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SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING

**PULL OUT BEHAVIOUR OF GEOSYNTHETICS WHEN TESTED AT BENCH
SCALE**

BY

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**Thesis Submitted for Partial Fulfilment for the Degree of Master of Science in Civil
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DEDICATION

I dedicate this report to my parents, Alice and Samuel Okinyi, who have been a pillar of success in my life.

ACKNOWLEDGEMENT

I would like to express my deep gratitude towards Prof. S.K. Mwea and Dr. S.N. Osano who gave me their valuable suggestions, motivation and direction to proceed at every stage.

ABSTRACT

Geosynthetic products are used for various applications and functions in pavement construction and design. The benefits in using geosynthetics in pavement applications have led to proliferation of geosynthetic products. This report investigates effectiveness of the lateritic gravel soil and geosynthetics used in constructing high fills or stabilized earth walls in the rehabilitation of the Nyamasaria - Kisumu Road project.

The increase of using geosynthetics in high fills has enhanced the necessity to evaluate the interface resistance and the pullout properties in different types of backfills. This report studies the use of lateritic gravel as an appropriate backfill in high fills. The interface considerations between the geotextile and soil was assessed in pull-out tests. Testing programs included carrying out laboratory pull-out tests on geotextile. Laboratory pullout testing was done using pull-out testing equipment at the University of Nairobi, Civil Engineering Department.

It was deduced that the pull-out load increased with increased surcharge pressure tested. An increase in the pull-out load was attributed to additional resistance caused by bearing stresses acting on the strap edges when the pressure was increased. The interaction between soil particles and surface of geobelt was increased when the surcharge pressure exerted was increased as compared to the control soil sample where lateritic soil offered less resistance resulting in a low bearing stress and consequently a low resistance. Similar to the test results on the geobelt, the effect of the specimen length was measured near the peak load at the late stage of pull-out. Thus, surcharge pressure of 5 kN/m^2 at a constant compaction had an output pull-out load of 1060N this was much lower as compared with a surcharge pressure of 10 kN/m^2 producing a pull-out load $<1400\text{N}$. This out-put is progressive as it increases as the surcharge pressure increases. An increase in the pull-out load was attributed to additional resistance caused by bearing stresses acting on the strap edges when the pressure is increased. These stresses resulted as the geobelt strap was pulled against motion and force exerted away from the centreline. The interaction between soil particles and surface of geobelt is increased when the surcharge pressure exerted is increased as compared to the control soil sample where lateritic soil offers less resistance resulting in a low bearing stress and consequently a low resistance. Thus lateritic gravel as a backfill and foundation material showed very small deformations. Since permeability is more for gravel and drainage is good. Consequently, there was less excess pore water pressure developed behind and beneath the pullout box.

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ABBREVIATIONS

CBR	California bearing ratio
G	Grams
H	height of wall
HMA	Hot mix Asphalt
K_a	soil pressure parameter
Kg	Kilo grams
L	Length of Geobelt
L_d	Design length of Geobelt
LL	Liquid Limit
LS	Linear Shrinkage
M	Metres
MC	Moisture Content
MSE	Mechanically Stabilized Earth
PET	Polyester
PI	Plasticity Index
PL	Plastic Limit
PP	Polypropylene
PVC	Polyvinyl chloride
PVA	Polyvinyl alcohol
RE	Reinforced earth
UBL	Upper boundary limit

CHAPTER 1

1 INTRODUCTION

1.1 BACKGROUND

The traditional high fills that failed as a result of natural disasters such as soil erosion, structural failure, earthquakes, floods, tsunamis, and typhoons have been replaced with geosynthetic reinforced soil. These are high fills with retaining walls having full height rigidity facings in practically all cases, which have excelled in performance. (T.G. Sitharam, 2013)

Most high fill landslides observed would occur due to the loss in strength of foundation soils rather than compacted fill soils as described by Pappin (2003). Consequently, probable triggers of these high fill landslides to failure relates to poor control of subsurface and surface water flows including diversion and water concentration; a true reflection of inadequate construction and maintenance of drainage. (Muckel, 2004)

Roads, canal, railway line and bridge are raised to a high embankment made of rock or compacted soil (typically rock-based or clay) to avoid change in levels primarily required by the terrain, the alternatives towards the topography being either having an unacceptable change in levels to also detour to follow a specific contour. A cut is used merely where land is originally higher than envisaged or required.

Recent advances are being made in the research of geosynthetics materials based on monitoring of high fill structures all through the years. New design methods have been realized and the versatility of their applications for soil reinforcement, environmental protection and performance during major earthquakes have increasingly become appreciated.

Geosynthetics are expected to enhance vital engineering properties of earth materials and performance thereof through the mechanisms of interlocking, confinement and friction by restraining/confining particle movement and lateral straining (movement). As a consequence, significantly enhanced strength, bearing capacity and deformation resistance (stiffness) are achieved. The Figure 1-1 shows how geosynthetics are applied in a mechanically stabilized earth structures.

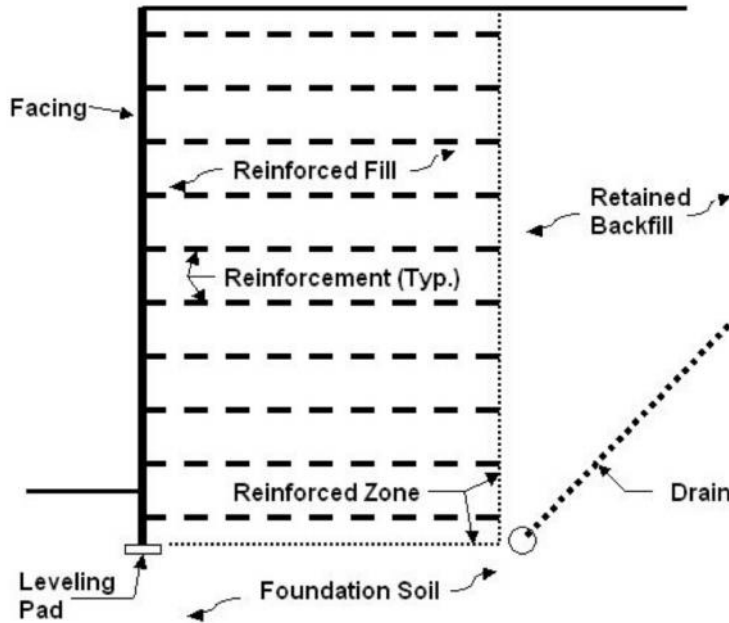


Figure 1-1: Generic cross segment of a mechanically stabilized earth structure

Failures within geosynthetic-reinforced/improved geo-structures tend to occur as a result of the lack of geo-scientific understanding. Lack of proper knowledge on how geosynthetics materials influence both the intrinsic and attained engineering properties of the pavement geomaterials and subgrade soils. These is through basic geomaterials as geosynthetics interaction mechanisms. The lack of appreciating the significant importance of comprehensively studying the physical and mechanical effects. Thus, the influencing factors as geometry/index properties of the geosynthetics, location of optimum embedment of reinforcement and mode of application, aimed at deriving maximum benefit, is clearly apparent. Research for example; shows that geotextiles are placed preferably near load; other research advocates that it should be at mid-height or near the bottom.

1.2 STUDY AREA

Kisumu is the third largest town in Kenya. It is the headquarters Kisumu County in Western Kenya, and lies generally on latitude 00°6' N and longitude 34° 45' E and is located about 340 km by road to the North-West of Nairobi on the Northern Corridor and borders Lake Victoria to the South West. The assessment is an assessment of the conditions input of soil compaction and reinforcement of high fills. The research mimics the ground conditions used in the Rehabilitation of Nyamasaria - Kisumu - Kisian Including the Kisumu Bypass

(A1/B1) Road. The road has two overpasses that act as interchanges in Kondele and another along Mumias road (near Kisumu Airport). The study area is generally well drained with run off and discharges eventually draining into Lake Victoria. In the upper reaches from Kondele towards the Lake Victoria the elevation within the study area varies from 1148m asl to 1145m asl. The soil profile changes to loamy soils with rocky patches. The lower reaches have soils which are a combination of laterites (Murrum), loamy and clay soils. The progressive change in the soil types occurs with movement from the hills towards the lake shores.

1.3 PROBLEM STATEMENT

A reduction in availability of good soil that can support engineering structures such as embankments and also be used in slope stability has lead engineers and researchers into thinking of ways of improving the existing soil which is of lower quality.

In addition, it has been realized that soil, even though it be of good quality can still be improved further. Consequently, giving it the capacity to support much larger and stronger structures. This has been achieved through alteration of soil-mass properties such as strength as shown by Gaturu (2007). This study has assessed the improvement of soil-mass strength by incorporating geosynthetics into the soil mass.

Some of the illustrations of the problem statement;

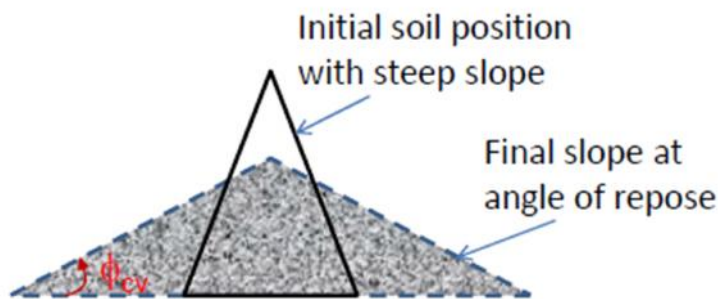


Figure 1-2: Need for a retaining wall (Rajagopal, 2012)

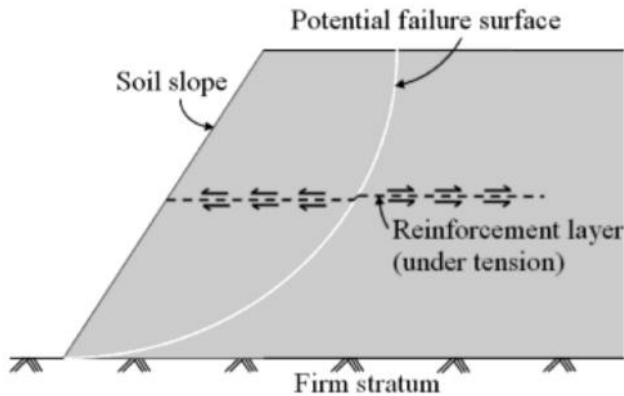


Figure 1-3: Basic reinforcement mechanism (Sanjay Kumar Shukla, 2012)

Retaining structures are majorly used in highway construction and design. These retaining structures are used for slope stabilization, wing walls and bridge abutments. Also, minimizing right-of-way of embankments as shown in Figure 1-2. Moreover, the retaining structures constructed of reinforced concrete are redesigned to gravity walls and cantilever. Consequently, rigid structures are not able to accommodate large differentially loaded settlements unless they are founded on very deep foundations. Thus, the cost of concrete reinforced retaining walls tend to rise rapidly with increased height of compacted soil retained. Such soils having poor subgrade or subsoil parameters. According to Ryan (2009), reinforced soil slopes and stabilized earth walls are cost efficient/effective earth retaining structures having to endure greater settlements than the concrete reinforced walls. Here, by introducing stabilized soils (tensile reinforced elements); where strength is improved significantly. Facing systems help stop soil ravelling sandwiched between different reinforcing elements; these permits steep slopes erection and also construction of safe vertical walls as shown in Figure 1-4.

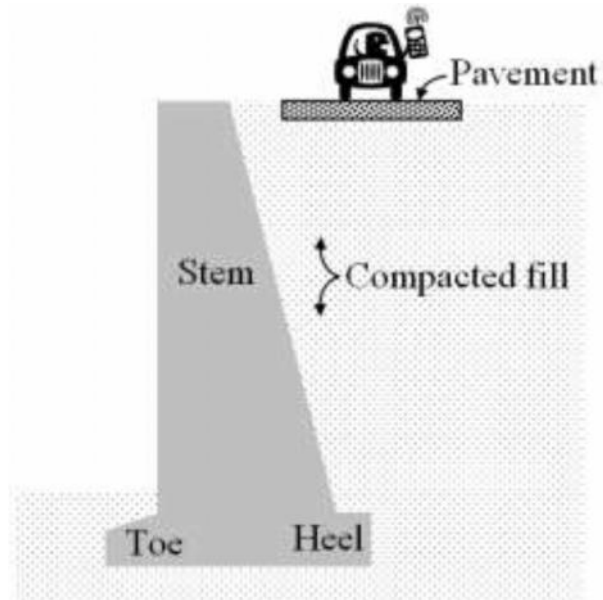


Figure 1-4: Need to reduce cost of retaining walls (Sanjay Kumar Shukla, 2012)

The primary function of geosynthetics is generally that of reinforcement. When the system is permanent and/or of critical nature such as High Fills, in-situ monitoring is considered necessary. Potential failure in a high fill due to lack of proper and enough reinforcing material as shown in Figure 1-3. According to Shukla (2007) such high fills require basic reinforcement mechanism. Primarily, the monitoring of the geosynthetics involves the determination of short term strains, long term creep and/or stress relaxation.

A summary of the problem statement is described as:

- i. Reduction in availability of good soil (lower quality)
- ii. Need to improve soil capacity to support high fills (improve soil parameter)
- iii. Minimizing right-of-way of embankments
- iv. Cost efficient/effective earth retaining structures having to endure greater settlements
- v. Reduce soil ravelling
- vi. Monitoring of the geosynthetics involvement in determination of short term strains and long term creep.

1.4 RESEARCH OBJECTIVES

The research was oriented towards achieving the following main objectives.

1. To perform soil tests on the soil sample and determine the soil properties.

2. To evaluate effect of reinforcement type and strength of geosynthetics in the reinforced earth wall sections.
3. To evaluate pull-out performance of geobelt (geotextile) in soils.

1.5 STUDY SCOPE AND LIMITATIONS

The study covers:

- a) Use of well-drained gravel soil as backfill.
- b) Soil tests to obtain soil parameters.
- c) Use of geosynthetics. (Geobelt)
- d) Pull-out tests on geosynthetic reinforced soil samples
- e) Analysis of various relationships between force, pressure, length and the corresponding orientation angles.
- f) Concluding the findings and recommending alternatives and/or further study.

1.6 HYPOTHESIS

Though, the quantities in mass of soil back fill sent to high fill site projects are slightly decreasing as a result of public policies for the reduction and environmental degradation of material sites. The stabilization of low quality soil reinforced through geosynthetics often remains the best option of soil improvement. For such reasons, reinforced earth sites will continue to be necessary, notably being the best treatment process for high fills. Thus, performance assessment of soil materials should be monitored and evaluated regularly.

It is hypothesized that parameters to evaluate and monitor soil improvement due to high fills can be established through model testing. Emphasis is laid in measurement and regulation of moisture content in soil back fill should be assessed in regard to pull out. Moreover, the use of geosynthetics in soil reinforcement has brought up several challenges with regard to surcharge pressure due to compaction of the soil, length of the geosynthetic in use and the angle of placement of the geosynthetic. Such factors in regard to pull out resistance should be assessed in terms of performance evaluation and system monitoring to provide proficiency in the structure.

1.7 LIMITATIONS OF THE STUDY

The limitations due to the study are:

- i. The study is based on a bench study model. Where tests done in the laboratory mimic external environmental conditions of Nyamasaria.
- ii. The study is limited to use of geobelts as a geosynthetic material.
- iii. The study focuses on monitoring and evaluation measurements of the performance of geobelts in reinforced earth through pull out tests.
- iv. The study focuses on definite variations in the disturbance parameters of reinforced soil through pull out tests.

1.8 JUSTIFICATION OF THE STUDY

The primary function of geosynthetics is generally that of reinforcement. When the system is permanent and or of critical nature such as high fills and/or when in-situ performance is considered necessary. Performance of the geosynthetics involves the determination of short term strains, long term creep and/or stress relaxation.

The lack of substantive and reliable or tested specifications that are long-term, tested and proven are wanting. The concept of geosynthetic earth reinforcement which entails homogeneity, uniformity, and exhibition of intrinsic mechanical and physical characteristics of geomaterials. The study requires tests and trials to determine the appropriate mode and level of strain measurements. The tests provided herein are intended to form the basis for future assessment of more comprehensive tests. Based on long-term research, element, and experimental testing for reinforced earth interface.

CHAPTER 2

2 LITERATURE REVIEW

2.1 INTRODUCTION

Traditionally, use of geosynthetics in pavement construction and application has addressed functions like: drainage, separation, filtration, mitigation of crack propagation and reinforcement. According to Jorge (2012), geotextiles are incorporated to construct a capillary break to act as an obstruction to moisture. He stated that, depending on the nature of the geotextile and position contained by the pavement structure, geotextiles can be able to execute these functions concurrently as part of the application. The tasks frustrating engineers who shall possibly practice geotextiles in road design is to choose a suitable application. Concurrently, then determine applicable properties with standards for choosing of a suitable product. Thus, practice installation with construction methods in order to guarantee the reliability of the positioned geotextile. He further stated that in order for geotextile to perform satisfactorily, the flexible pavement on which they are positioned must be structurally sound.

Geotextile products are manufactured as natural polymer. They are made from a variety of polymers such as polyester (PET), polyvinyl alcohol (PVA), polypropylene (PP), polyvinyl chloride, polyethylene, polyamide, and polystyrene. The value of polyester entails low elongation also high strength. Polyvinyl alcohol is endowed by way of high strength, exceedingly low elongation with higher chemical resistance. Polypropylene is more chemically resistant with suitable elongation. The reasons for using geosynthetics are economic reasons, construction expediency and, in some cases, functional superiority.

Reinforced earth soil refers to a construction material having compacted soil fill reinforced by the insertion of geosynthetics. These intermingle with soil by means of frictional resistance. Reinforcement strips were included as strengthening material as portrayed in Figure 2-1 below.

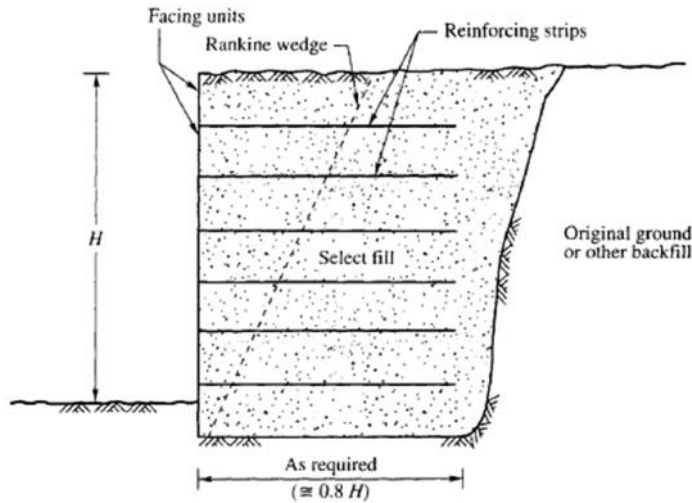


Figure 2-1: Detailed reinforced earth (Bowles, 1996)

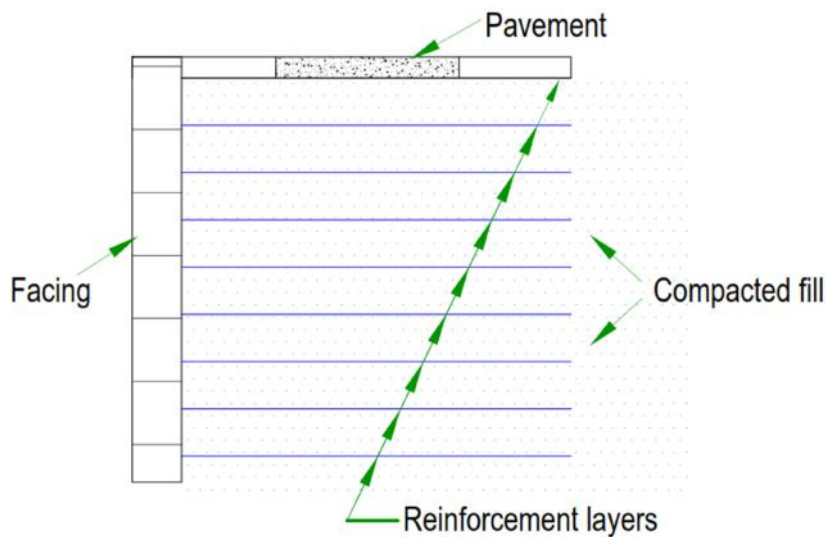


Figure 2-2: Reinforced soil retaining wall masonry

The geobelts outspreads from masonry panel into the soil to function as anchoring/securing the facing elements and restrain frictional stresses having been mobilized among the geotextile strips and earth backfill. Earth backfill forms lateral pressure which intermingles with geobelts to resist. These walls are fairly elastic compared to immense gravity structures. The flexible walls have benefits comprising significant lesser cost per meter squared of the exposed surface. Geobelts/ strips have various uses including:

- i. Geosynthetic reinforced walls
- ii. Anchored/ fixed gabion walls
- iii. Compact panels having tie back anchorage
- iv. Facing panels metal reinforcement

- v. Anchored/ fixed crib walls
- vi. Facing panels having wire mesh reinforcement

In greater circumstances, the earth behind the masonry wall facing is thought to be mechanically reinforced stabilized earth. The wall systems as shown in Figure 2-3 commonly referred to as MSE wall. The three constituents of an MSE wall are backfill, facing unit and reinforcing material.

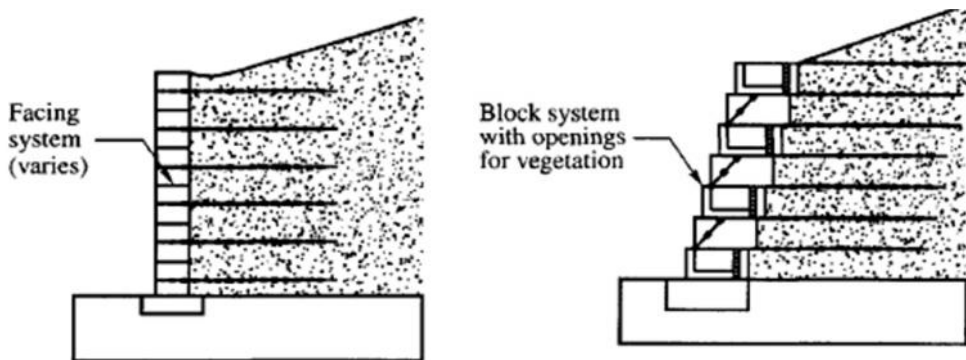


Figure 2-3: Reinforced walls (Robert M. Koerner, 2011)

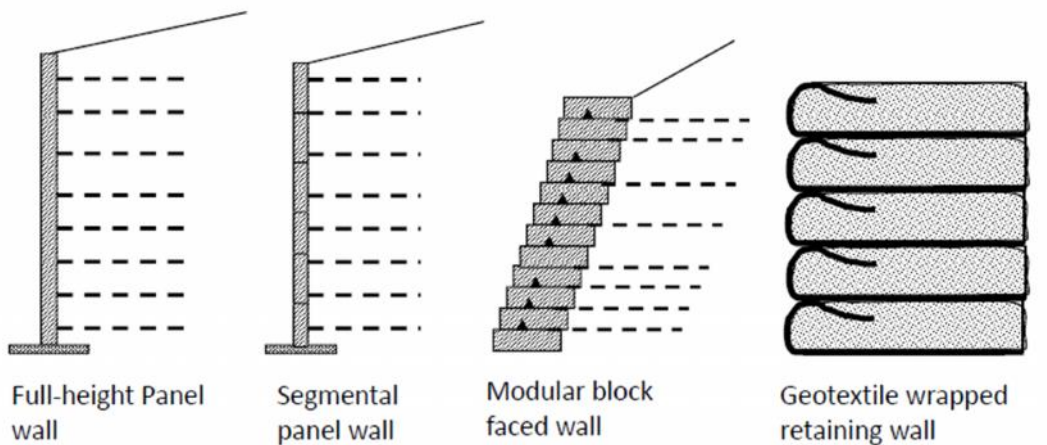


Figure 2-4: Types of wall facing (Rajagopal, 2012)

There exist requirements for different kinds of reinforced earth retaining walls having a face, backfill and reinforced elements as shown in Figure 2-4. The face is prepared from materials of dissimilar shapes and sizes, though essentially have enough resistance to maintain the soil particles with sufficient flexibility so as to permit settlement of backfill. Reinforcing components as documented by Pinto (2000), geosynthetics essentially have basic tensile strength so as to counter resist failure to breaking in tension so as to deliver the required frictional surface.

2.2 GEOSYNTHETICS

Geosynthetics refer to the planar product composed of polymeric component material that is used with aggregate, soil and geotechnical materials as a part in civil engineering project.

Geosynthetics are usually composites, grids, fabrics or membranes. They are geotextiles or fabrics nonwoven or woven and they are usually formed of thermoplastics like polyester and polypropylene but may contain polymers, nylon, fiberglass and organic natural materials. As described by Joe (2003), filaments in nonwoven fabrics are usually bonded (needle-punched) mechanically or by adhesion (like spun-bonded with heat and chemicals). Paving fabrics usually weigh about 135.62 to 271.25 g/m².

Geosynthetics designates a range of common polymeric products used to sort and address civil engineering problems. There are several types of geosynthetic products such as; Geofabric, Geotextiles, Geogrids, Geosynthetic Clay Liners, Geonets, Geomembranes, Geosynthetic Clay Liners, Geofabric, Geocells, Geobelts, Geocomposites and Geobelts. Focus is on geotextile. Geotextiles as described by (Caltrans, 2012) refers to the permeable geosynthetic. This encompassed solely of a textile material that is nonwoven or woven (consist of numerous synthetic polymers under different manufactured processes).

A geotextile refers to a permeable geosynthetic prepared of textile materials. Polymers that are used in geotextile fibres production contain the following polyester (12%), polypropylene (85%), polyamide (1%) and polyethylene (2%).

For pavement structures and embankments, geotextiles shall be installed at various interface of unbound subbase or base and also the subgrade and embankment foundation and fill, respectively. (Kensetsu Kaihatsu Ltd, 2012) The geotextile shall mainly be used as a separation geosynthetic to avoid the movement from subgrade soils into granular subbase/base materials and for effective stress mobilization within the subgrade and interface layer of the subbase/base to enhance bearing capacity, shear strength and deformation resistance.

2.3 FUNCTIONS OF GEOTEXTILES

The primary purposes of geotextiles used for pavement applications comprised of filtration, separation, reinforcement and drainage. Though, a geotextile product can achieve functions conversely, similar function can frequently be done by other kinds of geotextiles. To add to their main function, geotextiles achieve more secondary functions that essentially is

considered when choosing geotextile material to have an ideal performance. Here, a geotextile may offer to separate different soils (e.g., clay subgrade and aggregate base). Geotextile that offers filtration (secondary role) by reducing the increase of surplus pore water pressure forming within the earth underneath the separator. Giving a momentary summary of purposes typically accomplished by geotextiles built pavements.

Soil Reinforcement where they improve the bearing capacity of geomaterials with low bearing capacity through mechanical stabilization; Separation where they are applied between different materials where reliability and effectiveness of both the materials may stay intact and be improved, amongst other applications.

Some of the most commonly used geosynthetics for soil reinforcement are depicted in Figure 2-2, Figure 2-3 and Figure 2-4 showing some typical geosynthetics used in environmental protection, ground improvement and erosion control. Geosynthetics having vast advantages in application for civil, geotechnical, agricultural, and forestry engineering structures, as well as environmental protection works, the geosynthetics product development has become increasingly competitive to the advantage of the user in terms of cost and quality. Some of the functional use of geosynthetics are as shown in Table 2-1.

Table 2-1: Summary of functions of geosynthetics

Type of Geosynthetics	Description	Geo textile	Geo grid	Geonet	Geo spacer	Geosynthetic Clay Liner	Geo foam	Geo cells	Geo composite
Reinforcement	woven but some are high strength nonwovens if more elongation is allowable	x	x					x	x
Drainage	sheet/wall drains and prefabricated vertical drains	x		x					x
Filtration	geotextile are nonwoven but some have specially manufactured woven	x							x
Separation	woven for less elongation, nonwoven for better drainage properties	x					x	x	x
Fluid Barrier	geomembranes, geosynthetic clay liners				x	x			x
Protection	non-degradable and degradable rolled erosion control products (like geocells, blankets and mats, geotextiles both nonwoven and woven)	x						x	

Additional functions of geosynthetics are:

- Protection – geosynthetic utilised as a limited stress decreasing layer to avoid destruction to a specified surface and layer (like a geomembrane layer), it is assumed to achieve the protection purpose.
- Cushioning – wherever a geosynthetic is utilised to control and finally to dampen or reduce dynamic mechanical actions, it cushions as a function. This purpose has to be highlighted predominantly for the applications in geosynthetic strip layers as seismic base isolation of earth structures, canal revetments plus shore protections.
- Absorption –Method of fluid being incorporated or assimilated into a geotextile. This ideal may be deliberated for two particular environmental traits: salvage of floating oil from surface waters resulting from ecological disasters plus water absorption in erosion control applications.
- Interlayer –Task achieved by a geosynthetic to mend shear resistance between two layers of geosynthetic earth materials plus products.
- Containment –Task that a geosynthetic captures then contain a civil structure related material like soil, fresh concrete and rock to a specific geometry further prevents its damage.
- Insulation – Here a geosynthetic offers insulation when used to lessen the path of sound, electricity and heat.
- Screening – Refers to geosynthetic offers screening when located across the line or path of a fluid transport fine particles in suspension within the soil. Thus it retains particles though tolerating fluid to flow.

When mounted, geosynthetics perform a combination of various functions or tasks listed above simultaneously, but normally one function results in the lower factor of safety (FOS), therefore becoming the chief function. The utilisation of a geosynthetic in a particular application requires classification of its roles as secondary or primary. The major role and task ideal is commonly used in the design with the invention of a factor of safety, FS, that is evaluated as follows:

$$FS = \frac{\text{value of required (design)property}}{\text{value of allowable (test)property}}$$

Where $FS > 1$.

The definite magnitude of FS be contingent upon the consequence of failure, that is usually site specific. The significance of allowable property attained from enthused performance (index test), though the required property is acquired from the right design model; as

documented by Sanjay (2012), the choice of a geosynthetic for a specific application and process is overseen by a number of other features, such as durability, specification, cost, availability, etc.

2.4 ADVANTAGES AND DISADVANTAGES OF USING GEOSYNTHETICS

Advantages

Economic returns of creating a safe, steeper high fill would be a product of material plus right-of-way savings. Leading to a possibility to reduce value of various materials essential for construction. Thus, in restoration of landslides leads to probable recycle of the slide debris or to import excellent backfill. The right of way is an important benefit. Particularly for road expansion projects in major urban zones where gaining first-hand right of way is constantly expensive and unobtainable.

In relation to performance due to innate design of high fills, essentially safer than approved, where unreinforced slopes are planned at matching (FOS) factor of safety. Which is an outcome of lesser risk of stability in long-term complications developing of reinforced slope. Here, problems habitually happen in compacted/rummed fill slopes which are constructed of low (LOS) factors of safety plus the marginal materials. According to Ryan (2009) the reinforcement might also enable strength improvements in soil in time where soil aging with improved drainage improving performance.

Disadvantages

Potential disadvantages that are associated with reinforced earth structures, this dependent on project situations:

- i. Need a fairly large space (i.e excavation to cut) after the wall/ wall face to fix essential reinforcement.
- ii. MSE walls require choiced granular fill. (Price of importing proper fill material might render the structure uneconomical.)
- iii. Design and detailing of the soil-reinforced structures often entails a collective design obligation between material contractors and owners.

Types of retaining walls

Geosynthetics reinforcement of soil can help to enhance several kinds of retaining walls; such as:

- a) Gravity masonry walls, crib walls

- b) Reinforced Concrete walls. These are cantilever, counterfort, and buttressed walls
- c) RC Walls with shear keys
- d) Sheet Pile Walls
- e) Diaphragm walls
- f) Reinforced soil retaining walls
- g) Anchored reinforced soil walls
- h) Soil nailed walls. These refer to driven nails, screw nail, pre-stressed nailed walls to the soil mass retained.

2.5 DISTURBANCE FUNCTION FOR GEOSYNTHETIC–SOIL INTERFACE

There exist geosynthetics used for protection, encapsulation and reinforcement that are practical to major civil structures and high fills. The encompassing of geobelts as geosynthetics mostly involves the coupled and engaging behaviours of different specific materials which include minor displacement and strain-softening behaviours. The geosynthetic to soil interface depend on the shear force of the interface governed by several environmental and intrinsic features. These factors are moisture, thermal components, typical stress, and chemical parameters. Consequently, by use of disturbance function parameter a new chemical outcome of geosynthetics has been used as a new approach. These constraints are projected (disturbance function) to define the various chemical degradation of the geosynthetic–soil interface depending on the dynamic parameters.

The tests presented by Kwak (2013) focus on disturbance function. These tests have strength to each outcome and there after forecast the specific dynamic behaviour of materials. Thus, the disturbed earth is not individually relevant, but also appropriate to analysing the various dynamic behaviour of boundaries in studies.

The strain localisation of geomaterials due to inertia forces are normally disregarded. The data on acceleration generation in the course of the creation of shear-stress not being evidently stressed. Laboratory tests of acceleration that are interrelated to the slippage in faults, having dynamic soil–water coupled strain localisation analysis should be assessed. Where the geobelt is exposed to constant exerted cell force pressure with plane strain parameters.

Consequently, two kinds of oscillation viewed within the sample throughout acceleration where the sample is due of compression distortion at steady rate; (a) Sudden external compression and (b) Formation of strain localization.

The effect of time increment and confining pressure, are the stress-control loading experienced on the generated acceleration. Thus, under stress control and displacement control the induced acceleration result is quite differently. (Toshihiro Noda, 2013)

2.5.1 Analytical Formulation

Reference is placed on Rankine active earth pressure deduction that presumes the soil backfill in a retaining wall trails the direction movement of the retaining wall, notwithstanding the entire soil mass being subject to distributed lateral extension. These infers that a uniformly distributed stress force field exists, also the stress force field of the soil backfill in the retaining wall equals to that in the free field. The theory is in correct, since the stress experienced in the near field just behind the wall is dissimilar from that in the free field owing to the change in the effort and movement amongst the wall and the open field plus the effects of soil arching. (Magued Iskander, 2013)

This is pseudo-static method adopted by Magued in in his design to evaluate the seismic reaction of backfill on the high fills that overlooks the time effect of exerted confining pressure load.

2.5.2 Soil Behaviour During Wetting and Drying

Soil behaviour assessment when dry and wet is due to an increase in moisture contents. Tests conducted using various liquids as acidic, saline and distilled waters. The water content, void ratio plus volumetric deformation of the models is elaborated during cycles of drying and wetting. The outcomes would show that swelling potential improves with the number of drying and wetting cycles. This influence of the distilled water on the envisaged swelling potential is different from saline or acidic water, predominantly for diverse surcharge pressures.

Moreover reasons affecting the expansive behaviour are the magnitude of the surcharge pressure, type of soil, conditions of earth soil (like moisture content and dry density) and the volume of non-expansive material. Generally, the envisaged swelling potential improves proportionally with the dry density increasing rather water content decreasing. The hydro-mechanical viewed behaviour of compressed swelling soils at ambient temperature has a significant influence on the mechanical expansive behaviour of soils. (A.R. Estabragh, 2013)

2.6 Strength and the Deformation Behaviour of Soils

The movements in and around an excavation area or site assessed for strength and deformation behaviour varies. The analysis results may be effected by various aspects such as

mesh generation, simple geometry plus boundary parameters, the constitutive relationship and the initial input of the ground conditions selected to model and create the manners of the soils. The results of a mathematical analysis might be affected by many aspects, such as mesh generation simple geometry, the initial input of the ground parameters, the constitutive connection and boundary conditions chosen to model and create the behaviour of soils. The patterns of the retaining wall measures are governed by features such as the support system of the retaining wall (i.e., anchored or braced), type of subsoil encountered, and quality of the workmanship. (Suched Likitlersuang, 2013)

The outcome of the confining pressure plus the void ratio on the slight strain properties, comprising Poisson's ratio ν , strained modulus plus shear modulus. Thus, the void ratio plus the pressure required was establish to be higher for shear modulus rather than strained modulus. The median stress exponents for both modulus are generally larger than 1/3. Stress exponent for shear modulus tends to growth proportionally with increased void ratio. (Xiaoqiang Gu, 2013)

Subsequently, a better understanding of soil behaviour once treated as a range, demands a better knowledge and a critical study of the reaction of soil at their interactions. According to Kostas (2012), quantitative examination of the influence of the inter-particle coefficient of friction on the cyclic reactions of granular assemblies and monotonic responses, have also sustained this requirement. For instance, an increase in the inter-particle coefficient of friction proportionally improves the peak angle of the shearing resistance and the shear stiffness, with a more pronounced dilative response. He reiterated that, the parameter of coefficient of friction strongly effects the inherent stability of the resilient force chains. He assessed various studies and discovered that the increase in coefficient of friction significantly affected the behaviour of soils in the array of huge strains by improving the critical void ratio.

2.7 PERFORMANCE OF GEOSYNTHETIC REINFORCED SOIL

The increasing use and utilisation of geosynthetic reinforced soil walls to support heavy bridge foundations being abutment walls has notably been on the upsurge. On the geosynthetic reinforced soil abutment wall, definite large foundation footing loads are done next to the wall facing.

According to Chengzhi (2015) geosynthetic reinforced soil walls led to the settlements failure of the foundation loading plate and the lateral displacement occurring on wall facing were monitored during loading. He's evaluation of the effects of the influence

factors which included the length of geosynthetic reinforcement, the offset distance of strip footing, the connection method between geosynthetic and facing, on critical bearing capacities of strip footings and general width of the strip footing. He detected that the failure surface commenced at the edge of footing and further terminated at the wall facing.

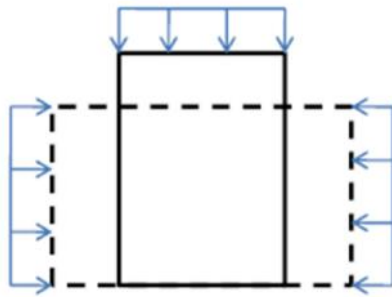
Geosynthetics have developed and are well used as construction materials for environmental and geotechnical applications. They are founded in manufactured materials, innovative products and design applications are developed on a casual basis to provide solutions to critical and routine problems. Results of various studies and monitoring of such structures all through the years have led to innovative design procedures for dissimilar applications of geosynthetics. There are significant advances on geosynthetic designs processes and products for reinforced soil plus environmental protection works. (Ennio M. Palmeira, 2008)

In transportation, it is advisable to considerably increase and improve the surface surcharge load in line to the wall. Moreover, transportation applications, where the surface surcharge is in most occasions used to simulate or rather live load effect, (this may implicate loads from aircraft, motor vehicles and trains adjacent to a retaining wall or bridge abutment) that are constantly in excess of the original loads design. Structurally retrofitted wall for the high loads tend to be difficult and expensive, as it leads to total replacement. According to John (2001) the incorporation of horizontal tensile reinforcement layers within the retained earth or soil permits the horizontal soil pressures exerted to reduce. This leads to tensile forces within the reinforcement to be mobilized as the geotextile exerts pressure on the retained soil that is undergoing controlled and regulated yielding. Resulting in a transformed retained soil which is then conventional mechanically stabilized earth mass being fundamentally independent of the rigid retaining earth or structure.

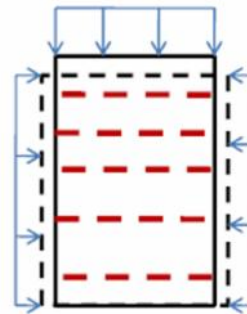
In the horizontal directions, soil is reinforced by the tensile forces developed along the geosynthetic and then transmitted into the soil. In the vertical direction, soil is also reinforced because additional resistance to the gravity force is provided by the horizontally placed reinforcement. (Robert D. Holtz, 2002)

2.8 BASIC PRINCIPLE OF REINFORCED SOIL

Response of unreinforced and reinforced soil to external loading.



Without reinforcement



With reinforcement offers stronger and stiffer response

Figure 2-5: Response of reinforced and unreinforced soil to loading (Rajagopal, 2012)

Reinforced earth slopes are mechanically stabilized earth using planar strengthening features in built earth sloped structures. Having a face inclination of not greater than 70 degrees, numerous stratum of reinforcement strips are positioned in slopes. These are constructed and rebuilt to strengthen the earth and deliver improved slope stability. Reinforced earth is cost efficient and an effective substitute for construction of the right-of-way. Below are some other concerns that might create a steeper slope anticipated and cost of fill.

The key reasons for utilizing reinforcement in engineering slopes.

- i. To offer improved compaction of a slope, thus reducing the affinity for surface sloughing.
- ii. To improve the strength of slope, mainly where steeper than safe unreinforced slope is anticipated and afterwards failure happened.

2.9 PULLOUT TEST

2.9.1 General

The growing use of geo-synthetics in pavement dictated the assessment of its geosynthetic reinforcement interaction constraints, characteristically the coefficient of interface friction. Generally, numerous factors tend to modulate various gauged properties; such factors like test equipment's and associated parameter effects, the soil properties after compaction, type of geobelt, confining pressure and geometry. The soil and geosynthetic interaction mechanism raises complications in interpretation of results in pullout test. The confined strain and stress of the geobelt in the experiment during pullout; tremendously affected by length, extensibility, geometry and level of soil confined. Pull-out resistance

between soil and geo-textile reinforcement provided by friction resistance in the soil and geotextile interface. Moreover, non-uniform shear strain and shear stress distribution is developing onward in geosynthetic geobelt throughout pullout owing to coupled effect of interface shear and the elongation.

A number of theoretical and empirical processes have advanced so as to model or create test soil and geosynthetics interface process due to pullout. Clearly it varies in such a models thus differ on expectations of material properties, the nature of the load and strain curve through pullout and the load transfer mechanism at the interface.

The soil and geosynthetic reinforcement interface process is difficult and raises complexity in interpretation of pullout test outcomes. Confined stress and strain of geosynthetic throughout pullout is considerably caused by its length, geometry, amount of soil confined and extensibility. Pullout interface resistance in geotextile strip reinforcement is offered primarily by friction force resistance laterally to the soil and geotextile interface. Consequently, the pullout interface resistance of a geotextile is essentially due to bearing passive resistance contrary to transverse members and soil frictional resistance. Furthermore, Khalid (2004), documented that non-uniform shear stress-strain distribution is advanced within the geosynthetic sample throughout pullout owing to coupled influence of its interface shear and elongation.

2.9.2 Pullout Resistance Interaction Mechanism

Shear stress is generated at the margin between non-dilating zones and dilating zones, thus resulting in an upsurge in stresses at the edges of geobelt strip reinforcement. The thickness of reinforcement becomes slimmer, thus effect of controlled dilatancy outcomes in the progress of a three dimensional interaction mechanism as shown in Figure 2-6.

An upsurge in stress at the edges and sides of the geobelt strip reinforcement, subdues soil dilatancy throughout interface thus shear displacement. Thus, where collective interaction mechanism, dispersal of stresses enforced on the strip reinforcement as shown.

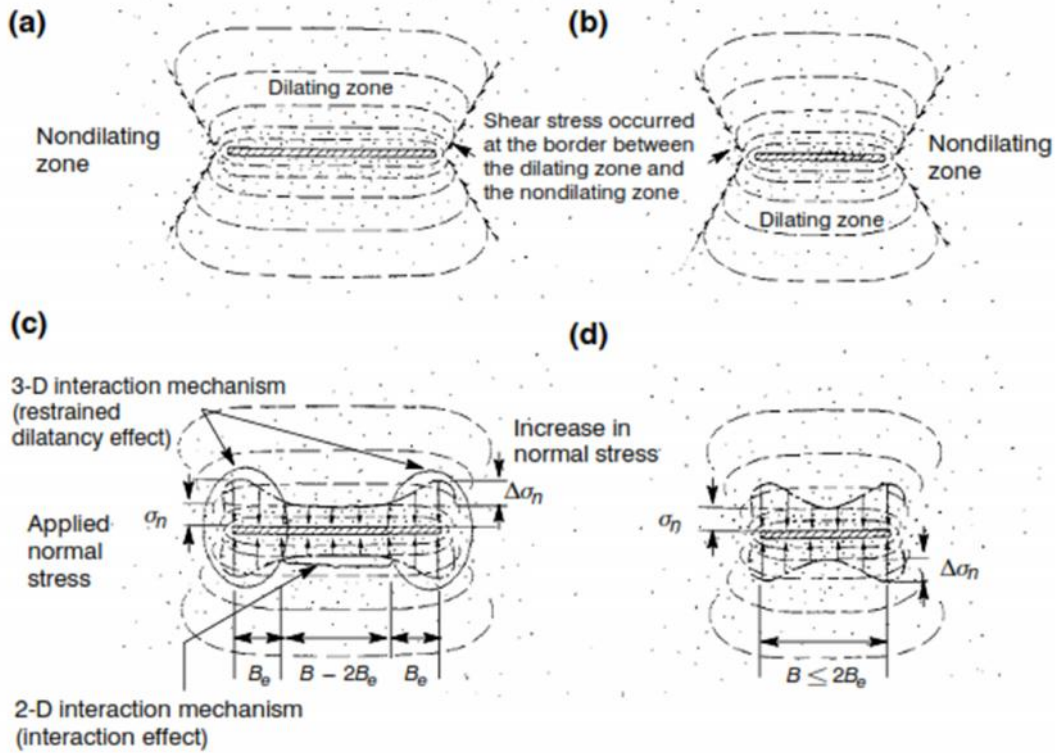


Figure 2-6: Strip reinforcement pullout interaction of shear stress-strain mobilization (a) wide geobelt strip, (b) narrow geobelt strip, (c) normal stress distribution on wide strip, and (d) normal stress distribution on narrow strip.

An alternative feature of the interaction mechanism that needs due consideration is that part of the geobelt reinforcement length to be organized as an extensible reinforcement, like geotextile, is pulled out against the compacted backfill earth.

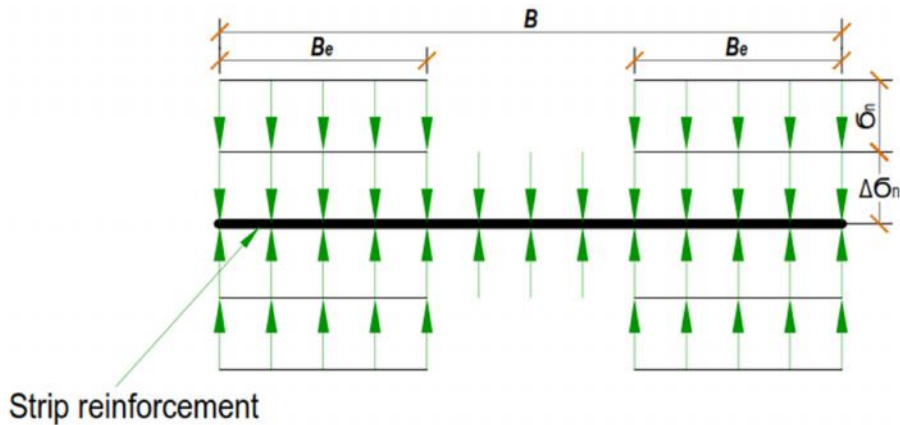


Figure 2-7: Generic distribution of stress on reinforced soil interface.

Such an influence is chiefly prevalent in high stresses where nodal displacements have a tendency of localize close to pullout load use resulting in smaller organized reinforcement length as shown in Figure 2-7. Therefore, their assessment of pullout maximum resistance ought to account solely the mobilized/actual reinforcement length. Here, interaction mechanism and subsequent relationship, is suggested for the effective maximum pullout resistance, P_{TE} :

$$P_{TE} = P_{2-D} + P_{3-D}$$

$$P_{TE} = 2BL_e \sigma_n \tan \phi + 4B_e L_e \sigma_n \tan \phi$$

where:

P_{3-D} = 3-D interaction resistance pullout force

P_{2-D} = 2-D interaction resistance pullout force, and

B = reinforcement width;

L_e = mobilized/effective reinforcement length;

σ_n = the applied stress;

B_e = the width at edge of reinforcement subjective by dilatancy effect;

$\Delta \sigma_n$ = an increase change in stress at earth reinforcement interface brought about by dilatancy on width B_e ; and

ϕ = friction angle.

Neglect interface adhesion that adopts friction angle of earth reinforcement that is same in three dimensional and two dimensional interaction mechanisms. Therefore, stress increase adds to the three dimensional interface resistance as computed by product, $B_e \Delta \sigma_n$ vestiges constant. As described by Alfaro (1995), values of $\Delta \sigma_n$ and B_e were attained from the pull-out tests by means of reinforcement samples of varying widths where dissimilar applied stresses.

2.10 GEOTEXTILE PROPERTIES

Geotextile properties are characterized in groups: physical, endurance, mechanical, degradation and hydraulic. Each group entails testing which characterizes a dissimilar aspect of geotextiles with their performance. Geotextile analysis may be categorized as either performance or index. Index tests are common depiction of geotextile product which do not offer standards that can be openly used to design purposes; whereas performance testing offers information on the projected geotextile in an engineered structure. Here, Index testing is done to the geotextile only, or in-isolation, whereas performance testing frequently

comprises both geotextile and the soil which be positioned in an engineered classification. Physical properties describe the geotextile in factory-made condition, thus are obtained by index testing. Thus its physical properties comprise of mass per the unit area, specific gravity, stiffness, and thickness. Remarkable

Mechanical properties offer notable geotextile strength with compressibility under unpredictable loads. Thus its mechanical properties comprise tensile strength, compressibility, tear strength, seam strength and puncture strength. A range of tests exist to depict geotextile strength, commonly planned to imitate conditions met in field installation. Subject to specific strength property, this testing may be defined as either performance or index. Common geotextile strength tests used for years in industrial fabrics industry; consequently, do not offer much beneficial engineering design data that might be defined as index tests. Nevertheless, designed having engineering drives in mind, these offer an extra representative strength value shall be used to define a geotextile’s projected performance in field.

2.11 SUMMARY OF LITERATURE REVIEW

Below is a summary and a brief description of literature reviews referenced in the literature review topic as shown in Table 2-2. The reviews describe the geosynthetic advances tested by different researchers under different environments. The gaps identified are described thereafter.

Table 2-2: Summary of literature reviews

References	Description
(Jorge G. Zomberg, 2012)	Geotextiles are incorporated to construct a capillary break to act as an obstruction to moisture. Also, depending on the nature of the geotextile and position contained by the pavement structure, geotextiles can be able to execute more functions.
M.I.M. Pinto (2000),	Geosynthetics essentially have basic tensile strength so as to counter resist failure to breaking in tension so as to deliver the required frictional surface.
(Kensetsu Kaihatsu Ltd, 2012)	For pavement structures and embankments, geotextiles shall be installed at the interface of unbound subbase/base.
Ryan R. Berg (2009)	Reinforcement enables strength improvements in soil in time where soil aging with improved drainage improving

References	Description
	performance.
(C.W. Kwak, 2013)	The dynamic behavior of interfaces and focus on disturbance function.
(Magued Iskander, 2013)	Seismic reaction of backfill on high fills, which overlooks the time effect of the exerted confining pressure load.
(A.R. Estabragh, 2013)	The hydro-mechanical viewed behaviour of compressed swelling soils at ambient temperature has a significant influence on the mechanical expansive behaviour of soils.
(Xiaoqiang Gu, 2013)	Effects of confining pressure exerted plus void ratio on the small strain properties effects. Stress exponent for shear modulus tends to growth proportionally with increased void ratio
(Kostas Senetakis, 2012)	The increase in coefficient of friction affects the behaviour of soils.
Chengzhi Xiao (2015)	Geosynthetic reinforced soil walls leading to settlement.
(Ennio M. Palmeira, 2008)	Significant progresses on geosynthetic design methodologies and products for environmental protection works and reinforced soil.
John S. Horvath (2001)	The incorporation of horizontal layers of tensile reinforcement within the retained backfill soil.
(Robert D. Holtz, 2002)	Soil is reinforced because additional resistance to the gravity force is provided by the horizontally placed reinforcement in retaining walls.
Khalid Farrag (2004)	Confined stress and strain of geosynthetic throughout pullout influenced by length, geometry, amount of soil confined and extensibility.

2.11.1 Gaps identified

The above summary does not address specific materials and their performance. This thesis has addressed notable factors affecting geosynthetic placement under pullout force.

These factors affecting pullout behaviour include surcharge pressure, moisture content, specimen length, angle of placement and time assessed.

CHAPTER 3

3 METHODOLOGY

3.1 APPROPRIATE TESTING, EQUIPMENT AND INSTRUMENTATION

To effectively carry out characterization of soils, geotextile and as well as geosynthetics ~ geomaterials interaction:

- Tests will be performed on both reinforced and unreinforced specimens of similar geomaterials and conditions.
- The geomaterials tested will be standardized to ensure; consistency, homogeneity, uniformity, and exhibition of intrinsic mechanical and physical characteristics in order to reduce or contain error factor within acceptable and reasonable tolerances.
- Trials shall be undertaken to determine the appropriate mode and level of strain measurement.

Measuring instruments/devices

The following measuring instruments are vital in carrying out the tests in the laboratory of geosynthetic earth reinforced model.

- Pressure cell to measure surcharge pressure
- Ruler to measure displacement
- Tape measure
- Balance (measure soil)
- A length of metal rod 1/8in (3mm) diameter

3.2 SURVEYS AND TESTING

Data was consistently kept in an inventory and a digital data bank to facilitate monitoring and evaluation.

Performance monitoring and evaluation surveys and tests were adhering to as follows;

i.Conditions and Visual Distress Surveys:

Observations and assessment of surface distress, structural conditions, and functional rating were manually captured and recorded. The conditions were to be compared with laboratory condition in the laboratory model.

ii.Physical Measurements:

Measurement of on-surface displacement of geo-structures were recorded. The displacement were manually read from a mounted ruler.

iii.Laboratory Testing

The tests done were soil tests and pullout resistance tests for characterizing soil-geosynthetics interaction. To geo-scientifically study the fundamental mechanisms of interlocking, friction, bonding and adhesion. Moreover, to facilitate the determination of mechanical and structural contribution and overall performance of geosynthetics.

3.3 SOIL TESTS

The soil will be stored in polythene bags to ensure that the moisture content of sample remained the same as the actual moisture content in the field. The soil tests performed so as to obtain the soil properties were;

- Sieve analysis
- Compaction test
- Atterberg limits
- California Bearing Ratio, CBR

The tests performed are described and characterized in Table 3-1 below. The moisture content was maintained throughout the tests. This involved proper storage of the soil in different polythene bags and regular testing of samples to define the moisture content of the soil.

Table 3-1: Characterisation of soil tests

	Soil Test	Description of Test	Standards & Characterisation
1	Sieve Analysis	Test done to define the percentage of different grain sizes in a soil sample.	ASTM C136 / C136M - 14 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. (ASTM C117-17, C136, 2017)
2	Compaction test	The test determines dry density of soil sample when compacted over a series of moisture contents.	ASTM D4914/D4914M-16 Standard Test Methods for Density of Soil and Rock in Place by the Sand Replacement Method in a Test Pit. (ASTM D4914 / D4914M-16, 2016)
3	Atterberg limits	Determines the liquid limit of air-dried soil	ASTM D4318-17e1 Standard Test Methods for Liquid Limit,

		Determines moisture content where a soil passes through plastic to the liquid state.	Plastic Limit, and Plasticity Index of Soils. (ASTM D4318-17e1, 2017)
4	California Bearing Ratio, CBR	Penetration test to evaluate the mechanical strength of base and sub grade courses The tougher the surface, the higher the CBR value	ASTM D1883-16 Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils. (ASTM D1883-16, 2016)

The soil used for the tests was Lateritic Gravel from Uzima Borrow Pit in Kisumu. The soil was used in the Rehabilitation of Nyamasaria - Kisumu - Kisian Including the Kisumu Bypass (A1/B1) Road [Northern Corridor Transport Improvement Project (NCTIP)]. The exact chainage location is 0+742 - 0+875.

3.4 PULLOUT RESISTANCE TESTS

Pullout tests were done to characterize soil-geosynthetic reinforcement movement with relative soil-geosynthetic reinforcement interaction; as the geosynthetic is subjected to pullout. Consequently, Pullout resistance test shall investigate and characterizes the soil ~ geosynthetics interaction. It is particularly essential in determining design and effective lengths of geosynthetics embedment within fill material to be used in RE-Walls, among others.

Pull out tests were executed with the following variations:

- i. Surcharge pressure
- ii. Moisture content
- iii. The length of the geosynthetic/ geobelt
- iv. Angle of geosynthetic
- v. The time taken for pull out

The tests were done in accordance with the standards used in soil characterisation. The Table 3-2 shows a summary of the tests done and some of the standards used in tandem with soil tests done.

Table 3-2: Characterization of pullout resistance tests

	Pullout Test Variations	Description of Test	Standards & Characterisation
1	Surcharge pressure	Varying surcharge pressure intervals of: <ul style="list-style-type: none"> • Designed soil 5 KN/m³, 4 KN/m³, 2 KN/m³ • Control soil - 10 KN/m³, 5 KN/m³, 4 KN/m³, 2 KN/m³ 	ASTM D6706-01(2013) Standard Test Method for Measuring Geosynthetic Pullout Resistance in Soil. (ASTM D6706-01, 2013)
2	Moisture content	Varying surcharge moisture content intervals of 7.3%, 14.6%, 21.9%, and 29.2% moisture content.	Vertical Pullout Test for Measurement of Soil-Geomembrane Interface Friction Parameters. (ASTM D5321-02, 2009) (El Mohtar, 2009)
3	The length of geobelt	Geobelt strap length at 100%, 75%, 50%, 25% were also tested.	
4	Angle of geosynthetic	Varying Strap orientations of 0°, 30°, 45°, and 60°.	
5	The time taken for pull out	Pull-out carried out at intervals of 30 minutes, 60 minutes, 120 minutes, 24 hours	

3.4.1 Apparatus

The apparatus consists of a metallic pull-out box developed at the University of Nairobi (UoN). The box has a plan dimension of 600mm x 600mm and a height of 600mm. The box represented a model created to simulate the earth conditions of a reinforced earth fill. The basis of the model box created was to compare results of experiments with the hypothesis prediction. Thus, provide a reasonable proposal that correlate between or among the set study. On one of the vertical sides of the box, there is a circular opening of 100 mm diameter through which the clamped geosynthetic strap(s) is placed between the soil layers.

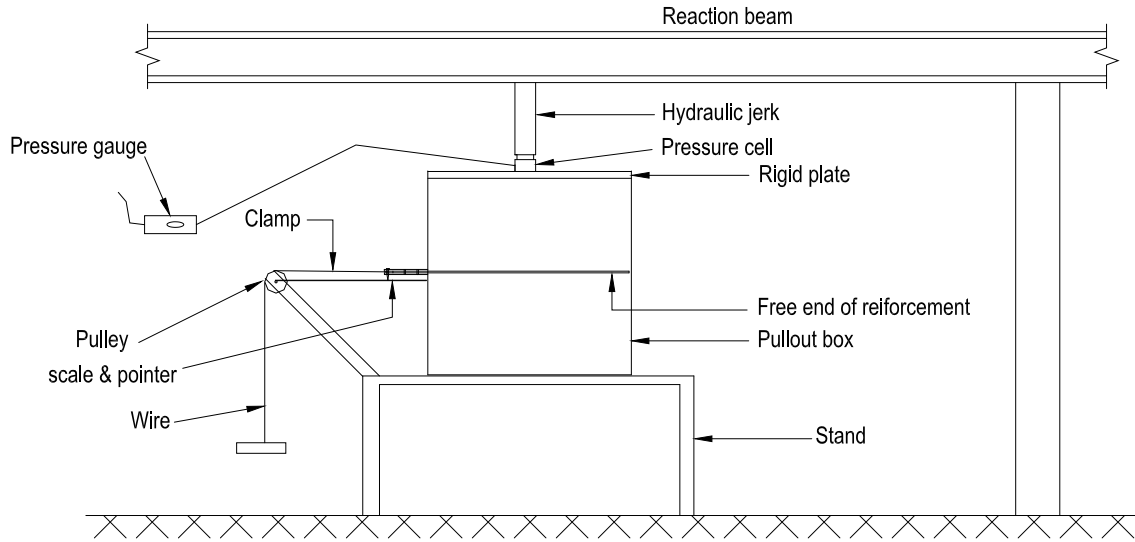


Figure 3-1: Schematic pullout resistance test apparatus

The circular opening is designed to contain the soil and allow the reinforcement pull out smoothly. After investigating a possibility increase of frictional resistance to pull-out at the circular opening, it is deemed absolutely essential that an exit slit be formed in such a manner that quality control due to pullout was maintained. This exit slit is formed by placing in the circular opening a circular plank of wood thus fully contains the soil; moreover, enabling pull-out of geotextile strap without significant resistance. The pull-out box is placed on a metallic stand to which a pulley system is attached to enable pull-out of the reinforcement strap upon loading to failure.

Another component of the apparatus is a steel rod welded to a square steel plate at one end for holding the weights. The other end of the rod is attached to a flexible steel wire which connected the rod to the clamping system. The clamping system consisted of two metal plates fixed together using nuts and bolts which is used for holding the geosynthetic strap tightly. The Plate 3-1 below show the arrangement of the apparatus.



Plate 3-1: Shows the pullout resistance test apparatus



Plate 3-2: Top view of the pullout test apparatus

3.4.2 Pullout Test Preparation

3.4.2.1 Soil Preparation

The required amount of soil necessary for the specific test was calculated in reference to the volume of soil in the pullout box and soil density from the field requirement. The soil afterwards was mixed by addition of the required quantity of water to attain the soil to be utilised in the pullout test, that was later stored in plastic bags to inhibit loss of water. Moreover, this aided the moisture to equilibrate in the earth-soil specimen. Indeed, the water content for the soils in the plastic bag was checked before every pullout test.

The soil to be utilised in the test was stored in polythene bags to maintain the natural moisture content at 7.8%.

Appendix A shows the calculations due to soil preparation procedure. Below is a summary of results due to the soil preparation:

Volume of soil Sample = 0.0828m^3

MDD = 1755 kg/m^3

OMC = 20%

Natural Moisture = 7.8

Amount of soil required = 165 kg

Compact to max dry density (MDD) = 5.6 %

Amount of water required = 13.68 litres

To start, the soil was mixed and preconditioned in a separate large tray before being placed in the test pull-out box. It was turned and spread, and water was added to achieve the target moisture content. Moisture content of 20% was used, which was selected based on the compaction test. The soil was then placed into the pull-out box and compacted portions of 150 mm thick layers with a 5 kg hammer having a circular base plate fitted to deliver the compaction force. Hammer blows were applied on each layer during compaction until the soil attained the required volume.

3.4.2.2 Instrumentation

The apparatus used throughout the test comprised of normal pressure application at the top of pullout box and pullout load application by means of a pulley system where a force was applied by adding known masses to the weight holder at the end of the pulley system. The pulley system was attached to the end of the geo-synthetic by means of clamping mechanism which ensured the pullout capacity of the geo-synthetic was obtained without slipping of reinforcement and the pulley system. The meter rule placed parallel to the

clamped end of the geobelt specimen was used for measuring the displacement of the geosynthetic embedded in test soil. Consequently, the rule was attached to the clamping system perpendicular to the model box. The displacement was read out on the metre rule and repeated twice to check the readings. The masses attached at the end of the pulley system measured pullout force. Finally, the meter rule measured displacement.

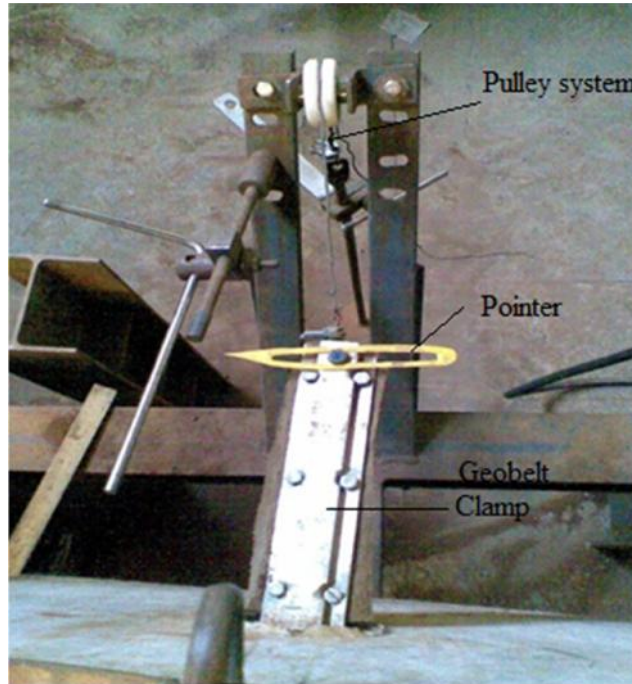


Plate 3-3: Clamping system (in plan)

3.4.2.3 Compaction Equipment

To compact the soil in the model pullout box, a 5 kg hammer was used in order to compact the soil to field density and field moisture content trial compaction were done to determine the thickness of each layer and compaction effort required (number of blows) to give the model the prototype characteristics of compaction soil tested and CBR tested. The excavation chisel was used to remove the soil at the end of each test.

3.4.2.4 Pullout Test Preparation

The specimen preparation for the pullout test entailed preparing the geosynthetic specimen to be bolted to the clamps. Also, preparing the soil to optimum moisture content and density, attaching the geo-textile to the clamp and lastly compacting the soil in layers within the pullout box.

3.4.2.5 Geo-synthetic Specimen Preparation

The geo-textile of the required size and dimensions was then cut and then clamped to metallic plates using nuts and bolts. During the test, the two plastics holding plates having the geo-synthetic, sandwiched between them were clamped to the two steel - sections with bolts as shown in Plate 3-4 below. The geosynthetic used in the experiment had a length of 60cm measured from the opening to the opposite end of the model box. The length varied with a different tests done.



Plate 3-4: Setting up the geotextile

The setup provided a rigid grip all through the geo-synthetic specimen consequently preventing differential slip of the element. The clamping device consists of two layers of steel plates 30 mm long encased with a resisting fabric/rubber layer that sandwich the geobelt; having 4 holes where nuts and bolts are joint in place to hold the geobelt (test specimen) firmly in place within the plates as shown in Plate 3-3. The model shown in Plate 3-3 in the test box is portrayed in the field as shown in Plate 3-6. The clamp is design to place the geobelt in place; thus remains horizontal as loading occurs; therefore, not interfering with the pull-out test and shear surface. The external connecting device attached to the clamp via a bolt attached to it ends allows the pull force be applied to the geo-synthetic throughout the length of the sample.



Plate 3-5: Geosynthetic material used



Plate 3-6: Sample geobelts erection on site

Displacement measurements

In order to take displacement measurements, a pointer was attached to the clamped geo-synthetic by means of bolting. Then the meter rule was fixed horizontally between the pullout box and the pulley end by clamping mechanism. During the test, as the geo-synthetic was pulled out, it caused the pointer to move, and this movement was measured by change in the corresponding reading in the meter rule.



Plate 3-7: Pull-out displacement measurement

Compacting the soil and geo-synthetic placement

Distribute the compression active effort equally all through the soil in the pullout box; it was concluded to compact soil in six layers of 15cm thickness each after trial tests conducted prior to pullout test. The weight of soil necessary for each 150mm layer was calculated later added and then compacted to required layers using the 5kg hammer so as to maintain field density. The surface of third layer was made as flat as possible. After the placement of third layer, the clamping plastic and the geo-synthetic were placed in between two section steel plates and steadily clamped with six bolts and nuts and placed in the box through the small groove at the side of the pullout box. Being essential to temporarily anchor the rear end of the geo-synthetic specimen so as to keep its level position on the surface of third layer. The other three layers of the soil backfill were then compacted in 150mm increments. The rigid wooden plate was later positioned above the compacted soil layer and pressurized to the required load pressure by jerking system as shown in Plate 3-7.

3.4.3 Pull-Out Test Procedures

3.4.3.1 Varying Surcharge Pressure

The pullout test commenced by turning on, the manometer system. At the same time, jerking was done to the wooden plate for generating normal pressure on the soil. At the first set up a 5KN/m^2 surcharge pressure loading was maintained for fifteen minutes so that it

equilibrated all through the soil before starting the test. This pressure was achieved by reading of the manometer gauge connected to the pressure cell, After fifteen minutes of initial loading; Surcharge pressure was applied to achieve the desired pressure after some of the pressure had dissipated as the soil consolidate. Through this stage, pullout resistance force and displacement of geo-synthetic were measured from the manually applied pullout load at an increment of 2Kg. The test was continued until the geo-synthetic pulled out. Pullout failure mode was assumed to have occurred when displacements of the pointer occurred without any further increment of the load. Tensile failure mode was assumed to have occurred if the geo-synthetic slipped at the clamping end.

Finally, the normal pressure was detached and the wooden plates were undone. The soil was removed and stored in the polythene bag. The form of the geosynthetic was checked to define the kind of failure that ensued in the specimen during the test. The same procedure was repeated under the same procedure by varying the surcharge pressures of 4 KN/m², and 2 KN/m².

Procedure

The pullout test commenced by turning on, the manometer system. At the same time, jerking was done to the wooden plate for generating normal pressure on the soil. To begin the test, a surcharge pressure of 5kN/m² was applied using the instron jack. (As shown in Plate 3-8) This pressure was derived from a load applied by the jack and acting on a flat wooden board (0.6 m x 0.6 m) which had an area of 0.36 m².

The surcharge pressure applied for minimum 15 minutes period prior to pull-out force application. Weights were then placed on the metallic plate welded to the steel rod starting with the smallest weight of 2 kg. The weights were increased in stages while monitoring the behavior of the geosynthetic strap in response to the applied incremental loads. Pullout failure mode was assumed to have occurred when displacements of the pointer occurred without any further increment of the load.

Having recorded the failure load, the surcharge pressure was released by unlocking the jack and the set-up was disassembled. A chisel was used to loosen the compacted soil which overlay the strap. The scooped soil was stored in polythene bags to prevent loss of moisture. The geosynthetic was unclamped from the clamping system and orientated back; then clamped back. The soil surface in the pull-out box was prepared by compaction of the loosened soil particles in readiness for the next set-up. The clamped geobelt was embedded in the soil and the same procedure as the previous one was followed. Geobelt strap pull-out tests

were carried out at varying surcharge pressure intervals of 5 KN/m², 4 KN/m², 2 KN/m² for designed soil and 10 KN/m², 5 KN/m², 4 KN/m², 2 KN/m² for control soil were also tested and the corresponding failure loads recorded. The moisture content was kept constant throughout the test.

3.4.3.2 Varying moisture content

Procedure

The soil was prepared by incrementally adding water to the soil in order to achieve different moisture content but maintaining the same surcharge pressure of 4 KN/m². The same procedure was followed as above and once the pullout load was achieved the set up was disassembled. The test was repeated by increasing the moisture content

The soil surface in the pull-out box was prepared by compaction of the loosened soil particles in readiness for the next set-up. The clamped geobelt was embedded in the soil and the same procedure as indicated in section 3.4.3.1 was followed. Geobelt strap pull-out tests were carried out at varying surcharge moisture content of poured intervals of 7.3%, 14.6%, 21.9% and 29.2% the corresponding failure loads recorded. The surcharge pressure was kept constant throughout the test.

3.4.3.3 Varying the length of the geo-synthetic

Different lengths of the geo-synthetic were prepared and clamped to the set up following the same procedure as section 3.4.3.1 above but maintaining the same surcharge pressure of 5 KN/m² and different pullout loads were obtained using the same procedure described above.

Procedure

Having recorded the failure load, the surcharge pressure was released by unlocking the jack and the set-up was disassembled. The clamped geobelt was embedded in the soil and the same procedure as the previous one was followed. Geobelt strap pull-out tests were carried out for length 100%, 75%, 50%, 25% were also tested and the corresponding failure loads recorded. (Total length of geobelt is 60 cm). The surcharge pressure and moisture content were kept constant throughout the test.

3.4.3.4 Varying the Angle of geo-synthetic

The test involved the use of a single geosynthetic strap clamped at varying horizontal angles measured from the centerline of the clamping system.

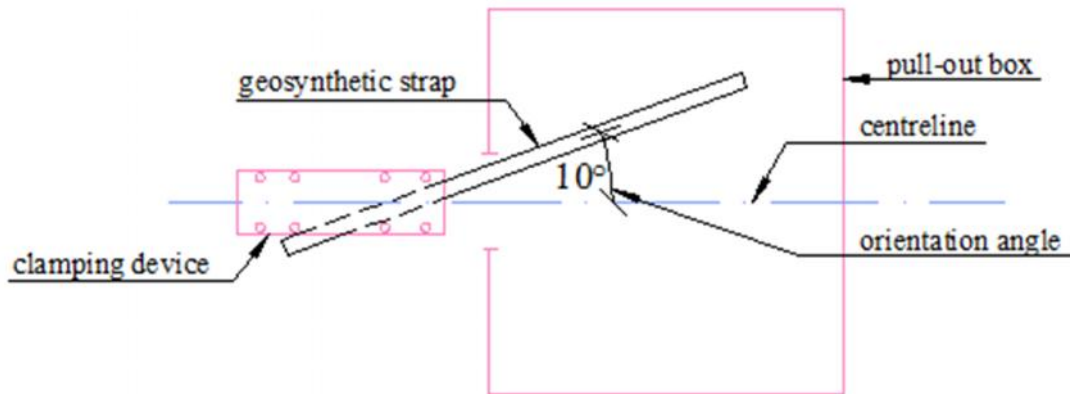


Figure 3-2: Setting the orientation angle for a single strap (in plan)

The soil was placed and compacted (5Kg hammer) in layers until it reached the level of the exit slit. The clamped geosynthetic strap, orientated at 0° from the exit slip into the compacted soil. Another layer of soil was added on top ensuring that the strap was not displaced from its position. The layer was compacted by applying 5 kg hammer blows to the soil layers.

A transducer connected to a meter box through a flexible cable was placed on below the jack. A wooden base plate was then placed on the wooden board at the middle and an Instron jack supported on top. The transducer was used to read the applied surcharge pressure to be read from the meter box, as shown in Plate 3-8.

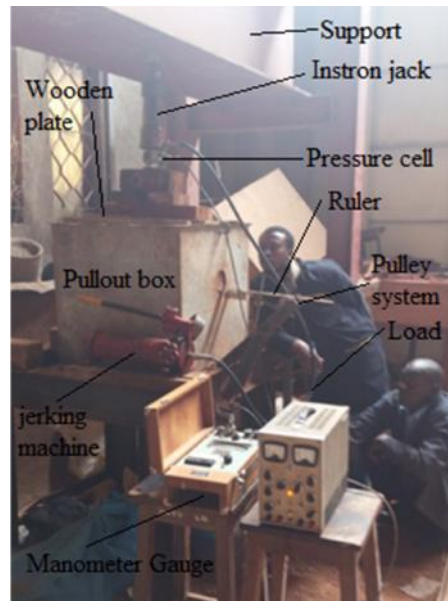


Plate 3-8: Pull out test instrumentation

Procedure

To begin the test, a surcharge pressure of 5kN/m^2 was applied using the Instron jack. The procedure was replicated as described in section 3.4.3.1 above.

Having recorded the failure load, the surcharge pressure was released by unlocking the jack and the set-up was disassembled. The clamped geobelt was embedded in the soil and the same procedure as the previous one was followed. Strap orientations of 0° , 30° , 45° , and 60° were also tested and the corresponding failure loads recorded. The surcharge pressure and moisture content were kept constant at various stages throughout the test.

3.4.3.5 Varying the Time Taken for Pull-Out Test

Procedure

To begin the test, a surcharge pressure of 4kN/m^2 was applied using the Instron jack. The procedure was replicated as described in section 3.4.3.1 above. Having recorded the pull-out load, the surcharge pressure was released by unlocking the jack and the set-up was disassembled. The clamped geobelt was embedded in the soil and the same procedure as the previous one was followed. Geobelt strap pull-out tests were carried out at 24 hours, 120 minutes, 60 minutes and 30 minutes tested and the corresponding failure loads due to pull-out recorded. The surcharge pressure and moisture content were kept constant throughout the test.

CHAPTER 4

4 RESULTS AND DISCUSSION

4.1 SOIL

The lateritic soil was tested for sieve analysis, compaction test, Atterberg limits, and California bearing ratio. To characterize and assess the different soil parameters and expected results within the model. The assessment was done with regards to the environment situation of certainty due to the Nyamasaria – Kisumu road environment. The following are the results due to the soil tests;

4.1.1 Sieve Analysis

The particles passing through sieve number 200 were found to be less than 40% hence the hydrometer test was not necessary. Thus, dry sieving analysis test was carried out. The soil contains traces of sand and lots of gravel (lateritic gravel). Particle size distribution determines the way materials perform in service. The curve in Figure 4-1 shows the output of the sieve analysis test. From the graph it's depicted that the soil contains a wide range of particles. From the graph one can conclude that the lateritic soil classified is suitable as a base material.

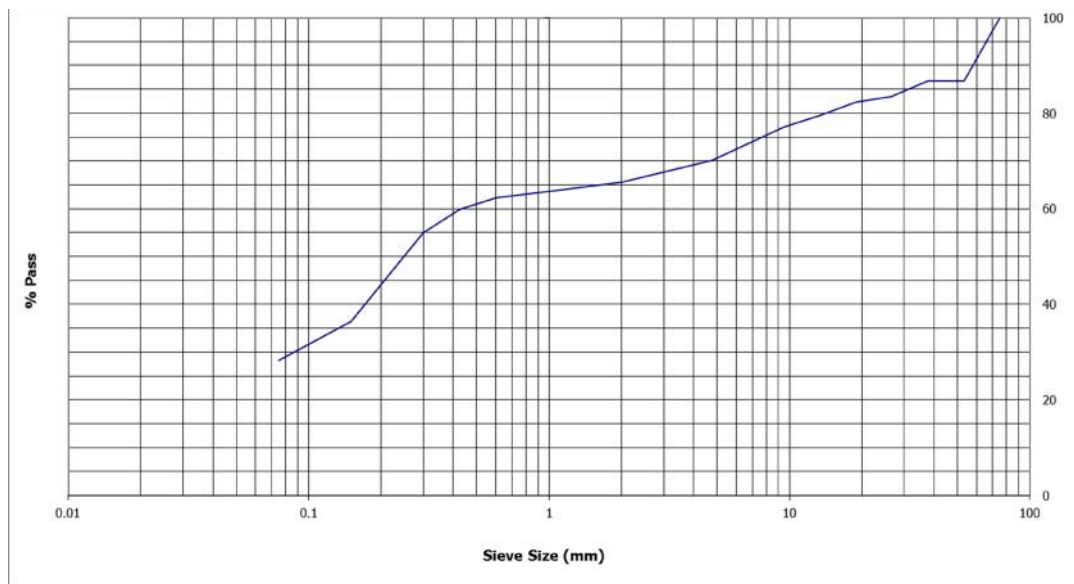


Figure 4-1: Cumulative chart against a sieve size

4.1.2 Atterberg limits

Table 4-1: Results for Atterberg limits

Plastic Limit, PL	20.5
Liquid Limit, LL	38.5
Plasticity Index, PI	18
Linear Shrinkage, LS (%)	8.7

This showed that it was of high plasticity since it had a PI >17%. The PI and to a lesser extent linear shrinkage (LS), gives a strong indication of the sensitivity of the material to water. As a guide, the LS should be about half of the PI, but depending on the clay mineralogy. As documented by South African National Roads Agency Ltd (2011), with experience, the PI can provide a clear indicator of the performance of a material. The objective was successfully achieved as the Atterberg limits of the soil sample were obtained and the moisture content determined at various plasticity stages.

4.1.3 Compaction Test

The compaction effort is directly proportional to dry density and then inversely proportional to moisture content. Therefore, an increase in compaction leads to increase in dry density thus decrease in moisture content. Thus, light compaction requires more water to counter resistance of soils grain packing.

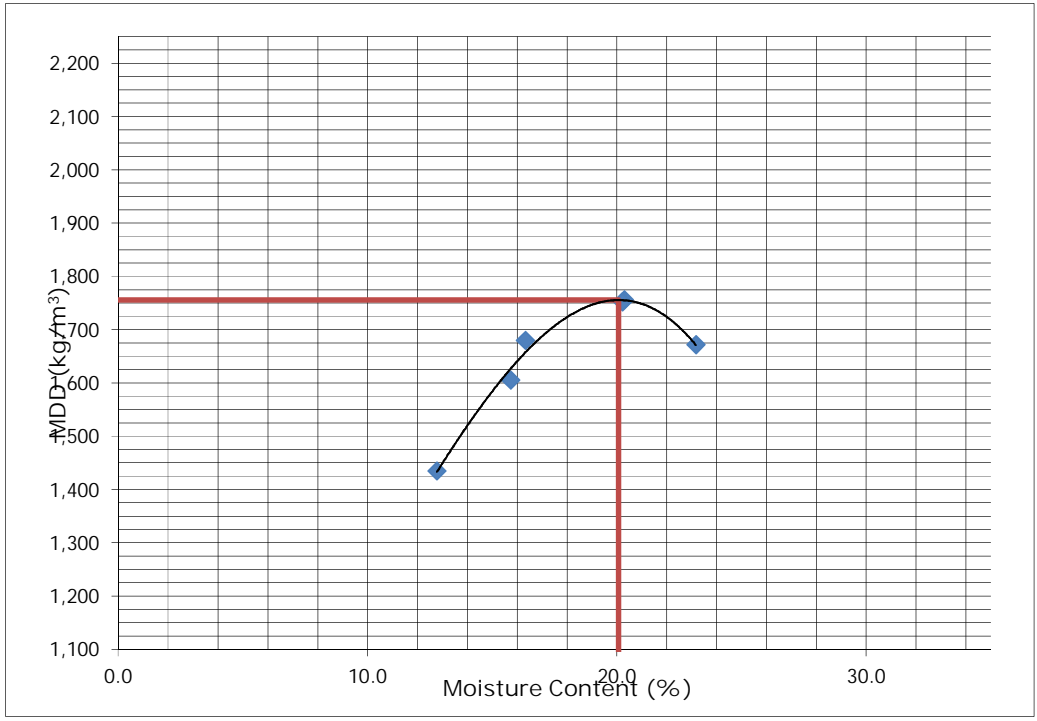


Figure 4-2: Graph showing MDD against Moisture Content

From the graph:

MDD, Maximum Dry Density is 1755 Kg/m³

OMC, Optimum Moisture Content, is 20%

Natural moisture content (NMC) is 10.6%

4.1.4 California Bearing Ratio CBR

As observed in Figure 4-3 the thickness of crust varies with the change in the value of C.B.R. A high C.B.R. value has a less crust thickness and applies vice versa. The CBR tested was found to be 38.5; CBR, values being an index of soil bearing capacity and strength; this value applied for base and sub-base design material for the flexible pavement.

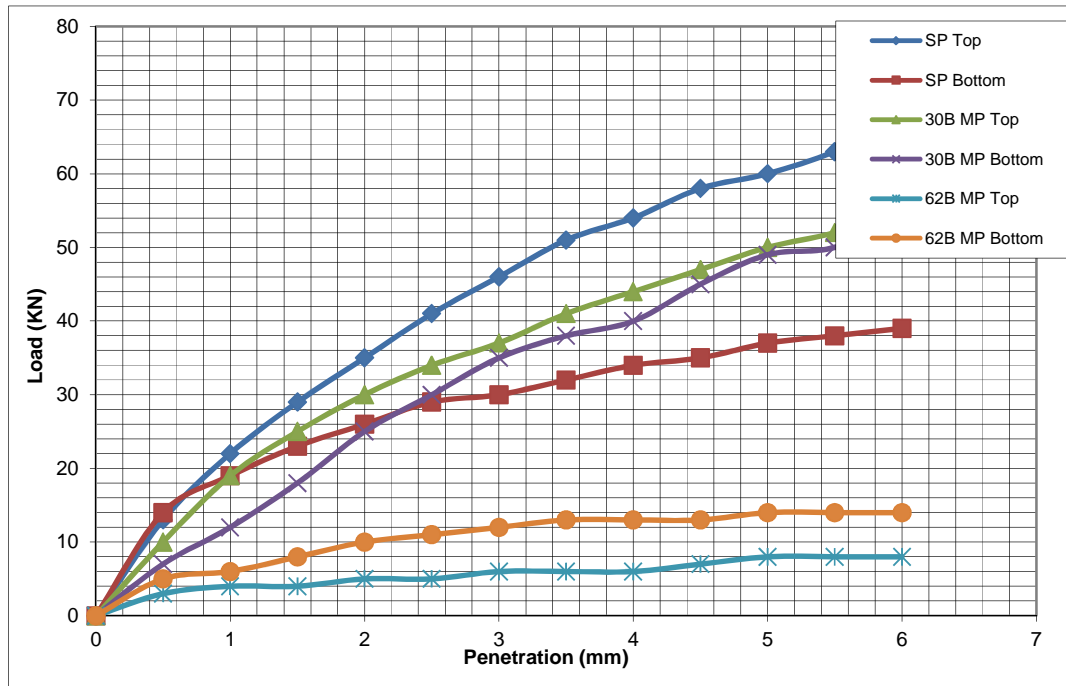


Figure 4-3: Chart showing Load (KN) against penetration

The evaluation concludes that lateritic soils have high plastic limits, California Bearing Ratios (CBR) and Maximum Dry Densities (MDD) whereas the Optimum Moisture Contents (OMC) is low. The lateritic soils were classified and characterised as suitable for sub-base, sub-grade, materials and good fill. This geotechnical numerical information attained serves as base line material information for prospective road pavement, foundation design and construction in the area of study.

4.2 GEOTEXTILE MATERIAL

Commercially available polypropylene geotextile (CAT30020B) used, having break strength 9KN/m, elongation rate 3% and normal intensity of 150Mpa (300 mm wide and 2.7 mm thick) having a tie-soil friction angle of 35° were utilised as reinforcing elements. The geotextile material used was manufactured by Li Shizhen Company located in China.

4.3 PULLOUT RESISTANCE

Pull-out resistance tests focused on characterization of soil and geosynthetic reinforcement behaviour and interaction. Also, the soil and geosynthetic reinforcement influence on movement, as the specimen (geobelt) is subject to pull-out process.

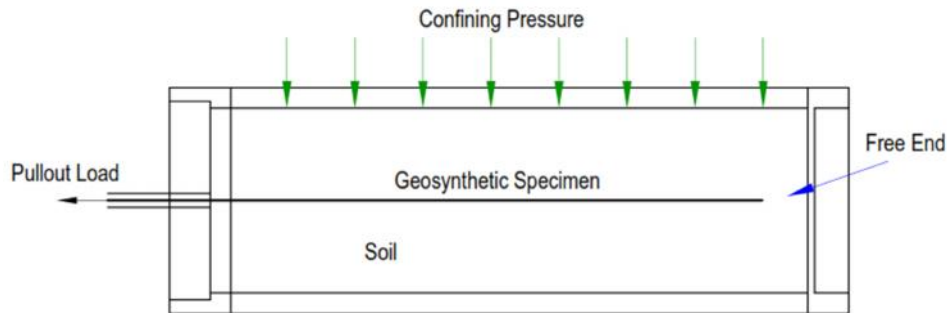


Figure 4-4: Pullout test

Pullout resistance test investigates and characterizes the soil ~ geosynthetics interaction within the model. The pullout test is particularly essential in determining design and effective lengths of geosynthetics embedment within fill material to be used in RE-Walls, among others

The research objective being to evaluate pullout performance of geobelts embedded in sub-grade soil. Several laboratory tests have been performed on the geobelt specimens that were used in the road project section. The section defines the pullout testing apparatus that was used to conduct simulated small scale model pullout testing on geo-synthetics at The University of Nairobi

Moreover, it additionally clarifies the methodology used and implemented for sample preparation and executing the test. Thus, it describes the outcomes analysed and achieved by the different tests conducted in the laboratory. The testing program on pullout test evaluated the effect of confining pressure, reinforcement length and moisture content on the pullout resistance, varying the angle of placement and varying the time taken for pull-out specimen

Normal Pressure Application Device

A load cell and a jerk device were used to exert and maintaining uniform stress (uniformly distributed stress) above the area covered by lateritic soil in the pullout box. The device consisted of one load cell, jerk, ruler, several weights, and pressure cell (the jerk was placed on top and connections were made from the pressure cell to the manometer) which indicate the magnitude/ surcharge pressure applied to the rigid wooden plate by the jerk. The

pressure applied to the soil by the wooden plate is the same as that measured by the manometer. The confining load that is exerted to the surface of the compacted soil sample acts from the reaction force generated by the jerk and rigid steel beam running over the pullout box. A pressure valve controls the amount of pressure supply to the jerk from the set hydraulic pump.

4.3.1 Effect of Varying Surcharge Pressure

The moisture content was maintained throughout the test. The surcharge pressure varied as shown in Table 4-2 below while the compaction and length of the geobelt remained constant.

Table 4-2: Pull-out test results for varying confining Pressure

Pressure (KN/m²)	Pull-out Load (Kg) for Control Soil	Pull-out Load (Kg) for Design Soil
2	32	90
4	74	94
5	86	106
10	98	<140

Load – Varying confining pressure

The graph of the pull-out load versus varying confining pressure test is as shown below;

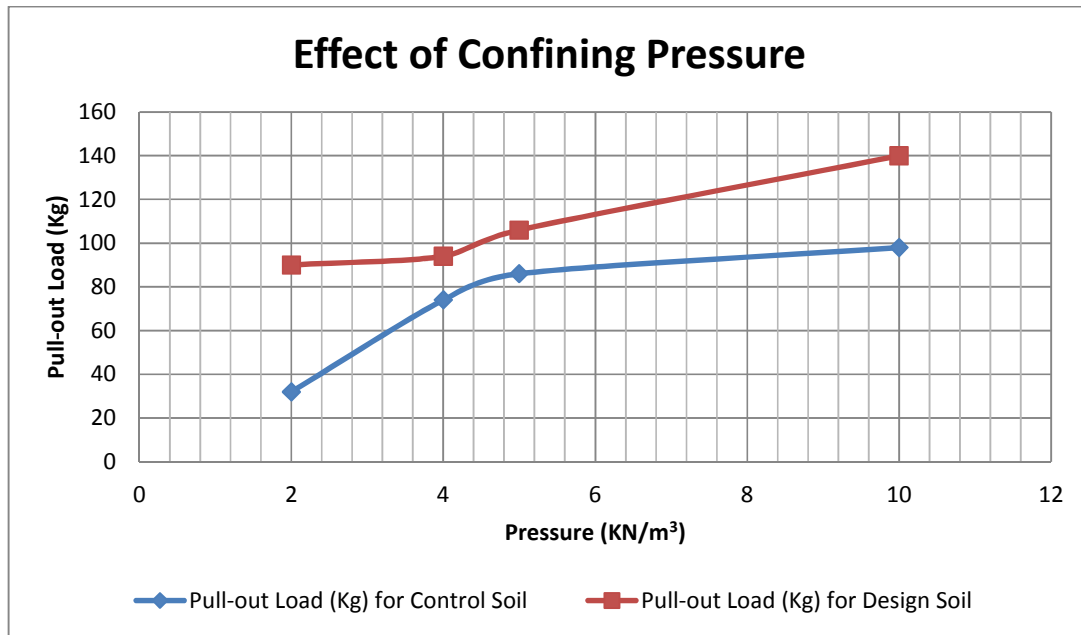


Figure 4-5: Pull-out Load versus Varying Confining Pressure

Using the pullout test results, it was deduced that the pull-out load increased with increased surcharged pressure exerted on the soil. Thus, the frictional resistance mobilized was higher due to the geobelt's larger surface-area to volume ratio. Surcharged pressure exerted by the soil mass was highest at the edges of the geobelt specimen that had a larger surface area. For a geobelt, the surface area subjected to friction was the top and bottom planar surfaces of the horizontally placed geobelt strap.

Moreover, the pull-out load increased with increased surcharge pressure tested. Note: Surcharge pressure of 5 KN/m² at a constant compaction had an output pull-out load of 106Kg this was much lower as compared with a surcharge pressure of 10 KN/m² producing a pull-out load <140Kg. This out-put is progressive as it increases as the surcharge pressure increases. An increase in the pull-out load was attributed to additional resistance caused by bearing stresses acting on the strap edges when the pressure is increased. These stresses resulted as the geobelt strap was pulled against motion and force exerted away from the centerline. The interaction between soil particles and surface of geobelt is increased when the surcharge pressure exerted is increased as compared to the control soil sample where lateritic soil offers less resistance resulting in a low bearing stress and consequently a low resistance. The varying surcharge pressure attained in the laboratory were considered adequate if coupled with proper/optimum compaction of the geobelt strap set on site for a particular pull-

out load. Comparable to the test results on the geobelt, the effect of the specimen length should be measured near the peak load at the late stage of pullout.

A high fill wall considers as a coherent block for flexibility, to sustain loads and deformations, which are developed due to interaction between the earth material and reinforcing material. According to Anand M. Hulagabali (2018) noticed that even the type of inclusion material has the significant effect on the wall movements.

Thus lateritic gravel as a backfill and foundation material showed very small deformations. Since permeability is more for gravel and drainage is good. Consequently, there was less excess pore water pressure developed behind and beneath the pullout box.

By the numerical analysis for varying surcharge magnitudes it is clear that smaller magnitudes show lesser deformations. Even the soil settlements observed to be lesser for small surcharge loads in the box along horizontal profile. Settlements and deformations was more for 10 kN/m as compared to 2 kN/m thus pullout resistance was much greater for the latter.

From the analysis of high fills model wall, it was clear that, wall deformations, settlement of ground behind the wall and deformations of facing panels were found to be small for the Polyethylene Terephthalate geobelt, lateritic gravel and for surcharge of 10 kN/m.

Also, from the results, it was observed that, high fill model with steel reinforcement, gravel backfill and surcharge of 5 kN/m², showed lesser wall deformations, ground settlement and deformations of facing panel. This was concluded after the pull out material did not distort the soil mass after pull out.

4.3.2 Effect of varying Moisture content

The surcharge pressure was kept constant throughout the test. The moisture content was varied as shown in table 4-3 below while the compaction and length of the geobelt remained constant.

Table 4-3: Pull-out test versus varying surcharge moisture content

Moisture Content (%)	Confining Pressure (5KN/m ²)	Confining Pressure (4KN/m ²)	Confining Pressure (2KN/m ²)
7.3	104	92	86
14.6	98	86	80
21.9	88	84	76
29.2	84	76	68

Load – Varying moisture content

The graph of the pull-out load versus varying moisture content test is as shown below;

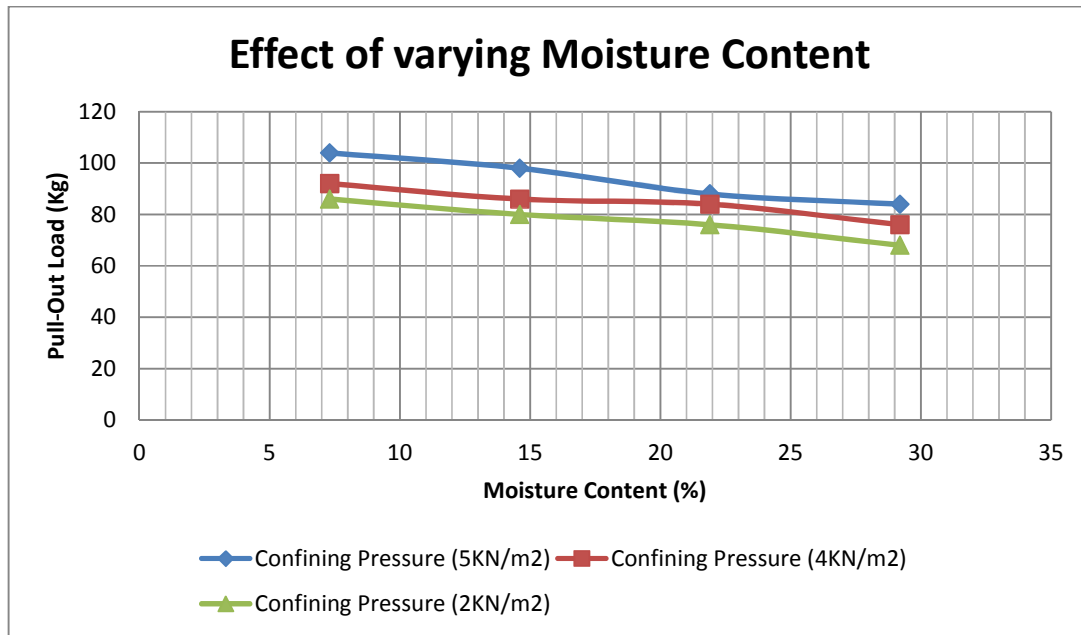


Figure 4-6: Pull-out test versus varying moisture content

Critical factors might have caused the low pullout resistance in this test such as higher moisture contents and low soil density. Increased moisture content is inversely proportional to friction at a constant confining pressure. Thus, increase in moisture content results to decrease in pull out resistance in the set up; resulting to decreased force required to pull-out the geobelt when the moisture content is increased.

The results of pullout tests at varying surcharge/confining pressure are shown in the table above for confining pressures of 5 KN/m², 4 KN/m², and 2 KN/m² respectively.

The increase in confining pressure resulted in an increase in pull-out resistance. This is due to a reduction of pore water pressure within the soil mass. However, the geobelt length had a small effect on pullout resistance at the early stages of pullout. The use of a relatively thin geobelt alone provides a substantial reduction in the increase in horizontal stress on the wall caused by the increased moisture content. The geobelt reinforcement produces significant reductions in horizontal stresses than a backfill alone.

The utilisation of a relatively thin geobelt alone provides a significant reduction in the increase in horizontal stress on the wall due to the surcharge and moisture content. The geobelt reinforcement produces more significant reductions in horizontal stresses as compared to non-inclusion.

The steel reinforcement makes dramatic reductions in the horizontal stress increase in comparison with the geobelt alone and eventually attains a condition of a zero earth pressure increase on an optimum moisture content.

4.3.3 Effect of Specimen Length

The surcharge pressure, compaction and moisture content were maintained throughout the test. Whereas the specimen length was varied as shown in Table 4-4 below.

Table 4-4: Pull-out test results for a varying geotextile length

Length of Geotextile (cm)	Pressure 5 KN/m ² exerted	Pressure 4 KN/m ² exerted	Pressure 2 KN/m ² exerted
60	106	94	90
45	90	86	76
30	78	66	62
15	60	46	44

Load – Varying length of geobelt

The graph of the pull-out load versus varying geotextile length test is as shown below;

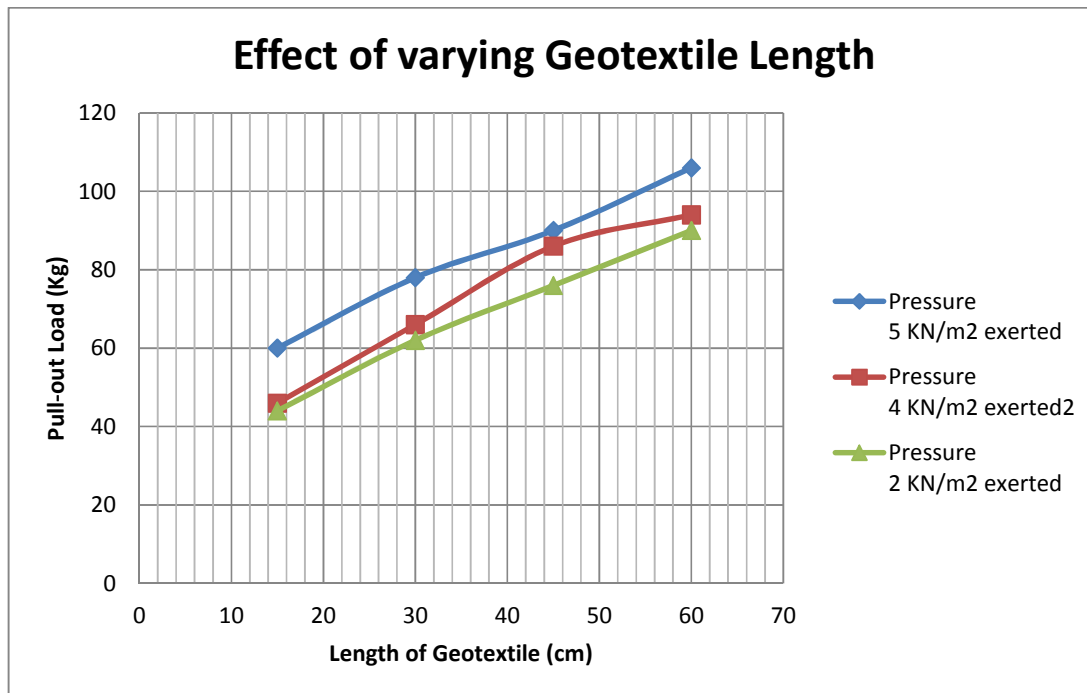


Figure 4-7: Pull-out test versus varying geotextile length

Using the pullout test results, it was deduced that the pull-out load increased with increased length of the geobelt specimen. Thus, the frictional resistance mobilized was higher due to the geobelt with larger surface area to volume ratio; force and pressure exerted by the soil mass, having larger surface area in the case of geosynthetic geobelt use as compared to having 75% or 50% of the geobelt specimen. For a geobelt, the surface area subjected to friction was the top and bottom planar surfaces of the horizontally placed geobelt strap.

Field pullout tests on the geobelt are shown in the table above. Pullout outcomes on the 60cm long specimens are shown for different varying confining pressures of 5 KN/m², 4 KN/m², and 2 KN/m². Pullout loads at varying specimen lengths are as shown above for the confining pressures. The length of the specimen has a limited effect on the pullout load until the specimen is wholly mobilized at later stages of pullout loading.

Moreover, the pull-out load increased with increasing length tested. Note: An increase in the pull-out load was attributed to additional resistance caused by bearing stresses acting on the strap edges when its longer as compared to when the belt length is reduced. These stresses resulted as the geobelt strap was pulled against motion and force exerted away from the centerline. The interaction between soil particles and surface of geobelt specimen is much longer in the belt that was 100% as compared with a reduction; resulting in a higher bearing stress and consequently a higher resistance.

The varying lengths attained in the laboratory were considered adequate if coupled with proper/optimum compaction of the geobelt strap set on site for a particular pull-out load. The analogy portrayed within the model showed that an increase in length in the case of a road pavement structure that is coupled with proper compaction and surcharge pressure. Resulted in an increased load and effort required to pull out the soil reinforcement. A decrease in geobelt length coupled with proper compaction and surcharge pressure, resulted to an increase in pull out load as compared to irregular or surcharge pressure.

According to Ali (2018), the results disclosed that an increase in surcharge lead to increases the lateral pressure. Thus, the higher values of surcharge pressure exerted. From the analysis, the distribution of lateral pressure along following the height of a reinforced model under the effect of a line surcharge was successful when the geobelt was 60cm. The load reduced as the geobelt length reduced.

4.3.4 Varying the Angle of geo-synthetic

The surcharge pressure and moisture content were kept constant at various stages throughout the test. Whereas the specimen angle of orientation was varied as shown in Table 4-5 below. The tests maintained the length of the geobelt under constant compaction.

Table 4-5: Pull-out test results for a displaced angle test

Pressure (KN/m ²)	Orientation Angle (Degrees)	Pull-Out Load (Kg) Design Soil	Pull-Out Load (Kg) Control Soil
5	0°	106	86
	30°	100	82
	45°	98	80
	60°	92	72
4	0°	94	74
	30°	88	70
	45°	86	68
	60°	80	60
2	0°	90	70
	30°	84	66
	45°	82	64
	60°	76	56

Load – Orientation curves

The graph of the pull-out load versus orientation angle for geobelt strap test is as shown below;

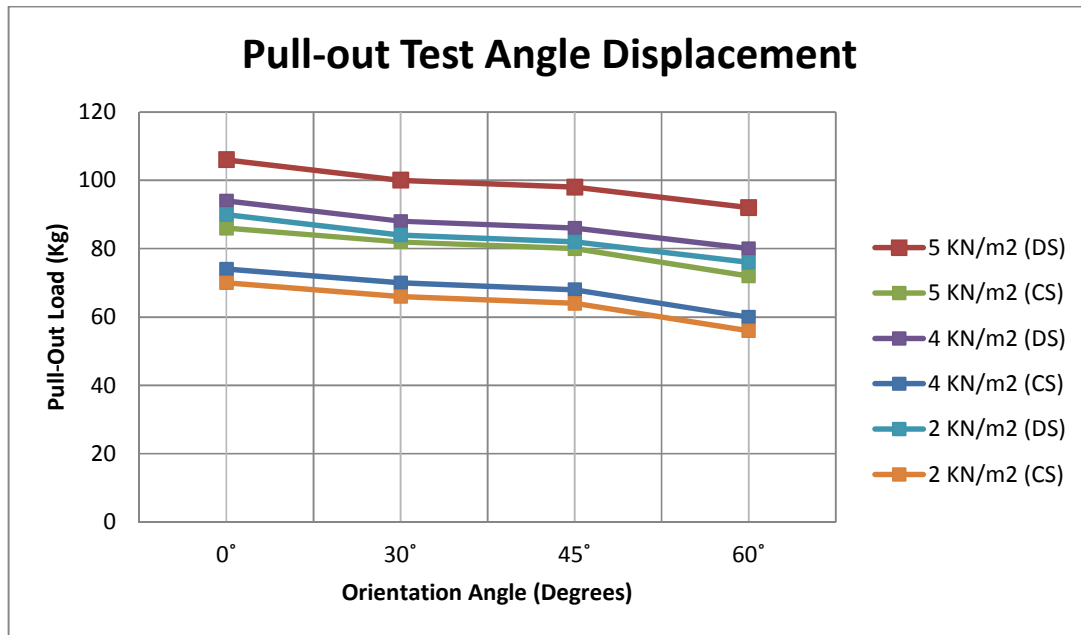


Figure 4-8: Pull-out test at an angle displaced geosynthetic at 5, 4, & 2 kN/m²

Key:

DS - Design Soil

CS - Control Soil

Using the pull-out test results, it was deduced that the pull-out load increased with increased compaction. Thus, the frictional resistance mobilized was higher when more force and pressure exerted on the soil mass, having larger surface area in the case of geosynthetic geobelt use as compared to having no geosynthetic geobelt. For a geobelt, the surface area subjected to friction was the top and bottom planar surfaces of the horizontally placed geobelt strap.

Moreover, the pull-out load decreased with increasing orientation angle for the range of angles tested. Note: A decrease in the pull-out load was attributed to additional resistance caused by bearing stresses acting on the strap edges. This reduction in stresses resulted as the geobelt strap orientation was against motion and force exerted away from the centreline (As shown Figure 3-2). As the angle decreased from 60° to 30° orientation angle, the interaction between the soil particles and the edges of the straps was reducing to near perpendicular resulting in a higher bearing stress and consequently a higher resistance and torsion effect.

The angles that were attainable in the laboratory were considered adequate if coupled with proper/optimum compaction and sufficient embedment length of the geobelt strap set on site.

The proposed concept is the result, which accounts for the soil–wall friction angle and the stress due to tension in the geobelt. The geobelt sloped and inclined backfill for the static analysis of soil-geobelt interface in the backfill. The tests provide an elucidation where the distribution of the net soil friction angle is easily attained.

4.3.5 Varying the time taken for pull-out test

The surcharge pressure and moisture content were kept constant throughout the test. Whereas the time taken for pull-out test to commence was varied as shown in Table 4-6 below. The tests maintained the length of the geobelt under constant compaction.

Table 4-6: Pull-out test results for varying time taken for compaction of soil

Pressure (KN/m ²)	Time taken (Min)	Pull-Out Load (Kg) Design Soil	Pull-Out Load (Kg) Control Soil
4	30	94	86
	60	102	86
	120	115	88
	24hrs	<140	90

Load – Time taken curves

The graph of the pull-out load versus the time taken for compaction of soil for geobelt strap test is as shown below;

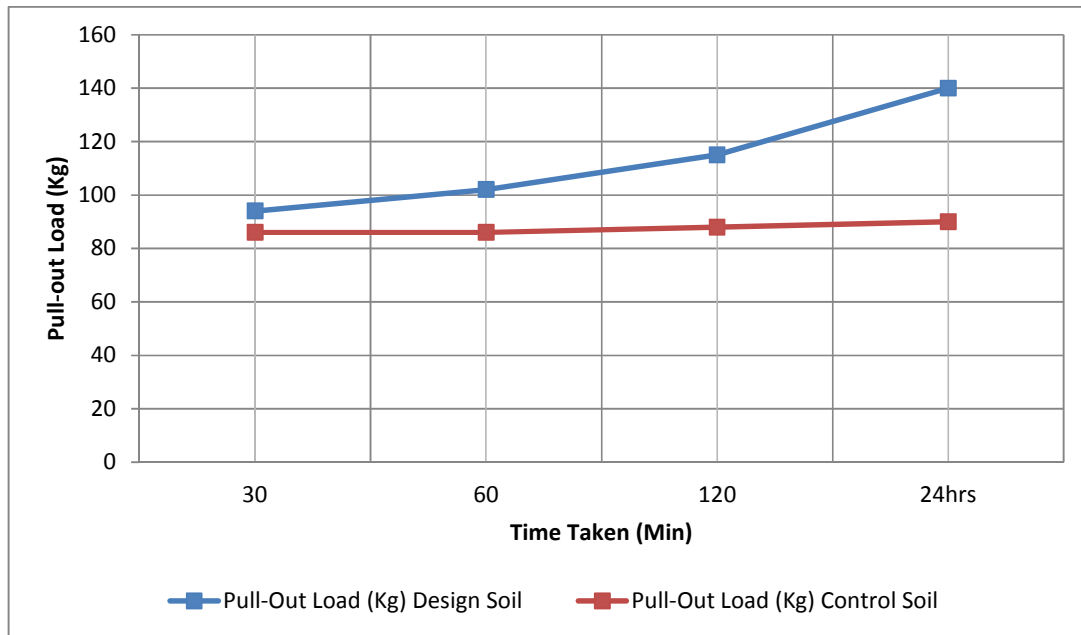


Figure 4-9: Pull-out load (Kg) versus the time taken (min) for soil compaction

Using the pull-out test results, it was deduced that the pull-out load increased with increased compaction and time left after compaction for the soil to connect; thus cohesion and adhesion forces in the soil to create a much stronger bond. Thus, the frictional resistance mobilized was higher when more time and same pressure exerted on the soil mass, having larger surface area in the use of geosynthetic geobelt use; compared to having control soil having geosynthetic geobelt.

The pull-out load increased with increasing time taken to perform the pull-out for the range of time taken tested. Note: An increase in the pull-out load was attributed to additional resistance caused by bearing stresses acting on the strap edges.

The time taken after set up to pull-out tests were considered adequate if coupled with proper/optimum compaction and sufficient embedment length of the geobelt strap set on site. Therefore, reinforcement of the soil with geosynthetic (geobelt) improves with time; when compaction is optimum and sufficient length is observed.

4.3.6 Evaluation of Pullout Coefficients

Pullout test, the interface friction along both sides of a specimen tested in pullout test experiment is coupled with reinforcement, resulting in uniform shear distribution along the specimen length. As documented by Khalid (2004), the pullout resistance in geosynthetics reinforcement is equal to the shear strength in line with the reinforcement length and it is expressed in the form:

$$P_r = 2 t_a L_e \quad \text{Equation 1}$$

Where,

L_e length of reinforcement resisting the pullout force.

P_r The pullout resistance (of geosynthetic unit width)

t_a Interface shear strength

Interface shear strength calculated as:

$$t_a = S_v \tan d_a + C_a \quad \text{Equation 2}$$

where:

S_v Normal stress (reinforcement level),

d Friction angle, and

C_a Soil cohesion at the interface.

The two equations (1 and 2) result in an equation of pullout resistance per unit width:

$$P_r = 2 (S_v \tan d_a + C_a) L_e \quad \text{Equation 3}$$

This equation can be written in terms of the soil shear strength parameters j and C in the form:

$$P_r = 2 C_i (S_v \tan j + C) L_e \quad \text{Equation 4}$$

Where:

- j soil friction angle, and
- C Soil cohesion
- C_i pullout coefficient of interaction:

$$C_i = \frac{S_v \tan d + C_a}{S_v \tan d + C_a}$$

The Interaction Factor, C_i is attained from laboratory and field pullout experiments ranging from 0.6 to 1.0 for geosynthetic reinforcement.

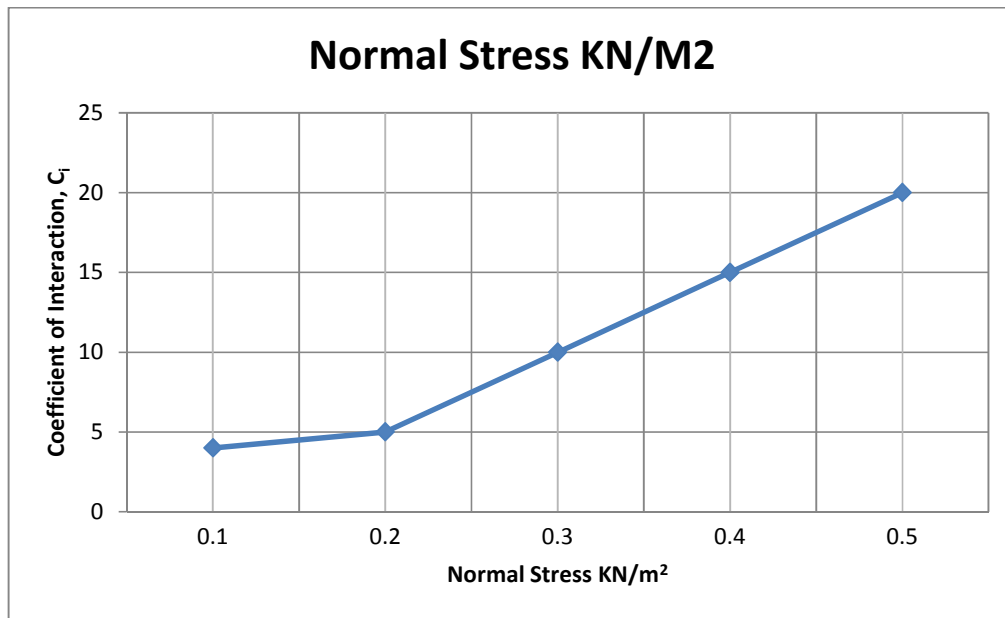


Figure 4-10: Variation of coefficient of interaction C_i with normal pressure

Inextensible reinforcement (i.e. geobelt encompassed with metal strips within the material) moves as a rigid member in the soil and developing a uniform shear strength distribution along its length. Also, the interface shear strength is not mobilized uniformly along length of extensible geosynthetic. Thus, resistance due to pullout is now a function to the length and extension of the specimen. Thus, an adjustment factor, a , is introduced to account the effect.

$$P_r = 2 F^* s'_v a L_e$$

Where:

- a correction factor. (i.e 1)
 F^* factor of pullout resistance. (approx. 6)

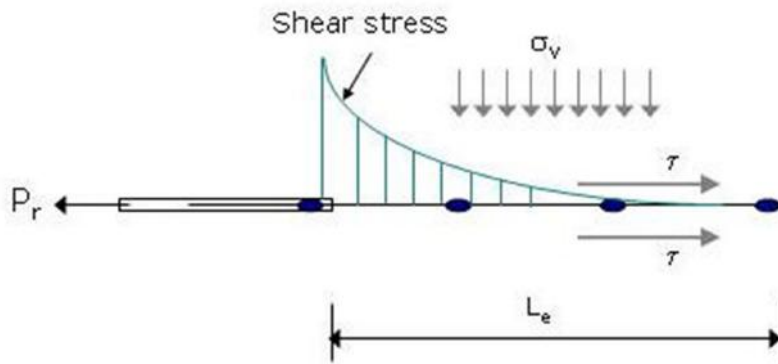


Figure 4-11: Schematic of forces in the geobelt specimen during pullout.

Values of pullout coefficients F^* and a is dependent on length, geometry, confining pressure and type of geosynthetic. Such effects and parameters were determined from laboratory results of the pullout tests done.

Table 4-7: Results for geobelt pullout test

Geobelt width section (cm) B	Exerted stress (KN/m ²) n	Multiplier coefficient F	Max. effective pullout force (Kg)	$t_a = P_r / 2L_e$ N/m
60	2	3.3	90	750
	4	6.7	94	783
	5	8.3	106	883
45	2	4.4	76	844
	4	8.9	86	956
	5	11.1	90	1000
30	2	6.7	62	1033
	4	13.3	66	1100
	5	16.6	78	1300
15	2	6.7	44	1467
	4	26.7	46	1533
	5	33.3	60	2000

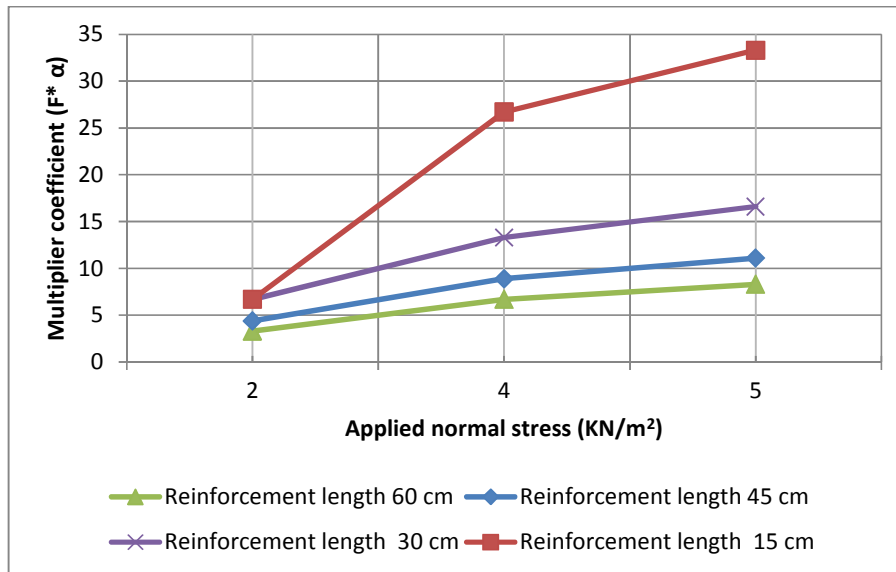


Figure 4-12: Variation of multiplier coefficient (F^*) and effective normal pressure

The outcome of laboratory pullout tests were used to calculate the multiplier coefficients (F^*) since both coefficients are a function of the reinforcement extensibility for 60 cm-long specimens and at various confining pressures.

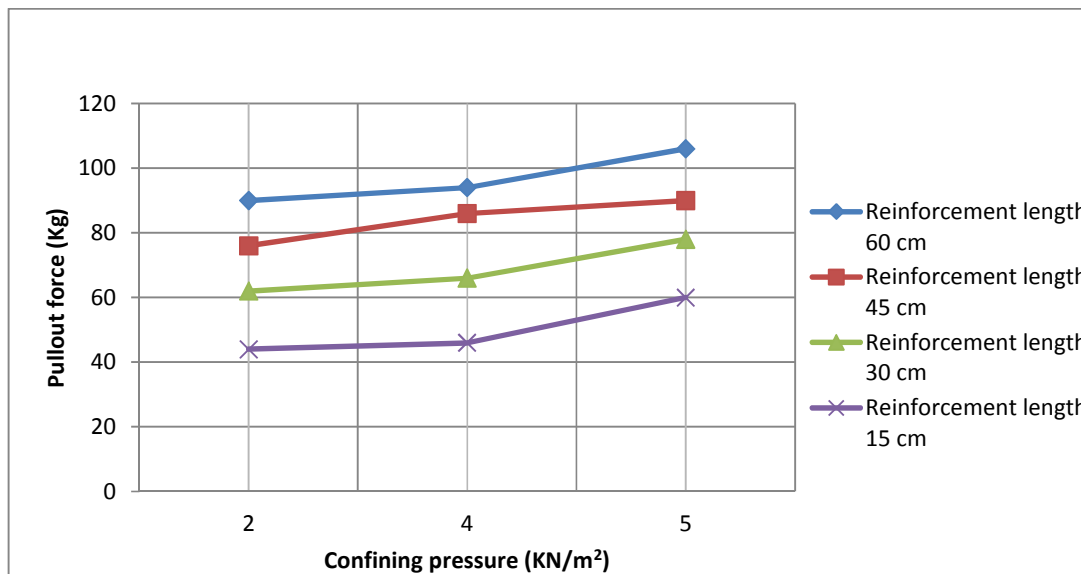


Figure 4-13: Variation of pullout force (Kg) with confining pressure (KN/m2)

The multiplier coefficient (F^*) is directly proportional to confining pressures applied as shown in Figure 4-13. As a result an increase in confining pressure applied leads to an increase in force required for pull-out to occur when compaction and moisture content are kept constant.

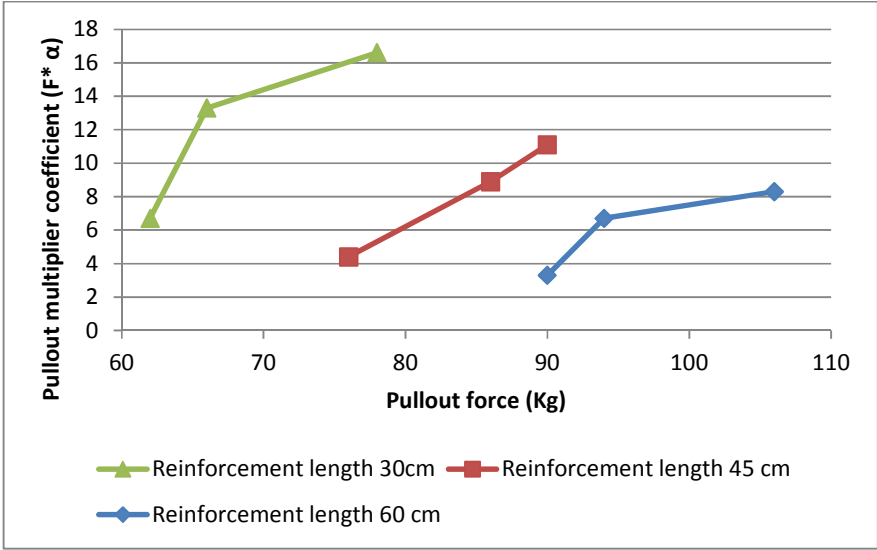


Figure 4-14: Variation of pullout multiplier coefficient (F* α) and pullout force (Kg)

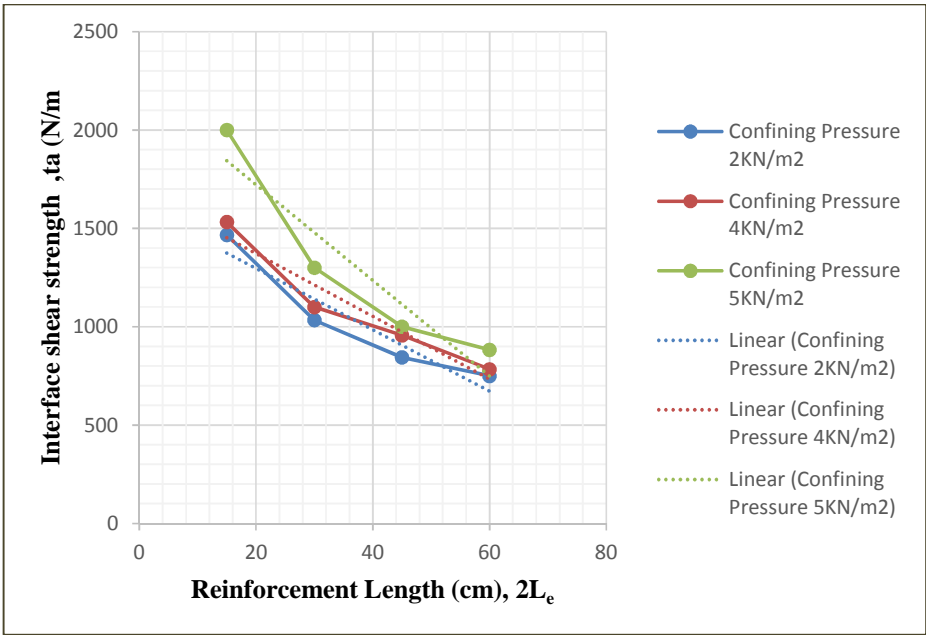


Figure 4-15: Variation of Interface shear strength against twice the reinforcement length

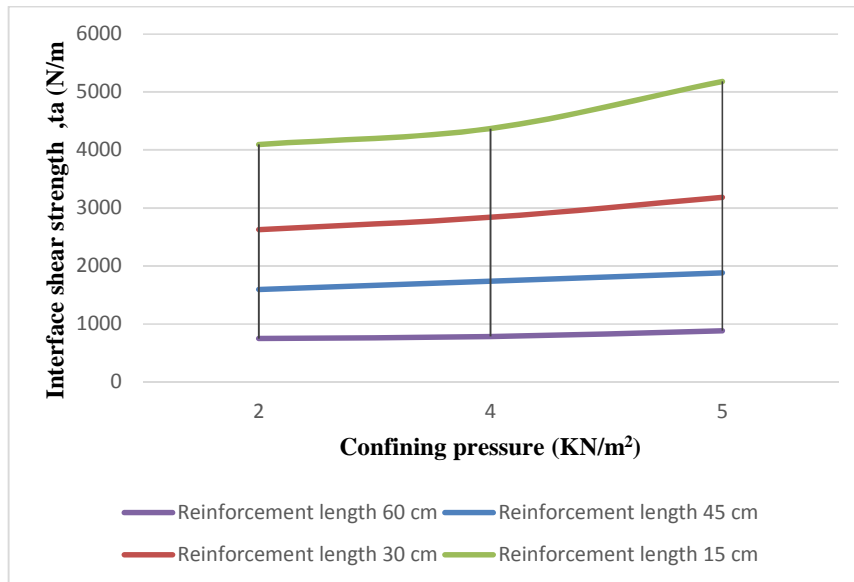


Figure 4-16: Variation of Interface shear strength against confining pressure

Therefore, interface shear strength improves occurs when the embedment length to pullout resistance ratio ($Pr/2L_e$) decrease as shown in Figure 4-15. In this range, the plastic failure state of the lateritic soil is intercepted by the geobelt layer and the stress distribution is prolonged much lower than it. This in effect results in distribution of the load into a broader area beneath the reinforced zone, that is formed by a quite rigid region of soil and reinforcement directly underneath. This effect leads to a developed load carrying capacity of the reinforced soil. However, when geobelt is placed too close to the surface the overload pressure exerted on the soil layer is inadequate in offering necessary anchorage resistance to the geobelt against pullout force.

But for $Z/B = 0.5-1.0$, the reinforcement enables much better load distribution over a larger area below

A procedure of this system is to design the wall reinforcement thus the earth contained by the wall backfill is barred from attainment of a state of failure. The method is consistent having the ideal of working stress conditions in pullout. This rational as described by Bathurst (2008), represents a methodology for internal stability design of geosynthetic reinforced earth-soil walls since deterrence of soil failure at a limit state is measured in addition to the existing norm of averting reinforcement break or rather rapture.

The constitutive behaviour of the geobelt interface with lateritic gravel is also hyperbolic. However, the constitutive behaviour is trailed by displacement softening and hardening behaviour. The dilatancy behaviour of a precise soil-geosynthetic interface is

found similar for all normal stresses. This research will be useful for geotechnical engineers, to choose appropriate backfill and geobelt reinforcements.

CHAPTER 5

5 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The influence of soil particle size on soil and geosynthetics interaction significantly depends on various factors; geobelt and the thickness of the geobelt bearing members, relative sizes of soil particles, determine soil and geobelt interface resistance. An increase in soil and geobelt interface resistance was observed where the soil contained particles with sizes slightly greater than the thickness of geobelt bearing members, but smaller than the geobelt. Tests, on geobelts where bearing members were reduced/ cut, this show a decrease in soil and geobelt interface resistance. Thus, influence of soil particle size is less important for geobelts/ geotextiles. Moreover, though the structure of geobelts/geotextile has an effect on soil and geobelt interface behaviour, pullout resistance is affected by axial tensile stiffness of the geobelt. Flexible geobelt reinforcement provides stability to a mass of soil via transferring destabilizing forces through active zone towards the resistant zone where the forces are safely absorbed.

It was deduced that the pull-out load increased with increased length of the geobelt specimen. Thus, the frictional resistance mobilized was higher due to the geobelt with larger surface area to volume ratio; force and pressure exerted by the soil mass, having larger surface area in the case of geosynthetic geobelt use as compared to having 75% or 50% of the geobelt specimen. Moreover, the pull-out load increased with increasing length tested. The varying lengths attained in the laboratory were considered adequate if coupled with proper/optimum compaction of the geobelt strap set on site for a particular pull-out load.

Surcharge Pressure

From the results, it was observed that, the high fill model with steel reinforcement, gravel backfill and surcharge of 5 kN/m^2 , showed lesser wall deformations ground settlement and deformations of facing panel as compared to a surcharge of 10 kN/m^2 . Thus, it was deduced that the pull-out load increased with increased surcharged pressure exerted on the soil

Moisture Content

The utilisation of a relatively thin geobelt alone provides a significant reduction in the increase in horizontal stress on the wall due to the surcharge and moisture content. Increased moisture content is inversely proportional to friction at a constant confining pressure. Thus,

increase in moisture content results to decrease in pull out resistance in the set up; resulting to decreased force required to pull-out the geobelt when the moisture content is increased.

Placement Angle

Reduction in stresses resulted as the geobelt strap orientation was against motion and force exerted away from the centreline. As the angle decreased from 60° to 30° orientation angle, the interaction between the soil particles and the edges of the straps was reducing to near perpendicular resulting in a higher bearing stress and consequently a higher resistance and torsion effect.

5.2 RECOMMENDATION

Pullout tests in the laboratory should be identical to field conditions; here the output is dependent in moisture content, type of geobelt, density and confining soil pressure.

The pullout tests should seek to establish the effects of close parking of the reinforcements on pullout resistance since it is the scenario in the field. This tests should also be done in a box with similar boundary condition as the field since the boundary condition has an impact on the results obtained.

Reinforcements with high tensile capacity should be used in construction of high fills to avoid over reinforcements at a given level which results to close parking of reinforcements and hence reducing the pullout resistance.

The combined multiplier factor (F^* , C_i) established in this study for lateritic gravel soils should be used to define the effect of stiffness, soil confining pressure and geosynthetic length for the types of geobelt or geotextiles used in the model. The coefficients are utilised in the internal stability analysis of soil reinforced structures.

Current design specifications and procedures of reinforced-soil walls necessitate the use of high quality of superior nature granular soil as a backfill material. The anticipated performance of high fill wall revealed the effectiveness of using lateritic gravel soil as earth backfill material. The utilisation of lateritic gravel soil with a PI greater than 18, which offers a practical and an economical solution for the building of reinforced walls. The use of such materials necessitates the proper control of soil moisture content throughout construction and a proper drainage system within the wall facing. Till the long-term performance of these walls can be assessed, enactment should be restricted to non-critical wall structures. The performance of the reinforced slopes showed the effectiveness of utilising geobelt material in reinforcing steep slopes with marginal soils.

Industrial Use

Potential applications of the pullout ideal to circumstances where surcharge loading be it involved include existing structures and new construction. In innovative construction, occasionally it is not economical or desirable to design and develop the retaining structure for lateritic soil plus surcharge loads. Predominantly, where surcharge load might exist only for some degree of time. An example, in the course of a construction project that is of short period compared with the design life of envisaged structure. Thus, it may possibly be extra economical to decrease the stresses permanently utilising geosynthetics rather than to replace the structural wall or strengthen it.

5.2.1 Future studies

At this stage in the improvement of use of geosynthetic geobelt, either small model or large scale field tests are necessary to corroborate the theoretical outcomes or results obtainable in this study. The prime area of research with regard to surcharge loading is evaluation and assessment of the effect on the surcharge-induced stresses of modulus changes, long-term creep and non-recoverable deformation of the geosynthetics, specifically the geobelt and non-recoverable deformations of the backfill retained soil subjected to numerous cycles of live load.

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APPENDIX

Appendix A

Soil Preparation

The amount of soil necessary for the given test was calculated in reference to the volume of the pullout box and soil density from the field requirement. The soil afterwards was mixed by addition of the needed amount of water to attain the soil to be used in the test, which was then kept in the plastic bags to prevent loss of water. This also aided the moisture to equilibrate within the soil specimen. The water content for the soils in the plastic bag was assessed and checked before every pullout test.

The soil to be used in the test was later stored in polythene bags to maintain the natural moisture content at 7.8%. The volume of the soil sample which was used in the test was;

Volume of soil Sample = Width (W) x Length (L) x Depth (H)

$$= 0.6\text{m} \times 0.6\text{m} \times 0.23\text{m} = 0.0828\text{m}^3$$

$$\text{MDD} = 1755 \text{ kg/m}^3$$

$$\text{OMC} = 20\%$$

$$\text{Natural Moisture} = 7.8$$

Design of the soil and water required for the pull-out tests were obtained: formulae;

$$\text{Soil required} = (\text{MDD}) \times (\text{Volume of Sample}) \times (1 + \text{OMC}) \times 95\%$$

$$\text{Water required} = (\text{OMC} - \text{NMC}) \times (95\% \text{MDD})$$

Where;

MC is the moisture content at which the pull-out test was carried out. The other parameters are as defined earlier.

The pull-out tests were done at a moisture content of 20%.

Therefore,

$$\text{Amount of soil required} = 1755 \text{ kg/m}^3 \times 0.0828 \text{ m}^3 \times (1 + 0.20) \times 95\% = 165 \text{ kg}$$

Compact to max dry density (MDD)

$$= 95\% \text{ MDD}$$

$$= 165 \text{ Kg}$$

Take 165 Kg of soil

$$(\text{OMC} - \text{NMC}) \times 165$$

$$= (0.14 - 0.106) \times 165$$

$$= 5.6 \%$$

$$\begin{aligned}\text{Amount of water required} &= (0.14 - 0.056) \times 165 \\ &= 13.68 \text{ litres}\end{aligned}$$

To start, the soil was mixed and preconditioned in a separate large tray before being placed in the test pull-out box. It was turned and spread, and water was added to achieve the target moisture content. Moisture content of 20% was used, which was selected based on the compaction test. The soil was then placed into the pull-out box and compacted portions of 150 mm thick layers with a 5 kg hammer having a circular base plate fitted to deliver the compaction force. Hammer blows were applied on each layer during compaction until the soil attained the required volume.