A Review on Geomembrane Characteristics and Application in Geotechnical Engineering

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Abstract**—**This paper represents the basic idea and mechanisms associated with the durability of geomembranes and discusses the factors influencing the service life and temperature of geomembrane liners. Geomembrane durability is stated as field performance and laboratory test outcomes under various conditions. Due to the high demand of geomembranes as landfill barriers and their crucial role in sensitive projects, sufficient service life of geomembranes is very important, therefore in this paper, the durability, the effect of temperature on geomembrane and the role of this type of reinforcement in different types of soil will be discussed. Also, the role of geomembrane in the earthquake will be considered in the last part of the paper.

Keywords**—**Geomembrane, durability temperature soil mechanic.

I. INTRODUCTION

GEOMEMBRANES are used in vast areas of construction in civil engineering due to their chemical bonds, which makes them highly impermeable. Therefore, according to the necessities of the project, they can be used with different variety of materials such as rock earth and soils. Landfills are the cheapest way for disposal of municipal solid waste which otherwise can be a problematic issue for countries. Geomembranes are significantly used in landfill barriers [13]. Some of the most popular geomembranes are polypropylene, polyvinyl chloride (PVC), medium-density polyethylene (MDPE), and linear low-density polyethylene (LLDPE) [11]. Geomembrane can be used as reinforcement, filter, and separator.

II. DURABILITY OF GEOMEMBRANES

Durability in geomembranes is also known as service life. The duration of time that geomembrane serves its purpose regarding the project's needs is called the service life of geomembrane [10]. In many cases, geomembrane acts as a barrier, therefore it is required to effectively prevent the leakage.

The sensitivity of the site plays a major role in choosing the geomembranes. The more vulnerable the project is to leach, the more resistant geomembranes will be used. Geomembranes can be used as single, double, or composite liners [10]. High-density polyethylene (HDPE) geomembranes are mainly used for more sensitive projects as bottom liners [11]. The main component of HPDE geomembrane is polyethylene resin. The presence of polyethylene resin enhances the durability of geopolymer against overburden pressure and temperature. With these parameters, geopolymers can work as hydraulic barriers against aggressive chemical leachate [3], [12].

In different projects, depending on the condition of the site, geomembrane may come into contact with different materials, which will affect the chemical degradation [10]. Therefore, in manufacturing process, geomembranes contain different kinds of antioxidants according to the purpose of the project.

The service life of HDPE geomembrane consists of three stages [4]. In the first stage, the antioxidants that are added to the geomembrane begin to deplete. The second stage is the start of polymer oxidation, and the third stage is polymer degradation. The difference between the second and third stage is that despite the fact that at the end of the first stage almost all the antioxidants have been depleted and reduced the second stage has no effect on mechanical properties whilst in the last stage mechanical and physical properties such as tensile strength will be changed [5], [13]. A comparison was conducted on the behavior of a new and 30-year old geomembrane the results showed that there was not a significant change in water adsorption or density of the geomembrane [11]. According to [11], if the major reason behind degradation was assumed to be oxidation then the summation of all three stages that was proposed in [3] model will be the service life of geomembrane.

III. PARAMETERS INFLUENCING THE GEOMEMBRANE SERVICE LIFE

Different physical and chemical parameters can affect the service life of geomembrane. According to [10], the source of the leachate, the degree of contamination, type of geomembrane liner, quantity and size of the holes are the main factors that influence the life service of geopolymer. Also, Parameters related to geolocation of the site such as slope instability and the base soil or rock type as well as surrounding materials such as aggressive chemicals may lead to or speed up the failure process [10].

A. *Effect of Environmental Surrounding on Geomembrane*

If the soil or surrounding materials contain metals in presence of moisture the metals may penetrate into the geomembrane but this process is complicated and it depends on the type of the polymer and components and valency of the metal [11]. Oxygen is an important factor in oxidative degradation. The amount of surrounding oxygen depends on

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location and usage of the geomembrane if it is used in the surface area the concentration of oxygen will be maximum and vice versa in projects that the geomembrane is in contact with soil the amount of oxygen is much less and this amount will be used in biodegradation of the waste material [11].

B. Effect of Temperature on Geomembrane

Oxidation of geomembrane has a direct relationship with temperature with increase of temperature the oxidation process will also increase [10]. Decomposition of material used in the site will cause the temperature to increase from 30 to 80 °C [5]. Other materials such as bioreactors and aluminum production waste as well as the presence of moisture will accelerate the temperature rate but one of the primary factors is biodegradation of municipal solid waste [5]. For exposed geomembranes, direct sunlight and heat can be a serious concern [11]. Although the maximum recommended temperature for HDPE geomembrane is 57 °C wastes that contain aluminum will have a reaction with the moisture in the environment and it is observed that the temperature will increase to 112 °C within the first 50 days after disposal of the material [5]. As it is demonstrated in Table I even the small duration of temperature elevation will affect the effective service life to the point that it can reduce several decades [5]. Table I Estimated Geomembrane Service Life subjected to (based on [11]).

The degradation process will continue to the point that the service life of the geomembrane comes to its end due to failure in mechanical and physical properties. As mentioned before in the manufacturing process of geomembranes different kinds of antioxidants will be added to delay the oxidation reaction [10].

TABLE I
ESTIMATED GEOMEMBRANE SERVICE LIFE SUBJECTED TO (BASED ON [11])

Temperature (°C)	Service Life (years)
20	565-900
30	205-315
35	130-190
40	80-120
50	35-50
60	15-20

C. Effect of Geomembrane Thickness

The thickness of geomembrane has a significant effect on its service life [12]. As mentioned, available oxygen has an important role in polymer degradation. When thicker geomembranes have used the availability of oxygen will reduce therefore the rate of oxidation process will decline [11]. In addition, the increased thickness will prevent the added antioxidant to migrate from geomembrane [11]. Thicker geomembranes have less tensile strain comparing to thinner ones therefor other than the environmental surroundings and chemical exposure other parameters like geomembranes thickness will affect the resistance [12].

D. Degradation of Geomembrane

Degradation in geomembrane can be caused by different parameters such as swelling, attack of a micro-organism or oxidative degradation [11]. This type of degradation accrues when the geomembrane comes in contact with leachate or any kind of moisture. If the leachate doesn't have a significant amount of contamination this degradation will not cause important damage to the geomembrane because after desorption some of the material will be removed [11]. After microorganism’s attack to components of geomembrane biological degradation will accrue but due to high molecular weights of the components especially resins (30,000-100,000), this kind of degradation is uncommon [11]. The most harmful degradation is oxidative degradation because the molecular structure of polymers will be changed after reaction with oxygen [11]. As it was noted before, adding antioxidants in the manufacturing process will add to the service life of geomembrane, therefore controlling depletion of antioxidant will affect the performance and durability of geomembrane [13].

E. Damage during Installation of Geomembrane

A study by [6] on the failure of 171 projects conducted with geo-synthetics shows that the primary reason for geomembrane failure is due to inadequate design or construction, which mainly caused by improper design of drainage, unsuitable foundation preparation such as compaction or/and error in placement. Physical damage of geomembranes mostly accrues during the installation process, which will lead to emerging of holes [10]. It was found that there was no problem with the geo-synthetic itself and the manufacturing process has no contribution to the failures [6]. Regarding the fact that 86% of the projects failed within the first 4 years after construction, it is very important to do a detailed study of the site and take proper measures to prepare the foundation and install the geomembrane. In the physical aspect of the failure most dangerous form of damage is the formation of holes. In some projects that deal with hazardous material, the development of holes has a crucial role in the performance of the geomembrane and therefore it's life service [10].

The holes that are remaining in the liner due to the construction process and during waste disposal operation can be detected by mobile or fixed electrical leak location surveys (ELL) and get repaired completely [10]. Mobile devices can be used before waste disposal but fixed ELL can be used after disposal as well. If the membranes have good quality and installed properly for 10-50 years, there is no cause for an increase in the number of holes. The formation of cracks after this period, however, depends on parameters like oxidation, temperature elevation and tensile stress [10].

IV. DETERMINATION OF GEOMEMBRANE SERVICE LIFE

There are two ways to determine the service life of geomembrane. One is to examine samples from the field during their aging and the second one is to use the laboratory test. The difficulty with testing the service life of geomembranes in ongoing projects is the longsome process of aging but in laboratory tests, due to acceleration in proceedings, this problem is resolved [13]. Laboratory tests for estimation of geomembrane life are very time consuming and costly one of the tests that are mostly conducted is immersion test [12]. Usually, in this test, the first stage of aging is examined. The downsides of this test are that it does not represent the real field condition due to the fact that the tensile stress in geomembrane is not considered, and the geomembrane is in contact with fluid from both sides therefor the service life obtained from this test is not the same as one of the field geomembranes [12]. In many cases, the chemical and physical changes occur parallel to each other. For instance, one of the reasons that will lead to formation of holes is long-term stresses that are applying on the geomembrane and will cause cracks in the liner which in time will turn to holes, now if at the same time a chemical degradation like oxidation is in process the formation of stress cracks and therefore the holes will increase [10]. As a result, the life service of geomembrane will come to its end faster.

V. INTERFACE FRICTION OF GEOMEMBRANE WITH DIFFERENT KINDS OF SOIL

Soil-geosynthetics interaction parameters have their own special effect on the stability of various structures. One of the key functions of geosynthetics is to perform as reinforcement when placed in soil structures [15]. The characteristics of geosynthetics are stated as either in the form of tensioned membrane action or through soil-geosynthetics interaction because of frictional, interlocking, adhesion and pullout characteristics [2]. The Mohr-Coulomb failure criteria are usually used to figure out the interface parameters between soils and geosynthetics [7].

$$\tau = \alpha + \sigma.\tan\delta \quad (1)$$

where α = Adesion; σ = Normal stress; δ = Interface friction angle.

The two most vital failure criteria to be carried out in reinforced soils- geosynthetics are described as direct shear in mode of failure and pull out mode of failure [1] declares that in the direct shear test the frictional resistance is dependent on the soil to reinforcement shear resistance and soil to soil shear resistance (for geogrid openings) whereas in the pull out test the frictional resistance is related to surface roughness, geosynthetic extensibility and interlocking [8].

Khusbu carried out a study to observe the interface friction parameters between different soils like sand, clay, and silt at different moisture contents with geomembranes (different thicknesses) and with the textured membrane as well [14].

A. *Experimental Program*

Interface properties of soil- geosynthetics were specified by direct shear and pullout test. In this experimental work, the direct shear test was carried out to assess the interface parameters.

1. Material

Smooth geomembranes of various thicknesses and textured geomembranes were interacted by three different soils. Poorly graded sand (Cu= 3.75 and Cc= 0.416), CI clay prepared at three different moisture content (at the dry, optimum and wet side of optimum water content) and SM silty soil prepared at three different moisture content (at dry, optimum and wet side of optimum water content).

2. Geosynthetic

HDPE geomembranes of various thickness (0.5, 0.75 and 1 mm) and textured membrane with 0.75 mm were applied in this laboratory work.

B. *Result and Analysis*

To analyze the interface interaction between soil-geosynthetics, the results of Direct shear tests were acquired.

1. Clay- Geosynthetic

Clay (different moisture contents) and geomembrane (different thicknesses) were interacted by each other. The results are shown in Fig. 1 (the normal stress versus shear stress relation for clay).

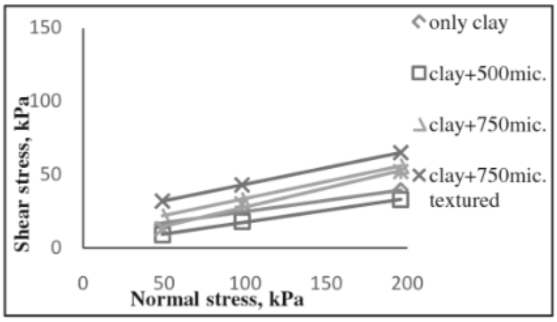

Fig. 1 Normal stress versus shear stress relation for clay at water optimum content with geomembrane

2. Silt-Geosynthetic

Silt (different moisture contents) and geomembrane (different thicknesses) were interacted by each other. The results are shown in Fig. 2.

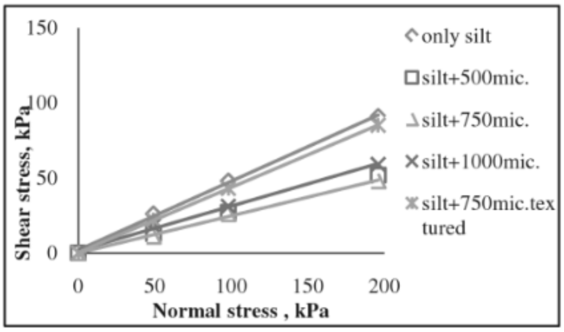

Fig. 2 Normal stress versus shear stress relation for silt at water optimum content with geomembrane

3. Sand-Geosynthetics

Sand with relative densities 60 % and 75 % interacted with different thickness of geomembranes. The outcomes of the test are shown in Fig. 3.

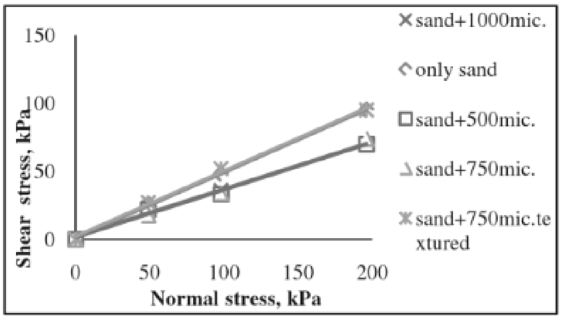

Fig. 3 Normal stress versus shear stress relation for sand at 60% relative density

C. Conclusion

The conclusion of this laboratory work is summarized as follows:

It was known that sand is in a good interaction condition with textured membrane compared to silty and clayey soil. It was observed that smooth geomembranes are suitable for silty soils compared to clayey soil. It was found through the results that clayey soil shows better interaction with textured geomembrane compared to smooth geomembranes of various thicknesses [14].

Another study is conducted to investigate the interface strength of soil-geosynthetic. In this research, the interaction of soil and smooth and texturized geomembranes under different test conditions were carried out. In this work, the author believes that the mechanisms of interaction between soil and geomembrane must be properly examined and failures along with soil and geomembrane interfaces in slope should be carried out. To obtain this, some experimental tests of shear strength mobilizations along soil-geomembrane were conducted (for different types of geomembranes and degree of saturation of soils).

D. Material and Methodology

In this study, to analyze the interface shear strength, ramp and conventional direct shear tests were conducted on sandy soil varying the degree of saturation between 5.5 and 66%. PVC and HDPE (smooth and texturized) geomembranes were used. 75 ramp tests and 50 conventional direct shear tests were performed. The ramp tests have a dimension of 51x51 cm, and normal stresses are 1.2, 3.2, and 7.2 kPa. The author declares that these values are based on other studies. Fig. 4 (a) and (b) shows a general view of one of the ramp tests performed.

E. Result Obtained

According to the result showing in Table II, it was known that the obtained interface angles were independent of changes on the soil saturation degree (S_r) for the interfaces tested. Moreover, the maximum interface friction angle in the tests with the texturized HDPE geomembrane was achieved for the highest value of the degree of saturation (Fig. 5). The outcome of the interface friction angle acquired in this study on HDPE geomembrane was smaller than those received for the texturized geomembrane. Similarly, it was specified that interface angles were insensitive to soil degree of saturation.

(a) (b)

Fig. 4 (a) Ramp test (b) Conventional direct shear test

TABLE II
INTERFACE FRICTION ANGLES OBTAINED IN THE RAMP AND DIRECT SHEAR TESTS

Sr(%)	φS-PVC S (°)		φS-HDPE S (°)		φS-HDPE T (°)
	Ramp test	Direct Shear	Ramp test	Direct Shear	Ramp test
5.5	29	30	26	27	32
10.8	30	30	28	29	33
15.7	30	31	27	27	34
20.3	30	32	29	32	30
26.3	31	33	29	31	36
45.1	31	33	30	31	37
58.4	30	33	27	29	36
66	34	39	27	31	39
Average	30.6	32.6	27.9	29.9	34.6

F. Conclusion

For the conditions applied in this study, the variation of the degree of saturation did not have any impact on interface friction angle between soil and geomembranes. An advancing progressive interface failure mechanism was observed in the tests with PVC geomembranes because of the more extensible nature of this kind of geomembrane. The maximum values of the interface friction angle were found in the test with the texturized HDPE geomembrane, while lower values were obtained in the tests with the smooth PVC and HDPE geomembranes. The higher adherence with soil, the largest mobilized tensile forces were achieved in the tests with the texturized HDPE geomembrane [9].

XI. SEISMIC PERFORMANCE OF GEOMEMBRANE

Geomembranes are one of the most frequently used geosynthetics in landfill liner systems. The leachate duet to the existence of waste is prevented by geomembranes. They are subjected to tough environmental conditions like excessive temperatures or earthquake loading. For this reason, there is a need to study the effect of the earthquake on geomembrane. Fig. 6 shows a typical diagram of landfill with a geomembrane.

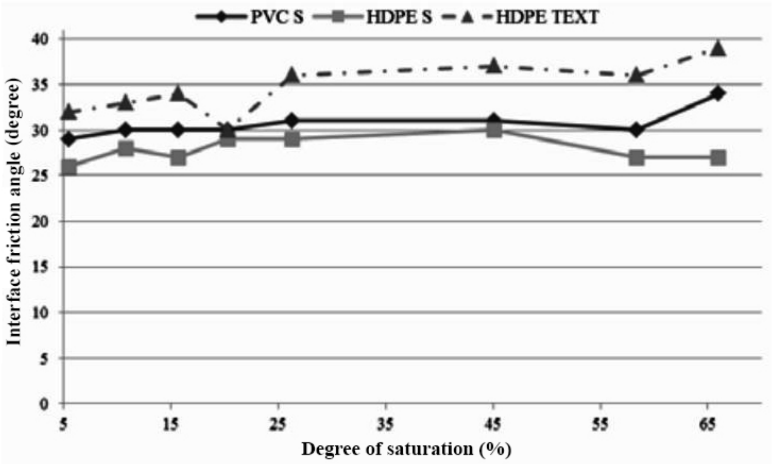

Fig. 5 Interface friction angle (φsg) versus degree of saturation

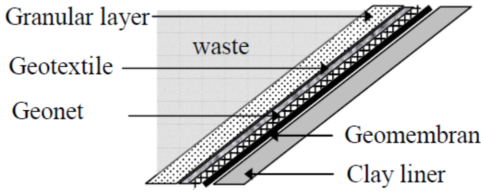

Fig. 6 Typical side liner cross section of a landfill

A laboratory work which is according to dynamic centrifuge testing is performed to consider the effect of simulated earthquake loading on the tension experienced by the geomembrane on a landfill slope. A municipal solid waste (MSW) landfill cell with a single geomembrane-clay liner system (45° side slope and 10 m slope length) was used in the landfill modeled in the dynamic centrifuge test.

A. Centrifuge Modeling of Landfill Components

Geomembrane, clay liner, and MSW were the main issues in the physical modeling of landfill component in the centrifuge modeling of landfills. The following parts illustrate how the centrifuge was prepared in this paper.

B. Modeling Clay Liner

In this research, a strip of consolidated kaolin clay was used to model the compacted clay liner. Then, the consolidated clay was embellished into 2-cm thick strips. A 2-cm thick layer shows a 1-m clay liner in a 50-g centrifuge test. The water content of consolidated clay was considered as 36%.

C. Modeling Geomembrane

The real geomembrane specimen can be utilized in the modeled centrifuge testing since the forces advanced in the centrifuge model are N2 times smaller, where the centrifuge acceleration is N×g (where N=50). As a result, the modeled centrifuge test does not have the strains experience of real landfill condition. Hence, a kind of geomembrane is needed to show similar stress-strain behavior and interface frictional angles as the real geomembrane experience in real condition.

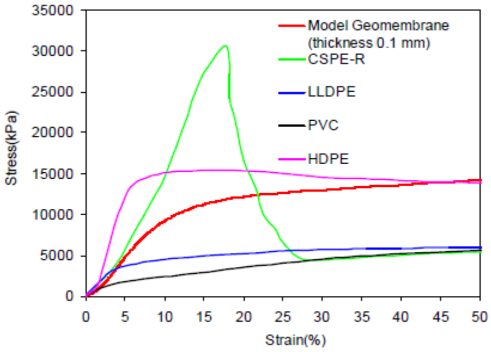

Fig. 7 Stress-strain behavior of model geomembrane (200 mm width specimen test)

G.Matching Stress-Strain Characteristics of Real Geomembrane

Tensile testing (200 mm wide-width testing) was done on different thin HDPE sheets and a 0.1 mm thick HDPE sheet was recognized as an appropriate model geomembrane (Fig. 7). Wide-width test on model geomembrane was conducted at a strain rate of 30% per minutes. The reason for choosing such a high strain rate is to provide a simulated earthquake loading condition for model geomembrane to reflect its own experience. The model geomembrane was considered satisfactory for the current study.

E. Matching Interface Friction Angle of Real Geomembrane

The tension happens on landfill slopes when the friction angle of geomembrane with clay is less than with the material above. Clay liner, geomembrane, geonet geotextile, and granular soil layer formed the modern multilayered liner system. It is difficult to rebuild such a complex liner system for centrifuge testing so an easy liner system of model geomembrane/clay was executed in the dynamic centrifuge test. The key target in this study is to figure out the tension progressed in the geomembrane, so it is enough if the model geomembrane shows a typical interface friction angle with the clay liner.

F. Centrifuge Model Preparation and Testing

A schematic cross-section of the centrifuge model is presented in Fig. 8. The dimension of container which is equivalent shear beam box (ESB) of internal dimensions 235mm x 560 mm x 222 mm. The sand was intently excavated to get a side slope of 45°. The 2-cm thick clay liner strips were located on the excavated bottom surface and the side slope. After that, the geomembrane has put the top of the clay liner. The highest edge of model geomembrane was claimed and fixed to a load cell (Figure 8). The model waste was located into the landfill in layers, making a 40° slope. Waste settlement (during earthquake loading and when the centrifuge was being accelerated) was measured by a linearly variable displacement transducer (LVDT).

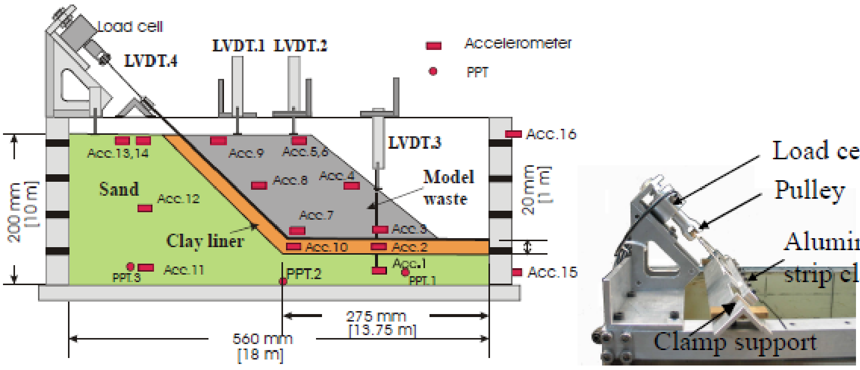

Fig. 8 Cross section of the centrifuge model

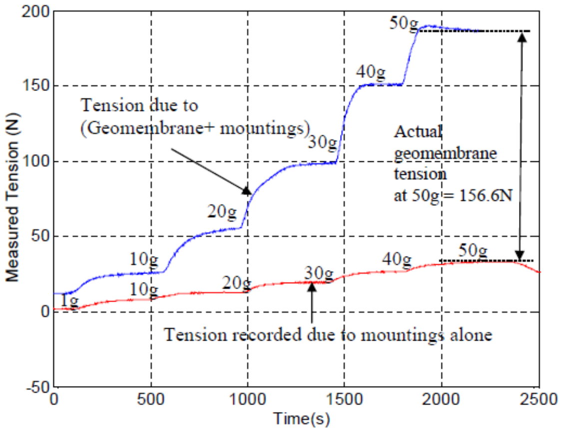

Fig. 9 Tension measured during swing up (model scale)

G. Tension in Model Geomembrane during Swing Up

The geomembrane tension and mounting weight form the load cell reading which both of them enhance during swing up (Fig. 9). To achieve component due to mounting alone, a separate test without any geomembrane was conducted. The real geomembrane tension is the difference between the two readings. The model geomembrane was subjected under different g level from (1 g to 50 g) which experienced 156.6 N at 50 g. This corresponds to a stress level of 7830 kPa which is well below the yield stress of the model geomembrane.

H. Tension in Geomembrane Due to Earthquake Loading

Fig. 10 presents the correct tension in geomembrane at prototype scale during the model earthquakes. E.1 can be related to a new landfill cell experiencing an earthquake loading for the first time while E.2 to E.6 can be linked to a landfill cell experiencing multiple earthquake landings (aftershocks).

Fig. 11 summaries the earthquake-induced tension in the geomembrane as a percentage of pre-earthquake geomembrane tension.

Earthquake loading persuades tension in the geomembrane even if the landfill has previously experienced earthquake loadings. Maximum and permanent tension developed in the geomembrane increases with the duration of the earthquake loading [16].

XII. CONCLUSION

A review of geomembrane characteristics and application in geotechnical engineering has been presented. Geomembrane has a widespread application in geotechnical engineering. From the above studies, it can be concluded that unlike geotextiles, geomembranes are highly impermeable which allows them to work as hydraulic barriers in land field structures. Surrounding condition plays a vital role in the durability and performance of geomembrane. Since most of the damage in geomembrane is caused in the installation process, it is very critical that the construction site is examined thoroughly. Depending on the type of hazardous material that comes in contact with geomembrane as well as temperature elevation and applied stresses, the service life of geomembrane varies.

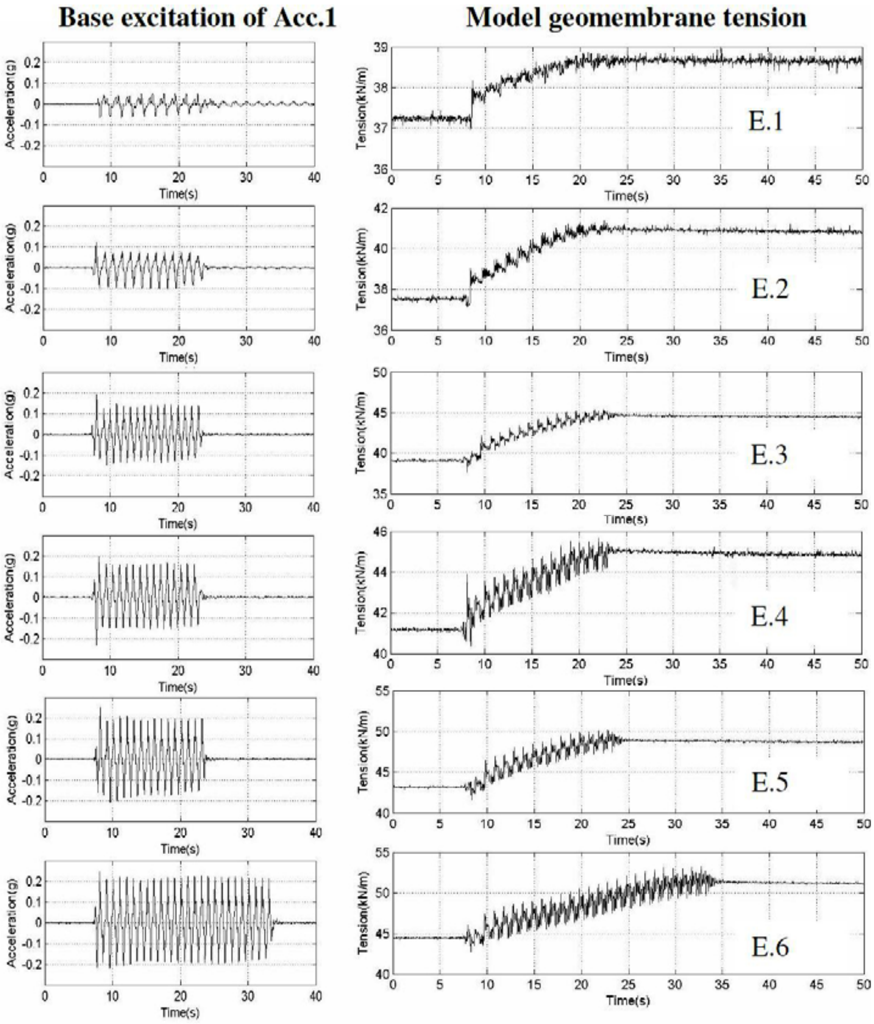

Fig. 10 Landfill base excitation records (Acc.1) and tension in model geomembrane during the earthquake (prototype scale)

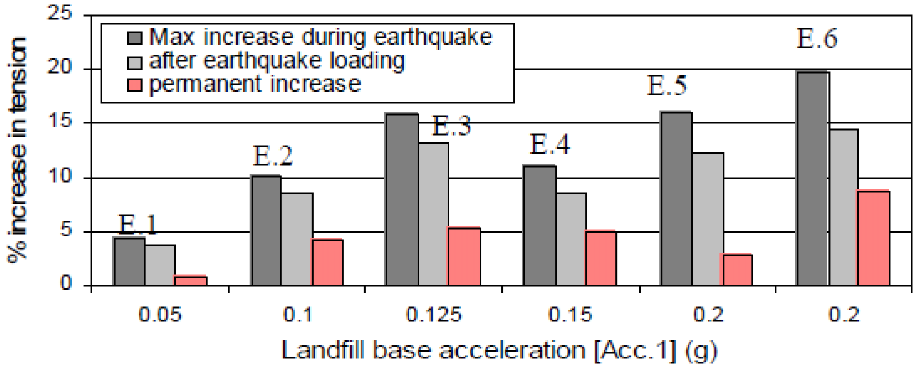

Fig. 11 Percentage increase in geomembrane tension versus base acceleration

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