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भारतीय मानक मसौदा

भूकृत्रिम – लाइनिंग के लिए पीवीसी भू झिल्ली – विशिष्टी

(IS 15909 : 2020 *का तीसरा पुनरीक्षण*)

Draft Indian Standard

Geosynthetics — PVC Geomembranes for Lining — Specification

(*Third Revision of* IS 15909 : 2020)

ICS 59.080.70

Last date for receipt of comment is **10 February 2025**

FOREWORD

(Formal clauses will be added later)

The standard was first published in 2010. The first revision of the standard was undertaken to incorporate a new variety of geomembrane with a thickness of 2.00 mm and the test methods for tear strength, puncture resistance, and to modify the requirement for stability to ultraviolet radiation. The standard was subsequently revised in 2015 to classify the standard in two categories based on their end use and thickness and incorporate geomembranes with thicknesses of 2.50 mm and 3.00 mm, along with their specific requirements.

The present revision of the standard has been made to incorporate the following major changes:

a) Provision has been made for manufacturing of bottom layer of Category B, PVC geomembranes in multiple layers, with a minimum of three layers;
b) Test method for measuring signal layer thickness and number of layers have been specified;
c) Peel strength for each set of layers has been specified for category B, PVC geomembrane;
d) Type tests for 100 years durability including accelerated ageing under permanent exposure to elevated temperatures, oxidation resistance, behaviour after immersion in aqueous solutions, soil burial test, have been incorporated for category B, PVC geomembrane;
e) Sampling clause has been modified: and
f) References given in Annex A to Indian Standard have been updated.

The guidelines for installation of PVC geomembranes are given in Annex Z for guidance only.

1 SCOPE

1.1 This standard covers the requirements for PVC geomembrane (flexible polyvinyl chloride) of two categories (Category A and B) depending upon their end use.

1.1.1 Category A includes lining for use in canals, ponds, reservoirs, water features (bodies) for seepage control, for lining of landfills, hazardous waste management, solid waste management and industrial effluent for waste containments and for water proofing of basement, roof/terrace.

1.1.2 Category B includes PVC geomembrane for unexposed application for use in large underground civil structures, basement, road underpasses, waterproofing of rail/road tunnels, bunkers, dams and other mega civil structures. These can also be used for water proofing of unexposed roofs and terrace.

2 REFERENCES

The standards listed in Annex A contain provisions which through reference in this text, constitute provision of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed in Annex A.

3 MATERIAL AND MANUFACTURE

3.1 Category A — PVC geomembrane shall be suitably manufactured from vinyl chloride resin homo polymer. Water soluble compounding ingredient shall not be used. Plasticizers that are resistant to migration and bacterial growth shall be used. The PVC geomembrane shall be pigmented to produce an uniform colour. Any dark colour like black, blue, grey and brown etc shall not be used for manufacturing so as to avoid use of recycled material.

3.2 Category B — PVC waterproofing membrane for unexposed applications shall be made from virgin raw material and shall have a smooth surface. Water soluble compounding ingredient shall not be used. Plasticizers that are resistant to migration and bacterial growth shall be used. The membrane shall be manufactured in twin colour with white signal layer (top layer) to allow visual check of the condition of membrane in case of any damage during the installation. The bottom part of the membrane shall preferably be in light orange colour, multi-layered and shall consist of at least 3 layers. Any dark colour like black, blue, grey and brown etc shall not be used for manufacturing of bottom layers so as to avoid use of recycled material.

3.3 The layers of PVC films shall be joined together by a suitable heat fusion lamination only. The lamination shall be such that the finished material meets the requirements as given in Table 1, Table 2 and Table 3.

NOTE — Layers shall not be joined by adhesive.

3.4 For making larger panel of geomembranes, two or more sheets of geomembrane shall be joined together by a suitable heat sealing process keeping an overlap of at least 2.5 cm.

4 CATEGORIES AND TYPES

4.1 Based on the end use and thickness of PVC geomembrane, the material shall be classified as under:

4.1.1 Category A

a) *Type I* — Having thickness of 0.30 mm;
b) *Type II* — Having thickness of 0.50 mm;
c) *Type III* — Having thickness of 0.75 mm;
d) *Type IV* — Having thickness of 1.00 mm; and
e) *Type V* — Having thickness of 1.50 mm.

4.1.2 Category B

a) *Type VI* — Having thickness of 2.00 mm;
b) *Type VII* — Having thickness of 2.50 mm; and
c) *Type VIII* — Having thickness of 3.00 mm.

5 REQUIREMENTS

Category A, PVC geomembranes shall conform to the requirements as specified in Table 1 whereas, Category B, PVC geomembranes shall conform to the requirements as specified in Table 2 and Table 3.

Table 1 Requirement of PVC Geomembranes, Category A

(*Clauses* 3.3 *and* 5)

Sl No.	Property	Requirement					Tolerance	Method of Test, Ref to
		Type I	Type II	Type III	Type IV	Type V		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Length and width	← As agreed →					±1 Percent	Annex B
ii)	Thickness , mm	0.30	0.50	0.75	1.00	1.50	±7 Percent	3.2 of IS 3464
iii)	Specific gravity	← 1.30 to 1.40 →					–	Appendix A (Method A) of IS 2076
iv)	Tensile strength, N/mm^2 (Longitudinal and transverse)	11.28	12.75	13.73	14.72	14.72	*Min*	Appendix B of IS 2076
v)	Elongation at break, percent (Longitudinal and transverse)	← 250 →					*Min*	Appendix B of IS 2076
vi)	Tear propagation strength, N/mm:							
	a) Machine direction	20	45	55	75	90	*Min*	Annex C
	b) Cross direction	15	40	45	65	70		
vii)	Index puncture resistance, N	95	230	290	350	425	*Min*	Annex D
viii)	Low temperature crack resistance	Shall not break, crack at (-) 23 ± 2^0C	Shall not break, crack at (-) 26 ± 2^0C	Shall not break, crack at (-) 28 ± 2^0C	Shall not break, crack at (-) 30 ± 2^0C	Shall not break, crack at (-) 30 ± 2^0C	–	Annex E
ix)	Hydrostatic resistance, kg/cm^2	2.5	4	6	7.5	10	*Min*	Annex F
x)	Seam strength, N	75 percent (*Min*) of original value or unbreakable seam					*Min*	Annex G
xi)	Volatile loss, percent	← 1 →					*Max*	7 of IS 3464
xii)	Peel strength for each set of layers, N/m (*see*	← 1050 →					*Min*	Annex H

	Note)			
xiii)	Resistance to soil burial (30 days): a) Tensile strength, percent change (Longitudinal and transverse) b) Elongation at break, percent change (Longitudinal and transverse)	5 20	*Max*	Annex J
xiv)	Water extraction, percent loss in weight	0.15	*Max*	Annex K
xv)	Stability to ultraviolet radiations, percent retention in tensile strength and elongation at break (Longitudinal and transverse)	80	*Min*	Annex L
NOTE — Requirement of peel strength is applicable only when the product manufactured is having two or more layers laminated by heat fusion technology to make a homogeneous product of required dimension.				

Table 2 Requirement of PVC Geomembranes, Category B

(*Clauses* 3.3 *and* 5)

Sl No.	Property	Requirement			Tolerance	Method of Test, Ref to
		Type VI	Type VII	Type VIII		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Length and width	← As agreed →			±1 Percent	Annex B
ii)	Thickness at 20 kPa pressure, mm	2.00	2.50	3.00	+ 10 percent, minus 0 percent	Method A of IS 13162 (Part 3)
iii)	Construction of membrane					
	a) Signal layer thickness	← 0.20 →			±0.02	Annex M
	b) Number of layers in the bottom part of membrane	← 03 →			*Min*	Annex H
iv)	Specific gravity	← 1.30 →			±0.03	Appendix A (Method A) of IS 2076
v)	Tensile strength, N/mm^2 (Longitudinal and transverse)	← 17 →			*Min*	Annex P
vi)	Elongation at break, percent (Longitudinal and transverse)	← 325 →			*Min*	Annex P
vii)	Tear propagation strength, N/mm:				*Min*	Annex Q
	a) Machine direction	← 100 →				
	b) Cross direction	← 100 →				
viii)	Peel strength for each set of layers, N/m	← 2000 →			*Min*	Annex H
ix)	Behaviour during perforation (Static puncture test), N	2 500	2 800	3 300	*Min*	IS 16078
x)	Height of fall without perforation, mm	1 100	1 400	1 800	No perforation	Annex R
xi)	Cold crack resistance at low	← (-)35º C →			Shall not	Annex E

	temperature, ºC		break/crack	
xii)	Hydrostatic pressure resistance	Waterproof at 5 bar for 24 h	–	Annex S
xiii)	Dimensional stability at 80 ºC for 6 h, percent	← 3 →	*Max*	Annex T
xiv)	Change of dimensioning after heating at 70 ºC for 2 h	← Stable →	–	Annex U
xv)	Behaviour after storage in aqueous solution, resistance to acid and alkali after 28 days	Change in tensile and elongation shall be within ± 10 percent of the original value	–	Annex V
xvi)	Strength of welded seam shear resistance, N/50 mm	← 1050 →	*Min*	Annex W
xvii)	Resistance to static puncturing	No perforation shall be observed	–	Annex Y
xviii)	Flammability test, horizontal and vertical rate of burning, mm/min	← 100 →	*Max*	Annex A and Annex B of IS 15061

Table 3 Type Tests for 100 Years Durability of PVC Geomembranes, Category B
(*Clauses* 3.3 *and* 5)

Sl No.	Property	Requirements			Method of Test, Ref to
		Type VI	Type VII	Type VIII	
i)	Accelerated ageing under permanent exposure to elevated temperatures (70 days at 80°C in hot air oven)				Annex AA
	a) Reduction in tensile strength and elongation at break	≤ 20 percent			
	b) Foldability at low temperatures	No cracks at (-) 20 °C			Annex AA
ii)	Oxidation resistance (90 days at 85°C in a hot air oven), reduction in tensile strength and elongation at break	≤ 20 percent			Annex BB
iii)	Behaviour after immersion in aqueous solutions of Ca $(OH)_2$ saturated limewash) for 360 days at 50°C				Annex CC
	a) Reduction in tensile strength and elongation at break	≤ 25 percent			
	b) Reduction in impact load (drop height)	≤ 40 percent			
	c) Mass change	≤ 7 percent			
iv)	Behaviour after immersion in aqueous solutions (0.5 percent sulphuric acid) (360 days at 50 °C)				Annex CC
	a) Reduction in tensile strength and elongation at break	≤ 25 percent			
	b) Reduction in impact load (drop height)	≤ 40 percent			
	c) Mass change	≤ 7 percent			
v)	Behaviour after immersion in hot water (360 days at 70 °C)				Annex CC
	a) Reduction in tensile strength and elongation at break	≤ 25 percent			
	b) Mass change	≤ 7 percent			

	c) Reduction in impact load (drop height)	≤ 40 percent	
	d) Dimensional change	≤ 5 percent	
vi)	Resistance to soil burial (112 days)		Annex J
	a) Reduction in tensile strength and elongation at break	≤ 25 percent	
	b) Mass change	≤ 10 percent	

6 DIMENSIONS AND TOLERANCES

The dimensions of PVC geomembrane when tested by the method given in Annex B shall be as agreed to between the buyer and the seller. A combination of width may be seam welded together to obtain desired width of panel. However, no sheet of the PVC geomembrane shall be less than 2 000 mm.

7 COLOUR, SURFACE CHARACTERISTICS AND FREEDOM FROM DEFECTS

7.1 The PVC geomembrane shall be uniform in colour, texture and finish. The PVC geomembrane shall be free from pin-holes and other foreign particles, when tested, by the method prescribed in Annex N. The laminated film shall not peel off.

7.2 The PVC geomembrane shall be reasonably free from defects such as holes, tears or blisters. The edges shall be free of nicks and cuts visible to the naked eye.

8 MARKING

8.1 The PVC geomembrane shall be supplied in roll form and each roll shall bear a label on which the following information shall be provided with indelible ink:

a) Name, category and type of the geomembrane;
b) Name and/or trade-mark of the manufacturer;
c) Thickness and declared length and width; and
d) Batch No. and date of manufacture.

8.2 BIS Certification Marking

The PVC geomembranes conforming to the requirements of this standard may be certified as per the conformity assessment schemes under the provisions of the *Bureau of Indian Standards Act*, 2016 and the Rules and Regulations framed thereunder, and the PVC geomembranes may be marked with the Standard Mark.

9 CONDITIONING OF TEST SPECIMEN

Unless otherwise specified, all samples shall be conditioned at a temperature of (27 ± 2)°C and relative humidity of (65 ± 5) percent for a period of 2 h.

NOTE — An alternate conditioning temperature of (23 ± 2)°C and relative humidity of (50 ± 5) percent for a period of 2 h or different conditioning time as specified in applicable test methods, may also be acceptable, in case of an agreement between the buyer and seller, without any change in any of the requirements of geomembranes specified in Table 1, Table 2 and Table 3.

10 SAMPLING

10.1 Lot — In any consignment all the geomembrane rolls of same category and type and dispatched to buyer against one dispatch note shall constitute a lot.

10.2 The number of geomembrane rolls to be selected from a lot shall be in accordance with Table 4. The geomembrane roll shall be selected at random with the use of random number tables (*see* IS 4905).

10.3 The conformity of the lot to the requirements of this standard shall be determined on the basis of the tests on the samples selected from it.

Table 4 Sample Size and Permissible Number of Non-conforming Rolls

(*Clause* 10.1)

Sl No.	No. of Rolls in Lot	Sample Size	Sub-sample Size	Permissible Number of Non-conforming rolls
(1)	(2)	(3)	(4)	(5)
i)	Up to 90	5	3	0
ii)	91 to 150	8	3	0
iii)	151 to 500	13	5	1
iv)	501 to 1200	20	5	1
v)	1201 to 10000	32	8	2
vi)	10001 and above	50	8	3

10.4 Criteria for Conformity

The number of rolls selected from the lot shall be tested for various requirements for determining conformity of the lot requirements specified in this standard shall be as given in Table 5.

Table 5 Number of Tests and Criteria for Conformity

(*Clause* 10.4)

Sl No.	Characteristics	Number of Samples	Criteria for Conformity
i)	Length, width, thickness	According to col 3 of Table 4	All the test pieces shall meet the requirement.
ii)	Tensile strength, elongation at break, tear resistance, index puncture resistance, static puncture, hydrostatic resistance, hydrostatic pressure resistance, seam strength, peel strength, water extraction, cold crack resistance, specific gravity, low temperature crack resistance, volatile loss, flammability test	According to col 4 of Table 4	Number of non-conforming pieces shall not exceed the corresponding number given in column 5 of Table 4.
iii)	Resistance to soil burial, stability to ultraviolet radiations, accelerated ageing under permanent exposure to elevated temperatures, oxidation resistance, behaviour after immersion in aqueous solutions	One sample shall be tested from each lot for each requirement.	All the test pieces shall meet the requirement.

NOTE — For the tests mentioned at Sl No. iii), the sample shall be tested once in every 5 years or whenever there is any significant change in formulation or production technology.

ANNEX A
(*Clause* 2)

IS No	*Title*
IS/ISO 105-B02 : 2014	Textiles — Tests for colour fastness Part B-02 Colour fastness to artificial light : Xenon arc fading lamp test
IS 229 : 2021	Ethyl acetate — Specification (*fourth revision*)
IS 2076 : 1981	Specification for unsupported flexible polyvinyl chloride sheeting (*first revision*)
IS 3464 : 1986	Methods of test for plastic flooring and wall tiles (*second revision*)
IS 4905 : 2015/ ISO 24153 : 2009	Random sampling and randomization procedures (*first revision*)
IS 13162 (Part 3) : 2021/ ISO 9863-1:2016	Geosynthetics — Determination of thickness at specified pressures (Part 3) : Single layers (*first revision*)
IS 15061 : 2002	Automotive vehicles — Flammability requirements
IS 16078 : 2013	Geosynthetics — Static puncture test (CBR test)

ANNEX B
[*Table* 1 *and Table* 2, *Sl No.* (i) *and clause* 6]

MEASUREMENT OF LENGTH AND WIDTH OF PVC GEOMEMBRANE

B-1 MEASUREMENT OF WIDTH OF PVC GEOMEMBRANE

B-1.1 Apparatus

A steel tape capable of measuring to the nearest 1 mm.

B-1.2 Conditioning

Unless otherwise specified, all samples shall be conditioned at a temperature of (27 ± 2)°C in air for at least 60 minutes.

B-1.3 Procedure

B-1.3.1 Condition the test specimen as specified in **B-1.2**.

B-1.3.2 Immediately after conditioning, lay the sheet or roll on a flat surface so as to fully expose the width without distortions.

B-1.3.3 Measure the width of the specimen in at least three different places along its length. During measurement, measuring tape shall be placed as nearly as possible at right angle to the edge of the sheet or roll.

B-1.3.4 Report the average of all three readings.

B-2 MEASUREMENT OF LENGTH OF PVC GEOMEMBRANE

Length of the PVC geomembrane shall be measured by any of the method given in **B-2.1** or **B-2.2**.

B-2.1 Method A (By using roll length counter)

B-2.1.1 *Apparatus*

Roll length counter, capable of measuring to the nearest 0.01 m.

B-2.1.2 *Conditioning*

Unless otherwise specified, all samples shall be conditioned at a temperature of (27 ± 2)°C in air for at least 60 minutes.

B-2.1.3 *Procedure*

B-2.1.3.1 Mount the PVC geomembrane roll on roll length counter and reset the counter meter to zero.

B-2.1.3.2 Now start the rolling length counter and record the reading after the complete unrolling revolutions.

B-2.1.3.3 The reading on the length counter shall be the length of sample in metres.

B-2.2 Method B (By using length measuring wheel)

B-2.2.1 *Apparatus*

Calibrated length measuring wheel, capable of measuring to the nearest 0.01 m.

B-2.2.2 *Conditioning*

Unless otherwise specified, all samples shall be conditioned at a temperature of (27 ± 2)°C in air for at least 60 minutes.

B-2.2.3 *Procedure*

B-2.2.3.1 Lay out the test specimen completely flat such that the upper side of the membrane (*in situ*) is facing upwards.

B-2.2.3.2 Now reset the measuring wheel reading to zero. The reading shall be taken from the centre of the test specimen axis.

B-2.2.3.3 The measuring wheel shall be rolled over to the complete length of the PVC geomembrane roll and the reading in the measuring wheel shall be reported.

B-2.2.3.4 The value so obtained shall be the length of sample in metres.

ANNEX C

[*Table* 1, *Sl No.* (vi)]

TEST METHOD FOR TEAR RESISTANCE

C-1 This test method covers the determination of the tear resistance of PVC geomembranes at very low rates of loading, 51 mm per min, and is designed to measure the force to initiate tearing.

C-2 PRINCIPLE

The force to initiate tearing across a specific geomembrane specimen is measured using a constant rate of grip separation machine. The force necessary to initiate the tear is calculated from the load-time or load-displacement data.

C-3 APPARATUS

C-3.1 Testing Machine – A testing machine of the constant rate of crosshead-movement type and comprising essentially following:

C-3.1.1 *Fixed Member* – A fixed or essentially stationary member carrying one grip.

C-3.1.2 *Movable Member* – A moveable member carrying a second grip.

C-3.1.3 *Grips* – It is preferably a set of self-aligning grips for holding the test specimen between the fixed member and the movable member of the testing machine. The grips should minimize both slippage and uneven stress distribution.

C-3.1.3.1 Fixed grips are rigidly attached to the fixed and movable members of the testing machine. Fixed grips may be used, if extreme care is taken to ensure that the test specimen is inserted and clamped so that the long axis of the test specimen coincide with the direction of pull through the centre line of the grip assembly.

C-3.1.3.2 Self-aligning grips are attached to the fixed and movable member of the testing machine in such a manner that they will move freely into alignment as soon as any load is applied so that the long axis of the test specimen coincide with the direction of the applied pull through the centre line of grip assembly.

C-3.1.4 *Drive Mechanism* – A drive mechanism capable of separating the movable member (grip) from the stationary member (grip) at a controlled velocity of 51 mm ± 5 percent/min.

C-3.1.5 *Load Indicator* – A suitable load-indicating mechanism capable of showing the total tensile load carried by test specimen held by the grips. The testing machine shall be essentially free from inertial lag at the specified rate of testing and shall indicate the load with an accuracy of ± 1 percent.

C-3.1.6 *Crosshead Extension Indicator* – A suitable extension indicating mechanism capable of showing the amount of change in separation of the grips (crosshead movement).

C-3.2 Thickness – The specimen thickness is measured by the test method as specified in method A of IS 13162 (Part 3).

C-3.3 Die – A die having the dimensions shown in Fig. 1 shall be used to cut all specimens. The 90° angle shall be honed sharp with no radius or have minimum practical radius. The cutting edge of the die shall have a 5° negative rake and shall be kept sharp and free from nicks to avoid leaving ragged edges on the specimen. Wetting the surface of the sample and the cutting edges of the die with water may facilitate cutting. The sample shall rest on the smooth, slightly yielding surface that will not damage the die blade. Lightweight cardboard or a piece of leather belting is suitable. Care should be taken that the cut edges of the specimen are perpendicular to its other surfaces and the edges have minimum of concavity.

C-4 TEST SPECIMEN

C-4.1 The test specimen shall be cut out with a die conforming to the dimension shown in Fig. 1 and shall not vary by more than 0.5 percent from these dimensions. The cutting edges of the die shall be kept sharp and free from all nicks to avoid leaving ragged edges on the specimens.

C-4.2 Machine direction specimens are cut perpendicular to the machine direction and transverse direction specimens are cut perpendicular to the transverse direction.

C-4.3 Test a minimum of the five specimens each in the machine direction and in the transverse direction.

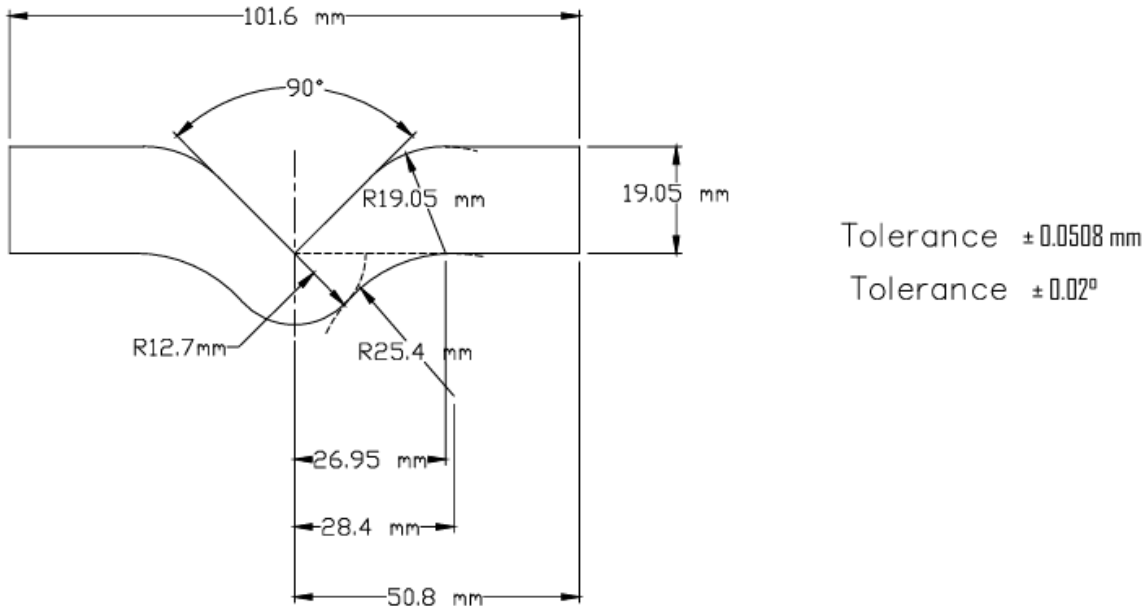


FIG. 1 DIE FOR TEAR TEST SPECIMEN

C-5 CONDITIONING

C-5.1 *Conditioning*

Condition the test specimen at (27 ± 2)°C and (65 ± 5) percent relative humidity for not less than 40 h prior to test.

C-5.2 *Test Conditions*

Conduct test in the standard laboratory atmosphere at (27 ± 2)°C and (65 ± 5) percent relative humidity.

C-6 PROCEDURE

C-6.1 An initial jaw separation of 25.4 mm shall be used. The rate of travel of the power activated grip shall be 51mm/min.

C-6.2 Measure the thickness of the specimen at several points in the notched area. Record the average thickness, in microns.

C-6.3 Place the specimen in the grips of the testing machine so that the long axis of the enlarged ends of the specimen in the line with the centre line of the grip assembly.

C-6.4 After complete rupture of the specimen, the maximum tearing load, in newtons, shall be recorded.

C-7 CALCULATION

Calculate the mean maximum resistance to tearing for all specimen tested in each principal direction of orientation.

ANNEX D

[*Table* 1, *Sl No.* (vii)]

TEST METHOD FOR INDEX PUNCTURE RESISTANCE

D-1 SCOPE

This test method is used to measure the index puncture resistance of PVC geomembrane.

D-2 PRINCIPLE

A test specimen is clamped without tension between circular plates of a ring clamp attachment secured in a tensile testing machine. A force is exerted against the centre of the unsupported portion of the test specimen by a solid steel rod attached to the load indicator until rupture of the specimen occurs. The maximum force recorded is the value of puncture resistance of the specimen.

D-3 APPARATUS

D-3.1 Tensile/Compression Testing Machine, of the constant-rate-of extension (CRE) type.

D-3.2 Ring Clamp Attachment, consisting of concentric plates with an open internal diameter of 45 ± 0.025 mm capable of clamping the test specimen without slippage. A suggested clamping arrangement is shown in Fig. 2. The external diameter is suggested to be (100 ± 0.025) mm. The diameter of the six holes used for securing the ring clamp assembly is suggested to be 8 mm and equally spaced at a radius of 37 mm. The surfaces of these plates may consist of grooves with O-rings or coarse sandpaper bonded onto opposing surfaces.

D-3.3 Solid Steel Rod, with a diameter of (8 ± 0.01) mm having a flat end with a 45° × 0.8 mm chamfered edge contacting the test specimen's surface (*see* Fig. 2 and Fig. 3).

D-4 TEST SPECIMEN

The test specimens shall be cut from the PVC geomembrane and shall have a minimum diameter of 100 mm to facilitate clamping. If the 100 mm diameter sample is not available, smaller diameter may be taken provided sample is properly clamped. Take fixed numbers of 5 specimens.

D-5 CONDITIONING

Bring the specimens to moisture equilibrium in the atmosphere for testing [(65 ± 5) percent relative humidity and (27 ± 2)°C temperature]. Equilibrium is considered to have been reached when the increase in the mass of the specimen, in successive weightings made at intervals of not less than 2 h, does not exceed 0.1 percent of the mass of the specimen.

D-6 PROCEDURE

D-6.1 Select the load range of the tensile/compression testing machine such that the rupture occurs between 10 and 90 percent of the full-scale load.

D-6.2 Centre and secure the specimen between the holding plates ensuring that the test specimen extends to or beyond the outer edges of the clamping plates.

D-6.3 Test at a machine speed of (300 ± 10) mm/min until the puncture rod completely ruptures the test specimen.

NOTE — The rate of testing specified is not an indication of the performance of the specimen for its end use.

D-7 CALCULATION

Calculate the average puncture resistance and standard deviation for all tests as read directly from the recording instrument.

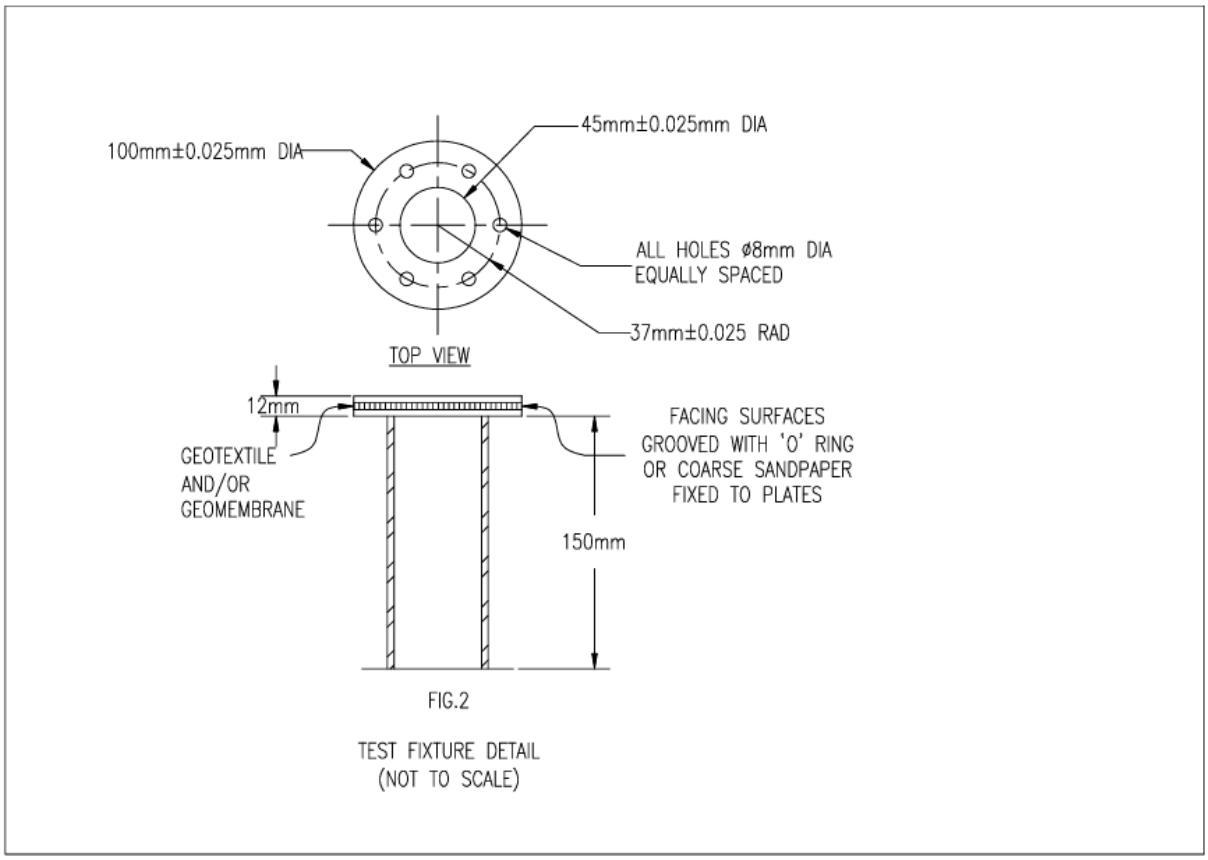


FIG. 2 TEST FIXTURE DETAIL (NOT TO SCALE)

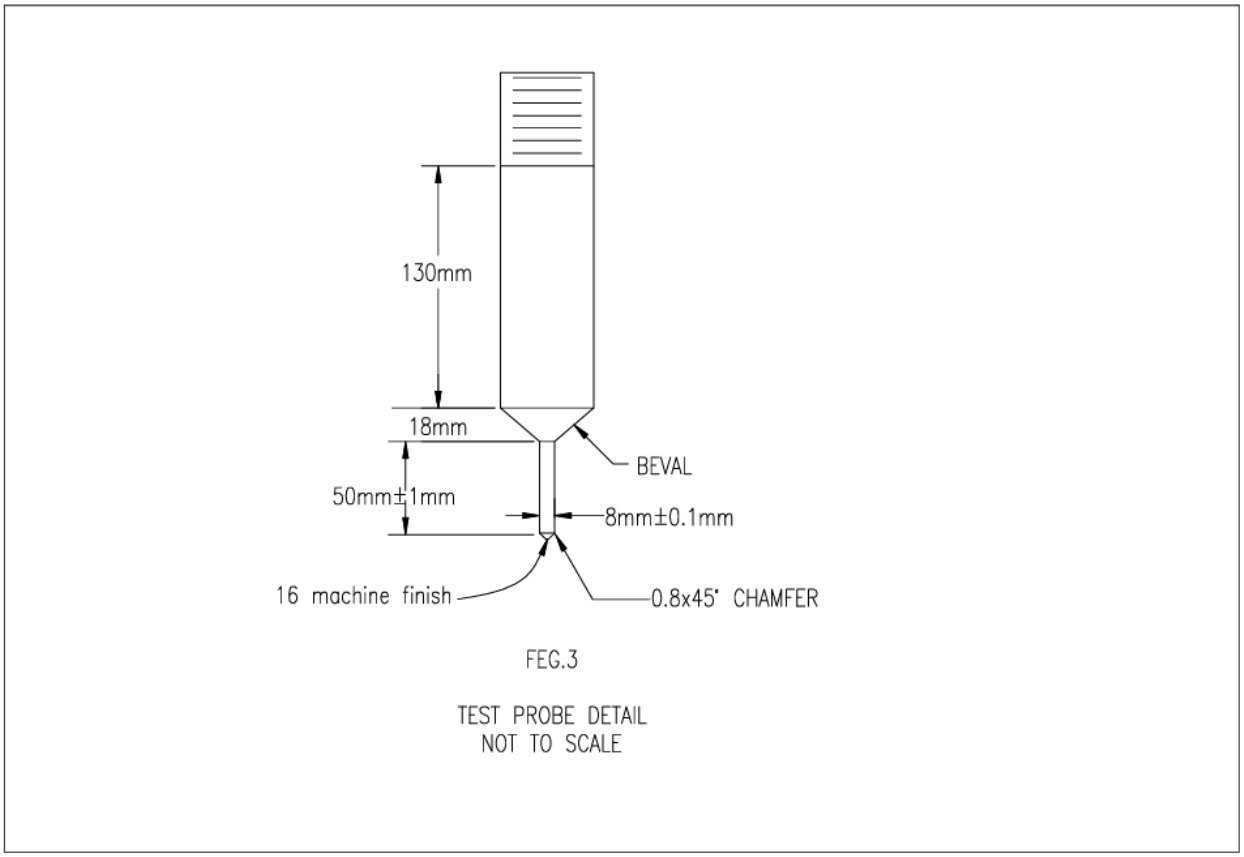


FIG. 3 TEST PROBE DETAIL (NOT TO SCALE)

ANNEX E

[*Table* 1, *Sl No.* (viii) *and Table* 2, *Sl No.* (xi), *Annex* AA]

LOW TEMPERATURE CRACK RESISTANCE

E-1 APPARATUS

A 40 mm diameter mandrel and a low temperature chamber suitable to maintain required temperature with a tolerance of ± 2°C.

E-2 PROCEDURE

The test piece shall be a strip of the geomembrane 50 mm wide and 225 mm long. Six test pieces shall be cut at random from the sample. Each test piece shall be kept at the test temperature as given in Table 1 or Table 2 for at least 60 min immediately prior to testing. The mandrel shall also be cooled to the test temperature. The test piece shall be bent by hand over the mandrel with the wearing surface outwards through an arc of 180° in approximately 3s.

E-3 REPORT

The bent portion of the test piece shall be examined in good lighting and under magnification of 4X, and shall be reported for crack, breaks or other signs of failure.

ANNEX F

[*Table* 1, *SI No.* (ix)]

DETERMINATION OF HYDROSTATIC RESISTANCE

F-1 PRINCIPLE

The hydrostatic resistance of the geomembranes shall be determined by Mullen type hydrostatic tester.

F-2 APPARATUS

The testing machine shall permit the clamping of the material to be tested between two circular clamps about 76 mm in diameter having coaxial apertures of their centre (31.5 ± 0.5) mm in diameter. The surfaces of the clamps between which the specimen is to be placed shall be concentrically grooved. The grooves shall be spaced 0.8 mm apart and of a depth not less than 0.15 mm. The grooves shall not start closer than 3.18 mm from the edge of the aperture. The lower clamping surface shall have a recession concentric to the aperture capable of accepting an O-ring having a cross-sectional diameter of (4.7 ± 0.1) mm.

The machine shall have means of applying hydraulic pressure to the underside of the clamped specimen until the specimen fails. The pressure shall be generated by means of a piston forcing water into the pressure chamber of the apparatus at the rate of (1.4 ± 0.1) cm^3/s. The machine shall be fitted with a pressure gauge maximum-reading type, with the scale divided to read in kg/cm^2 units. Accuracy shall be 1 kg/cm^2 on readings from 0 to 40 kg/cm^2. When the gauge is calibrated, it shall be mounted in the same relative position as on the bursting tester.

NOTE — Any machine that operates on the above principle and maintains the specified displacement rate of 85 ml/min, and in addition possesses the opening in the upper clamping surface of (31.5 ± 0.25) mm, is a valid machine for this test.

F-3 TEST SPECIMENS

The test specimen cut from the geomembrane shall be of such size that the smallest dimension is at least 12.7 mm greater than the outside diameter of the ring-clamp mechanism of the testing machine.

F-4 PROCEDURE

Before clamping the specimen into the testing machine, bring the water level up flush with the top of the lower clamp so that no air pocket exist between the water surface and the geomembrane being tested. The temperature of the water shall be the same as the atmospheric temperature of the testing room. Increase the pressure steadily in the chamber in which a screw shall operate to force a liquid pressure medium at a uniform rate of 1.4 ± 0.1 cm^3/s. Take a reading at the first appearance of water through the geomembrane being tested. Make ten different determinations and take the average as the hydrostatic resistance of the geomembrane. Discard an isolated high or low result that is not repeated in duplicate when a consistent average has been obtained without the abnormal reading and substitute a re-test.

ANNEX G

[*Table* 1, *SI No.* (x)]

DETERMINATION OF SEAM STRENGTH

G-1 APPARATUS

Tensile testing machine as described in Appendix B of IS 2076.

G-2 PREPARATION OF TEST SAMPLES

A test piece 25 mm wide and approximately 100 mm in length shall be cut at right angles to the direction of the weld in such a manner that seam is equidistant from each end of the test piece. At least three test pieces shall be cut from weld piece.

G-3 PROCEDURE

Place the specimen in the jaws of the tensile testing machine with the seam centered between and parallel to the jaws and width of the specimen at right angles to the direction of application of force. Start the machine and observe by means of an autographic recording device the load necessary to slip the seam or rupture the specimen. The rate of extension of specimen between the jaws shall be 100 mm/min. If a specimen slips between the jaws, breaks or tears in a direction other than parallel to the seam or if for any reason due to faulty technique an individual measurement falls 20 percent below the median test results for the sample unit, discard and test another specimen until six specimens are checked. If the sample breaks other than a seam it should be considered as unbreakable seam or the seam strength is 75 percent (min) of the breaking strength of the same size specimens at the same conditions.

G-4 CALCULATION AND RESULTS

The seam strength of the specimen shall be calculated from breaking load, in kg. The mean value shall be reported.

ANNEX H

[*Table* 1, *SI No.* (xii), *Table* 2, *Sl Nos*. (iii) *and* (viii)]

DETERMINATION OF PEEL STRENGTH FOR EACH SET OF LAYERS AND DETERMINATION OF NUMBER OF LAYERS

H-1 OBJECTIVE

To determine the peel strength for each set of layers (top to middle, middle to middle and middle to bottom) of PVC Geomembrane.

H-2 APPARATUS AND TEST REAGENT

H-2.1 A tensile testing machine having the rate of movement of (280 ± 25) mm per minute of the driven grip measured before each series of tests with the machine at zero load. The machine shall be capable of reading to ± 2 N.

H-2.2 Beaker of minimum 250 ml capacity.

H-2.3 Ethyl acetate of pure grade conforming to IS 229.

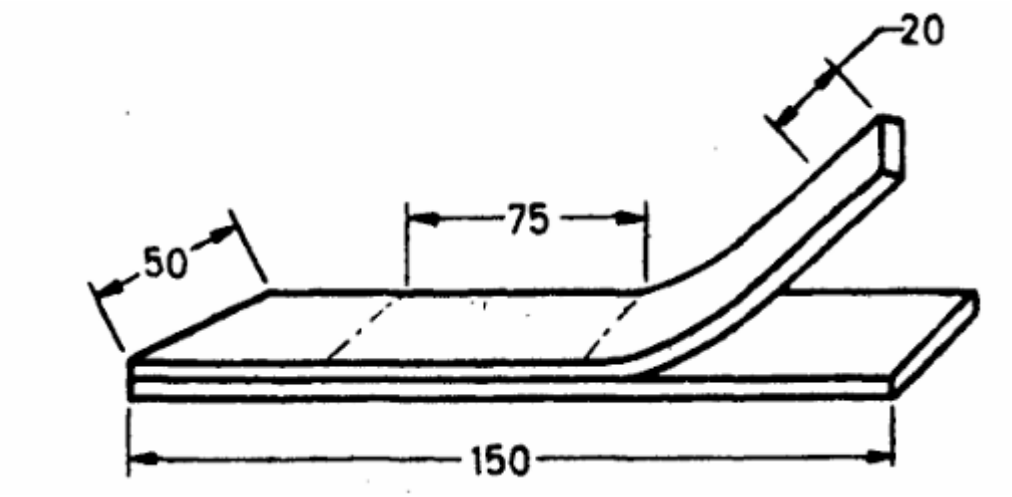
H-3 TEST SPECIMEN

Six test pieces each measuring 150 mm × 50 mm shall be cut from the specimen, having 03 samples from longitudinal direction and 03 samples from transverse direction.

H-4 PROCEDURE

The width of each test piece shall be measured at the three-quarter points and the average shall be regarded as the width of the test piece. Three parallel lines shall be marked on the surface of each test piece (*see* Fig 4). Each test piece shall be supported vertically for the period of 45 minutes in ethyl acetate to a depth of not more than 20 mm. After immersion that part of the laminate which has been in the solvent shall be separated by hand but without undue force (wet PVC tend to break easily).

The test pieces shall then be allowed to dry at a temperature of $27^0C \pm 2^0C$ until all the solvent has evaporated and in any case for not less than 90 minutes. Each test piece shall then be separated in the tensile testing machine. The load for separation of 75 mm marked section of the test piece shall be noted.



All dimension in millimeters

FIG 4 PEELING ADHESION TEST PIECE

H-5 EXPRESSION OF RESULT

H-5.1 Peeling strength for each set of layers in test piece for machine and transverse direction shall be calculated as follows:

$$\text{Peeling strength (N/m)} = \frac{\text{Average load of separation (N)}}{\text{Width of the test specimen(mm)}} \times 1000$$

H-5.2 The lowest value shall be reported. If layer breaks before separation of 30 mm, then it will be considered as fused, the sample shall pass the test.

H-5.3 The following values shall be recorded:

a) Number of layers
b) Peeling strength (N/m)

NOTES

1 If layers do not get separated in 40 minutes, the immersion period may be extended up to 2 hours and specimen shall be checked for separation of layers after every 30 minutes. If no separation is observed, specimen must be kept immersed for 24 hours to check whether it is a multilayered product or not.

2 If there is no apparent separation of three layers in any of the specimen after immersion for 24 hours in ethyl acetate, the material will not be considered as multi-layered.

ANNEX J

[*Table* 1, *SI No.* (xiii)]

DETERMINATION OF RESISTANCE TO SOIL BURIAL

J-1 Prepare a composite soil for the specimen burial according to usual greenhouse practice and having a *p*H of 6.5 to 7.5. Maintaining the moisture content of the soil between 25 percent to 30 percent on an oven dry basis. Perform the test with soil containers stored in a room maintained between 32°C to 38°C. Check the microbiological activity of the soil frequently by burying specimen of untreated cotton duck having mass of 340 to 360 g/m^2 for 1 to 2 week period. Satisfactory activity is indicated by tensile strength losses above 70 percent in 1 week and above 90 percent in 2 weeks of cotton duck.

J-2 Perform the soil burial test by preparing six test specimen three in machine and three in cross machine direction and burying them vertically to the depth of about 200 mm to 500 mm in soil that is rich in cellulose destroying micro-organism. At the end of specified time clean the test specimen with ethanol water mixture and determine the tensile strength and elongation at break in accordance with Appendix B of IS 2076 for category A, geomembranes and as per Annex P for category B, geomembranes and change in mass in accordance with Annex CC.

ANNEX K

[*Table* 1, *SI No.* (xiv)]

DETERMINATION OF WATER EXTRACTION (PERCENT LOSS IN WEIGHT)

K-1 TEST SPECIMEN

Three test pieces measuring 50 mm × 50 mm shall be cut from the roll.

K-2 PROCEDURE

The test piece shall be immersed completely in distilled water for 24 h at room temperature. Immediately after removal from water, the surfaces of the test piece shall be wiped dry with filter paper and reweighed.

K-3 CALCULATION

$$\text{Water extraction} = \frac{M_1 - M_2}{M_3} \times 100$$

M_1 = mass of the test piece before immersion, in g; and
M_2 = mass of the test piece after immersion, in g.

K-4 REPORT

The average of the three specimen tested shall be reported.

ANNEX L

[*Table* 1, *SI No.* (xv)]

DETEMINATOIN OF RESISTANCE TO THE EXPOSURE OF ULTRAVIOLET LIGHT (XENON-ARC TYPE APPARATUS)

L-1 PRINCIPLE

Specimens of PVC geomembrane for the machine and cross directions are exposed for 500 h of ultraviolet exposure in a Xenon-arc apparatus. The exposure consists of 120 min cycles consisting of 102 min of light only, followed by 18 min of water spray and light. After the exposure, the specimens are subjected to tensile strength and elongation at break as prescribed in IS 2076. The test results are compared to the test results for unexposed specimens and the deterioration which has taken place due to ultraviolet exposure is assessed.

L-2 ATMOSPHERIC CONDITIONS FOR CONDITIONING AND TESTING

Condition the test specimens to moisture equilibrium from the dry side in the standard atmosphere of 65 ± 2 percent relative humidity and 27°C ± 2°C temperature. When the specimens have been left in such an atmosphere so that both the faces are exposed to the standard atmosphere as far as possible for 24 h, they shall be deemed to have reached the state of moisture equilibrium.

L-3 PREPARATION OF TEST SPECIMENS

L-3.1 Cut 5 test specimens from each of the machines and the cross directions from the test pieces.

L-3.2 Specimens shall not contain dirt, irregular spots, creases, holes or other visible faults.

L-3.3 Any two specimens shall not contain the same longitudinal or transversal position. If it is not possible, it shall be reported.

L-4 APPARATUS

L-4.1 The working details of Xenon-arc apparatus has been described in IS 105-B02.

L-4.1.1 The apparatus should be capable of exposing the specimens to cycles of light only, followed by water spray and light under controlled atmospheric conditions.

L-4.1.2 The apparatus should be equipped with an inner and outer filter glass as described in IS 105-B02.

L-5 PROCEDURE

L-5.1 Operate the Xenon-arc apparatus as given in IS 105-B02 to provide 120 min cycles as follows:

102 min of light only at 65 ± 5°C black panel temperature, and 30 ± 5 percent relative humidity, followed by 18 minutes of light and water spray.

L-5.1.1 Set the minimum level of radiation to 0.5 W/m^2, 1 nm bandpass at 340 nm.

L-5.2 Randomly expose five specimens for each direction for 500 h exposure time. Place 10 specimens (5 for each direction) in the apparatus, such that the side most likely to be exposed to the effects of ultraviolet light will be exposed in the apparatus.

L-5.3 At the end of exposure time, remove the test specimens for tensile strength and elongation at break as given in IS 2076.

L-5.4 Test five unexposed specimens (zero exposure time) and five exposed specimens for each direction for tensile strength and elongation test using cut strip test as given in IS 2076.

L-6 CALCULATIONS

L-6.1 Calculate the average tensile strength and elongation at break for all exposed and unexposed specimens for each direction.

L-6.2 Calculate the percent loss of tensile strength and elongation at break for the exposed specimens for the average results for each direction.

ANNEX M

[*Table* 2, *SI No.* (iii)]

DETERMINATION OF THICKNESS OF SIGNAL LAYER

M-1 PRINCIPLE

The thickness of signal layer is determined by a measuring device. If there is hindrance by surface profile or removal of signal layer to its backing, in this case, optical measurement device shall be used.

M-2 TERMINOLOGY

M-2.1 Surface Texture — Textured pattern on one or both surfaces of the sheet creating a difference between the effective and overall thickness not exceeding 0.15 mm.

M-2.2 Surface Profile (surface structure) — raised area on the surface of the sheet creating a difference between the effective and overall thickness exceeding 0.15 mm.

M-2.3 Overall Thickness (d) — thickness of the sheet excluding any surface profile [*see* Fig. 5(A)].

M-2.4 Effective Thickness (d_{eff}) —thickness of the sheet providing the waterproofing function including any surface texture but excluding any surface profile and backing [*see* Fig. 5(A)].

M-3 PROCEDURE

M-3.1 Method A — By Using Measuring Device

M-3.1.1 Apparatus

Dial thickness gauge, with an accuracy of 0.01 mm. The measuring surfaces shall be planar and have a dimeter of (10 ± 0.05) mm exerting a pressure of (20 ± 10) kPa on the sheet surface.

M-3.1.2 Test Specimen

Six test pieces, each measuring 150 mm × 50 mm, shall be cut from the test specimen. Three pieces shall be taken from the longitudinal direction, and three pieces from the transverse direction.

M-3.1.3 Procedure

Separate the signal layer as per the procedure given in Annex H. The test pieces then shall be allowed to dry at a temperature of (27 ± 2) ^{0}C, until all the solvent has been evaporated and in any case for not less than 90 minutes. Check the zero point of the measuring device before starting the measurements and recheck after each series of measurements. When determining the thickness, lower the foot gently to avoid deformation of the material.

M-3.1.4 Expression of Result

Check the thickness of each specimen and record the mean value.

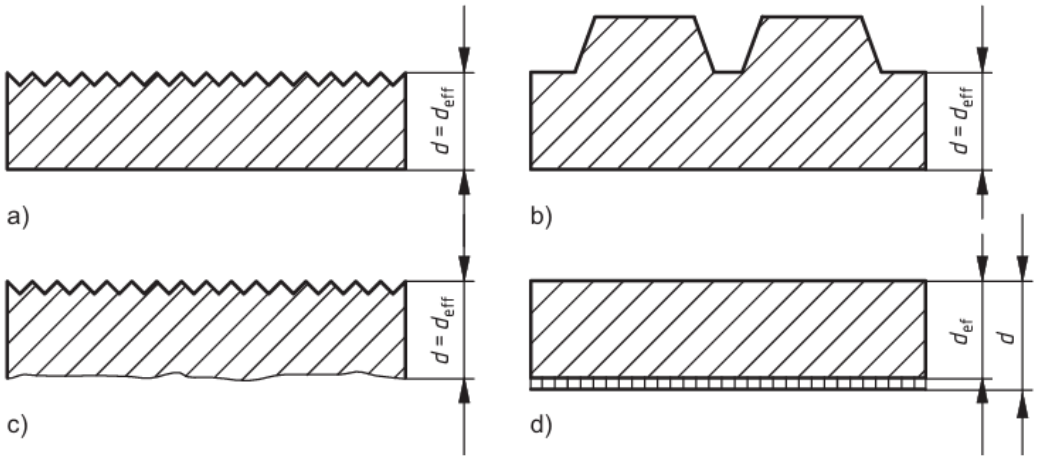
M-3.2 Method B — Optical Device

M-3.2.1 Apparatus

Microscope (magnification of 10x or 20x), razor-sharp knife

M-3.2.2 Procedure

To measure the thickness of a single layer optically, prepare a small specimen no longer than 10 mm for the optical measurement. Cut the specimen from each test sample using a razor-sharp knife. Ensure the cut cross-section is positioned at an angle of (90 ± 5)° relative to the viewing direction under a microscope. Capture and print the microscope's viewing image.



Key:
a) sheet with surface texture on one side
b) sheet with surface profiles
c) sheet with surface texture on both sides
d) sheet with backing

FIG. 5 (A) TYPES OF SURFACES

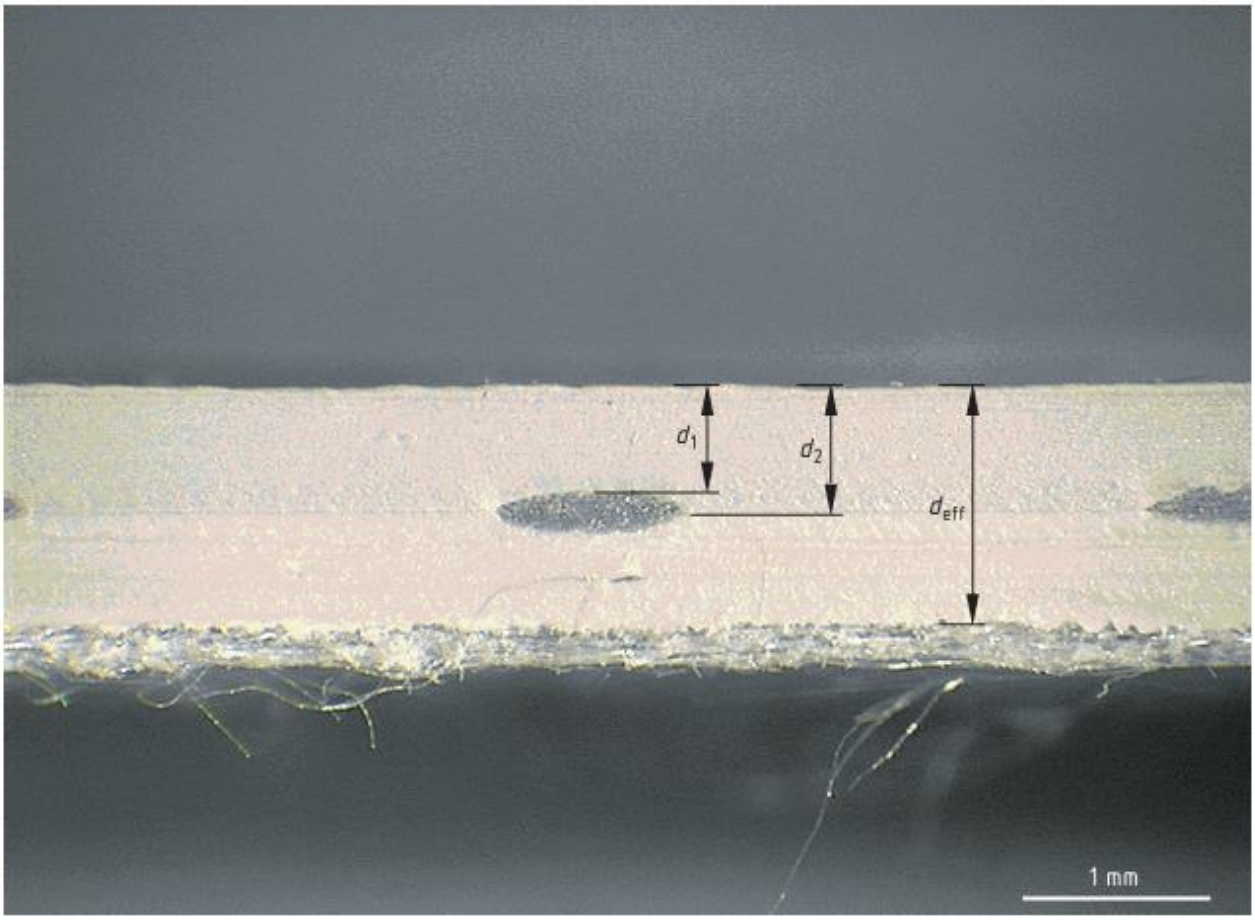


FIG. 5 (B) CROSS SECTION OF TEST SPECIMEN CUT WITH RAZOR BLADE UNDER MICROSCOPE

M-3.2.3 Expression of Result

The overall thickness (d) shall be stated as the mean thickness of all test specimens. The effective thickness (d_{eff}) shall be stated as the mean thickness of all test specimens without taking into account any surface profile and/or backing. State all the results of sheet thickness and standard deviation to the nearest 0.01 mm.

ANNEX N
(*Clause* 7.1)

PIN HOLES AND CRACKS

Examine for pin holes and cracks by viewing the surface of the PVC geomembrane held under slight tension. Position the bright light source behind the PVC geomembrane so as to clearly illuminate the surface without producing a glare in the observer's eyes. A pinhole is defined as any opening observed in the geomembrane under the condition specified above which is not visible when the geomembrane is viewed normally in average daylight or the equivalent thereof.

ANNEX P
[*Table* 2, *Sl No.* (v) *and* (vi), *Annexes* A, AA, BB]

TEST METHOD FOR TENSILE STRENGTH AND ELONGATION

P-1 PRINCIPLE

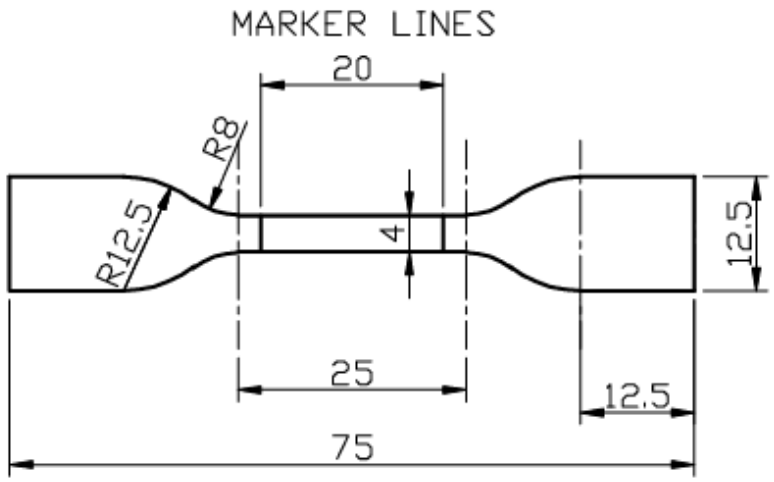
The test specimen is extended along its major longitudinal axis at constant speed until the specimen fractures. During this procedure the load sustained by the specimen and the elongation are measured.

P-2 APPARATUS

Tensile testing machine shall be of at least 2000 N capacity with a constant speed of grip separation (100 ± 10 mm/min). The grip width shall be at least 50 mm. The tensile testing machine shall be equipped with suitable grips that do not allow specimen to slip from the grips.

P-3 PREPARATION OF THE SPECIMEN

The dumbbell shaped test specimens shall be prepared, 5 nos. each in longitudinal and transverse direction as shown in Fig. 6.



All dimensions in mm

Over all length (Min.) -75mm

Width of ends - 12.5±1.0mm

Length of narrow parallel portion - 25±1.0 mm

Width of narrow parallel portion- 4.0±0.1 mm

Small radius - 8.0±0.5mm

Large radius - 12.5±1.0 mm

FIG. 6 DUMBBELL SHAPED TEST SPECIMEN

P-4 CONDITIONING

The test specimens, prior to testing, shall be kept for at least 20 h at (27 ± 2)°C and relative humidity of (65 ± 5) percent.

P-5 PROCEDURE

Measure the thickness and width of the specimen. Afterwards the specimen shall be secured in the upper and lower grip of the tensile testing machine ensuring that the marks coincide as accurately as possible with the edges of the grip. The grip separation speed of the tensile machine shall be (100 ± 10) mm/min. A reading shall be taken of the maximum force indicated (at break) and elongation is measured with the help of a divider or any suitable measuring device.

NOTE — The test specimens breaking outside the gauge marks shall be discarded.

P-6 CALCULATION

P-6.1 Tensile strength, (N/mm^2) $T = F/A$

where

T = tensile strength, N/mm^2;
F = force, N; and
A = initial cross-sectional area of the specimen, mm^2.

P-6.2 Elongation percent $= (L_2 - L_1)/L_1 \times 100$

where

L_1 = gauge length of the test specimen, mm; and
L_2 = distance between the gauge marks after extension, mm.

P-7 EXPRESSION OF RESULT

Average values for tensile strength and elongation shall be reported.

ANNEX Q
[*Table* 2, *Sl No.* (vii)]

TEST METHOD FOR RESISTANCE TO TEARING (TEAR PROPAGATION STRENGTH)

Q-1 PRINCIPLE

The principle of the test is measurement of the force required to completely tear the test specimen in continuation of the cut already produced in the specimen. The tearing force is applied by means of a tensile testing machine at a constant speed until the test specimen tears completely. The maximum peak load shall be reported.

Q-2 APPARATUS

Q-2.1 Tensile testing machine shall be at least 2000 N capacity with a constant speed of grip separation (100 ± 10 mm/min). The grip width shall be at least 50 mm. The tensile testing machine shall be equipped with suitable grips that do not allow specimen to slip from the grips.

Q-2.2 The template used for cutting the test specimens shall have dimensions as shown in Fig. 7.

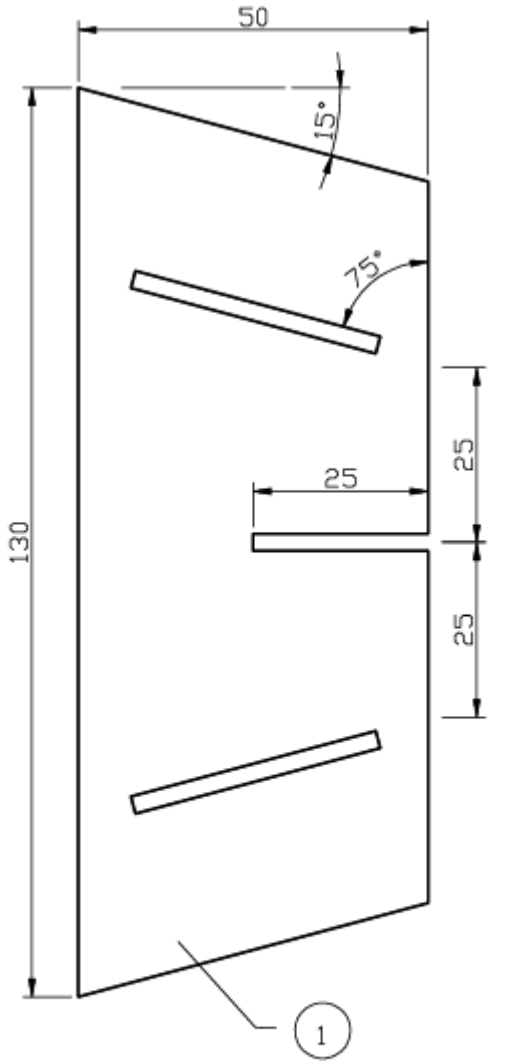


FIG. 7 TEMPLATE FOR CUTTING TEST SPECIMEN

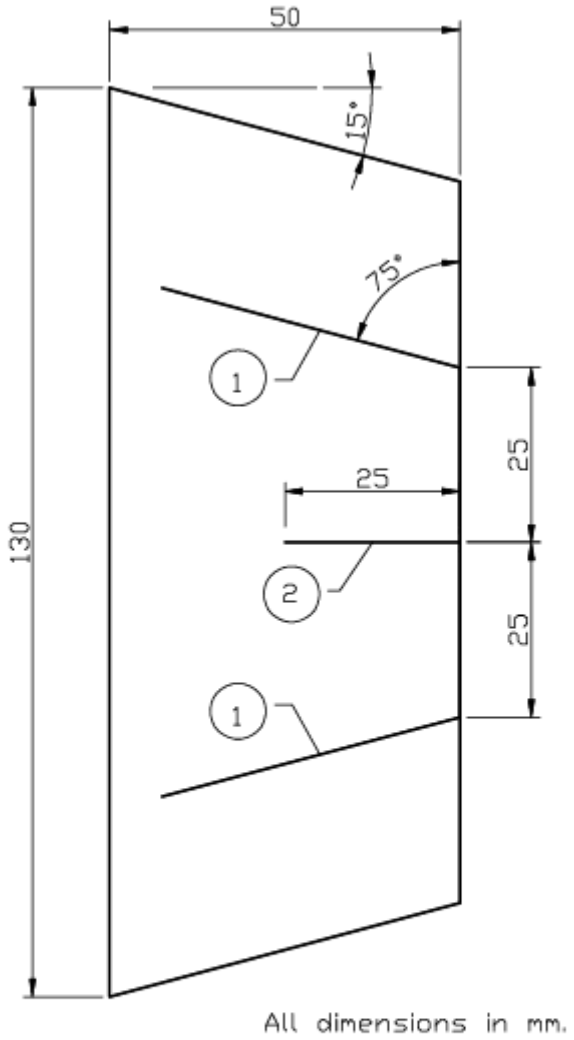


FIG. 8 SHAPE AND DIMENSIONS OF TEST SPECIMEN

Q-3 PREPARATION OF TEST SPECIMENS

Q-3.1 The shape and dimension of the test specimens shall be as given in Fig. 8.

Q-3.2 Using the template cut five specimens with nick or cut in the longitudinal direction and five with the nick or cut in the transverse direction of the sheet.

Q-3.3 Make lines on every test specimen indicating the position of the grips.

Q-4 CONDITIONING

The test specimens, prior to testing, shall be conditioned for at least 20 h in a standard atmosphere of (27 ± 2)°C and (65 ± 5) percent relative humidity.

Q-5 PROCEDURE

The thickness of the specimen is measured. Afterwards the specimen shall be secured in the upper and lower grip of the tensile testing machine ensuring that the marks coincide as accurately as possible with the edges of the grip (*see* Fig. 9). The speed of the tearing (grip separation) shall be 100 ± 10 mm/min. A reading shall be taken of the maximum force indicated.

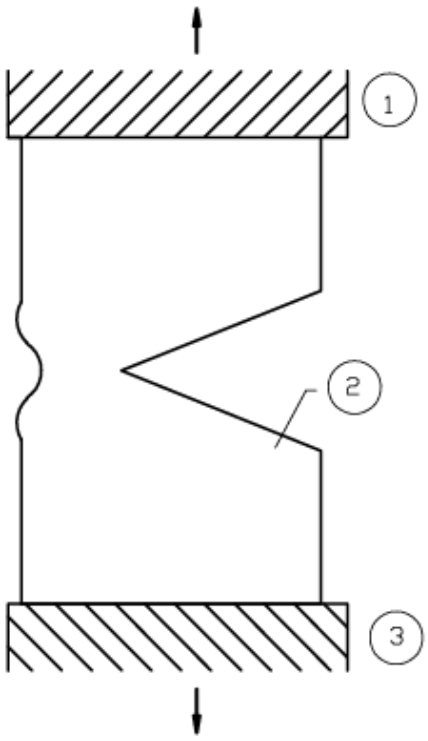
Q-6 CALCULATION

Note the maximum force separately for the longitudinal and transverse direction and tear strength is calculated in N/mm as detailed below:

$TS = L/t$

where

TS = tear propagation strength;
L = maximum force, N; and
t = average thickness of the specimen, mm.



Key

1 Upper grip
2 Test specimen
3 Lower grip

Test specimen mounted the grips

FIG. 9 SPECIMEN IN GRIPS PRIOR TO TEST

Q-7 EXPRESSION OF RESULT

Mean value shall be reported.

ANNEX R
[*Table* 2, *Sl No.* (x), *Annex* CC]

HEIGHT OF FALL WITHOUT PERFORATION (IMPACT RESISTANCE)

R-1 PRINCIPLE

To establish whether PVC membrane are punctured at a given test temperature by mass falling from a given height.

R-2 APPARATUS

R-2.1 Steel cylinder of 25 mm diameter and 130 mm length, with a mass of 500 g, into one end face of which a ball of 12.7 mm diameter is pressed, and the other end of which is designed so that the mass can be vertically suspended (electromagnetically or mechanically).

R-2.2 Stand to which the suspension mechanism is attached so as to be adjustable in height.

R-3 PREPARATION OF TEST PIECES

Five specimens of size 150 mm × 150 mm shall be used for testing.

R-4 PROCEDURE

R-4.1 For testing, the test pieces shall be placed on the aluminium plate and pressed down by the metal ring. It shall be noted that the aluminium plate is not to be exposed to impact at the same point more than once.

R-4.2 Assessment whether the sheet has punctured is to be made by applying a positive pressure on the side subjected to impact, using compressed air or, by applying a vacuum on the other side, the pressure differential being 0.1 bar, shall be maintained for one minute.

R-4.3 The test pieces to which the pressure is applied, shall have a diameter of 80 mm. The point of impact shall be coated with a foaming agent. A bursting pressure test apparatus, a slotted disc pressure test device or a vacuum bell jar are suitable equipment for this test.

ANNEX S
[*Table* 2, *Sl No.* (xii)]

TEST METHOD FOR HYDROSTATIC PRESSURE RESISTANCE

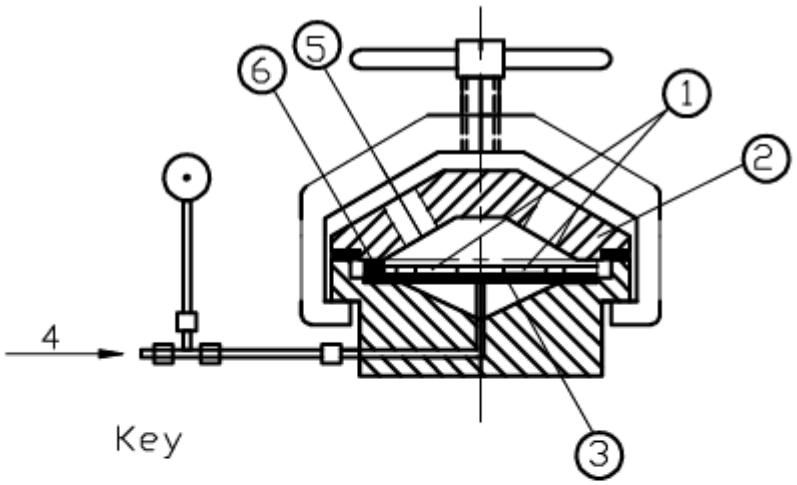
S-1 PRINCIPLE

This test procedure is used for PVC geomembranes intended for use in high pressure application for example special roofs, tunneling and tanking. In this method, a test specimen is submitted to a

specified water pressure for 24 h against a disk containing four slots of specified form and dimension. The test specimen is observed to establish whether it remains watertight.

S-2 APPARATUS

S-2.1 The apparatus consists of a device (*see* Fig. 10 and Fig. 11) by which a pressure shall be applied to one side of a test specimen.



Key

1 Slots

2 Cover

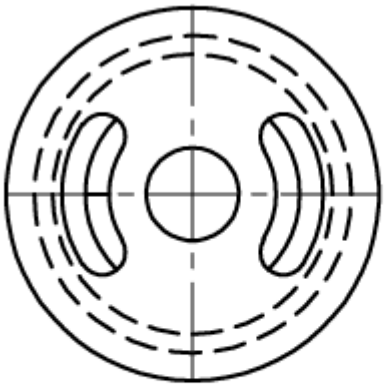
3 Test specimen

4 Hydrostatic pressure

5 Observation gap

6 Slotted plate

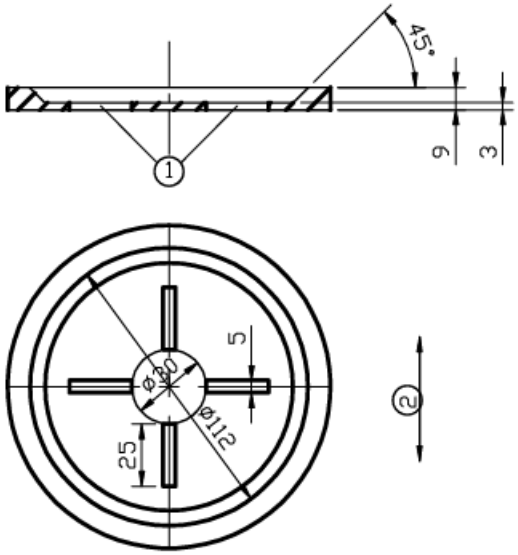
FIG. 10 SLOT PRESSURE TESTING FOR WATER TIGHTNESS AT HIGH PRESSURE



Device for the slot pressure test
sketch of the cover

FIG. 11 DEVICE FOR THE SLOT PRESSURE TEST SKETCH OF THE COVER

S-2.2 The test specimen shall be covered by a circular disk containing four slots. The form and dimensions of the slots shall be as specified in Fig. 12.



All dimensions in mm.

KEY

1 All edges of the slotted plate are rounded to a radius of 0.5 mm approximately
2 Longitudinal direction of the membrane

FIG. 12 SLOTTED PLATE

S-3 CONDITIONING OF TEST SPECIMENS

The test specimens shall be conditioned for at least 6 h at (27 ± 2)ºC prior to testing.

S-4 PREPARATION OF TEST SPECIMENS

The specimens shall be taken evenly distributed across the width of the sheet, the outer ones 100 mm of the edges. The longitudinal direction on the test specimens shall be marked parallel to direction of production. The number of test specimens shall be a minimum of three. Dimensions of the test specimens shall be circular test specimens with a diameter equal of the external diameter of the slotted plate (approximately 130 mm).

S-5 PROCEDURE

S-5.1 Test Conditions

The test shall be carried out at (27 ± 2)ºC and (65 ± 5) percent relative humidity. The test pressure shall be 5 bar. It shall be ensured that the margins are watertight.

S-5.2 METHOD

S-5.2.1 Fill the apparatus (*see* Fig. 10) with water until overflowing. Purge the water line thoroughly.

S-5.2.2 Place the test specimen with its upper side downwards in the apparatus and cover with specified slotted plate, one of the slots (*see* Fig. 12) being parallel to the longitudinal direction of the sheet. Place the cover and progressively tighten until the specimen is tightly in place.

S-5.2.3 Dry the non-exposed side of the specimen with a cloth or with compressed air. Pressurize progressively to the specified test pressure of 5 bar.

S-5.2.4 Once the test pressure of 5 bar has reached, the pressure shall be maintained for a period of (24 ± 1) h.

S-5.2.5 Observe the water tightness of the test specimen after the testing time (sudden pressure drop or presence of water on the non-exposed face of the test specimen.

S-6 EXPRESSION OF RESULTS

The water tightness test shall be considered pass if all the three test specimens remain watertight after the specified testing time.

ANNEX T

[*Table* 2, *Sl No.* (xiii), *Annex* CC]

TEST METHOD FOR DETERMINING DIMENSIONAL STABILITY

T-1 PRINCIPLE

The principle of the test is measurement of the initial longitudinal and transversal dimensions of the test specimen followed by heating of the test specimen for a specified time at a specified temperature. Resulting longitudinal and transversal dimensions of the test specimens after reconditioning shall be determined and dimensional variations shall be calculated and reported.

T-2 APPARATUS

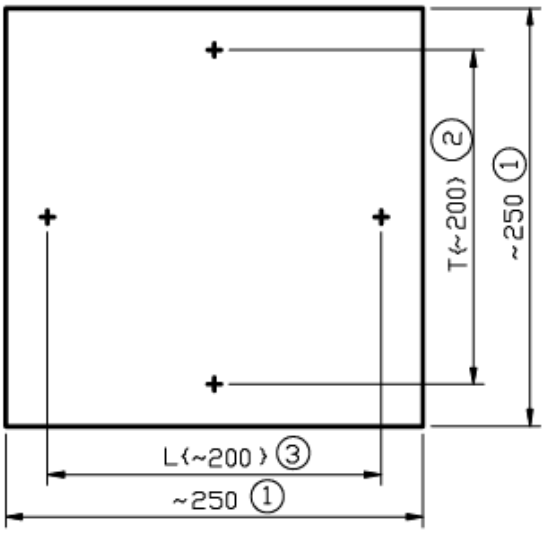
T-2.1 A circulating air oven having thermostatic control that shall maintain a temperature of (80 ± 2) ºC and equipped with horizontal rigid metal plates or wired shelves for supporting the test piece. The shelves shall be at least 25 mm larger than the test piece in each direction.

T-2.2 The measuring device shall be capable of determining the longitudinal and transversal dimensions of the test specimens with an accuracy of at least 0.1 mm.

T-3 TEST SPECIMENS

T-3.1 Three test specimens of approximately 250 mm × 250 mm, evenly distributed across the width of the sheet, the outer ones 100 mm ± 10 from the edges shall be taken.

T-3.2 Test specimens shall be marked as shown in Fig. 13.



All dimensions in mm.

KEY
1 Permanent marking
2 Transversal center line
3 Longitudinal center line

FIG. 13 DIMENSIONS OF TEST SPECIMEN

T-4 CONDITIONING OF TEST SPECIMENS

Condition the test specimens, prior to testing, for at least 20 h in a standard atmosphere of (27 ± 2)ºC and (65 ± 5) percent relative humidity.

T-5 PROCEDURE

T-5.1 Measure the initial longitudinal and transversal dimensions (L_0 and T_0) of the conditioned test specimens as indicated in Fig. 13 with an accuracy of 0.1mm.

T-5.2 Place the test specimens on the plate with the top surface uppermost in the oven at a temperature of (80 ± 2)ºC.

T-5.3 After 6 h, take the test specimens out of the oven on the plate and recondition them for at least 60 minutes in a standard atmosphere of (27 ± 2)ºC and (65 ± 5) percent relative humidity. Measure again the longitudinal and transversal dimensions (L_t and T_t) as indicated in Fig. 13 with an accuracy of 0.1 mm.

T-6 EXPRESSIONS OF RESULTS

T-6.1 For each test specimen, calculate and state the variation in dimension (ΔL) and (ΔT), expressed as a percentage of initial dimensions, using the equations given below:

$$\Delta L = \frac{L_t - L_0}{L_0} \times 100$$

$$\Delta T = \frac{T_t - T_0}{T_0} \times 100$$

where,

L_0 and T_0 are initial dimensions in mm, measured with an accuracy of 0.1 mm.

L_t and T_t are dimensions after exposure to elevated temperature, in mm, measured with an accuracy of 0.1mm.

ΔL and ΔT can be positive or negative and shall be rounded to 0.1 percent.

T-6.2 Mean values of ΔL and ΔT for the samples tested shall be reported.

ANNEX U

[*Table* 2, *Sl No.* (xiv)]

TEST METHOD FOR CHANGE OF DIMENSION AFTER HEATING AT 70ºC FOR 2 HOURS

U-1 PRINCIPLE

Test specimens taken from the test sample shall be suspended vertically in an oven at a specified temperature. The displacement/change in the dimension of the test specimen shall be measured after a specific time. Failure is defined as a mean displacement/change in dimensions greater than 2.0 mm.

U-2 APPARATUS

U-2.1 Oven with circulating air and a maximum temperature deviation of ± 2ºC in the test area after the door has been opened for 30 s. The recovery period to attain the required temperature again shall not exceed 5 minutes.

U-2.2 Stand for hanging the samples.

U-2.3 Suitable measuring device capable of measuring to an accuracy of 0.1 mm.

U-3 TEST SPECIMEN

Three test specimens of size 100 mm × 100 mm shall be taken.

U-4 CONDITIONING OF TEST SPECIMENS

Condition the test specimen at temperature 27 ± 2ºC and relative humidity 65 ± 5 percent for 2 h prior to testing.

U-5 PROCEDURE

Test specimens shall be suspended vertically at (70 ± 2)ºC for 2 h at the same height in the oven with at least 30 mm distance between them. As soon as the heating period is completed, the test specimens together with the stand devices shall be removed from the oven without contact and allowed to cool by hanging freely for at least 2 h at (27 ± 2) ºC, afterwards the hanging stand is removed.

U-6 EXPRESSION OF RESULTS

U-6.1 For each test specimen, calculate the variation in dimension (ΔL) and (ΔT), expressed as change in dimensions, using the equations given below:

$$\Delta L = L_t - L_0$$
$$\Delta T = T_t - T_0$$

where,

L_0 and T_0 are initial dimensions in mm, measured with an accuracy of 0.01 mm in direction A and B.

L_t and T_t are dimensions after exposure to elevated temperature, in mm, measured with an accuracy of 0.01mm in direction A and B.

U-6.2 Calculate the mean values of displacement/change in the dimension (ΔL and ΔT) for the specimens tested.

U-6.3 If the displacement/change in the dimension is not greater than 2 mm, then the test specimen shall be considered as stable.

ANNEX V

[*Table* 2, *Sl No.* (xv)]

TEST METHOD FOR BEHAVIOR AFTER STORAGE IN AQUEOUS SOLUTION RESISTANCE TO ACID AND ALKALINE

V-1 OBJECTIVE

To determine effect of certain chemicals on PVC Geomembranes.

V-2 APPARATUS

V-2.1 Tensile testing machine of at least 2000 N capacity with a constant speed of grip separation (100 ± 10) mm/min. The grip width shall be at least 50 mm. The tensile testing machine shall be equipped with suitable grips that do not allow specimen to slip from the grip.

V-2.2 Chemicals

V-2.2.1 NaCl, H_2SO_3 and $Ca(OH)_2$

V-2.2.2 Beakers and bottles of minimum 500 ml capacity

V-3 TEST SPECIMENS

The dumbbell size test specimens shall be prepared, 5 numbers each in longitudinal and transverse directions as per Annex P.

V-4 TEST CONDITION

The specimens shall be stored in each one of the aqueous solution separately given in Table 5 at (27 ± 2)ºC for 28 days. After removing the samples from the chemicals, these samples are conditioned for 7 days in standard atmospheric condition.

Table 5 Aqueous Solution
(*Clause* V-4)

Sl No. (1)	**Test liquid** (2)
i)	10 percent sodium chloride (NaCl) solution (salt water)
ii)	Milk of lime, $Ca(OH)_2$
iii)	5 to 6 percent sulfurous acid, H_2SO_3

S-5 PROCEDURE

The specimen as per Annex P shall be kept in the chemicals as given in Table 5 for 28 days. After removing the sample from chemicals, these samples shall be conditioned for 7 days in standard atmospheric conditions. Conditioned test specimen shall be tested as per Annex L.

S-6 EXPRESSION OF TEST RESULTS

Average value of test results of variation in tensile strength and elongation shall be reported.

ANNEX W
[*Table* 2, *Sl No.* (xvi)]

TEST METHOD FOR DETERMINING THE STRENGTH OF WELDED SEAM SHEAR RESISTANCE

W-1 PRINCIPLE

The test is to pull a specimen of a joint in shear at a constant speed until it breaks or separates. The tensile force is continuously recorded throughout the test.

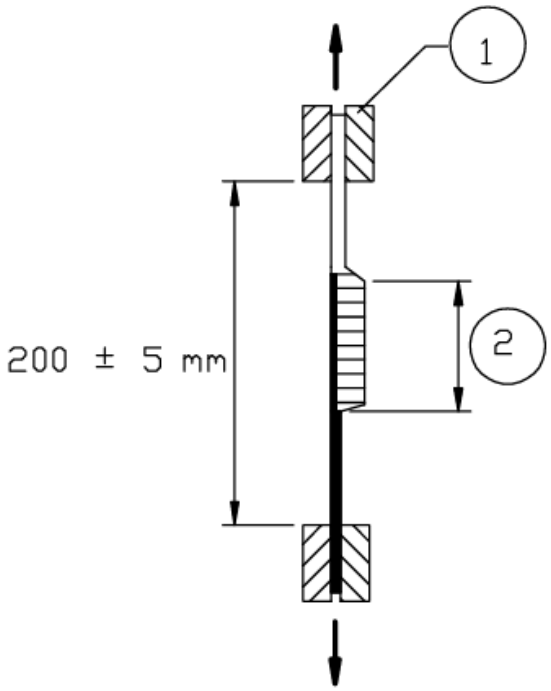
W-2 APPARATUS

Tensile testing machine shall be at least 2000 N capacity with a constant speed of grip separation (100 ± 10) mm/min. The grip width shall be at least 50 mm. The tensile testing machine shall be equipped with suitable grips that do not allow specimen to slip from the grip.

W-3 PREPARATION OF TEST PIECES

W-3.1 Test pieces of the sheet are joined by the hot air gun, both for side lap and end lap jointing, with an overlap of 50 ± 1 mm. After jointing, the test piece shall be conditioned for a minimum of 2 h at 27 ± 2°C and at 65 ± 5 percent relative humidity.

W-3.2 From each of these joint test pieces five rectangular test specimens of (50 ± 1) mm width shall be taken perpendicular to the joint. These shall have such a length, so that the ends of the initial distance between the two grips are (200 mm ± 5) with the joint in the middle (*see* Fig. 14).



Key
1 Grip
2 Width of joint

FIG. 14 SHEAR STRENGTH TESTING OF A JOINT

W-4 CONDITIONING

Test pieces to be used for jointing shall be previously conditioned for at least 20 h at (27 ± 2)°C and at a relative humidity (65 ± 5) percent.

W-5 PROCEDURE

W-5.1 The test specimen shall be firmly held in the grips of the tensile testing machine, taking care that the longitudinal axis of the test specimen, the axis of the tensile testing machine and the grips are correctly aligned.

W-5.2 Each test specimen shall be marked at the grips in order to identify any slippage out of the grips. The clear distance between the grips shall be (200 ± 5) mm. No preload shall be applied. Test shall be carried out on a test specimen at a temperature of (27 ± 2)°C and at a constant separating speed for the grips of (100 ± 10) mm/min. The applied tensile force shall be recorded continuously until the test specimen ruptures or shears. The mode of failure shall be recorded.

W-6 EVALUATION

W-6.1 The mode of failure of the specimen shall be reported. The shear resistance of the specimen is the maximum force recorded during the test.

W-6.2 Individual values for each set of five specimens in newton shall be noted. The shear resistance of the joint as the mean value to the nearest newton shall be calculated and reported.

W-6.3 Any test result where the test specimen breaks less than 10 mm from the grips or slips by more than the permitted limit within the grips of the tensile testing machine shall be discarded and retested with a replacement specimen.

W-7 EXPRESSION OF RESULTS

From the results of each set of 5 test specimen, shear resistance as the mean (using the maximum average shear resistance as occurs for each specimen) expressed in N/50 mm shall be calculated and reported.

ANNEX Y

[*Table* 2, *Sl No.* (xvii)]

TEST METHOD FOR DETERMINING THE RESISTANCE TO STATIC PUNCTURING

Y-1 PRINCIPLE

A concentrated load over a period of time is applied, through a puncturing tool on the surface of the PVC geomembrane while lying on a specified hard support and resistance to static load puncturing is observed.

Y-2 APPARATUS

Y-2.1 Guide Rail —The guide rail holds the loading rod in vertical position. The vertical movement of the puncturing tool from the surface of the test specimen shall be limited to (40 ± 2) mm by the guide rail.

Y-2.2 Loading Rod —The loading rod consists of a puncturing tool at the lower end and a support for the loading discs in the middle. Both shall be calibrated with the support disc to have a mass of 2 kg.

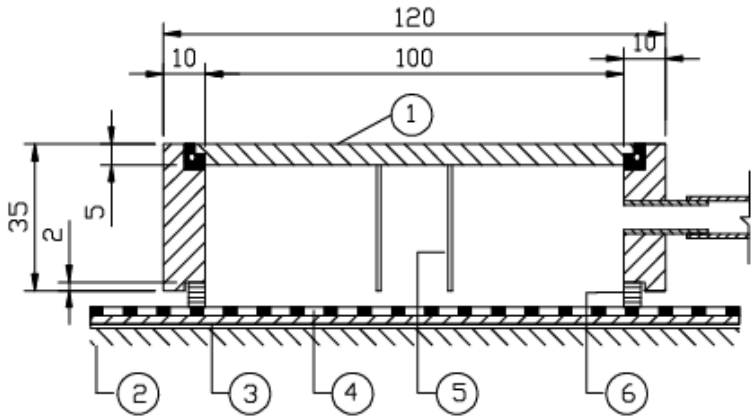
Y-2.3 Loading Discs —There is a complete set of four loading discs in which one disc is of 3 kg and other three discs with a mass of 5 kg each.

Y-2.4 Puncturing Tool —The puncturing tool is in the shape of a ball having 10 mm diameter. The diameter of thread for attachment to the loading rod is 5 mm. The specification of the puncturing tool material shall be given below:

a) Material : Steel;
b) Hardness : 50 HRC;
c) Ball diameter : 10 ± 0.05 mm; and
d) Polished, unmarked, spherical and defect free.

Y-2.5 Support — The test piece is placed loosely directly on a concrete paving slab of about 300 mm × 300 mm × 40 mm. The concrete surface shall be even and free from defects.

Y-2.6 Vacuum or Pressure Device — It is used for the verification of possible perforation. The inner diameter of the device shall be at least 20 mm. The schematic diagram of the vacuum device is shown in Fig. 15.



Key

1 Glass plate

2 Supports

3 Air permeable layer

4 Specimen

5 Transparent plastic tube

6 Gasket

FIG. 15 VACUUM DEVICE (EXAMPLE)

Y-2.7 The schematic diagram of the test assembly is given in Fig. 16.

Key

1 vertical movement

2 guide rail

3 loading rod

4 puncturing tool with diameter 10mm

5 clip

6 frames (20mmx20mm)

7 nail

8 test specimen (300x300±2mm)

9 concrete (300mmx300mmx40mm)

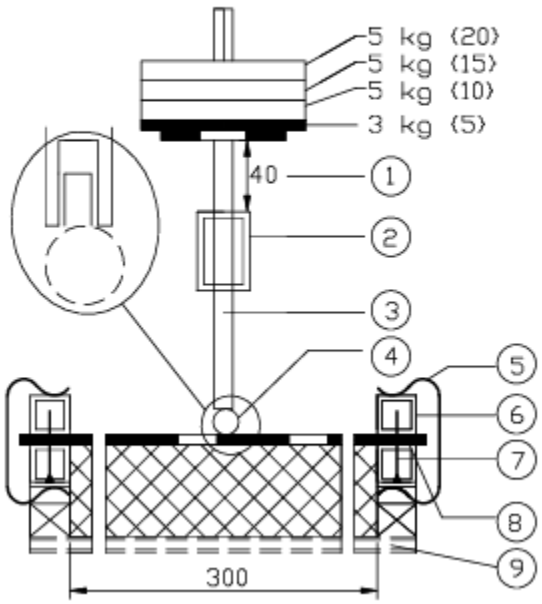


FIG. 16 STATIC LOADING ASSEMBLY

Y-3 TEST SPECIMEN

Y-3.1 The test specimens shall be cut from the PVC geomembrane with dimensions 300 mm × 300 mm (length × width) with a tolerance of ± 2 mm both sides.

Y-3.2 Specimens shall be taken across the width of the roll excluding 100 mm from the edges of the PVC membrane sheet/roll.

Y-3.3 Number of Test Specimens

The number of test specimens shall be 3 for each loading stage.

Y-4 CONDITIONING

Condition the test specimen at temperature (27 ± 2)ºC and relative humidity (65 ± 5) percent for at least 24 h prior to testing.

Y-5 PROCEDURE

Y-5.1 Maintain the temperature such that the testing shall be carried out at (27 ± 2)ºC.

Y-5.2 Lay the specimen loosely on the support (*see* **Y-2.5)** during testing such that the upper side of the membrane (in situ) is facing upwards (is exposed).

Y-5.3 During testing at each loading interval a new test specimen shall be used.

Y-5.4 Position the puncturing tool at the centre of the test specimen.

Y-5.5 Testing shall be carried out with three test specimens in intervals of loading with initial load of 5 kg. Duration of the loading shall be 24 h for each loading interval.

Y-5.6 Increase the load by steps of 5 kg until the perforation is observed or up to a maximum load of 20 kg.

NOTE — Load shall be applied carefully without a shock.

Y-5.7 Examine the test specimens for a possible puncture after each loading interval as per method specified in **U-5.8**.

Y-5.8 Coat the surface of the membrane where load was applied, with a soap solution within (7 ± 2) minutes after the test. Apply a pressure difference of 15 kPa to the area where the load was applied by means of vacuum or pressure device, with the lower pressure at the surface of the sheet. Examine the test specimen for at least 60 s. If no air bubbles are visible then the test specimen shall be considered as not punctured.

Y-5.9 Repeat the procedure for all test specimens and the material under testing shall be considered as resistant to static puncture if all test specimens are found not punctured.

ANNEX Z
(*Foreword*)

INSTALLATION GUIDELINES FOR PVC GEOMEMBRANE

Z-1 INSTALLATION PROCEDURE FOR LAKE/ RESERVOIRS/ WATER BODIES

Z-1.1 Preamble

Z-1.1.1 The primary function of geomembrane applied in ponds/ reservoirs is to prevent loss of water due to seepage. The successful performance of geomembrane is based on a good quality material, installation and appropriate design of ponds/ reservoirs.

Z-1.1.2 To improve the service lifetime of geomembrane, it is essential that the geomembrane are placed on the pond/ reservoir surface according to the dimensions and contours of the pond/reservoir ensuring full contact with the sub-grade. To achieve this onsite laying, joining and fixing is imperative.

Z-1.2 Storage at Site

The geomembrane shall be stored so as to be protected from puncture, dirt, grease, water, moisture, mud, mechanical abrasions, excessive heat or other damage. The rolls shall be stored on a prepared surface and to be stacked not more than three rolls.

Z-1.3 Earthwork and Site Preparation

The selected site shall be free from hard rocks/ murrum, a natural water source, mountain etc. The proposed site shall be free of any decomposable organic materials/vegetation as it can result in upliftment due to generation of gases beneath the geomembrane.

Z-1.4 Design and Sub-Grade Preparation

Z-1.4.1 The excavation of the pond/ reservoir shall be done in such a way the slope to bed ratio (V:H) shall be 1:1.5 minimum.

Z-1.4.2 Sub-grade surface shall be levelled and made free of undesirable angular and sharp fragments, foreign and organic matter, stones and pebbles, as the presence may lead to cause pinholes and or puncture the geomembrane.

Z-1.4.3 Soil sterilization may be necessary to kill roots of certain types of grasses by using an effective sterilant/chemical, however the sterilant or the chemical used shall not be detrimental to the liner and shall be applied in accordance with the geomembrane manufacturer's recommendations.

Z-1.4.4 The bed and slopes of the constructed pond/reservoir shall be inspected for burrows of crab's rodents, etc. All such burrows shall be emptied by removing the crabs and rodents and disposed off to a safe site away from the pond/reservoir site.

Z-1.4.5 The empty burrows and potholes (cavity between the stones) on the bed/slope of pond/reservoir shall be filled with soil. Thereafter it shall be compacted and the entire area shall be cleaned and leveled. The entire area shall be uniform and smooth.

Z-1.4.6 A layer of soft soil shall be applied and the top layer of soft bed and slope shall be compacted by water showering for at least 90 percent of proctor density by vibro compaction equipment or by any other suitable equipment or manually.

Z-1.4.7 The compaction shall be achieved at least up to a depth of 300 mm from the final sub-grade level of inside of the pond. Perfect compaction and leveling of bed and slopes will give good support to the geomembrane.

Z-1.5 Anchor Trench

Z-1.5.1 For the purpose of anchoring the geomembrane, an anchor trench of 500 mm × 500 mm × 500 mm shall be excavated at the inside edge of the top of the embankment (*see* Fig. 17).

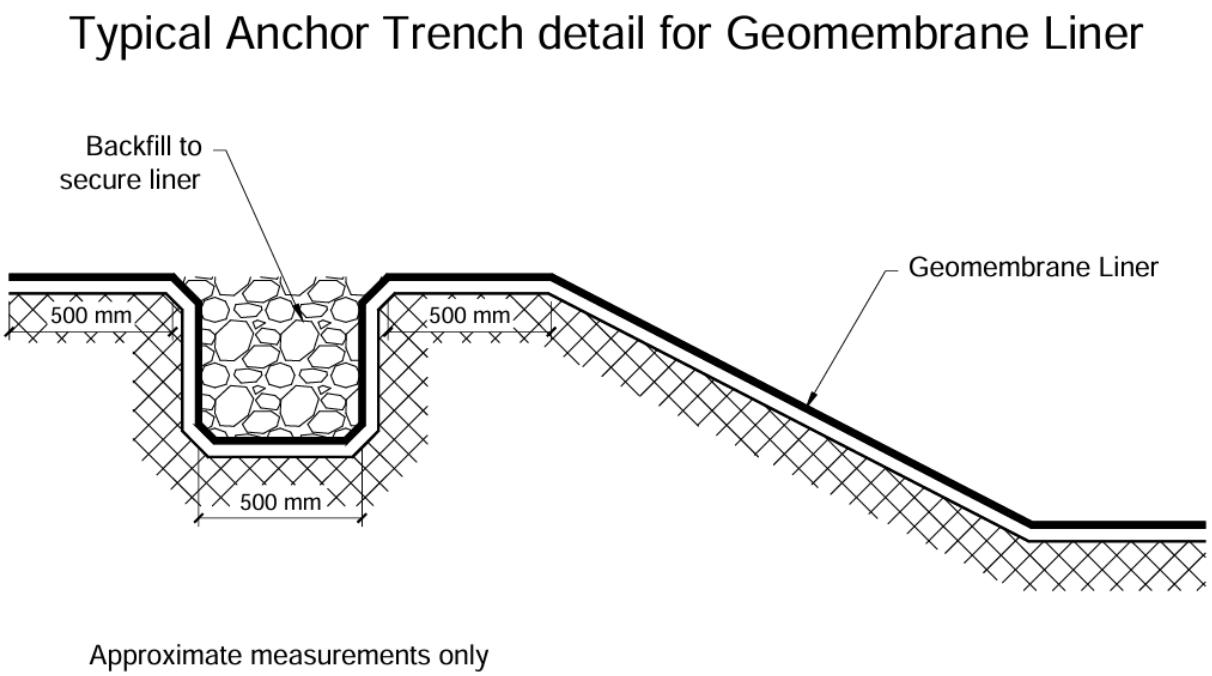


FIG. 17 TYPICAL INSTALLATION OF PVC GEOMEMBRANE

Z-1.5.2 Rounded corners shall be provided in the trench to avoid sharp bends in the geomembrane. It is imperative that the anchor trench is complete in all respects before lining work is undertaken to ensure the speed of lining and schedule. The anchor trench shall be back filled after filling the pond, till then filled sand bags shall be kept as counter weight.

Z-1.6 Geomembrane Laying Operations

Z-1.6.1 Geomembrane panels shall be placed properly on the bed and the slopes with an overlap of 50 to 75 mm for field seeming, or as specified, but not less than 50 mm.

Z-1.6.2 Counter weight of filled sand bags along the edges of geomembrane panels and toe of the bunds shall be provided in order to minimize the risk of flow of wind under the panels. The geomembrane interface where seams are to be made shall be clean and free from dust.

Z-1.6.3 Geomembrane shall not be laid during rains, any precipitation, in the presence of excessive moisture, in an area of standing water, or during high winds, fog, dew, etc. Geomembrane deployment shall stop in excessive temperatures since this results in imperfect seaming.

Z-1.7 Field Seaming of Geomembrane

The fundamental mechanism of seaming geomembrane sheets together is to temporarily reorganize the polymer structure (by melting or softening) of two opposing surfaces to be joined in a controlled manner so that, after the application of pressure, results in the two sheets being bonded together and the joined sheets shall perform as on single geomembrane sheet. Therefore field seaming is a very

important and crucial operation and any negligence on this part shall compromise severely the performance of geomembrane system.

Z-1.8 Factors Affecting the Field Seams

Z-1.8.1 Many factors contribute to the quality of field seam such as ambient temperature, moisture, wind, dust and quality of the field personnel. Field seaming shall be performed when weather conditions are favorable. Seaming below 5°C and above 40°C may result in a decrease in the overall quality of installation.

Z-1.8.2 Moisture caused due to precipitation or high humidity is likely to result in improper bonding resulting in failure of seams. Therefore the surface of panel in seaming shall remain dry at all times. Winds causing displacement of geomembrane panels may interfere with the proper alignment of seams, resulting in wrinkles or 'fish mouths'.

Z-1.8.3 The geomembrane panels shall be maintained in a broom clean condition with no dust allowed on or near the seaming areas.

Z-1.9 Quality of Field Personnel

The critical parameters for the hot air fusion welding machine are temperature and speed which shall be strictly maintained. Therefore, well trained professionals/technicians shall be employed for field seaming. Excessive melting weakens the geomembrane and inadequate melting results in poor strength. Hence a well-trained technician shall be able to apply adequate melting and pressure making proper seams.

Z-1.10 Field Testing of Seams

Z-1.10.1 To ensure the quality of seams, it is necessary to have a check on the seams at site by visual and manual methods to identify any defective field seams involving presence of unbounded or open seams, fish mouth created due to wrinkles and restraints, burning of liner due to excessive heat during thermal bonding.

Z-1.10.2 For seams between adjacent sheets of waterproofing membranes, the testing for tightness shall be carried out by means of compressed air pumped in to the test channel which is formed by the double welded joint. Initial test pressure shall be 2 bars for a test period of 5 minutes or 1.5 bar for a test period of 10 minutes. The joint shall be considered waterproof if the loss of air pressure in both cases is not more than 20 percent.

Z-1.11 Post Installation Precautions

Z-1.11.1 If there is no proposal of fixing cover system over the geomembrane, the pond/reservoir shall be filled as soon as possible after installation work to ensure that the geomembrane fully adheres to the sub-grade surface.

Z-1.11.2 A shade net shall be laid at corner of the pond/reservoir. There are chances of some reptiles entering into the pond, in spite of fencing. These reptiles can't come out of the pond/reservoir as they cannot crawl on the geomembrane. Hence to prevent damage to the geomembrane, shade nets shall be installed at the corners over the geomembrane.

Z-2 INSTALLATION OF THE PVC GEOMEMBRANE FOR TUNNEL LINING

Z-2.1 Description

Z-2.1.1 The purpose of the membrane waterproofing to underground structures is to prevent leakage of groundwater into the tunnels and to protect the final concrete lining against deleterious chemical influences. Waterproofing shall be applied to crown and sidewalls above footing or invert arch level. The waterproofing membrane shall always be located between shotcrete support and final concrete lining. As the underground structures referred to be not immersed below a distinct groundwater table no membrane waterproofing shall be provided for tunnel inverts.

Z-2.1.2 The waterproofing system shall consist of two layers: the first shall consist of a protective felt fastened to the shotcrete surface; the second layer shall be the actual waterproofing membrane properly fixed by special means as recommended by the manufacturer.

Z-2.1.3 While the sealing function shall be provided by the membrane, the layer of felt is required to protect the waterproofing membrane against damage from contact with the shotcrete surface, to prevent interlocking between concrete and shotcrete in case of differential movements of shotcrete support and final lining and to provide a drainage layer allowing to drain off groundwater into the longitudinal lateral drainage pipes, thus preventing a build-up of hydrostatic pressure on the tunnel lining.

Z-2.2 Surface Preparation

All surfaces to which waterproofing is to be applied shall be sufficiently clean smooth and free from deleterious materials and projections. The following treatment of surfaces shall be performed prior to the installation of waterproofing:

a) For the fixing of the protective felt and the waterproofing membrane minimum shotcrete cover of 50 mm to rock is required.

b) Irregularities of the shotcrete lining surface shall be eliminated by means of additional shotcrete. The ratio of the diameter to depth of irregularities shall be not less than 5:1. Rounding at rock bolts (where applicable), etc shall have a minimum radius of 0.3 m.

c) Transitions and intersections of tunnel profiles shall be rounded off with a minimum radius of 500 mm.

d) Protruding steel bars, wires, spacers, pipes etc shall be cut of unless treated with additional shotcrete cover.

e) Exposed steel parts such as rock bolts, if not intended to remain accessible shall be covered with shotcrete.

f) All shotcrete surface shall finally be smoothened with fine-graded shotcrete (rounded aggregates, grain size 0.8 mm), applied in a layer of 50 mm minimum thickness.

Z-2.3 Fixing of Felt

The protective felt (geotextile) of minimum 4 mm thickness for protection of waterproofing membrane and drainage on the finished outer lining surface shall be attached to the shotcrete surface using suitable fixings specified by the manufacturer. Depending on the location, 2 to 4 number of roundals shall be used per square meter. The felt shall be laid with sufficient slack to avoid overstress during concreting. Adjacent sections of felt shall be overlapped by 100 mm and joined by point welding or similar suitable method. Along the bottom of the tunnel side walls, the felt shall extend sufficiently to cover the lateral drainages.

Z-2.4 Fixing of Waterproofing Membrane

Adjacent sheets of waterproofing shall be joined by a double weld. Along the bottom of the tunnel side walls the membrane shall extend sufficiently to cover the lateral drainages.

Z-2.5 Fixing of Protective Membrane

With above joining procedure, the protective membrane is fixed to the water proofing one by means of thermal welding or by glueing of velcro and felt disks systems on the two membranes and connecting.

Z-2.6 Testing of Seams

All seams shall be tested and records of these tests shall be submitted by the contractor to the engineer.

Z-2.7 Seam Test with Compressed Air

For seams between adjacent sheets of waterproofing membrane, the testing for tightness shall be carried out by means of compressed air pumped into the test channel which is formed by the double welded joint. Initial test pressure shall be 2 bars for a test period of 5 minutes or 1.5 bar for a test period of 10 minutes. The joint shall be considered waterproof if the loss of air pressure in both cases is not more than 20 percent.

Z-3 CONSTRUCTION QUALITY ASSURANCE (CQA) OF PVC GEOMEMBRANES

Z-3.1 Construction Quality Assurance (CQA) — A planned system of activities that provide assurance that the facility was constructed as specified in the design. Construction quality assurance includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility. Construction quality assurance refers to measures taken by the CQA organization to assess if the installer or contractor is in compliance with the plans and specifications for the project.

Z-3.1.1 The quality of the waterproofing system should be controlled for its entire service life. During first filling, drain discharge must be continuously monitored, and records subjected to interpretation as the reservoir level rises. Control of drain discharge must continue during the operational life of the structure, so that any deviation from the normal drain discharge will signal the possibility of abnormal functioning of the system. Visual inspection, and leak detection systems, can spot the damage if any.

Z-3.2 Procedures to Assure Survival

Z-3.2.1 For any geomembrane sealing system to function properly, it is necessary that the geomembrane survive the packaging, transportation, handling, and installation demands that are placed on it. This aspect of design cannot be taken lightly or assumed simply to take care of itself. Some of the major variables affecting a given situation are the following:

a) Storage at the manufacturing facility;
b) Handling at the manufacturing facility;
c) Transportation from the factory to the construction site;
d) Offloading at the site;
e) Storage conditions at the site;

f) Temperature extremes at the site;
g) Subgrade conditions at the site;
h) Deployment at the approximate location;
j) Movement into the final seaming location;
k) Treatment at the site during seaming;
m) Exposure at the site after seaming; and
n) Placement of the cover material or soil backfill on the completed geomembrane where applicable.

Z-3.2.2 With a well-planned construction quality assurance (CQA) document, competent full-time inspection by CQA personnel, and cooperation of the installation contractor, the geomembrane can survive to the point of beginning to function as designed.

Z-3.2.3 While being stored, transported, handled, and installed, geomembranes are most often vulnerable to tear, puncture, and impact. Such events often come about accidentally, by vandalism, or by poor workmanship. Typical situations are the dropping of tools on the geomembrane, the driving of autos or pickup trucks on the unprotected liner, high winds getting beneath the geomembrane during placement, the awkwardness of moving large sheets of the geomembrane into position, and so on.

Z-3.3 CQC Items

Z-3.3.1 CQC includes:

a) Acceptance of materials at site;
b) Acceptance of surface;
c) Installation of geotextile supporting the geomembrane;
d) Installation of geomembrane sheets/panels;
e) Installation of fastening system on upstream face if applicable;
f) Field joints of geomembrane sheets/panel;
g) Water tightness of perimeter seals;
h) Final concluding inspection of geomembrane;
j) Placement cover layer if applicable; and
k) Final concluding inspection of geomembrane sealing system (after cover placement).

Z-3.3.2 The waterproofing contractor should provide the CQA manual related to the waterproofing works prior to starting of construction of the sealing system, to allow all parties involved to familiarize and become conscious of the possible mutual influences of the various construction steps. The CQA manual must address procedures for installation and inspections, tolerances, testing procedures and standards, corrective actions, and must include QC forms for all documented steps of QC. Depending on how construction is organized, some of the above steps can be performed and documented together.

Z-3.4 Acceptance of Materials at Site

All materials shall arrive at site with relevant documentation identifying their characteristics. QC shall verify by their labels that they correspond to specifications and that they are in conditions adequate for installation.

ANNEX AA

[*Table 3, Sl Nos.* (i) *and* (ii)]

TEST METHOD FOR ACCELERATED AGEING UNDER PERMANENT EXPOSURE TO ELEVATED TEMPARATURES

AA-1 PRINCIPLE

Test specimens are exposed to an elevated temperature in air during a fixed time period, using a regulated laboratory oven with forced air circulation.

AA-2 APPARATUS

A thermostatically regulated oven with air circulation, capable of exposing test specimens to a specified temperature, with a tolerance of ± 2°C, shall be equipped with hanging rigid metal plates or wired shelves to support the test pieces.

AA-3 TEST SPECIMEN

A total of four specimens, each with dimensions of 20 cm × 30 cm, shall be cut for the purpose of testing. Out of the four test specimen, two specimens shall be cut along the longitudinal direction, the other two shall be cut along the transverse direction.

AA-4 TEST PROCEDURE

AA-4.1 Oven Temperature

Set the oven temperature as specified ± 2°C. Monitor the temperature at least every 15 minutes.

AA-4.2 Specimens

Place the specimen in the oven once the temperature has reached a steady value. Place the specimens in the center of the oven, not touching each other, and so that the distance from each wall shall be at least 100 mm.

AA-4.3 Duration of the Oven Test

The duration of exposure and temperature shall as specified.

AA-4.4 Determine Tensile Strength and Elongation at Break

When the fixed time period of oven ageing has elapsed, the specimens shall be removed from the oven and cooled at (27 ± 2)°C for 4 h. The tensile strength and elongation at break shall be measured for exposed specimens according to Annex P. The average percentage reduction in tensile strength and elongation compared to the original results shall be recorded.

AA-4.5 Low temperature foldability test (where applicable)

After heat exposure the specimens shall be tested for foldability at low temperature (as specified) as per Annex E.

ANNEX BB

[*Table 3, Sl No.* (iii)]

TEST METHOD FOR DETERMINATION OF OXIDATION RESISTANCE

BB-1 PRINCIPLE

Sample for assessment are stored for specified time at elevated temperature. The evaluations to be performed before and after thermal ageing and the exposure duration using the relevant tests.

BB-2 APPARATUS

Ventilated air oven, regulated in such a way that the test specimen can be maintained at a constant temperature of (70 ± 2) °C during the full test duration.

BB-3 TEST SPECIMENS

BB-3.1 Four specimens, each with dimensions of 20 cm × 30 cm (02 along the longitudinal direction, the other two shall be cut along the transverse direction).

BB-3.2 To avoid edge effects test specimens for the evaluation tests are cut from test pieces only after thermal treatment. Normally, initial evaluation tests are performed before exposure. If this is not the case sufficient reference material shall be stored in dark conditions at (23 ± 2) °C and (50 ± 10) percent relative humidity for the evaluation testing at the same time as the exposed material.

BB-4 PROCEDURE

BB-4.1 Set the oven to maintain at specified temperature. Lay down the test specimens horizontally in the oven, their top face being exposed to the air. The bottom face shall lay on an anti-adhesive and continuous support, normally a sheet of siliconized paper.

BB-4.2 After exposure for specified duration, the specimens are stored for at least 24 h at (23 ± 2) °C and (50 ± 10) percent relative humidity before evaluation tests are performed.

BB-4.3 Expression of results and precision

Samples shall be tested for tensile strength and elongation at break in accordance with Annex P. The average percentage reduction in tensile strength and elongation compared to the original results shall be recorded.

ANNEX CC

[*Table 3, Sl Nos.* (iv), (v) *and* (vi)]

TEST METHOD FOR BEHAVIOUR AFTER IMMERSION IN WATER BATH

CC-1 PRINCIPLE

This test is used to determine the behaviour of PVC Geomembrane after immersion in aqueous solution, alkaline solution and hot water.

CC-2 APPARATUS

CC-2.1 Analytical Balance — A balance with a minimum measurement range of 200 g and a precision of at least 0.01 g.

CC-2.2 Water Bath

A recipient with a volume of at least one litre per sample, comprising:

a) an exposure tank made of inert, non-corrosive material, impermeable to the solution being used;
b) a cover to prevent the intrusion of light;
c) a stirring device to maintain the homogeneity of solvent, solutes and temperature;
d) a system for maintaining the liquid at (50 ±2)°C; and capable of being sealed with a chemically resistant material in order to prevent loss of volatile components of interest;

CC-2.3 Drying Chamber

A chamber with circulating air of (50 ±2) °C for drying the samples.

CC-2.4 Desiccator

A desiccator and desiccating agents (silica gel or calcium chloride).

CC-3 TEST SPECIMEN

A total of four specimens, each with dimensions of 20 cm × 30 cm, shall be cut for the purpose of testing. Out of the four test specimens, two specimens shall be cut along the longitudinal direction, the other two shall be cut along the transverse direction.

CC-4 PROCEDURE

CC-4.1 Determination of Dry Mass

The specimens are stored for 24 hrs in a drying chamber at (50 ± 2)^{o}C and then cooled to room temperature in an desiccator with desiccants. Immediately after removal from the desiccator, the specimens are weighted (M_1) individually to the nearest 0.01g.

CC-4.2 Immersion of Test Specimen

CC-4.2.1 Weigh the samples and immediately immerse them in the temperature-controlled test solution (use a weight if necessary) as specified in Table 6. Each sample shall be separated by at least 10 mm from all other samples and from the tank wall. Add the liquid and ensure that it covers the samples completely. Ballast the samples if necessary to prevent them from floating. Only samples based on the same material shall be placed in the same liquid bath.

Table 6 Test Solution

(*Clause* CC-4.2)

Sl. No. (1)	Test Liquid (2)
i)	0.5 percent sulphuric acid (Aqueous solution)
ii)	Saturated solutions of limewash [Ca $(OH)_2$] (Alkaline solution)
iii)	Distilled or de-ionized water solution at specified temperature (Hot water solution)

CC-4.2.2 Renew the volume of the liquid completely at least every seven days. Renewal shall be done within 30 minutes. During the whole test, the test liquid shall be stirred continuously. If light is likely to have influence on the action of the test liquid, it is recommended to operate either in darkness or in defined illumination conditions. It is recommended to use closed containers.

CC-4.3 Duration

The test duration shall be as specified. Determine the mass changes of the specimens after the end of test.

CC-4.4 Measurement and Analysis

CC-4.4.1 Mass Change

At the end of the immersion period, the specimens are dried with a non-fibrous filter paper. The mass change of the specimens is then determined by drying at (50 ± 2) ^{o}C in a convection drying chamber. After drying for 24 hrs and cooling, the first determination of mass by weighting takes place. This is

followed by drying for a second time for 24 hrs. Then weighting for second time. If the weight after the second drying varies by less than 0.20 percent from the weight after the first drying, the weight after second drying is used as drying mass (M_2). If weight reduction is greater, drying continue for 24 hours at (50 ± 2) ^oC each time, until a weight changes of less than 0.20 percent is obtained. The mass changes M_2-M_1 in percentage is determined after 1, 2, 4, 8 & 12 months (as applicable) on all specimens.

CC-4.4.2 Visible Defect

After the end of test, the specimens shall be free from visible defects.

CC-4.4.3 Tensile Strength and Elongation at Break

After the end of test, the tensile strength and elongation at break (according to Annex P) is determined on the dried specimens.

CC-4.4.4 Reduction in impact load (drop height)

After the end of test, the reduction in impact load (drop height) (according to Annex R) is determined on the dried specimens.

CC-4.4.5-Dimensional Change (where applicable)

After the end of test, the dried specimens shall be checked for dimensional change as per Annex T (only for measurement).

CC-5 EXPRESSION OF RESULT

The test report shall include the following information for both before and after immersion, along with the observed changes:

a) Mass changes
b) Visible defects
c) Tensile and elongation at break.
d) Reduction in impact load (drop height)