before applying. If training is required, the participants (especially when starting application of sprayed membranes) can make use of education courses. However, the support documents to accompany the scheme and pre-training based on these notes could be included by those doing the assessment.

Certificates are issued to the applicators through the independent body which should be endorsed by a well-accepted authority like ITA-CET on the recommendation of the examiner. The certificates are valid for 5 years and can be prolonged once by a theoretical assessment. The practical and theoretical assessment will have to be redone, after a maximum period of 10 years.

The education courses are aimed at applicators and engineers/supervisors gaining their first experiences with spray applied waterproofing membrane systems and technologies.

2.1. EDUCATION FOR APPLICATORS

The education course for applicators includes:

- Theoretical information
- Practical application work

The theoretical part will focus on basic understanding of the application of spray applied membranes; appreciating what is necessary to carry out proper practical application. The following topics will be included:

- Assessment of the underground
- Roughness of surface to receive membrane
- Wetness of surface
- Equipment operation
- Proper operation of equipment
- Quality check of delivered material (age, storing conditions,..)
- Maintenance and cleaning of equipment
- Drainage systems which could be applied with sprayed membranes
- Issues of application
- Controlling application thickness
- Construction joints
- Repairing of any defects
- Joints with other materials
- Quality control measures
- Health, Safety and environmental issues
- Handling of material
- Personal protection equipment
- Cleaning of machinery

During the practical application work each participant has to apply spray applied membrane and take into account the aspect mentioned in the theoretical part and additional:

- Control of thickness of membrane
- Curing of membrane if required

The practical part should take at least 10 hours.

2.2. EDUCATION FOR ENGINEERS, DESIGNERS AND SUPERVISORS

Education for engineers, designers and supervisors will also include theory, which will be followed by practical demonstrations.

The theoretical part will include:

- Concept of water-protection of underground structures
- Systems of water-protection
- Specification requirements and design criteria
- Preparation requirements
- Roughness of surface to receive membrane
- Wetness of surface and methods of dealing with water ingress prior to membrane installation
- Drainage systems which could be applied with sprayed membranes
- Issues of application
- Construction joints
- Joints with other materials
- Quality control
- Health, Safety and environmental issues
- Handling of material
- Personal protection equipment
- Cleaning of machinery

During the practical demonstration the participants will see typical application processes and learn how to assess the process and examine the quality of the installed membrane. By the end they should feel comfortable in being asked to sign an installed membrane off as complete.

3 >> CERTIFICATION

Certification for applicators of spray applied membranes will be given by an independent certification body (ICB) on the basis of an assessment by an experienced examiner, who will evaluate the applicator at his construction site. The examiners are to be approved according to a standard scheme.

3.1. EXAMINERS

The Examiner must be a named individual, not an organisation.

The Examiner shall have a wide experience of underground construction and spray applied membrane applications. Examiners shall be able to demonstrate suitable experience within the industry.

The Spray Applied Membrane Examiner Assessment Course will be organised by an organisation with the necessary facilities to run both classroom and practical spray applied membrane application assessment in accordance with the scheme. The scope of the assessment course will cover the following themes:

- Aims of the Certification Scheme
- Theoretical workshop highlighting the key topics of application of sprayed membranes to gain a common understanding among the examiners
- Practical workshop demonstrating best practice application and testing of spray applied membranes
- Theory examination
- Practical assessment of applicator with intentional errors that the candidate Examiner should note and record
- Oral examination and final assessment to recommend the award of Examiner Certificate

3.2. APPLICATOR

The applicator will have the necessary experience of application and can demonstrate his technical knowledge and practical ability.

The assessment of membrane applicators will cover the following areas:

- Theory examination. This may be written but is preferably done verbally by the Examiner.
- Practical assessment. The Examiner will observe all stages of a sprayed membrane application and shall ask the application questions related to critical processes, equipment and spraying operation and health, safety and environment.
- Overall assessment as to whether a Certificate should be awarded.

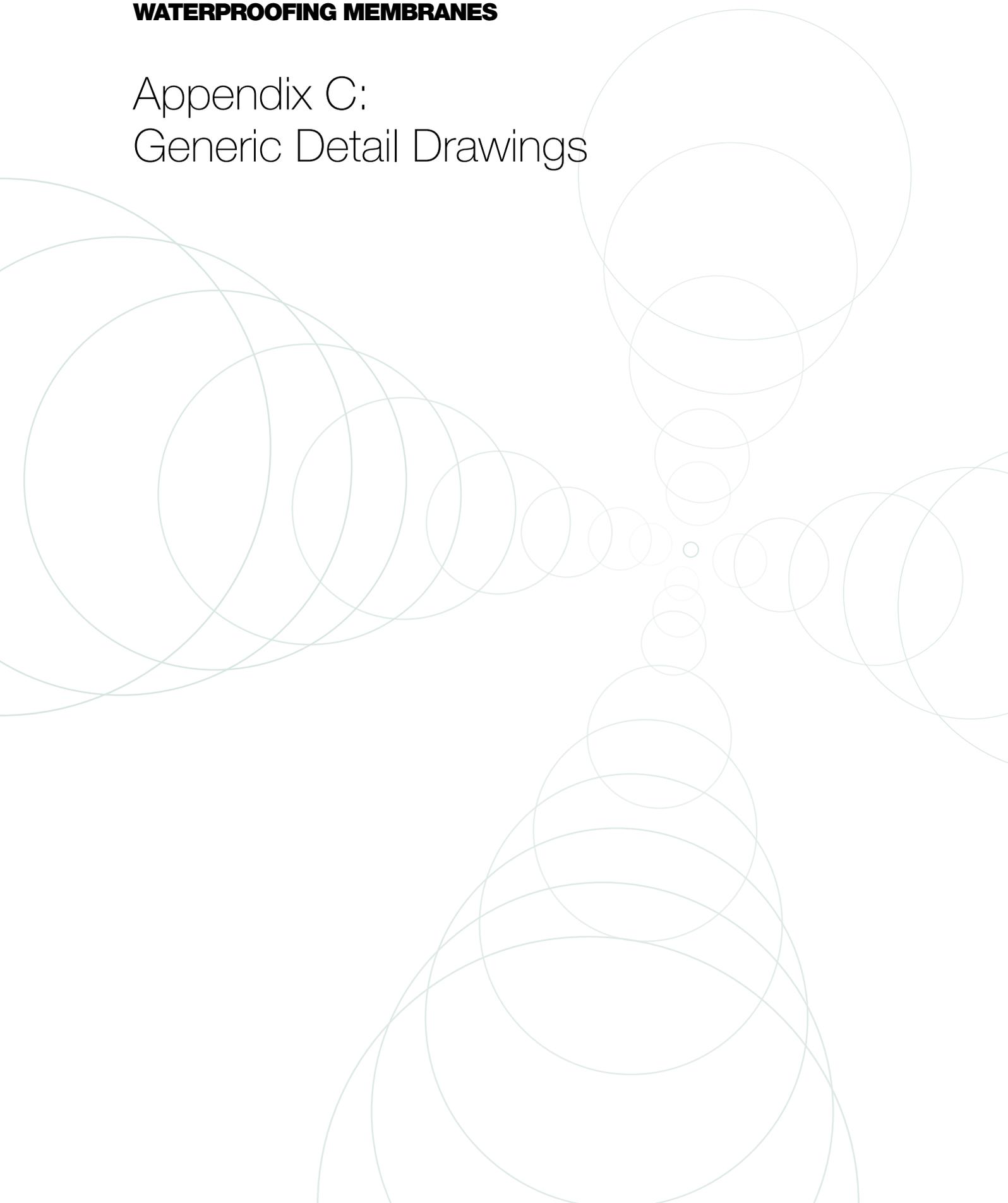
Training is not part of the scheme, though examiners may run their own training course. In this case the training and the assessment will have to be clearly separated.

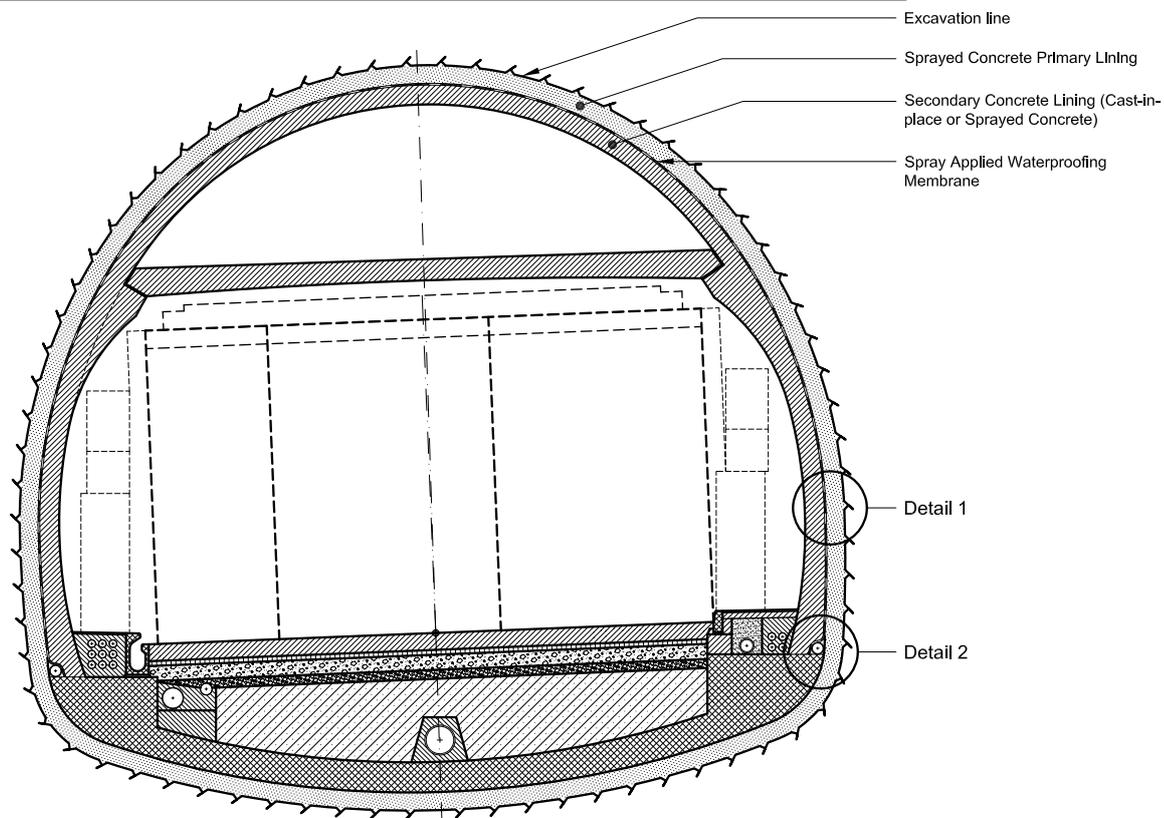
4. ATTACHMENTS

Under construction.

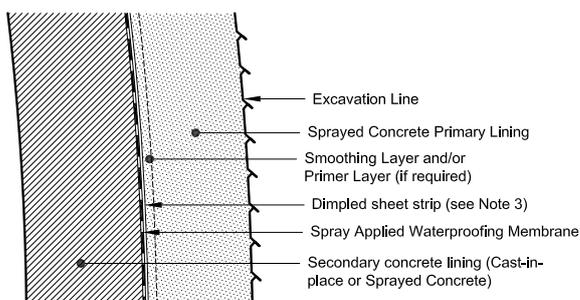
**ITAtch DESIGN GUIDANCE FOR SPRAY APPLIED
WATERPROOFING MEMBRANES**

Appendix C:
Generic Detail Drawings

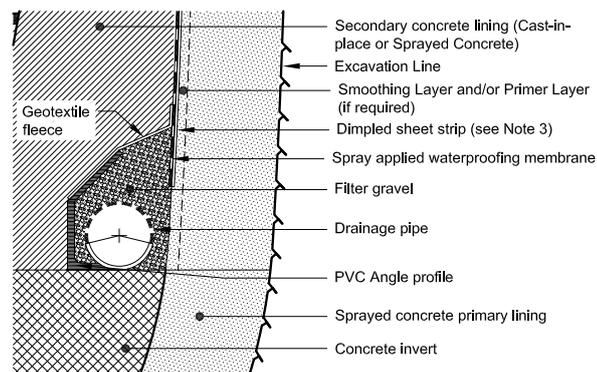




Detail 1
(not to scale)



Detail 2
(not to scale)



Note 1:

The receiving substrate shall be appropriate for application of the spray applied waterproofing membrane. It shall be treated (smoothing layer and/or primer) prior to membrane application according to the membrane supplier's instructions and/or to the Work Specification.

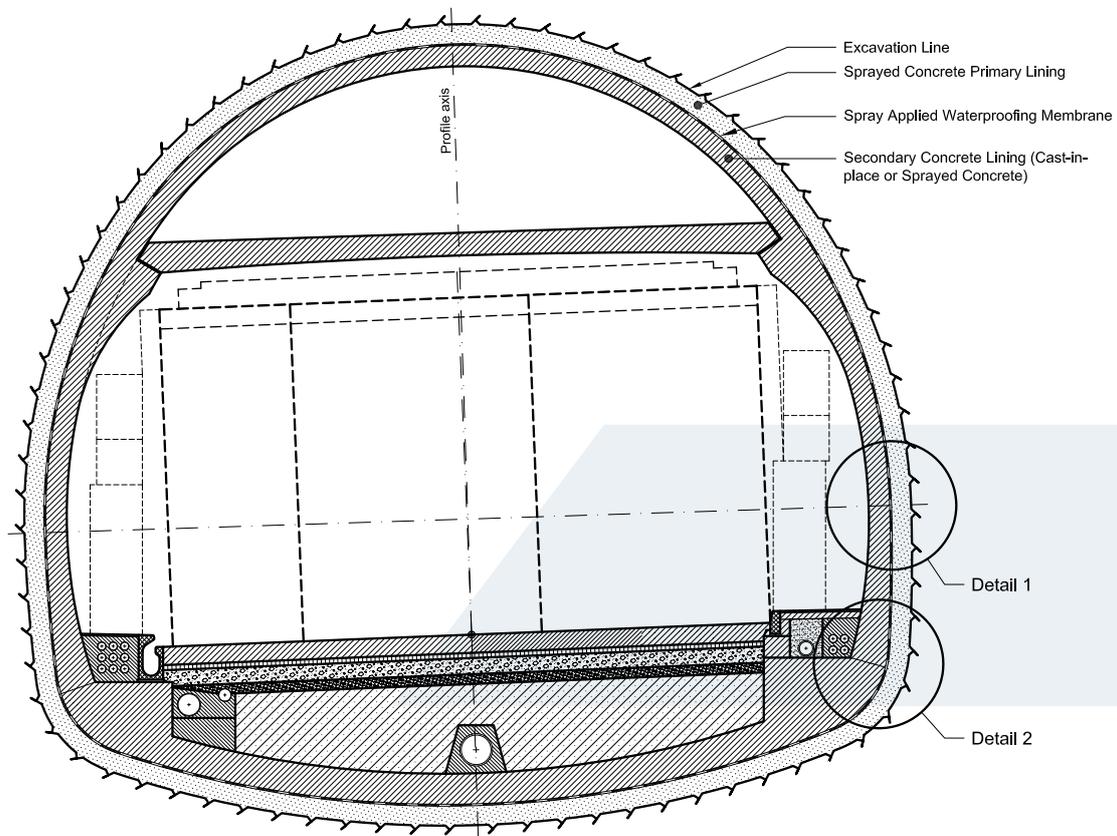
Note 2:

This drawing and all included details are only illustrative. Detailed design shall be done by the design engineer based on the specific project requirements.

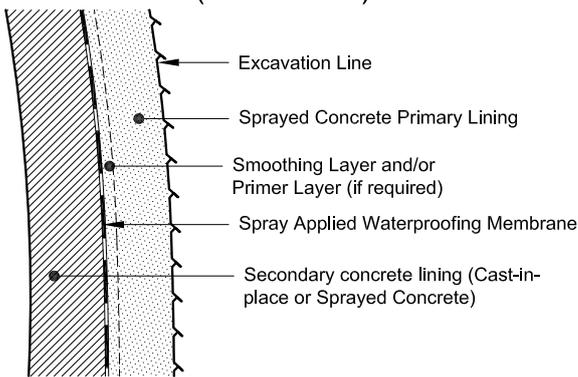
Note 3:

Dimpled sheet strips shall be properly installed onto the primary concrete lining (typically in the tunnel crown and bench) at regular distances, for example 3 m, and be connected to the groundwater drainage system (see Detail2). They can be interconnected at the tunnel drainage level with a regulating layer of sprayed concrete (not shown in Detail 1 and 2) prior to membrane application.

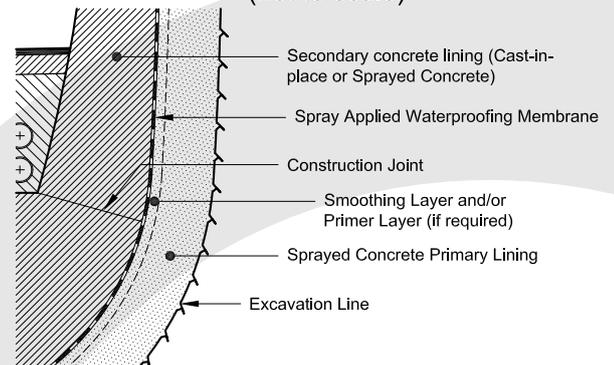
Example Road Tunnel			
Sprayed concrete Lining with Spray Applied Waterproofing Membrane			
Systematically drained Waterproofing System			
Cross Section, Detail			
Date/Draw	03.04.13/MFile	Approval	
Check		Project No.	
		Drawing No.	
		CSL-D_100A	



Detail 1
(not to scale)



Detail 2
(not to scale)



Note 1:

The receiving substrate shall be appropriate for application of the spray applied waterproofing membrane. It shall be treated (smoothing layer and/or primer) prior to membrane application according to the membrane supplier's instructions and/or to the Work Specification.

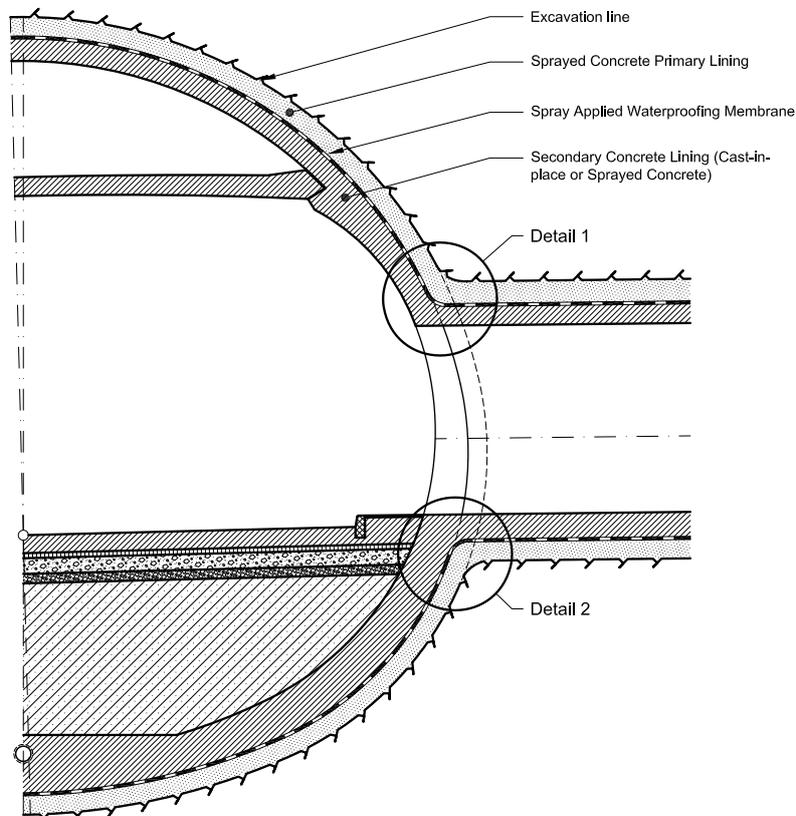
Note 2:

This drawing and all included details are only illustrative. Detailed design shall be done by the design engineer based on the specific project requirements.

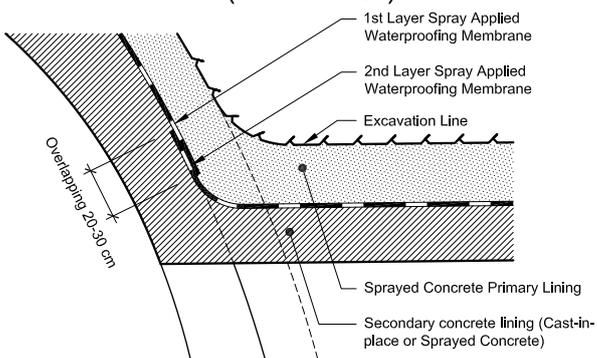
Note 3:

The design of construction and expansion (dilatation) joints depends on the type of spray applied membrane in use on the project requirements. It shall comply with the specific project requirements and the recommendations of the membrane's supplier.

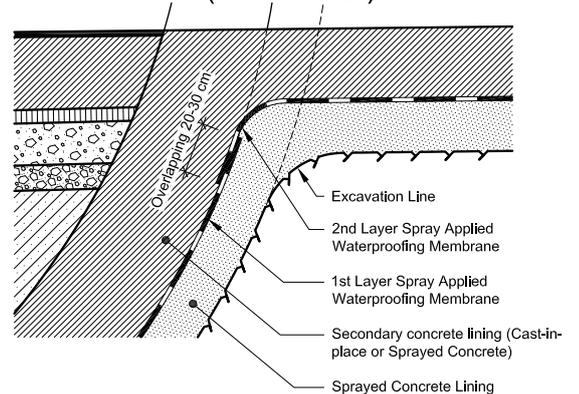
Example Road Tunnel			
Sprayed concrete lining with spray applied waterproofing membrane			
Non-drained (fully-tanked) waterproofing system			
Cross section, Detail			
Date/Draw	03.04.13/MFie	Approval	
Check		Project No.	
		Drawing No.	
		CSL-ND_100A	



Detail 1
(not to scale)



Detail 2
(not to scale)



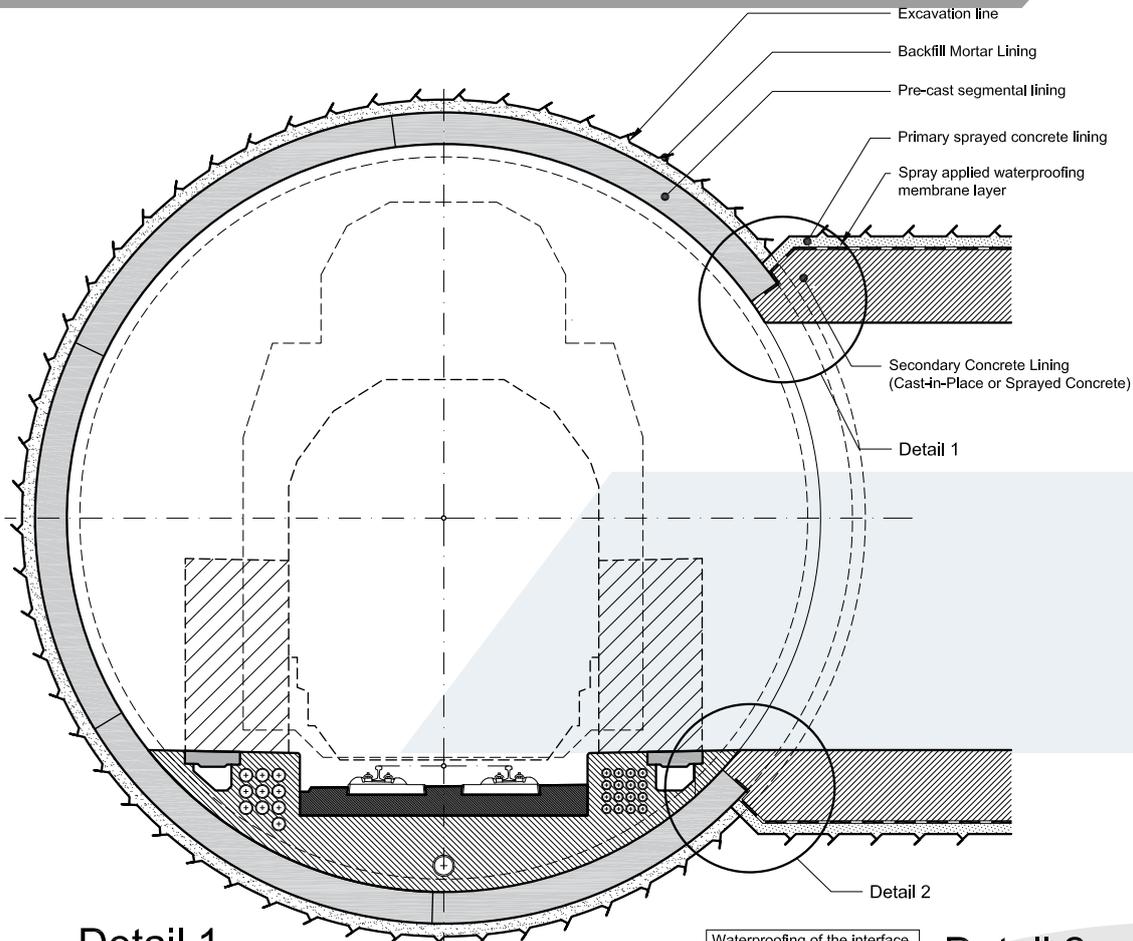
Note 1:

The receiving substrate shall be appropriate for application of the spray applied waterproofing membrane. It shall be treated (smoothing layer and/or primer) prior to membrane application according to the membrane supplier's instructions and/or to the Work Specification.

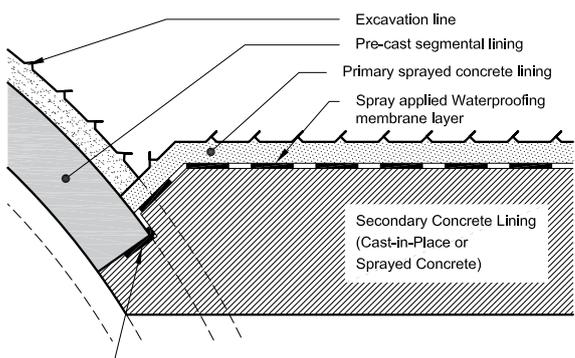
Note 2:

This drawing and all included details are only illustrative. Detailed design shall be done by the design engineer based on the specific project requirements.

Example Road Tunnel			
Sprayed concrete Lining with Spray Applied Waterproofing Membrane			
Non-drained (fully-tanked) Waterproofing System Interface with Crossing Passage Cross and Longitudinal Sections, Details			
Date/Draw	17.12.12/MFile	Approval	
Check		Project No.	
		Drawing No.	
		CSL-ND_200	

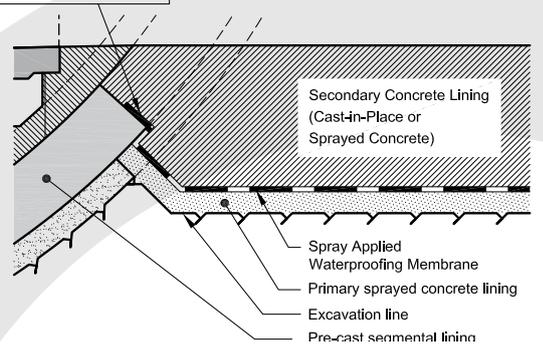


Detail 1
(not to scale)



Waterproofing of the interface between sprayed concrete and segmental linings shall comply with the design requirements (see Note 3)

Detail 2
(not to scale)



Note 1:

The receiving substrate shall be appropriate for application of the spray applied waterproofing membrane. It shall be treated (smoothing layer and/or primer) prior to membrane application according to the membrane supplier's instructions and/or to the Work Specification.

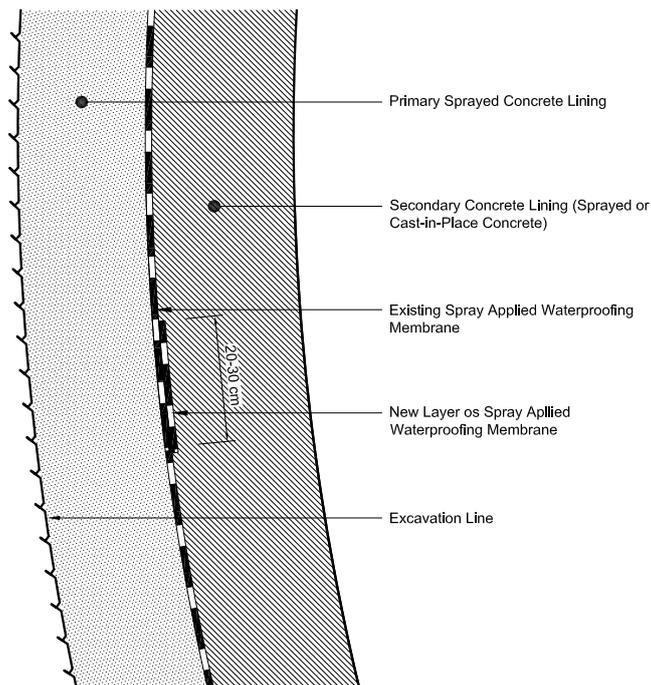
Note 2:

This drawing and all included details are only illustrative. Detailed design shall be done by the design engineer based on the specific project requirements.

Note 3:

Waterproofing of the interface between sprayed concrete and segmental linings depends on the design requirements of the project, including water pressure and anticipated differential settlement. A combination of spray applied waterproofing membrane and sheet membrane and/or other waterproofing materials may be required.

Example Railway Tunnel			
Sprayed concrete Lining with Spray Applied Waterproofing Membrane			
Non-drained (fully-tanked) Waterproofing System Interface with Crossing Passage Cross and Longitudinal Sections, Details			
Date/Draw	03.04.13/MFie	Approval	
Check		Project No.	
		Drawing No.	
		CSL-ND_300B	



Note 1:

The receiving substrate shall be appropriate for application of the spray applied waterproofing membrane. It shall be treated (smoothing layer and/or primer) prior to membrane application according to the membrane supplier's instructions and/or to the Work Specification.

Note 2:

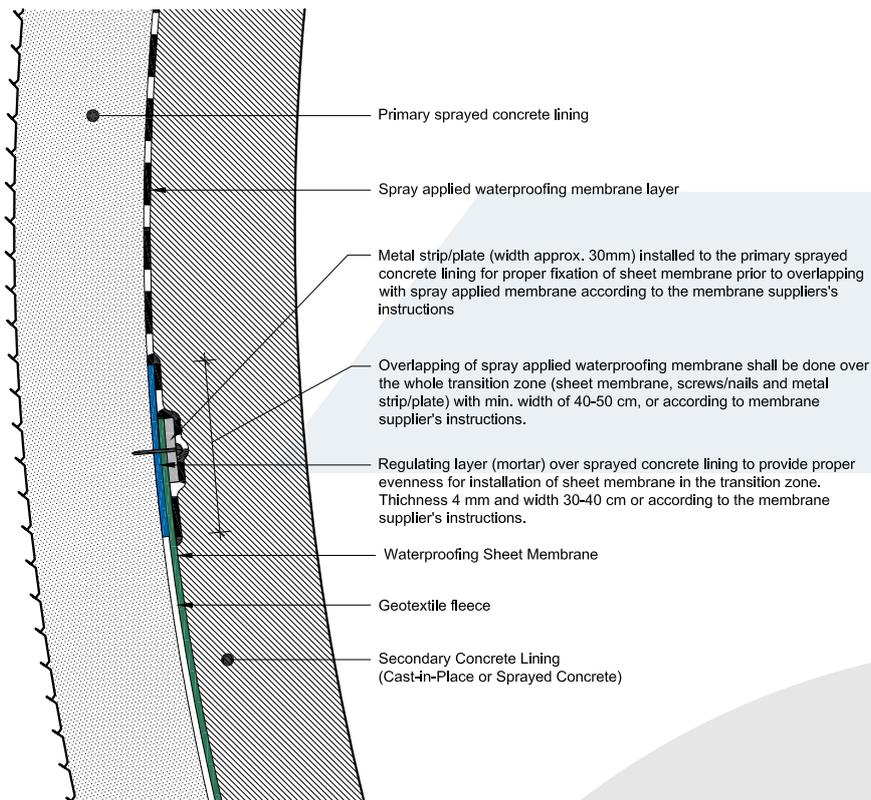
Overlapping shall be done according to supplier's instructions. the existing membrane shall be properly cleaned and inspected prior to application of the new membrane to build and overlap, according to supplier's instructions.

Note 3:

This drawing and all included details are only illustrative. Detailed design shall be done by the design engineer based on the specific project requirements.

Sprayed concrete Lining with Spray Applied Waterproofing Membrane			
Detail of Cross Section with Membrane Overlapping			
Date/Draw	17.12.12/MFie	Approval	
Check		Project No.	
		Drawing No.	CSL-WP Details_100

(not to scale)



Note 1:

The receiving substrate shall be appropriate for application of the spray applied waterproofing membrane. It shall be treated (smoothing layer and/or primer) prior to membrane application according to the membrane supplier's instructions and/or to the Work Specification.

Note 2:

Overlapping shall be done according to supplier's instructions. the existing membrane shall be properly cleaned and inspected prior to application of the new membrane to build and overlap, according to supplier's instructions.

Note 3:

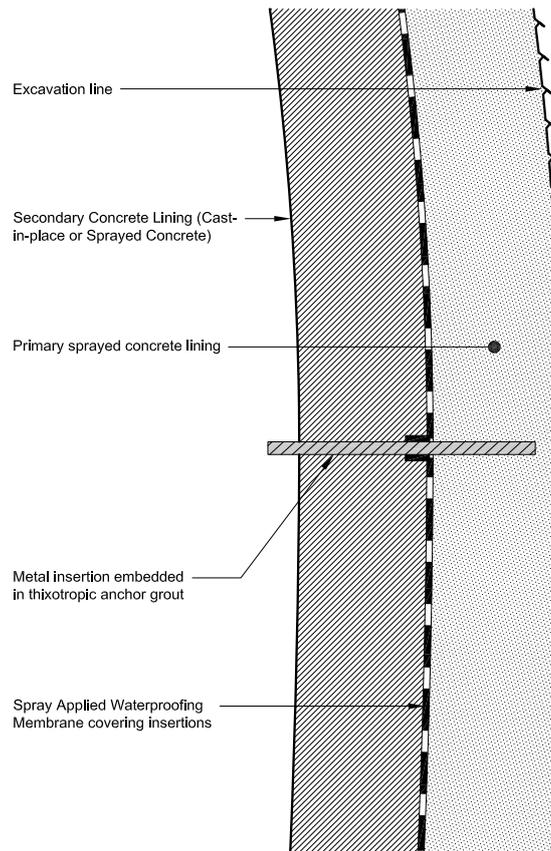
This drawing and all included details are only illustrative. Detailed design shall be done by the design engineer based on the specific project requirements.

Sprayed concrete lining with Spray Applied Waterproofing Membrane

Detail of Cross Section, Interface with a Waterproofing Sheet Membrane

Date/ Draw	18.12.12/MFile	Approval	
Check		Project No.	
		Drawing No.	
		CSL-WP Details_110	

(not to scale)



Note 1:

The receiving substrate shall be appropriate for application of the spray applied waterproofing membrane. It shall be treated (smoothing layer and/or primer) prior to membrane application according to the membrane supplier's instructions and/or to the Work Specification.

Note 2:

The spray applied waterproofing membrane shall cover insertions with a min. of 50 mm or according to the membrane supplier's instructions. If possible, insertions shall be installed after the membrane application, the membrane shall be re-applied onto the interfaces with insertions.

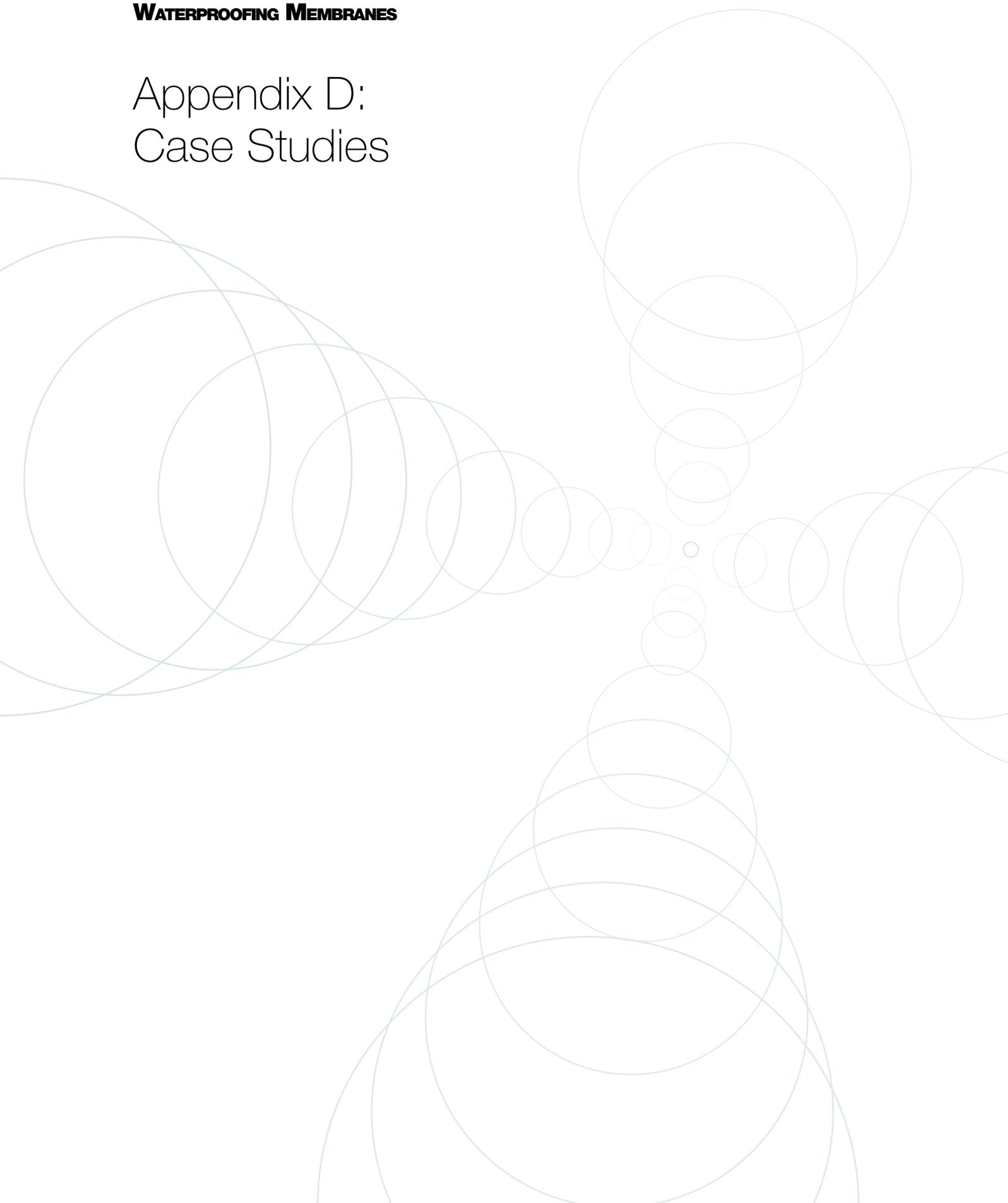
Note 3:

This drawing and all included details are only illustrative. Detailed design shall be done by the design engineer based on the specific project requirements.

Sprayed concrete Lining with Spray Applied Waterproofing Membrane Detail of installed Spray Applied Waterproofing Membrane in Spots with Insertions			
Date/Draw	14.01.13/MFie	Approval	
Check		Project No.	
		Drawing No.	CSL-WP Details_120

**ITAtch DESIGN GUIDANCE FOR SPRAY APPLIED
WATERPROOFING MEMBRANES**

Appendix D:
Case Studies



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1 >> GISWIL ROAD ESCAPE TUNNEL, SWITZERLAND



1.1. PROJECT DETAILS

The 2,066 m long Giswil road tunnel in the Canton of Obwalden, Switzerland, was opened in 2004. It provides a bypass for the town of Giswil. The project consists of a two-lane road tunnel and an emergency escape tunnel running approx. 20 m parallel to the main tunnel. Connections between the main tunnel and the emergency escape tunnel are provided every 300 m. The tunnel was excavated in rock by the drill-and-blast method. The portal zones were built as cut-and-cover sections. The emergency escape tunnel was excavated by a 4 m diameter hard-rock TBM and partly by the drill-and-blast method. The project owner is the Canton of Obwalden and the total project cost is approx. CHF 133 million.

1.2. DESIGN APPROACH ADOPTED

The spray applied waterproofing membrane MASTERSEAL 345 was installed as a fully-tanked (non-drained) waterproofing system in between two sprayed concrete linings in the southern part of the emergency escape tunnel (area of approx. 2,000 m²).

1.3. APPLICATION APPROACH AND CONTROL

MASTERSEAL 345 application was done by manual handheld nozzle, as described in the following:

- 1- Treatment of water seepages through the substrate with PU and acrylic injection
- 2- Cleaning of the substrate with water and air
- 3- Application of MASTERSEAL 345 (min. 3 mm) on the tunnel bench and crown (70-80 m²/h)
- 4- Installation of the secondary (inner) lining one day after membrane application
- 5- Installation of the primary lining in the invert
- 6- Cleaning of the substrate in the invert

7- Application of MASTERSEAL 345 (min. 3 mm) onto the substrate in the invert (70-80 m²/h)

8- Installation of the secondary lining in the invert one day after membrane application.

Quality control was done mainly by measuring the membrane curing status and achieved membrane thickness, as well as thorough inspection of the cured membrane surface before application of the secondary (inner) concrete layer. Furthermore, groundwater pressure has been monitored since 2004.

1.4. PROJECT BENEFITS

The related project benefits include:

- No water ingress since installation in 2004.
- Continuous membrane application with full membrane coverage.
- Compatibility with other sealing systems.
- Continuous waterproofing from the bored tunnel to the cut-and-cover tunnel section.
- Faster installation of the waterproofing system and the inner sprayed concrete lining.
- Reduced construction time.

2 >> GEVINGÅSEN RAILWAY TUNNEL, NORWAY



2.1. PROJECT DETAILS

The Gevingåsen single track horseshoe-shaped railway tunnel is 4 km long and was built between Hommelvik and Hell on the Nordland Line between the city Trondheim and the Trondheim airport. Prevailing ground conditions were hard rock with mica and green schist. Tunnel excavation was done by drill and blast method (30-100 m overburden). The tunnel was put into operation by the Norwegian National Rail Administration in 2011. It reduces travel time by five minutes and has contributed to increased capacity from 5.4 to 8 trains per hour. Tunnel costs are about NOK 635 million (approx. EUR 86 million). This was the first full-scale use of a spray applied waterproofing system in a Nordic country.

2.2. DESIGN APPROACH ADOPTED

The tunnel lining consists of permanent sprayed concrete with a waterproofing layer in between two concrete layers. Any groundwater approaching the finished tunnel is diverted through to the tunnel invert and channelled to a main pumping station. Following its successful application to a short section in 2009 and tests at SINTEF the spray applied waterproofing membrane MASTERSEAL 345 was installed with a thickness of 3 mm in the central part of the tunnel (45,000 m²). Conventional waterproofing with PE-Foam insulation and drainage shield was used in the portal zones and in two zones with very high water ingress.

2.3. APPLICATION APPROACH AND CONTROL

MASTERSEAL 345 application was done by manual handheld nozzle, as described below:

- 1- Installation of a smoothing layer onto the primary sprayed concrete lining (substrate)
- 2- Temporary drainage of seepage spots
- 3- Application of MASTERSEAL 345 in one pass
- 4- Inspection and eventual treatment of water seepage and membrane application
- 5- Installation of the secondary (inner) sprayed concrete lining onto the membrane.

Quality control was done mainly by measuring the membrane curing status, achieved membrane thickness and coverage. Systematic inspection of the cured membrane surface was carried out before application of the secondary (inner) concrete lining.

2.4. PROJECT BENEFITS

The related project benefits include:

- Faster installation of the waterproofing system, with reduced construction time.
- Reduced maintenance over service lifetime.
- Simple routine inspection of the final lining.
- No use of inflammable materials (no PE-Foam insulation), where the membrane was applied.
- Longer service lifetime than the originally tendered technical solution.

3 >> TORONTO TRANSIT SHEPARD LINE EXTENSION, CANADA



3.1. PROJECT DETAILS

The Sheppard Line Extension of the Toronto Light Rail project, that had been cancelled by the Mayor in 2007, earned a reprieve in 2012 and work on the project recommenced to increase the scope of Toronto's public transport system. The project is being constructed by the McNally/Kiewit/Aecon JV (MKA JV). It was decided to use Tamseal 800 spray applied waterproofing membranes in the cross passages.

3.2. DESIGN APPROACH ADOPTED

The project designers Hatch Mott MacDonald (HMM) have opted to use Tamseal 800 spray applied waterproofing membrane in conjunction with a drainage fleece. The membrane will bond to the primary lining, but should water breach the membrane in any location it will travel through the fleece applied to the back into the drainage system.

3.3. APPLICATION APPROACH AND CONTROL

The surface of the primary lining was prepared using a regulating layer: giving a surface finish without fibres and large holes. The membrane was then applied in two layers using hand application with rollers/brushes.

The two layers of membrane were in contrasting colours: the first in orange, the second in white/grey. This approach allowed the thickness of the membrane to be controlled and allowed for easier quality control checking of the application.

Coverage was checked using a combination of visual inspection and frequent depth gauge and patch testing.

3.4. PROJECT BENEFITS

Using Tamseal 800 spray applied waterproofing membrane for the cross-passages allowed the project to install the membrane quickly and easily without the need for additional specialist equipment or the manual handling involved in cutting, welding and testing a sheet membrane to changing profiles.

- Bonded membrane solution with drainage.
- Membrane installed using basic equipment already available on site.
- Cross passages easily integrated into the rest of the tunnel system.
- No requirement for complex secondary lining shutters.
- Easier connection details to running tunnels.



4.1. PROJECT DETAILS

The Mass Transit Railway Project in Hong Kong is being extended. On Contract 708, the West Island Extension TamSeal 800 was used to waterproof magazine caverns where explosives could be stored for use in the rest of the project. The material was used in several locations across the project, by both Gammon Construction and by Super Rich Engineering.

4.2. DESIGN APPROACH ADOPTED

The design approach adopted by the Arup/Atkins Joint Venture was to use TamSeal double sided geotextile fleece strips. This allowed a systematic dissipation of water to a drainage system, reducing pressures onto the membrane and the secondary lining.

The use of the TamSeal 800 EVA co-polymer membrane system that allows double bonding in the areas where the sheet strips are not applied, allows quick and easy application of the waterproofing and sprayed concrete secondary lining.

4.3. APPLICATION APPROACH AND CONTROL

TamSeal 800 was spray applied using dry shotcreting equipment. It was applied in one layer, approximately 3mm thick using hand spraying techniques. The sheet membrane strips had been previously installed and the membrane was applied directly over the top. A 10mm thick layer of TamCrete TopShot had been applied to the surface of the sprayed concrete between the geotextile strips to give a suitably smooth substrate on which to apply the TamSeal 800 in one single pass, ensuring approximately 3mm membrane thickness. The membrane was checked using depth gauges and test patches as well as visual inspection to ensure the membrane was complete.

4.4. PROJECT BENEFITS

Using TamSeal 800 spray applied waterproofing membrane allowed the caverns to be constructed more quickly and efficiently than if a sheet membrane solution had been chosen. The secondary lining installed inside the membrane was permanent sprayed concrete, using the bond of the waterproofing to the substrate to give a suitable firm surface without the need to install mesh and frames to support the lining as might have been the case using a sheet membrane. This approach also avoided the need to create bespoke shuttering to cast a secondary lining in-situ.

- Effective waterproofing system, keeping the contents of the caverns safe and dry.
- Quick and easy application of the waterproofing system without the need to bring in additional teams and equipment.
- Sprayed concrete secondary lining applied over the membrane, saving further time and money.

5 >> BUENOS AIRES METRO LINE B EXTENSION, ARGENTINA



5.1. PROJECT DETAILS

The extension to Buenos Aires Metro Line B includes additional stations and terminates in a parking garage and workshop for the metro trains. The new garage cavern is 18m diameter at its widest and 11m high, of NATM construction, with primary and secondary linings of sprayed concrete, and is 10–15m below the water table in permeable ground. The workshop structure utilised a similar construction method and is about 12m wide and 6.4m high, and around 20m below the water table. The requirement from the client, Sbase, was for a higher level of watertightness than achieved in previous projects.

5.2. DESIGN APPROACH ADOPTED

The main contractor Benito Roggio required a sprayed waterproofing membrane that could be tested in-situ, after it had been installed but before the secondary lining was applied, to prove that a continuous, defect free waterproofing installation had been achieved.

Sbase were adamant that the workshop cavern in particular needed to be as dry as possible. The workshop cavern was also the deepest structure on the site and subject to the most water ingress during construction, with the ground remaining wet despite dewatering. High adhesion to both the concrete linings was also required, to prevent tracking of water. Benito Roggio selected the Integritank HF sprayed membrane from Stirling Lloyd, which accommodates moisture within the concrete and has a cure unaffected by humidity, and a local specialist applicator was trained by Stirling Lloyd to install the system.



5.3. APPLICATION APPROACH AND CONTROL

The Integritank HF system comprises a primer followed by two coats of membrane, each 1.5mm thick in contrasting colours – yellow then white - sprayed by hand for maximum quality control. Each cured typically in 30 minutes, and wet film thickness was measured constantly. To confirm that effective high performance waterproofing had been achieved the membrane was tested qualitatively after installation by electrical integrity spark testing that provided reliable results quickly and without damage

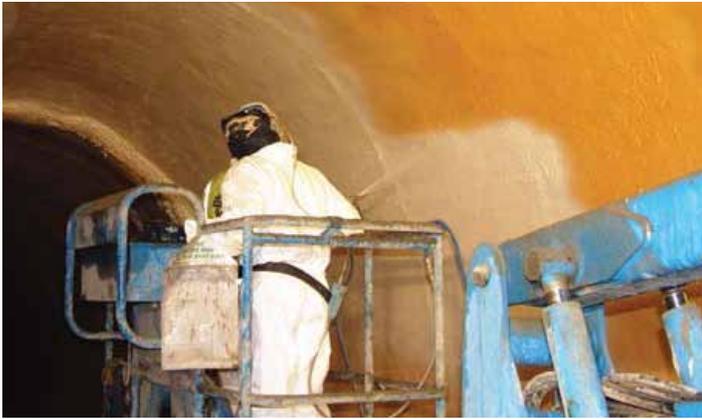
to the membrane (see photo, right, above). 20,000m² of Integritank HF membrane was installed, meeting the demands of both the contractor for rapid installation and the client's for high watertightness.

5.4. PROJECT BENEFITS

Integritank HF's unique project benefits included:

- Non-destructive testing of the waterproofing membrane enabled confirmation of its 100% integrity prior to secondary lining installation.
- Rapid application and cure of the membrane, assisting in shortening the construction programme: each coat cured in 30 minutes.
- Excellent durability and adhesion: Integritank HF minimized potential physical damage to the waterproofing from other site activities.

6 >> CROYDON CABLE TUNNEL, UNITED KINGDOM



6.1. PROJECT DETAILS

As part of the expansion its high voltage power distribution in SE England, National Grid plc contracted Morgan Tunnelling to build a 4m diameter cable tunnel to carry heavy duty power cables. Construction was by TBM, with the linings of the front and back shunts being formed by primary and secondary sprayed concrete with an effective waterproofing membrane sandwiched between the two layers.

6.2. DESIGN APPROACH ADOPTED

The chosen waterproofing system needed to be capable of forming a tenacious bond to both layers of sprayed concrete as well as being tough enough to withstand the spray application of the second concrete lining. Following extensive testing and evaluation, Morgan Tunnelling selected Stirling Lloyd's Integritank HF, a spray-applied, seamless methacrylate resin based membrane system.

6.3. APPLICATION APPROACH AND CONTROL

The application, by Stirling Lloyd Construction Ltd, consisted of Integritank HF Primer followed by two coats of Integritank HF membrane. Two coats aid quality control, and the thickness of each coat was checked every 2 m² using wet film techniques. The final quality check was the use of high voltage holiday detection testing to confirm the 100% integrity of the waterproofing.

6.4. PROJECT BENEFITS

By using the Integritank HF spray-applied system, Morgan Tunnelling were able to construct a tunnel not only with effective long term protection to the assets within, but also to achieve it in a very cost-effective manner with both decreased build time and cost. Additionally, Integritank HF's tolerance of difficult site and weather conditions enabled application in February in a northern winter when the temperature varied between 0°C and 4°C, which would preclude the application of membranes based on other resins. The use of a liquid sprayed system that could follow the contours of the tunnel meant no time consuming and costly scaffolding or detailing associated with sheet membranes was necessary.

Integritank HF's unique project benefits included:

- Non-destructive testing of the waterproofing membrane enabled confirmation of its 100% integrity prior to secondary lining installation.
- Rapid application and cure of the membrane, assisting in shortening the construction programme.
- High durability and adhesion: Integritank HF minimized potential physical damage to the waterproofing from other site activities.

7 >> TESIMO TUNNEL, ITALY



7.1. PROJECT DETAILS

The Tesimo tunnel is situated on the Italian provincial road which leads from Lana to Tesimo (in the province of Bolzano).

The tunnel was built about ten years ago in basaltic rock formations that were strongly fractured, and with low over-burden, which have led every year during the winter season, to water infiltrations and thus ice formation on the road.

The section of the tunnel is quite narrow and crossed by heavy daily traffic. It was therefore decided to intervene with a waterproofing treatment without interfering with that section of the tunnel.

7.2. DESIGN APPROACH ADOPTED

As the surface of the tunnel appeared highly irregular with open fractures in the rock up to several centimeter, it was necessary to provide a uniform layer of structural shotcrete to the arch, in order to provide a sufficiently regular and continuous surface for the sprayed membrane.

As it was not possible to modify the section of the tunnel, the protection of the membrane was insured by applying a layer of structural premixed mortar of 3 cm.



7.3. APPLICATION APPROACH AND CONTROL

The application of shotcrete has been designed to smooth the surface but also to temporarily stop the residual water infiltration still present in summer time. After checking the regularity of the surface of shotcrete, an application of the membrane was carried out. Since an application of this type of material had never been performed, a teaching course by our MAPEI UTT technical staff was organized for the company workers.

The control of the thickness of the membrane was performed in two ways:

- By checking the coverage area using each Mapelastich TU System packing.
- By measuring with a special feeler gauge the thickness of the applied material on each square meter

7.4. PROJECT BENEFITS

The intervention allowed to waterproof the tunnel and also to prepare an appropriate surface for the application of subsequent coatings to improve the brightness, obtaining the following advantages:

- No traffic interruption.
- Minimum variation of the tunnel width.



8 >> SPECIAL UNDERGROUND PROJECT, INDIA



8.1. PROJECT DETAILS

An important project is underway in India: the construction of a tunnel for a special purpose. The tunnel has been mined inside terrain with very different soil characteristics, ranging from loose earth to hard rock. The excavation process was determined not only by the ground conditions but also by the presence of ground water which had to be managed to allow for fast excavation.

The tunnel must be completely dry before it can be used, so the decision was made to use the waterproofing MAPELASTIC TU SYSTEM spray-applied membrane in order to ensure the efficacy of the waterproofing system.

The whole project consists of a tunnel of 10 meters in diameter, 2.4 km long.

8.2. DESIGN APPROACH ADOPTED

The design of the tunnel has this typical configuration:

- Steel ribs.
- Wet shotcrete
- Final wet shotcrete to ensure an even layer
- Spray-applied waterproofing with the MAPELASTIC TU SYSTEM
- Temporary shotcrete layer, 50 mm thick, to protect the waterproofing system as the final lining will be made only after total completion of the work.
- Final cast in situ concrete lining, in some sections reinforced with steel rebar.

8.3. APPLICATION APPROACH AND CONTROL

The application of shotcrete has the purpose not only of leveling the surface but also temporarily stopping the residual waters present during summertime. After testing the shotcrete surface to verify the smoothness, the membrane is applied.

A 24-hour on-site UTT MAPEI technician has been assigned to provide client support as needed.

- By verifying the area covered with the use of each package of MAPELASTIC TU SYSTEM.
- By measuring with the proper feeler gauge the width of the material applied per square meter.

Where there are water inflows present which are too big to be managed with shotcrete, a pre-treatment of the section of the tunnel is carried out with specific methods and materials, in order to correctly apply MAPELASTIC TU SYSTEM.

8.4. PROJECT BENEFITS

The application of MAPELASTIC TU SYSTEM allows the client to have a tunnel with a very high waterproofing characteristic, with an extremely fast application, and no requirement of heavy equipment to install a standard waterproofing membrane.

The whole waterproofing method suggested to the client gives reliable results onsite even in difficult ground conditions.



