ASHGHAL

Interim Advice Note No. 004/14

Specification for Waterproofing of Cut and Cover Tunnel and Underpass Highway Structures

Revision No. A1

Summary
This Interim Advice Note (IAN) provides information and guidance on the specification to be adopted for waterproofing of cut and cover tunnel and underpass highway structures which are designed to exclude ground water. Typically this will include tunnels and underpasses that are below or close to the water table.

This IAN takes immediate effect. The following shall be noted:

- This Interim Advice Note is for use with the existing Qatar Construction Specifications (QCS) 2014 only.
- This IAN does not make any amendments to the existing Qatar Construction Specifications (QCS) 2014.
- This IAN adds a new Section and new Part to QCS 2014, namely Section 101, Part 1, Waterproofing of Cut and Cover Tunnel and Underpass Highway Structures.

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A1	April 2016	Issued for All Relevant Infrastructure Projects	IF	MG	DOR
Rev	**Date**	**Reason For Issue**	**Auth**	**Chk**	**App**

Contents

1. Foreword

1.1 Interim Advice Notes (IAN) may be issued by Ashghal from time to time. They define specific requirements for works on Ashghal projects only, subject to any specific implementation instructions contained within each IAN.

1.2 Whilst IANs shall be read in conjunction with the Qatar Highway Design Manual (QHDM), the Qatar Traffic Manual (QTM) and the Qatar Construction Specifications (QCS), and may incorporate amendments or additions to these documents, they are not official updates to the QHDM, QTM, QCS or any other standards.

1.3 Ashghal directs which IANs shall be applied to its projects on a case by case basis. Where it is agreed that the guidance contained within a particular IAN is not to be incorporated on a particular project (e.g. physical constraints make implementation prohibitive in terms of land use, cost impact or time delay), a departure from standard shall be applied for by the relevant Consultant / Contractor.

1.4 IANs are generally based on international standards and industry best practice and may include modifications to such standards in order to suit Qatar conditions. Their purpose is to fill gaps in existing Qatar standards where relevant guidance is missing and/or provide higher standards in line with current, international best practice.

1.5 The IANs specify Ashghal's requirements in the interim until such time as the current Qatar standards (such as QHDM, QTM, etc.) are updated. These requirements may be incorporated into future updates of the QHDM, QTM or QCS, however this cannot be guaranteed. Therefore, third parties who are not engaged on Ashghal projects make use of Ashghal IANs at their own risk.

1.6 All IANs are owned, controlled and updated as necessary by Ashghal. All technical queries relating to IANs should be directed to Ashghal's Manager of the Design Department, Infrastructure Affairs.

Signed on behalf of Design Department:

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2. Ashghal Interim Advice Note (IAN) – Feedback Form

Ashghal IANs represent the product of consideration of international standards and best practice against what would work most appropriately for Qatar. However, it is possible that not all issues have been considered, or that there are errors or inconsistencies in an IAN.

If you identify any such issues, it would be appreciated if you could let us know so that amendments can be incorporated into the next revision. Similarly, we would be pleased to receive any general comments you may wish to make. Please use the form below for noting any items that you wish to raise.

Please complete all fields necessary to identify the relevant item			
IAN title:			
IAN number:		Appendix letter:	
Page number:		Table number:	
Paragraph number:		Figure number:	
Description comment: Please continue on a separate sheet if required:			
Your name and contact details (optional):			
Name:		Telephone:	
Organisation:		Email:	
Position:		Address:	

Please email the completed form to:

Abdulla Ahin AA Mohd

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We cannot acknowledge every response, but we thank you for contributions. Those contributions which bring new issues to our attention will ensure that the IANs will continue to assist in improving quality on Ashghal's infrastructure projects.

3. Introduction

3.1 This Interim Advice Note (IAN), which takes immediate effect, provides the Specification to be used for the waterproofing of cut and cover tunnel and underpass highway structures which are designed to exclude ground water. This IAN will provide interim guidance prior to issue of a revision to the Qatar Construction Specification (QCS).

3.2 The specification is applicable to cut and cover tunnels or underpass highway structures that are below or close to the water table and are designed to exclude groundwater.

3.3 The use of flexible self adhesive bituminous membranes is not considered adequate and these materials should not be used for waterproofing of tunnel and underpass highway structures which are designed to exclude ground water.

4. Additional Standard

4.1 For application to cut and cover tunnels and underpass highway structures which are designed to exclude ground water; Section 101, Part 1 is additional to the existing Qatar Construction Specifications (QCS) 2014.

5. Implementation

5.1 This IAN is to be used with immediate effect on projects as follows:

- All Ashghal projects in Design Stage
- All Ashghal projects in Tender Stage

5.2 Ashghal projects in Construction Stage shall be reviewed by the Project Consultant / Contractor and the implications of adoption of this Interim Advice Note discussed with the respective Ashghal Project Manager.

5.3 If in doubt, Consultants / Contractors should seek guidance from the respective Ashghal Project Manager or designated Programme Management Consultant (PMC) on a scheme specific basis.

6 Disclaimer

6.1 This Interim Advice Note and its recommendations or directions have been provided for application on Ashghal's infrastructure projects within Qatar only and they are not warranted as suitable for use on other roads, highways or infrastructure with Qatar or elsewhere. Should any third party, Consultant or Contractor choose to adopt this Interim Advice Note for purposes other than Ashghal's infrastructure projects, they shall do so at their own risk.

Appendix A

QATAR CONSTRUCTION SPECIFICATIONS (QCS) 2014

Additional Section 101, Part 1, Waterproofing of Cut and Cover Tunnel and Underpass Highway Structures

SECTION 101,

PART 1 WATERPROOFING OF CUT AND COVER TUNNEL AND UNDERPASS HIGHWAY STRUCTURES

CONTENTS

PART 1 WATERPROOFING OF CUT AND COVER TUNNEL AND UNDERPASS HIGHWAY STRUCTURES

1.1 GENERAL

1. Bridge underpasses, cut and cover tunnels and their approach structures which are designed to exclude ground water shall be externally protected by a water proofing membrane as indicated on the drawings and in this document.

2. The waterproofing system shall ensure water tightness and provide long term protection to the concrete from the ingress of water borne chlorides or other deleterious substances.

3. The waterproofing system forms an essential part of the tunnel and therefore needs careful consideration during construction. It is imperative that the main contractor:

   (i) understands the needs of a specialist waterproofing contractor during installation of the water proofing system;

   (ii) makes allowance in his construction methodologies for this work;

   (iii) ensures close coordination with the waterproofing contractor throughout construction and backfilling operations to avoid any mechanical damage. If damage areas are identified they should be immediately repaired in accordance with the manufacturer's guidelines;

   (iv) enforces cooperation between the waterproofing applicator and other trades to ensure damage by other trades to the waterproofing membranes is reported timely and otherwise avoided;

   (v) provide all chamfers, fillets, and laps as recommended by the waterproofing manufacturer and he shall put in place appropriate measures to ensure that no damage occurs to the waterproofing membrane after placing or installation;

   (vi) does not permit unless absolutely necessary the storage of chemicals, rebar or any other material on top of the waterproofing membrane.

4. All elements of the waterproofing system shall be stored, applied and protected in strict accordance with the manufacturer's recommendations and in accordance with all relevant health and safety regulations.

5. The waterproofing system shall be designed to be fully effective over the design life of the structure and shall be demonstrated by the Contractor to be suitable for very aggressive groundwater and soils.

6. The waterproofing material shall be specifically formulated to allow application in the hot climatic conditions encountered in the Middle East and it should not be adversely affected by temporary heat gain whilst exposed during construction.

7. Any references to a superseded standard in this document shall be taken as a reference to the replacement standard that was current forty-two days prior to the date of return of Tenders. If no replacement standard exists, then the reference shall be taken as referring to a comparable, internationally recognized standard as directed by or approved by the Engineer.

8. This Specification is based primarily on products manufactured from PVC. Alternative materials may be permitted provided that it can be demonstrated to the Engineer that such materials can equally fulfill the same function as those specified. Any alternative materials must be fully compatible with all other elements of the waterproofing system. Alternative materials shall not be used without the written approval of the Engineer.

9. A list of all documents and standards referred to in Part 1 is included in Clause 2.12.

1.2 CERTIFICATION / APPROVALS

1. The waterproofing system shall have a proven record of use in the cut and cover construction method for underpasses and tunnels as well as immersed Tube tunnels.

2. All waterproofing materials shall be compatible with each other and shall be supplied by a manufacturers and installers operating a BS EN ISO 9001 or similar approved quality assurance scheme.

3. The Contractor shall submit to the Engineer for approval details of the proposed waterproofing system, which shall include shop drawings of all the typical waterproofing details (such as the construction and expansion joints, method of compartmentalization, etc.)

4. The waterproofing applicator must submit a Method Statement inclusive of Inspection and Test Plan and Safety Plan inclusive of Risk Assessment to cover all aspects of the waterproofing work to be approved by the Engineer.

5. The Waterproofing Applicator must be a certified or approved applicator of the manufacturer's waterproofing material. Waterproofing Applicator site staff shall have individual certification of training in the application of the materials. The Waterproofing Applicator's Certificate from the waterproofing manufacturer shall be annually renewable as from the date of issue.

1.3 APPLICATION / INSTALLATION

1.3.1 BONDED SYSTEM

1.3.1.1 Below Base Slabs and up Both Sides of the Base Slab

1. The waterproofing system shall be a sheet membrane system based on flexible PVC resins. Alternative materials may be permitted provided that it can be demonstrated to the Engineer that such materials are fully compatible with all other elements of the waterproofing system. Alternative materials shall not be used without the written approval of the Engineer.
2. A 100mm thick blinding layer shall be finished with a smooth finish, free from any projections prior to the installation of the sheet membrane.
3. The PVC sheet membrane shall be laid directly on the blinding layer with a minimum overlap of 80 mm; all overlap joints shall be double seam continuous machine welded.
4. Where double seams are not possible the single welded seams shall have a width of not less than 30mm. At the commencement of each days installation production, the wedge welding shall be trialed on test pieces of membrane and the resultant welding shall resist tearing apart by hand under reasonable force.
5. The membrane shall be capable of mechanically bonding to the underside and to the sides of the base slab of the tunnel. It shall not require protection boards or screeds above the membrane and shall be UV resistant.
6. The membrane shall have a Keyed Preformed Membrane (KPM) equipped with continuous keys, extruded on a preformed sheet membrane at regular intervals to form compartments and to form an integral bond when cast into concrete.
7. The membrane shall be made continuous across all construction, contraction and expansion joints.
8. The membrane/waterstop detail at expansion joints shall be capable of accommodating the full design movements (vertical and horizontal) of the structure.
9. The compartmentalization of the membrane shall not exceed the section of tunnel base slab between external waterstops at construction, contraction and expansion joints.
10. All joints between the membrane and the external waterstops, to form the compartmentalization, shall be double seam continuous machine welded and where double seams are not possible the single welded seams shall have a width of not less than 30mm.
11. Any modifications required to the sheet membrane for heat welding to the external waterstop shall be carried out strictly in accordance with the manufacturers recommendations and procedures.
12. The membrane shall be manufactured from polymer resins, be chemically resistant and shall have the minimum specified mechanical and physical properties as stated in Table 1.3.1.1 below:

Table 1.3.1.1 Required Properties for Bonded System Below Base Slabs and up Both Sides of the Base Slab		
Property	**Test Method**	**Value**
Thickness	Direct measurement	2.0mm
Density	ASTM D792	≥1.25g/cm^3
Puncture Resistance	ASTM E154	500N minimum
Elongation at Break	ASTM D638	250%
Tensile Strength	ASTM D638	≥15MPa
Tear Resistance	ASTM D1004	300N
Shore D hardness	ASTM D2240	54D (1 second)
Hydro Static Pressure Resistance	ASTM D5385-93	≥69m
Water Absorption	ASTM D570	<0.4%
Chemical Resistance to the following substances: Sulphuric Acid (10%); Hydro Chloric Acid (10%); Kerosene; benzene; Sodium Hydroxide; Sodium Chloride and Sodium Sulphate		No effect

13. The membrane shall be manufactured under BS EN ISO 9001 quality control, tested by the manufacturer to be free of pinholes, cracks or other defects and be certified that all batches of material meet the manufacturer's quality control and technical specifications before it is dispatched from the factory.

14. Reinforcement concrete spacer blocks in contact with the membrane shall be a minimum of 50mm wide and 50mm long. The concrete spacer blocks shall be positioned so that no spacer block has more than 500kg of load placed on it.

1.3.1.2 Walls and Roof of Tunnel

1. The waterproofing system shall be an elastomeric cold spray liquid system comprising a primer and two separately applied coats of membrane.

2. The physical properties of the system shall be resistant to any such effects from the sun, including but not limited to, UV, radiation and heat.

3. The density of the applied cured membrane shall be greater than 1.05g/cm^3.

4. All waterproofing materials including primers, tack coats etc. shall be compatible with each other and shall be supplied by a manufacturer and installer operating the BS EN ISO 9001 or similar approved quality assurance schemes. The membrane shall have a valid Agreement Certificate for Road and Bridge Structures approved by a member of the European Union of Agreement (UEAtc), and shall comply with UK Highways Authorities Product Approval Scheme (HAPAS).

5. The membrane shall be cold applied using a proportioning spray pump system. Each coat of membrane shall be applied strictly in accordance with the manufacturer's guidelines to a minimum dry film thickness of 1.0mm in order to produce a minimum total membrane dry film thickness of 2mm.

6. Checks shall be carried out every 10m^2 to ensure that the minimum thickness is being applied. These checks shall use a wet film thickness gauge or other appropriate method by the manufacturer or their representative. The method of testing shall be approved by the Engineer.

7. Before application of the second coat the fully cured surface of the first coat shall be examined and any visible defects made good in accordance with the manufacturers guidelines. Only after this QA/QC inspection has been completed may the second coat be applied. Following the application of the second coat the membrane will again be checked for defects and for pinholes by performing electrical holiday detection tests over the full surface area of waterproofing.

8. Increased wind can effect coverage rates and cause overspray. These effects can be mitigated by adjusting spray pressure and spray technique. For wind speeds in excess of 25kmh application can be difficult unless some form of wind shield is used. At these wind speeds measures must be taken to prevent overspray. Spraying shall be suspended when it is unsafe to continue e.g. flying objects, airborne sand/and or in the opinion of the Authorised Applicator compliance with the manufacturer's Quality Assurance is at risk.

9. Any termination of the waterproofing system at day joints for subsequent lapping of the waterproofing system shall be staggered with a minimum lap of 50mm for the primer, first coat and second coat.

10. To ensure that the integrity of any day joints and lapping is assured no component of the waterproofing system shall have a critical over coating time.

11. The physical properties and performance of all components of the waterproofing system shall not be affected by atmospheric humidity. The waterproofing system will be able to be applied in levels of Relative Humidity of up to 99%.

12. The details of the membrane at construction, contraction and expansion joints shall be in accordance with the section on joints of this specification (See Section 2.6.Joints).

1.3.1.3 Adhesive

1. The adhesive shall be a two component, flexible resin adhesive capable of bonding PVC sheets to concrete and steel as well as facilitating an intimate bond formation between the sprayed waterproofing membrane and PVC base slab and wall waterproofing or PVC Expansion Joints at the overlap. This bond will need to be proven by tensile adhesion testing.
2. The adhesive shall be capable of being applied underwater.
3. Lapping of the spray applied liquid waterproofing system onto the PVC base slab sheet membrane system shall be a minimum of 200mm.
4. Sufficient time for bonding of surfaces on site shall be allowed in the setting time of the adhesive.

1.3.1.4 Preparation of Surfaces

1. The minimum age of new concrete shall be 15 days prior to application of the waterproofing system provided that all required surface preparation is completed and that the minimum tensile adhesion value of 0.7MPa of the waterproofing system to the concrete is achieved.

2. All concrete surfaces to receive the sprayed applied waterproofing shall be dry, free of all traces of loose material, laitance, shutter oil, grease, curing compound, windblown deposits and other contaminants which could result in an adverse reaction with the protective system.
3. The concrete surfaces shall be free from surface defects including but not limited to small holes, minor cracking or defective joints. The Engineer's approval shall be obtained for the method of repairing any surface defects. Any preparatory filling required shall normally be carried out using an approved shrinkage compensated cementitious mortar.
4. The quality of formed concrete finish to surfaces receiving the waterproofing membrane shall be:
   (i) Uniform, dense and smooth surface with no grout runs;
   (ii) Abrupt irregularities permitted to be <3mm for formed concrete surface after stripping of forms. However these abrupt irregularities shall be removed by grinding;
   (iii) Gradual irregularities permitted are <5mm in 2m:
      (a) Tie bolt holes need to be repaired with an appropriate cementitious mortar;
      (b) Bugholes, blowholes and the like must be broken out and then repaired to an agreed method statement;
      (c) Honeycombed concrete areas of concrete must be repaired to an agreed method statement.
5. The quality of unformed finish to tunnel roof shall be:
   (i) Uniform, dense and smooth surface;
   (ii) Abrupt irregularities permitted to be <3mm during finishing work of poured concrete. However these abrupt irregularities shall be removed by grinding;
   (iii) Gradual irregularities permitted are <10mm in 2m;
   (iv) Finish concrete with a wooden or steel trowel;
   (v) Target finished concrete surface strength to be 0.7MPa at 14 days.
6. Prior to the application of the primer all concrete surfaces shall be sandblasted
7. To verify the quality of the concrete substrate for bonding of the membrane, a minimum of 1 tensile adhesion test is to be carried out on the substrate every 50m^2 prior to the application of the primer and membrane, subject to a minimum of 6 tests for each structure being tested.
8. The maximum ambient and substrate temperature permissible for application of any component of the waterproofing to take place is +50° Celsius.
9. The primer shall be compatible with the waterproofing membrane and will be recommended by the waterproofing manufacturer and shall meet their approval for use on this project. It shall be applied to the concrete substrate following the surface preparation and prior to the application of the first coat of waterproofing membrane. The primer is used to seal the surface of the concrete and to improve the adhesion of the waterproofing membrane.

1.3.1.5 Construction and Contraction Joints

1. A 175mm wide Polyester reinforcement scrim, as recommended by the manufacturer of the waterproofing system, shall be embedded into the first coat of membrane when the waterproofing system bridges over construction or contraction joints.

1.3.1.6 Technical Specification of the Spray Applied Liquid Membrane

1. The membrane shall have the minimum specified mechanical and physical properties as stated in Table 1.3.1.6 below:

Table 1.3.1.6
Required Properties for Spray Applied Liquid Membranes

PROPERTY	TEST METHOD	VALUE
Minimum Thickness	ASTM D412	2mm minimum
Elongation	BS903:A2 BS ISO37; ASTM D412	>80%
Density of cured membrane	ASTM D792	>1.05g/cm^3
Tensile Adhesion Strength of membrane	BS EN ISO 4624 Concrete Substrate Steel Substrate PVC Substrate	 ≥0.7 MPa ≥ 2.0 MPa ≥ 2.0 MPa
Water Vapour transmission	ASTM E96 at 23ºC	<4g/m^2 /day
Tensile Strength	BS 903:A2 BS ISO 37; ASTM D412	≥9MPa
Tear Strength	BS ISO 34-1 or ASTM D624	≥40 N/mm
Shore Hardness	BS2782: Part 3 Method 365BBS EN ISO 868	≥40 (Shore D) or equivalent approved by the Engineer.
Water penetration	BD47 or equivalent standard approved by the Engineer.	Zero
Static Crack-Bridging	ASTM C836	2mm @ 0ºC
Dynamic Crack Bridging	BD47 or equivalent standard approved by the Engineer.	≥1mm @ -10°C, 23°C & 40°C
Chemical resistance: - Anti-freeze (ethylene glycol) - Calcium Chloride - Diesel Fuel - Gasoline - Motor Oil - Sodium Chloride	TRL Research Report 248 or equivalent standard approved by the Engineer.	 Resistant Resistant Resistant Resistant Resistant Resistant
Resistance to Chloride ion penetration (%)	BD47 or equivalent standard approved by the Engineer.	0.00% increase in chloride
Immersion In Sea Water	BS EN ISO 2812-2 or equivalent standard approved by the Engineer.	No statistically significant change
Resistance to aggregate indentation	BD47 or equivalent standard approved by the Engineer.	0.00% increase in chloride & >95% recovered thickness at 40˚C, 80˚C and 125˚C
Resistance to chisel impact Chloride ion penetration (%) at -100C, 230C and 400C	BD47 or equivalent standard approved by the Engineer.	0.00% increase in chloride
Resistance to abrasion	SNCF Taber Method H22 Wheel – 1000 cycles or equivalent test approved by the Engineer.	<0.60g
Puncture resistance	SNCF Vibrogir, 41kN – 185kN Frequency of 5 Hz 2 million cycles using Mohr & Federhaff PV200 dynamic pulsator or equivalent standard approved by the Engineer.	No puncture without protection
Hydrostatic Testing	SNCF requirements on product specimens following the required ballast puncture resistance test. Equivalent tests may be used subject to the approval of the Engineer	10 bar resistance

1.3.1.7 Protection of Waterproofing Membrane

1. A minimum 75mm screed protection shall be provided on the waterproofing membrane on the roof slab and on top surfaces of foundations.

1.3.2 UNBONDED SYSTEM TYPE 1

1.3.2.1 General

1. The waterproofing system shall be a single layer unreinforced synthetic PVC 2.00 mm thick twin colour membrane below base slabs, walls and top slabs of the tunnel. Alternative materials may be permitted provided that it can be demonstrated to the Engineer that such materials are fully compatible with all other elements of the waterproofing system. Alternative materials shall not be used without the written approval of the Engineer.
2. For the integrity and water tightness of the waterproofing system, it is recommended that the entire waterproofing system is supplied by one manufacturer. Specifically, membranes and waterstops should be manufactured out of virgin raw materials only from the same formulation of raw materials.
3. All materials shall be compatible with other materials to which they abut. Particular attention shall be paid to the compatibility of interfaces and junctions with adjacent structures.
4. The system shall be compartmentalised with PVC waterstops and shall be welded to the membrane.
5. The compartmentalization shall be limited to the length of tunnel between construction and expansion joints.
6. Repairs to a leak need to be limited to the section of tunnel within the compartment where the leak has been identified.

1.3.2.2 Preparation of Surfaces

1. Surfaces to receive waterproofing shall be prepared in strict compliance with the requirements of the manufacturer. All contaminants, such as dust, loose particles, moisture, tar, bitumen, oils and greases, shall be removed from the surface. If necessary, rough or other unsuitable surfaces shall be improved to satisfy the manufacturer's recommendations for the product to be applied.
2. The Contractor shall examine substrate surfaces and ensure there are no conditions which will adversely affect the performance of the waterproofing works. Waterproofing works must not be commenced until unsatisfactory conditions have been corrected.

1.3.2.3 Below Base Slabs and up Both Sides of Base Slab

1. The blinding shall be finished with a smooth finish, free from any projections.
2. Formwork or blockwork up to the top of base slab level plus an additional height equal to half of the horizontal construction joint external waterstop shall be installed prior to the installation of the water proofing system on the underside and up the sides of the foundation or tunnel floor slab.

3. The geotextile shall be installed over the width of the base and up the sides of the formwork on a dry surface with a minimum overlap of 100 mm.
4. The PVC membrane shall then be laid on the geotextile with a minimum overlap of 80 mm; all overlap joints shall be double seam continuous machine welded.
5. After the completion of the membrane laying and testing, the waterstops for construction joints / compartment shall be installed and welded to the membrane to form closed compartments of maximum 150 m².
6. The control & injection flanges shall be fixed with each compartment connected with a PU pipe and terminated in an inspection box.
7. The second layer of geotextile shall be laid over the PVC membrane.
8. A protection screed of 75 mm shall be then laid on the geotextile over the width of the floor slab only, the waterstops shall at all times be exposed.
9. Special care shall be taken not to damage the waterproofing membrane on the sides of the foundation slab when fixing of reinforcement. A temporary protection board may be used in this area to prevent damage to the membrane.

1.3.2.4 Vertical Walls

1. Prior to casting of the walls, the control and injection flanges shall be fixed on the formwork, connected with a PU pipe and terminated at the inspection box. The re-injectable hose shall be installed at all construction joints of the walls and terminated at the junction box. All accessories for the injection hose shall be from the hose manufacturer. The swelling profile (acrylic base 20 x 10mm) shall also be fixed at the construction joints.
2. After casting of the wall, the geotextile shall be fixed on the concrete wall with the fixing discs spaced 2 m horizontal and vertical.
3. The PVC membrane shall be fixed on the vertical surface and welded to the fixing discs, overlap shall be of minimum 80 mm double seam continuous machine welded. The membrane shall be welded to the pre-installed waterstops to form the compartment.
4. A protection layer of Polypropylene board shall be fixed on the PVC membrane by a contact adhesive followed with a geotextile layer prior backfilling.

1.3.2.5 Top Slabs

1. The concrete top slab shall be finished with a smooth finish, free from any projections.
2. A sealing tape (PVC tape with fabric strips) shall be fixed with the epoxy adhesive at expansion, contraction joints and compartment.
3. The geotextile shall be installed on a dry surface with a minimum overlap of 100 mm.
4. The PVC membrane shall then be laid on the geotextile with a minimum overlap of 80 mm, all overlap joints shall be double seam continuous machine welded. The membrane shall be welded on the sealing tape to form the top slab compartment.
5. The second layer of geotextile shall be laid.
6. A protection screed of 75 mm shall then be laid on the geotextile, followed by the backfilling.

7. Special attention shall be taken when connecting the sealing tape to the external waterstop at the outer edges of the tunnel roof to ensure water tightness. This detail needs careful thought, designed and shop drawings prepared for approval by the Engineer.

1.3.2.6 Geotextile Protection

1. The geotextile protection and slip membrane shall be manufactured from Polypropylene base of minimum 350 g/m² applied on both sides of the membrane.

2. The geotextile sheet shall comply with the minimum following properties:

Table 1.3.2.6
Required Properties for Geotextile Protection

Test	Test Method	Requirement
Mass	BS EN ISO 9864	350 g/m^2
Elongation at break	BS EN ISO 10319	≥ 55%
Tensile Strength	BS EN ISO 10319	≥ 25 kN/m
Thickness under 2 Kpa	BS EN ISO 9863	≥ 2.9mm
CBR Puncture Resistance	BS EN ISO 12236	≥ 4.0 kN
Cone Drop Test	BS EN ISO 13433	≤ 10 mm

1.3.2.7 Technical Specification of the Unbonded Membrane

1. The membrane shall comply with the following minimum properties:

Table 1.3.2.7
Required Properties for Unbonded Membranes

Test (units)	Test Method	Requirement
Tensile Strength (N/mm^2)	BS EN ISO 527 - 1/3/5	> 15 N/mm^2
Elongation at break (%)	BS EN ISO 527 - 1/3/5	> 280%
Tear Strength	BS ISO 34 B	> 42 kN/m
Impact Resistance (500 g/750 mm)	BS EN 1107 – 2	No leakage
Static Puncture	BS EN ISO 12236	> 2 kN
Water tightness to liquid water (5 bar/72 h) (10 bar/ 24h)	BS EN 1928	No leakage
Thermal Ageing (70 d/70 ºC)	BS EN 1296	< 2%
Reaction to fire	SIA V280-12 (or equivalent standard approved by the Engineer)	Class 4.1

1.3.2.8 PVC Control and Injection Flanges

1. For unbonded systems, compartmentalization is required and will be limited to the length of tunnel between construction and expansion joints. Compartments should never extend beyond construction and expansion joints.
2. PVC control and injection flanges shall be spot-welded to the membrane fixed to the formwork (minimum 4 No. per compartment) for control and future injection of the compartment. The flange shall be connected with a PU pipe resistant to 10 bar pressure and terminated in an injection box at walls / roof slabs.

1.3.3 UNBONDED SYSTEM TYPE 2

1.3.3.1 General

1. The waterproofing system shall be a double layer unreinforced synthetic PVC 2.00 mm thick twin colour membrane and unreinforced synthetic PVC 1.5 mm thick one color respectively below base slabs and walls of the tunnel and one layer unreinforced synthetic PVC 2.00 mm thick twin colour membrane for top slabs of the tunnel. Alternative materials may be permitted provided that it can be demonstrated to the Engineer that such materials are fully compatible with all other elements of the waterproofing system. Alternative materials shall not be used without the written approval of the Engineer.
2. For the integrity and water tightness of the waterproofing system, it is recommended that the entire waterproofing system is supplied by one manufacturer. Specifically, membranes and waterstops should be manufactured out of virgin raw materials only from the same formulation of raw materials.
3. All materials shall be compatible with other materials to which they abut. Particular attention shall be paid to the compatibility of interfaces and junctions with adjacent structures.
4. The system shall be compartmentalized with 320 mm with 4 ribs PVC waterstops and shall be welded to the membrane.
5. The compartmentalization shall be limited to the length of tunnel between construction and expansion joints.
6. Repairs to a leak need to be limited to the section of tunnel within the compartment where the leak has been identified.

1.3.3.2 Preparation of Surfaces

1. Surfaces to receive waterproofing shall be prepared in strict compliance with the requirements of the manufacturer. All contaminants, such as dust, loose particles, moisture, tar, bitumen, oils and greases, shall be removed from the surface. If necessary, rough or other unsuitable surfaces shall be improved to satisfy the manufacturer's recommendations for the product to be applied.
2. The Contractor shall examine substrate surfaces and ensure there are no conditions which will adversely affect the performance of the waterproofing works. Waterproofing works must not be commenced until unsatisfactory conditions have been corrected.

1.3.3.3 Below Base Slabs and up Both Sides of Base Slab

1. The blinding shall be finished with a smooth finish, free from any projections.
2. Formwork or blockwork up to the top of base slab level plus an additional height equal to half of the horizontal construction joint external waterstop shall be installed prior to the installation of the water proofing system on the underside and up the sides of the foundation or tunnel floor slab.
3. The geotextile (min 350g/m^2) shall be installed over the width of the base and up the sides of the formwork on a dry surface with a minimum overlap of 100 mm.
4. The PVC membrane (2mm) shall then be laid on the geotextile with a minimum overlap of 80 mm; all overlap joints shall be double seam continuous machine welded.
5. After the completion of the membrane laying and testing, the waterstops for construction joints / compartment shall be installed and welded to the membrane to form closed compartments of maximum 150 m^2.
6. Install the second (protection) PVC (1.5mm) layer on top of the first PVC membrane and weld to the waterstops in each compartment to provide protection and act as a separation layer.
7. The control & injection flanges shall be fixed with each compartment fully welded to the second PVC layer connected with a PU pipe and terminated in an inspection box.
8. The second layer of geotextile (min 200 g/m2) shall be laid over the PVC protection membrane.
9. A protection screed of 75 mm shall be then laid on the protection geotextile over the width of the floor slab only, the waterstops shall at all times be exposed.
10. Special care shall be taken not to damage the waterproofing membrane on the sides of the foundation slab when fixing of reinforcement. A temporary protection board may be used in this area to prevent damage to the membrane.

1.3.3.4 Vertical Walls

1. Prior to casting of the walls, the control and injection flanges shall be fixed on the formwork, connected with a PU pipe and terminated at the inspection box. The re-injectable hose shall be installed at all construction joints of the walls and terminated at the junction box. All accessories for the injection hose shall be from the hose manufacturer. The swelling profile (acrylic base 20 x 10mm) shall also be fixed at the construction joints.
2. After casting of the wall, a layer of geotextile (min. 200 g/m2) shall be fixed on the concrete wall with the fixing discs spaced 2m horizontal and vertical.
3. The protection PVC membrane (1.5mm) shall be welded to the fixing discs and fully welded to the inner edges of pre-installed waterstops and also must be fully welded to the injection flanges.
4. The PVC membrane (2mm) shall be fixed on the vertical surface by spot welding to the PVC protection layer spaced 2m horizontal and vertical, overlap shall be of a minimum 80

mm double seam continuous machine welded. The membrane shall be welded to the pre-installed waterstops to form the compartment.

5. A protection layer of Polypropylene board shall be fixed on the PVC membrane by a contact water base adhesive followed with a geotextile layer (min. 350 g/m2) prior backfilling.

1.3.3.5 Top Slabs

1. The concrete top slab shall be finished with a smooth finish, free from any projections.
2. A PVC sealing tape (with fabric strips) shall be fixed with the epoxy adhesive at expansion, contraction joints and compartment.
3. The geotextile (min. 350g/m2) shall be installed on a dry surface with a minimum overlap of 100 mm.
4. The PVC membrane (2mm) shall then be laid on the geotextile with a minimum overlap of 80 mm, all overlap joints shall be double seam continuous machine welded. The membrane shall be welded on the sealing tape to form the top slab compartment.
5. The second layer of geotextile (min 350 g/m2) shall be laid.
6. A protection screed of 75 mm shall then be laid on the geotextile, followed by the backfilling.
7. Special attention shall be taken when connecting the sealing tape to the external waterstop at the outer edges of the tunnel roof to ensure water tightness. This detail needs careful thought, designed and shop drawings prepared for approval by the Engineer.

1.3.3.6 Geotextile Protection (350g/m²)

1. The geotextile protection (350g/m²) and slip membrane shall be manufactured from Polypropylene base of minimum 350 g/m² applied in the following locations:
   (i) Base – below membranes.
   (ii) Walls – to backfilled faces of membranes
   (iii) Top Slab – above membranes.

2. The geotextile sheet (350g/m²) shall comply with the minimum following properties:

Table 1.3.3.6
Required Properties for Geotextile Protection (350g/m²)

Test	Test Method	Requirement
Mass	BS EN ISO 9864	350 g/m^2
Elongation at break	BS EN ISO 10319	≥ 55%
Tensile Strength	BS EN ISO 10319	≥ 25 kN/m
Thickness under 2 Kpa	BS EN ISO 9863	≥ 2.9mm
CBR Puncture Resistance	BS EN ISO 12236	≥ 4.0 kN
Cone Drop Test	BS EN ISO 13433	≤ 10 mm

1.3.3.7 Technical Specification of the 2mm Unbonded Membrane

1. The membrane shall comply with the following minimum properties:

Table 1.3.3.7
Required Properties for the 2mm Unbonded Membrane

Test (units)	Test Method	Requirement
Tensile Strength (N/mm^2)	BS EN ISO 527 - 1/3/5	> 15 N/mm^2
Elongation at break (%)	BS EN ISO 527 - 1/3/5	> 280%
Tear Strength	BS ISO 34 B	> 42 kN/m
Impact Resistance (500g / 750 mm)	BS EN 1107 – 2	No leakage
Static Puncture	BS EN ISO 12236	> 2 kN
Dynamic Puncture	DIN 16726-5.12	≥ 1100 mm
Root Resistance	CEN TS 14416	No Penetration
Water tightness to liquid water (5 bar/72 h) (10 bar/ 24h)	BS EN 1928	No leakage
Thermal Ageing (70 d/70 ºC)	BS EN 1296	< 2%
Resistance to Oxidation – Tensile Strength Variation	BS EN 14575	< 25 %

1.3.3.8 Technical Specification for the Combined Protection System of 1.5mm PVC Membrane Layer and 200g/m^2 Geotextile (Base Slab & Vertical Walls)

1. The 200g/m^2 Geotextile shall comply with the following minimum properties:

Table 1.3.3.8.1
Required Properties for the 200g/m^2 Geotextile

Test (units)	Test Method	Requirement
Mass	BS EN ISO 9864	200 g/m2
Elongation at break	BS EN ISO 10319	≥ 30%
Tensile Strength	BS EN ISO 10319	≥ 14 kN/m
Thickness under 2 Kpa	BS EN ISO 9863	≥ 1.1mm
CBR Puncture Resistance (Static Puncture)	Refer to Table 1.3.3.8.3	
Cone Drop Test	Refer to Table 1.3.3.8.3	

2. The protection PVC membrane (1.5mm) shall comply with the following minimum properties:

Table 1.3.3.8.2 Required Properties for the 1.5mm Unbonded Membrane		
Test (units)	**Test Method**	**Requirement**
Mass	BS EN 1849-2	2040 g/m2
Elongation at break	BS EN ISO 527 - 3	≥275%
Tensile Strength	BS EN ISO 527 - 3	≥17 N/mm2
Thickness under 2 Kpa	BS EN 1849 -2	1.5 mm
CBR Puncture Resistance (Static Puncture)	Refer to Table 1.3.3.8.3	
Cone Drop Test	Refer to Table 1.3.3.8.3	
Tear Strength	BS ISO 34 B	>48 KN/m
Dynamic Puncture	DIN 16726-5.12	>800mm
Hydrostatic pressure resistance	EN 1928 method B	Waterproof @ 5 Bar.
Impact Resistance (500g / 750mm)	BS EN 1107-2	No leakage
Resistance to oxidation - Tensile strength verification	BS EN 14575	<20%
Root resistance	CEN TS 14416	No roots growth - root resistant
Water tightness to liquid water (5bar/72h)(10bar/24h)	BS EN 1928	No leakage
Thermal ageing (70d/70C)	BS EN 1296	<3%

3. The protection PVC membrane (1.5mm) and the 200g/m^2 geotextile shall comply with the following minimum properties when tested as a combined system:

Table 1.3.3.8.3 Required Properties for the 1.5mm Unbonded Membrane and 200g/m^2 Geotextile when tested as a combined system		
Test (units)	**Test Method**	**Requirement**
CBR Puncture Resistance (Static Puncture)	BS EN ISO 12236	≥ 4.0 kN
Cone Drop Test	BS EN ISO 13433	≤ 10 mm

1.3.3.9 PVC Control and Injection Flanges

1. For unbonded systems, compartmentalization is required and will be limited to the length of tunnel between construction and expansion joints. Compartments should never extend beyond construction and expansion joints.

2. PVC control and injection flanges shall be spot-welded to the membrane fixed to the formwork (minimum 4 No. per compartment) for control and future injection of the compartment. The flange shall be connected with a PU pipe resistant to 10 bar pressure and terminated in an injection box at walls / roof slabs.

1.4 REINJECTABLE HOSES AND RESIN

1. The type of reinjectable hoses shall be specified by the water proofing manufacturer and detailed on the shop drawings for approval by the Engineer.
2. The system shall be 100% reinjectable at any time during its lifespan.
3. The reinjectable grout hose shall be suitable to be placed and fixed over rough concrete substrates and to maintain a continuous contact with that substrate.
4. The injection resin shall be based on a 3 component polyacrylic resins. The resin shall be chemically resistant and not be reliant on adhesion to the substrates it is in contact with for waterproofing performance. The gelling time (from 8 to 50 minutes) of the resin shall be able to be retarded or accelerated to suit the conditions of water outflow and length of injection path required. The resin manufacturer shall supply accelerator and or retarder materials suitable for mixing with the resin to alter the gelling time.
5. The compressive strength of the mixed resin after gelling should be very low to allow reinjection at high pressure.
6. The injection shall be suitable for reinjection at low temperature to very high temperatures (-10°C to +80°C).
7. The resin shall be a low viscosity reactive to water (swellable) and have a PH in the range of 8 to 11.

1.5 WATERSTOPS

1. The waterstop shall be based on flexible PVC resins preformed to shape and thickness and to a suitable profile for both internal and external locations of the concrete structure. Alternative materials may be permitted provided that it can be demonstrated to the Engineer that such materials are fully compatible with all other elements of the waterproofing system. Alternative materials shall not be used without the written approval of the Engineer.
2. The waterstop shall be chemically resistant and shall have the minimum specified mechanical and physical properties as stated in Table 2.5 below:

Table 1.5
Minimum Required Properties for Waterstops

Property	Test Method	Value
Specific gravity	ASTM D792	1.27 (± 0.3)g/m^2
Elongation at rupture	ASTM D638	350%
Tensile Strength	ASTM D638	>15 MPa
Water absorption	TS 3078 (or equivalent standard approved by the Engineer)	1% by weight
Hardness	TS 3078 (or equivalent standard approved by the Engineer)	75 (±5) Shore A

3. The waterstops shall be of sufficient thickness and width, have sufficient embedment capacity into the concrete to withstand 2.5bar negative water pressure without failure and take the movement indicated on the drawings. The waterstop shall be at least 4mm thick.

1.6 JOINTS

1. The detail of the waterproofing membrane at construction, contraction and expansion shall be shown on the shop drawings for approval by the Engineer. Of particular interest will be the following:

   (i) The location of the reinjectable grout hoses and injection points;
   (ii) The location of the swelling bars;
   (iii) The location of all internal and external waterstops;
   (iv) The details of the additional PVC sheet membrane above the external waterstops at expansion joints;
   (v) The overlapping joint details of the spray membrane with the external waterstop and PVC sheet membrane;
   (vi) The waterproofing expansion joint detail at the top corners of the tunnel, given that the external waterstop stops at that location;
   (vii) The waterproofing details at expansion joints at the top of the tunnel roof slabs.

2. The following details are however recommended:

   (i) The concrete substrate at all construction joints is scabbled to remove all laitance and expose the aggregate. Wetting the surface of the concrete substrate at the expansion joint to establish a saturated surface dry condition prior to the placement of concrete is also recommended;
   (ii) Reinjectable hoses should be installed at all construction and expansion joint locations strictly in accordance with the manufacturer's specifications. They are preferably located at or close to the ends of the internal waterstop at expansion joints and on the concrete surface close to the centre of the section at all construction joints;
   (iii) Swelling bars shall also be fixed with swelling mastic on the prepared concrete substrate at all construction joints. Preparation of the concrete substrate at construction joints shall include scabbling of the concrete surface to remove all laitance and expose the aggregate;
   (iv) All external and internal water stops shall be made of PVC, manufactured preferably from the same raw material as the membrane for full compatibility. For construction, contraction joints and compartments (for unbonded system) the water stops shall be 310 mm wide with 6 no. ribs, while for expansion joints the water stops shall be 320 mm wide with 6 no. ribs;
   (v) All expansion joints shall be sealed internally with a PVC water stop of 320 mm wide. The waterstop shall be able to accommodate the design movements (horizontal and vertical) of the structure;
   (vi) All internal waterstops shall be maintained in their designated location during concrete placement by means of non-corrosive tie straps with the purpose of locating the outer edges of the waterstop to the reinforcement cage. This is particularly important for the waterstops along the foundation slab to wall construction joint. These waterstops if left unsupported will be flattened onto the

concrete substrate surface during concrete placement thus rendering them ineffective.

1.7 BACKFILLING OPERATION

1. A layer of geotextile together with a protection board shall be provided to protect the waterproofing system on the outer walls of tunnels and retaining walls prior to backfilling. However in the case of the bonded system, if due care is exercised during backfilling and fulltime supervision is provided from the waterproofing manufacturer during the entire backfilling operation, it shall be acceptable to do away with the geotextile layer and protection board.
2. The backfilling material shall consist of a selected graded backfill from 0 to 75mm max size of aggregate.
3. During the compaction of the graded backfill material the compaction machines must take care not to come into contact with the waterproofing system. If contact occurs the contact area shall be inspected to see whether the waterproofing system has merely been marked by the tracks of the compaction machine or whether it has been damaged. If damaged, the waterproofing system must be repaired prior to continuation of the backfilling operation.
4. If the backfilling contractor notices any potential damage to the waterproofing system during compaction they are to inform the waterproofing applicator immediately.

1.8 ADDITIONAL REQUIREMENTS

1. All waterproofing systems shall be bonded to the external waterstop on the entire circumference of the tunnel at all construction and expansion joints to ensure compartmentalization requirements.
2. Where ever possible double seals shall be installed at all joints in the unbonded systems.
3. Shear keys at construction and expansion joints shall be continuous on the entire circumference of the tunnel.
4. Internal waterstops shall preferably be installed at the centre of the shear key or at a distance of at least 300mm from the external waterstop.
5. Waterstops with anchoring and sealing ribs shall not be used at the top of concrete sections such as at wall foundations and tunnel roof slabs. An alternate system which does not require the anchoring and sealing ribs for sealing from water ingress shall be utilized.
6. The connection between this alternate system and the wall external waterstop (for example at the top external corner of a tunnel) shall be carefully designed and submitted for approval prior to use.
7. A triple barrier system which will include the internal waterstop, the external waterstop and an unbounded section of waterproofing membrane shall be provided at all expansion joints.
8. Paddle flanges or swelling bars shall be installed on both sides of all pipes passing through expansion joints. Movement joints in the pipes shall also be designed to be water tight and to accommodate the expansion and contraction movements of the expansion joints.

1.9 QUALITY ASSURANCE AND QUALITY CONTROL

1. All sampling and testing shall be carried out in compliance with the specified sampling and testing standards.
2. The testing frequency stipulated herein shall be mandatory unless otherwise stated. The tests are to be conducted as per the demands of the site as applicable. The same testing sequence and frequency shall be adopted for the recycled materials as applicable.
3. All testing will have to be carried out on site or at a designated laboratory irrespective of whether the materials have been tested by the manufacturer or by an intermediate party or the availability of the conformity certificates.
4. Where the testing frequency specified in a standard differs from a specific requirement stated in this document, the higher frequency is deemed to be applicable. Sampling and testing frequency may be modified as directed by the Engineer.
5. Product manufacturers shall provide independent test reports for each of the properties listed in the following:

Table 1.3.1.1	Required Properties for Bonded System Below Base Slabs and up Both Sides of the Base Slab
Table 1.3.1.6	Required Properties for Spray Applied Liquid Membranes
Table 1.3.2.6	Required Properties for Geotextile Protection
Table 1.3.2.7	Required Properties for Unbonded Membranes
Table 1.5	Required Properties for Waterstops

6. Product manufacturers shall provide a Certificate of Conformity for each batch of material delivered to site, confirming compliance with the technical requirements herein.
7. The contractor shall submit samples and full technical details for approval by the Engineer. Samples shall include 300 x 300 mm of membranes and 300mm of strip products, as appropriate. The submission shall be full and complete and include components of the whole of the waterproofing system as a single package.
8. The Contractor shall execute a trial test section on vertical and horizontal surfaces which shall include details of construction and expansion joints, complete with protection system for testing and approval by the Engineer before continuing with the application/installation to the structures.
9. The membrane shall be visually inspected and any necessary remedial work shall be carried out before the application of the subsequent covering up. All repairs shall be inspected and approved by the Engineer.
10. The manufacturer shall be present on site at critical stages of the application/installation and during all testing and shall be responsible for maintaining standards and quality and for training of the Material Applicator's staff when required.
11. Where ever possible double seam welds shall be provided at joints in unbonded systems. All double seam welded joints shall be tested under air pressure of 2bar in the gap between weld runs. This pressure shall be held for 10 minutes and the pressure should not drop by more than 15%. All single seam welds shall be tested non-destructively using a spark testing device at a voltage of approximately 10,000V. All of these joints shall also

be tested for any discontinuity of welding by running a blunt bladed instrument along the entire length of all the welds in accordance with the manufacturer's recommendations.

12. The manufacturers on-site Quality Assurance procedures shall be followed without exception and shall include but not limited to the following:
    (i) Site inspection;
    (ii) For bonded systems:
        (a) Substrate cleaning and preparation,
        (b) Adhesion testing,
        (c) Primer application,
        (d) Wet film thickness measurements or other appropriate method by the manufacture or their representative,
        (e) Holiday detection testing,
        (f) Material consumption monitoring and evaluation;
    (iii) For unbonded systems:
        (a) Membrane cutting to size and laying,
        (b) Membrane joint welding and testing,
        (c) Membrane terminations detailing;
    (iv) Final inspection;
    (v) Reinjection system:
        (a) Grout tube fixing and inlet/outlet tube fixing,
        (b) Resin mixing and gel time testing,
        (c) Injection inspection (low pressure),
        (d) Second injection (high pressure);
13. The following testing shall be carried out on site:
    (i) Substrate and spray membrane shall include tensile adhesion tests on the cured membrane (3 per 500m^2);
    (ii) Wet film thickness checks or other appropriate method by the manufacture or their representative (1 per 10m^2);
    (iii) Pinhole holiday detection tests (100% of area);
    (iv) Elongation at break, shore hardness, tensile strength and tear strength (1 per 10,000m^2)

    The test methods and standards indicated in Table 1.3.1.1, Table 1.3.1.6, Table 1.3.2.6, Table 1.3.2.7 and Table 1.5 shall be used to verify compliance.
14. Records shall be maintained on a daily basis for each of the following:
    (i) Coverage rates where appropriate;
    (ii) Weather;
    (iii) Substrate surface condition.

1.10 WARRANTY

1. All components and elements of the waterproofing system which are needed to make the structure watertight shall be proven to work together. There shall be a single source of responsibility and performance of the products. The manufacturer shall confirm full and proven compatibility of the entire waterproofing system in writing.
2. The Contractor shall provide 15 years unlimited warranty on all workmanship and 25 years on all waterproofing material and waterstops. The warranty will ensure the tunnel remains dry during the warranty period and that leaks will be repaired in a timely manner at no extra cost to the Client.

1.11 MEASUREMENT AND PAYMENT

1. The tendered rate for waterproofing shall include full compensation for supply and application of all materials and all complementary works, for all labour, equipment, tools and incidentals necessary to complete the work to the satisfaction of the Engineer.
2. The unit of measurement shall be the square metre area of concrete surfaces receiving the membrane.

1.12 STANDARDS AND DOCUMENTS REFERRED TO IN PART 1

British Standards Institution

BS ISO 34	Rubber, vulcanized or thermoplastic. Determination of tear strength.
BS ISO 37	Rubber, vulcanized or thermoplastic. Determination of tensile stress-strain properties.
BS EN ISO 527	Plastics. Determination of tensile properties.
BS EN ISO 868	Plastics and ebonite. Determination of indentation hardness by means of a durometer (Shore hardness).
BS 903-A2	Physical testing of rubber. Determination of tensile stress-strain properties.
BS EN 1107	Flexible sheets for waterproofing. Determination of dimensional stability.
BS EN 1296	Flexible sheets for waterproofing. Bitumen, plastic and rubber sheets for roofing. Method of artificial ageing by long term exposure to elevated temperature.
BS EN 1928	Flexible sheets for waterproofing. Bitumen, plastic and rubber sheets for roof waterproofing. Determination of watertightness.
BS 2782-3	Methods of testing plastics. Mechanical properties. Flexural vibration. Non-resonance method.
BS EN ISO 2812-2	Paints and varnishes. Determination of resistance to liquids. Water immersion method.
BS EN ISO 4624	Paints and varnishes. Pull-off test for adhesion.
BS EN ISO 9001	Quality management systems. Requirements.
BS EN ISO 9863	Geosynthetics. Determination of thickness at specified pressures.
BS EN ISO 9864	Geosynthetics. Test method for the determination of mass per unit area of geotextiles and geotextile-related products.
BS EN ISO 10319	Geosynthetics. Wide-width tensile test.
BS EN ISO 12236	Geosynthetics. Static puncture test (CBR test).
BS EN ISO 13433	Geosynthetics. Dynamic peroration test (cone drop test).

ASTM International

ASTM C836	Standard Specification for High Solids Content, Cold Liquid Applied Elastomeric Waterproofing Membrane for Use with Separate Wearing Course.
ASTM D412	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension.
ASTM D570	Standard Test Method for Water Absorption of Plastics.
ASTM D638	Standard Test Method for Tensile Properties of Plastics.
ASTM D792	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.
ASTM D1004	Standard Test Method for Tear Resistance (Graves Tear) of Plastic Film and Sheeting.
ASTM D2240	Standard Test Method for Rubber Property 8212;Durometer Hardness.
ASTM D5385-93	Standard Test Method for Hydrostatic Pressure Resistance of Waterproofing Membranes.
ASTM E96	Standard Test Methods for Water Vapor Transmission of Materials.
ASTM E154	Standard Test Methods for Water Vapor Retarders Used in Contact with Earth Under Concrete Slabs, on Walls, or as Ground Cover.

Highways Agency (United Kingdom)

BD 47	Waterproofing and Surfacing of Concrete Bridge Decks.

Transport Research Laboratory

TRL Research Report 248	Laboratory tests on waterproofing systems for concrete bridge decks.

Swiss Association for Standardization

SIV V280	Polymer Membranes, Materials Testing and Requirements

European Committee for Standardization

TS 3078	PVC Plastic for Construction and Expansion Joints In Concrete