DURABILITY OF BITUMINOUS GEOMEMBRANE WATER PROOFING WORKS

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ABSTRACT
The resistance of bituminous geomembranes to ageing under mechanical and physico-chemical stresses and dual mechanical and physico-chemical stresses is described along with the properties of bituminous geomembrane samples from works after many years of service (e.g., 5, 10, 15, and 20 years). Compliance with the installation conditions prescribed by the quality control plans (QC/QA) and the essential role played by each actor of the work, the engineering firm, the geomembrane supplier, the earthworks firm, installers, and inspectors, is stressed as fundamental for guaranteeing the durability of the waterproofing works.

RÉSUMÉ
La tenue au vieillissement sous contraintes mécaniques, physico-chimiques, ainsi que sous contraintes mixtes mécaniques et physico-chimiques des géomembranes bitumineuses sont décrites, ainsi que les caractéristiques d'échantillons de géomembrane bitumineuse prélevés sur les ouvrages après plusieurs années de service (5, 10, 15 ou 20 ans par exemple). Le respect des conditions de pose imposées par le plan Qualité et le rôle essentiel joué par chaque acteur du chantier, bureau d'étude, fournisseur de la géomembrane, entreprise de terrassement, poseurs, contrôleurs est souligné comme élément fondamental de la durabilité de l'étanchéité réalisée.

1. INTRODUCTION

COLETANCHE bituminous membranes are widely used in Europe and to a lesser extent in Africa, the United States, Canada, and Japan. To date, approximately 97 million square feet have been manufactured and installed.
The main uses of this geomembrane, which is manufactured in 5.15-metre-wide rolls, are for waterproofing—

1) Potable water structures such as canals (irrigation, navigation), water reservoirs, recreational water bodies, and firefighting water reservoirs

Ospedale Dam, Corsica, France, 1978
Angliers Dam, Quebec, Canada, 2004

2) Environmental protection works such as landfill sites, covers for domestic and industrial waste sites,

Landfill site, Falklands, 2003

Industrial waste site, Colmar, France, 2002, 2003, 2004

covers for mine tailings and short-lived (300 years) low to intermediate-level radioactive waste, biogas barriers,

Radioactive waste cover
ANDRA, La Hague, France, 1993 to 1997

Commercial building, Kirkland, QC, Canada, 2003
Wall-Mart, Shawinigan, QC, Canada, 2003

and lagoons, domestic and industrial wastewater storage basins, ditches and retention basins for polluted highway runoff, and

3) Civil engineering structures such as bridge decks, extrados of tunnels, and railway tracks (in this case, to protect sensitive substrata such as gypsum and clay from rain and to prevent fines from rising into the ballast).

BNSF Railroad, Crawford, Nebraska, USA, 2000, 2003

All these applications, which are intended for works that have a long service life and that have an impact on the safety of property and individuals, required numerous studies and laboratory tests to determine the durability of bituminous geomembranes under these conditions of use and to monitor their performance over time under a variety of mechanical and physico-chemical and dual mechanical and physico-chemical stresses.

2. INDEX PROPERTIES OF BITUMINOUS GEOMEMBRANES

2.1 Tensile Strength

Tensile strength is measured both longitudinally and perpendicularly.

For example, COLETANCHE NTP 2, which has a minimum thickness of 4.00 mm according to ASTM D 5199 01, has the following ASTM D 4595 86 tensile properties:

Tensile strength at break
1) Longitudinal: 22.2 kN/m
2) Perpendicular: 18.40 kN/m

Elongation at break
1) Longitudinal: 68%
2) Perpendicular: 77%

2.2 Puncture resistance

Bituminous geomembranes display excellent resistance to puncturing by aggregates, which means that they can be used directly under railroad ballast.

Many laboratory tests have been performed on bituminous geomembranes. The following table provides the results for static puncture resistance (ASTM D 4833), aggregate puncture resistance (NFP 84510), and hydrostatic resistance (ASTM D 751).

Aggregate puncture testing (CEMAGREF, FR)

COLETANCHE Geomembrane	Puncturing		
	Static N	Aggregate kN	Hydrostatic kPa
NTP 1	404	10	100
NTP 2	485	15	200
NTP 3	538	20	250
NTP 4	681	25	250
ES 1	450	20	1050
ES 2	550	25	1300
ES 3	614	25	1500

2.3 Cold bending

Cold bending is evaluated by determining the temperature at which a geomembrane cracks when folded around a standard 50-mm-diameter mandrel.

According to ASTM D 751, NTP 1 to NTP 4 blown bitumen membranes should not crack before reaching 0°C (32°F) while ES 1 to ES 3 elastomeric geomembrane should not crack before reaching –25°C (–13°F). This means that ES geomembrane can be safely installed even at temperatures as low as –10°C to –15°C (14°F to 5°F) (worksites in Alberta, November 2003; Washington State, February 2003; Oregon, February 2002; Angliers Dam, Quebec, March 2004).

2.4 Water permeability

The procedure developed by LIRIGM (Grenoble, France) was used to test COLETANCHE membranes. The following table presents the results of the tests under various conditions:

COLETANCHE Geomembrane	Pressure (kPa)	Elongation (%)	Permeability (10^{-14} m/s)
NTP 1	100		10
NTP2	100		7
NTP 3	100		4
NTP 4	100		2
NTPES	100		7
NTP 2	750		1.0
	500		1.3
	250		2.7
	100		7.4
	50		8.5
NTP 4	100	0	2
	100	10	15
	100	17	43
	100	25	340

Water permeability of bituminous geomembrane

2.5 Water vapor and gas permeability

The results of tests performed on a 4-mm-thick ES 2 bituminous membrane are given below:

1) Water vapor transmission: 0.15 g/m^2 per day
2) CO_2 flux below the 7.8 10^{-7} m^3 (m^2.j.atm) threshold
3) N_2 flux below the 7.8 10^{-7} m^3 (m^2.j.atm) threshold
4) CH_4 flux below the 9,3 10^{-7} m^3 (m^2.j.atm) threshold

Reference: Betec (USA)

Conclusions of paragraph 2

These values ensure longevity insofar as the underlying support and the installation procedure comply with the requirements of the installation manual.

Installation Manual

It should be noted that other tests such as burst strength and weld tensile strength may also be used to complement the tests mentioned above.

3 RESISTANCE OF BITUMINOUS GEOMEMBRANES TO AGEING IN THE LABORATORY

3.1 Resistance to physico-chemical stresses

Bituminous membranes are mainly composed of needle-punched, non-woven, polyester geotextile impregnated and faced with a bituminous mastic (mixture of bitumen and filler). Since the threads of the geotextile are completely coated with bituminous mastic, they are protected against outside physico-chemical attack. The physico-chemical resistance of geomembranes is thus the same as that of bitumen.

3.1.1 UV radiation – Long-Term exposure

Most UV resistance tests, including those for the ASTM D 5147 standard, take six months to complete and correspond to approximately 25 years exposure to a moderate North American climate. The results of such tests for unprotected bituminous roofing membranes are available.

Unprotected bituminous membranes used to waterproof basins and reservoirs display good performance even after 20 years of service (E. Alonso et al. 1990).

Basins – exposed Coletanche
Mud basin, Fréjus, France, 1987
Leachate pond, Pitsea, UK, 2000

3.1.2 Resistance to chemicals and leachates

The "Shell Bitumen Industrial Handbook" (1995, pages 390 to 395) contains tables listing the chemical resistance of bitumen to over 200 chemical products at temperatures ranging from 0°C to 75°C (32°F to 167°F). Blown bitumen is very resistant to chemical attack.

Resistance to chemicals and leachates must be studied on a case-by-case basis, i.e., as a function of the pH and chemical makeup of the effluent, the concentration of the chemicals, the temperature, and the length of the contact (accidental or permanent).

Resistance to domestic waste site leachates has been studied and the results have been published (C. Duguennoi et al. 1995, CEMAGREF, France; laboratory of the French Ministry of Agriculture). The control leachate was a mixture of two leachates from different sites, one with an aerobic degradation system and the other with an anaerobic system. The authors concluded that after six years of immersion in the domestic waste leachate, the properties of the bituminous geomembrane had not changed.

A number of protecting underground water works (domestic waste site, 1983; green waste composting sites, 1995), which are monitored every three months, have remained completely watertight.

Marmitaine landfill site, Rouen, France, 1993, 1997, 2002

3.1.3 Resistance of bituminous geomembranes to biodegradation

Bituminous artifacts dating back 3000 years to Mesopotamia are examples of the resistance of bitumen, a natural material, to biodegradation.

Nevertheless, in order to quantify resistance to biodegradation, laboratory testing is necessary.

Barletta et al. (1987) studied the aerobic biodegradation of oxidized bitumen under various soil conditions in the presence of bacteria. The aerobic degradation of the bitumen was correlated with the production of CO_2.

The mean rate of degradation, when nutrients were added to the soil to promote bacterial growth, was 5 microns/year. Based on this extremely slow rate of biodegradation in conditions that were favorable for bacterial growth, a 5.6-mm-thick bituminous membrane was chosen as a cover for the La Hague (France) storage site for short-lived (300 years) low- to intermediate-level radioactive waste (Convert et al. 1993).

3.2 Resistance to dual mechanical and physico-chemical stresses

Resistance to dual mechanical and physico-chemical stresses of capping for low- to intermediate-level radioactive waste storage sites was tested. A brief description of the methods used and the results obtained are given in a presentation for a CEIFDI training day by Georges Aussedat, Department Director, Centre d'Étude du Bâtiment et des Travaux Publics CEBTP (Centre for the Study of Buildings and Public Works, France).

Geomembrane samples under light pressure (0.09 kN/m) at 60°C were subjected to an oxidizing mist (water + H_2O_2). After 2, 4, 6, and 12 months of accelerated ageing, the samples were stretched at 10°C.

The results led to the following recommendations to ensure maximum longevity:

1) Geomembranes must not be subjected to any mechanical stresses, whether during transportation, handling, or installation. Stresses must be minimized once the geomembrane is installed by ensuring the substrate is perfectly level (care must be taken with the vertical transition with the concrete structure). This is why rolls of Coletanche geomembrane are stored on mandrels to avoid compressing the spools and why they are unrolled using a hydraulic beam.

Storage of rolls

Excavator equipped with a hydraulic beam

Joints must be welded once the geomembranes are correctly positioned. Because of their low thermal expansion coefficient, geomembranes remain flat and joints are—

1) easy to weld,
2) not subject to stress-cracking because there is no excessive strain at the joints.

4 INSPECTION OF BITUMINOUS GEOMEMBRANES: CONDITION AND AGEING AFTER MANY YEARS OF SERVICE

4.1 Buried bituminous geomembranes

Bituminous geomembranes that are protected from UV radiation age extremely slowly.

In Europe, ditches for collecting polluted highway runoff are often waterproofed with earth-covered bituminous geomembranes.

Breul et al. (1995) tested samples of the COLETANCHE NTP 2 bituminous geomembrane installed in 1979 in the ditches along French Highway A81 (Le Mans-Rennes). The geomembrane had been placed on a sand bed and covered with a layer of earth and gravel 10 to 25-cm-thick. The results of the tests on the NTP 2 geomembrane after 14 years of service are presented below (sampling date: 19/8/1993).

Test	Sample	No. of measurement	Average	Spec. NTP 2 (1993)		
				Min.	Theor	Max.
Unit Mass (kg/m^2)	1	12	4.69	4.10	4.43	
Thickness (mm)	1	36	4.23		4.00	
Tensile strength at break NF G 07-001 (daN/cm)	Width	10	14.70		13.0	
	Length	10	14.80		18.0	
Elongation at break (%) NF G 07-001	Width	10	38.70	35.0		45.0
	Length	10	37.10	35.0		45.0
Permeability (m/s)	1	2	4.0×10^{-13}			10^{-13}

LTR file L72/345/98

4.2 Exposed bituminous geomembranes

Alonso et al. (1993) published a review of 20 hydraulic structures in France that are waterproofed with bituminous geomembranes:

Name	Date	Purpose	Surface (m^2)	High (m)	Slope of berm
Lanoaille	1983	Leisure	4,700	12	1 / 2.5
Doissat	1982	Irrigation	2,000	13	1 / 2.5
Le Lambon	1977	Leisure	3,200	6	1 / 1.7
Vallon Bimes	1973	Firefighting	1,000	9	1 / 2.0
Bangon	1973	Leisure	6,000	17	1 / 2.5
Bourjas	1975	Firefighting	5,000	11.5	1 / 2.5
Campaux	1975	Leisure	2,200	13	1 / 2.0
Maraval	1977	Firefighting	1,000	8	1 / 2.0
Albi	1988	Leisure	2,000	13	1 / 2.0
Ayron	1976	Leisure	40,000	6	
10 basins	1979 - 1983	Lagooning	4,650	3	1 / 1.5

List of structures waterproofed with bituminous geomembranes that are monitored by CEMAGREF (France).

The following conclusions were reached:

1) The general condition of six structures with a geomembrane exposed on the top face (Le Lambon, Maraval, Vallon des Bimes, camp Bourjas, Bangon, and Campaux dams) was satisfactory 20 years after construction. Only minor defects due to mud-curling, i.e., 0.1-mm-deep (4 mils), 1 to 5-cm-long cracks (alligatoring) were occasionally noted that, however, did not compromise geomembrane performance. Alligatoring is generally mitigated when elastomeric Coletanche ES membranes are used.

2) Bituminous geomembranes protected by a 30-cm-thick layer of soil were installed to waterproof ten basins. After 19 years, the condition of the geomembranes was satisfactory.

Samples of the Coletanche NTP 2 bituminous membrane protecting the Guazza basin in Corsica (France), which was built in 1981 and which is still in operation, were taken from above-water, wash and below-water zones after 7 and 14 years of service.

The table below shows that the permeability of the geomembranes remained practically constant over the years despite the appearance of very superficial cracks due to mud-curling.

Properties of NTP 2 samples taken from the Guazza basin in Corsica, France.

Properties		A	B	C
Thickness (mm)		3.0	3.0	4.1
Unit Mass (kg/m^2)		4.5	4.5	4.7
Tensile Strength at break (daN/cm)	Longitudinal	17	17	14.8
	Transverse	15	15	14.8
Elongation at break (%)	Longitudinal	41	40	37.1
	Transverse	49	33	38.7
Permeability (10^{-13} m/s)	Under 0.1 mpa	6	2	4

A = 7 years exposed and 7 years underwater
B = 7 years underwater
C = 14 years exposed

Irrigation water storage basin
Guazza, Corsica (1978)

5 CONCLUSIONS

Their intrinsic properties, their proven stress relaxation rate (CEBTP, 70% of the stress disappears within 3 hours), their 30 year history of commercial use, and laboratory studies conducted over seven years, which have been corroborated by analyses in France and the United States of samples taken from actual structures, prove that bituminous geomembranes have an excellent service life subject to compliance with recommended installation and welding procedures.

Echography – Ultrasound inspection of welds

Generally speaking, to ensure the longevity of a work waterproofed with a geomembrane—

1) Consultants must, for a given application, stipulate the best type(s) of membrane(s):

a. Perform the calculations or tests needed to determine the correct membrane thickness and protection (do not systematically use 1 or 1.5 mm membranes to save money)

b. Take construction requirements into consideration, i.e., waterproofing around intrusions, connections between structural elements, etc. because the durability of a structure does not depend solely on the longevity of the membrane.

Transition with concrete structure
Navigable canal, UK

c. Take seasonal constraints into consideration by selecting, as warranted, membranes that are less sensitive to climatic conditions (bypass, Kildare, Ireland; Angliers Dam, Quebec, Canada).

Kildare, Ireland

d. Advocate natural solutions, e.g., membrane-natural clay soil-membrane (bypass, Kildare, Ireland)

e. Minimize the initial investment by, for example, proposing a geomembrane that can be covered after 20 years of service (Washington State, USA).

f. Resist the attraction of new products; use products that have stood the test of time.

2) Suppliers must propose the right products for the intended use.

3) Installers must make submissions that enable them to comply completely with quality plans and install membranes at the right pace, time of day, and season to avoid or limit defects.

Geomembranes used in works have an important role to play in protecting the environment and preserving water resources.

The Nuclear Safety Agency
opts for bituminous geomembranes

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