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INFLUENCE OF GEOTEXTILE ON THE BEHAVIOUR OF GEOTEXTILE—GEOMEMBRANE COMPOSITES

INFLUENCE DES GEOTEXTILES SUR LE COMPORTEMENT DES COMPOSITES GEOTEXTILE — GEOMEMBRANE

EINFLUSS DER GEOTEXTILIEN AUF DAS VERHALTEN DER GEOTEXTIL-GEOMEMBRAN-KOMBINATIONEN

Geomembranes used in water-retaining structures as an impermeable barrier can be combined with geotextiles to form a composite in order to increase their tensile strength and resistance to puncturing. Since the current test results are generally available either for geomembranes or for geotextiles separately, a laboratory testing programme was undertaken to determine the influence of low temperatures and ultra-violet rays on the tensile strength and the strain at failure of the composite. Composites using five different types of geomembranes, glued on both sides to a thick non-woven geotextile, were tested for tensile (uniaxial) and burst strengths at temperatures ranging between +23 and -35°C.

The results of the tensile and burst tests show that the strength of the composites is increased by a factor of 10 to 20 in comparison to that of the individual geomembranes. At room temperature, the behaviour of the composite is governed by the geotextiles since they fail at strains (40%±) lower than those of the geomembranes, the geotextile being many order stiffer than the geomembranes. At very low temperature (-35°C), some geomembranes become brittle and they fail at low strains (5-10%), whereas the geotextiles remain relatively unaffected. Short exposure of the composite to the ultra-violet light leads to a marked decrease in its strength.

Des géotextiles peuvent se retrouver en association avec des géomembranes, sous forme composite dans les ouvrages de retenue d'eau, dans le but d'en augmenter la résistance à la traction et au poinçonnement. Etant donné que les résultats d'essais sont généralement obtenus séparément sur les géotextiles ou les géomembranes, un programme d'essais de laboratoire a été mis sur pied dans le but de cerner l'influence des basses températures et des rayons ultra-violet sur la résistance à la traction et l'allongement à la rupture de différents composites. Cinq principaux types de géomembranes préalablement collées de part et d'autre à deux géotextiles épais non tissés aiguilletés ont été soumis à des essais de traction et d'éclatement à des températures variant entre + 23° et - 35° C.

Les résultats ont clairement démontré la contribution des géotextiles sur les courbes effort déformation et sur la résistance des composites: à la température de la pièce, le comportement est contrôlé par les géotextiles. Ils sont beaucoup plus rigides et la rupture se développe à l'intérieur de ce matériau. A basses températures, certaines géomembranes deviennent fragiles et la rupture se produit à faible déformation alors que les géotextiles demeurent relativement déformables. En dernier lieu, on a trouvé un effet marqué des rayons ultra-violet sur la résistance des composites: des périodes d'exposition relativement courtes ont entraîné une diminution de leur résistance.

INTRODUCTION

The use of geomembranes as an upstream impervious facing can offer a valuable alternative to current dam materials such as concrete or bituminous facings. The mechanical properties of geomembranes needed to achieve imperviousness under a given head of water can compare favourably with other products. Indeed, the use of geomembranes can be economically and technically attractive on projects that involve one or many of the following constraints.

1 - Remoteness of the construction site and associated high transportation costs.
2 - Scarcity of suitable natural materials for impervious fill near the site.
3 - Difficult climatic conditions for conventional construction and compaction procedures.
4 - Compressible dam foundation inducing which could induce differential settlements and eventual cracking of the impervious element.

However, geomembranes are relatively thin and their susceptibility to puncturing can have a negative impact on a potential design. This difficulty can be eliminated if a geomembrane is combined with thick needle-punched geotextiles to increase its resistance to different kinds of failure:

- puncturing or tearing during transportation and construction.
- puncturing by angular agregates.
- significant stretching either at anchor points or in localized areas subject to subsidence.

After the composite has been properly installed, the presence of the geotextiles against the geomembrane has many beneficial effects:

a) they tend to soften and enlarge the outline of the sharp points of early contacts of the supporting soil layer

b) they fill up the most depressed areas of the granular material, allowing the geomembrane to find a continuous and complete support without significant stretching

c) the presence of a deformable medium like the geotextiles between the geomembrane and the sharp edges of soil support, can eliminate points of fixity on the geomembrane and facilitates the transfer of force from the most stressed areas towards those under lower stresses.

The use of geotextile-geomembrane composites in water-retaining structures of significant height in cold climates poses some problems such as:

1 - *Behaviour Under Low Temperatures* Tests run on different types of geomembranes at temperatures as low as - 35° C (10, 11) show that although elastomers remained ductile, thermoplastic and bituminous membranes can become brittle and crack at very low strains. Such a characteristic is undesirable since cracking would mean the loss of imperviousness of the facing.

2 - *Integrity of Seams* The seams must be continuous, completely impervious (geomembrane to geomembrane seams) and they must have, at least, the same tensile properties as those of the individual geomembrane.

3 - *Influence of Ultra-Violet Exposure* The composites may be exposed for some period of time, during its installation, to the effects of sunlight. It is well known that the strength properties of geotextiles are significantly altered by outdoor exposure (8, 9).

In order to evaluate the influence of these factors, an extensive laboratory investigation was undertaken at Ecole Polytechnique of Montréal on 21 different types of commercially available geomembranes including bituminous, thermoplastics, elastomers and thermoplastic-elastomers. The results of the tests on the individual geomembranes have been presented and discussed in a paper by Rollin et al. (11). The present paper treats the results of the second phase of investigation that was carried out on 5 of the 21 products previously tested. The purpose of this second phase was to analyse the behaviour of the geomembranes in a composite form: a central geomembrane was bonded on both sides with a non-woven needle-punched geotextile weighing 800 g/m².

IMPORTANCE OF TENSILE STRENGTH OF COMPOSITES IN WATER-RETAINING STRUCTURE

The analysis was based on the evaluation of tensile strengths because they give relevant mechanical properties required in the design of dams.

Three parameters can be obtained from tensile test:

a) the force per unit width, at failure (α_f),
b) the elongation at failure (ε_f) and
c) the modulus (J), (corresponds to the slope of the α vs ε curve).

The tensile test can reproduce stresses that are susceptible to be encountered in water-retaining structures. For example, the first parameter (α_f) can be compared to stresses computed at anchor points, that is at the crest and at the toe of the upstream facing. Limit equilibrium was considered by Giroud and Ah-Line (6) and graphs developed by them, give values of the tensile stress as a function of slope and friction angles at soil-geotextiles and/or geotextile-geomembrane interfaces. The theoretical unsupported length bridged by a geomembrane can also be computed as a function of the fluid pressure and of its force per unit width at failure (5).

The elongation at failure (ε_f) is also an important parameter and movements within the impervious element must be kept within the maximum tolerable values. Although analyses of displacements, assuming homogeneous materials, indicate that they generally involve less than 10% unit strain, inspection of some buried geomembranes in the Terzaghi dam (7) has shown that in localized sinkholes, the membrane has been stretched up to 160%. It is therefore important that geomembranes can tolerate local elongations without failure, so that their imperviousness may not be compromised even if they are substantially stretched.

Finally information about the elastic properties of the membrane (modulus J) is also obtained by plotting the stress-strain curve. The results of the first phase of tests (11) show that when the initial modulus is relatively high, brittle failure of the geomembrane occurs at very low strain (non-elastomeric membranes at sub-zero temperature), whereas a ductile behaviour is generally associated with low modulus geomembranes.

TESTING PROGRAMME

Two types of tensile strength tests were used: the direct tensile test and the burst test.

The direct tensile test was carried out on rectangular samples measuring 150 mm (height) X 100 mm (width) as shown in fig. 1. These dimensions were preferred to those given in the ASTM standard D-1682 in order to insure that the transverse striction induced by the axial elongation is kept to a minimum. Furthermore, failure was forced in the free length because the section of the geomembrane between the clamps was cut oversize. The samples were tightened by means of 6 bolts at each end with a uniform torque of 7 kN-m. The rate of straining of the samples was set at 3.8 mm per min, equivalent to 2.5% per min. Continuous recording of the stress-strain curves was made, the stress being defined as the axial force divided by the width of the sample (independent of the thickness of the composite).

The burst tests were conducted on circular specimen 200 mm in diameter, clamped between the cover and the top flange of a 150 mm dia. steel cylinder (11). The pressure was applied from the center of the top section and it was read on a manometer installed on the line. The pressure was increased in steps of 50 kPa and the corresponding center deflection was measured by a marker until bursting occurred as noted by a sharp decrease in the air pressure.

Table 1 gives the principal characteristics of the tested composites. The EPDM and Butyle membranes were constituted of cross-linked elastomers bonded between two 800 g/m² non-woven geotextiles using respectively 560 and 1190 g/m² of glue (15% and 25% of the total mass). The CSPE and PVC were thermoplastic membranes

Table 1 - General Properties of Tested Composites

GEOMEMBRANE'S DESIGNATION	GEOMEMBRANE COMPOSITION	GEOMEMBRANE THICKNESS (mm)	GEOMEMBRANE MASS (g/m2)	GEOTEXTILE TYPE	GEOTEXTILE MASS (g/m2)	BONDING DESCRIPTION	BONDING APPROXIMATE MASS OF SOLVENT (g/m2)	MEASURED TOTAL MASS OF COMPOSITE (g/m2)
EPDM	ethylene propylene diene monomer	1.6	1600	double NP-NW*	800	solvent	560	3760
Butyle	isobutylene rubber	1.7	1940	double NP-NW*	800	solvent	1190	4730
CSPE	hypalon (trade mark of Dupont)	1.7	2300	double NP-NW*	800	solvent	230	4130
PVC-800	polyvinyl-chloride	1.8	2330	double NP-NW*	800	heat-pressing	0	3930
PVC-400	polyvinyl-chloride	1.8	2330	double NP-NW*	400	heat-pressing	0	3130
PVC-240	polyvinyl-chloride	1.7	2000	single-NP-NW*	240	heat-pressing	0	2440
CIM	chevron industrial	11.0	4400	double NP-NW*	800	impregnation of the geotextile	-	6000
	membrane	1.4	1400	none	-	-	-	-

* NP-NW: needle-punched non woven

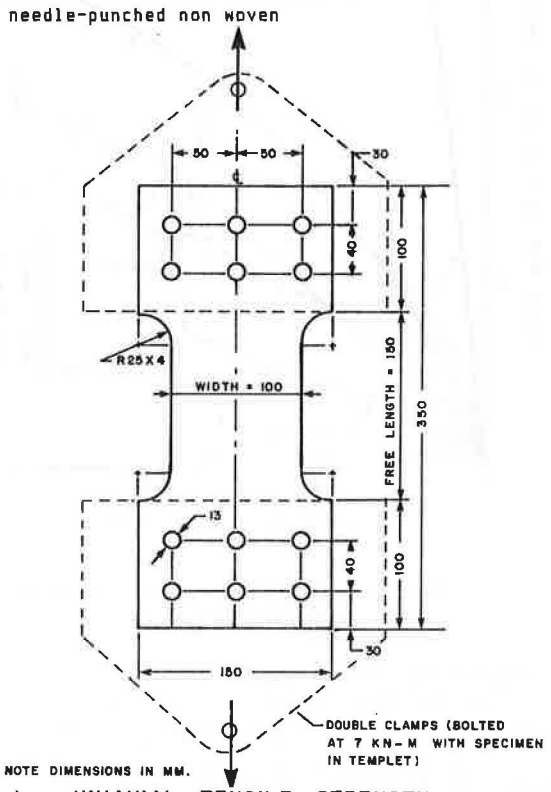


Fig. 1 — UNIAXIAL TENSILE STRENGTH SPECIMEN

with two bonded geotextiles; the bonding between the PVC and the geotextiles was minimal since it was achieved by heat pressing; the geotextiles employed weighed 800 and 400 g/m² respectively. The last geomembrane (CIM) is an elastomer, mainly polyurethane. In the composite form, the geomembrane was relatively thick (11 mm), whereas the geomembrane without geotextile was only 1.4 mm thick. Due to the reaction of the polyurethanes with water, which produces carbon dioxyde (CO_2), some entrapped voids were found in the thick CIM composites. The geotextiles were impregnated to the central elastomer during the manufacturing process.

STRENGTHENING EFFECT OF GEOTEXTILES

The increase in strength of the composites can be evaluated from fig. 2. The dotted lower curves represent geomembranes without geotextiles; they were strained up to 80% without failure and the force per unit width corresponding to this strain ranged between 0.7 and 5 kN/m. For the sandwiched geomembranes (full lines), the maximum unit load ranged between 30 and 80 kN/m. This figure also shows that the strength increase of the composite is a function of the thickness of the geotextiles as shown by the stress-strain curve of the composite. The strength of the composite with 800 g/m² geotextiles is more than twice (76 kN/m) that of the composite with 400 g/m geotextiles; the geomembrane used in both cases being the same (1.8 mm thick). The arrows indicate the strain at failure in the geotextiles; it ranged between 40%, for the CIM, and 65%, for the Butyle. Despite the fact that the tests were not continued beyond these points, it is believed that the strength of the composite would have fallen to the value corresponding that of the single geomembrane.

Table 11 summarizes the results of both tensile and burst tests. It shows that the strength increase of the composite, from both axial tensile and burst tests, when compared with the single geomembrane has a multiplication factor of 7 to 23. The high values for CIM (84 & 119) are related to the difference in the thickness between the composites (11 mm) and the geomembrane without geotextiles (1.4 mm) and to the spraying of the geotextiles by an elastomeric product which forms the impermeable geomembrane of the composite. The moduli are greatly influenced by the addition of geotextiles; the composites are 170 to 180

Table II - Strengthening Effect of Geotextiles

GEOMEMBRANE'S DESIGNATION	AXIAL TENSILE TEST						BURSTING TEST		
	α_φ (kN/m)			J_1 (kN/m)			P_B (kPa)		
	G*	C*	C/G	G	C	C/G	G	C	C/G
EPDM	2.0	40	20	3	55	180	125	1800	14
Butyle	1.3	30	23	3	50	170	125	>2100	>17
CSPE	5.8	42	7	44	80	20	-	-	-
PVC-800		76	14	15	250	170	150	1500	10
CIM	0.7	83	119	15	250	170	25	>2100	84

C : composite
G : geomembrane (without geotextiles)

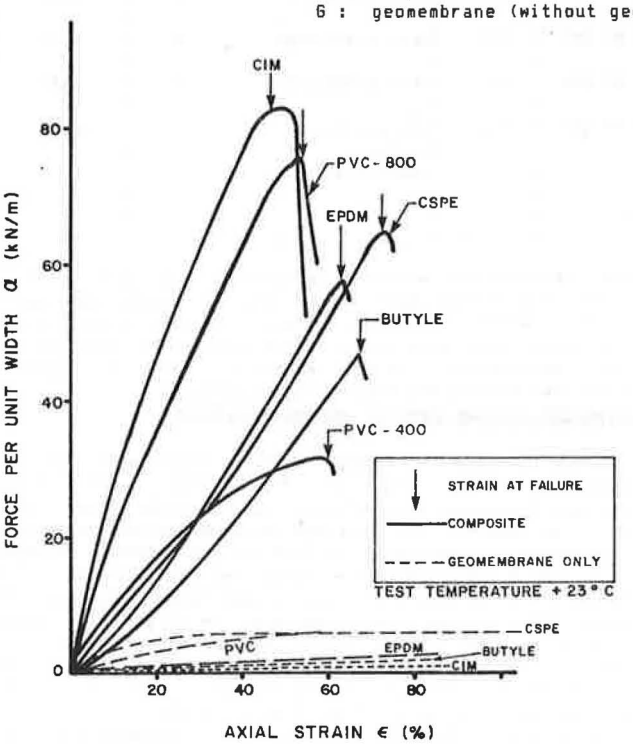


Fig. 2 — STRENGTHENING EFFECT OF TWO 800 G/M² BONDED NON-WOVEN GEOTEXTILES

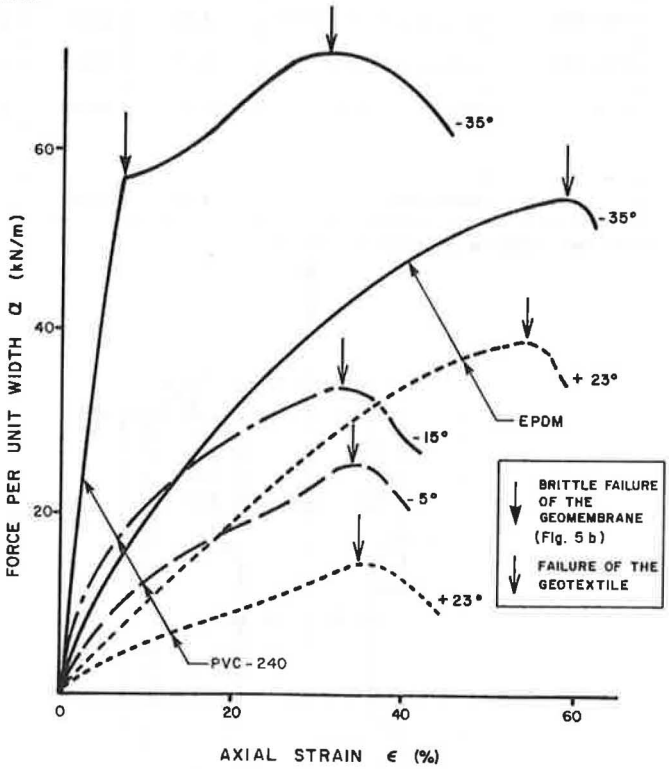
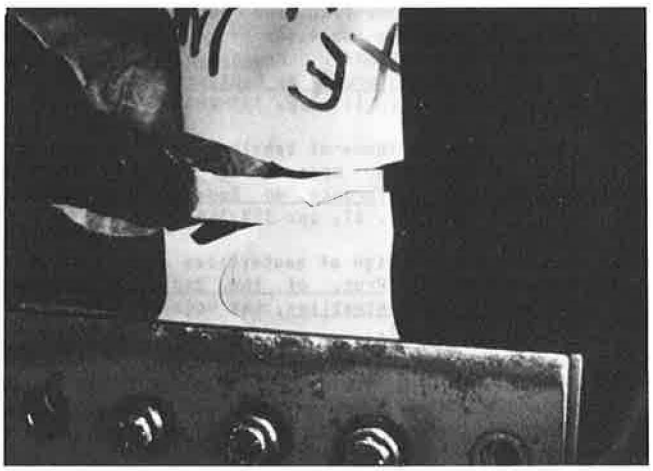


Fig. 3 — EFFECT OF TEMPERATURE ON COMPOSITE'S BEHAVIOUR

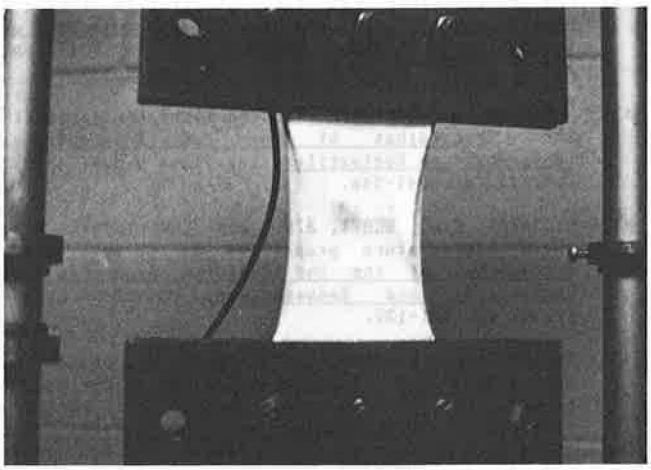
times stiffer than the single geomembranes. The CSPE composite is an exception because of the significantly higher J value (44 kN/m) of the single geomembrane.

EFFECT OF THE TEMPERATURE

Figure 3 gives the results of two materials: EPDM and PVC-240 were tested at temperatures between -35 and 23°C. EPDM composite appears to be unaffected by extreme cold since its modulus, strain at failure and strength are slightly increased at sub-zero temperatures. However the behaviour of the PVC composite is strongly dependent on temperature since its stress-strain curves gradually get steeper. It is believed that on one hand, the portion of the stress carried by the geomembrane increases with decreasing temperature until it reaches -35° where the geomembrane fails in a brittle manner at a low strain of 5%. On the other hand, the contribution of the geotextile at low temperature is not significantly altered, a conclusion shared by Allen et al (3). This behaviour is illustrated in fig. 4 which shows pictures of a strained PVC-240 at 23° and -35°. At 23° the failure occurs at ε = 35% in the geotextile that has been gradually unglued from the geomembrane. At -35°C, brittle failure occurs in the geomembrane and the specimen broke sharply like glass on multiple irregular planes (a further straining of the specimen also caused the geotextile to fail at 35/strain, as shown in fig. 3).



a) at 23°C



b) at - 35°C
Fig. 4 Strained PVC -240 at extreme temperature

EFFECT OF ULTRA-VIOLET EXPOSURE

Axial tensile tests were conducted on composite specimens by exposing one of its sides to 500 hours (21 days) of continuous radiations from 4 ultra-violet fluorescent lamps located 50 mm from the composite. These conditions are relatively severe and produce an accelerated alteration of the polymers. In our tests, all the composites have shown an appreciable decrease in their tensile strengths. Figure 5 shows typical stress-strain curves for EPDM and PVC composites, the strength decrease being 33 and 25% respectively.

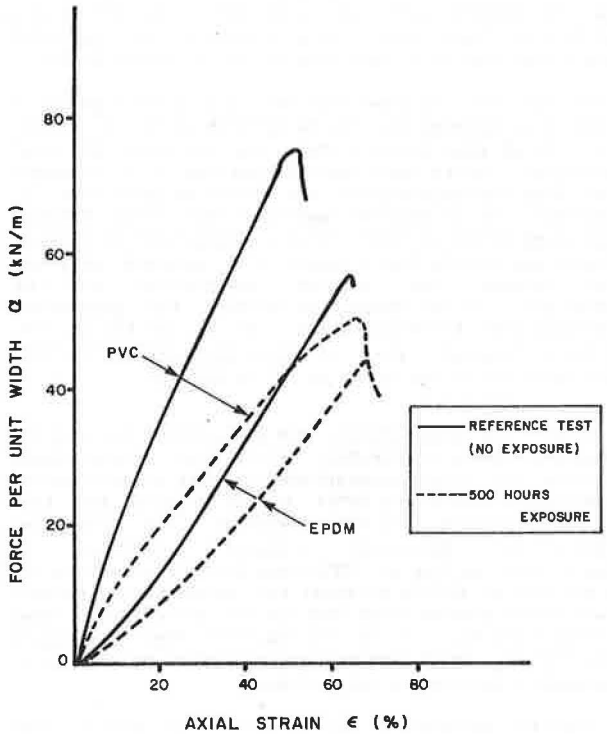


Fig. 5 — EFFECT OF ULTRA-VIOLET EXPOSURE ON TENSILE STRENGTH

JOINTS BEHAVIOUR

For the different materials, the joints between two pieces of geomembranes were tested in tension. The overlap length and methods used are given in table III. These methods are described in more details by Frobel (4). In every case the samples failed outside the joint indicating that they were capable of sustaining stresses at least equivalent to that of the geomembrane itself.

It is to be noted however that these tests were made on geomembranes without geotextiles. The tensile tests on composites show that their strength is mainly derived from the geotextiles. It is therefore stressed that seaming of the geotextiles is of utmost importance to preserve structural integrity and it must be combined with joining of the geomembrane, a prerequisite to insure imperviousness.

Table III - Seam of geomembranes

GEOMEMBRANE'S DESIGNATION	OVERLAP LENGTH mm	METHOD
EPDM	50	vulcanization
Butyle	100	contact adhesive + tape + pressure
CSPE	50	nitrile solvent
PVC	50	fusion welding
CIM	not tested	

CONCLUSIONS

The effects of bonding geotextiles to different types of geomembranes was evaluated from tensile and burst tests. These tests were conducted at sub-zero temperatures and after exposure to ultra-violet light.

The test results show that the tensile strength of a 1.6 mm thick geomembrane can be multiplied by a factor of 10 to 20 when bonded between two non-woven 800 g/m² geotextiles. Since the composite derives its strength mainly from the geotextiles, the amount of glue used can be minimal. It is however important that this bonding be achieved since it facilitates installation on sloping surfaces and avoids the presence of a minimum adhesion plane between the unglued geotextiles and the geomembrane. In the absence of bonding, the geotextile - geomembrane friction angle can be as low as 20°, whereas a typical value of soil-geotextile friction angle would be in the order of 28 to 30° (1).

Under low temperatures, the geotextiles forming the composites remain unaffected, while the stress-strain behaviour of some geomembranes changes significantly. Thermoplastics (PVC and CSPE), become brittle and fail at low strains (5-10%) whereas the elastomers stress-strain behaviour remains unaltered by temperatures as low as -35°C, and failure occurs in the geotextiles at 40-50% strains; the geomembrane failure strain being greater than that of the geotextiles. Based on these results, it is recommended that elastomers protected by thick non-woven geotextiles be used as an impermeable barrier in cold climate.

Finally, exposure of any composite to ultra-violet light is detrimental to its tensile properties. Composites should therefore be protected from sunlight by either a earth cover (rip-rap) of prefabricated elements if their tensile strength is to be relied upon.

ACKNOWLEDGMENT

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