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Development of a Device (D-LLGs) for Monitoring Time-Dependent Behaviour of an Embankment on Soft Ground Reinforced with Limited Life Geotextiles

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ABSTRACT

A laboratory device for the application of Limited Life Geotextiles (D-LLGs) for the reinforcement of an embankment erected on soft soil is developed in this study. The results are applicable for civil engineering students as well as general geotechnical professionals who are looking for design tools and methods that can be routinely used to demonstrate the practical, real-world problems encountered when dealing with the reinforcement of an embankment on soft soil using Limited Life Geotextiles. This device demonstrates the time-dependent stress conditions and the distribution and dispersion of pore water pressure at different positions below an embankment erected on soft soil. The tests results obtained using this equipment confirm the elastic theory models for stress distribution. That is, non-uniform contact stresses applied at the surface of the compressible layer are transmitted to regions surrounding the strip of compressible layer, and are not just transmitted to the region that is directly below the point on the surface to which the load is applied. Also this device has successfully highlighted the application and behavior of biodegradable materials such as Limited Life Geotextiles (LLGs) for ground reinforcement.

1. INTRODUCTION

It is advisable for research engineers to conduct full-scale geotechnical tests to gain physical insight of soil fabrics and the interaction between undisturbed soil particles and soil pore water during load application. Full-scale tests can provide quick resolutions to imposing problems that could have been too complex to be resolved by a simplified analysis or too critical for engineering design to be completed by other means. Full-scale tests also provide for physical insights that otherwise may not have been recognized. However, results for full-scale tests, such as an embankment erected on soft soil, requires a large amount of space, and has high costs associated with large amounts of equipment, labour and materials. Because constructing and testing a full scale model is not always possible, other means of finding a solution have to be devised.

In geotechnical engineering several small and middle scale apparatus and equipment have been used for many years. However, there is need to introduce apparatus which can also be used as a teaching aid to explain difficult phenomenon, such as the effectiveness of new concepts, such as using Limited Life Geotextiles (Mwasha 2005, Sarsby 2005) for the reinforcement of an embankment erected on soft soil. The concept of limited life geotextiles seeks to emphasize a clear definable geotextile working life, where materials used to manufacture the geotextiles are designed so that progressive loss of their capability with time is match by the improvement in the ground conditions with time (Mwasha, 2005) and (Sarsby 2005). Limited Life Geotextiles (LLGs) are reinforcing geotextiles that are only required to perform their duty for a short time. In the case of reinforcing embankment erected on the soft soil, LLGs are required at the end of construction. However the need of geotextiles diminishes with time as pore water pressure dissipates and the foundation soil gains shear strength. Authors such as Pritchard (1999, Sharma and Bolton (2000)) Mwasha (2009a), Mwasha (2009b), Sarsby (2007) have recommended the use of biodegradable fibres for the reinforcement of an embankment erected on soft soil due to their initial high strength as these biodegradable geotextiles strength diminishes over time, simultaneous with the dissipation of the pore water pressure in the foundation. However, for students and even professional geotechnical engineers, the concept of using biodegradable geotextiles to reinforce an embankment erected on soft soil has been difficult to comprehend. In this paper a small-scale tests using D-LLGs is used to demonstrate this concept.

2. THEORY AND ASSUMPTIONS

In this method it is assumed that the location of maximum geotextile tensile/strain is a maximum at the midpoint of the embankment (Fabian, and Fourier 1988). Another assumption is that the tensile strength decreases linearly away from the embankment midpoint to zero at the embankment toe (Fowler *et al* 1983). Based on these assumptions, a new tensile/strain gauging method is proposed. This method is intended to minimize or eliminate the limitations of previously used tensile-strain measurement methods. This new method attaches gauges “externally” to a high strength steel wire that is connected to a proving ring that is then connected to the geotextile via T shaped rods. The geotextiles held by the T rod support the loading from the embankment as well as the outward directed lateral force caused by the horizontal stress the fill induces on the foundation surface. The advantages of this method over traditionally used methods is that the role for the reinforcement to support the outward shear stress which relieves the foundation of critical loading is observed by the process of diminishing need for the geotextile as pore pressure dissipates. This device is an improvement of equipment suggested by the Mwasha and Petersen (2010). The principal improvement is that the propagation of soil pore water pressure is monitored using four stations situated at different positions beneath an embankment, beneath the embankment toe, and away from the embankment toe. The tests results obtained using this equipment confirm with the elastic theory models for stress distribution, i.e., where (1) non-uniform contact stresses at the surface of the compressible layer are distributed to regions surrounding the strip of compressible layer and not just to the region that is directly below the point on the surface that experiences the contact point loading, (2) soil pore water pressure dissipates non-uniformly, and the basal reinforcement becomes redundant as the pore water pressure dissipates and the soil gains strength. Based on the test results, this device can be used to effectively demonstrate the behavior and potential application of Limited Life Geotextiles, including their use as a sustainable method for ground reinforcement.

3. CONSTRUCTION OF THE DEVICE FOR INVESTIGATION OF LLGS

The major components of the D-LLG are: a soil tank/box made of reinforced Plexiglas (with open tank dimensions of 1.0m height, 0.7m width, and 1.2 meters length); four glass tubes for measuring pore water pressure connected to piezometers; a proving ring meeting standards ASTM D-3080 and AASHTO [19] T-236; a pulley; weights ranging from 0.5 kg – 30kgs; two metal rods; and a 12 mm PVC pipe. Figure 1 shows the schematic setup of the equipment with the following components:

1- Weight station attached to proving ring; also shown in Figure 2.
2- Proving ring;
3- Glass tubes fitted onto ceramic porous cups (piezometers) to capture dissipated excess pore water;
4- Embankment;
5- Foundation soil

6- Geotextiles;

7- Reinforced Plexiglas tank/box.

8- Reinforcing steel angle, 50 x50 mm

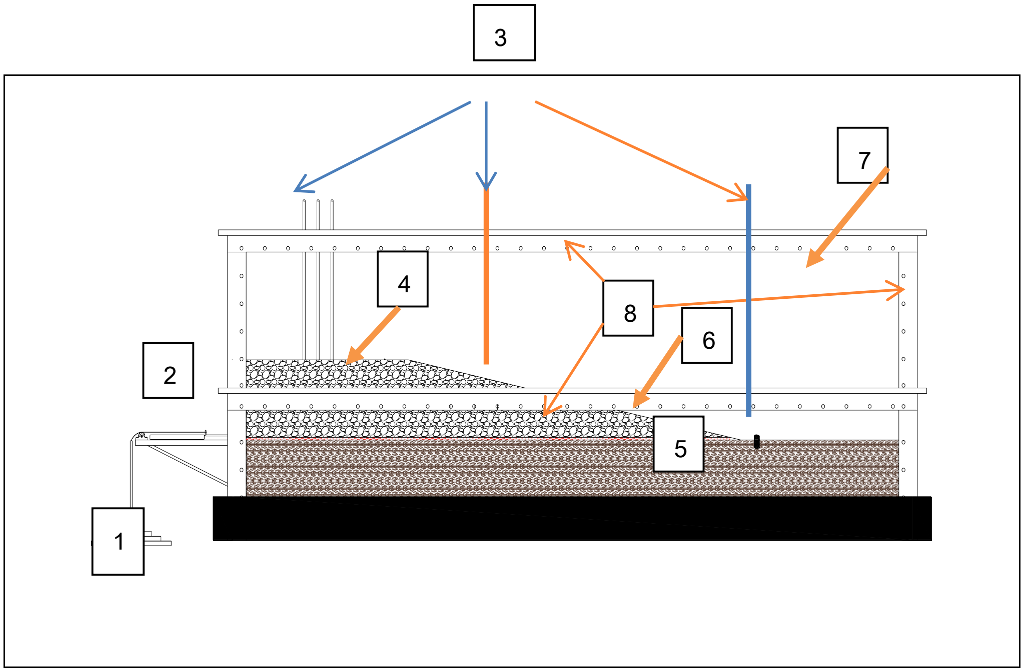


Figure 1: Reinforced Plexiglas tank

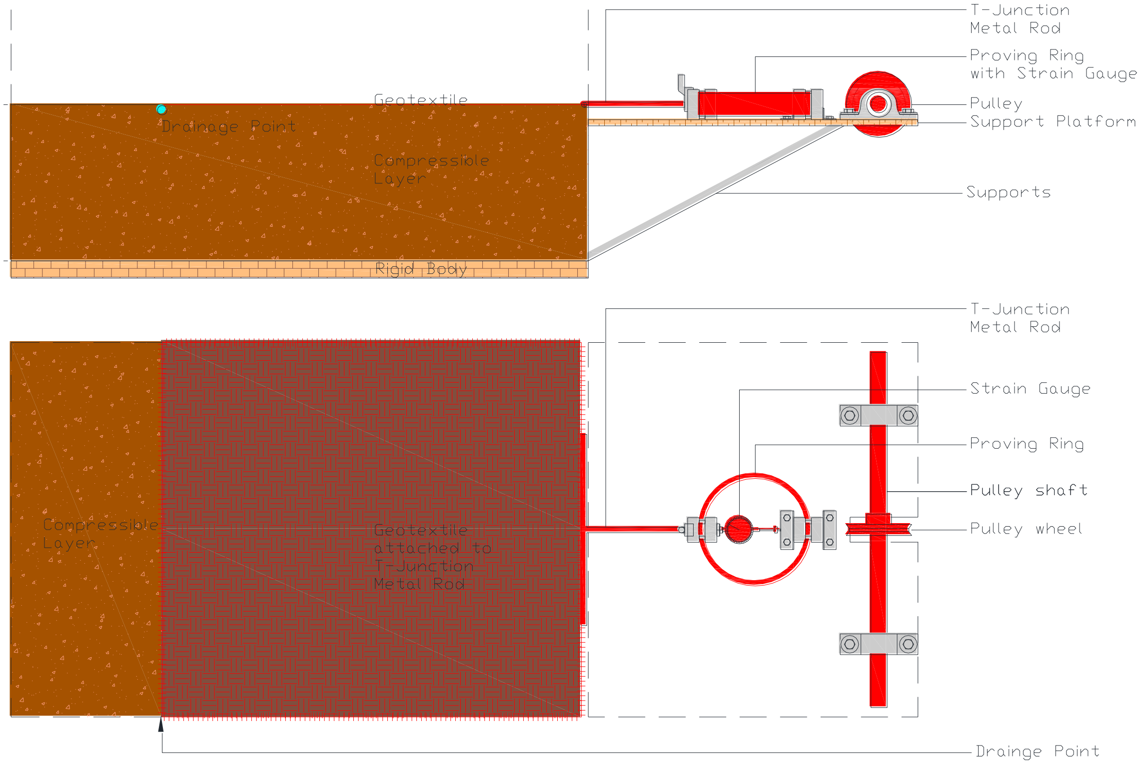


Figure 2 Weighing mechanism

4. MATERIALS

4.1 Foundation soil

The foundation soil was extracted from the Caroni Swamp. The Caroni Swamp is located near the Capital of Trinidad and Tobago (10°34'N 61°27'W), and occupies approximately 8,398 hectares. The Caroni Swamp is an extraordinarily important wetland near the capital of Trinidad, Port of Spain, since it is ecologically diverse, consisting of marshes, mangrove swamp (5,996 ha), and brackish and saline lagoons. Caroni Swamp is important economically for oyster and fish harvesting, for hunting and for ecotourism. These unique ecosystems support a wide range of wildlife habitats with unique biodiversity that are specially adapted to such environments. These ecosystems are also fundamental due to their vital functions in hydrological and geochemical cycles. Due to increasing agricultural activities the swamp lands are target for extensive reclamation.

The properties of the soil samples obtained from the Caroni swamp for use in the tests had an average moisture content of 119%; a bulk unit weight between 20 and 21 kN/m^3; and internal angle of friction ≤ 25°. The surface bearing strength ranged from 0 to 40 kPa. The high moisture content and low strength of these soils necessitate that in most cases the process of land reclamation requires ground improvement.

4.2 Embankment Soil

The quartzite gravel used for erecting the embankment was from Guanapo, Valencia, in Trinidad. These aggregates are mostly located in the foothills of the northern range and are normally overlain by 2 – 3 meters of heavy clay. Guanapo quartzite is a relatively pure forms of quartz (~ 99% quartz). The yellow brown color of the Guanapo is a result of staining of the deposit by ferric oxide. The ferric oxide staining is mainly a surface deposit, but it has moved over time into the micro cracks of the crystalline particles and in some cases has become an inter-crystalline impregnation (Suite, 1977). The properties of the Guanapo quartzite gravel used to construct the tests embankments are as follows: angle of internal friction = 0°; effective angle of internal friction = 35°; and bulk unit weight 18 kN/m^3.

Sisal fiber geotextiles shown in Figure 3 were used as basal reinforcement material. Sisal is a natural fiber, the actual fibers themselves are quite variable. They have diameters typically in the approximate range of 0.1 mm to 0.5 mm, and have high initial strengths of the order of 400 to 600 MPa (Ghavami 1999).

Figure 3 Sisal fiber geotextiles

The sisal fiber geotextiles used in this research are manufactured by METL Tanzania limited, the manufacturer of vegetable fiber textiles including canvas, tents and bags The properties of sisal fiber Standard D used in this research was tested at Trinidad and Tobago Bureau of Standards according to ASTM D 5199 for nominal thickness, ASTM D4595 grab strength and ASTM D 4632 for tensile strength.

5. TESTS AND EQUIPMENT SETUP

The slope was such that a half-embankment of a non-cohesive free draining fill material was constructed with a gradient of 2 horizontal to 1 vertical (2H:1V). The embankment was constructed on a reinforced compressible layer that was placed at the bottom of the tank. This tank maintained the boundaries of the compressible layer and the vertical boundary at the end of the half-embankment. The compressible layer was reinforced using a geotextile made of woven Sisal fiber. The in situ tension on the reinforcement was mechanically varied and manually monitored using a system of free weights, a proving ring with strain gauge and a T-junction metal rod.

5.1 Equipment Setup

The following procedure was followed when setting up the equipment for each test:

1. Mineral oil was applied to the sides of the Plexiglas tank to reduce friction.

2. A wire mesh was placed on top of the Plexiglas tank. This wire mesh screened roots, leaves, pebbles, and stones from the soil as the soil is poured into the tank.

3. The T-bar with the attached geotextile was connected to the proving ring
4. The geotextile was secured in such a way as to not interfere with the installation of the compressible layer.
5. The compressible layer was installed by emptying the soil in the box and spreading the soil uniformly across the surface of the rigid body.
6. The compressible layer was filled up to a height of approximately 1.0 m, where the orifice for the geotextile is situated.
7. The geotextile with the attached T-bar was then placed along the surface of the compressible layer.
8. Construction was completed in one stage, with an approximately 0.24 m high half-embankment constructed to have an approximate gradient of 2H:1V.
9. The strain gauge was observed daily and the deflection of the strain gauge measuring dial was recorded.
10. Weight increments were either added or removed in order to maintain zero deflection on the strain gauge.
11. The pore water heights in the monitoring tubes were recorded at 4 stations.

5.2 Installation of the Pore Water Pressure Measurement Stations

The pore pressure measurement stations are distributed and installed at the following depths from the surface:

- Station 1 at 0.79m to record the consolidation process at the full embankment section.
- Station 2 at 0.35 m to record the consolidation process below the full embankment height. This station should record the consolidation of the upper layer of the foundation below the foundation.
- Station 3 to record the pore pressure at 0.97 m. Station 3 is installed away from the toe to record the effects of the embankment on the pore water pressure distribution.
- Station 4 records the pore water pressure at the toe of the embankment.

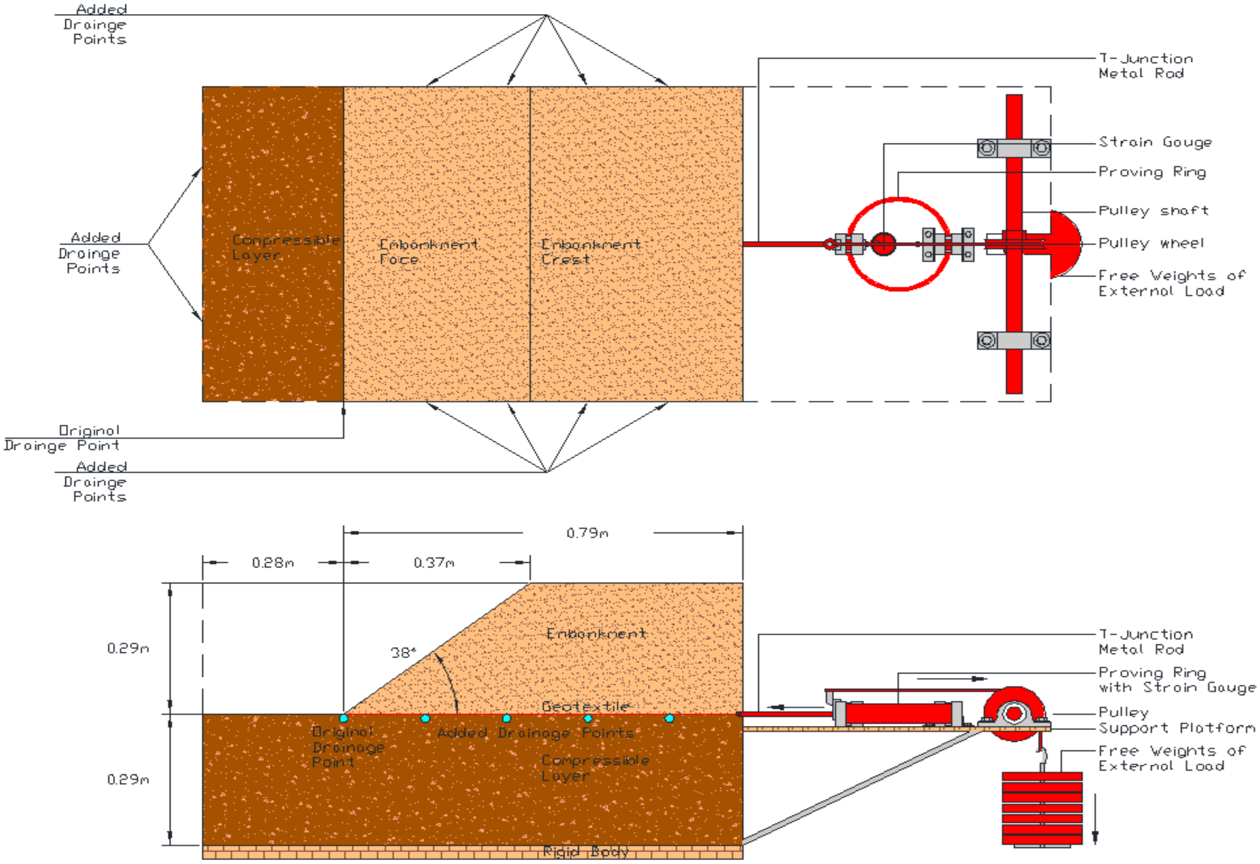


Figure 4 Equipment set

Stations 1 and 4 were installed approximately the same depth to record and to compare the influence and the distribution of the stress below the embankment and away from the embankment, respectively. The positions of these pore water pressure measurement stations are shown in Figure 5.

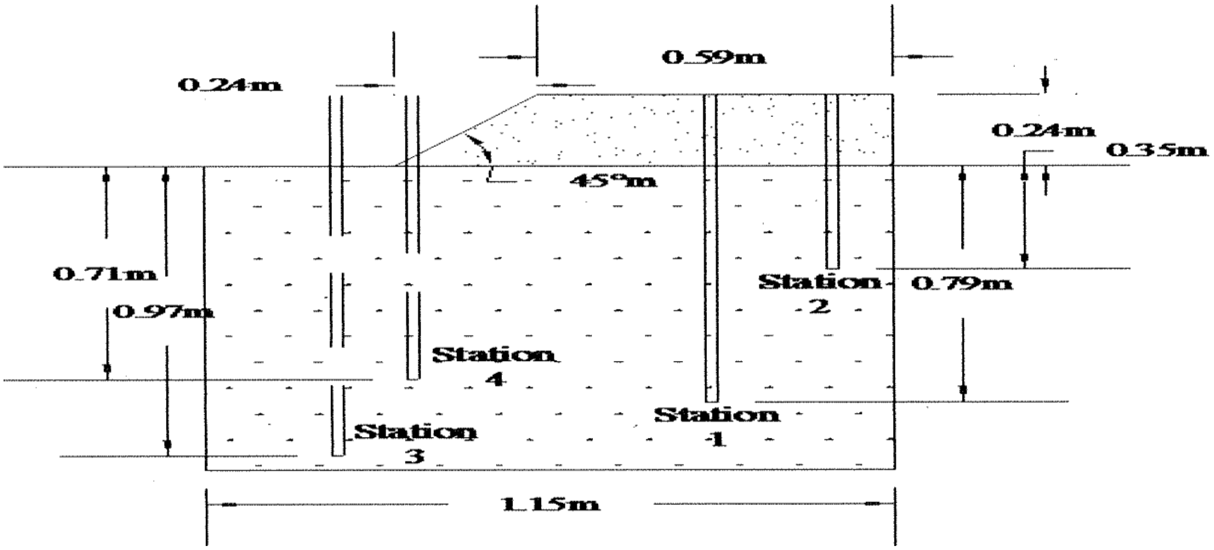


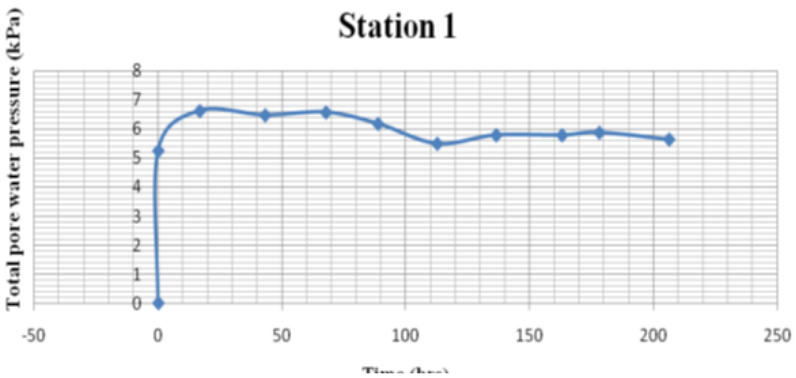
Figure 5 loaded equipment and the position of the installed pore water stations.

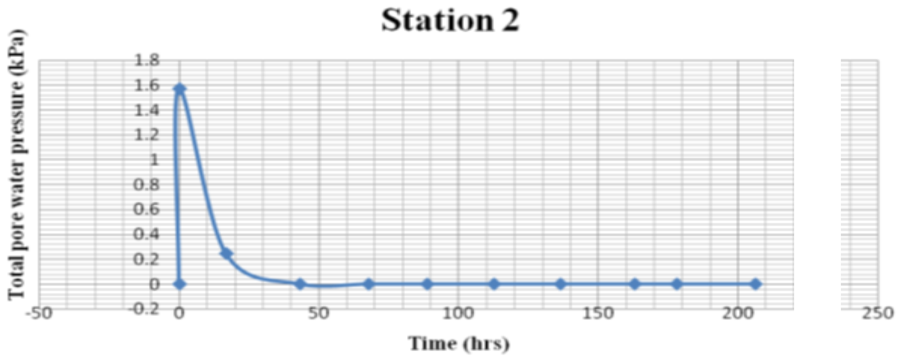
6. DISCUSSION AND RESULTS

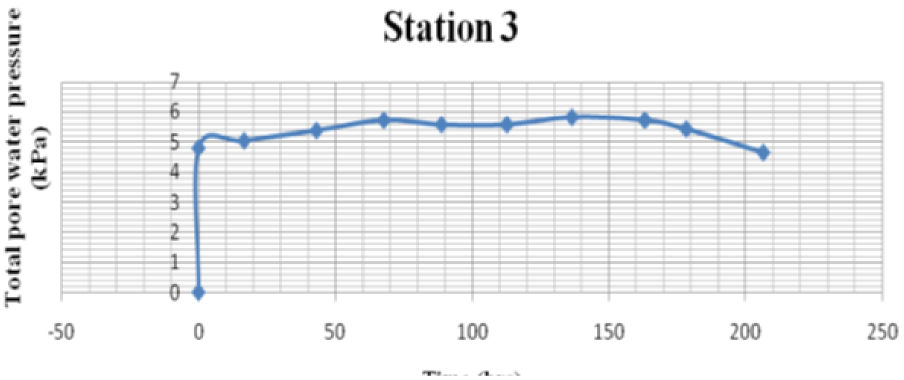
6.1 Stations Observations

After the embankment was constructed, the pore water pressures at each station increased. The increase in pore water pressures at Stations 1, 2, and 4 was due to the overburden pressure generated by the self-weight of the sand embankment. The increase in pore water pressure at Station 3 is due to both the shear stress distribution and the embankment.

The results in Figure 6 reveal that as time increased all pore water pressure increased instantaneously at $T_v = 0$, however, the water height at Station 1 decreased gradually as $T_v > 0$. For Station 2 the pore water pressure, increased for a short while, and then decreased relatively quickly until there was no pore water in the monitoring tube. Station 2 data indicate the consolidation process has ended at that particular depth, located 0.35 m beneath the embankment. For Stations 3 and 4 the consolidation process was extremely slow. Station 3, which was located away from the embankment toe, was the slowest station to dissipate excess pore pressure. Measurements at this station indicate the embankment loading influenced the pore water pressure beyond the embankment toe and the pore water pressure at this station do not dissipate much differently than the pore water pressure does at stations located below the embankment.







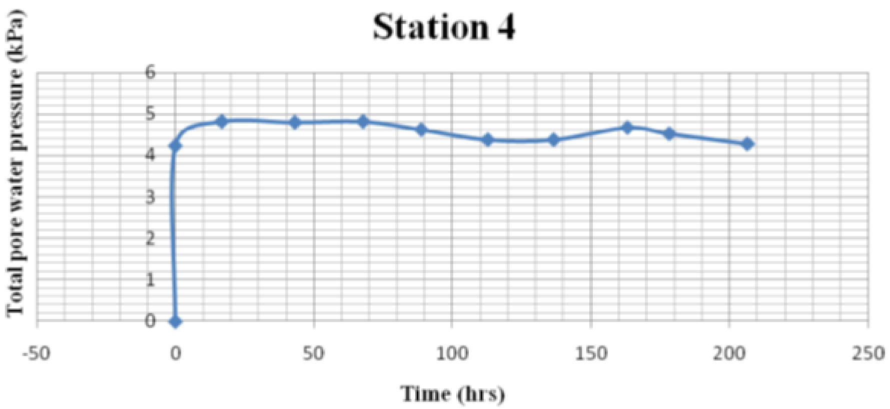


Figure 6. Total pore water pressures versus time at stations 1, 2.3 and 4

6.2 Time Dependent Behavior of Reinforcement Tensile Strength

It was found that a tensile force of 0.43 kN generated within in the geotextile was required to maintain static equilibrium of the sand embankment. This meant that 0.43 kN was required at the end of construction to restrict lateral movement of the embankment. As pore water pressure at Station 2 dissipated, the external load required to maintain static equilibrium of the embankment decreased until the geotextile reinforcement was providing no external load and yet the system maintained zero deflection on the strain gauge. This decrease in end load signified that the geotextile was becoming redundant and it would no longer be functional after the ninth day from the start of the test, even though measurements at Stations 1, 3 and 4 in the deeper foundation soil still had elevated pore water pressure.

The required tensile strength was also determined manually by back-calculation based on Mwasha (2005).) As shown in Figure 7 the back analyses method seems more conservative in estimating the amount of reinforcement required to reinforce an embankment on soft soil. Based on the slow dissipation of pore pressure in the deeper foundation soil layers, for the embankment configuration considered the methods of Mwasha (2005) and Sarsby (2006) may be appropriate for designing limited life geotextiles for the reinforcement of an embankment on soft ground.

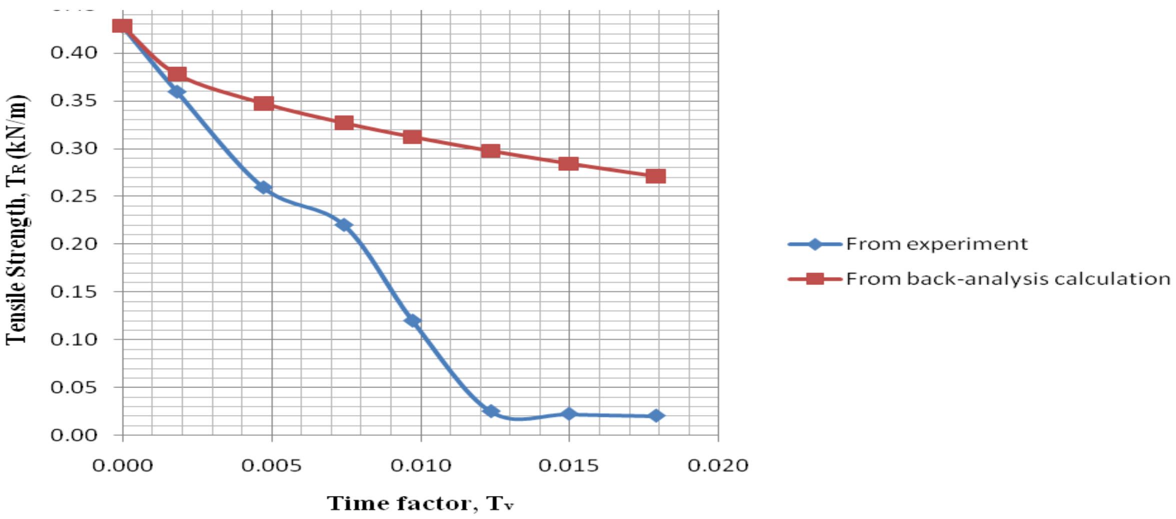


Figure 7 Tensile strengths obtained from experiment and from back-analysis method for different time factors

7. CONCLUSION

The results from this research have confirmed that the developed laboratory device to study Limited Life Geotextiles (LLGs) can be used to demonstrate the practical, real-world behavior of the reinforcement of embankment on soft soil using Limited Life geotextiles, as analyzed by both Mwasha (2005) and Sarsby (2006). The tests results performed have also been confirmed with elastic theory models for stress distribution where non-uniform contact stresses applied at the surface of the compressible layer are transmitted to regions beyond the limits of the embankment and not just to the region that is directly below the point on the surface to which load is applied. The results also showed that dissipation of pore pressure strongly depends on the layer depth. Finally it was observed that the pore water pressure beyond the embankment dissipated much gradually compared to the pore water pressure at same depth below the embankment.

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